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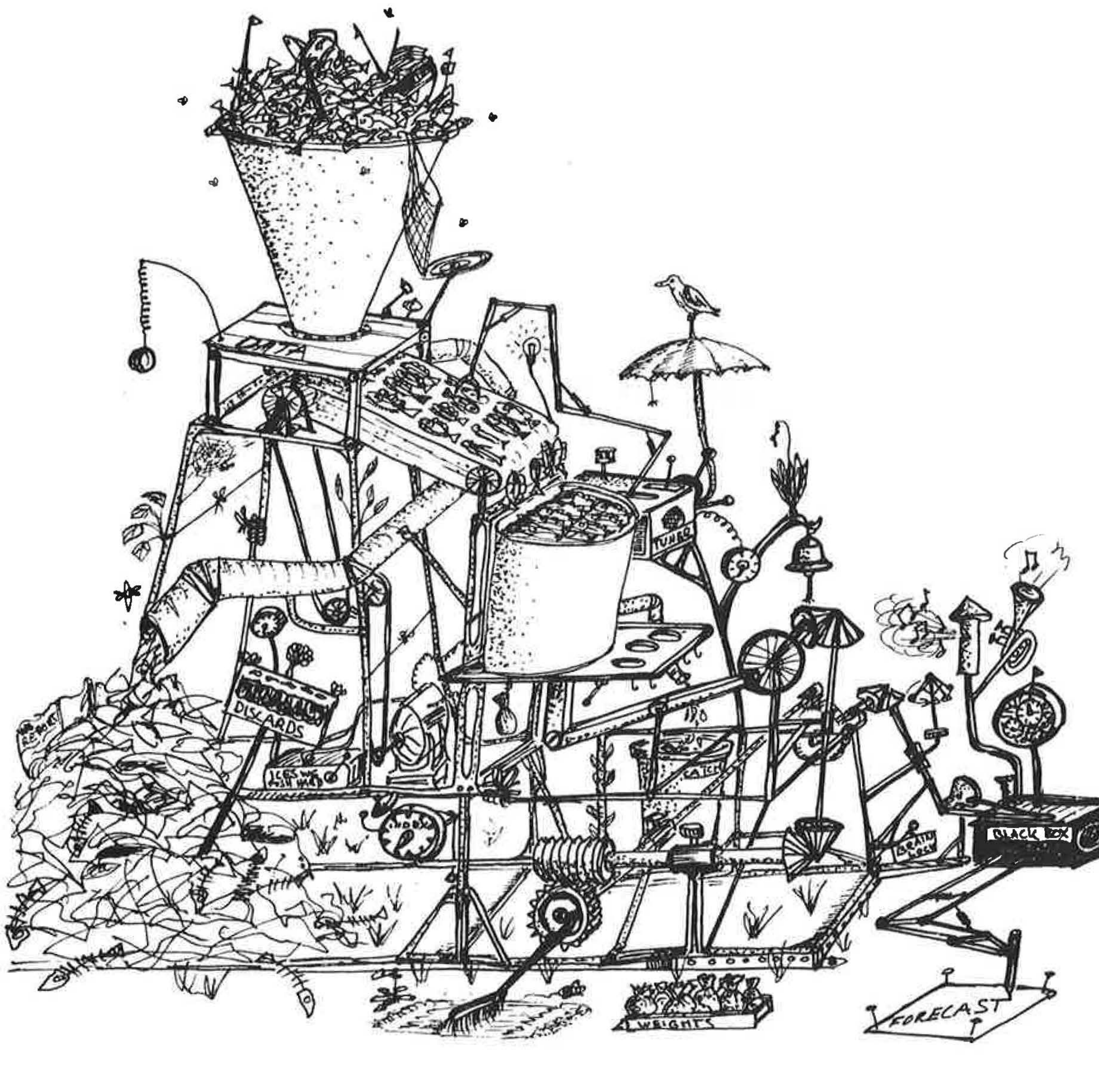

"The Ultimate Filter"
by M Hilden

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Participants

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Dr E.D. Anderson, ICES Statistician, also attended the meeting.

1.2 Terms of Reference

It was decided at the Statutory Meeting in Copenhagen in 1984 (C.Res.1984/2:4:14) that the Working Group on Methods of Fish Stock Assessment (Chairman: Dr J.G. Shepherd) would meet at ICES Headquarters from 20-26 November 1985 to examine:

i) sensitivity of assessment techniques to assumptions concerning natural mortality,

ii) effects of discarding on assessment calculations especially mesh assessments,

iii) advances in simpler methods of assessment (especially those based on size composition).

In addition, the Working Group decided to return briefly to two of its previous topics, the estimation of recruitment and the "tuning" of terminal fishing mortalities for VPA.

1.3 Working Papers

Working papers were available on all these topics and are listed in Appendix A. Where the material has not and will not be published elsewhere, the content of these has, where appropriate, been summarized in this report. The reports of previous meetings of the Working Group are available in the ICES Cooperative Research Report Series (Nos. 129 and 133).

1.4 Notation

The Working Group adhered so far as possible to the standard notation used previously, expanded as necessary. An updated summary is given in Appendix B.

1.5 Work Carried Out

The Working Group discussed in detail the working papers on the effects on assessments of age-dependent mortality and discards. It was apparent that, in both cases, there were discrepancies between the theoretical expectations of the effects of these factors on short-term forecasts and the results of practical tests using real data. The theoretical studies had also not covered all ramifications of interest. The Working Group decided to undertake further investigations of these aspects. The techniques required for the study of the effects of age-dependent natural mortality and of discards are very similar, both theoretically and practically, for both short-term and long-term assessments. It was, therefore, decided to organize both the investigative work and the report along these lines rather than on the basis of the topics distinguished in the terms of reference. The report of the work on short-term aspects is, therefore, in Section 2, and that on long-term aspects in Section 3.

The Working Group also considered in some detail the more relevant papers on length-based assessments available from the FAO/ICLARM/KISR Conference in Sicily (Anon., 1985b) together with the working papers presented at this meeting, but did not undertake any further investigations of these topics. An account of the discussion is given in Section 4.2.

The report on the "reprise" topics is in Section 5, and Conclusions and Recommendations are in Section 6.

1.6 Discarding: Background and Preliminary Overview

1.6.1 Background on discarding

Fishery discards are among the most difficult of population assessment data to monitor accurately. The operational problems of estimating the size, age, and magnitude of discards at sea can be great (Daan, 1976; Jermyn and Robb, 1981; Saila, 1983). Fishermen generally cull small (undersized) fish and unwanted species from the catches virtually as soon as the catches are deposited on deck. Under these circumstances, it may be impossible to obtain unbiased samples of the raw fishery catch. The number of trips necessary to be sampled at sea in order to quantify the magnitude and size composition of discards to within levels of precision similar to landings from a particular fishery may well be beyond the resources of most scientific organizations. Thus, data on fishery discards (if available at all) are expensive to obtain by direct observation and are generally imprecise relative to landings information. It is, thus, relevant to consider the potential sensitivity of assessment calculations to the inclusion of discard estimates before embarking on large-scale and expensive programs to improve discard estimates or maintaining those discard sampling programs currently deemed adequate.

Fish and invertebrate catches may be discarded for a variety of reasons, including:

1) undersized individuals of marketable species (under legal or market minimum size),

2) undesirable (unmarketable or prohibited) species,

3) specimens damaged as a result of fishing operations,

4) specimens infected with parasites or otherwise unmarketable,

5) by-catch or trip quota regulations in force resulting in discarding of fish otherwise marketable.

The amount of fishery discards in relation to landings is, in turn, influenced by a variety of factors including net mesh size (relative to minimum legal or market sizes of fish landed), season and area fished, the age or size structure of the population, the particular regulatory scheme in place, and various economic considerations (e.g., discarding of less desirable species may be greater at the beginning of a vessel trip than near the end in order to leave hold capacity for valuable species).

Few analytical investigations of the sensitivity of assessment calculations to the inclusion of discard mortalities had been published prior to this Working Group meeting. It was, thus, a task of this Group not only to consider the theoretical consequences of including or not including such data, but to demonstrate these effects in several worked examples both for short-term and long-term assessment calculations (Sections 2 and 3).

The Working Group did not extensively consider discard sampling and analysis schemes, but noted that significant methodological and statistical issues remain to be explored (Saila, 1983; Murawski, 1985). Several different methods have been employed in the past to estimate the amount and size/age composition of discards from individual vessels or fleets. These methods can be grouped as either being based on direct observation of the discards (at sea or in the ports) or based on "back-calculation". Briefly, five such methods are:

1) direct measurement of discard at sea (e.g., Daan, 1976; Jermyn and Robb, 1981),

2) assessment of discards from unsorted catches landed and subsequently subjected to culling on land,

3) interview observations from vessel landings (combined with a small subsample of discards returned to the port) (Nicholson and Brown, 1985),

4) back-calculation of the size structure and total weight of discards, given size frequency samples of the unsorted catch and the resultant landings (method of Hillis, 1981),

5) back-calculation of the magnitude of discards of undersized commercial fish and less desirable species based on comparison of commercial landings and the results of research vessel surveys (Mayo et al., 1981).

A working paper by Nicholson and Brown (1985) reviewed methodology to estimate discard weight, number, length frequency, and associated variance statistics for Nephrops catches, given data from landings samples, combined with a small unsorted sample obtained by the vessel skipper. If the unsorted sample can be considered unbiased, then the overall technique may be preferable to standard "at-sea" discard sampling methods because of the likely increase in sampling frequency possible at comparable costs.

1.6.2 A preliminary overview of assessment calculations in relation to discards

It seems very likely that the importance of discards is highly dependent on the calculations concerned; some may be quite sensitive, others not (Shepherd, 1985; Murawski et al., 1985). The effects of omitting discards may also be a systematic error (bias) of some sort in the results of a calculation. Since discard estimates are invariably subject to sampling error, including them will introduce random errors and, thus, increase the variance. Thus, ideally, one should consider the trade-off between bias and variance arising from including or excluding discards. It is possible that, if discards are significant but subject to high sampling variability, including them may increase the total prediction error.

Certain general principles regarding the handling of assessment calculations seem clear (and these largely apply to the inclusion of variable natural mortality). It is essential to treat discards in all parts of the stock assessment consistently (i.e., it may be misleading to compute biological reference points (F_{max}, $F_{0.1}$) with discards included in the partial selection pattern and not treat the VPA calculations likewise). Traditional Y/R isopleth sections (Murawski et al., 1985) computed with various selection patterns simulating discarding may overemphasize the negative impacts of discarding on fishery yields, since higher Fs on earlier ages will be associated with larger estimates of population numbers at age. Thus, there will be a partial compensatory effect in steady-state yield calculations [(Y/R) x Recruitment] of including discards simultaneously in Y/R and VPA.

Also, if such a compensation occurs, then it is difficult to directly compare Y/R results based on two different assumed selection patterns.

Similarly, if catch numbers at age are inclusive of discards, then landings forecasts based on population size estimates from the VPA should deduct projected discards from the catch projections.

If the proportions of discards in relation to landings remain stable between years, then their effects may cancel out in the calculations. However, if discard rates are likely to change (e.g., as a function of year-class size or change in fishing practice), then catch projections and biological reference point computations must reflect the projected selection pattern. If discard rates vary (Section 1.6.3), the question then becomes whether or not they are predictable. If they vary predictably, it is, in principle, possible to include their effects and estimate them. If they vary unpredictably, one can only assume that they remain constant and accept that the estimates are subject to increased error. In this context, the level of sampling error can clearly be included as a contribution to unpredictability.

These arguments suggest that a useful analysis of the effects of discards could be set as in Table 1.6.1 (Shepherd, 1985). Here there are several key factors identified:

1) the nature of discard rates (constant, variable but predictable, or variable and unpredictable),

2) the nature of the calculation (constant selection or changing selection at age),

3) time scale of calculation (short- or long-term),

4) quantity being estimated (yield or biomass).

If discards are significant, but are not included in VPA assessment calculations, then the resultant stock sizes cannot be regarded as nominal estimates of populations. Rather, they represent relative abundance indices calibrated to give appropriate catches from the <u>relative</u> fishing mortality rates, ignoring the discard mortalities. In the context of stock assessment, the biases cancel to some extent. However, appropriate caution should be used when employing the results of such VPA calculations to the wide range of ecological studies outside of strict stock assessment (multispecies modelling, trophic dynamics, studies of density-dependent growth and mortality). If discards are not included in assessment calculations, then instantaneous fishing mortality rates (F) calculated from cohort data on sequential research vessel surveys will be higher than from the VPA, with the magnitude of the bias dependent on the proportion of the various ages discarded.

1.6.3 <u>Statistical analysis of discard rates</u>

Theoretical expectations of the probable impact of discarding on various assessment calculations (Table 1.6.1) highlight the need to determine both the variability and predictability of the proportion of the catch of each age group which is discarded. A substantial data set on discarding of haddock in Roundfish Sub-area IV for the period 1975-1984 (Table 1.6.3.1) has been compiled primarily based on sampling of the Scottish fisheries. Inspection of the proportion of the human consumption catch discarded by the international fishery indicates variability particularly for ages 2-4. However, detailed analysis of this effect in the underlying

Scottish data was necessary to assess both the magnitude and predictability of the variation.

The basic data analyzed were the proportion discarded of the Scottish human consumption catch (i.e., landings and discards) in 1975-1984 by age (Figure 1.6.3.1) and gear type. An analysis of variance was performed for each age separately using a fixed-effects model of the discard proportion, i.e.,

$$D_{ij} = M_{..} + Y_{i.} + G_{.j} + e_{ij}$$

where D_{ij} is the discard proportion in year i for gear type j, Y_i is the year effect, $G_{.j}$ is the gear effect, M is the grand mean, and e_{ij} is the residual error assumed to be independent normal random variables with mean 0 and variance σ^2. The residuals from the models for each age were plotted and appear to be approximately normal (Figure 1.6.3.2). Various transformations (square root, arcsine square root, natural logarithm) were tried, but did not improve the model fits or normality of the residuals.

The fitted ANOVA shows that there is a significant (P = 0.05) effect of year for ages 2-5, with the effect strongest for ages 3 and 4 (Table 1.6.3.2). The analysis for age 1 shows that, since almost the entire age 1 catch is usually discarded, the proportion is essentially constant. There was also a significant effect of gear type for age 2 which is attributable to a very low discard proportion from the Nephrops trawl.

The presence of significant year effects can, at least in part, be attributed to changing discard practices due to the influence of large or small year classes entering the fishery leading to higher or lower discarding rates, respectively. These year-class effects can be traced through the data in a multiple classification analysis which tabulates the cell means as deviations from the grand mean for each year and gear type (Table 1.6.3.3). The large 1979 year class is a case in point.

Correlations between IYFS estimates of the abundance of age 1 haddock and catch-per-unit-effort data from the human consumption fishery were performed using CPUE data with and without discards. Correlations were significantly improved with the addition of the discard data:

Correlation coefficients: CPUE age 1

	Human consumption landings	Landings and discards
IYFS (age 1)	0.057	0.715
Landings and discards	0.143	-

The discard rates of age 1 haddock are generally in excess of 90%, and the overall fit of IYFS to CPUE data was improved greatly by accounting for the variability in discard proportion.

1.7 Age-Dependent M: Background

1.7.1 Overview

A number of working papers were presented on these two subjects. Papers D1, D2, D3, and DM1 all considered the effects of discard mortality on the calculation of yield curves, while DM1, M1, and M2 all considered the effect of different levels of natural mortality or of its variation with age on the calculation of yield curves. One general point to arise was that, when assumptions about the natural mortality or the discard rate are changed, it is necessary to reinterpret the data (by VPA or otherwise) in order to re-estimate other parameters in a consistent fashion. Secondly, it is very much less confusing if yield curves are presented as yield (or yield per recruit) relative to the current level on the Y-axis, and fishing mortality relative to the current level on the X-axis. An illustration of such a plot for different assumed levels of natural mortality is shown in Figure 3.1.1.

Such a plot is useful because it takes account of all the consequent changes in other estimates (fishing mortality, exploitation pattern, recruitment, yield per recruit) that are affected by the change in natural mortality. Such plots arise naturally when the method of Jones (1961) is adopted, and this, moreover, is a remarkably simple way of investigating the effects of changed assumption.

Investigations reported in working papers included work on the following:

1) Investigations of the effect of eliminating discard mortality.

Murawski et al. (D2) conducted an investigation into what effects discards have on yield per recruit. These were presented in the more familiar form of Y/R against absolute fishing mortality. They indicated that the losses and gains that might be obtained from eliminating hypothesized levels of discarding from a series of fish species on Georges Bank could be considerable.

2) Investigations of the effect of ignoring discards when calculating the effect of changes in fishing mortality on yield.

Both Shepherd (D5) and Stokes (DM1) used Jones' (1961) approach to consider whether omitting estimates of discards from the calculation of the response of yield (landings) to fishing intensity change would seriously affect the conclusions that would be drawn. Both Shepherd, who developed general formulae, and Stokes, who considered a specific case, concluded that ignoring discards in the calculation of relative yield (landings) curves would have little effect on our perceptions of likely changes in yield when fishing mortality changes.

3) Investigations of the influence of the general level of constant natural mortality rate on the calculation of yield curves.

In a verbal presentation, Stefansson showed that, for Icelandic cod, the influence of adopting different levels of constant mortality rate was to change both the shape of yield-per-recruit curves and the position on them of the current level of fishing mortality (see Section 1.7.2).

Pope (M1) showed similar results and showed how such curves could be rescaled as relative yield curves (see Figure 3.1.1). He noted that, quite generally at the current position, dy/df would be a monotonically increasing function of M.

4) Investigations of the influence of variable M at age on yield calculations.

Using the concept of relative yield, Pope was able to produce a tentative theory that the shape of such curves would be more influenced by the average level of M (over the exploited life) than by its distribution with age. He also produced several examples based upon North Sea roundfish which supported this theory. He stressed, however, that, when natural mortality varied with age due to predation mortality, it was inappropriate to calculate yield curves (relative or otherwise), since the level of natural mortality would change with exploitation levels on predators and other prey species/years. He drew attention to work of the Multispecies Working Group on this subject and to two new working papers presented to that meeting by Shepherd and by Pope.

Sparholt (M2) presented results for North Sea herring showing the different perceptions caused by using the Multispecies Working Group levels of predation mortality rather than the level used by the Herring Working Group. He presented these results in terms of Y/R. It was considered that this work might be used to give an example of how the problem could be recast in terms of relative yield curves to help clarify the changes in perception.

1.7.2 Icelandic cod: example of effect of varying M

A study had been carried out by Stefansson with catch data on Icelandic cod to examine the effect of varying M on fishing policy. The data used were landings for the period 1964-1983, and the interest lies in the effect of M on the TAC for 1984 on the one hand, and on long-term fishing policy on the other.

To automate the whole estimation procedure, the following computational approach (which includes a number of approximations) was used. First, initial terminal F values were inserted, with a value of M, into a VPA procedure which yielded an F table. From this table, a new set of F values for the terminal year was computed from the average for each age group over the years 1977-1980. For the oldest fish, F was reset to the average over the three oldest age groups of the new terminal F values. A new VPA run was then done to obtain a set of stock sizes and average Fs for prediction. Recruitment for the terminal year was set to the average recruitment from the latter VPA run.

This whole procedure was repeated for values of M ranging from 0 to 0.4, whereas M is usually assumed to be 0.2. As was to be expected, the current stock size estimate (Figure 1.7.1) varies immensely with M. Thus, our views will change quite a bit about the stock size, depending on which M we assume to be correct.

Note, however, that the ordering of age-group sizes remains unaffected. Similarly (Figure 1.7.2), our view of what values of F are being used varies a lot depending on what level of M is assumed, but note that the overall pattern is always similar. Naturally, neither of the above two results is of primary interest, since they individually say nothing about fishing policy.

For short-term fishing policy, we used the status quo TAC of Pope (1983). The results are shown in Figure 1.7.3 and are seen to be almost completely independent of M. Thus, short-term advice for the Icelandic cod seems completely independent of what values of M are used, at least when they are taken as constant over all age groups.

Long-term advice is a different matter, however, as the yield curves (Figure 1.7.4) tend to vary quite a bit as M changes. One must realize that the yield curves are not strictly comparable since the perception of the current F value also varies with M. The perceived current state is indicated with an arrow for each curve. On the extreme curve for M = 0, we would believe ourselves to be heavily overfishing the stock, so that one would see an increase in yield by decreasing the effort. However, at the other extreme for M = 0.4, the yield curve is monotonically increasing over the range of F values considered, and one is led to believe that an increase in effort would result in greater yield. This controversial result is also obtained by going from M = 0.1 to M = 0.3. These results show that long-term management advice does indeed depend on the value of M assumed and may even be critical in some cases, although not this one.

2 SHORT-TERM ASSESSMENTS

2.1 Introduction

2.1.1 Theoretical background

The Multispecies Working Group (Anon., 1986) estimated very high levels of natural mortality on the younger ages of most North Sea fish species studied. This was particularly true for the roundfish. Preliminary assessments of the impact of these changes on catch forecasts suggested that they could be substantial for North Sea haddock and whiting but relatively small for North Sea cod. Further studies in the current meeting using standard North Sea roundfish methodology (see Section 2.2) confirm that result, although they indicated that the differences were much less if fishing mortality were not changed on 1-year-old fish in year t and t+1 to make the catches and the survey indices compatible. Equivalent studies of Icelandic cod (Section 1.7.2) suggested that changing M had very little effect on catch forecasts. These results, thus, contradict each other. Those for haddock and whiting are also at variance with a theory due to Pope (1983) that status quo catch forecasts are little affected by the level of M. This theory was developed on the assumption of separability of fishing mortality into age and year effects. In simple terms, the theory states that if fishing mortality is constant then the average catch ratio between successive ages in cohorts can be used as a multiplier to predict catches in non-recruit ages in year t+1 from catches in year t, e.g.,

$$C(a+1,t+1) = C(a,t) \times \text{Average } [C(a+1,y+1)/C(a,y)] \qquad (1)$$

In the constant F situation, catches of recruits can be predicted by using the average ratio of these catches to relevant recruit studies to act as a multiplier for the recruitment index R(r,y) which predicts recruitment in year y for age r fish, e.g.,

$$C(r,t+1) = R(r,t+1) \times \text{Average } \frac{C(r,y)}{R(r,y)} \qquad (2)$$

Thus, in this simple case, catches of all ages may clearly be predicted without any use of natural mortality. When F changes from year to year, it is possible to adapt the formulae using fishing effort without any use of M being made. These arguments are based upon the separability of fishing mortality into year and age effects, but it is possible that separability is a sufficient rather than a necessary condition for M to have no effect on short-term catch forecasts. The result for the Icelandic cod (see Section 1.7.2) shows that M changes have little effect on catch forecasts for this stock, which is confidently asserted to be non-separable, and suggests that this is the case. It may, therefore, be that the effects of M changes on catch forecasts may at least partially be a result of the prediction methodologies used. A search for the conditions under which prediction methodologies are invariant under M change (or at least robust with respect to it) thus seemed indicated.

Increasing natural mortality in an assessment produces two main effects. Fishing mortalities are generally reduced and population sizes are increased. The changes are, of course, such that

$$C(a,y) = P(a,y)\, \frac{F(a,y)}{Z(a,y)}\, [1-\exp-Z(a,y)] \qquad (3)$$

holds for any M(a).

We will consider two levels of natural mortality: M(a), representing the traditional assumption (e.g., M = 0.2) and M*(a), which is some new level. We use * to denote all parameters estimated with this level of M*(a). We note, therefore, an important consequence of equation (3) is that

$$\begin{aligned}\frac{C(a+1,y+1)}{C(a,y)} &= \text{CRATIO}\\ &= \frac{F(a+1,y+1)Z(a,y)[1-\exp-Z(a+1,y+1)]\exp-Z(a,y)}{F(a,y)Z(a+1,y+1)[1-\exp-Z(a,y)]}\\ &= \text{CRATIO*} \qquad (4)\\ &= \frac{F^*(a+1,y+1)Z^*(a,y)[1-\exp-Z^*(a+1,y+1)]\exp-Z^*(a,y)}{F^*(a,y)Z^*(a+1,y+1)[1-\exp-Z^*(a,y)]}\end{aligned}$$

Thus, if such Fs and F*s are computed from the same cohort, they will have the relationship to one another indicated in equation (4). We will call this condition <u>cohort compatibility</u>, indicating that they are equivalent results from VPAs run with M(a) and M*(a) for one cohort of fish.

If the fishing mortalities for the terminal year F(a,t) are chosen in such a way that they are cohort compatible with the F*(a,t) that would arise if M*(a) were used in the assessment, and if they are also applied in years t+1 and t+2, then catches in years t+1 and t+2, which derive from the catches in year t, will clearly be independent of changes in M.

Studies of two VPA runs of North Sea haddock made with M(a) = 0.2 and M*(a), as in Table 2.1.1, strongly suggest

1) that the vector of fishing mortality F(a,y) generated in a particular year y would be cohort compatible with F*(a,y), providing terminal Fs are suitably compensated for M change,

2) that the mean $\bar{F}(a)$ from a number of years would also be cohort compatible.

Table 2.1.2 shows estimated CRATIO and CRATIO* calculated for a number of years and also for the average of 1980-1982. Each pair of CRATIO and CRATIO* calculated can be seen to be almost equivalent. (In the case of the haddock, M*(11) = 0.2, so terminal Fs are the same in both VPAs, and they do not need compensation for the change.)

It follows from this that, if average Fs are adopted for the final data year, no problems with cohort compatibility arise. The question of whether different tuning methods might affect the cohort compatibility of terminal Fs remains to be investigated, and it is at least possible that some methods might produce F(a,t)s incompatible with F*(a,t)s generated by the same method.

More importantly, modifying the F(1,t) and F(1,t+1) to make young fish survey indices compatible with catch data [C(1,t) and C(1,t+1)] will almost certainly destroy cohort compatibility in a very sensitive area of the catch prediction.

The other consequence of changing M is to change the size of population estimates, particularly of recruits. These naturally lead to different calibrations of the young fish survey indices. If survey index regressions are forced to pass through the origin (assuming error variances proportional to the means), then estimates of 1-year-old populations are

$$P(1,t) = R(1,t)\,\frac{\bar{P}(1,y)}{\bar{R}(1,y)} \qquad (5)$$

under the M(a) assumption

and

$$P^*(1,t) = R(1,t)\,\frac{\bar{P}^*(1,y)}{\bar{R}(1,y)} \qquad (6)$$

in the M*(a) case.

Hence

$$\frac{P^*(1,t)}{P(1,t)} = \frac{\bar{P}^*(1,y)}{\bar{P}(1,y)} \qquad (7)$$

Noting from (3) that

$$P(1,y)\,\frac{F(a,y)}{Z(a,y)}\,[1-e^{-Z(a,y)}] = P^*(1,y)\,\frac{F^*(a,y)}{Z^*(a,y)}\,[1-e^{-Z^*(a,y)}] \qquad (8)$$

we might reasonably expect that

$$\frac{\bar{P}^*(1,y)}{\bar{P}(1,y)}$$

would be roughly equivalent to the average of CE(1,y)/CE*(1,y), where CE(1,y) is the catch equation expression for C/P.

Values of CE(1,y)/CE*(1,y) were, thus, calculated for haddock from 1969 to 1983 and are shown in Table 2.1.3 (the years for which IYFS data are available). The average level of these ratios was 2.973 which compares very well with the ratio 2.860 found between estimates of P*(1,t) and P(1,t) estimated from regressions of VPA and IYFS forced through the origin. Table 2.1.3 also shows that CE/CE* was generally lower in earlier years (except 1969) and higher in the more recent years. Thus, the current ratio between CE/CE* is somewhat different from the average and can be expected to cause recruitment to be overestimated in the M = 0.2 case [assuming M*(a) is correct]. The results of a simple catch forecast of the North Sea haddock for both M assumptions are shown in Table 2.1.4. Fs used in both cases were based on the average level from 1980 to 1982 and VPA/IYFS regressions were forced through the origin. With the Fs chosen, CE(1,t)/CE*(1,t) = 3.18 and, hence, we might expect catches of ages 1 and 2 in 1985 and ages 2 and 3 in 1986 to be overestimated by a factor of 3.18/2.86 = 1.11. Older ages should be estimated identically in either case.

As can be seen from Table 2.1.4, the actual results of the assessments are in very close accordance with this theory. The 12% overestimation of yield on the 2- and 3-year-old fish in 1986 leads to an overestimate of 5% in the annual total catch.

Given that the change in CE(1,y)/CE*(1,y) shown in Table 2.1.3 has a time trend and is strongly related to F(1,y) (see Figure 2.1.1), it should be possible to predict the likely size of bias due to the use of an inappropriate M. This should be the subject of further research.

The above work does, however, suggest that it is possible to make catch forecasts which are relatively robust to changes in M by chosing a tuning method which gives cohort-compatible terminal Fs and regressing VPA/IYFS through the origin. It may also be possible to do even better if CE/CE* ratios can be predicted for age 1. Most importantly, however, when survey index derived population estimates are inserted into the calculation, <u>the corresponding F values should be left strictly untouched</u> in order to preserve cohort compatibility. This merely corresponds to setting aside the associated catch values, which are presumably unreliable, or the Fs are known to be unpredictable, else there would be no need to carry out such a replacement in the first place.

Such robust catch estimators would be generally desirable given the uncertainty which is bound to surround the correct level of M at age in the next few years while the Multispecies Working Group is getting its act together.

2.1.2 Effect of discards and average M on short-term forecasts: application of a generalized SHOT method

A slightly more rigorous derivation of the SHOT method may be generalized to include discarding and natural mortality (average for the exploited stock) explicitly, to examine their effect on short-term forecasts.

This shows that the level of M and d should not affect the short-term forecast unless they vary with time, in which case fluctuations of d may be particularly significant.

Put $$B(y+1) = \exp(G-Z)\ B(y) + W_r\ (R(y+1)$$

where B is exploited biomass, G is average (exponential) growth rate in weight of exploited fish, R(y) is recruitment (to the exploited stock) at the beginning of year y, and W_r is average weight at recruitment.

