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# Stock Rebuilding Strategies Over Different Time Scales

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## ABSTRACT

In this paper we examine, using a simple Monte Carlo simulation, the implications for stock structure and yield of a 50% reduction in the fishing mortality rate of George's Bank groundfish staged over three different time scales. Two example stocks are considered, cod and haddock, using information from recent assessments and stock projections are made with stochastic recruitment drawn from a gamma distribution.

To provide scientific advice on rebuilding strategies for depleted stocks, projections of yield, spawning stock biomass and age composition must be presented in order for managers to determine the best time scale for fishing mortality reductions. In the examples given here, rapid reductions have a high cost in terms of short term yield, while slow reductions have a high risk to the spawning stock and the rebuilding of the age composition. Medium term strategies have the advantage of sacrificing relatively little yield in the short term, while obtaining the advantages of increased yield in the latter half of the decade and a low risk in of recruitment failure by improving both age composition and spawning biomass relatively quickly.

Two major caveats are necessary for these general conclusions however. Firstly, the assumption made here is that the distribution of recruitment remains unchanged from that observed over the past 15 years for these stocks. Secondly, the pattern obtained over different time scales depends on the current level of fishing mortality. No account has been taken here of the uncertainty in the estimates of F, i.e., the risk analysis assumes perfect knowledge of F. Both of these assumptions mean that the conclusions will be optimistic in terms of risk assessment.

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## Introduction

Fisheries resources in many areas are currently depleted to levels where their yields are well below the estimated potential ( NEFC 1989a). It is a major task of fisheries managers to improve the sustainable yield and the principle of developing fish stock rebuilding strategies has recently been set out in guidelines for the development of fishery management plans for U.S. resources (Dept. of Commerce 1989). These fishery management plans are developed by regional fishery management councils under U.S. law. For stocks which have been identified as overfished by the Councils, the guidelines specifically state that a stock rebuilding program must be established and that the time frame for rebuilding is to be determined by the Council.

This paper considers the question of how to present relevant scientific information to fishery managers to enable them to determine the appropriate time frame for a stock rebuilding program. We work with a simple age structured population model, incorporating stochastic recruitment as one component of the uncertainty inherent in the problem of stock rebuilding. Two examples were considered both from the northwest Atlantic, George's Bank cod and George's Bank haddock. These stocks have recently been assessed (NEFC 1989b; Gavaris 1988) and both appear to be depleted to low levels (NEFC 1989a).

The target for rebuilding a stock is often expressed in terms of the fishing mortality rate or spawning stock biomass. Here, we assumed that the strategy chosen to rebuild the stock was to reduce the rate of fishing mortality by 50% with a constant exploitation pattern over a time period of two to ten years. While the choice of a 50 % reduction was somewhat arbitrary, it serves to illustrate the sort of information required to choose between different time scales. The exploitation rates of the two example stocks are quite different, as are the degrees of stock depletion. For the last assessed year, the George's Bank cod stock had an estimated instantaneous fishing mortality rate of 0.775 (weighted average of exploited age groups) and a spawning biomass of under 40 000 MT compared with 80 - 90 000 Mt in the early 1980's (NEFC 1989). Haddock had an estimated F for 1987 of about 0.26, the $F_{0.1}$ level. However, the haddock biomass is at very low levels, around 10 % of the level in the 1960's and, while exploitation rate is low on older haddock due to their scarcity, the assessment notes that the F on younger fish is still too high rapid stock recovery (Gavaris 1988). We examined the response to a 50% cut in exploitation rate in both cases to provide a contrast.

The central question is, what measures of stock rebuilding must managers weigh to choose the appropriate time scale for reducing exploitation of overfished stocks. We considered three basic quantities, the yield in weight, the spawning stock biomass and the compression of the age structure. Each of the measures used here makes some assumptions concerning the biology of the fish in terms of the productivity of the stock and the relationship of recruitment to parent stock. These are not extreme assumptions however in that a functional relationship is not postulated, simply a general assumption that a very depleted spawning stock is likely to produce poorer recruitment than a larger stock with a less skewed age composition. The inclusion of random variation in recruitment in the model implies that a probability is associated with any degree of stock rebuilding, so we have examined the probability of obtaining a given yield or spawning biomass level over different time scales to account for this uncertainty.

## Model Description

An age structured model was constructed with stochastic, gamma distributed, recruitment. The model equations were

$$N_{t,1} = R_t \sim \text{gamma}(a,b)$$

$$N_{t,i} = N_{t-1,i-1} \exp[-Z_{t-1,\,i-1}] \qquad i = 2\ldots I$$

$$Z_{t,i} = F_{t,i} + M$$

$$C_{t,i} = F_{t,i}/Z_{t,i}\{\ 1 - \exp[-Z_{t,i}]\}\ N_{t,i}$$

where N is the number of fish at time t, age i, R is the recruitment in year t which is distributed as gamma with parameters a and b, Z is the total instantaneous mortality rate which is the sum of $F_{t,i}$ the fishing mortality at time t and age i and M is the natural mortality rate which has a constant value. C is the catch in numbers in year t and at age i. The yield or spawning biomass is obtained by multiplying numbers at age with input weight at age.

For the two example stocks, numbers at age and instantaneous fishing mortality rate age for the most recent year in the assessment was used as input to the model along with the weight at age in the most recent year, the maturity schedules and the natural mortality rate ( 0.2 for both stocks). The parameters of the gamma distribution for each stock were determined by fitting a gamma probability density function to the historical recruitment data available in the assessment documents. For cod recruitment at age one in the years 1978 - 1988 gave a = 3.74, b = 0.00018. For haddock recruitment in the years 1965 - 1987 a = 0.64 and b = 0.000038. The small value for b for haddock gives a distribution of recruitment which is very strongly skewed to the left, with a long tail to the right (Figure 1a). Cod has a less skewed recruitment distribution (Figure 1b).

Simulations for each species were run for 13 years , beginning in 1987 until the end of the century to project the yield, stock biomass and age structure under four different scenarios of exploitation. The first scenario ("no reduction") was that the rate of fishing mortality at age remains constant at the 1987 level through until the end of the century. The second scenario ("2 year") reduces F at age by 50% over a two year period beginning in 1989, i.e., by 25 % of the 1987 value each year, and then constant until the end of the century. The third scenario ("5 year") was a 50 % reduction over a five year period beginning in 1989, i.e., reducing by 10 % of the 1987 value each year for five years, and then remaining constant thereafter. The final scenario ("10 year") was to spread the reduction over 10 years.

Five hundred runs for each species were done under each scenario. Therefore, five hundred sets of thirteen random recruitment values were drawn from the respective gamma distributions for the species. To facilitate comparison between the methods the same five hundred sets were used for each scenario.

## Results

### Cod

The yield that will be obtained under a proposed scenario for controlling fishing mortality is one measure of the efficacy a strategy. The average yield for cod (Figure 2) if the no reduction scenario is followed remains relatively constant near the present level. However, the variability of that yield is high. In other words, the actual cod yield that will be realized in any given year is very uncertain.

There is a predictable pattern in expected (average) yield for each scenario for cod (Figure 3). A rapid reduction in F results in an expected large loss in yield in the short term before a substantial increas is realized by the end of the century. This sharp reduction in short term yield is substantially less for the other two scenarios, and in the case of the 5 year strategy, the resulting payoff by is the same.

