IMPLICATION OF VARIABILITY IN RECRUITMENT FOR FISHERY MANAGEMENT IN THE WATERS OFF THE NORTHEASTER COAST OF THE UNITED STATES.

BY

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INTRODUCTION

The central tenant drawn by any observer of fishery resources in the open ocean be that observer a scientist, fishermen, or fish buyer can be summed up in one word - variability. Such observers are well aware of periods of time when populations are up and at other times when populations are low. Sometimes the length of these periods may be short, other times quite long. During periods of relative stability with regards to total abundance the variability within population comes to the fore. That is, in a given year the fish may be all relatively small while a few years later they may be relatively large. The driving factor behind this variability is the inherent nature of the recruitment process.

Recruitment in fisheries is defined here as the result of the process through which young fish are produced through the initial spawning and survival of eggs and larvae to the stage at which they "recruit" to the adult population. It is at the point of entry into the fishery that variability in recruitment is most frequently observed.

It has been the occurrence of extremely strong recruitment in a given year (fish hatched in a given year in the jargon of fishery scientists are called a year class or a cohort) that has resulted in the establishment of new or expanding fisheries. The occurrence of a very large year class of mackerel that was hatched in 1967 spurred the attention of the large distant water fleets onto these resources. The occurrence of the extremely large 1963 year class of haddock on Georges Bank triggered the attention to this stock by the distant water fleets the following years. All attempts to utilize and to manage fishery resources must face up to variability. This paper will examine the variability that has been observed in Georges Bank.
stocks of herring, cod, and silver hake and review the implications of this variability for selected fishery management considerations.

DESCRIPTION OF RECRUITMENT VARIABILITY

Recruitment variability has long been recognized by observers of fish populations and fisheries. The evidence of this can be found in numerous papers which have described histories of various fish stocks. Hennemuth, Brown and Palmer, in a series of papers beginning in 1979 and continued in 1980, reviewed patterns of recruitment distributions in various fishery resources around the world. Occasionally the plotted distributions of recruitment numbers resemble a typical normal distribution (Figure 1) that is a bell shaped curve with most of the sizes of the year classes clustered around a mid point with roughly equal numbers smaller and larger. However, most graphs of frequency of recruitment by size showed a distinctly different distribution. In these cases, most of the year classes were clustered quite close to the lower end of the scale of the observations with a few very large ones stringing out to the right. This can be seen in Figure 1 which is a schematic summary of the distributions of recruitment observation from 22 different stocks from around the world. They are scaled so that all stocks can be placed on one graph. For example, the point labeled 5x means that the numbers in those year classes are five times the mean of the numbers in the category labeled 1x.

In this paper we examine three stocks of interest on Georges Bank, cod, herring, and silver hake, their particular patterns of recruitment, and their
implications for fishery management. The Georges Bank cod stock is one of very few stocks in which the observed distribution of year class size appears to be relatively normal (Figure 4). The Georges Bank herring stock (Figure 5) follows the more typical pattern illustrated in Figure 1 as it is very dependent on infrequent large year classes. Similarly silver hake in the Georges Bank area shows the same dependency on large year classes (Figure 6).

Hennemuth et al. (1980) fit statistical distributions to these data and indicated that a normal distribution could be used to describe the cod data, while a lognormal distribution (a normal distribution fit to the logged recruitment data) best described the herring and silver hake. The lognormal distribution observed here can be contrasted with the regular normal in that it allows for a much longer tail that accounts for the occasional very large year class (Figure 3). Work is continuing on attempting to find the best distribution to describe these various sets of recruitment. In some cases the best description of what is taking place might not be a smooth curve connecting all of the observations from large to small but instead a distribution that occurs in two stages. One stage, occurring most of the time when environmental and ecological conditions are such that the average year class is relatively small with the spread around the average ranging from very small to slightly larger. Another stage occurring when environmental conditions are such that extremely successful year classes are produced. Nevertheless, the important observation here is that in most cases it appears that it is the infrequent occurrence of very large year classes that drives and supports many fisheries and this implies that much of fishery management revolves around how to utilize these very large year classes which occur only occasionally.
The term simulation refers to establishing a set of circumstances as close to that occurring in an actual situation as possible. These simulated data can then be treated by a variety of different conditions to try to gain an understanding of what their effects in real life might be. In the series of simulations in this paper the first step was to randomly draw numbers from the fitted descriptions described above for cod, herring and silver hake. This procedure results in an example of what the recruitment pattern in any given period of time could look like. Each simulation was run for a 67 year example. In simulation studies examples are run over and over again to determine the average of all the various runs. An example of the recruitment simulation for each species is given in Figures 7 through 9. It should be noted that such simulations are not predictions but rather examples of likely patterns that could occur. Therefore, these numbers do not relate to any given year. However, when one looks at the pattern of the data throughout the entire series one would expect in any given set of years to see the same relative frequency and magnitude of high and low year classes.