Catch in weight (including discards) is given by

$$C_w(y) = F\ B(y) = F\ B(y)$$

where $\bar{F}$ is the catch/biomass ratio, approximated by

$$\bar{F} = F\ \exp(G-Z)/2$$

where the exponential factor corrects an initial estimate to an average over the year; then

$$C_w(y+1) = \bar{F}(y+1)B(y+1) = \bar{F}(y+1)\{\exp[G-Z(y)]B(y) + W_r R(y+1)\}$$

But $$C_w(y) = \bar{F}(y)B(y)$$

and thus

$$C_w(y+1) = \frac{F(y+1)}{F(y)}\{\exp[G-Z(y)]C_w(y) + W_r\ \bar{F}(y)R(y+1)\}$$

The term in brackets is the <u>status quo</u> catch.

Thus $$C_w(y+1) = \frac{F(y+1)}{F(y)}\ C_w(SQ)$$

where $$C_w(SQ) = h\ C_w(y) + p\ r(y+1)$$

and h = exp[G-Z(y)] is the hangover factor, r is an estimator of recruitment (i.e., an index or a derivative thereof), and p [proportional to $W_r\ \bar{F}(y)$] is the coefficient for the recruitment term.

It is clear that the coefficients h and p (which are usually estimated by guesswork or regression, not <u>a priori</u>) are only constant if F is constant. If they vary with time, some error will arise (although partial compensation occurs). Since discards enter the calculation only through their effects on $\bar{F}$, they do not affect the result unless the proportion is variable, when some small effect on total catches would be expected.

When the coefficients are estimated by fitting the data, the level of M is irrelevant, unless it varies, when again some error will occur.

These equations apply to catches. One may also deduce the SHOT estimator for landings (yield).

In this case $$Y(y) = \bar{F}[1 - d(y)]B(y)$$

and $$Y(y+1) = \frac{\bar{F}(y+1)[1-d(y+1)]}{F(y)[1-d(y)]} \{h\,Y(y) + p[1-d(y)]r(y+1)\}$$

If d(y) is constant, the factor outside the braces { } cancels, and that inside is subsumed in a modified regression coefficient $p_1 = (1 - d)p$, so that there would likewise be no effect on the forecast.

If d varies, the cancellation fails, and errors will occur. Note, however, that d here is the fraction of the total catch weight discarded. If this is not large, the errors should be moderate with a similar CV to the standard deviation of d.

2.1.3 Error propogation and consistency in short-term catch forecasts

Catch-at-age data are subject to sampling error. When VPAs are "tuned" either by averaging F over several years or by any of the present *ad hoc* CPUE tuning methods (see Section 5.2), the errors are, to some extent, smoothed out of the terminal F values by the averaging or regression process. Any errors in the catch data are, therefore, passed directly into the population estimates for the final year and, thus, into the catch forecast.

This may be a significant contribution to the error of catch forecasts, and is not the most efficient use of the available data, because the population estimates depend heavily on the catch data for the final year, all previous estimates of year-class size, thus, being ignored.

It is perfectly possible to construct methods of analysis in which both the terminal F and terminal population values are "smoothed" by taking appropriate account of all available data. These include the method of Collie and Sissenwine (1982), the "survivors" method of Doubleday (1981), the Icelandic fisheries model (Gudmundsson, in press), the "integrated analysis" of Pope and Shepherd (1984), the multiplicative model of Shepherd and Nicholson (Working Paper S2) and separable VPA (Pope and Shepherd, 1982).

It is, therefore, of interest to know whether the use of one of these techniques prior to catch forecasting might lead to more stable (precise) estimates. It was not possible to explore this question in detail, but preliminary investigations using the multiplicative model were conducted and are reported in Section 4.4.

A further potential source of error in catch forecasts is internal inconsistency. The arguments which lead to the belief in the precision of _status quo_ catch forecasts (Pope, 1983) are based on the cancellation of various factors between the data year and a forecast year. If critical parameters are _changed_ as one moves from data to forecast, this precision is degraded, and errors may actually be introduced if the process is inconsistent.

It seemed possible that some of the failure of computations to exhibit the stability expected when assumptions about M are changed, referred to in the Introduction, might be due to inconsistencies of this sort. The North Sea Roundfish Working Group, for example, uses "tuned" terminal Fs for the data year and rescales recent average Fs for the intermediate and forecast years. They also insert population estimates for 0- _and_ 1-group fish from IYFS indices and revise the F values in the data year accordingly. This does, however, lead to these F values being different (possibly substantially different) from those used in the forecast years.

To test whether these procedures are associated with the problems encountered in validating theoretical expectations, a series of alternative forecast procedures was run for North Sea haddock, and this work is described in Section 2.2.

2.2 Short-Term Catch Forecasts for North Sea Haddock

Theoretical considerations suggest that using variable natural mortality at age, as opposed to constant values, should have only a minor effect on short-term forecasting. Similarly, only a minor effect on catch forecasts is expected when discards are excluded from the data sets. These beliefs were examined in relation to catch forecasts for North Sea haddock.

The two principal effects examined were those of age-variable M vs. constant M and the inclusion/exclusion of data on discards. However, catch forecasts may also be affected by the procedures adopted when computing them. For this reason, various alternatives to the standard conventions adopted by the North Sea Roundfish Working Group, with respect to the use of IYFS data, the method for establishing the exploitation pattern for the prediction years, and the estimation of F at age in the last data year, were also investigated. Table 2.2.1 shows the standard North Sea Roundfish Working Group practice and the alternatives adopted in this investigation.

All possible combinations of the five alternatives were investigated giving a total of thirty-two forecasts. It was found that varying the way in which the exploitation pattern was estimated for the prediction years had negligible effects. This is not a surprising result since the alternative method produced very similar exploitation patterns to those obtained using North Sea Roundfish Working Group procedures, and these results are not reported here. The sixteen remaining sets of results are shown in Table 2.2.3.

Using variable (and higher) natural mortality results in lower predicted human consumption landings and discards if the numbers of 0- and 1-group fish were estimated from the IYFS. Excluding discards from the catch data results in lower predicted human consumption landings. In this context, it should be recalled that similar simulations for North Sea cod carried out by the ad hoc Multispecies Working Group produced no significant effect of variable natural mortality (Anon., 1986).

The observation that excluding discards from the catch data produces lower predicted catches was true for all simulations. This is not the case for variable natural mortality. If the IYFS data are not used to tune population numbers on the 0- and 1-group in the last data year, there is little difference in catch forecasts using variable or constant natural mortality. It is clear, however, that the difference in predictions arising when natural mortality is changed and IYFS tuning is employed can be traced to the two year classes estimated by the IYFS. Apparently the higher values of natural mortality rate do not produce exactly compensating effects in the population predicted by the survey index.

This difference can be magnified by the way in which the survey index is used to determine the value of F at age 1 in the last data year in the VPA. Conventional North Sea Roundfish Working Group practice adjusts this F in line with the catch. When this F is used in the prediction, the sensitivity of the catch forecasts to M can be considerable. A more robust procedure is to set aside the catch of 1-year-old fish in the last data year and to use the IYFS population size in conjunction with a recent year's average F for calculation of the catch forecasts. Table 2.2.4 shows predicted catches for 1986 under two assumptions about natural mortality (constant or variable with age) and two assumptions about F at age 1 in 1984 (recent average or IYFS tuned). It can be seen that, when a recent F is used, the catch predictions are not as sensitive to changes in M. It may be possible to further reduce this sensitivity by making a correction to the IYFS/VPA regressions, but this aspect needs further investigation. At present, however, it is recommended that F in the last data year is not adjusted on the populations estimated by the IYFS, but that average F is used.

These effects of variable natural mortality and discards on catch predictions may be understood in general from the treatment given in Section 2.1. The largest effects of varying M arise when recruit estimates are inserted and F is adjusted to conform with the catch data.

Additionally, it is becoming apparent from the work of the ad hoc Multispecies Working Group that, at least in the case of some North Sea fish stocks, the use of variable natural mortality in VPA and prediction is probably justified on biological grounds. Furthermore, it should not be forgotten that the use of data on discards and the use of age-variable natural mortality in VPA should give improved estimates of historical biomass, population numbers (including recruitment), and fishing mortality rate, especially at the younger ages. In the case of fisheries where it is believed or known that large quantities of fish are discarded, it is advisable to set up an appropriate sampling scheme for discards.

3 LONG-TERM ASSESSMENTS

3.1 Theoretical Background

The most suitable method for theoretical analysis of the effects of age-dependent M and/or discards on long-term assessments is that of Jones (1961), because this automatically ensures that the estimated fishing mortality, exploitation pattern and recruitment are kept consistent when the assumptions are changed. The method has not been widely used for practical calculations perhaps because it requires an estimate of the steady-state age composition of the catch as a basis, and this is not usually available. This is, however, no disadvantage for a theoretical analysis, and the simple ratio method proposed by Jones may, in any case, be generalized, and a multiplicative model may be fitted to catch-at-age data to estimate the steady-state age composition (Shepherd and Nicholson, 1985). With this preprocessing of the data, the Jones (1961) method becomes a practicable computational tool as well as a useful basis for analytical studies.

Modern practice (Gray, 1977) suggests the inclusion of an extra factor of exp(-Z/2) to approximate the effects of converting from initial to average populations in each year, and the use of the cohort approximation to estimate fishing mortality rather than the approximation to VPA he gives in Appendix II. In standard notation, one has

$$L(a) = RF_sS(a)b(a)\ \exp[-\mathrm{cum}\ Z(a)] \qquad (1)$$

where L indicates landings as opposed to catch, F_s is the overall fishing mortality conditional on the selection pattern S(a), and b(a) is the fraction retained (and landed). Thus, as is usual, F and Z are taken to include discard mortality. The notation cum is shorthand for

$$\mathrm{cum}\ Z(a) = \sum_{a'=0}^{a-1} Z(a') + Z(a)/2 \qquad (2)$$

so the exponential term in (1) is just mean survival to mid-year.

Equation (1) is just the usual catch equation. The principal technique proposed by Jones is to examine the effects of <u>changes</u> of interest on equation (1) and to use the resulting conversion factors to modify the vector L(a) as estimated from available data.

Very often it is changes relative to the current position which are of principal interest. Denoting the old (reference) values by *, one has

$$\frac{L(a)}{L^*(a)} = \frac{f\ S(a)}{S^*(a)}\ \frac{b(a)}{b^*(a)} \times \exp\{-\mathrm{cum}[Z(a)-Z^*(a)]\} \qquad (3)$$

where f is relative fishing mortality $F_s/F_s{}^*$.

This equation provides the basis for assessing the effects of changes in f, S(a), or b(a) within the context of a given assessment (e.g., with some fixed assumptions about natural mortality).

If one is not assessing the effects of modifying or eliminating discard rates in the fishery, b(a) must be considered to remain constant in a long-term assessment unless some explanatory model for its variability is available. Thus, $b(a) = b^*(a)$. Similarly, $M(a) = M^*(a)$, and

$$\frac{L(a)}{L^*(a)} = \frac{f\ (S(a)}{S^*(a)} \exp\{-\mathrm{cum}[F(a) - F^*(a)]\} = \frac{f\ S(a)}{S^*(a)} \exp[-(f-1)\ \mathrm{cum}\ F^*(a)] \qquad (4)$$

For asssessing changes in fishing mortality but not selection pattern, S(a) is also unchanged, and this reduces to the remarkably simple result

$$\frac{L(a)}{L^*(a)} = f \exp[-(f-1)\ \mathrm{cum}\ F^*(a)] \qquad (5)$$

Thus, for each age (and, therefore, for the total), landings are a function of relative F and cumulative reference F only. Thus, any difference in interpretation of the effect on landings of a given change in relative F if discards are included in the assessment (or not), depends only on the differences in the estimated $F^*(a)$ which would occur.

There is, thus, no direct effect of discard rates on the assessment of the effects of changing fishing mortality whilst discard rates stay the same, as there would be for the effects of changing the discard rates themselves. The effects arise only through the different interpretation of the data in terms of fishing mortality. Yield is, of course, a summation of landings and weight at age.

$$Y = \Sigma L(a)\ w(a) = f\Sigma w(a)\ L^*(a) \exp[-(f-1)\ \mathrm{cum}\ F^*(a)] \qquad (6)$$

and $w(a)\ L^*(a)$ (yield in weight at age) is a strongly peaked function of age. Since the exponential term is a monotonic function of age, equation (6) may, to a good first approximation, be replaced by the term for the age contributing most to the yield ($\hat{a}$) only, i.e.,

$$Y = f\ w(\hat{a})\ L^*(\hat{a}) \exp[-(f-1)\ \mathrm{cum}\ F^*(\hat{a})] \qquad (7)$$

The reference yield is just

$$Y^* = \Sigma w(a)\ L^*(a)$$

and, thus, writing $\alpha = w(\hat{a})\ L^*(\hat{a})/\Sigma w(a)\ L^*(a)$ for the proportion of the landings contributed by the age $\hat{a}$

$$y = \frac{Y}{Y^*} = \alpha\ f \exp[-(f-1)\ \mathrm{cum}\ F^*(\hat{a})] \qquad (8)$$

The slope of the relative yield/relative fishing mortality curve is

$$\frac{dy}{df} = \alpha[1-\mathrm{cum}\ F^*(\hat{a})] \times \exp[-(f-1)\ \mathrm{cum}\ F^*(\hat{a})] \qquad (9)$$

We usually wish to evaluate this slope at the reference F level (f = 1) and, thus, the exponential term disappears and

$$\frac{dy}{df}\Big|_{f=1} = \alpha[1 - \text{cum } F^*(\hat{a})] \qquad (10)$$

This is an amazingly simple result for the key quantity of interest relating to long-term yield curves, and it is easily shown by an exactly parallel argument that the change in relative biomass is given by the same expression without the "1" in the parentheses, i.e.,

$$\frac{d(B/B^*)}{df} = -\alpha' \text{ cum } F^*(\tilde{a}) \qquad (11)$$

where α' is the proportion of the biomass contributed by the age contributing the maximum ($\tilde{a}$). This equation actually also remains valid if the selection pattern is changed.

Now, increasing natural mortality on the younger ages reduces the estimated fishing mortalities and, therefore, [1-cum $F^*(a)$] becomes less negative (or more positive). Thus, the incorporation of high juvenile mortalities should reduce any "signals" from dy/df that f should be reduced. This is made clear by the family of relative yield curves given in Figure 3.1.2.1 drawn directly from equation (8).

The effect of including or excluding discards is a little more subtle, since $F^*(a)$ is defined as including discard mortality, whether or not the discards have actually been included in the assessment! Thus, $F^*(a)$ is, in principle, not changed by including or excluding discards. However, in practice, the $F^*(a)$ would have been underestimated on some ages by the exclusion of discards and overestimated on others. The size of the change, therefore, depends on the exact pattern of Fs, as well as the assumption about natural mortality, and is not clearly predictable.

The effects of changing selection patterns can also be assessed by this method. If

$$S(a) = S^*(a)[1 + \sigma(a)] \qquad (12)$$

so that $\sigma(a)$ is the relative change in selection at each age, equation (4) implies that

$$\frac{L(a)}{L^*(a)} = f\ [1 + \sigma(a)] \times \exp[-\text{cum } F^*(a)\ \sigma(a)] \qquad (13)$$

The key quantity of interest when selection is changed is the change in yield whilst F_s is held constant at the reference value (f = 1), for which

$$\frac{L(a)}{L^*(a)} = [1 + \sigma(a)] \exp[-\text{cum } F^*(a)\ \sigma(a)]$$

The new yield is

$$Y(a) = \sum_a w(a)\ L^*(a)\ [1 + \sigma(a)]\ \exp[-\mathrm{cum}\ F^*(a)\ \sigma(a)]$$

As a simple example, consider a change in selection on one age (â) only. Then $\sigma(a) = 0$ except for age â

$$\Delta Y = Y(a) - Y^*(a) = W(\hat{a}) \times \{[1 + \sigma(\hat{a})]\ \exp[-\mathrm{cum}\ F^*(\hat{a})\ \sigma(\hat{a})] - 1\}$$

Clearly, the effects of selection changes also are largely determined by the reference value of cum F*.

3.2 Sensitivity Analysis of Assessment Results

3.2.1 Theoretical results

Computations involved in assessments of stocks and fisheries are based on functions of a number of parameters which are known with some degree of uncertainty. It is, therefore, quite important to evaluate how robust (or sensitive) the results (and subsequent advice based on them) are to the likely or known magnitude of errors in the parameters.

For such sensitivity analysis, one may wish to derive coefficients relating relative variations in the results to relative variations in the parameters, since these are usually the most easy-to-handle measure of sensitivity. This can be done from simulations, but, in a number of cases, the underlying systems of equations are sufficiently explicit that the coefficients can be determined analytically.

Using a first-order Taylor's expansion of a function f(p) of a single parameter p, yields the approximation

$$\Delta f(p) \backsim \frac{df}{dp} \times \Delta p$$

or equally
$$\frac{\Delta f}{f} \backsim \frac{1}{f} \times \frac{df}{dp} \times \Delta p$$

or preferably
$$\frac{\Delta f}{f} \backsim (\frac{1}{f} \times \frac{df}{dp} \times p)\ \frac{\Delta p}{p}$$

where the desired coefficient is the quantity inside parentheses. The approach can be extended to higher orders and to functions of several parameters. The problem, thus, is one of obtaining the derivatives of the function relative to the parameters. Examples of such coefficients for results of length VPA are given in Tables 3.2.1 - 3.2.3 taken from Laurec and Mesnil (1985a).

If we consider equilibrium yield, for example, it is obtained by summing up the contributions of each age (or length) group. These are functions of the F value at the age considered, of the natural mortality M, and of the number of fish entering the age group. The latter is, in turn, a function of M (taken here as constant over ages) and of the F(a)s at all younger ages.

The problem is further complicated due to the fact that the F(a)s at age are computed by means of such techniques as VPA, in which each is again a function of natural mortality. This dependence upon M must, and generally can, be stated explicitly, and its actual form depends on the specific technique used (iterative solution or linearized cohort analysis equation, forwards or backwards sequential computation).

When all these stages are properly taken into account, it can be shown that

$$\frac{dy}{dM} = \frac{\delta Y}{\delta M} + \sum_{a} \frac{dY}{dF(a)} \times \frac{dF(a)}{dM}$$

where the first right-hand-side term stands for the effects of M in the course of yield computation itself, taking the F(a)s for known, while the second one reflects its effects upon the estimates of the F(a)s. This formula further supports the requirement of internal consistency when examining effects of changes in the parameters, which must be incorporated in the whole process of the assessment.

An additional stage to take into consideration is the way the F(a)s at age are combined over years to arrive at some steady-state reference fishing pattern.

The sensitivity analysis can be carried out further with the investigation of effects of uncertainties in M upon marginal yield (relative changes in yield subsequent to a relative change in overall level of fishing mortality), or upon relative changes in yield obtained under two regimes of exploitation (e.g., mesh assessment), in which case one is interested in the robustness of estimated gains or losses. For the construction of sensitivity coefficients of marginal yield, one may take advantage of a simplified relationship (see Section 3.1) based on an equation established in Working Paper D5, which is shown to hold whether landings or catches are considered (discards excluded or included) provided that discarding rates are constant.

Similar approaches to the one presented for yield can be used for sensitivity analysis of other assessment results such as estimated stock numbers at age or functions of these such as total or spawning stock biomass. One can have an insight into the propagation of errors on numbers at age up to recruitment and even proceed further with sensitivity analysis of the stock-recruitment relationship, as was done in Working Paper M4 (Hilden). It can be shown that the lower the F at age, the more the numbers at age are subject to uncertainty in M under the assumption that this is a constant over ages and years. This means that numbers at age obtained by VPA are not consistently affected by a given error in M, and the perception of the stock-recruitment relationship, for example, can be distorted.

Similar effects are likely to occur if M is allowed to vary between years, although they cannot be quantitatively stated at the present time and might not permit general conclusions. As a first step, one should at least identify those years when M takes extreme values. Effects on recruitment estimates from VPA should be especially considered in the case when these are to be related to independent information (survey indices, samples from industrial fisheries or from power plant intake).

3.2.2 Computational studies

Rivard (1982) presents the basic assessment methods (VPA, cohort, yield per recruit, etc.) in the APL language. His programs contain the option of carrying out a sensitivity analysis. Sensitivities are usually expressed as changes in stock variables with respect to descriptive parameters. Rivard's programs treat the input data as parameters. That is, catch data and natural mortality are both handled in the same manner in estimating sensitivity. The sensitivities are estimated by perturbing each "parameter" 0.01% and comparing the resulting output with the unperturbed results. The sensitivities are presented as relative sensitivities. For example, if the relative sensitivity of F_{msy} with respect to natural mortality were -2, then a 1% increase in M would be expected to produce a -2% change in F_{msy}.

As a sample of the calculated sensitivities, Table 3.2.2.1 presents the population numbers from VPA with respect to terminal F and natural mortality.

This example is chosen as the sensitivity of recruitment to natural mortality was addressed in a working paper by Hilden. As expected, the error caused by an incorrect F is corrected as one goes down a cohort and the error due to an incorrect M increases.

3.3 Computational Study for North Sea Haddock

A computer program was developed by Stokes (Working Paper DM1) to carry out Jones' stable age analysis using a spreadsheet. His program was translated into the NOTIS-CALC spreadsheet on the ICES NORD computer. This program requires catch data and natural mortality estimates as input. The stable catch-at-age compositions were generated using Shepherd's multiplicative model for haddock landings and haddock landings plus discards. Both age-dependent and age-independent natural mortalities were used. A cohort analysis is performed on the catch data and the estimated Fs are cumulated for use by Jones' method.

Once the program was working, it was checked against Stokes' results and a published cohort analysis to assure fidelity. The principal effects to be investigated were the impact of discards and age-dependent natural mortality on stable-age yield predictions.

The discard question was addressed by comparing results from the two stable catch-at-age vectors mentioned above. The results are in terms of yield as a function of fishing mortality. The yield, biomass, and fishing mortalities are all relative values, in that they have been normalized with respect to the results when F = F*. The age-dependent M vector was produced from a preliminary multispecies assessment and was compared to results using a constant M of 0.3 which equals the mean over ages 0-8 (the only ages used in this study). The results are illustrated in Figures 3.3.1 and 3.3.2.

An additional set of figures was produced to display the effects of a change in selectivity. The change was modelled as a change to knife-edge recruitment at age 2, with no 0- or 1-group catch.

The results of the selectivity studies were not normalized in the same manner as above. They were first corrected for recruitment level (Table 3.3.1) and then normalized to the yield or biomass from the appropriate analysis, with no increase in age at first exploitation.

The results of these selectivity calculations are shown in Figure 3.3.3.

A final set of long-term projections was performed to investigate the effects of changes in the pattern of natural mortality (Figure 3.3.4). Three projections were made, all of which had an average natural mortality of 0.3. The base run had a constant M at all ages. A second run, labelled senescent M, had a natural mortality of 0.25 at all ages except the oldest which had the value of 0.7. The third run had Ms of 0.25 on all ages except age 4 which had the higher value of 0.7.

Figures 3.3.1a-d compare the yield and biomass estimates between variable M and age-independent M. Figures 3.3.1a-b do not include discards in the calculations, while Figures 3.3.1c-d do. It is seen that the yield for the variable M peaks at a higher value at low (F = 0.3) fishing mortality. This observation is independent of whether or not discards are included in the analysis. The biomass is also slightly higher with variable M. In the region of current fishing intensity (relative F near 1.0), the two curves are effectively indistinguishable.

Figure 3.3.2 displays the same data as Figure 3.3.1, but the curves are paired to compare the effects of including discards in the stable catch analysis. The predicted yield curves are still quite similar, while the biomass based on data including discards is slightly higher at low fishing mortalities.

Figure 3.3.3 shows the effects of delaying exploitation until age 2. In terms of yield, the delayed exploitation curves (labelled "modified selection") show a value considerably higher than that of the current fishing pattern. As would be expected from Figure 3.3.2, the inclusion or exclusion of discards (curves labelled "I" and "E", respectively) has only a modest effect on the estimated increase in yield due to the change in selection. Biomass estimates are also approximately doubled at high fishing intensity by delaying exploitation.

The final figure (Figure 3.3.4) shows that varying the M pattern while maintaining a constant average level affects the peakedness of the yield curve. The senescent M produces a more peaked relationship than an age-independent M. The high natural mortality at age 4 has the opposite effect and makes a flatter yield curve.

The long-term yields based on a stable age distribution and an age-dependent natural mortality are basically the same as Thompson-Bell yield-per-recruit analyses. They are, therefore, subject to the same criticisms: stable age, time variant weight at age, etc. The use of the Jones approach was convenient for use with a spreadsheet. Also, it should be mentioned that the total mortalities at age often exceeded 1.5. Mortalities of this magnitude exceed the levels advised by Pope for use in cohort analysis, and an "exact" VPA might be preferable.

The inclusion of discard information had only small influences on the expected yields. These influences were much smaller than the noise level associated with normal fisheries data. The inclusion of discards caused about 30-50% (Table 3.3.1) increase in recruitment estimates and would have an effect on tuning against recruitment indices if they varied in time or were included in an inconsistent manner.

Figures 3.3.3a-d show that, for constant M, a change in selection corresponding to delaying the age of first exploitation would produce higher yields at current F levels and a rather flatter yield curve. The effect is somewhat more pronounced when discards are included in the calculation. With variable M, the results are very similar but quantitatively smaller. Similar effects are seen for biomass; modifying the selection pattern increases biomass at current F levels, but the effect is estimated to be a little larger when discards are included in the calculation.

Inclusion or exclusion of discards has a rather larger, but still modest, effect on the perceived effects of a change of selection pattern, whether M is taken to be constant or variable.

When all consequential changes are taken into account, it, therefore, seems that the incorporation of discard data may affect the magnitude of the estimated effects of normal long-term management measures to a small extent. The overall picture of gains and losses is, however, unlikely to be altered significantly.

4 SIMPLE METHODS OF ASSESSMENT

4.1 Introduction

The Working Group considered various simple methods for preparing short-term forecasts at its 1984 meeting (Anon., 1985a). Various other assessment calculations may also be amenable to simpler methods than the traditional ones based on age composition data.

Methods based on length compositions are of particular interest when ageing is difficult or impossible. A conference convened by FAO, ICLARM, and KISR was held on this subject in Sicily in February 1985. The proceedings are to be published by ICLARM and should be consulted for a detailed account. Several members of the Working Group had attended the conference and gave brief reports of the proceedings and their own work in particular. A short account of this subject is given in Section 4.2.

Further progress is also being made on simpler and/or more stable methods for the analysis of catch-at-age data, and working papers on these aspects were discussed (S1 and S2). Brief accounts of these topics are given in Sections 4.3 and 4.4.

4.2 Length-Based Methods of Assessment

4.2.1 FAO/ICLARM/KISR Conference (Sicily, February 1985)

In February 1985, FAO/ICLARM/KISR jointly sponsored a conference in Sicily on length-based methods of stock assessment. A list of the papers presented at the meeting was included in Working Paper L1 and the proceedings are to be published by ICLARM in the coming year.

The meeting was, in part, motivated by the recent widespread distribution of D. Pauly's ELEFAN programs, the main parts of which attempt to estimate von Bertalanffy growth parameters from length composition data and apply these estimates to Jones' length cohort analysis. However, the ELEFAN programs required testing and many related methods for length-based assessments were discussed at the Sicily meeting.

4.2.1.1 The estimation of growth parameters

A schematic representation of the process of analyzing length composition data (Figure 4.2) shows that good growth parameter estimates are a prerequisite for most procedures. Two Monte Carlo studies presented in Sicily (Rosenberg and Beddington; Hampton and Majkowski) indicate that ELEFAN I produces unreliable estimates. An alternative procedure which treats length compositions as mixtures of (normal or otherwise) distributions has been developed by MacDonald and Pitcher (1978), Schnute and Fournier (1980), Sparre (Sicily meeting), and Pope (Sicily meeting). This method has high data requirements and is very sensitive to gear selectivity. Because there is a large number of parameters for the distribution mixture and the fitting surface is rather flat, these methods also have convergence problems.

Shepherd (Sicily meeting) presented another method, which is conceptually similar to ELEFAN I, based on the time-series analysis procedure of complex demodulation. It has produced encouraging results in several trials, but has not yet been tested fully with simulated data. A method for projecting the length compositions forward in time (Shepherd, Sicily meeting) was presented for forecasting catch at length, but can be simply adapted for estimating growth from a series of samples by choosing those parameter values which best reproduce the observed length compositions when projected from the first sample. This method, while very simple, seems fairly robust and requires only the assumption of the form of the growth equation (Rosenberg, in prep.).

All of the available methods of estimating growth parameters encounter difficulties with multiple maxima of the objective function. This results from the fact that we can only hope to see clear modes in the length compositions for the first few age groups at best (Rosenberg and Beddington, Sicily meeting). The age of large individuals is poorly determined such that various combinations of L_∞ and K give virtually the same value for the objective function. Estimates of L_∞ and K are known to be highly correlated, and only a quantity related to their product is adequately estimated. In practice, in the absence of additional information, it is necessary for the investigator to examine the fitting surface and subjectively choose which maximum to accept.

The addition of some age information to the analysis of growth could greatly improve the estimates (Morgan, Sicily meeting). This is particularly true if the age data are for larger fish where the length composition contains the least information on growth (or size at age). Methodology for combining age and length composition information should be investigated further. The ageing data should be weighted more for longer fish, while length data may dominate for smaller fish if clear modes are present.

4.2.1.2 Length-based assessment alternatives

Based on the schema of Figure 4.2, if good estimates of growth are obtained, the investigator may either choose a route which leads to length cohort analysis or assign fish to cohorts (deconvolution of the length composition) and proceed as with an age-based analysis. The relationship of mean length to age does not provide sufficient information to correctly estimate age at length. Variability in age at length may significantly affect further assessment calculations (Laurec and Mesnil, Sicily meeting; Pope, 1985c). A third alternative, as noted above, is to directly produce short-term forecasts using a transition matrix approach (Shepherd, Sicily meeting). A fourth possibility was set out by Gudmundsson (1985) and is described in Section 4.2.2.