The expected yield on average from 1989-1999 is another measure of the impact of the rebuilding strategy. This can be expressed as the probability of obtaining a given level of yield over the period by simply counting the number of simulated realizations above a given yield level. For cod, these probabilities are virtually identical for all the scenarios (Figure 4). In other words, there is little risk in terms of total yield resulting from adopting on of the rebuilding strategies for cod versus maintaining the status quo.

In addition to risk, it is also useful to consider the probability of obtaining a better yield in a give year than would be obtained if the no reduction strategy was used. Figure 5 shows the probability of obtaining a cod yield greater than the no reduction case in each year. Both the two and five year strategies rapidly increase the probability of improved yield with an obvious tradeoff in the short term as indicated in Figure 3.

The improvement of yield must be balanced with increases in the spawning stock biomass for depleted stocks. Seeking to increase the spawning stock biomass assumes that there is less risk of recruitment failure at higher stock levels, i.e. there is a relationship between stock and recruitment at least to the extent that some notional threshold level of biomass exists below which poor recruitment becomes more likely. We adopt this assumption in considering the benefits of increasing stock biomass.

The more rapid reductions in exploitation rate obviously rebuild the cod spawning stock biomass more quickly (Figure 6) at the expense of short term yield. In effect the implication is that the risk of poor recruitment decreases rapidly under the 2 year or 5 year strategy. In terms of probability, it is informative to look at the chance that the average spawning stock will be above a given level over the decade (Figure 7a) and the probability of attaining a given level by the end of the decade (Figure 7b). There is a better chance of obtaining a higher average biomass with rapid reduction over two years, but the the probabilities of rebuilding the spawning stock to between 60 and 80,000 MT by the end of the decade are virtually identical for the 2 and 5 year strategies. There is a substantially lower chance of obtaining this level of rebuilding with the 10 year scenario and with the no reduction case *there is little chance of having a cod stock above 50 000 MT in* 1999.

The final measure of rebuilding considered here for cod is the compression or skewness of the age distribution. While a higher spawning biomass may be obtained when a good yearclass matures, the productivity of the stock may largely depend on only one or two yearclasses. The implicit assumption here is that if the fish are allowed to spawn for more than one season, they have a better chance of replenishing the stock than if they are all cropped after one or two years. A simple measure for the age distribution is its skewness

$$\text{skew}(X_1 \ldots X_N) = 1/N \text{ SUM}( (X_i - \text{Xbar})/s )^3$$

where N is the number of age groups, $X_i$ is the relative abundance of the ith age group, Xbar is the average relative abundance and s is the standard deviation of relative abundance. As a stock becomes more heavily exploited, the skewness of its age distribution will increase as more individuals will be concentrated in fewer age classes. In this context, the skewness of an unexploited population can be calculated from a stable age distribution with total mortality equal to the rate of natural mortality. For cod,this equals 0.71.

Under the different fishing mortality rate reduction scenarios the average skewness in each year across the 500 realizations shows the more rapid improvement obtained with the 2 year case (Figure 8). Again, the 2 year and 5 year strategies converge quite quickly an give essentially identical results in terms of the likely stock structure by the end of the decade.

## Haddock

Under the no reduction strategy, the haddock yield is expected to increase slightly over the next decade, but this increase is highly uncertain due to the large standard deviation of yield obtained in the simulations (Figure 9a). The expected yield from the no reduction strategy remains above any of the other scenarios (Figure 9b) because the current level of fishing mortality is quite low, so a 50 % cutback necessitates a reduction in yield even if the stock rebuilds. For the 2 and 5 year strategies, yield initially is low, but is on an increasing trend at the end of the decade, while for the 10 year scenario it is still decreasing. In effect the reduction in exploitation rate reduces yield unless the increase in stock size resulting from this decreased exploitation compensates. For the rapid reduction scenarios, the stock begins rebuilding rapidly by the end of the decade and yield is on the increase. If the rate of fishing mortality is reduced slowly, 50 % in 10 years, then insufficient recovery has occurred by 1999 for yield to begin to increase.

The probability of obtaining a given level of yield is lower for the more rapid reduction strategies (Figure 10a). However these yield levels, between 7 and 15 000 MT are very low compared to the estimated potential yield of nearly 50 000 MT (U.S. Dept. Commerce 1989). The probability of obtaining a yield greater than under the no reduction strategy is of the order of 20 % and would be expected to increase over a longer time frame (Figure 10b).

For haddock, because the yields are so low currently, the main issue is the recovery of the population, here measured by increasing spawning biomass and the age structure of the stock. The more rapid the reduction in the rate of fishing mortality the more rapid is the increase in spawning stock (Figure 11). The probabilities of obtaining higher spawning stock levels is also greater with the rapid reduction strategies (Figure 12). Note that the 2 and 5 year strategies are again very similar in terms of the level obtained by the end of the decade.

Under the no reduction scenario, even though the F level is fairly low and may be appropriate for maintaining the stock, there is virtually no improvement in the age structure of the stock (Figure 13). The reduction strategies all lower the degree of skewness of the stock, indicative of rebuilding (unexploited population skewness = 0.51).

## Discussion

The results of this simulation exercise show the importance of looking at several measures of stock rebuilding. It would be very misleading to choose a management strategy only on the basis of a single measure such as average yield or spawning stock biomass or rate of fishing mortality. In the cod example, the average yield over the 1990 decade is similar for all scenarios. However, there are large differences in the degree of stock rebuilding under the different strategies as shown by the spawning stock biomass and skewness projections. In the case of haddock the current level of mortality is low, around the $F_{0.1}$ but there is still little rebuilding of the stock by 1999 unless reductions are made from this level. The crucial point here is that the stock is currently at such a low level that substantial improvements in yield can only occur after massive rebuilding has been accomplished. Our results show that even though yield remains low under all strategies, rebuilding has begun in stock biomass and age composition when the fishing mortality is reduced by 50%. A similar picture was obtained by Overholtz et al. (1986) in their examination of rebuilding strategies for haddock.

There are clear differences between the time scales for stock rebuilding with respect to these two examples. Rapid reduction of exploitation rate in the 2 year scenario results in a large loss in short term yield which is later recouped due to rebuilding of the stock. Such a short term outlook may be undesirable in terms of the risk to the fishing industry even if the stock benefits. The reduction spaced over 10 years on the other hand seems to be too long a time scale to see any effective recovery by the end of the century. Both the no reduction case and the 10 year strategy have substantially higher risks to the resource but less rapid changes in yield and perhaps lower risk for the industry. For cod, decreasing the fishing mortality rate by 50 % over two years causes a 30 % drop in yield before recovery begins to take over. For both stocks, the middle, 5 year plan appears to give the least drastic changes in expected yield (lower risk to the fishery) while rebuilding the stock fairly rapidly (lower risk to the resource.

There are several major caveats which are important in interpreting the analysis presented here. Uncertainty in incoming recruitment is only one component of the uncertainty associated with rebuilding a resource (for discussion see Walters 1986). Another major component is the uncertainty in the assessment information, i.e., the measurement error. The analysis so far has assumed that the available information on the stock is perfect and that all of the biological parameters are known and constant. This simplification is likely to result in an optimistic picture of the results of rebuilding program. In addition, the uncertainty incorporated in recruitment is also a simplification in the sense that the distribution is assumed constant over time and therefore over all observed stock sizes. If sufficient data were available it may be possible to relax this assumption to some extent by fitting recruitment distributions to parts of the series separately.