To evaluate the effects on differing fishing strategies an initial population for each stock was established based on information from virtual population analyses presented in the various Northeast Fisheries Center (NEFC) assessment documents. These initial stock sizes (numbers at age) were from values estimated for 1971. These initial stocks were subjected to a particular fishing strategy for a year. The population of the following year resulted from the remaining individuals which had not been caught or died naturally and a random input value of new recruitment from the recruitment distribution function. This was repeated each year. After several years
the entire population was made up of values generated from the recruitment distribution because all of the fish in the initial population has passed through the fishery.

Two strategies were examined. One was a constant catch strategy. Frequently, individuals in fisheries think in terms of maximum sustainable yield (MSY) and this leads to consideration of the maximum sustainable yield as a single value that should be harvested every year. In this particular simulation for each stock a constant catch value is obtained through trial and error as one that could be caught in all years. On a theoretical basis the catch that could be sustained over all years would have to be set to an extremely low level. It would be the value that the lowest recruitment would give if that recruitment happened to occur for the number of years equal to the number of age groups in the fished population. However, this is such an extremely unlikely event, so the more practical value would be one which could be sustained regularly under various recruitment frequencies generated in simulation runs.

In addition to the constant catch situation we examined constant fishing mortality. This latter situation is one which says managers will try to maintain the same effective fishing effort year after year perhaps by regulating the numbers of days fished by various vessel categories. This is also the constant fishing mortality that would occur under a quota system in which managers attempt to obtain a fishing mortality rate by estimating the populations at the beginning of the year and setting a quota at the value that would result in the desired fishing mortality.

Numerous studies have indicated fishing mortality rates that are of use in fishery management and these values of $F_{0.1}$ and $F_{\text{max}}$ were utilized in these
studies. $F_{0.1}$ is a modest fishing mortality rate that is frequently recommended because of its economic advantage as it gives higher catch rates. It has a biological advantage of maintaining a robust population size under most circumstances. $F_{\text{max}}$ is the value that would result in maximum yield per recruit with no consideration for catch per unit effort or stock size. In the management strategy of setting quotas to obtain a desired fishery mortality rate the mortality achieved each year would not be expected to be exactly the desired $F$ but should average to that value over time. In an attempt to regulate effort directly there is the problem of changes in effort and in availability of fish to the gear creating variation in the exact value of $F$ achieved each year. Nevertheless these simulations provide guidelines as to expected patterns of catch, stock size and fishing mortality that would be observed in these populations under strategies designed to maintain constant fishing mortality and catch.

RESULTS

**Herring**

For Georges Bank herring, fishing mortality rate at the $F_{0.1}$ level of 0.33 was used (Figures 10 and 11). This rate of removal has been considered as a possible management strategy for herring stocks. With herring this rate implies a situation where 59 percent of the stock survives from one year to the next and the 62 percent of those dying are harvested by fishing. This strategy gave an average catch of 127,000 metric tons (MT) essentially the same as the NEFC estimated MSY estimated value of 120,000 MT. This might be expected as the estimate of MSY was made from the same data base. However,
the implication that MSY could be taken on a constant year to year basis is obviously seen to be a misinterpretation. This average came from a series of catches ranging from 75,000 to 217,000 MT. The catch exceeded 200,000 MT in only one year and dropped below 95,000 MT 11 times. This contrasts with the observed history of the Georges Bank fishery where between 1961 and 1976 catches ranged from 43,000 to 373,000 MT and for five years in a row the catches exceeded 200,000 MT. The stock is now at such low levels that the commercial fishery is non-existent.

A second simulation was run with a constant catch (Figures 12 and 13). A constant catch of 120,000 MT caused the stock to be driven to levels where 120,000 MT could not be sustained. Runs with 100,000 tons were successful. It should be noted that if enough trials were run a few with 120,000 MT would be sustained and a few for 100,000 MT fail. However, 100,000 is the largest that could be sustained on a significant proportion of runs. This level of constant catch was achieved by low fishing mortality rates and large stock sizes. Such a strategy would result in very short seasons in some years. The fishing mortality values required ranged from .09 to .28. This means that fishing effort would be three times greater in a year of low abundance than in one of high abundance. All the values are quite low and the average (.16) for herring means a population where 70 percent survive from one year to the next and of those dying 44 percent are taken by fishing.

**Cod**

The simulation was run for the Georges Bank cod stock using a fishing rate of \( F_{\text{max}} - 0.3 \) (Figures 14 and 15). This is essentially the same rate
of removals as for herring. The value of $F_{\text{max}}$ rather than $F_{0.1}$ was chosen as this is the rate that was used in the groundfish management plan. In recent years fishing at this rate for cod has been compatible with fishing at a $F_{0.1}$ rate on haddock in the mixed cod and haddock fishery. The observed recruitment for cod does not show the occasional very large year classes common to a number of other species and thus a more level stock size results. The catches ranged from 23,000 to 33,000 MT with the average being 29,000 MT. Even this range while much less than that for herring is still greater than is often conceptualized when fishing at a MSY effort level is discussed. The 29,000 MT catch is less than the earlier NEFC MSY estimate of 35,000 MT. However, the situation with cod estimates are confounded by inadequate estimates of distant water fleet effort, limited sampling for age composition data in earlier years, and uncertain recreational catch statistics.