Deconvolution of the length composition may be accomplished by estimating the proportions in the length composition assignable to each age group by using the distribution mixture approach of MacDonald and Pitcher (1978). Note that this is different from attempting to estimate growth parameters and proportions simultaneously for the mixture. Clark (1981) presents a quadratic programming approach to deconvolution. Shepherd (1985c) has proposed a straightforward numerical approach using non-linear optimization. Once the length composition deconvolution has been accomplished, conventional methods for short- and long-term forecasting may be used.

4.2.1.3 Use of length-based VPA

It should be made clear beforehand that the length VPA, such as designed by Jones (1974), does not rest upon the linearized form adapted from Pope (1972), but can be treated with any means of solving the basic catch equation with uneaqual time intervals derived from some given growth model.

The method implies equilibrium assumptions by which all the cohorts implicitly represented in the catch-at-length array must proceed from equal recruitments and have all been exploited under an identical pattern. In effect, it is equivalent to a "steady-state" catch-at-age analysis in which the contribution of each age group is obtained by slicing the length composition on the basis of the growth parameters. It does not permit one to trace the evolution of cohorts with time.

Shepherd (1985c) presented a method which allows one to derive a steady-stage age composition free of year and year-class effects. Pope (1985b) proposed an ANOVA-like test of these effects which should be performed before running a length VPA to ensure that its results are acceptable.

Laurec and Mesnil (1985b) proposed formulae for the sensitivity and bias in the analysis which can be easily incorporated in a VPA program to check how well the data set behaves with regard to uncertainty in the parameters. In most cases, the coefficients obtained will confirm that the length VPA should be initiated from a terminal length class which is far enough from L_∞ (approx. 2/3 of L_∞) (see Pallares and Pereiro, 1984) and may help to define an appropriate terminal class. They give no indication, however, on whether or not the basic assumptions are met. Pope (1985c) suggests starting the calculations at least 3 standard deviations below L_∞.

As it is most commonly implemented at present, the length VPA closely depends on accurate estimates of K and L_∞, and one may be concerned that these vary widely depending on the samples and the fitting techniques used.

These considerations on the requirements for a sensible use of the length VPA should not discourage users from trying it. There are a number of circumstances where, apart from the lack of a long time series of catch-at-age data, the basic assumptions are reasonably met (in some cases by smoothing or averaging the data) with stocks showing rather stable recruitments and a range of years of rather steady exploitation pattern. The method is then able to provide robust estimates of fishing patterns and their decomposition by fleet components for fleet interactions analyses. In addition, gear selectivity parameters are easier to incorporate into an equilibrium yield model together with fishing mortalities for mesh assessment since both share length as a common variable.

4.2.2 Statistical analysis of catch-at-length data

A model of growth is incorporated in the usual differential equations describing the change in the size of a stock through deaths from fishing and natural causes. According to this model, the growth of a fish at any time is stochastic and depends on its length. The assumption that growth lines do not cross is, thus, generally abandoned, but can be implemented as a special case. Estimation of stocks, fishing mortalities, and possibly some aspects of growth by means of catch-at-length data is carried out in a similar way as described by Gudmundsson (1984). The method is not restricted to any particular model of growth or patterns of recruitment or mortalities.

There is rather limited practical experience yet of the application of this method, but it is clear that the accuracy of the results will depend critically on the extent and accuracy of the prior information employed about fishing mortality and growth.

For fish where age determinations are not available, fair knowledge about the average growth of the shortest fish and the length where growth has largely ceased may have to suffice, together with the assumption that the average growth follows the von Bertalanffy curve. The assumption of proportionality between fishing mortality and an observed index of fishing effort is often inconsistent with catch-at-age data. So is the assumption of separable fishing mortalities. Changes in growth, leading to variations in length at age, may be an important cause of this. In that case, the analysis of catch-at-age data may be a worthwhile complement to the analysis of catch-at-age data, as both assumptions should hold better. The whole matrix of average growth at length might be fairly well known.

The model of growth involves both an increase and spreading (as time goes on) of the length of fish which were of the same length at one time. It is unclear how far the choice of model in this respect must be based on biological considerations and how much can be learned from the data.

4.3 The Use of Kalman Filters for Short-Term Estimates of Yield

Pope and Pope (1985) presented two methods for using the Kalman filter (KF) to smooth short-term yield predictions. They also presented a short, simple explanation of the Kalman filter in terms of a navigation example. The first method applied the KF to Shepherd's (1984) "SHOT" estimates (Anon., 1985a) and the second to a variant of Pope's (1983) Leapfrog method. Both were based on rather short time series, but showed encouraging results. These are illustrated in Figures 4.3.1 and 4.3.2, prepared from data taken from Pope and Pope (1985).

The Kalman filter approach consists of making a "dead reckoning" prediction based on previous estimates and then using this to predict the values of the new observations. The difference between these predicted observations and the actual observations is then used to correct the dead reckoning prediction. The degree of correction will be dependent on the relative variance of the dead reckoning update and the new data.

In general, the Kalman filter procedure of improving past estimates with new data, rather than accepting new data at face value, seems useful and might be used even where the actual Kalman filter method is too restrictive to be used directly.

Many assessment methods adopt the most recent data point as though it were exact. For example, in some VPA tuning methods, fishing effort is supposed to be directly related to fishing mortality rate. Such estimates, therefore, have the full variance of the single data point. In many cases, however, an alternative predictor might be found based on past values. For example, fishing mortality could be assumed to be equal to the average of the last five years. A suitable combination of both types of estimates may well give a less variable estimate than either taken singly. Such approaches have not been used in the past because, in general, the variance of methods is not considered and unbiasedness has been emphasized at the expense of small variance.

4.4 Multiplicative Modelling of Catch-at-Age-Data

The model presented in Shepherd and Nicholson (1985) analyzes catch-at-age data in terms of year, age, and year-class effects, similar to those of analysis of variance. The model is:

$$C(y,a) = \bar{F}(y)\ R(k),\ S'(a)$$

and is fitted by log transformation of the data and general linear modelling techniques, paying attention to the error structure of the data and the indeterminacy of the solution. The estimated factors may be used interpretatively, providing estimates of relative overall fishing mortality in each year, the time series of year-class strength, and the stable age composition (i.e., a corrected catch curve). The fitted parameters may also potentially be used to generate short-term forecasts directly, without directly using this interpreation. The model was used to analyze catch-at-age data from three stocks: Gulf of St. Lawrence cod, North Sea cod, and North Sea haddock.

4.4.1 Southern Gulf of St. Lawrence cod

The model was used to analyze groundfish survey data for the southern Gulf of St. Lawrence cod stock. The results were compared to VPA results from Rivard (1982). The resulting trends in year, age, and year class are given in Figure 4.4.1. The year effect showed very little variation, as expected for survey data. The age effect indicated a constant Z from age 2-10 which was not entirely expected, since full recruitment to the fishery is not complete until age 6. This may reflect higher natural mortality on young fish than is conventionally assumed. The year-class trends showed considerable structure, and these are highly correlated with the VPA age 2 abundance (r^2 = 0.92) (Figure 4.4.2).

To investigate the effect of undetected violations of the constraint imposed on the year effects, the input data were perturbed by adding linearly increasing year and age effects. The results indicated that, if there is an undetected trend in the year effect, the year-class estimates would be biased by (see Figure 4.4.3) an amount bk, where b = the slope of the trend and k = the sequential year class, beginning with the oldest. Similarly, the age-effect estimates were biased by an amount ba, where a = age.

On the other hand, the introduction of a linear age effect did not affect the year-class estimates, although the age effects were, of course, biased by an amount ba. These results are entirely consistent with expectation.

In particular, it is clear that undetected violation of the constraint will have significant effects on the estimated parameters.

4.4.2 North Sea cod

The model was also used to analyze commercial catch data from the North Sea cod fishery. Data were taken from Table 5.2 of the

March 1985 North Sea Roundfish Working Group report (Anon., 1985c).

Figure 5.1 of the Working Group report indicates that, over the period 1963-1984, there has been a linear effect in F on this stock. A curve was fitted by eye to the data, and a slope of 0.014 per year was determined. Three analyses were performed to compare results under different assumptions. The first used the raw data and the assumption of constant F. The second constrained the F to the calculated trend. In the third, the input data were perturbed to remove the F trend. Therefore, the first two modelled catches could be used to predict future catches, and the third modelled catch per unit effort or abundance.

In the first analysis, the parameter estimates were biased because the year constraint was violated. Specifically, the age effects were underestimated while the year-class effects were overestimated. However, the predicted values of catch at age were identical to those fitted in the second model. This is as it should be because the model is overparameterized. In the third analysis, where catch per unit effort is modelled, the parameter estimates were the same as those obtained if the year effect is included in the model (model 2). However, the predicted values differed from those obtained in the first two analyses (since different things were being modelled).

Catches in 1986 were predicted using the output from models 1 and 2, the estimated effects, and the geometric mean predicted catch at age 1 (31,257,000). Weights at age were taken from Table 5.6 of the 1985 North Sea Roundfish Working Group report. The 1986 predicted catch was 279,000 tonnes (t) under model 1 and 273,000 t under model 2. The difference was due to the higher Z values calculated under model 1. The Working Group predicted a catch of 210,000 t.

4.4.3 <u>North Sea haddock</u>

The model was also used to analyze catch-at-age data for North Sea haddock. The input data were for ages 0-10 from Table 9.3 of the North Sea Roundfish Working Group report. Catches at age 0 and 1 were taken from a text table on page 22 of the report.

Input data for catch predictions were the estimated effects and weights at age from Table 9.7 of the North Sea Roundfish Working Group report. Catch at age for 1985 and 1986 was taken as the catch from the assumed year-class size (2,455,000) using F = 0.33 from Table 9.7 of the Working Group report. The predicted catch was 283,000 t compared to 239,000 t predicted by the Working Group.

This preliminary study suggests that the model is useful for estimating year-class size and corrected catch curves (the steady-state age composition), but that its use for catch forecasting requires further investigation.

5 OTHER TOPICS

5.1 Introduction

The Working Group also returned briefly to two of the topics which it has considered in previous years, namely the *ad hoc* tuning of VPA using effort data, and methods for construction of recruitment indices. In both cases, recent work has clarified the problems involved and indicated promising directions for future work. A brief account of the discussion on these topics is given in Sections 5.2 and 5.3.

5.2 "Tuning" of VPAs Using CPUE and/or Survey Data

The Working Group pointed out in the report of its 1983 meeting (Anon., 1984a) that the determination of terminal F values using CPUE data ("tuning" of VPAs) is essentially a problem of modelling and fitting of catchability data (see Appendix F of the report and Appendix Table F.1 in particular).

Considerable progress has been made since then in the construction of appropriate methods of analysis which recognize this explicitly. In particular, the method of Lewy (described in Appendix 1 to the 1985 report of the North Sea Roundfish Working Group) fits a linear trend in catchability for each fleet, and the modification by Armstrong, which is currently used by the North Sea Roundfish Working Group, allows for down-weighting of old data in the fitting of regression lines. This refinement is a useful practical way of recognizing the lower value of old data and could also be applied to many other methods.

Shepherd reported that work at Lowestoft had identified the fact that almost all the methods which have been tried recently came from a general family for the analysis of catchability. These are, in general, "iterative tuning" methods (see 1983 report, Appendix F), now commonly known as *ad hoc* tuning methods, in which an explicit analysis of catchability (usually by regression) is used to predict terminal Fs, and these are used (iteratively, if necessary) to initiate a new VPA. They are not guaranteed to minimize any particular statistical criterion of quality, hence, the use of the term "*ad hoc*". As illustrated in Table 5.2.1, there are essentially four questions to be decided:

1) Are the data to be aggregated (over fleets) before analysis of catchability, or is the analysis to be carried out on disaggregated data, with combination of the estimated fishing mortalities afterwards?

2) Is a logarithmic transformation to be applied to the catchability estimates, or not?

3) Is catchability to be assumed constant, or allowed to depend on time, stock size, or effort?

4) Are the estimates of total fishing mortalities to be combined by weighting by the proportion of the catch to which they relate, or by taking account of their standard errors of prediction?

These options generate a total of 22 possible methods, some of which have been used and named, whilst others remain virgins (and should probably be left intact!). A weighting procedure such as that of Armstrong may be applied in each case.

Previous studies by the Working Group clearly indicate that disaggregated analysis is to be preferred, and that regression against time (whilst theoretically dubious) is probably the most useful practical procedure. Only two named methods fall in this class, namely the Lewy/Armstrong method and the "Hybrid" method described by Pope and Shepherd (1983). These methods are, thus, in principle, preferable to the other options. The former analyzes untransformed data and recombines by proportion of the catch (i.e., summation of partial Fs raised to the total), whilst the latter applies a log transform and recombines by weighting according to prediction errors.

Workers at the Lowestoft Laboratory have run all 22 methods on the North Sea cod data set. The results are illustrated in Figures 5.2.1 - 5.2.3. It is clear that there is substantial variation between and within classes of methods. This is not surprising since all imply a different choice of weighting among the conflicting estimates given by individual fleets, which are quite variable. It is, however, of interest that the preferred methods give results which agree to within about 10%, which is close to the apparent coefficient of variation of the catch-at-age data for this stock as assessed by separable VPA.

These methods are probably as refined as is worthwhile for this type of ad hoc VPA tuning. As pointed out in Appendix F of the 1983 report, ad hoc tuning is not formally a procedure for fitting a known statistical model and is used only as the best operational tool currently available. It suffers from the important disadvantage that, although the terminal F values are somewhat smoothed by the procedure, the catch-at-age data for the final year are accepted at face value and used directly to initiate both VPA and catch forecast procedures.

More rigorous methods which recognize and allow for the likely errors of catch-at-age data are desirable, and this Working Group agreed to adopt the development and testing of such methods as a topic for its next meeting.

Methods to be resurrected, developed, and/or updated include:

1) the Icelandic fisheries model (Gudmundssen et al., 1982),

2) Collie and Sissenwine (1982),

3) survivors (Doubleday, 1981),

4) integrated analysis (Pope and Shepherd, 1984),

5) the Pacific halibut model of Quinn et al. (1985).

Criteria for testing should include:

1) accuracy of reproduction of hindcast estimates,

2) prediction error in catch in the next year,

3) error in estimation of year-class size,

4) prediction error in catch forecasts.

5.3 Estimation of Recruitment Indices

One working paper by J. Pope (1985d) and two verbal reports by Shepherd and Rosenberg were presented to the Working Group. Pope used both the Kalman filter (KF) and an equivalent general linear model to calibrate seven recruitment survey series to 1-year-old VPA results for Division VIIa cod. The approach used was to treat both the VPA and the recruitment survey series as Y variates (data) to be interpreted in terms of the unknown "states of nature" of year-class strength and (for all but VPA) a survey effect. These are treated as regression coefficients. Log-linear relationships were assumed between the VPA and survey indices and year-class strength.

In the case of VPA, this was supposed to have unit slope, and slope 0.5 in all other cases. It was apparent that the generalized linear model (GLIM) and KF results were very similar and the calibration coefficients were effectively the same. The KF estimates of the year class based only on two 0-group survey series were, however, consistently less erratic than those from the GLIM model. This suggests that the Kalman filter approach, which effectively "shrinks" the survey estimates towards the geometric mean, is beneficial. The drawback with both the GLIM and the KF models is that they require a considerable degree of prior knowledge of the model.

The advantages of the Kalman filter method in particular are that:

1) it allows for updating with new information at any time,

2) it permits prior information to be combined with later observations in an appropriate way,

3) it uses a model of the "system" under study to condition the results (in this case, the system model is that, once established, the strength of a year class at a particular age is a constant).

The first two of these useful properties may also be achieved by less complicated calculations. If all estimates are accompanied by their standard errors, they may be combined by computing weighted averages, where the weights are the reciprocal of their variances (see e.g., Topping, 1962). The variance of the new mean estimate may also be calculated in two ways (based on the expectation based on the assumed variance, and the actual deviations of the values), and these may be tested for consistency using what is essentially a weighted one-way analysis of variance. This procedure may be repeated whenever and as often as necessary and shows that the Kalman methodology may not be entirely necessary in this very simple case. The procedure is, however, somewhat ad hoc, and the estimates of variance may be misleading if the survey indices are not independent.

A general approach to the problem of combining information from several sources to estimate abundance or recruitment has been given in Myers and Rosenberg (1985). The problem can be framed as a structural equation model, that is, relating sets of random variables to one another. Recruit abundance is treated as an underlying unobserved variable which explains the linear associations between the various recruitment indices such as VPA and survey results. Each survey index is assumed to be linearly related to the underlying recruit abundance and to contain some measurement error. The simplest case is with three indices whose measurement errors are all uncorrelated. That is:

$$Y_{1t} = \lambda_1 x_t + e_{1t}$$
$$Y_{2t} = \lambda_2 x_t + e_{2t}$$
$$Y_{3t} = \lambda_3 x_t + e_{3t}$$

where Y_{it}, $i = 1,\ldots 3$ are the observed survey indices, e_{it} are the measurement errors, and x_t is the unobserved recruit abundance. The method proceeds by first setting the scale of the unobserved recruitment by setting one of the λ_i equal to 1. In practice, this should be the λ_i associated with VPA. We should use all variables as deviations from their means (or, perhaps, the origin) to simplify the calculations. Then, the covariance matrix of the observed indices is written in terms of the model parameters, that is, the λ_i and the variances of the error terms and the unobservable. The estimates are obtained by minimizing the difference between the sample and model covariance matrix. Estimates of the x_t are then calculated as:

$$\chi_i = \delta_x^2 \frac{\sum_i \frac{\lambda_i}{\delta_i^2} Yi}{\sum_i \lambda_i^2 / \delta_i^2} = \delta_\chi^2 \frac{\sum_i (\lambda_i / \delta_i^2) Y_i}{\sum_i \lambda_i^2 / \delta_i^2}$$

This procedure, illustrated by the simple three-variable case, is called confirmatory factor analysis in statistics or econometrics. Programs to implement a very general form of this model are available in SPSS-X under the program name LISREL.

The factor analysis method may have difficulties if one of the abundance indices is very good compared to the others. VPA will often contain most of the information, and so it will not be possible to estimate its associated measurement error. One solution is to use the method simply for calibration by setting the measurement error of VPA to zero (i.e., VPA equals recruit abundance and its mean and variance are sufficiently described by the sample mean and variance). The other indices may then be calibrated to VPA by the method outlined above.

A simple worked example showed that the results of the factor analysis method were very similar to those using the simple weighting method. The methods are, in practice, quite similar, but the simple estimates of variance are suspect.

Further investigation and tests of these procedures are desirable. It should be noted that, when recruitment estimates from surveys at different times of year are used, it may be necessary to allow for seasonal mortality during the year in the VPA.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Discards

1) Inclusion of discards and age-dependence of natural mortality, when these are significant, should reduce the bias of historical estimates (especially of recruitment) and improve the correlation with other independent data (e.g., research survey data).

2) These factors may be particularly important when the purpose of the study is not just fishery management (e.g., multispecies studies, ecological modelling, environmental impact assessment).

3) In general, it is, therefore, desirable to estimate discards and age-dependant natural mortality where these are non-trivial and include them in assessment calculations.

4) This should, however, be done with appropriate caution, because appreciable variance may be added to certain critical calculations if the data are of poor quality.

5) Data on discards of good quality are often expensive to collect and are not always necessary for certain assessment calculations. It may not, therefore, be cost-effective to collect such data unless there are particular problems or the level of discarding is known to be high (say, as a rough guide, exceeding 10% of the catch weight).

6) Elimination of catches which are subsequently discarded would generally lead to increased yields and stock sizes, and implemention of appropriate technical measures is, therefore, generally desirable. The conclusions which follow relate only to the desirability, or otherwise, of taking account of discarding in assessment calculations and should not be misconstrued to modify this general conclusion.

7) If discards are included in assessment calculations, it is vital to include them in all parts of the assessment <u>consistently</u>. In particular, if discards are included in the catch data, they should be deducted from forecast catches when preparing forecasts of landings.

8) It is misleading to calculate yield-per-recruit curves and calculate biological reference points with discards included, unless the consequential adjustments are also made to the selection pattern, estimated current fishing mortality, and estimated recruitment levels.

9) Consistent calculations can most easily be understood in terms of yield or biomass relative to the current (reference) level as a function of fishing mortality relative to the current level.

10) The importance of including or excluding discards depends greatly on the variability of the proportion discarded.

11) If the proportions discarded vary substantially, they will have a significant effect on almost all assessment calculations. If they are predictable, then they should be estimated and allowed for. If they are not predictable, then assessments can only be based on average levels, and appreciable prediction error is inevitable.

12) Sampling variability is a contribution to the unpredictability of discard proportions and may be significant.

13) Different assessment calculations are affected to differing extents by discarding. The position, as assessed by the Working Group, is summarized in Table 1.6.1.

14) Preliminary statistical analysis of discard data for North Sea haddock indicates that discard proportions are strongly dependent on age and quite variable (standard deviation up to about 0.1). There is statistically significant variation from year to year of the same order for the principal age groups concerned.

15) These levels and their variability are sufficient to cause errors of the order of 20% in catch forecasts if they are ignored and to increase the variance to the calculation by a comparable amount. The net effect on total prediction error is not certain.

16) Assessment working groups should conduct critical statistical examination of discard data and consider the evidence for systematic variability of discard proportions.

17) If the data are insufficiently precise to allow reliable estimates of year-to-year variation, working groups should consider whether their aims could be met by the estimation and use of average proportions discarded at age.

18) Use of different discard proportions in the most recent year and in the forecast may cause serious error in short-term catch forecasts if the proportions have appreciable variance. The use of the same (average) proportions throughout a forecast (including the most recent data year) is a more robust procedure and to be preferred unless it is believed that the proportions are estimated reliably.

19) For long-term assessment calculations, discard proportions must inevitably be assumed to be constant at some average value. In this circumstance, their effect is mainly dependent on the difference in the estimated cumulative fishing mortality. A partial cancellation occurs, and the total effect may be quite small. One practical example studied by the Working Group showed remarkably small effects arising from the inclusion or exclusion of discards on either yield or biomass, but this result may not be general.

6.2 Age-Dependent Natural Mortality

20) Multispecies assessments indicate that the natural mortalities on young fish are higher than conventional values and are dependent on age and on the abundance of predators and other prey species.

21) Inclusion of higher and/or age-dependent mortality assessment calculations affects the estimated fishing mortality, selection pattern, and recruitment estimates, as well as modifying estimates of yield and biomass.

22) Uses of inaccurate levels of natural mortality may bias estimates of year-class strength, stock sizes, etc. required for various purposes (see Conclusion 2 above), and working groups may wish to use appropriate average levels in order to reduce this bias.

23) If natural mortality levels are to be changed, it is vital to change them in all related assessment calculations including the estimation of selection pattern, fishing mortality levels, and recruitment.

24) Assessment working groups are warned that using age-dependent natural mortality levels does not take proper account of all relevant multispecies effects, which cannot be properly assessed except using a multispecies model. In particular, levels of natural mortality are likely to vary somewhat from year to year.

25) The effects of changing natural mortality levels from year to year are unpredictable, and this should not be done except when incontrovertible evidence to support it is available. Failure to heed this warning may lead to serious error in critical calculations.

26) Use of age-dependent natural mortalities does not affect the results of short-term catch forecasts significantly provided that the calculations are carried out in an appropriate fashion. It is not, therefore, necessary to revise natural mortality estimates simply in order to improve such calculations, although it may be desirable for other reasons.

27) Great care should be exercised when carrying out catch forecasts to ensure maximum consistency of the assumptions throughout the period of the forecast, including the data year.

28) Exploitation patterns should be changed during a forecast only if there is excellent reason for doing so.

29) Great care should be taken when inserting independent estimates of population sizes (e.g., from recruitment surveys). These should be deduced from a regression on an appropriate data set (using the same assumptions about M). When such estimates lead to inconsistencies with expected (e.g., average) fishing mortalities and the catch data, the fishing mortality should not be adjusted unless the same adjustment is made throughout the calculation, unless excellent justification is available, or else major and unpredictable effects on the estimated catches may occur.

30) Increasing natural mortality on young fish in long-term calculations causes appreciable effects on calculations of long-term yield and biomass at average recruitment, but these are mainly at levels of fishing mortality far from current levels.

31) The effect is always to make the slope of the yield curve at current F less negative (or more positive) and, thus, to shift the maximum of the yield curve (if any) to a higher level of relative F.

32) Similarly, the effect of increased M is always to reduce the (negative) slope of the biomass curve at all levels of relative mortality.

33) Use of higher natural mortalities has a detectable effect on the calculations of the effect of changing selection patterns, but only modifies, to a moderate extent, the size of the effect concerned, and not its sign.

34) It should be remembered that use of single-species yield- and biomass-per-recruit calculations for predators may be seriously misleading (see Section 4.4 of the 1985 Multispecies Working Group report). The Working Group repeats and endorses its earlier remarks concerning the use of yield per recruit as a basis for management strategy, particularly the use of F_{max} and $F_{0.1}$.

6.3 Length-Based Methods of Assessment

35) Length-based assessment methods are, if applied with appropriate care, a viable alternative to age-based methods when age data are not available.

36) Length-based methodology has been mainly developed for steady-state calculations (R. Jones' method), but short-term forecasts, etc. are clearly feasible, although the methodology requires further development.

37) The determination of growth parameters is crucial to the use of length-based methods. The methods for modal analysis, in particular, need to be tested carefully.

38) General statistical models of length data, whilst preferable on theoretical grounds, do not so far perform well in practice. The most practical procedure seems to be to analyze the data in a sequential and modular fashion using general models for final "polishing" of the results once good approximate solutions have been obtained.

39) For interpretation of length data, the relationship of age to length is usually required (except for deconvolution). This is not correctly estimated by fitting mean length at age, and this may lead to significant errors in the interpretation in terms of age, especially if simple "cohort slicing" is used, as in the Jones method.

40) Numerical deconvolution of length compositions into age compositions is possible, given information about the mean and standard deviation of length at age. Suitable methods leading to non-negative solutions are required. This technique may be useful when limited age data are available. It permits age-length data obtained in one year to be used for another, which is otherwise incorrect.

41) The Jones method assumes that a steady-state length composition is available. The data should be tested for stationarity. Techniques for estimating the steady-state composition, other than simple averaging, are available and should be used if necessary.

42) Growth of fish is clearly a stochastic rather than a deterministic process, and methods which explicitly take account of this should be further developed.

43) The inclusion of even a small amount of age information, particularly for larger individuals, may greatly improve the estimates of growth parameters. Methods for combining age-at-length data with length composition data to determine growth rates need further development and have, potentially, widespread application.

6.4 Other Simpler Methods of Assessment

44) Current working group practices often effectively assume a state of ignorance each year and ignore prior information (e.g., year-class strengths). Methodology, particular that of the Kalman filter, exists which permits appropriate combination of prior and new information.

45) The Kalman filter may be applied to the problem of short-term forecasting using both "short-cut" and more traditional methods. Tests so far give encouraging results, and these applications should be pursued.

46) A very simple multiplicative (log-linear) model of catch-at-age data, either from research surveys or commercial landings, is capable of explaining the greater part of the structure of the data in terms of a year effect, an age effect, and a year-class effect.

47) The method may be used to estimate the steady-state age composition and the time series of year-class strength, and seems to perform surprisingly well. It may also be used to construct a simple and probably robust short-term catch forecast, and this application should be further studied, together with the statistical adequacy of the model.

6.5 Other Topics

48) The methods available for *ad hoc* "tuning" of terminal Fs for VPAs are now understood to belong to one general family of methods for the analysis and prediction of catchability.

49) For practical use, methods which analyze each age group, separately using disaggregated fleet data and regression against time are recommended for the time being. These include the Lewy/Armstrong method and the "hybrid" method.

50) *Ad hoc* tuning methods are not ideal because they lead to population estimates which are heavily dependent on the last year's catch-at-age data and are, therefore, somewhat noisy. Further development of existing (but not fully operational) methods, based on fitting statistical models, is required, and the Working Group should carry out comparative destructive testing of such methods at its next meeting.

51) Statistical methods for combining alternative (and possibly conflicting) estimates of recruitment are available. These include Kalman filters, factor analysis, and simple variance-weighted means. Such procedures are to be preferred to simple *ad hoc* selection of one index rather than another, and may also be useful for the preparation of the indices themselves from disaggregated data. The further study and use of such methods is recommended.

6.6 General

52) The reports of the Working Group should continue to be distributed to all members of assessment working groups, and published in the Cooperative Research Report series to make them accessible to a wider readership.

53) The Working Group considers that suitable topics for consideration at its next meeting would be:

   a) development and applicability of stock-production models,

   b) utilization of research survey data,

   c) development and testing of statistical models for the joint analysis of catch-at-age and CPUE and/or survey data.

54) The juxtaposition of the Multispecies and Methods Working Groups places an unacceptable strain on those who attend both groups, and the meetings should be separated in the future, perhaps meeting in alternate years.

55) The work of the Group would have been assisted very considerably if facilities had been available for graphical output and connection of micro computers to the ICES computer. The Working Group, therefore, endorses the suggestions made in the 1985 Multispecies Working Group report.

56) The Working Group acknowledges with thanks the assistance of T.K. Stokes, C.T. Macer, M.D. Nicholson, C.G. Brown, and A. Laurec, who had contributed working papers but were not present at the meeting.

57) The Working Group is seriously concerned that its advice does not seem to be getting through to ACFM, and feels that this situation could be improved by having one or two ACFM members present at its meetings. The Working Group, therefore, recommends that at least one ACFM member should be nominated as a member of this Working Group.

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Table 1.6.1 Consideration of the likely impacts of discards on various types of assessment calculations given several assumptions of the variability and predictability of discard rates. A zero (0) indicates no effect, a star (*) small, two (**) medium and three (***) major effect.

			Discards		
				Variable proportions	
Selection	Assessment calculation		Constant proportion	Predictable	Unpredictable
Constant (e.g., catch forecast,YPR, BPR)	Short-term catch forecast		0	**	0 + error
	Long-term catch forecast	Relative yield	*	***	* + error
		Relative biomass	*	**	* + error
Changing (e.g.,mesh assessment)	Short-term losses/gains		**	***	** + error
	Long-term losses /gains	Relative yield	**	***	** + error
		Relative biomass	*	*	* + error

Table 1.6.3.1 Proportion of the Sub-area IV international haddock catch discarded between 1975 and 1984.