A third issue in examining these results relates to our chosen time horizon to the year 1999. For many stocks, full rebuilding will obviously require more than ten years. While management regimes are usualy focused on a long-term or sustainable yield, rebuilding strategies are likely to be guided by intermediate term results in line with planning by induxtry. Both long and intermediate term considerations must be taken into account in advising managers. Long-term advice could be given in a similar framework using stochastic recruitment and the probability of maintaining yield and stock biomass above a given level as presented in Rosenberg et al. (1990).

Presenting the advice to managers in terms of probabilities is an effort to quantify the risk involved with chosing a particular strategy. The probability expresses the chance that the strategy will achieve the manager's goals. Preferably, this risk analysis should include the uncertainties associated with measurement error as well as the variability in biological processes.

In summary, these results illustrate the types of scientific advice which will be useful to managers in determining the most appropriate time scale for a stock rebuilding program. The time scale will of course depend on the goal of rebuilding, and we have chosen an arbitrary 50 % fishing mortality rate reduction here, and on the tradeoff between yield and stock size which is acceptable from a management point of view.

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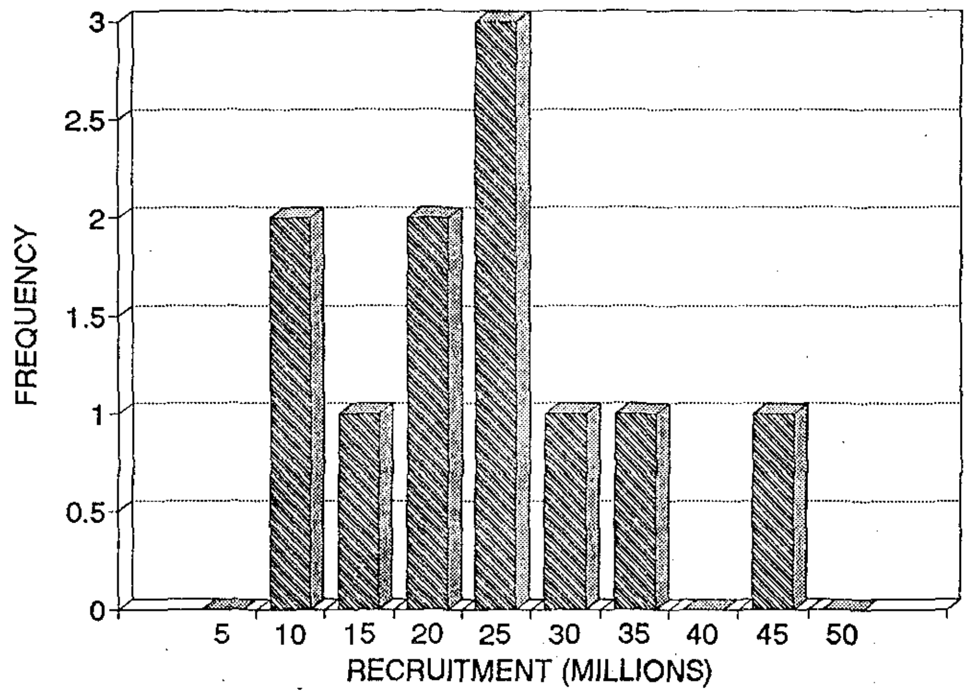
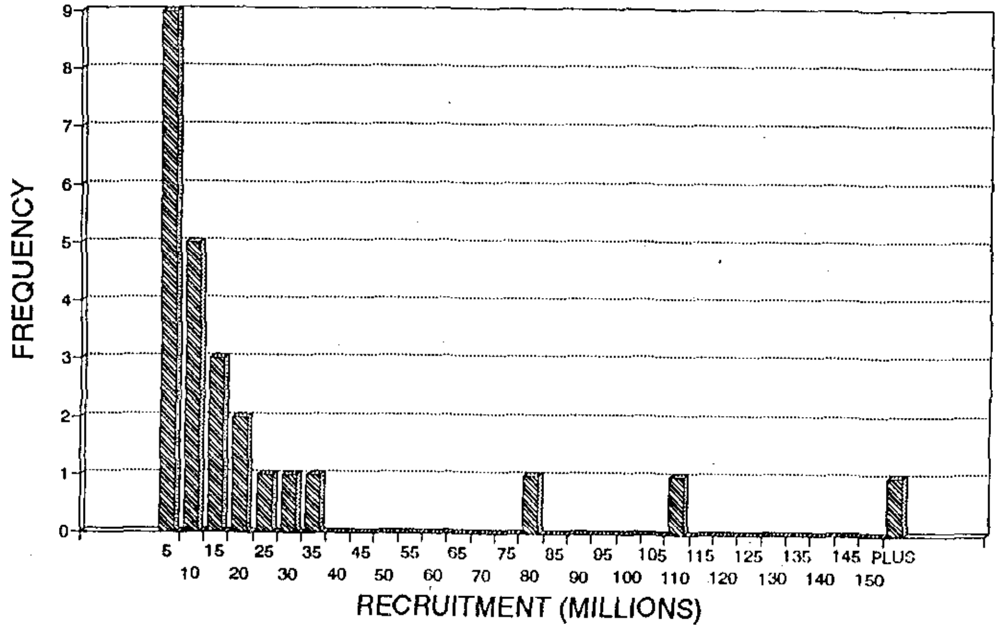


GEORGES BANK COD



GEORGES BANK HADDOCK

1964 - 1988

Figure 1: a) Frequency histogram of George's Bank cod recruitment at age 1 in numbers of fish. Data is for the years 1978-1988 (NEFC 1989); b) frequency histogram of George's Bank haddock recruitment at age 1 in numbers of fish. Data is for the years 1964-1988 (Gavaris 1989).

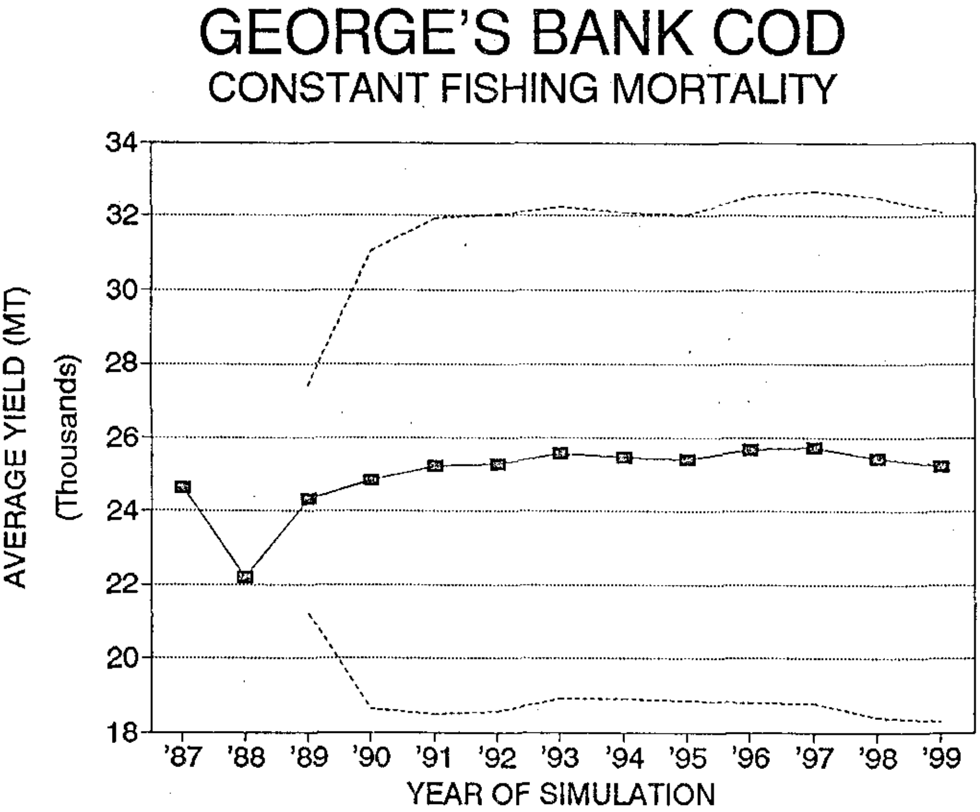


Figure 2: Projected yield from simulations of the George's Bank cod stock where the rate of fishing mortality remains at the 1987 level. The filled squares are the average over the 500 realizations, the dashed lines are plus and minus one standard deviation.