Simulations to sustain a constant catch were initially started with 35,000 MT. However, several different random selection of yearly recruitment failed to sustain a catch of 35,000 and 30,000 MT. Only when the catch used was lowered to 25,000 MT was it sustained (Figures 16 and 17). The fishing mortality rate ranged from .11 to .24 averaging .15. This is close to the $F_{0.1}$ value of 0.16. This is not unexpected as 25,000 MT is 86 percent of the 29,000 MT average under $F_{\text{max}}$, but the fishing rate required is 50 percent less. (A run at $F_{0.1}$ would of course give a range of catch some less than 25,000 MT and some greater.) The range of fishing mortality rates means that two times as much effort must be expended in a year of low abundance as in one of high abundance. An $F$ of .15 means that only 70 percent of the cod survive from one year to the next with 43 percent of those dying taken by fishing.
Silver hake

Silver hake catch simulations were run at $F_{0.1}$ of .65 (Figures 18 and 19). As silver hake have a higher rate of natural deaths than cod or herring, this fishing rate can be interpreted as a stock where only 35 percent survive from one year to the next and where of the 65 percent who die, 62 percent are harvested. The average catch was 69,000 MT considerably higher than the current NEFC estimate of MSY of 55,000 MT. Further study is necessary to resolve this difference. It should be noted that of the 67 years in the simulation, 14 had yields of 50,000 MT or less. However, the range was between 31,000 and 139,000 MT. These catches contrast with silver hake catches of 170,000 and 239,000 MT in 1964 and 1965 after which catch declined to 18,000 MT by 1969.

Constant catch at 60,000 MT was sustained at fishing mortality rates that ranged from $F = .17$ to $F = .98$ (Figures 20 and 21). This means that to maintain this catch the effort required in a given year of high abundance was less than one fifth that needed in a year of low abundance. A fishing rate of .98 means that only 25 percent of the silver hake population survives from one year to the next and of those dying 71 percent are removed by fishing.

CONCLUSION

The simulations examined in this paper were designed to examine the degree of stability that would occur under certain differing strategies of fisheries management. The value of MSY is quite different depending on whether it is considered to be the highest value that can be sustained over a period of time instead of the average of the values that can be taken at a fishing effort level estimated to be the rate of fishing that can be sustained
over time. The latter definition is the one used in the publication of the Northeast Fisheries Center. To achieve stability in catch requires a level low enough so that the fish produced in peak years can be carried over to provide yields during years of lower recruitment. This strategy implies the ability to widely vary the fishing effort. Considering that the total effort available does not change rapidly this strategy requires moving from species to species. One might expect that the level of total catch that could be sustained would be less than the sum of the individual species if there are fisheries and biological interactions. A constant effort strategy results in a variable catch although the catch would be less variable when summed over all species than the individual species values due to fishing interactions.

Neither strategy can be easily applied. Tying up vessels to maintain constant catch is difficult while attempts to maintain constant effort is influenced by price fluctuations. If prices do not increase when abundance is low vessels may divert their efforts as catch rates decline. However, the opposite could happen if prices go up as catch goes down in such a way as to increase the profit margin. At high levels of abundance effort may be diverted elsewhere if prices fall.

Nevertheless, review of simulations of those strategies based on distribution functions of historic recruitment can be instructive as to the results that might be expected over time. The central tenet of variability in fish stocks driven by differing recruitment is clearly illustrated.
LITERATURE CITED

Figure 1. Composite frequency of year class size for 22 different fish stocks for time periods of 15-40 years.
Figure 2. Normal probability density function.

Figure 3. Lognormal probability density function.
Figure 4. Frequency distribution of Georges Bank cod recruitment estimates, 1960-1975.

Figure 5. Frequency distribution of Georges Bank herring recruitment estimates, 1963-1974.

Figure 6. Frequency distribution of Georges Bank silver hake recruitment estimates, 1955-1973.
Figure 7. Cod recruitment values used in simulation of fishery at $F = 0.3$. 

Recruitment (no. x 10^6) vs. Year
Figure 8. Herring recruitment values used in simulation of fishery at F=3.3.
Fig. 9. Silverhake recruitment values used in simulation of fishery at $F = 0.65$. 

![Graph showing recruitment values over years with peaks and troughs indicating variability.](image-url)
Figure 11. Herring stock size of catch at F = .33.
Figure 12. Herring stock size at catch of 100,000 mt per year.
Figure 13. Harvest fishing mortality rate value at catch of 100,000 MT per year.
Figure 14. Cod catch at F = 3.
Figure 11. Cod stock size at catch of 25,000 MT per year.
Figure 17. Cod fishing mortality rate value at catch of 25,000 MT per year.
Figure 18. Silverhare catch at F = 0.65.
Figure 19. Silverhake stock size of catch at $P=0.65$. 

Graph showing the size of the silverhake stock over time with peaks and troughs indicating variations in catch size.
Figure 20: Silverhake stock size at catch of 60000 MT per year.
Figure 21. Silverhake fishing mortality rate value at catch of 60,000 mt per year.