Age	Year										Mean	Std.dev.
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984		
1	0.98	0.98	0.92	0.96	0.94	0.98	0.95	0.93	0.93	0.94	0.95	0.023
2	0.64	0.75	0.60	0.62	0.42	0.56	0.62	0.46	0.56	0.55	0.58	0.095
3	0.30	0.22	0.24	0.15	0.08	0.04	0.19	0.18	0.23	0.12	0.17	0.078
4	0.13	0.02	0.02	0.11	0.005	0.004	0.01	0.05	0.06	0.05	0.04	0.047
5	0.009	0.005	0.002	0.008	0.003	-	0.002	-	0.04	0.008	0.008	0.013

Table 1.6.3.2 Results of analysis of variance of discard proportions of haddock in five Scottish fleets by gear effect and year effect.

Age	Mean	MS-Total	SS-Gear/SS-Total	SS-Year/SS-Total	MS-Error
1	0.94	0.0021	0.0762	0.2952	0.0018
2	0.52	0.0246	0.3339**	0.2542*	0.0138
3	0.16	0.0093	0.0815	0.4141**	0.0064
4	0.04	0.0028	0.0222	0.7556**	0.0008
5	0.03	0.0002	0.0780	0.3811	0.0001

*significant at 5% level

**significant at 1% level

Table 1.6.3.3 Multiple classification analysis of discard proportions of haddock in five Scottish fleets corresponding to the ANOVA in Table 1.6.3.2. This table gives the difference between the grand mean and the observed mean in a particular fleet or year.

Age	Gear				
	1	2	3	4	5
1	-0.02	0.01	0.01	-0.01	0.01
2	0.07	0.04	0.03	-0.18	0.04
3	0.05	-	-	-0.04	-
4	0.02	-0.01	-0.01	-	-
5	0.01	-	-	-	-

Age	Year									
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
1	-	-	-0.03	0.01	-0.02	0.05	0.03	-0.02	-0.02	0.01
2	-	0.06	0.09	0.02	-0.16	-0.01	0.08	-0.12	-	0.06
3	0.06	0.07	0.08	-0.03	-0.07	-0.12	-0.02	-0.01	0.03	0.02
4	0.10	-0.03	-0.02	0.07	-0.03	-0.04	-0.04	-0.01	-	-0.01
5	0.01	0.01	-	0.01	-	-	-	-	-	-

Table 2.1.1 $M^*(a)$ values used for North Sea haddock.

Age	M*
0	2.036
1	1.435
2	0.361
3	0.249
4	0.239
5	0.209
6	0.200
7	0.200
8	0.200
9	0.200
10	0.200
11	0.200
12	0.200

Table 2.1.2 CRATIO values for various years for $M(a) = 0.2$ and $M^*(a)$.

Age	1965		1970		1975		1980		1980-82 ave.	
	CRATIO	CRATIO*	CRATIO	CRATIO*	CRATIO	CRATIO*	CRATIO	CRATIO*	CRATIO	CRATIO*
0	1.568526	1.576949	2.021250	2.043483	3.905894	3.823538	0.363037	0.361454	0.453557	0.448817
1	0.042837	0.041201	0.349116	0.355950	0.546717	0.552435	0.854803	0.871338	0.706033	0.701472
2	0.572928	0.579291	0.268106	0.269696	0.315929	0.314887	0.501091	0.508060	0.648416	0.649921
3	0.722776	0.724748	0.257414	0.258770	0.201758	0.202681	0.231869	0.232171	0.304777	0.304858
4	0.362300	0.362122	0.142118	0.141972	0.249721	0.249599	0.210051	0.210190	0.251534	0.254240
5	0.199812	0.199815	0.692903	0.692380	0.257223	0.257071	0.309616	0.309471	0.351556	0.350980
6	0.274112	0.274112	0.098840	0.098840	0.526783	0.526783	0.317114	0.317114	0.429724	0.429724
7	0.193275	0.193275	1.183252	1.183252	0.176245	0.176245	0.244639	0.244639	0.267795	0.267795
8	0.974934	0.974934	0.068801	0.068801	0.276088	0.276088	0.637042	0.637042	0.419762	0.419762
9	0.254940	0.254940	2.362614	2.362614	0.197654	0.197654	0.143801	0.143801	0.309202	0.309202
10	0.332871	0.332871	0.332871	0.332871	0.332871	0.332871	0.332871	0.332871	0.332871	0.332871
11	0.332871	0.332871	0.332871	0.332871	0.332871	0.332871	0.332871	0.332871	0.332871	0.332871

Table 2.1.3 CE(1,y)/CE*(1,y) by year and the associated F(1) and F*(1) from VPA's with M(a) = 0.2 and M*(a).

Year	F	F*	CE/CE*
1969	0.052	0.023	3.797484
1970	0.956	0.512	2.513725
1971	0.911	0.487	2.542755
1972	0.381	0.180	3.236398
1973	0.747	0.390	2.693642
1974	0.711	0.369	2.730863
1975	0.687	0.352	2.777600
1976	0.639	0.327	2.813516
1977	0.681	0.352	2.760409
1978	0.781	0.409	2.665181
1979	0.390	0.185	3.216197
1980	0.419	0.197	3.217065
1981	0.413	0.195	3.209788
1982	0.423	0.204	3.138817
1983	0.345	0.162	3.287732

Table 2.1.4 Results of a catch forecast of North Sea haddock made with two levels of M(a).

Age	F	M	F*	M*
0	0.480	0.2	0.064	2.036
1	0.420	0.2	0.199	1.435
2	0.590	0.2	0.533	0.361
3	1.005	0.2	0.968	0.249
4	1.034	0.2	1.009	0.239
5	0.818	0.2	0.816	0.209
6	0.785	0.2	0.785	0.200
7	0.978	0.2	0.978	0.200
8	0.786	0.2	0.786	0.200
9	0.944	0.2	0.944	0.200
10	0.900	0.2	0.900	0.200
11+	0.900	0.2	0.900	0.200

Age	Yield(a,85)	Yield*(a,85)	%	Yield(a,86)	Yield*(a,86)	%
0	8,299	9,782	85	8,299	9,782	85
1	30,436	27,363	111	53,075	61,902	86
2	203,806	182,048	112	47,397	42,337	112
3	49,982	50,098	100	210,337	188,318	112
4	22,755	22,761	100	20,896	20,950	100
5	4,186	4,231	99	6,811	6,886	99
6	11,741	11,721	100	2,012	2,031	99
7	1,658	1,658	100	5,146	5,137	100
8	271	271	100	738	738	100
9	66	66	100	146	146	100
10	26	26	100	16	16	100
11+	92	92	100	34	34	100
Total	333,318	310,118	108	354,909	338,278	105

Table 2.2.1 Options included in catch predictions.

Parameter	North Sea Roundfish Working Group convention	Alternative convention
Natural mortality	Constant = 0.2	Variable with age (see Table 2.2.2)
Discards	Included	Excluded
IYFS	Used to tune 0- and 1-group in 1984	Average F 1980-82 used to generate 0- and 1-group
Tuning	Catchability tuning ages 2-9	F at ages 2-9 in 1984 = mean for period 1980-82
Exploitation pattern for prediction years	Average pattern for period 1980-84	Same as in 1984

Table 2.2.2 Values of M at age used in catch predictions.

Age	M
0	2.036
1	1.435
2	0.361
3	0.249
4	0.239
5	0.209
6	0.200
7	0.200
8	0.200
9	0.200
10	0.200
11	0.200
12	0.200

Table 2.2.3a Results of catch predictions with 0- and 1-group estimated using IYFS.

Catch category	M	Catchability tuned		Average F tuned	
		Discards included	Discards excluded	Discards included	Discards excluded
Human consumption landings	Constant	295	230	306	235
	Variable	237	196	246	205
Discards	Constant	86	0	77	0
	Variable	70	0	65	0
Industrial by-catch	Constant	10	9	11	10
	Variable	11	10	9	8

Table 2.2.3b Results of catch predictions with 0- and 1-group estimated using mean F for 1980-84 and not tuned using IYFS.

Catch category	M	Catchability tuned		Average F tuned	
		Discards included	Discards excluded	Discards included	Discards excluded
Human consumption landings	Constant	114	79	129	86
	Variable	117	73	130	87
Discards	Constant	45	0	59	0
	Variable	48	0	65	0
Industrial by-catch	Constant	17	13	12	12
	Variable	13	14	14	14

Table 2.2.4 Total catch of North Sea haddock under different prediction regimes.

F	Variable M	Constant M
F(1,84) tuned using IYFS	320	393
F(1,84) as historical average	335	351

Table 3.2.1 Results of length VPA on the standard data sets (solutions of the generalized catch equation). Terminal E = 0.7, M = 0.2, L_∞ = 70 and K = 0.5.

Length (cm)	F	Numbers	Length (cm)	F	Numbers	Length (cm)	F	Numbers
14	0.001	19,658.3	14	0.013	19,656.7	10	0.000	20,180.9
15	0.025	19,516.2	16	0.044	19,354.0	15	0.045	19,489.6
16	0.035	19,355.6	18	0.055	19,000.5	20	0.377	18,600.7
17	0.054	19,186.5	20	0.109	18,624.4	25	1.254	16,472.6
18	0.063	19,002.1	22	0.467	18,161.1	30	2.003	11,695.4
19	0.047	18,809.2	24	0.923	17,158.6	35	2.128	6,493.2
20	0.091	18,626.0	26	1.288	15,528.2	40	2.115	3,167.6
21	0.126	18,408.4	28	1.275	13,520.4	45	2.230	1,361.6
22	0.453	18,162.6	30	1.622	11,707.7	50	2.147	460.4
23	0.481	17,669.8	32	2.222	9,711.6	55	2.216	119.3
24	0.710	17,160.0	34	2.317	7,473.9	60	0.787	16.8
25	1.133	16,487.1	36	2.293	5,605.4	65+	0.467	4.3
26	1.473	15,528.2	38	1.864	4,143.1			
27	1.106	14,378.8	40	1.738	3,174.2			
28	1.206	13,521.6	42	2.272	2,429.3			
29	1.343	12,635.6	44	2.273	1,684.0			
30	1.496	11,708.4	46	2.179	1,133.5			
31	1.746	10,744.8	48	2.352	749.2			
32	2.099	9,711.7	50	2.091	460.6			
33	2.344	8,591.2	52	2.264	284.2			
34	2.291	7,473.3	54	1.990	159.0			
35	2.342	6,494.7	56	2.165	88.6			
36	2.300	5,604.7	58	2.374	42.7			
37	2.287	4,827.5	60	1.049	16.7			
38	2.061	4,142.4	62	0.697	9.6			
39	1.671	3,588.4	64+	0.467	5.7			
40	1.578	3,174.2						
41	1.895	2,813.6						
42	2.256	2,428.9						
43	2.289	2,031.5						
44	2.495	1,683.6						
45	2.057	1,362.8						
46	2.113	1,133.4						
47	2.245	930.9						
48	2.408	749.1						
49	2.299	587.7						
50	2.011	460.5						
51	2.171	367.0						
52	2.141	284.0						
53	2.387	217.3						
54	2.020	158.8						
55	1.969	119.3						
56	2.172	88.4						
57	2.173	62.2						
58	2.549	42.5						
59	2.238	26.4						
60	1.342	16.6						
61	0.795	12.0						
62	0.914	9.5						
63	0.514	7.0						
64	0.555	5.6						
65+	0.467	4.3						

Table 3.2.2 Effects upon estimated stock numbers of uncertainties in the parameters. A_K, A_L, A_M and $A_{1/E}$ designate the first-order sensitivity coefficients associated, respectively, with K, L_∞, M and 1/E. A_{KK}, A_{LL}, A_{MM} designate the second-order sensitivity coefficients associated with K, L_∞ and M. A_{KL} is the coefficient of crossed sensitivity associated with K and L_∞. Terminal E (Cl. 65) = 0.70, K = 0.5, L_∞ = 70.0 and M = 0.20.

Length (cm)	A_K	A_L	A_{KK}	A_{KL}	A_{LL}	A_M	A_{MM}	$A_{1/E}$
14	-0.186	-0.329	0.209	0.397	0.747	0.186	0.022	0.0006
15	-0.179	-0.320	0.200	0.384	0.733	0.179	0.021	0.0006
16	-0.172	-0.311	0.192	0.371	0.718	0.172	0.020	0.0006
17	-0.164	-0.301	0.183	0.357	0.703	0.164	0.018	0.0006
18	-0.157	-0.291	0.175	0.344	0.687	0.157	0.017	0.0006
19	-0.149	-0.281	0.166	0.330	0.671	0.149	0.016	0.0006
20	-0.142	-0.271	0.157	0.315	0.653	0.142	0.015	0.0006
21	-0.134	-0.260	0.148	0.301	0.636	0.134	0.014	0.0006
22	-0.126	-0.249	0.140	0.287	0.619	0.126	0.013	0.0006
23	-0.120	-0.241	0.133	0.276	0.608	0.120	0.012	0.0006
24	-0.114	-0.233	0.126	0.265	0.598	0.114	0.011	0.0006
25	-0.109	-0.227	0.120	0.256	0.592	0.109	0.011	0.0007
26	-0.106	-0.224	0.116	0.251	0.597	0.106	0.010	0.0007
27	-0.104	-0.225	0.114	0.250	0.610	0.104	0.010	0.0007
28	-0.100	-0.221	0.110	0.243	0.613	0.100	0.009	0.0008
29	-0.096	-0.217	0.105	0.237	0.617	0.096	0.009	0.0008
30	-0.092	-0.215	0.102	0.232	0.625	0.092	0.009	0.0009
31	-0.089	-0.213	0.098	0.228	0.637	0.089	0.008	0.0009
32	-0.087	-0.214	0.096	0.226	0.657	0.087	0.008	0.0010
33	-0.087	-0.219	0.096	0.228	0.692	0.087	0.008	0.0012
34	-0.088	-0.227	0.097	0.233	0.739	0.088	0.008	0.0013
35	-0.088	-0.236	0.098	0.237	0.790	0.088	0.008	0.0015
36	-0.089	-0.246	0.099	0.242	0.849	0.089	0.008	0.0017
37	-0.090	-0.256	0.100	0.246	0.912	0.090	0.009	0.0020
38	-0.092	-0.267	0.102	0.250	0.983	0.092	0.009	0.0023
39	-0.092	-0.276	0.102	0.249	1.046	0.092	0.009	0.0026
40	-0.089	-0.276	0.099	0.240	1.085	0.089	0.008	0.0029
41	-0.085	-0.274	0.095	0.227	1.117	0.085	0.008	0.0032
42	-0.083	-0.278	0.093	0.216	1.176	0.083	0.008	0.0036
43	-0.083	-0.289	0.093	0.208	1.275	0.083	0.008	0.0043
44	-0.083	-0.302	0.094	0.197	1.390	0.083	0.008	0.0051
45	-0.085	-0.322	0.097	0.185	1.550	0.085	0.008	0.0062
46	-0.084	-0.332	0.096	0.159	1.674	0.084	0.008	0.0073
47	-0.083	-0.345	0.096	0.126	1.822	0.083	0.008	0.0088
48	-0.083	-0.363	0.098	0.084	2.018	0.083	0.008	0.0107
49	-0.085	-0.391	0.102	0.027	2.286	0.085	0.009	0.0134
50	-0.086	-0.419	0.105	-0.052	2.583	0.086	0.009	0.0167
51	-0.085	-0.438	0.106	-0.158	2.852	0.085	0.009	0.0206
52	-0.085	-0.467	0.110	-0.307	3.226	0.085	0.009	0.0260
53	-0.086	-0.499	0.115	-0.511	3.667	0.086	0.009	0.0332
54	-0.089	-0.557	0.126	-0.818	4.352	0.089	0.010	0.0443
55	-0.089	-0.599	0.133	-1.217	4.984	0.089	0.010	0.0574
56	-0.089	-0.642	0.144	-1.775	5.720	0.089	0.010	0.0752
57	-0.091	-0.720	0.164	-2.657	6.865	0.091	0.011	0.1037
58	-0.096	-0.825	0.195	-4.010	8.402	0.096	0.012	0.1466
59	-0.113	-1.054	0.263	-6.554	11.344	0.113	0.014	0.2281
60	-0.134	-1.335	0.357	-10.427	15.000	0.134	0.015	0.3488
61	-0.133	-1.425	0.422	-14.307	16.644	0.133	0.013	0.4616
62	-0.110	-1.279	0.452	-17.829	15.558	0.110	0.008	0.5551
63	-0.084	-1.059	0.514	-23.475	13.314	0.084	0.004	0.7059
64	-0.031	-0.457	0.531	-28.393	5.733	0.031	0.001	0.8227

Table 3.2.2.1a Partial derivatives of population with respect to terminal F.

Age	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
2	-0.035	-0.057	-0.031	-0.012	-0.027	-0.040	-0.131	-0.216	-0.417	-0.464	-0.615	-0.818	-0.942
3	-0.079	-0.039	-0.059	-0.033	-0.018	-0.031	-0.047	-0.160	-0.250	-0.435	-0.518	-0.728	-0.922
4	-0.037	-0.082	-0.046	-0.063	-0.036	-0.028	-0.036	-0.073	-0.186	-0.302	-0.473	-0.639	-0.860
5	-0.117	-0.046	-0.089	-0.058	-0.069	-0.044	-0.052	-0.058	-0.165	-0.264	-0.417	-0.603	-0.836
6	-0.210	-0.139	-0.076	-0.114	-0.089	-0.092	-0.080	-0.090	-0.125	-0.259	-0.353	-0.586	-0.819
7	-0.523	-0.240	-0.177	-0.131	-0.145	-0.121	-0.134	-0.128	-0.222	-0.232	-0.373	-0.579	-0.819
8	-0.290	-0.548	-0.314	-0.305	-0.262	-0.205	-0.217	-0.235	-0.244	-0.410	-0.349	-0.557	-0.819
9	-0.791	-0.337	-0.750	-0.357	-0.594	-0.376	-0.308	-0.384	-0.452	-0.407	-0.573	-0.462	-0.819
10	-0.933	-0.840	-0.831	-0.768	-0.844	-0.773	-0.754	-0.675	-0.753	-0.837	-0.824	-0.839	-0.819
2+	-0.056	-0.062	-0.062	-0.048	-0.058	-0.066	-0.104	-0.200	-0.272	-0.363	-0.511	-0.663	-0.865
3+	-0.076	-0.063	-0.073	-0.073	-0.063	-0.074	-0.091	-0.147	-0.245	-0.327	-0.454	-0.653	-0.845
4+	-0.073	-0.087	-0.079	-0.089	-0.088	-0.084	-0.110	-0.139	-0.220	-0.303	-0.426	-0.606	-0.839
5+	-0.172	-0.090	-0.115	-0.105	-0.113	-0.111	-0.133	-0.170	-0.261	-0.310	-0.413	-0.590	-0.825

Table 3.2.2.1b Partial derivatives of population with respect to natural mortality.

Age	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
2	0.758	0.941	0.786	0.411	0.619	0.506	0.652	0.643	0.704	0.531	0.406	0.272	0.095
3	0.871	0.623	0.769	0.616	0.380	0.493	0.377	0.577	0.530	0.529	0.380	0.262	0.094
4	0.470	0.695	0.520	0.613	0.467	0.324	0.359	0.326	0.453	0.418	0.367	0.246	0.092
5	0.545	0.361	0.550	0.424	0.456	0.346	0.318	0.315	0.414	0.403	0.339	0.240	0.091
6	0.573	0.430	0.334	0.472	0.397	0.378	0.348	0.277	0.362	0.392	0.304	0.236	0.090
7	0.558	0.442	0.319	0.303	0.375	0.304	0.304	0.297	0.337	0.387	0.321	0.234	0.090
8	0.339	0.380	0.347	0.277	0.304	0.289	0.267	0.258	0.276	0.337	0.332	0.229	0.090
9	0.280	0.177	0.284	0.181	0.245	0.194	0.184	0.196	0.203	0.194	0.230	0.207	0.090
10	0.094	0.091	0.091	0.088	0.091	0.088	0.087	0.084	0.087	0.091	0.090	0.091	0.090
2+	0.689	0.669	0.626	0.476	0.443	0.394	0.435	0.589	0.537	0.459	0.372	0.249	0.092
3+	0.625	0.562	0.572	0.520	0.412	0.359	0.333	0.401	0.507	0.432	0.353	0.248	0.091
4+	0.492	0.502	0.479	0.483	0.429	0.330	0.314	0.289	0.393	0.411	0.341	0.239	0.091
5+	0.549	0.379	0.434	0.405	0.411	0.333	0.300	0.271	0.320	0.366	0.333	0.236	0.090

Table 3.2.3 Effects upon fishing mortalities of uncertainties in the parameters. Terminal E (Cl. 65) = 70, K = 0.50, L_∞ = 0.70 and M = 0.20.

Length (cm)	A_K	A_L	A_{KK}	A_{KL}	A_{LL}	A_M	A_{MM}
14	1.186	1.590	0.012	1.550	-0.224	-0.186	0.012
15	1.179	1.604	0.011	1.565	-0.219	-0.179	0.011
16	1.172	1.619	0.009	1.579	-0.215	-0.172	0.010
17	1.164	1.634	0.008	1.595	-0.211	-0.164	0.008
18	1.157	1.651	0.007	1.612	-0.206	-0.157	0.007
19	1.149	1.667	0.006	1.629	-0.202	-0.149	0.006
20	1.142	1.685	0.005	1.646	-0.198	-0.142	0.005
21	1.134	1.703	0.004	1.665	-0.193	-0.134	0.004
22	1.126	1.723	0.003	1.685	-0.189	-0.126	0.003
23	1.120	1.747	0.002	1.710	-0.187	-0.120	0.002
24	1.114	1.772	0.001	1.736	-0.185	-0.114	0.002
25	1.109	1.800	0.001	1.765	-0.184	-0.109	0.001
26	1.106	1.833	0.000	1.799	-0.186	-0.106	0.001
27	1.104	1.872	0.000	1.839	-0.190	-0.104	0.001
28	1.100	1.907	0.000	1.876	-0.192	-0.100	0.000
29	1.096	1.946	0.000	1.916	-0.195	-0.096	0.000
30	1.092	1.987	0.001	1.958	-0.199	-0.092	-0.000
31	1.089	2.031	0.001	2.004	-0.204	-0.089	-0.000
32	1.087	2.081	0.001	2.055	-0.212	-0.087	-0.001
33	1.087	2.137	0.001	2.113	-0.224	-0.087	-0.001
34	1.088	2.199	0.001	2.179	-0.240	-0.088	-0.001
35	1.088	2.265	0.001	2.248	-0.256	-0.088	-0.001
36	1.089	2.335	0.002	2.324	-0.275	-0.089	-0.000
37	1.090	2.410	0.002	2.405	-0.295	-0.090	-0.000
38	1.092	2.490	0.002	2.492	-0.317	-0.092	-0.000
39	1.092	2.571	0.002	2.582	-0.337	-0.092	-0.000
40	1.089	2.649	0.002	2.669	-0.353	-0.089	-0.000
41	1.085	2.730	0.003	2.760	-0.368	-0.085	-0.001
42	1.083	2.823	0.003	2.864	-0.393	-0.083	-0.001
43	1.083	2.930	0.004	2.989	-0.429	-0.083	-0.001
44	1.083	3.047	0.004	3.128	-0.471	-0.083	-0.001
45	1.085	3.179	0.005	3.292	-0.525	-0.085	-0.001
46	1.084	3.311	0.005	3.458	-0.573	-0.084	-0.001
47	1.083	3.456	0.006	3.645	-0.630	-0.083	-0.001
48	1.083	3.619	0.008	3.866	-0.703	-0.083	-0.001
49	1.085	3.806	0.009	4.135	-0.798	-0.085	-0.001
50	1.086	4.009	0.011	4.443	-0.903	-0.086	-0.001
51	1.085	4.221	0.014	4.777	-1.005	-0.085	-0.002
52	1.085	4.467	0.017	5.195	-1.141	-0.085	-0.002
53	1.086	4.742	0.022	5.701	-1.300	-0.086	-0.002
54	1.089	5.073	0.028	6.395	-1.525	-0.089	-0.002
55	1.089	5.426	0.036	7.181	-1.735	-0.089	-0.002
56	1.089	5.828	0.047	8.176	-1.977	-0.089	-0.002
57	1.091	6.320	0.064	9.621	-2.311	-0.091	-0.003
58	1.096	6.912	0.090	11.666	-2.697	-0.096	-0.003
59	1.113	7.721	0.137	15.270	-3.203	-0.113	-0.001
60	1.134	8.704	0.205	20.473	-3.381	-0.134	0.003
61	1.133	9.660	0.272	25.441	-2.881	-0.133	0.005
62	1.110	10.612	0.330	29.753	-1.983	-0.110	0.004
63	1.084	11.828	0.423	36.380	-0.794	-0.084	0.003
64	1.031	13.184	0.499	42.002	0.291	-0.031	0.000

Table 3.3.1 Maximum biomass at age and recruitment from long-term model

M	Discards	Biomass (a = 5)	Recruits (f = 1)
Variable	included	3,053	8,929
Variable	excluded	2,328	6,449
Constant	included	2,601	4,923
Constant	excluded	2,047	3,689

Table 5.2.1 Recent methods used in the analysis of catchability.

			Explanatory variate			
Combination of data	Weights for recombination	Data transformation	1 Time	2 Stock size	3 Effort	4 None (constant q)
Aggregated ("before")	n/a	Log	Log-Rho	Gamma	-	Modified gamma
		Lin	Rho	-	-	Hoydal-Jones-Armstrong (mean of three)
Disaggregated ("after")	catch numbers	Log	-	-	-	-
		Lin	Armstrong catchability	-	-	-
	variance	Log	Hybrid	Quasi Gamma	-	Laurec-Shepherd
		Lin	Quasi Rho	-	-	-

Figure 1.6.3.1 Analysis of the variability of North Sea haddock discard rates based on Scottish sampling, 1975-84. Data are given as the proportion of catch discarded (Discards/ Discards + Landings), by age (1-5) and gear type.