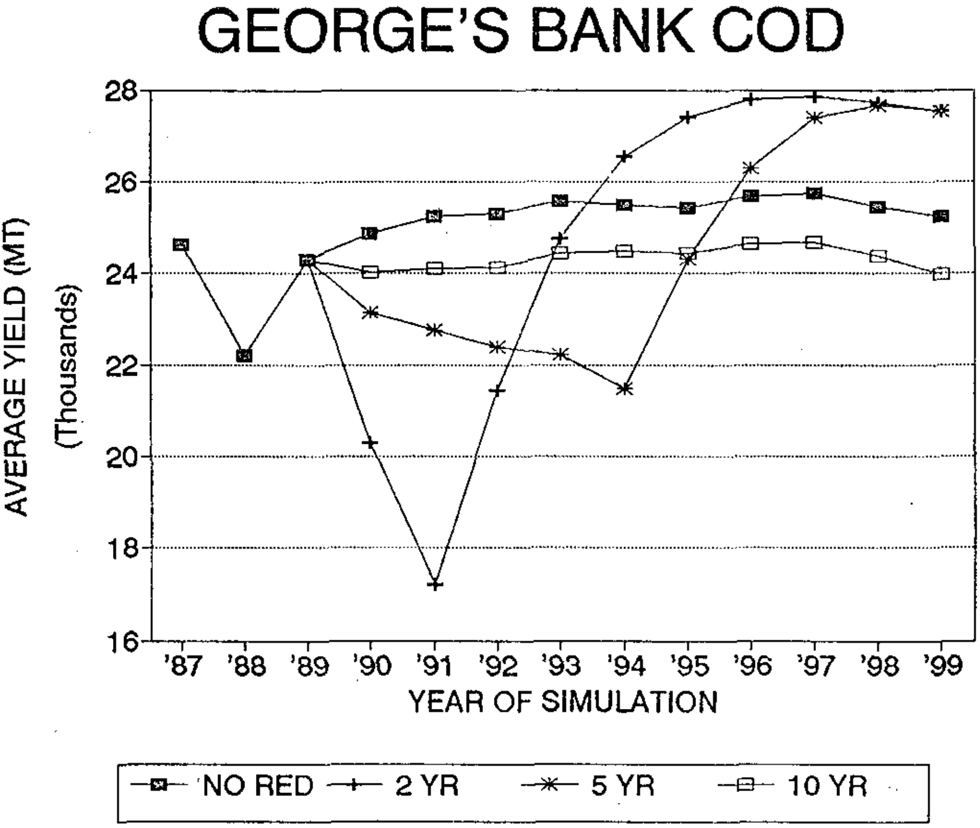


Figure 3: Projected yield from simulations of the George's Bank cod stock under four different scenarios for the rate of fishing mortality (see text for details). Each line is the mean of 500 realizations for the given scenario.

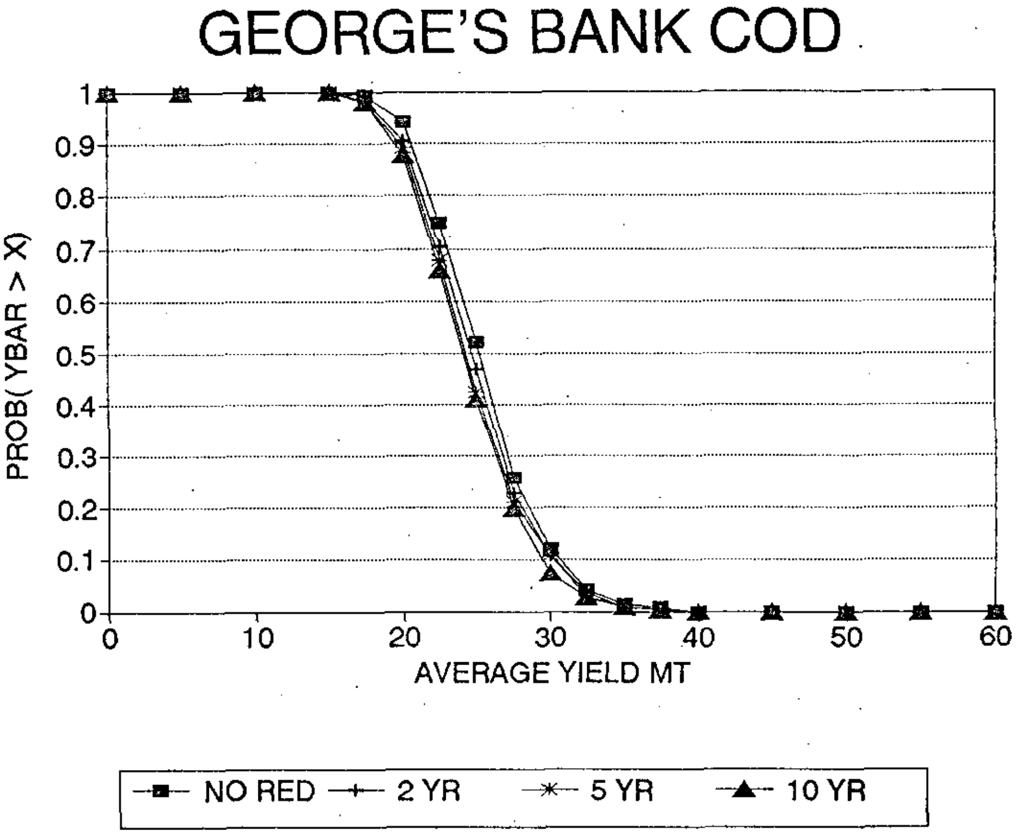


Figure 4: Probability that the average yield over the decade 1990-1999 is above the amount given on the abscissa for four scenarios of the rate of fishing mortality on cod.

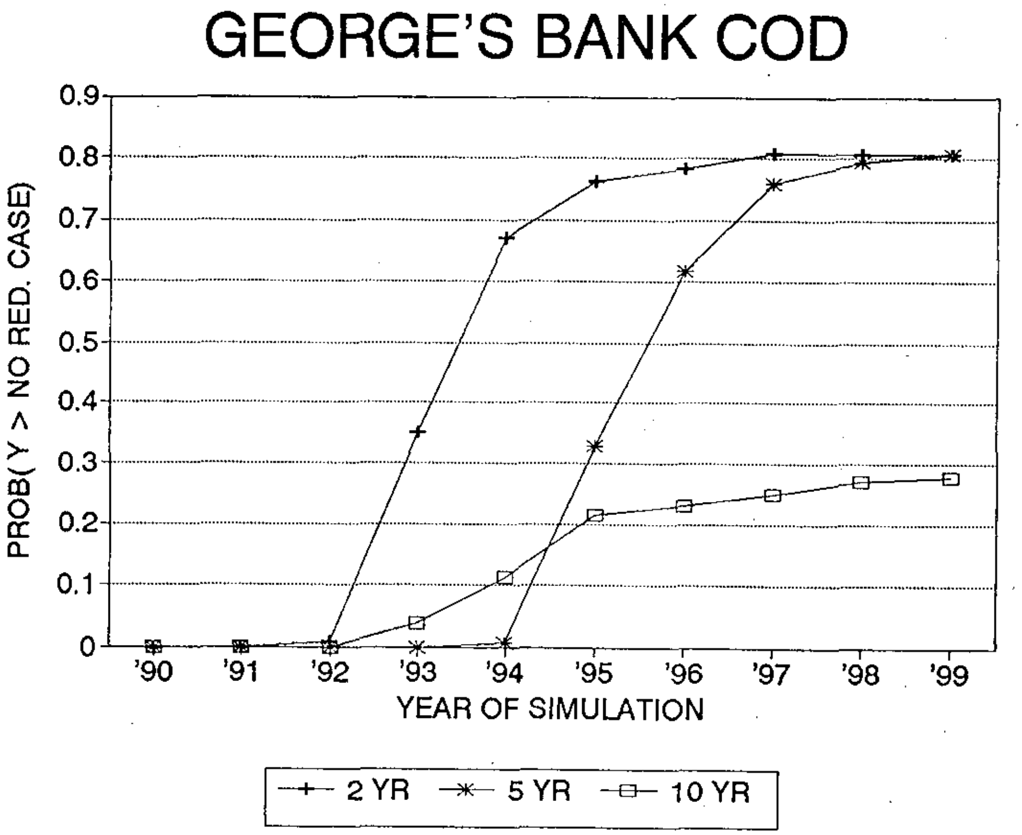


Figure 5: Probability that the yield in each year of the simulation for the three scenarios where the exploitation rate is reduced will be above the yield achieved by the no reduction case for cod.

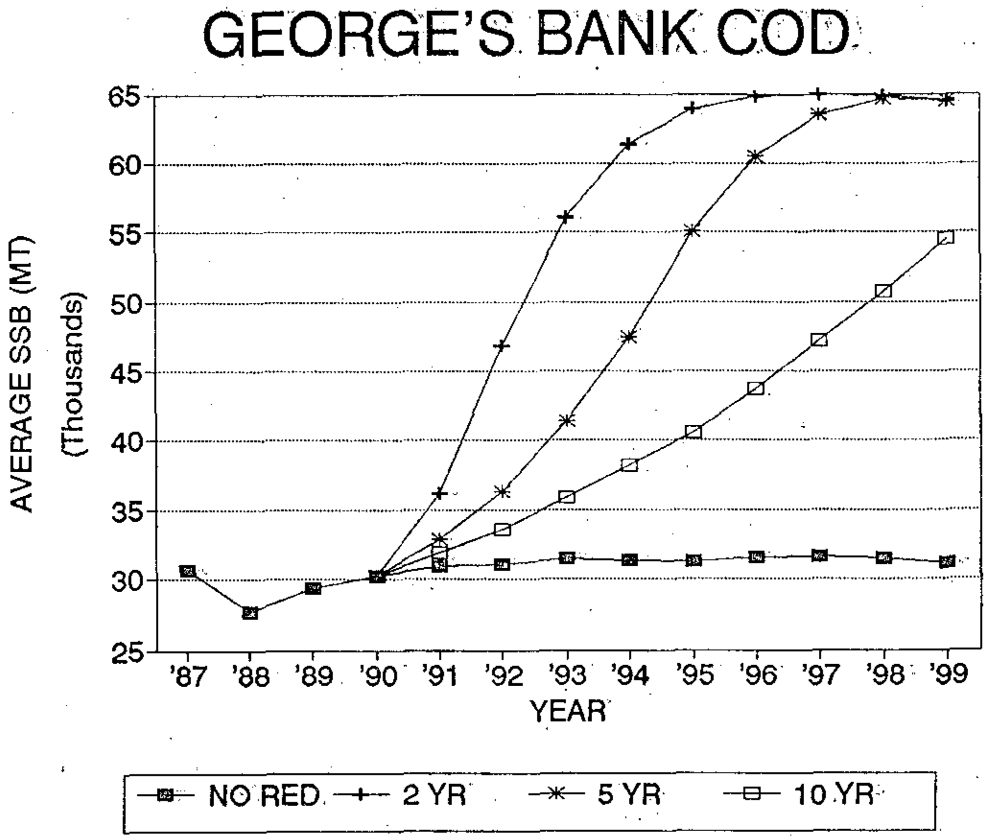


**Figure 6:** Projected average spawning stock biomass of cod under four scenarios of exploitation over the next decade. Each line is the average of 500 realizations.