AGE	SYMBOL	COUNT	MEAN	ST.DEV.
1	B	49	.944	.046
2	C	50	.520	.157
3	D	50	.165	.096
4	E	50	.041	.052
5	F	49	.007	.013

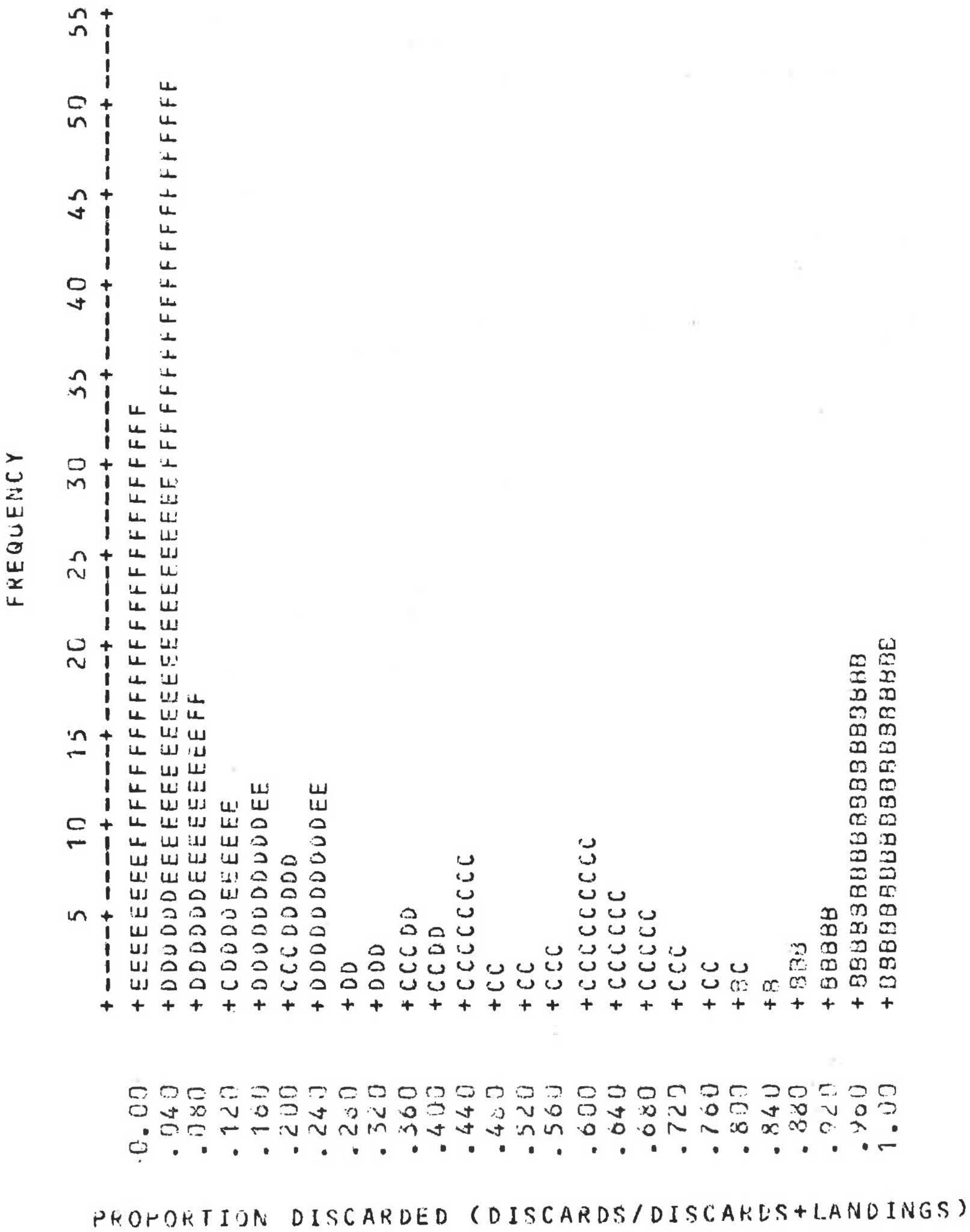


Figure 1.6.3.2 Analysis of residuals from ANOVA models fitted to discard proportion data from North Sea haddock, 1975-84.

```
                              AGE 1

                       ESTIMATE          ST.ERROR                    H
MEAN                  -.0000548          .0051959                   HHH
MEDIAN                 .0050000          .0048873                   HHH
MODE                  NOT UNIQUE                                   HHHHH
                                                                   HHHHH
                                                           H  H  HH HHHHHHH
  95% CONFIDENCE                   Q1=      -.0144200     L----------------U
LOWER            UPPER             Q3=       .0261200
-.0104963         .0103867         S-=      -.0367954
                                   S+=       .0366857        L=        -.1500
                                                             U=         .0900

                                                                   H
                              AGE 2                                H
                                                                   H
                       ESTIMATE          ST.ERROR                  HH
MEAN                  -.0000166          .0142244                  HH
MEDIAN                -.0031450          .0127017               H HHH H
MODE                  NOT UNIQUE                                H HHH HH
                                                                H HHHHHH
                                                             H  HH HHHHHHH
     95% CONFIDENCE                 Q1=      -.0544900       H HHHHHHHHHHHHHH
   LOWER           UPPER            Q3=       .0684400      L----------------U
   -.0286017        .0285685        S-=      -.1005986       L=        -.2400
                                    S+=       .1005654       U=         .2400

                              AGE 3                                H
                                                                   HH
                       ESTIMATE          ST.ERROR                  HH
MEAN                  -.0000006          .0096826               H  HHH
MEDIAN                -.0004150          .0072169               H HHHHH
MODE                  NOT UNIQUE                             H HHHHHHHHHH H
                                                            L----------------U
     95% CONFIDENCE                 Q1=      -.0257700
   LOWER           UPPER            Q3=       .0383000        L=       -.2000
   -.0194585        .0194573        S-=      -.0684670        U=        .2000
                                    S+=       .0684658

                                                                 H
                              AGE 4                              H
                       ESTIMATE          ST.ERROR                HH
MEAN                  -.0001646          .0034577               HHH
MEDIAN                -.0010000          .0025692              HHHH H
MODE                  -.0010000                                HHHH H
                                                           H  HHHHHHHHHH H
    95% CONFIDENCE                 Q1=      -.0130000     L----------------U
  LOWER            UPPER           Q3=       .0100000
  -.0071131         .0067839       S-=      -.0246142      L=        -.0800
                                   S+=       .0242850      U=         .0800

                              AGE 5                                H
                                                                   H
                                                                  HHH
                        ESTIMATE          ST.ERROR                HHH
MEAN                   -.0000006          .0013405                HHH
MEDIAN                 -.0000600          .0010508                HHH
MODE                   NOT UNIQUE                                 HHHH H
                                                               HH HHHHHH H
     95% CONFIDENCE                                           L----------------U
   LOWER            UPPER            Q1=      -.0057400
   -.0026958         .0026946        Q3=       .0027000        L=       -.0350
                                     S-=      -.0093839        U=        .0450
                                     S+=       .0093827
```

Figure 1.7.1 Plot of current stocksize for various M

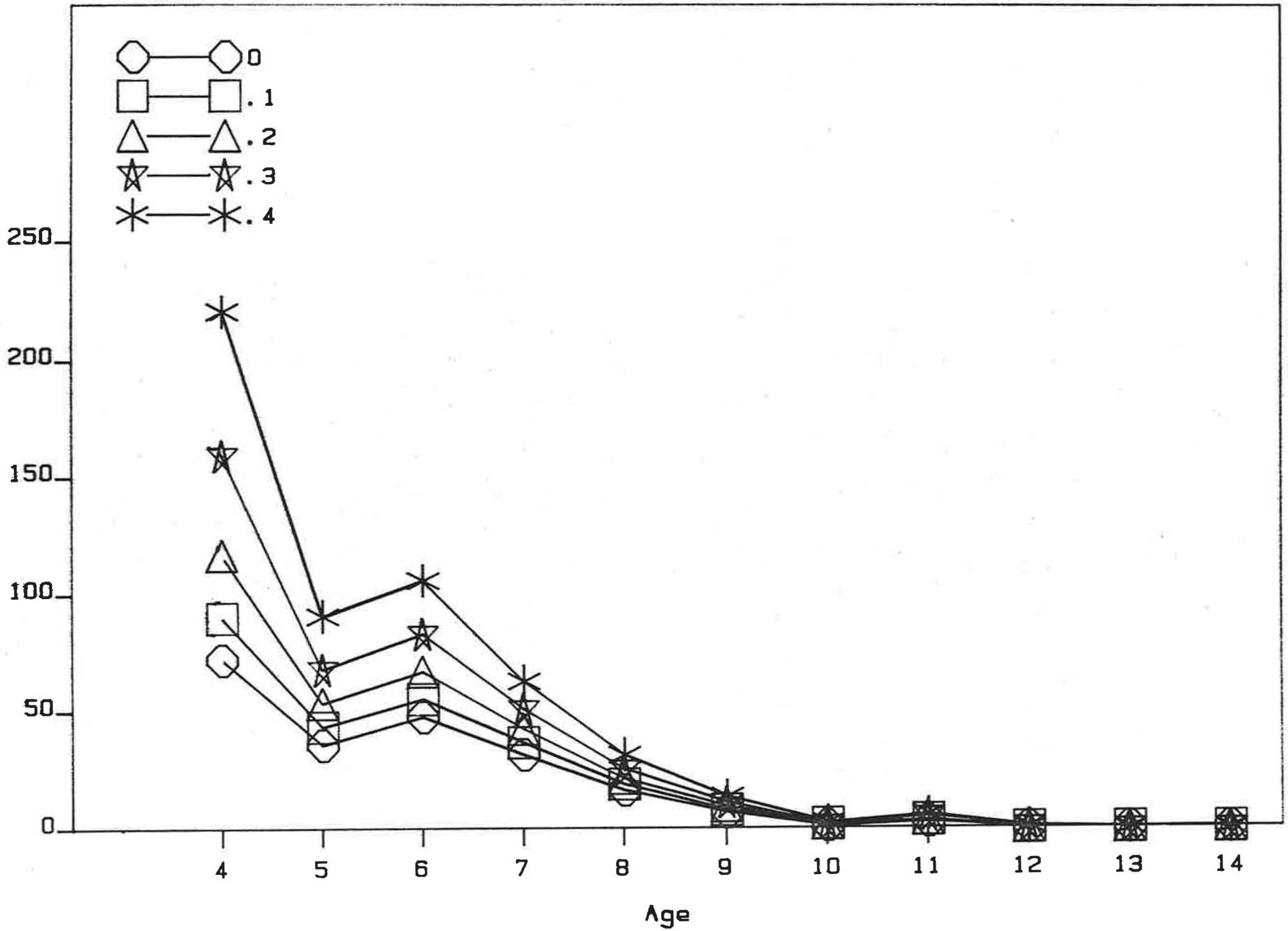


Figure 1.7.2 Plot of input F (average F) for various M

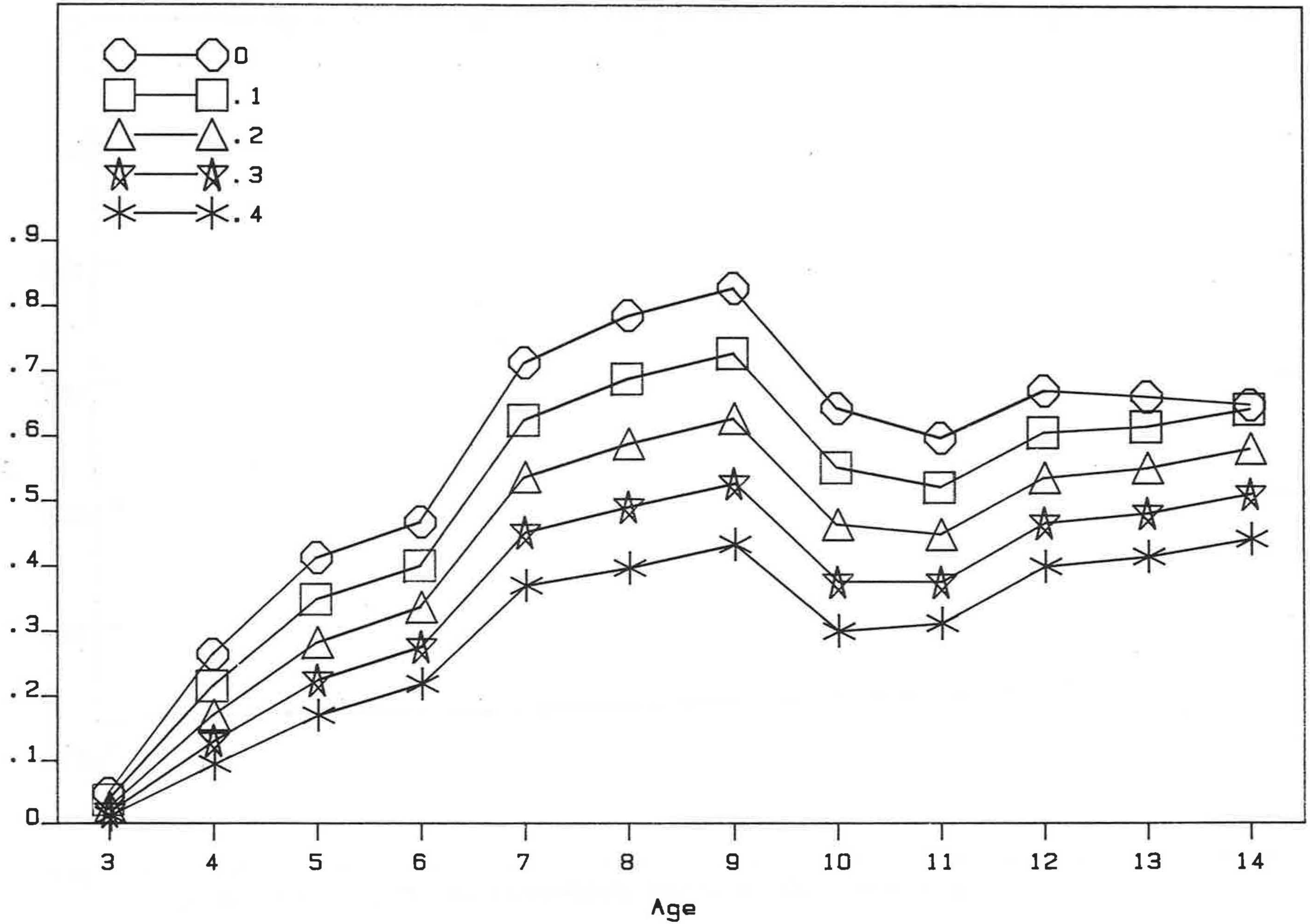


Figure 1.7.3 Plot of predicted catch weight versus M

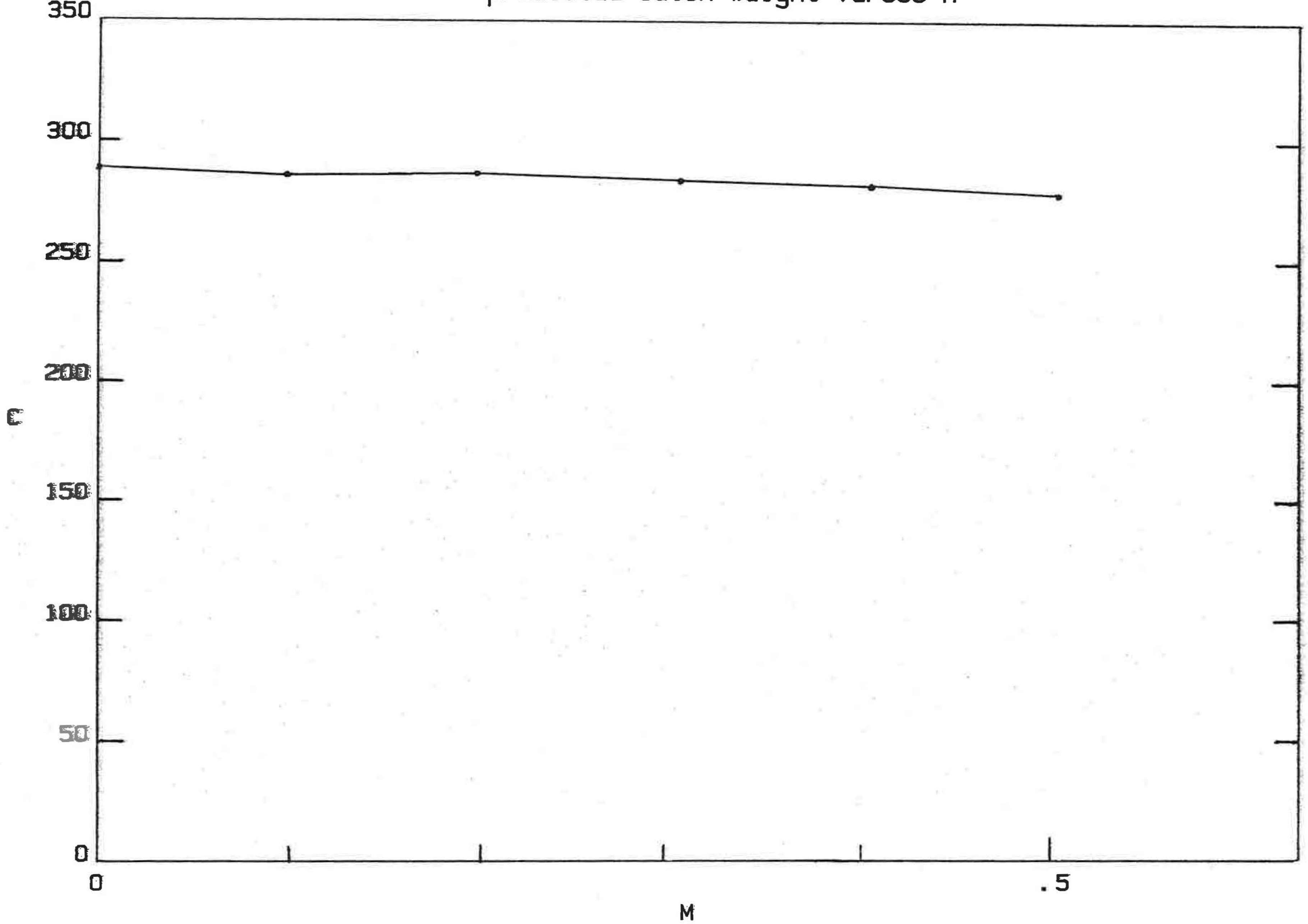


Figure 1.7.4 Yield per recruit for various values of M
(F-pattern adjusted for M)

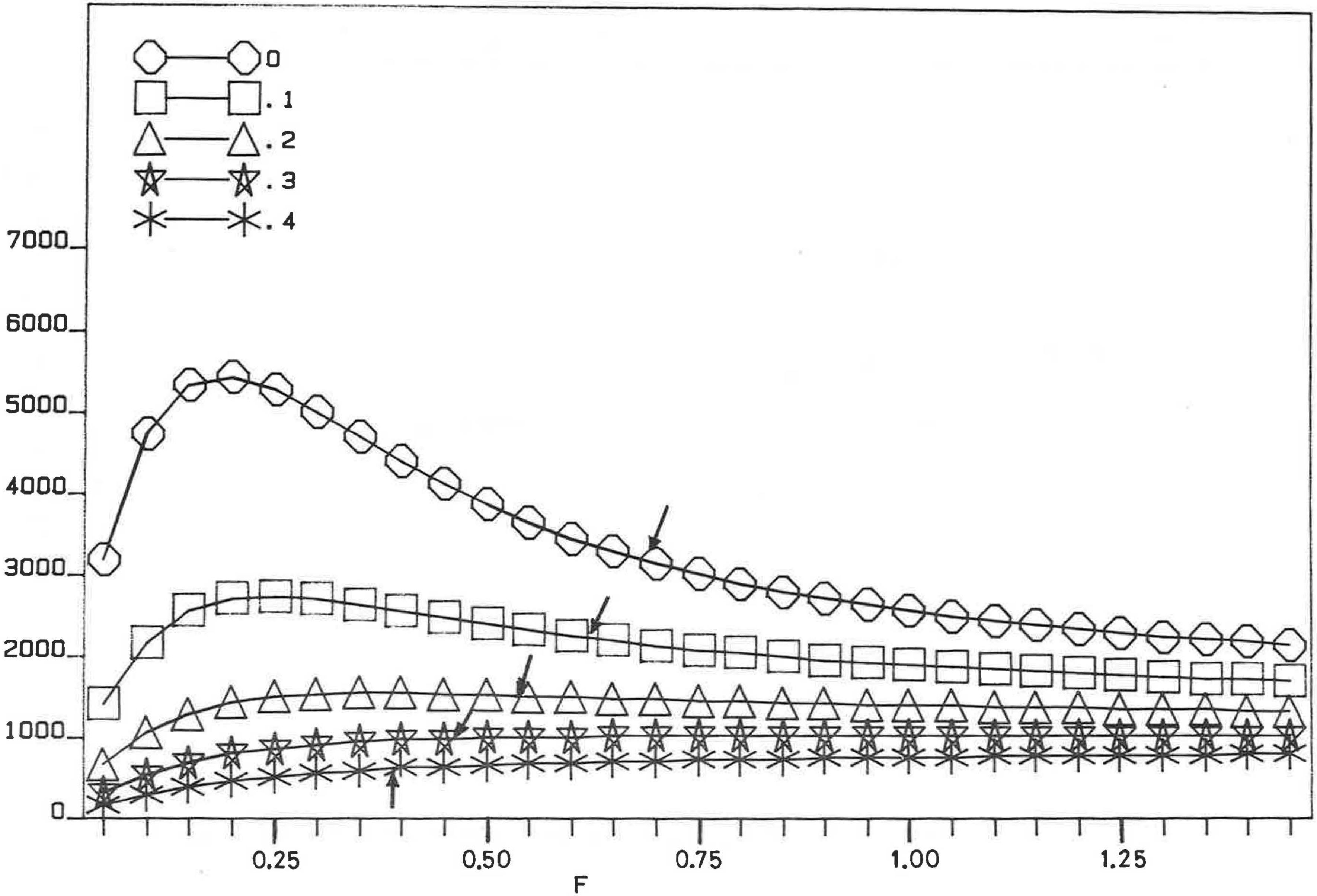


Figure 2.1.1 A comparison of $CE(1,y)/CE^*(1,y)$ with $F(1,y)$.