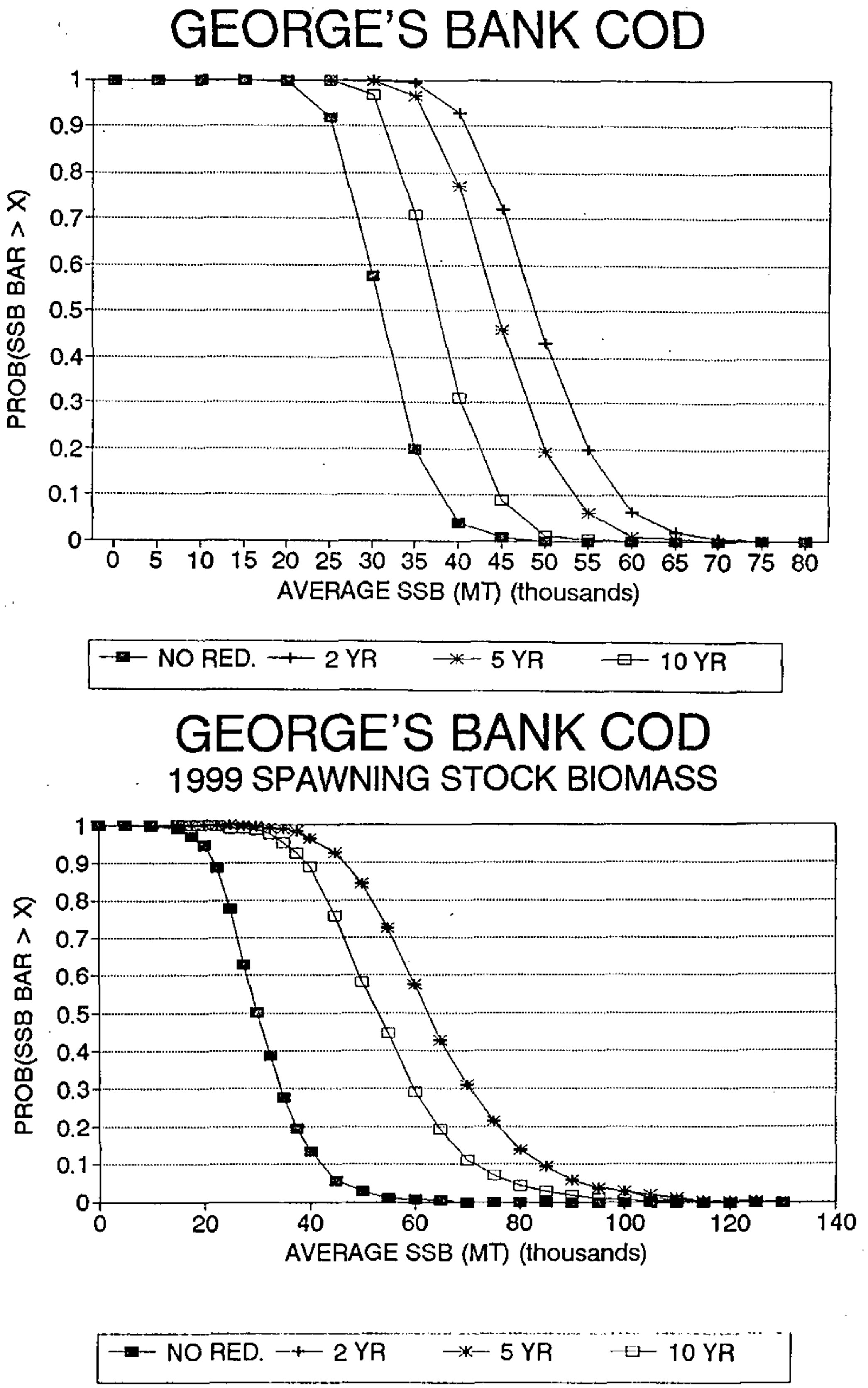


Figure 7: a) Probability that the average spawning stock biomass of cod over the 1990 decade will be greater than the amount given on the abscissa for the four different scenarios ; b) probability that the 1999 spawning stock biomass of cod will be greater than the amount given on the abscissa for the four scenarios.

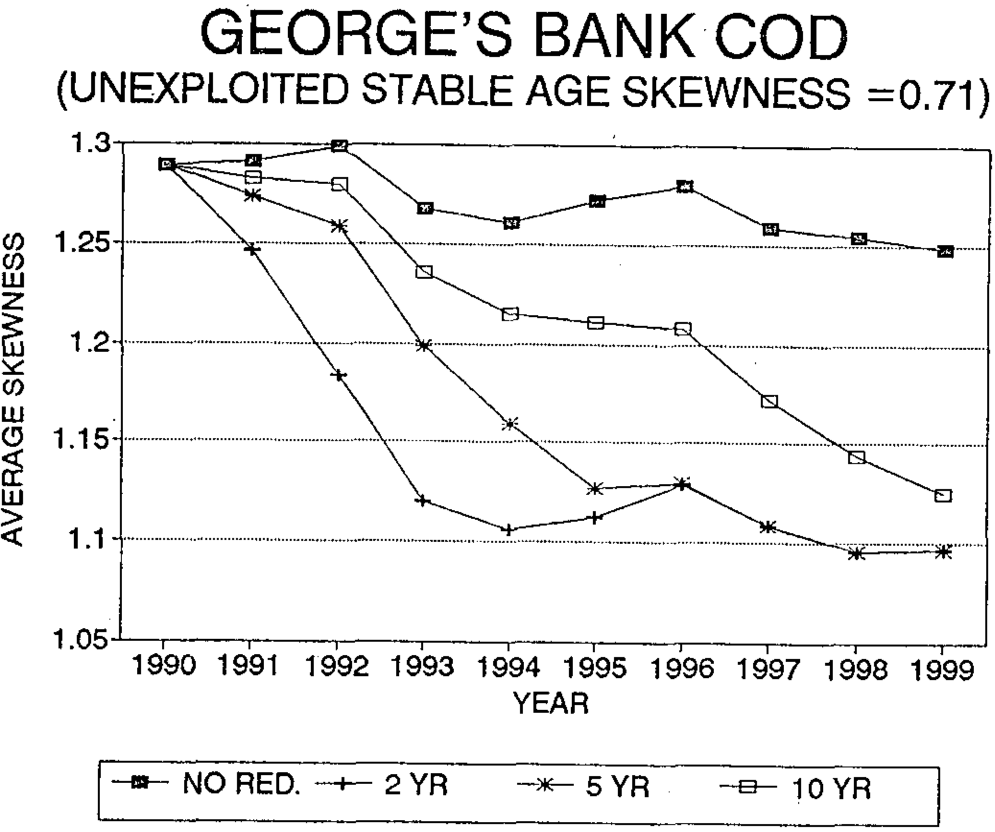


Figure 8: Average coefficient of skewness in each year for each of the scenarios. The unexploited skewness coefficient is estimated to be 0.71 for cod.

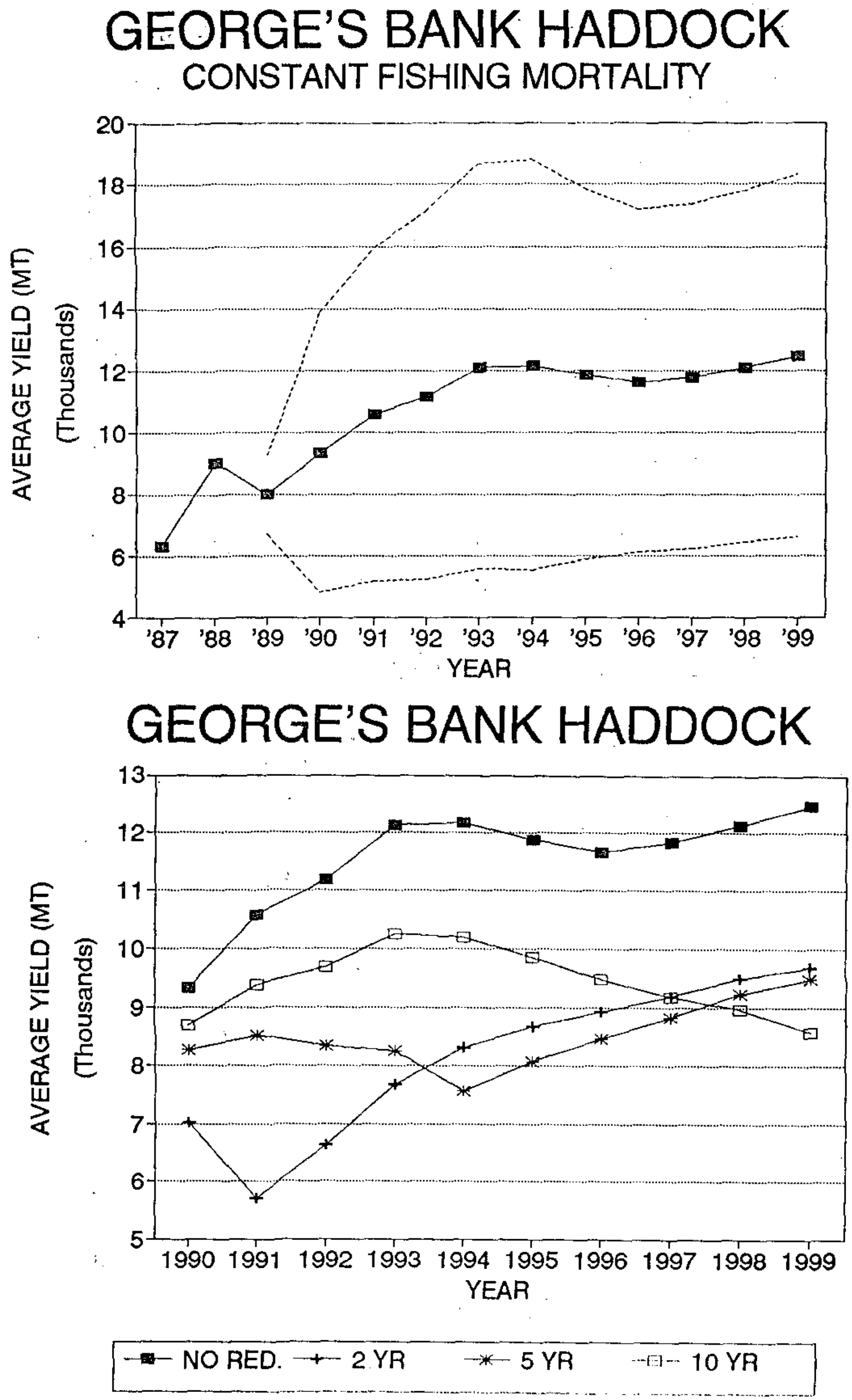


Figure 9: a) Projected yield for George's bank haddock over the 1990 decade. The solid squares are the means of 500 realizations with the rate of fishing mortality kept constant at the 1987 level, the dashed lines are plus and minus one standard deviation around the mean; b) projected average yield for the four scenarios of the rate of fishing mortality for haddock. Averages are over the 50 realizations.

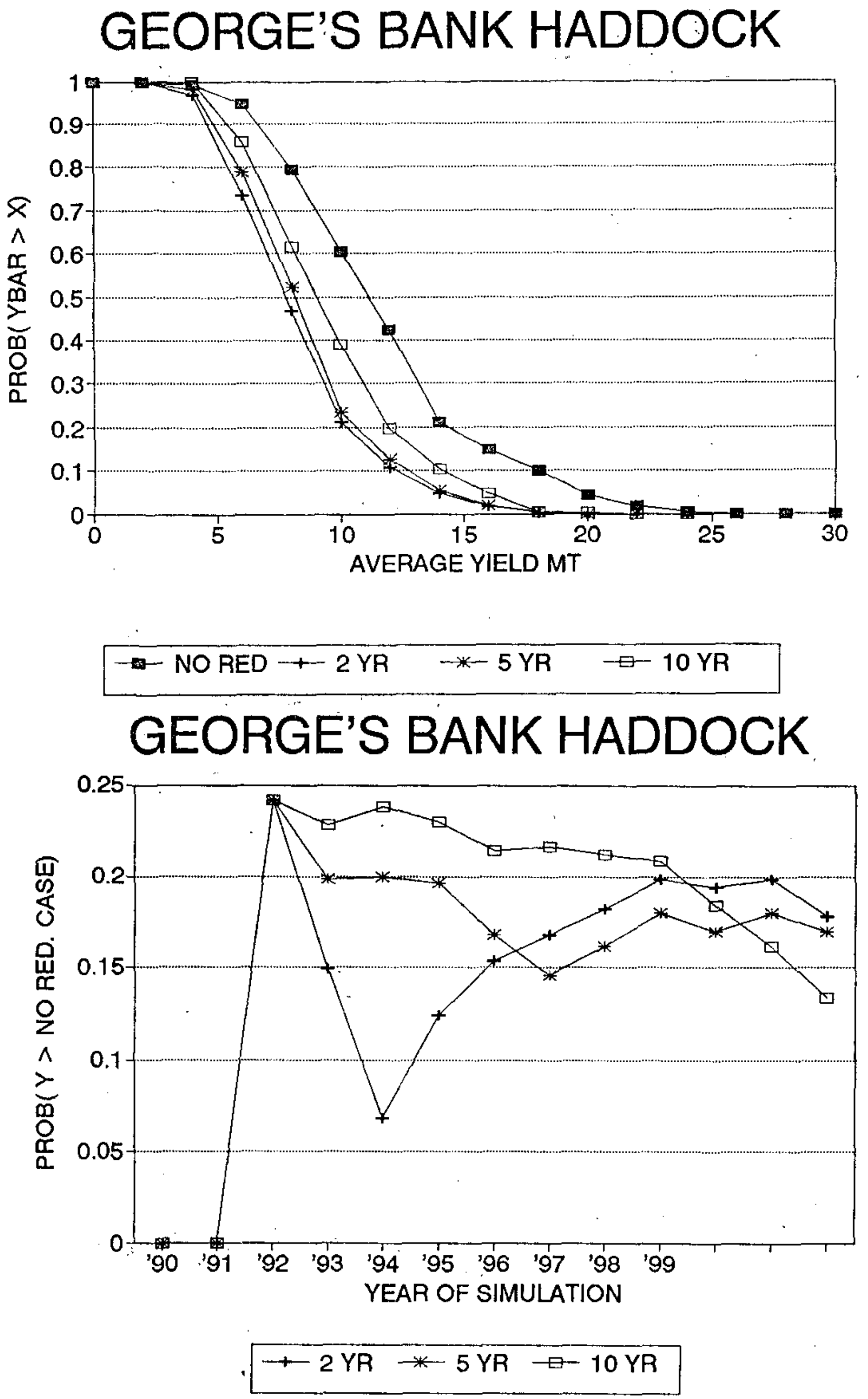


Figure 10: a) Probability that the average yield of haddock over the decade will be greater than the amount given on the abscissa for the four scenarios of exploitation; b) probability that the yield will be greater than the strategy of keeping the fishing mortality rate at the 1987 level.

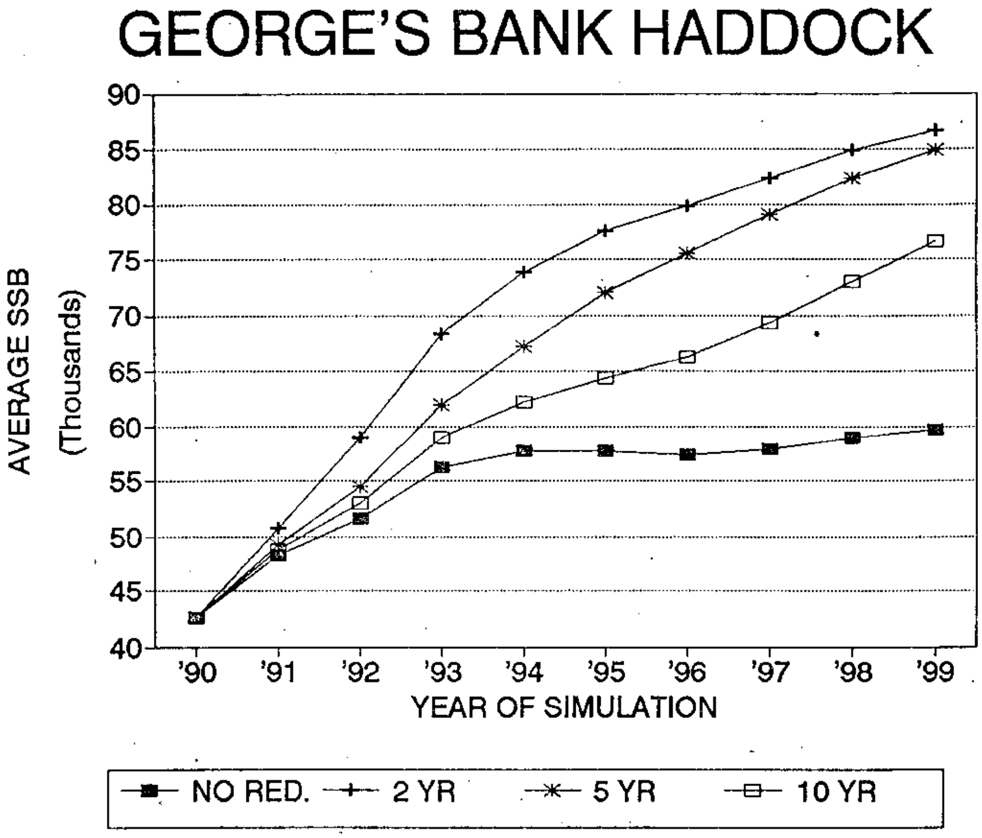


Figure 11: Projected average spawning stock biomass of haddock under four different exploitation scenarios.