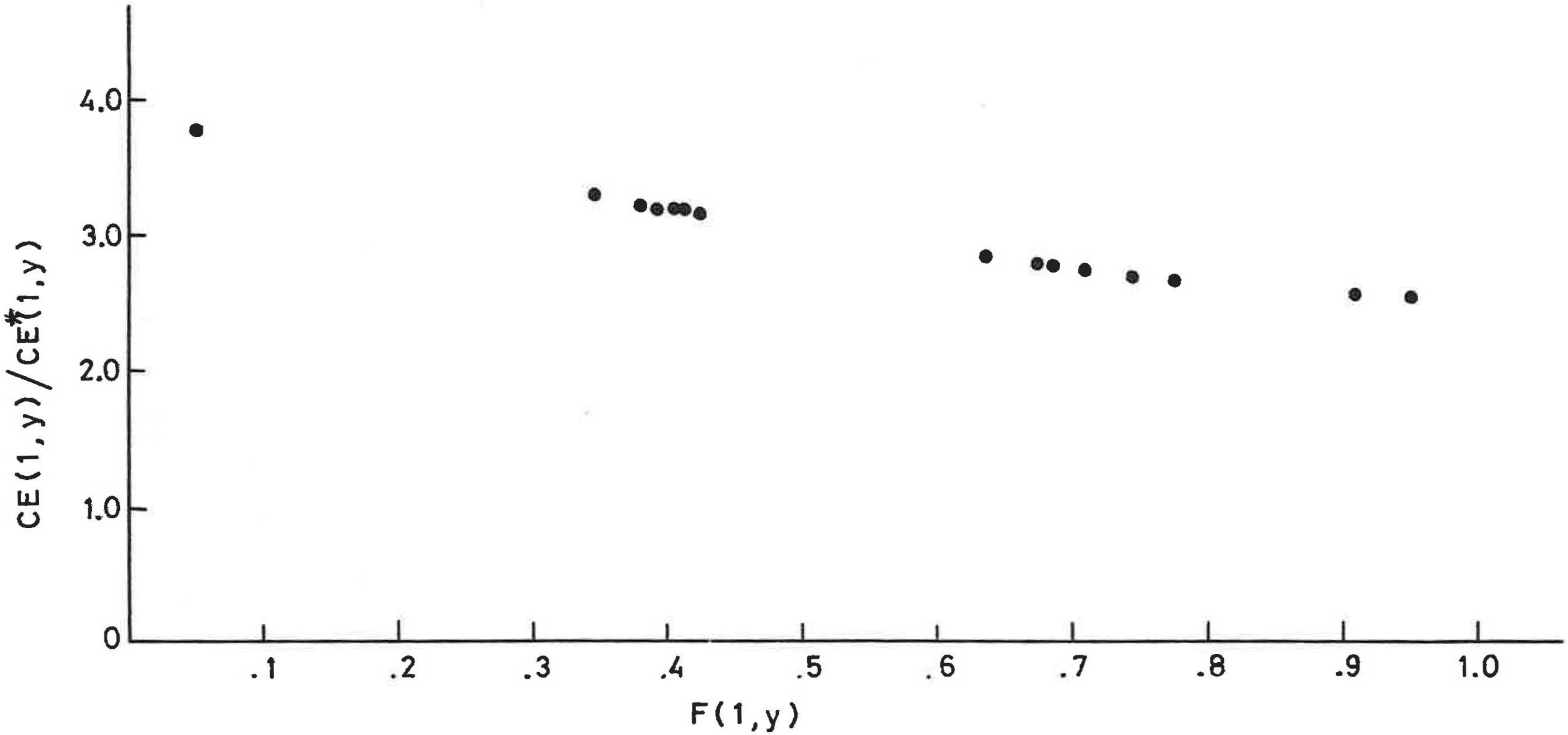


Figure 3.1.1

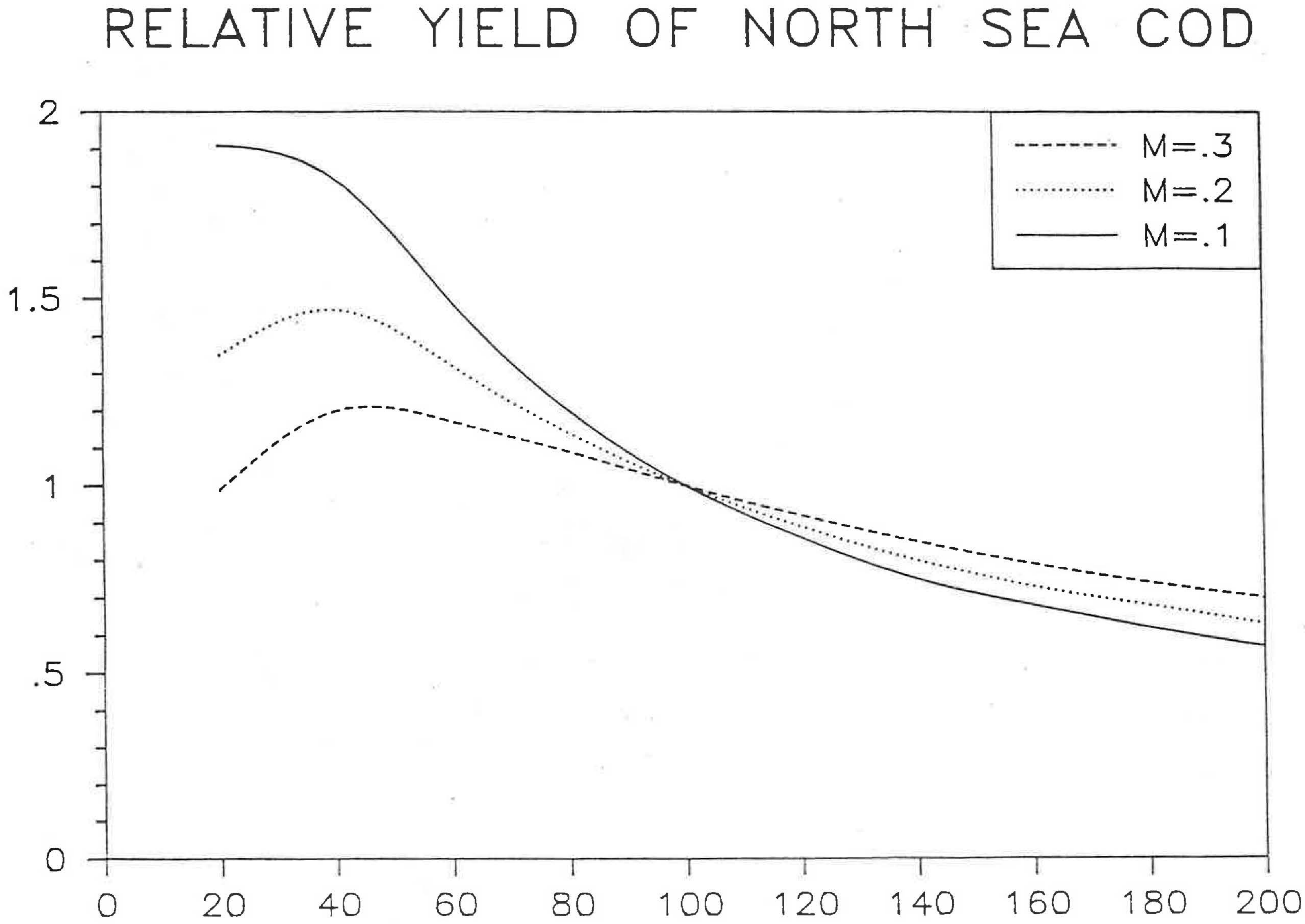

RELATIVE YIELD OF NORTH SEA COD
M=.3
M=.2
M=.1
2
1.5
1
.5
0
0
20
40
60
80
100
120
140
160
180
200

Figure 3.1.2.1

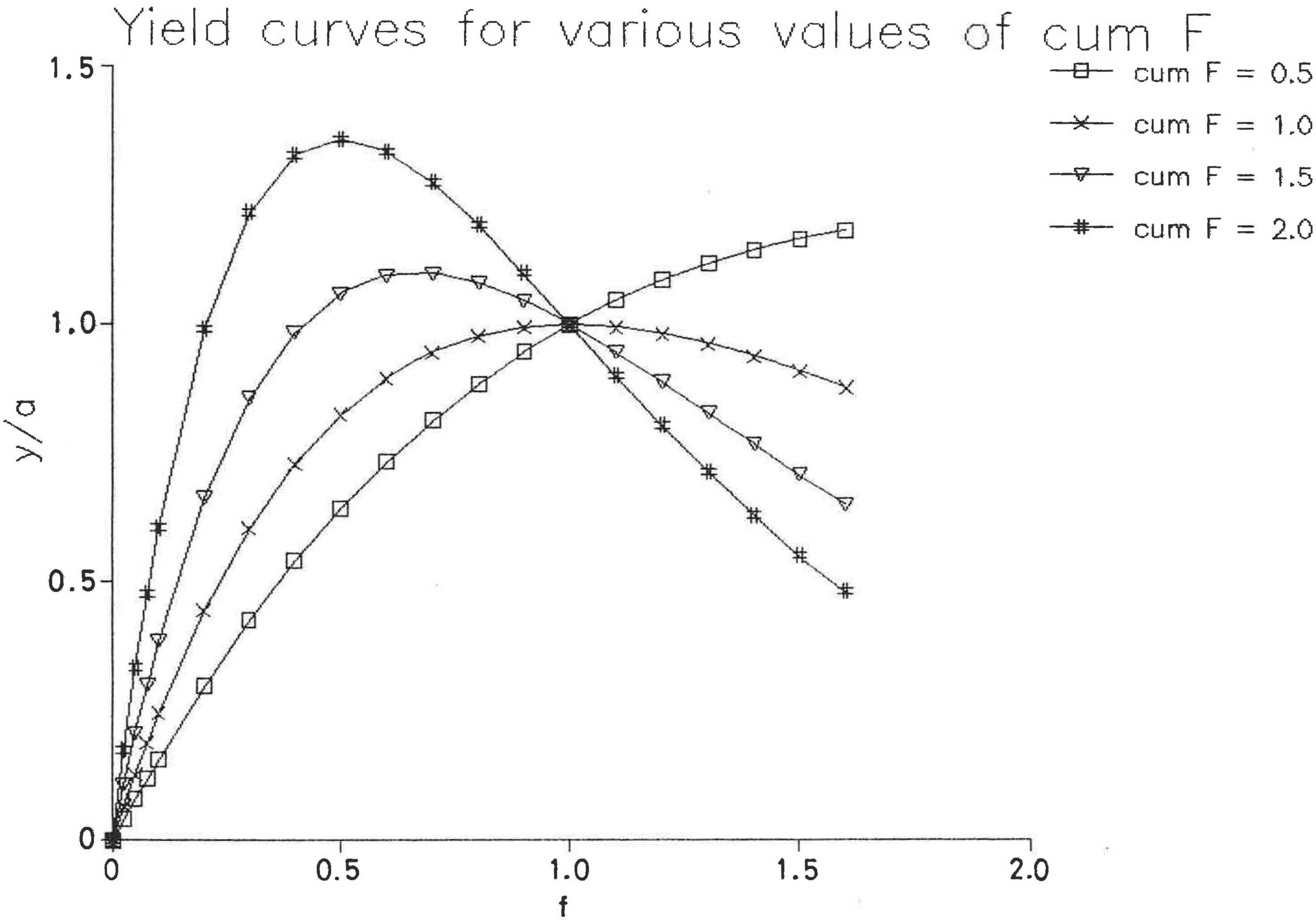
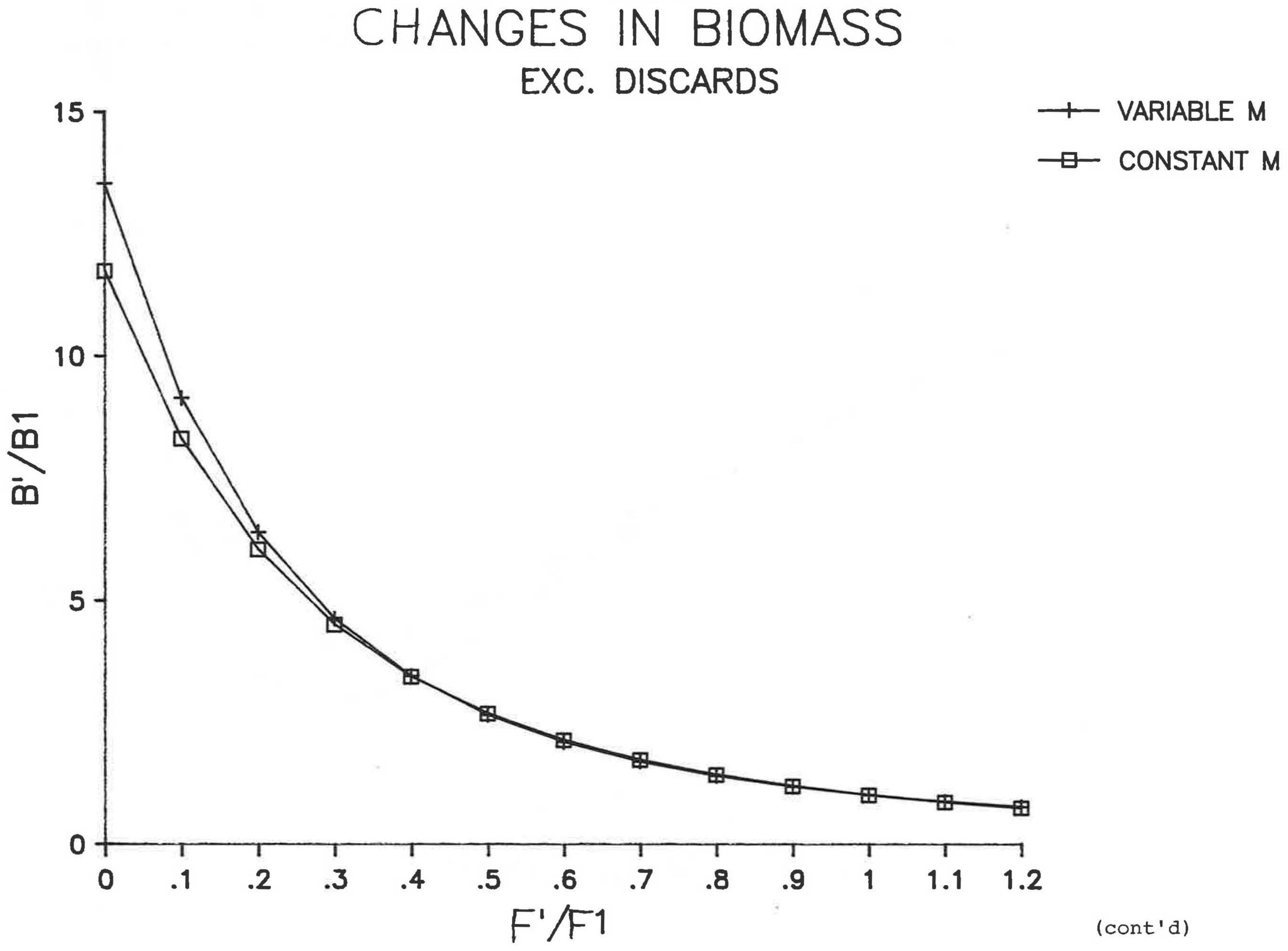
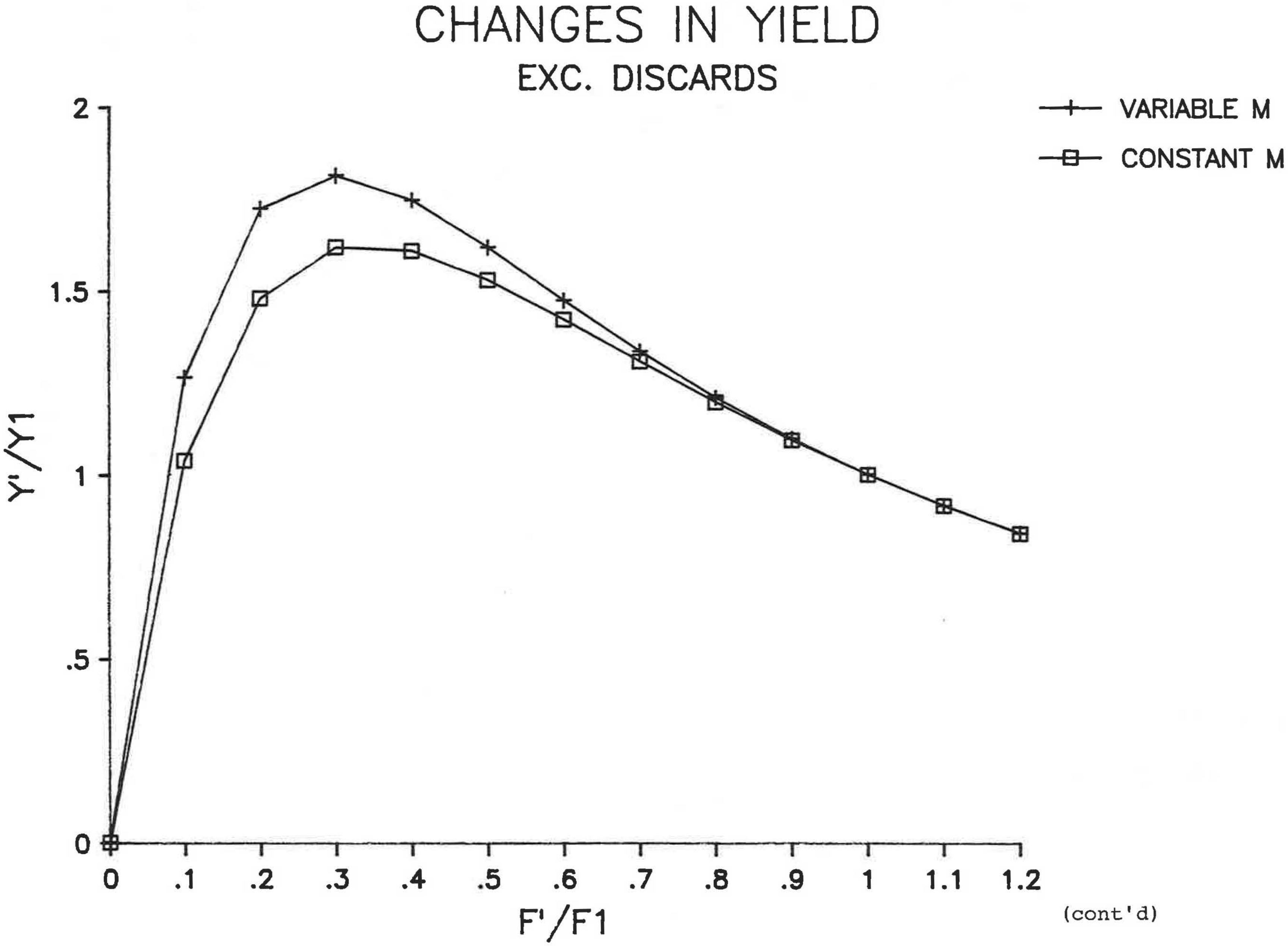

Yield curves for various values of cum F
cum F = 0.5
cum F = 1.0
cum F = 1.5
cum F = 2.0
y/a
f
1.5
1.0
0.5
0
0
0.5
1.0
1.5
2.0

Figure 3.3.1 (a) Comparison of effect of using a constant variable M, on biomass and yield curves, including and excluding discards.



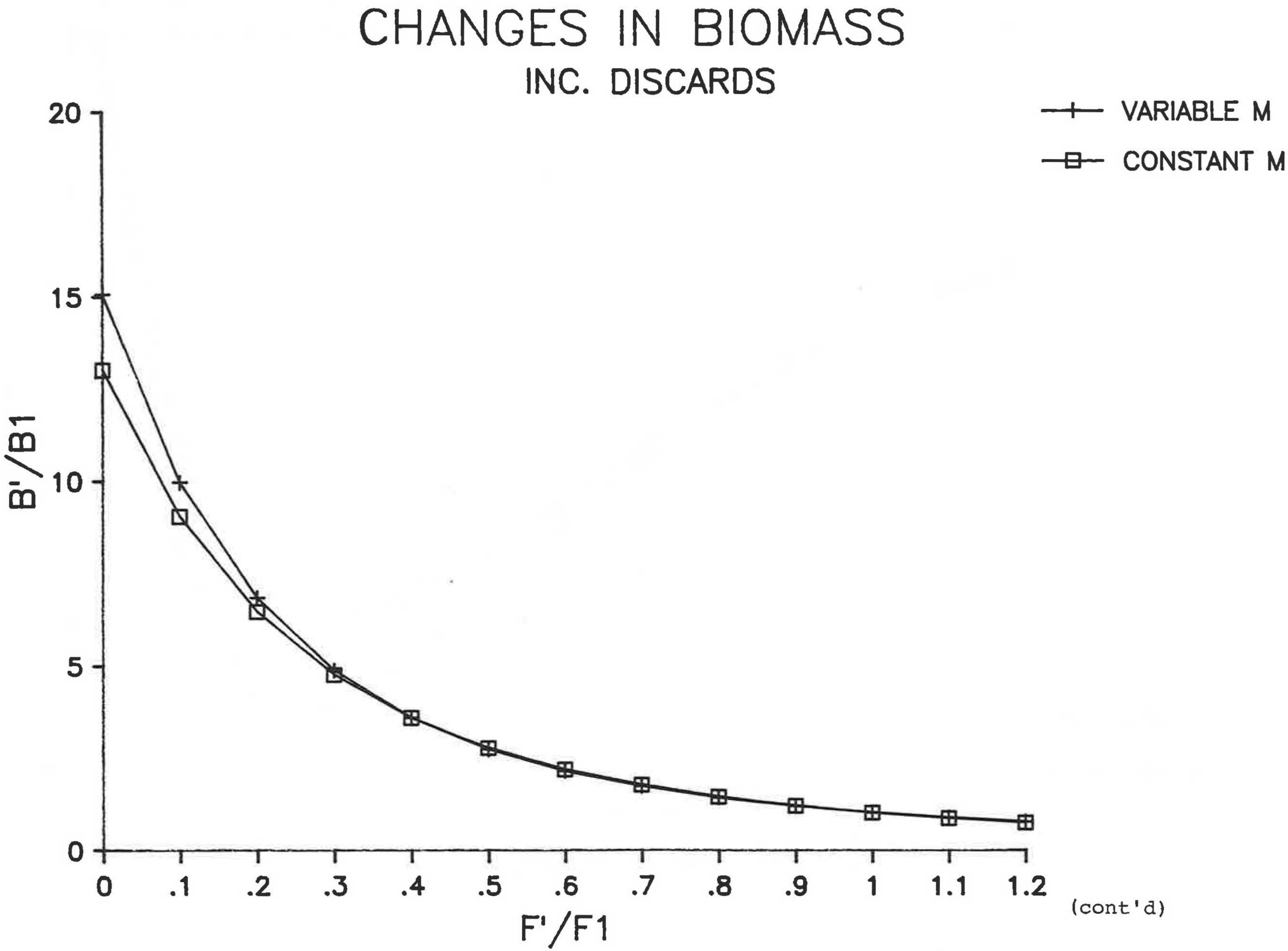
(cont'd)

Figure 3.3.1 (b) (cont'd)



(cont'd)

Figure 3.3.1 (c) (cont'd)



(cont'd)

Figure 3.3.1 (d) (cont'd)

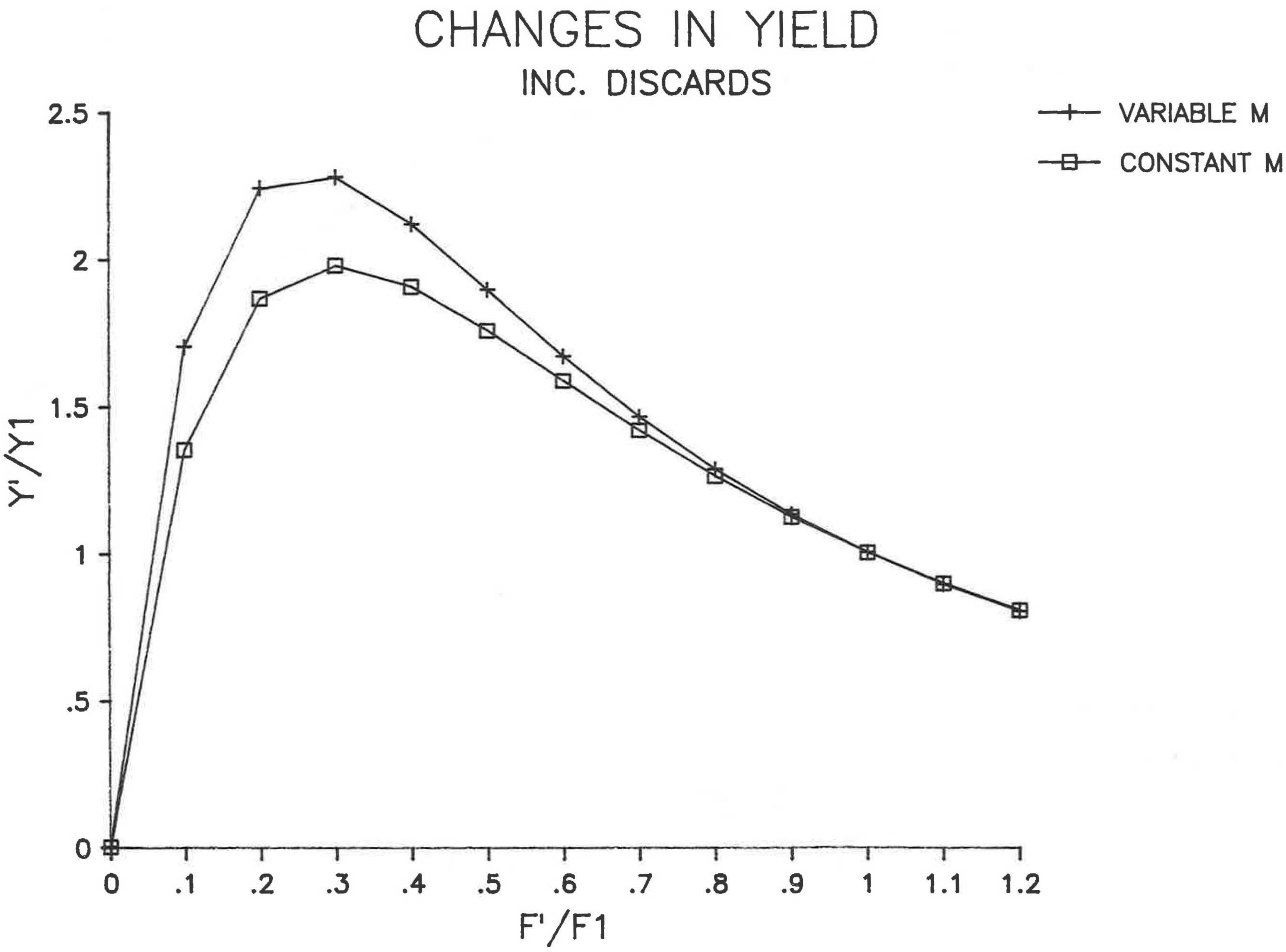
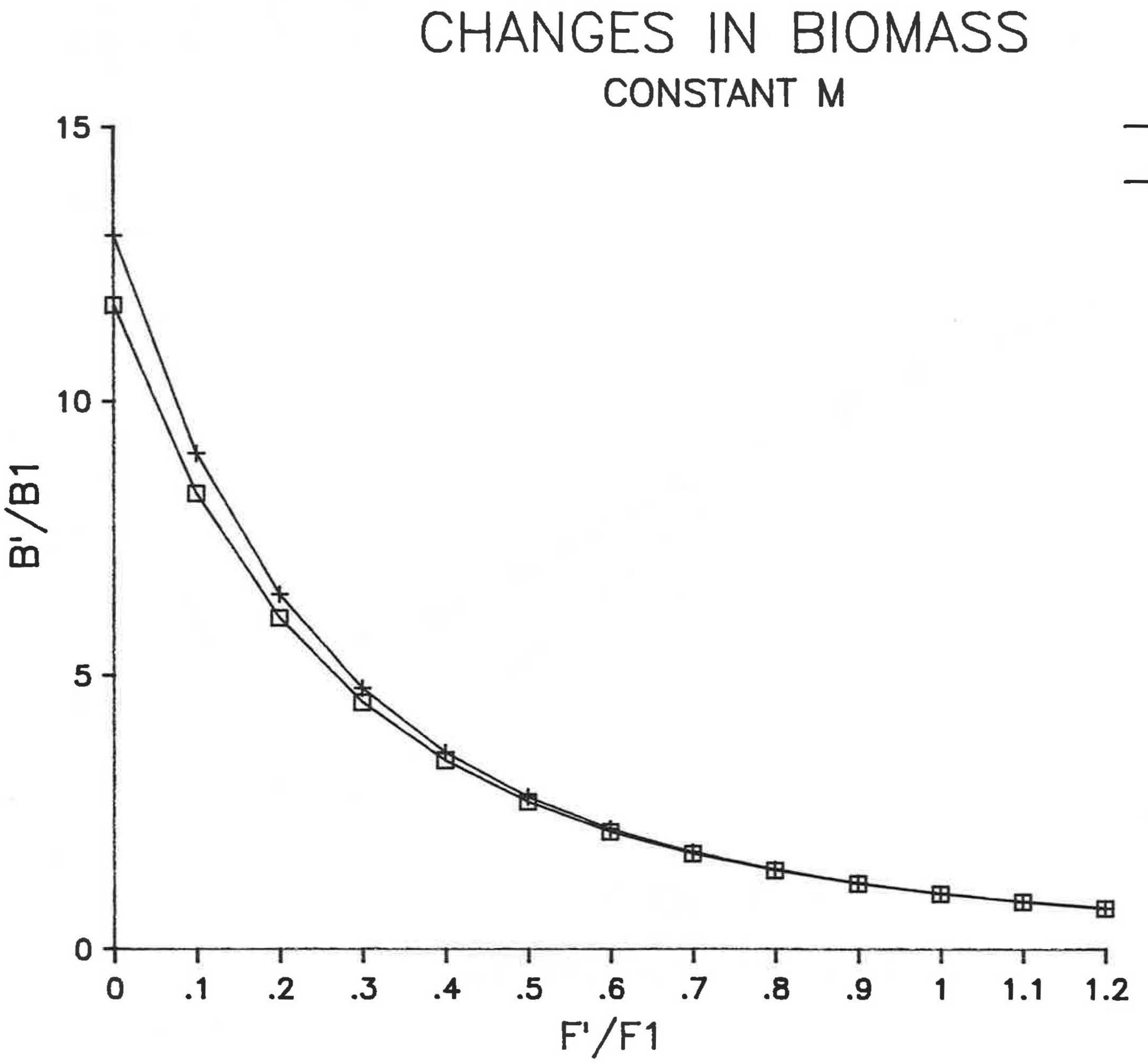
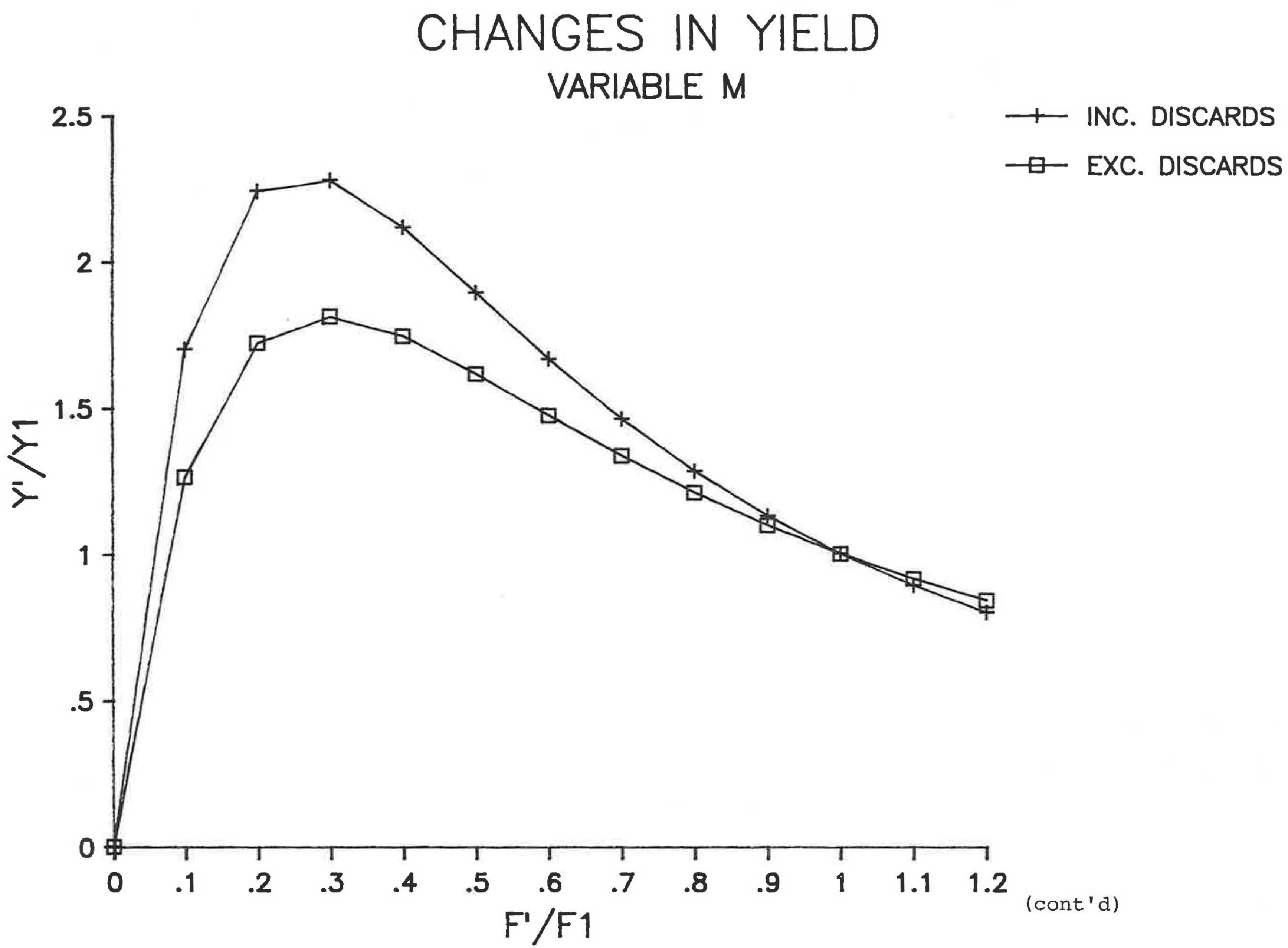


Figure 3.3.2 (a) Effect of discards on biomass and yield curves, with constant or variable M.



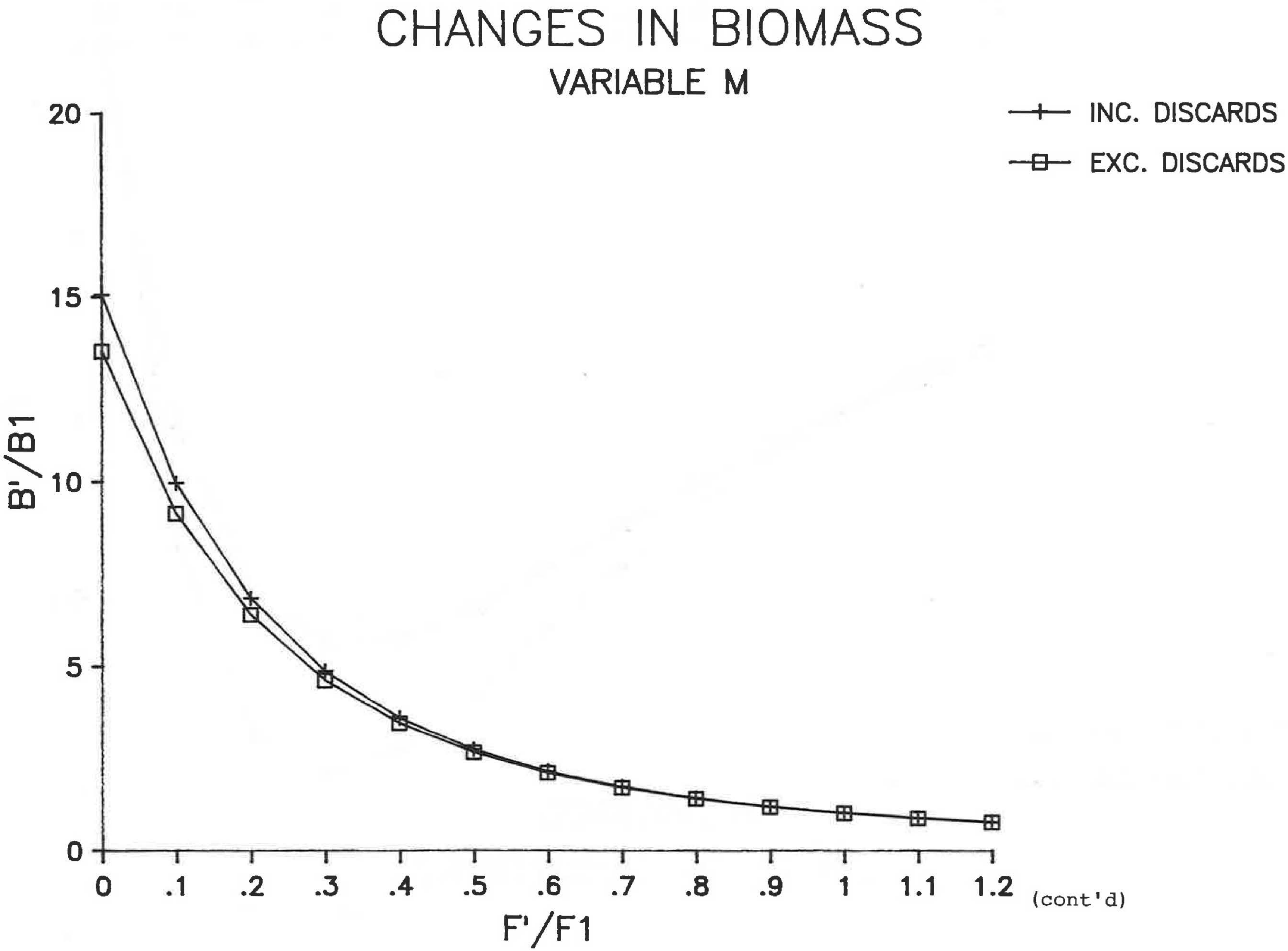
(cont'd)

Figure 3.3.2 (b) (cont'd)



(cont'd)

Figure 3.3.2 (c) (cont'd)



(cont'd)

Figure 3.3.2 (d) (cont'd)

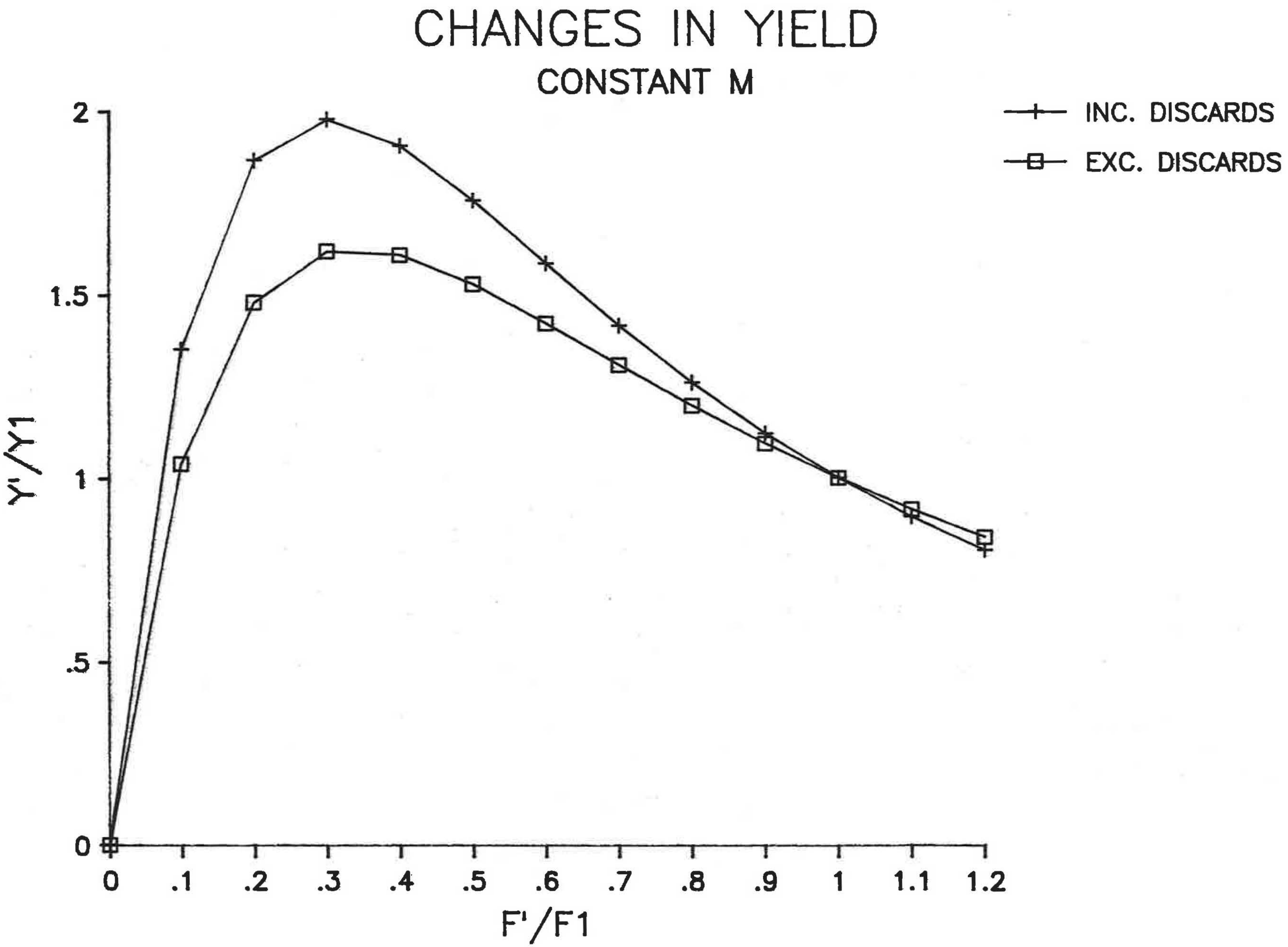
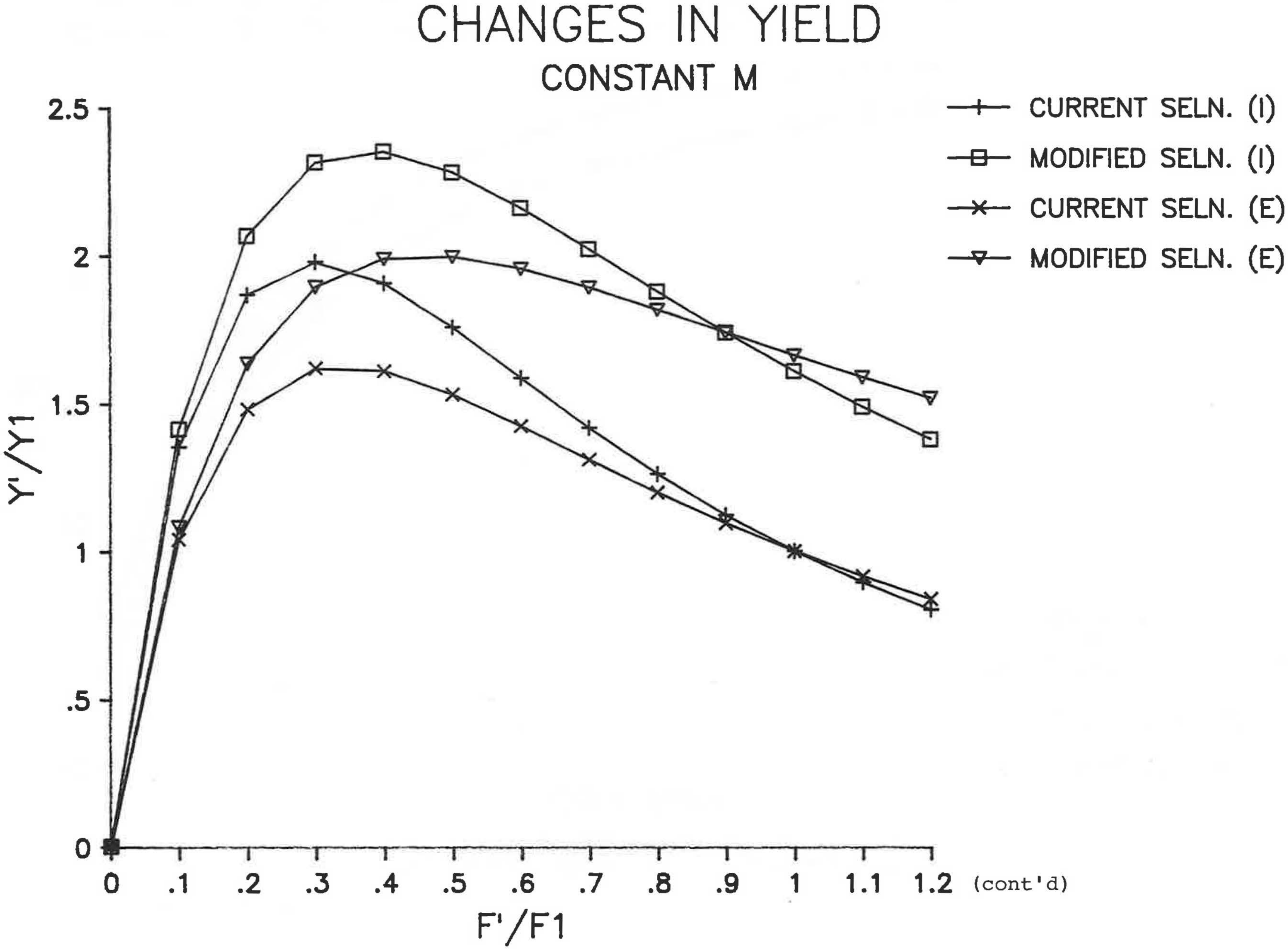
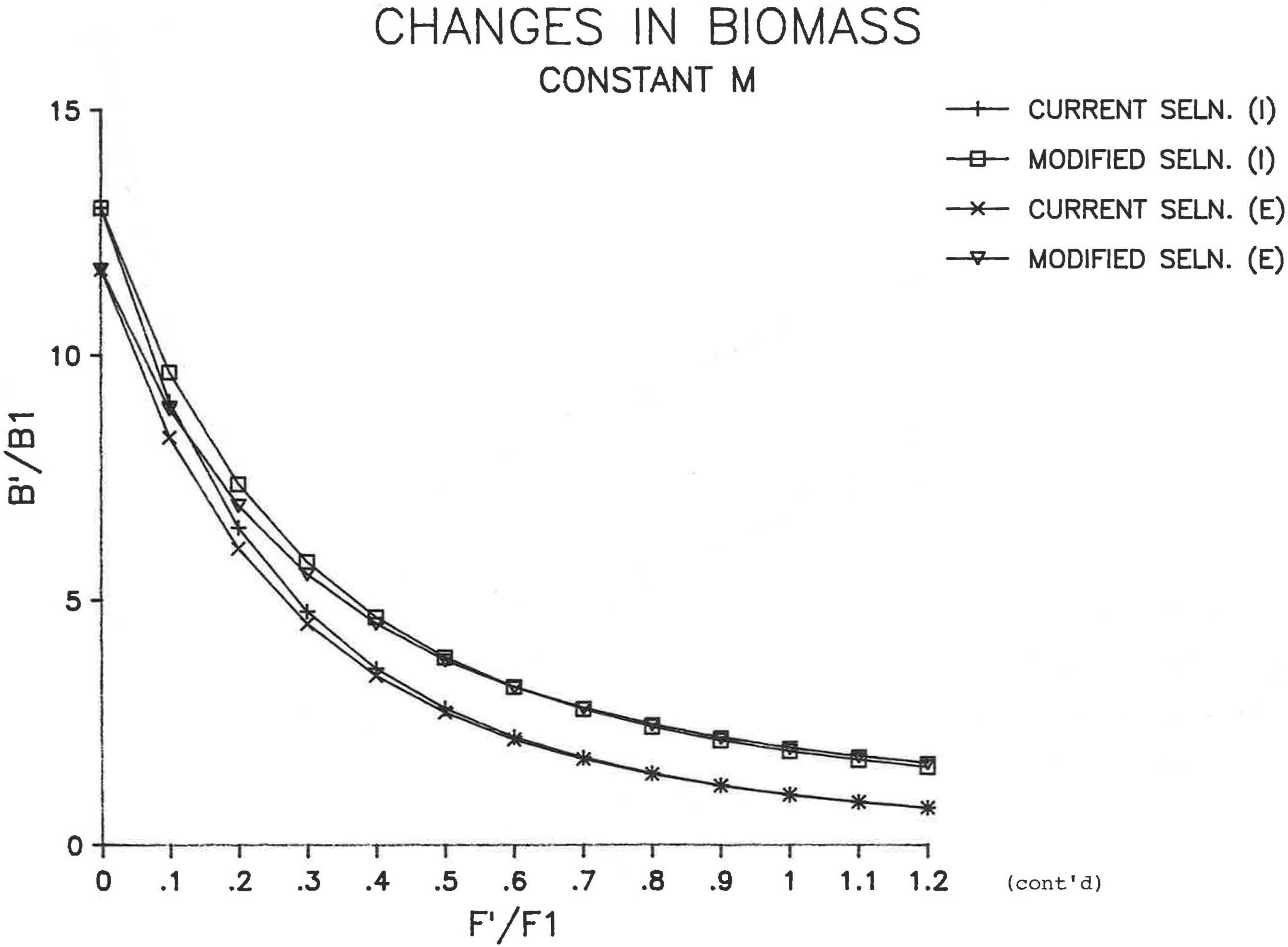


Figure 3.3.3 (a) Effect of changes in selection on biomass and yield curves, including or excluding discards.



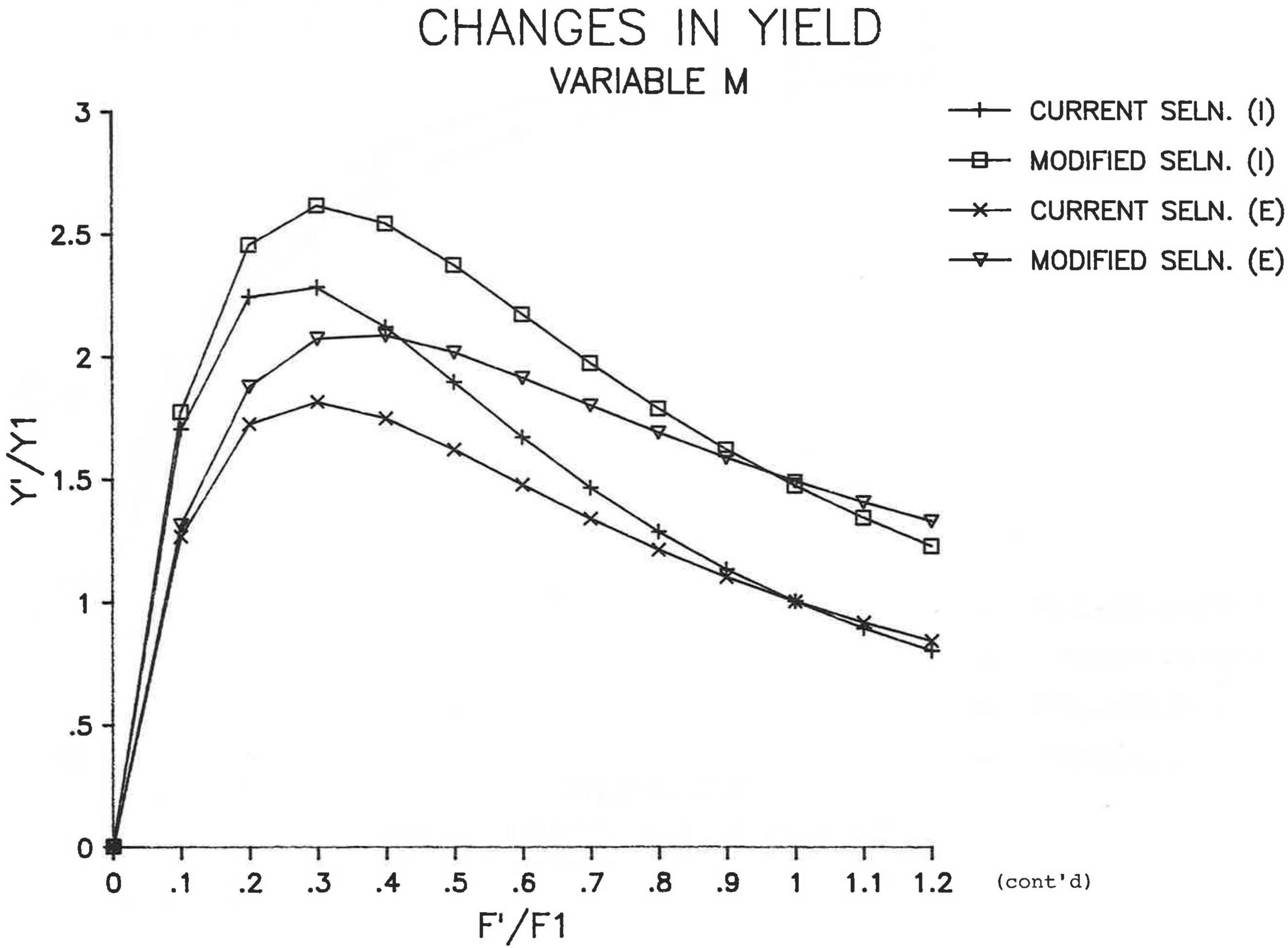
(cont'd)

Figure 3.3.3 (b) (cont'd)



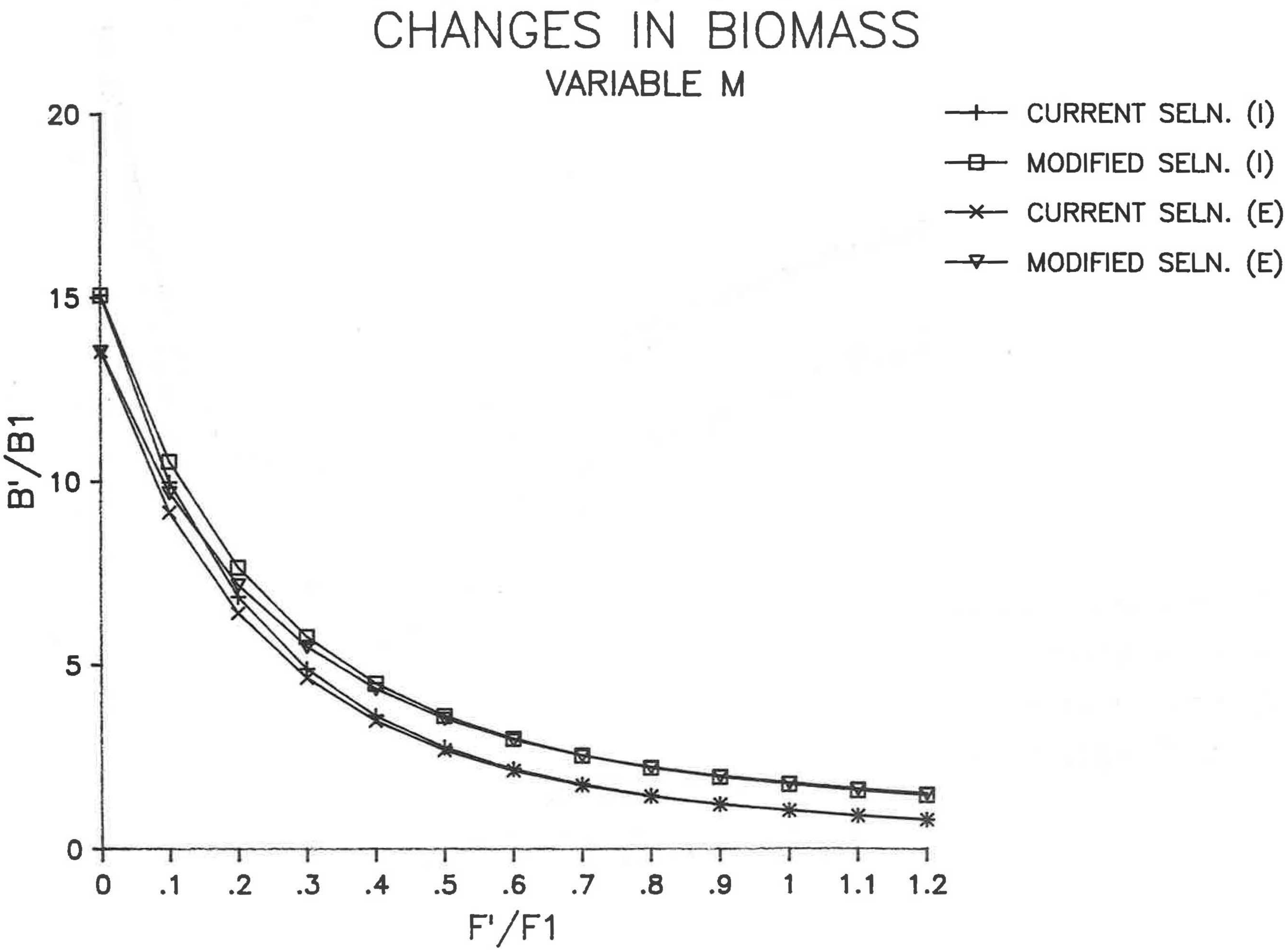
(cont'd)

Figure 3.3.3 (c) (cont'd)



(cont'd)

Figure 3.3.3 (d) (cont'd)



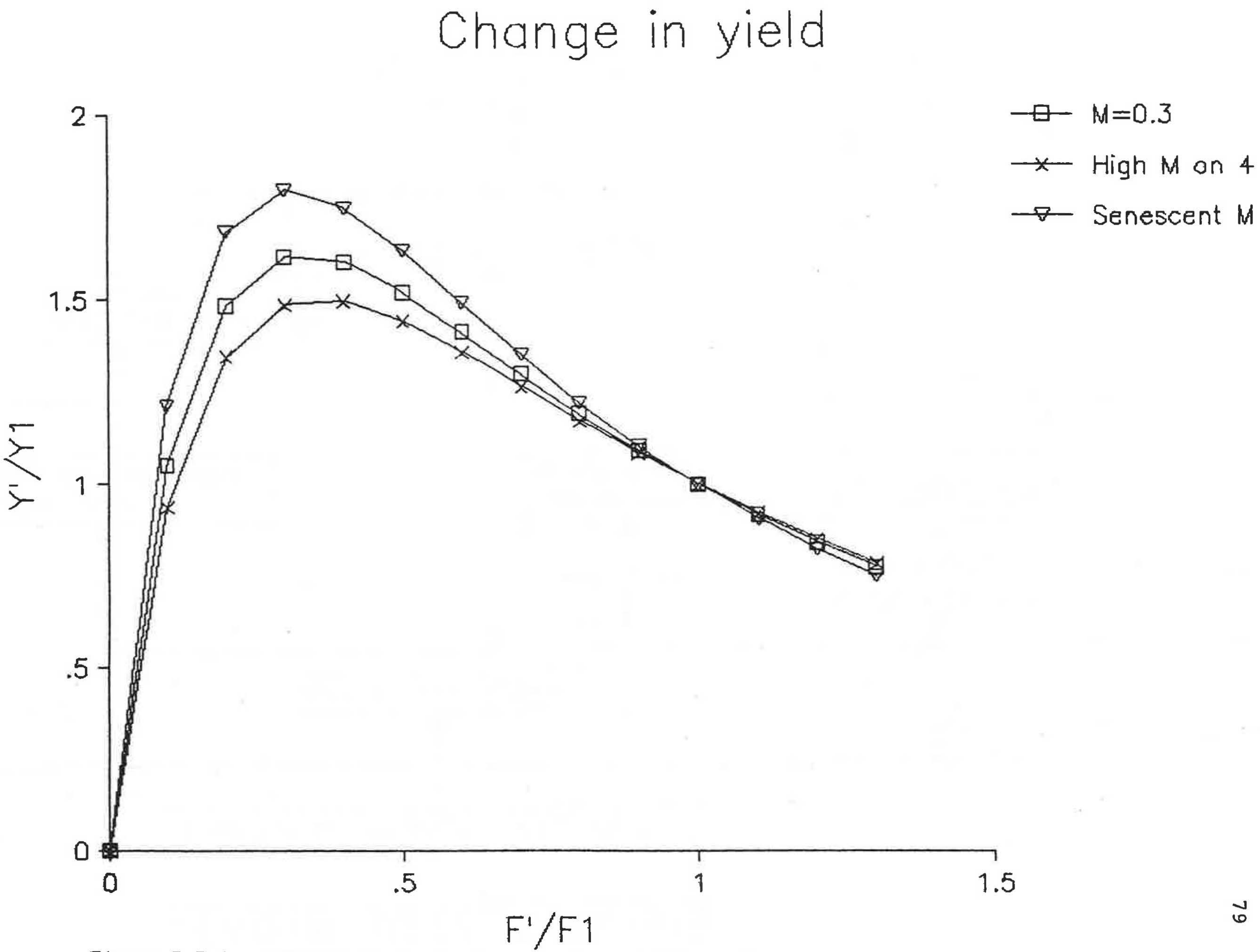


Figure 3.3.4 Effects of change in natural mortality pattern.

Figure 4.2

LENGTH DATA ANALYSIS

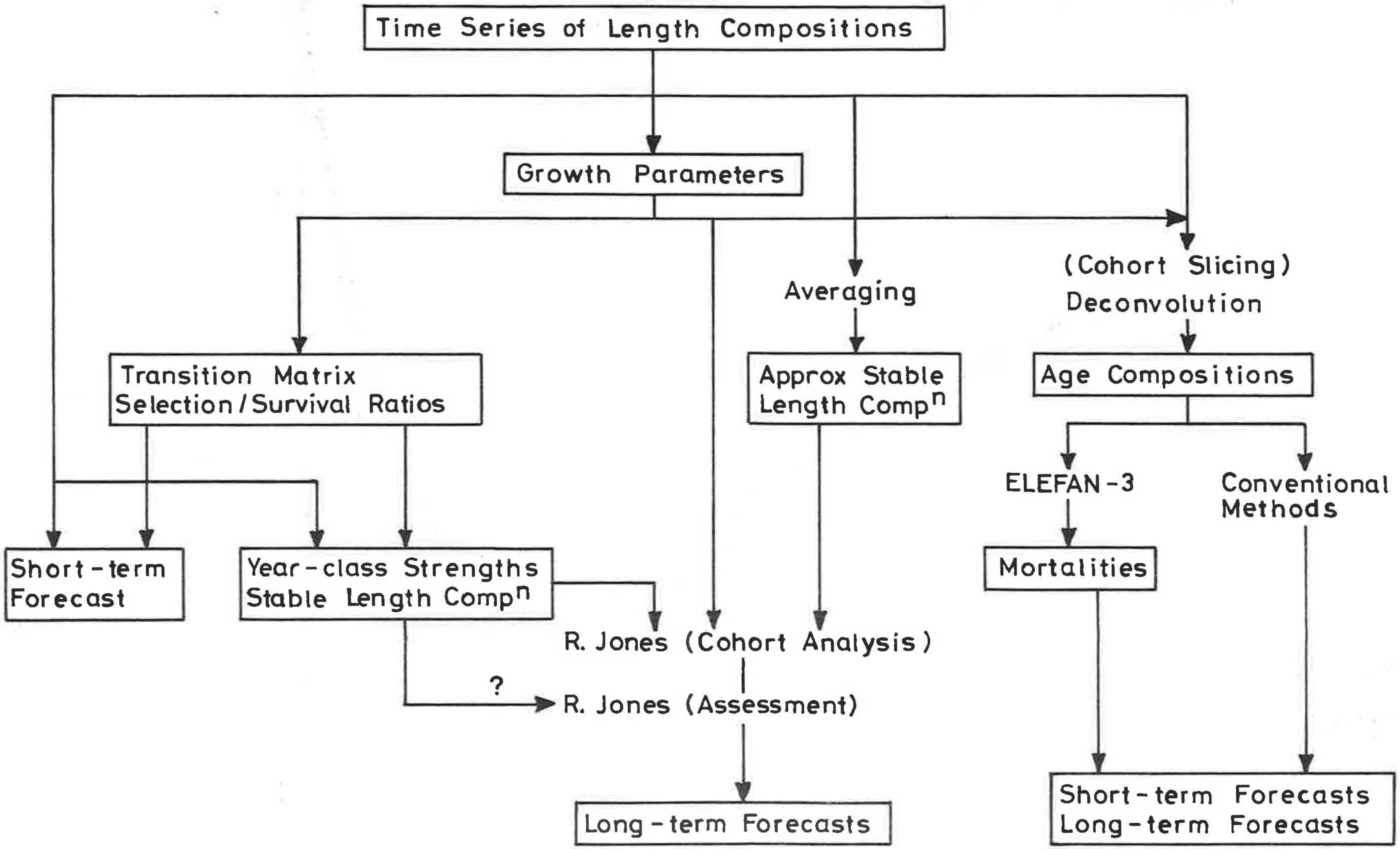


Figure 4.3.1

NORTH SEA COD LANDINGS
RESULTS OF SHOT AND KALMAN
FILTERED SHOT

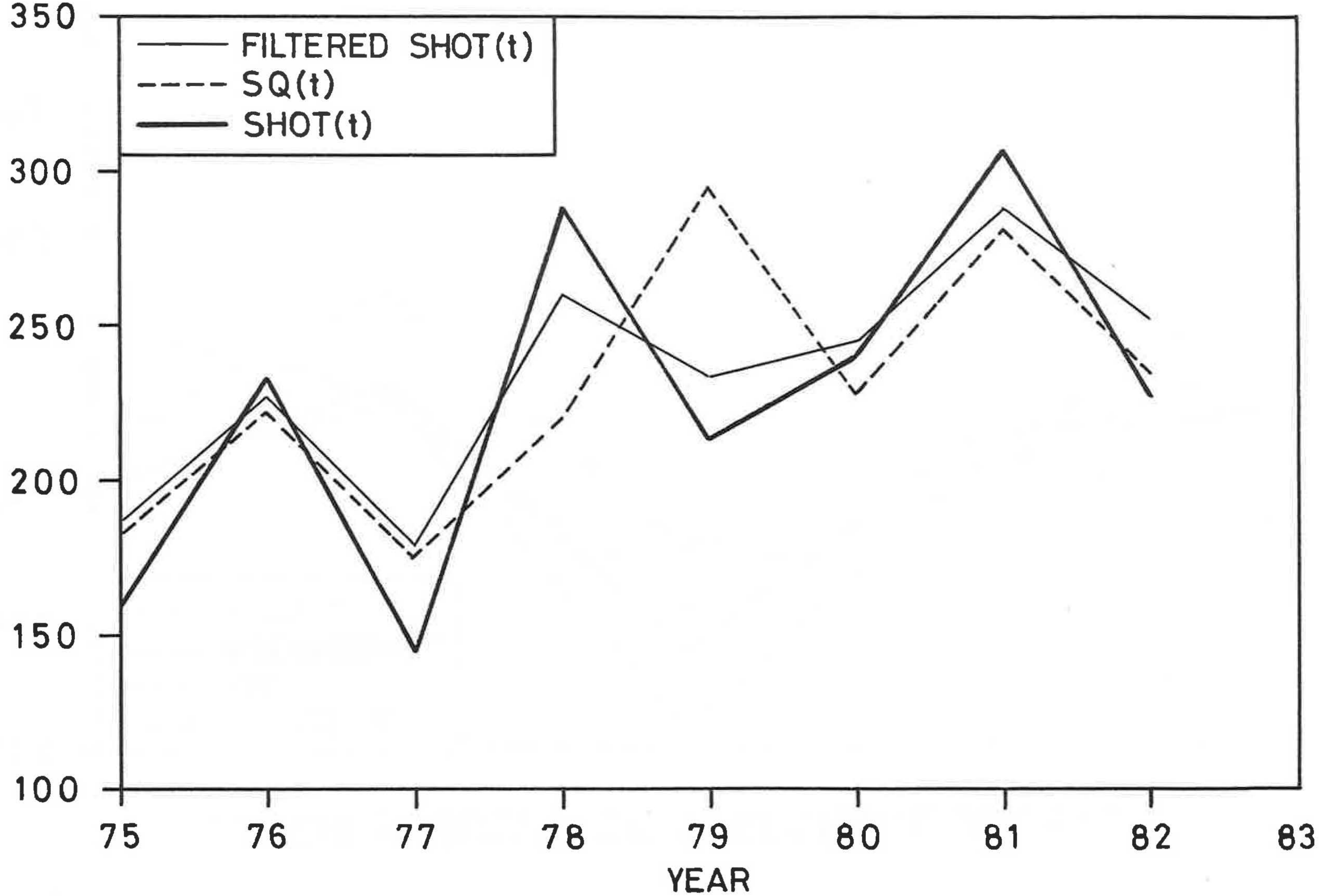
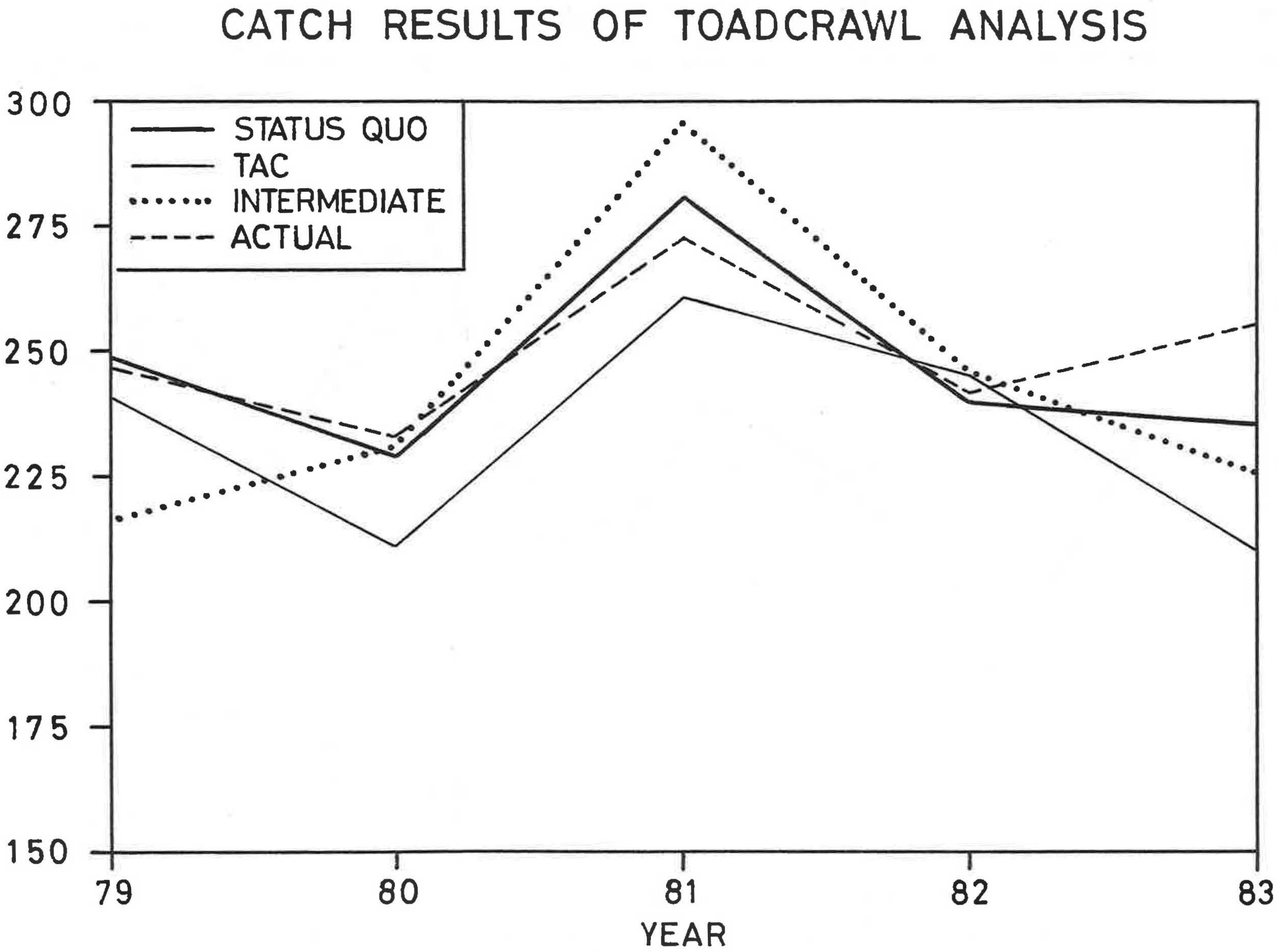


Figure 4.3.2


CATCH RESULTS OF TOADCRAWL ANALYSIS
STATUS QUO
TAC
INTERMEDIATE
ACTUAL
300
275
250
225
200
175
150
79
80
81
82
83
YEAR

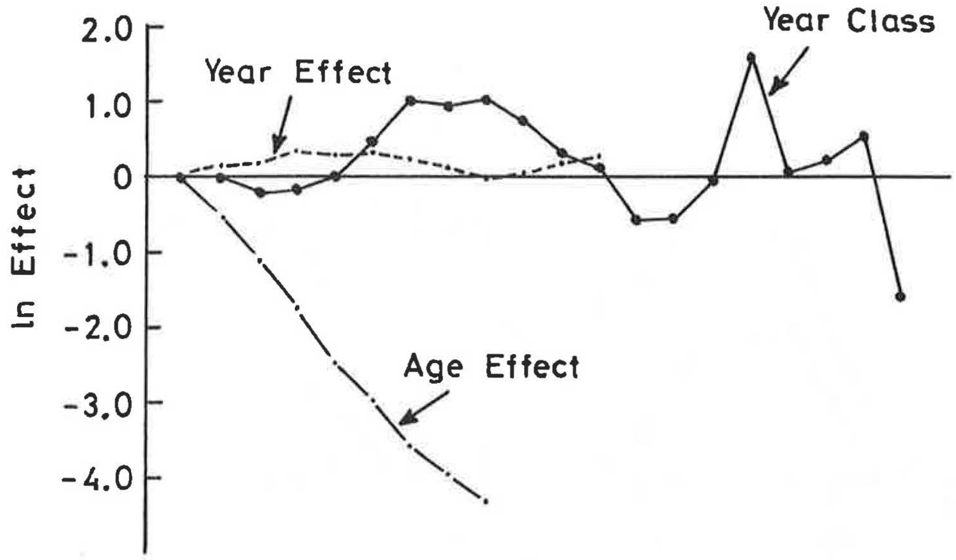


Figure 4.4.1 Trends in parameters from a multiplicative analysis of Gulf of St. Lawrence Cod. Survey population-at-age estimates.