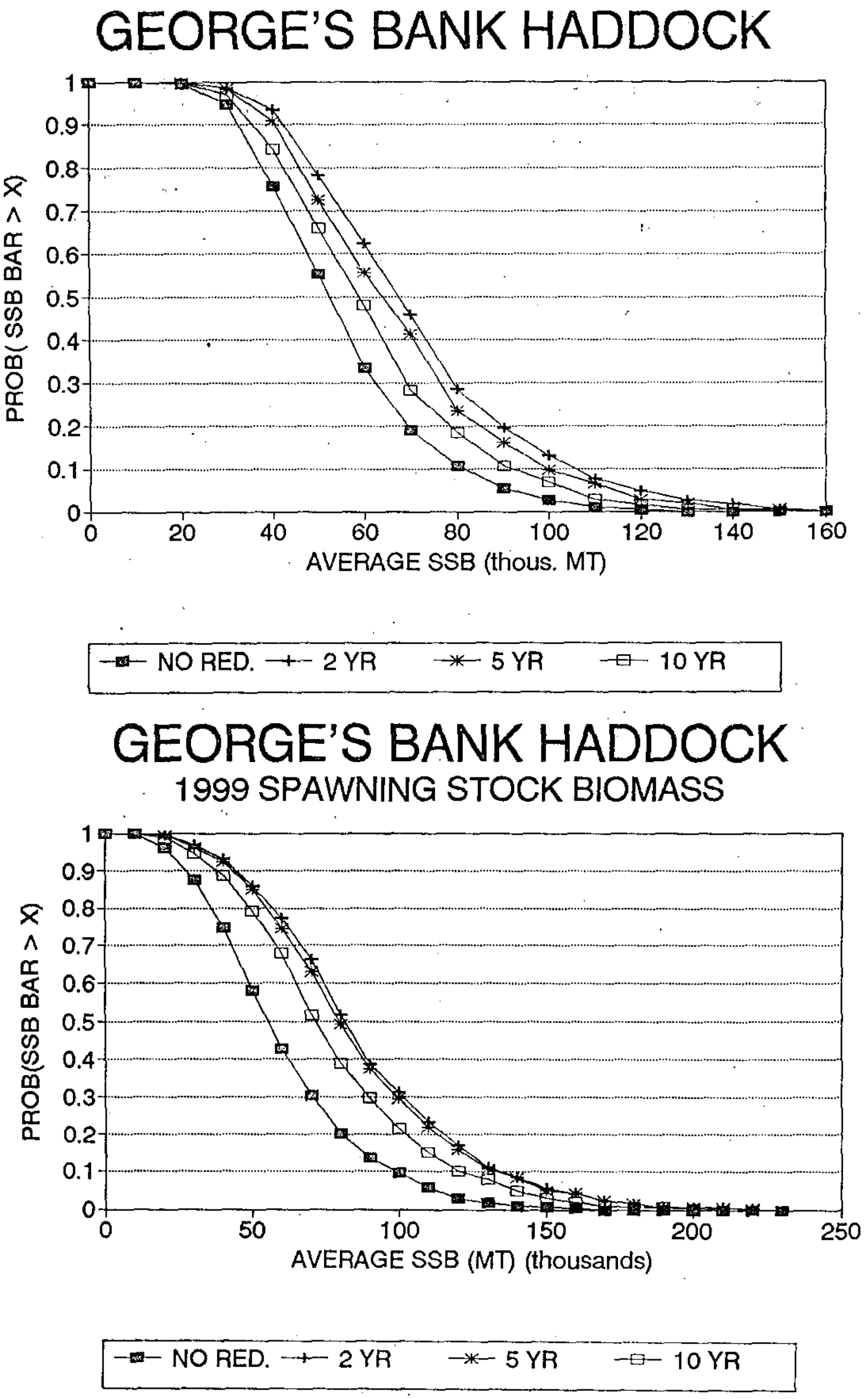


Figure 12: a) Probability that the average spawning biomass of haddock over the 1990 decade will be greater than the amount given on the abscissa under the four scenarios; b) probability that the spawning biomass of haddock in 1999 will be greater than the amount given on the abscissa.

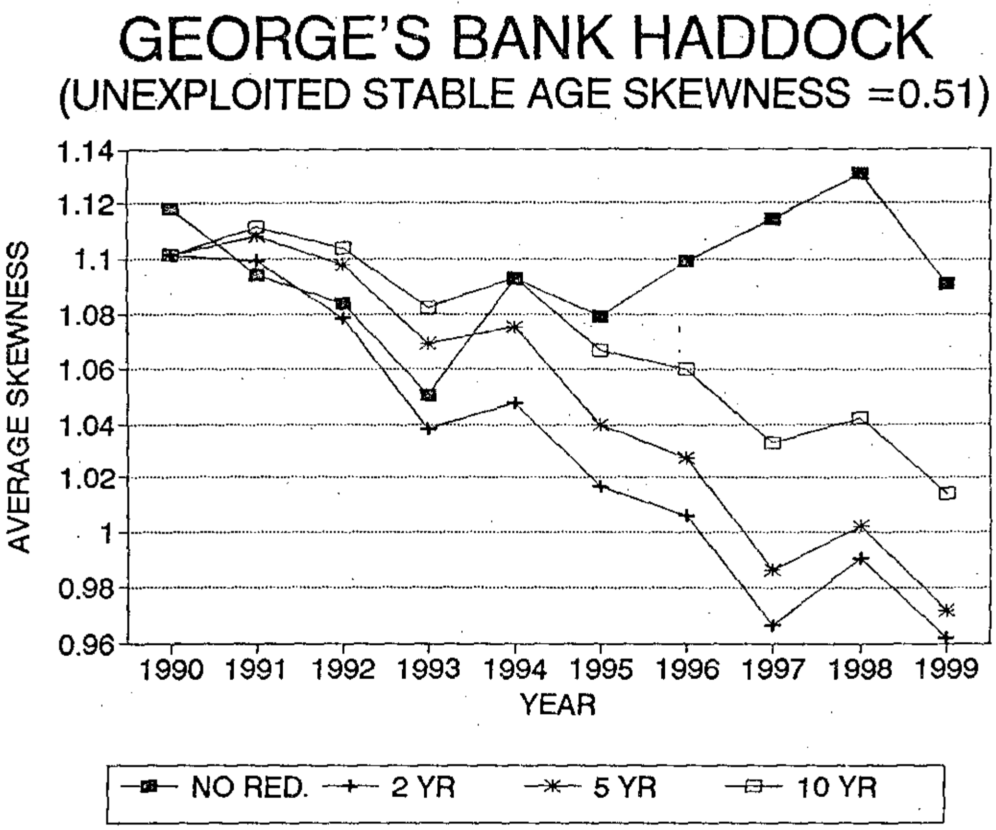


Figure 13: Average coefficient of skewness in each year. The unexploited coefficient of skewness for haddock is estimated to be 0.51.