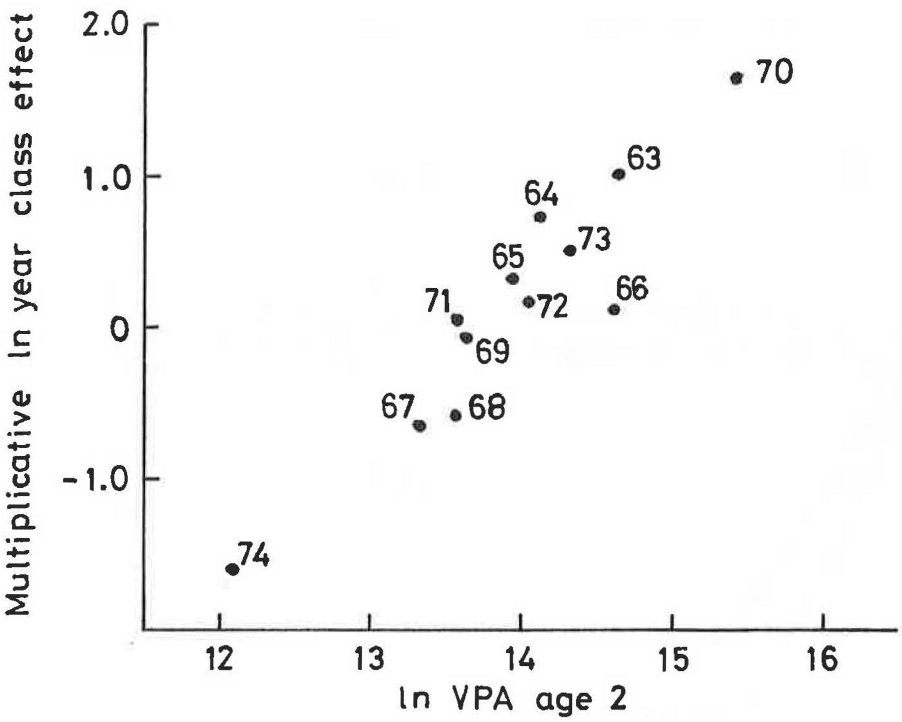
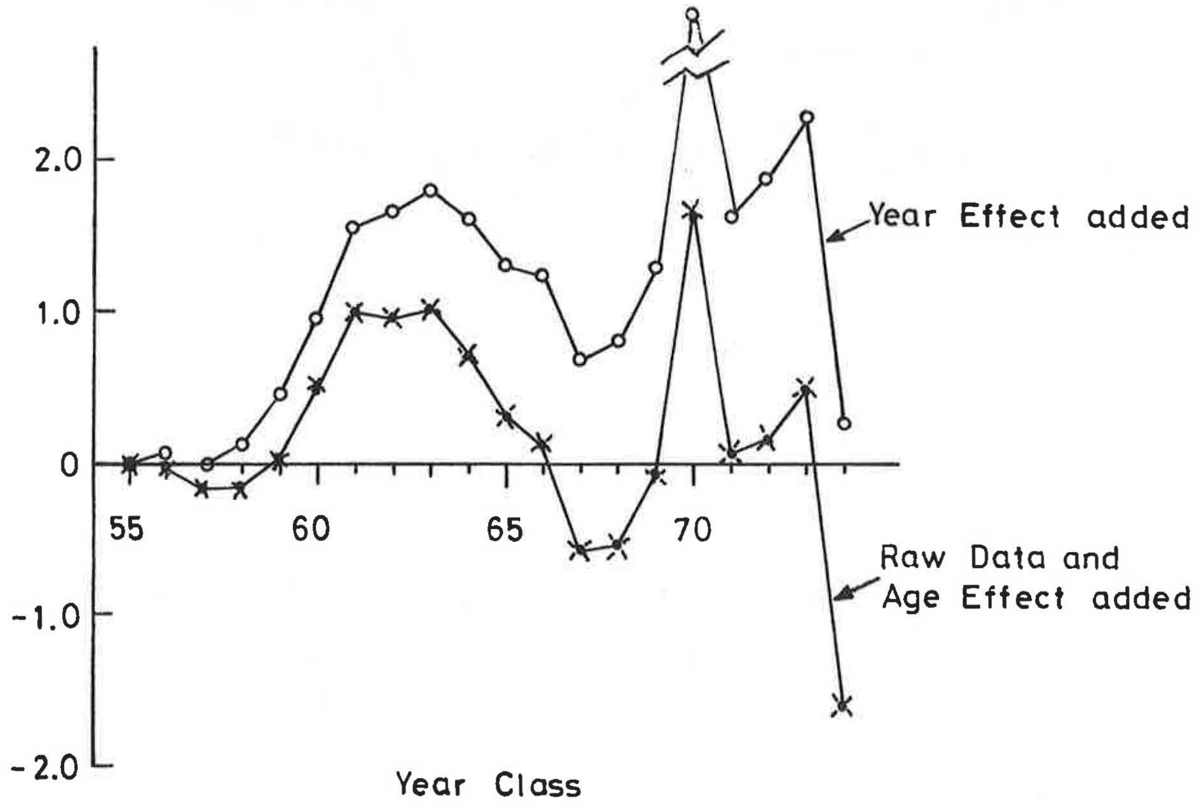


Figure 4.4.2 Comparison of year-class estimates from VPA and multiplicative analysis (survey) for Gulf of St. Lawrence Cod.

Figure 4.4.3 Comparison of parameter estimates for Gulf of St. Lawrence cod survey population-at-age estimates. Trends are for raw data, age effect added, year effect added.



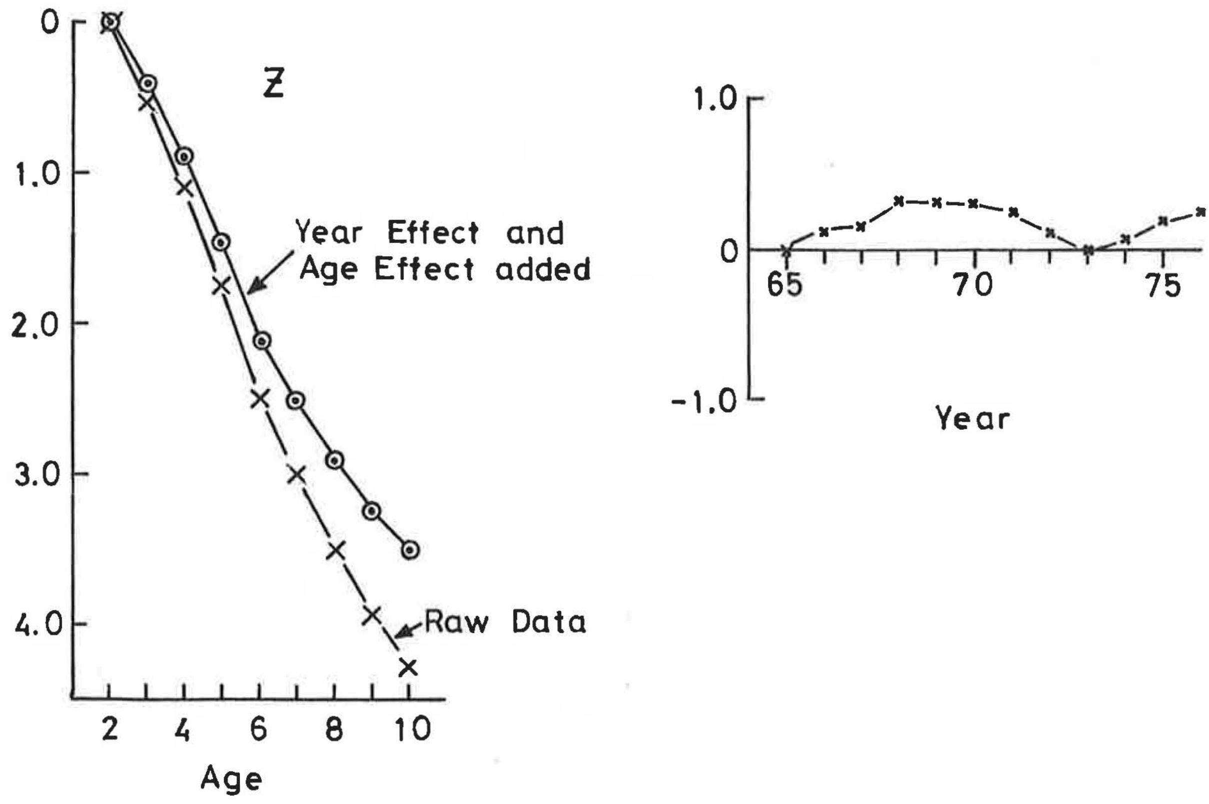


Figure 5.2.1

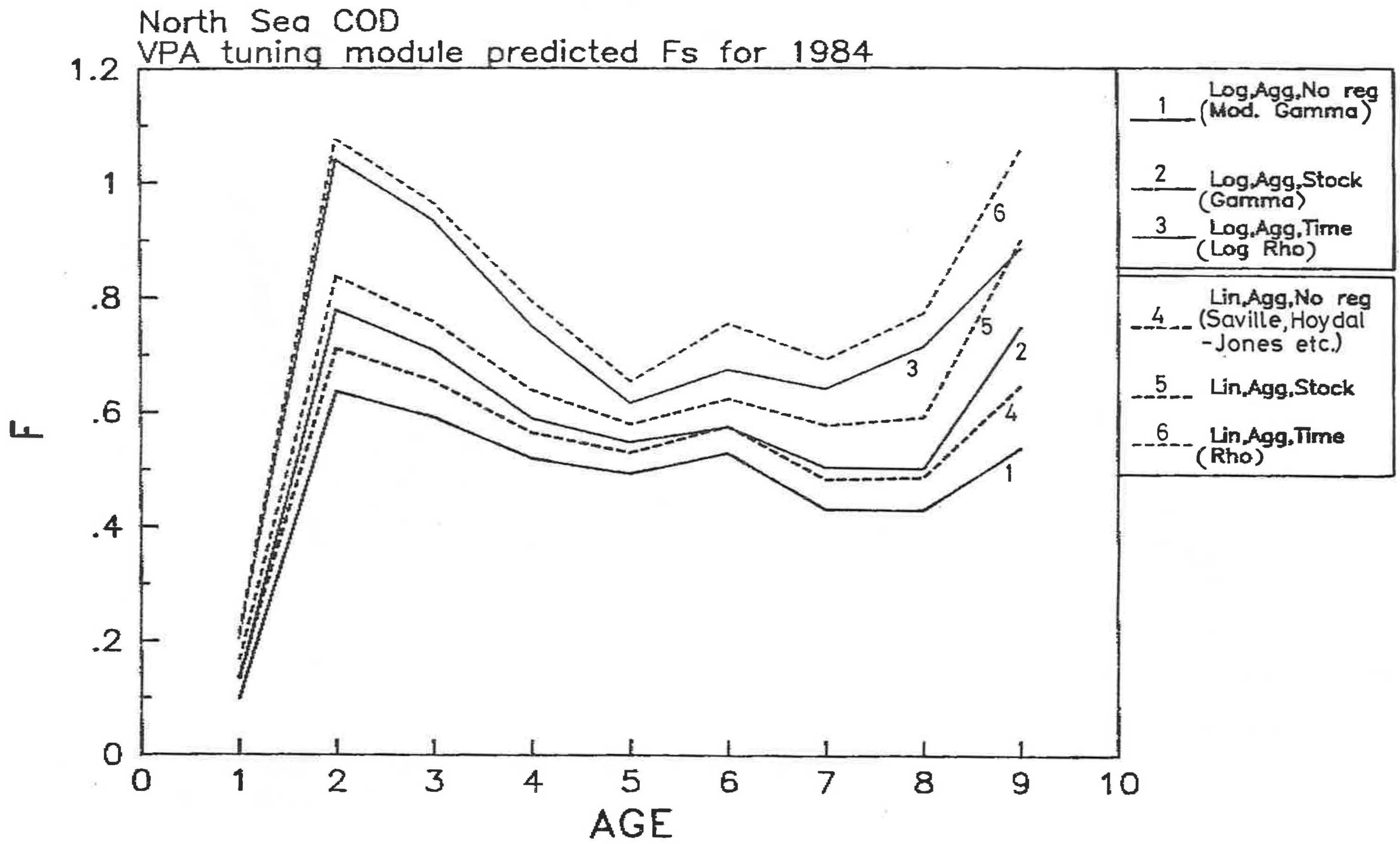

North Sea COD
VPA tuning module predicted Fs for 1984
F
AGE
0
.2
.4
.6
.8
1
1.2
0
1
2
3
4
5
6
7
8
9
10
1 (Log,Agg,No reg (Mod. Gamma))
2 (Log,Agg,Stock (Gamma))
3 (Log,Agg,Time (Log Rho))
4 (Lin,Agg,No reg (Saville,Hoydal -Jones etc.))
5 (Lin,Agg,Stock)
6 (Lin,Agg,Time (Rho))

Figure 5.2.2

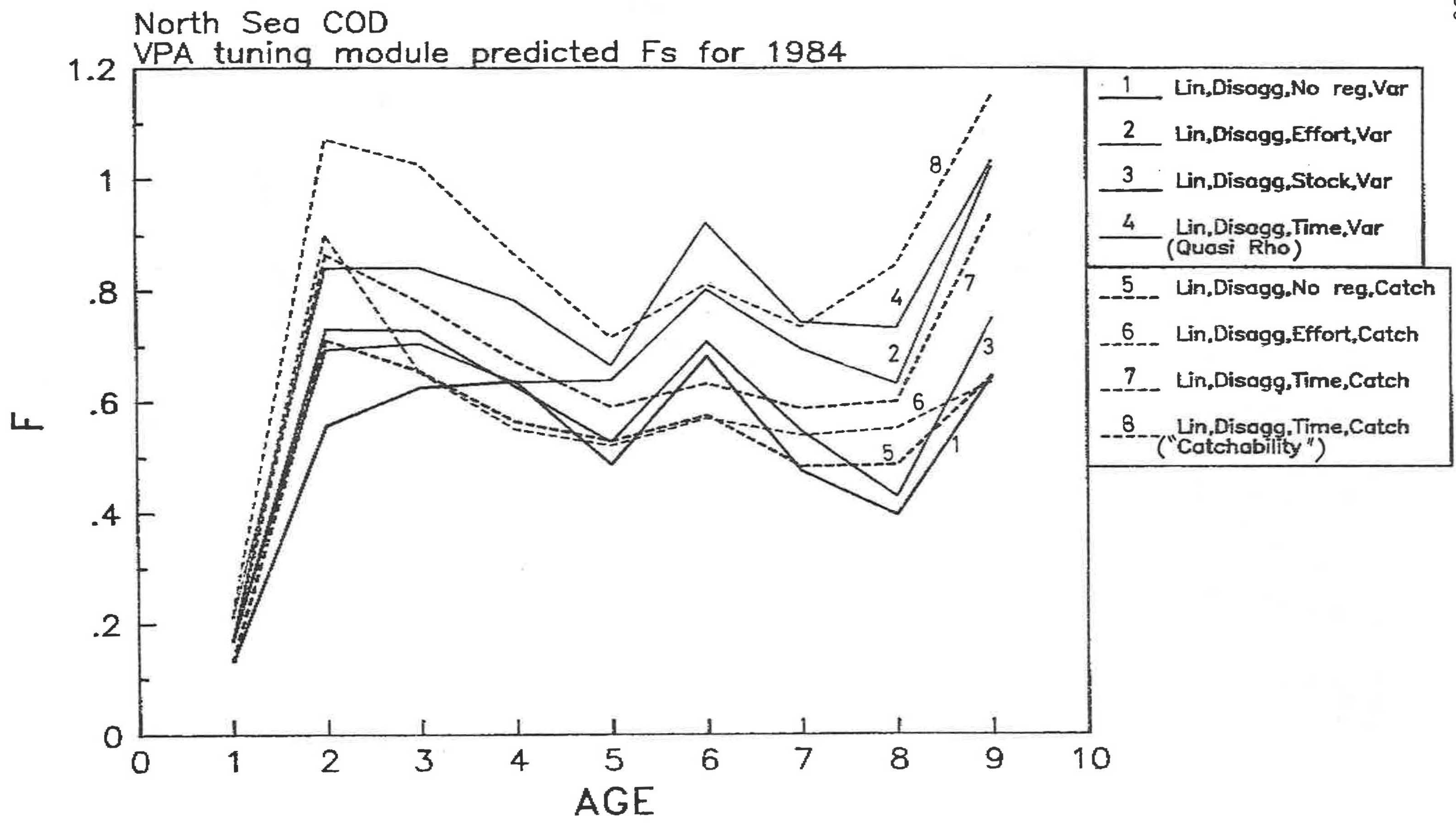
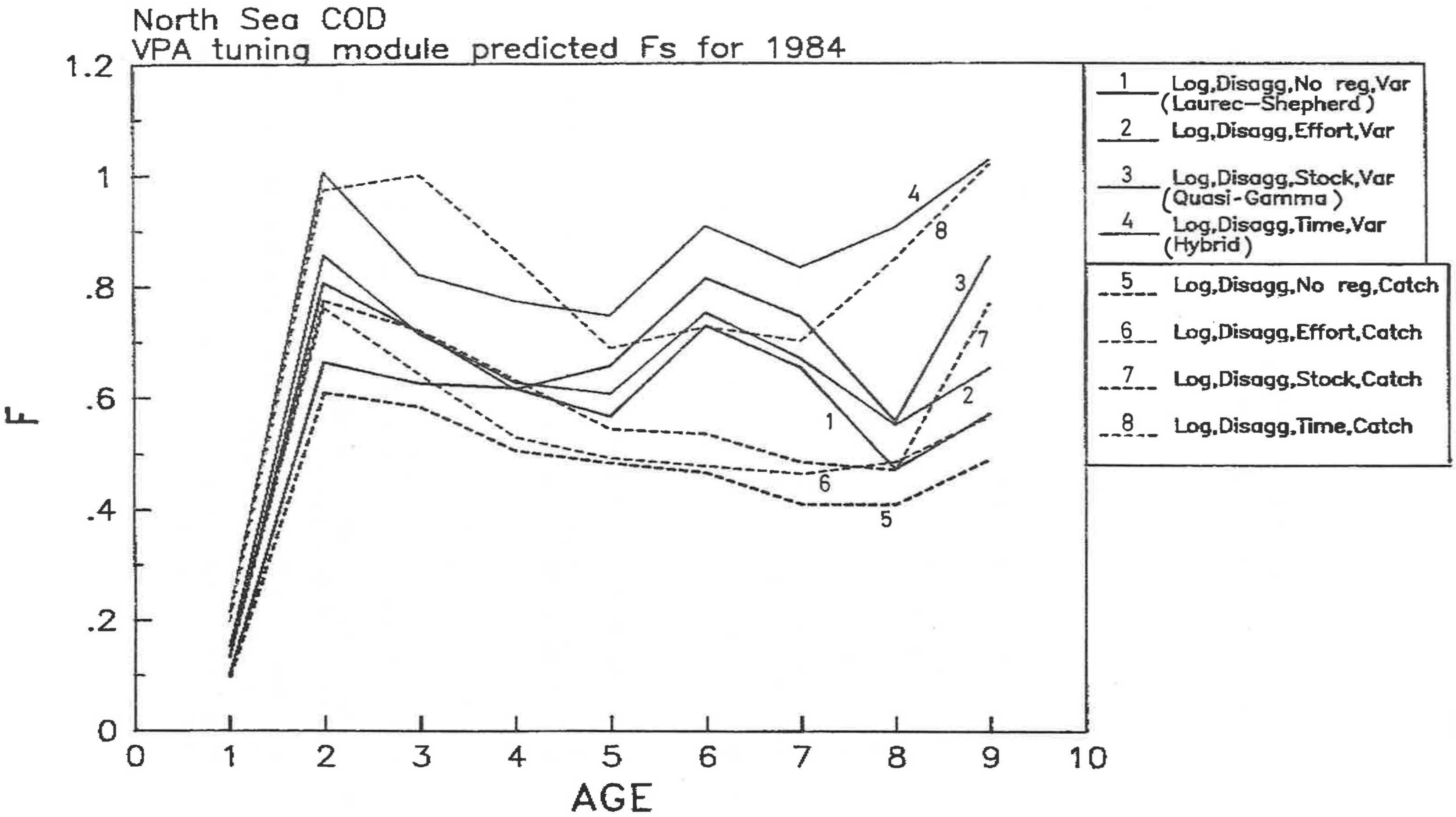

North Sea COD
VPA tuning module predicted Fs for 1984
1.2
1
.8
.6
.4
.2
0
F
0
1
2
3
4
5
6
7
8
9
10
AGE
8
4
7
2
3
6
5
1
1 Lin,Disagg,No reg,Var
2 Lin,Disagg,Effort,Var
3 Lin,Disagg,Stock,Var
4 Lin,Disagg,Time,Var (Quasi Rho)
5 Lin,Disagg,No reg,Catch
6 Lin,Disagg,Effort,Catch
7 Lin,Disagg,Time,Catch
8 Lin,Disagg,Time,Catch ("Catchability")

Figure 5.2.3


North Sea COD
VPA tuning module predicted Fs for 1984
F
AGE
0
.2
.4
.6
.8
1
1.2
0 1 2 3 4 5 6 7 8 9 10
1 Log,Disagg,No reg,Var (Laurec–Shepherd)
2 Log,Disagg,Effort,Var
3 Log,Disagg,Stock,Var (Quasi-Gamma)
4 Log,Disagg,Time,Var (Hybrid)
5 Log,Disagg,No reg,Catch
6 Log,Disagg,Effort,Catch
7 Log,Disagg,Stock,Catch
8 Log,Disagg,Time,Catch

APPENDIX A

WORKING PAPERS, 1985 MEETING OF WORKING GROUP ON METHODS OF FISH STOCK ASSESSMENTS

Discards

D1 S.A. Murawski: A brief outline of the estimation and importance of fishery discards to assessment calculations.

D2 S.A. Murawski, S.H. Clark, and V.C. Anthony: Impacts of fishery discards on stock size and yield calculations (ICES, Doc. C.M.1986/G:60).

D3 T.K. Stokes: Using the ANOVA TAC method with landings-at-age data - do discard rates matter?

D4 C.T. Macer: The effect of inclusion of discards on catch predictions for North Sea haddock.

D5 J.G. Shepherd: The effects of discards on assessment calculations: a preliminary view.

D6 M.D. Nicholson and C.G. Brown: A note on analysing discard data.

Discards and Varying Natural Mortality

DM1 T.K. Stokes: Assessing the effects of age-dependent natural mortality and/or discards using the method of Jones (1961).

Varying Natural Mortality

M1 J.G. Pope: A note on the relationship of long-term yield effects to some assumptions about natural mortality.

M2 H. Sparholt: Some problems encountered because of lack of precision of biological parameters.

M3 A. Laurec and B. Mesnil: Sensibilité des analyses de cohortes et des projections déduites.

M4 M. Hilden: The natural mortality and the perceived stock-recruitment relationship.

Length-Based Methods of Assessment

L1 List of contributions presented at FAO/ICLARM/KISR Conference on Length-Based Methods of Assessment (Sicily, February 1985).

L2 J.G. Pope: Some tests of the assumptions of the Jones length cohort analysis.

L3 J.G. Pope: A note on age-length and length-age relationships.

L4 J.G. Shepherd: Deconvolution of length compositions.

L5 G. Gudmundsson: Statistical analysis of catch-at-length data.

Other Simple Methods of Assessment

S1 J.G. Pope and J.W. Pope: Kalman filter approaches to the estimation of status quo TACs.

S2 J.G. Shepherd and M.D. Nicholson: Multiplicative modelling of catch-at-age data.

Forecasting of Recruitment

R1 J.G. Pope: A possible use of the Kalman filter for making routine updates of recruitment indices.

APPENDIX B

STANDARD NOTATION

NOTE: This standard (and largely mnemonic) notation is followed so far as possible, but not slavishly. Other usages and variations may be defined in the text. Array elements are denoted by means of either indices or suffices, whichever is more convenient. The same character may be used as both an index or a variable, if no confusion is likely.

Suffices and Indices

y	indicates	year
f	"	fleet
a	"	age group
t	"	last (terminal) year
g	"	oldest (greatest) age group
l	"	length
k	"	year class
$	"	summation over all possible values of index (usually fleets)
#	"	summation over all fleets having effort data
@	"	an average (usually over years)
*	"	a reference value

Quantities (all may have as many, and whatever, suffices are appropriate)

C (y,f,a)	Catch in number (including discards)
E (y,f)	Fishing effort
F (y,f,a)	Fishing mortality
F_S (y,f)	Separable estimate of overall fishing mortality
q	Catchability coefficient (in F = qE)
Y	Yield in weight
W	Weight of an individual fish in the catch
W_S	Weight of an individual fish in the (spawning) stock
B	Biomass
P	Population number (also fishing power)
E	Fishing effort
U	Yield or landings per unit of effort

<u>Quantities</u> (cont'd)

C_w	Catch in weight of fish (including discards)
N	Stock in numbers of fish
F	Instantaneous fishing mortality rate
Z	Instantaneous total mortality rate
M	Instantaneous natural mortality rate
S	Selection coefficient defined as the relative fishing mortality (over age)
R	Recruitment
f	Relative F (e.g., F/F*)
y	Relative yield (e.g., Y/Y*)
d	Fraction discarded
b	Fraction retained (b = 1-d)
h	Hang-over factor
G	Instantaneous growth rate (in weight)
L	Landings in number (excludes discards)
l	Length
l_∞	Von Bertalanffy asymptomic length
K	Von Bertalanffy "growth rate"
r	Recruit index

APPENDIX C

SUMMARY OF TOPICS

	Topic	1981[1,2]	1983[2]	1984[3]	1985	1987
1.	Application of separable VPA	-	M	r	-	-
2	Simpler methods of assessment	-	-	M	M	-
3.	Measures of overall fishing mortality	-	-	-	-	-
4.	Use of effort data in assessments	M	M	r	r	P
5.	Need for two-sex assessments	-	-	-	-	-
6.	Computation and use of yield per recruit	-	M	m	i	-
7.	Inclusion of discards in assessments	-	-	-	M	-
8.	Methods for estimation of recruitment	-	-	M	r	-
9.	Density dependence (growth, mortality, etc.)	-	-	-	-	-
10.	Linear regression in assessments	-	-	M	-	-
11.	Effect of age-dependent natural mortality	-	-	-	M	-
12.	Stock-production models	-	-	-	-	P
13.	Utilization of research survey data	-	-	-	-	P

M = major topic;

m = minor topic;

r = reprise;

i = incidentally considered;

P = proposed;

[1]Meeting of ICES ad hoc Working Group on Use of Effort Data in Assessments.

[2]Report of this meeting available as Coop. Res. Rep. No. 129.

[3]Report of this meeting available as Coop. Res. Rep. No. 133.

Indication of spine colours

Reports of the Advisory Committee on Fishery Management	Red
Reports of the Advisory Committee on Marine Pollution	Yellow
Fish Assessment Reports	Grey
Pollution Studies	Green
Others	Black

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