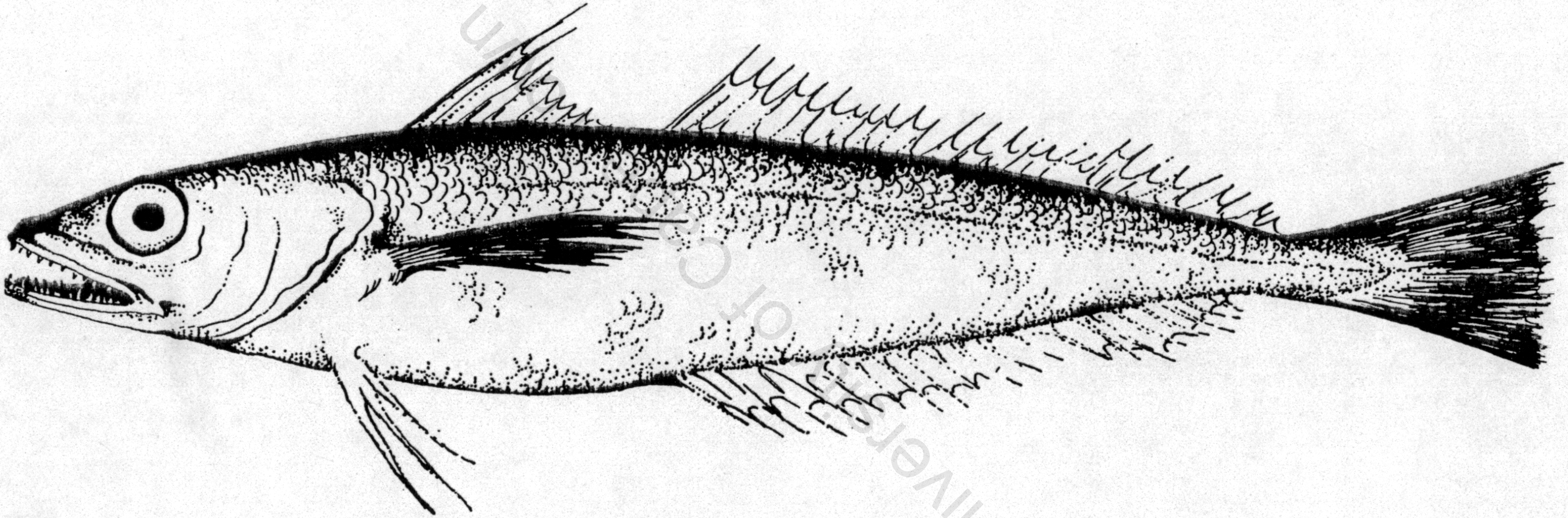

HAKE : *Merluccius paradoxus*

University of Cape Town
Department of Applied Mathematics

DYNAMIC CATCH-EFFORT MODELS FOR THE SOUTHERN AFRICAN HAKE POPULATIONS

by

P. A. ANDREW

(P.A. SYMINGTON)

Supervisor: Dr. D.S. Butterworth

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ABSTRACT

Until 1984, hake quota recommendations made by the ICSEAF Scientific Advisory Council were based on the production model approach with evaluations made using a continuous equilibrium approximation. However, serious discrepancies between model predictions and data became apparent and this thesis examines the extent to which these are consequences of the failure to allow for dynamics in fitting models to the data.

The biology of the hake population and the history of the hake fisheries off the coast of southern Africa are reviewed briefly and the objectives of fishery management defined. This is followed by a presentation of the data used in subsequent calculations together with details of the sources from which they were obtained.

The basis for the surplus production model for the evaluation of sustainable yields is discussed. It is shown that the steady-state assumption will probably lead to positively biased sustainable yield estimates for fisheries whose history is dominated by a declining CPUE trend. In an attempt to correct for such biases, evaluations are also carried out using Gulland's method of averaging effort data. However it is not clear to what extent this equilibrium approximation approach compensates for such errors.

Consequently, discrete dynamic versions of the Schaefer and Fox models are fitted, using nonlinear minimization procedures, to catch-effort data for the four ICSEAF areas commonly chosen for hake stock assessment purposes, namely Divisions 1.3 + 1.4, 1.5, 1.6 and 2.1 + 2.2 (all of which indicate generally downward CPUE trends for the major part of their histories). Monte Carlo simulation methods are employed to estimate coefficients of variation for the model parameter and yield values assessed.

The dynamic models are shown to provide distinctly improved fits to the CPUE time series compared to those obtained using the Gulland Functional Regression (GFR) or the steady-state approaches. MSY estimates obtained from dynamic model fits are, on average, approximately 10% less than those resulting from the GFR procedure.

Since the effects of uncertainties (such as adverse environmental variability and the imprecision of stock biomass estimates) can critically influence the outcome of management decisions, caution should be exercised when making catch limit recommendations. Various conservative approaches are advocated, and the associated current catch limit recommendations evaluated. These include the Gulland and Boerema $f_{0.1}$ procedure, and an approach where the quota is reduced by a fraction of the standard error of the initial quota estimate.

The dynamic model is also employed to predict future biomass (as well as CPUE and quota) values. A historical examination of the accuracy of such projections is used to comment upon the efficacy of the Schaefer and Fox dynamic models.

Dynamic model biomass estimates are compared to those provided by the Virtual Population Analysis (VPA) procedure for Division 1.6 . Large discrepancies in both recent trends and absolute values are evident, with biomass estimates being much lower in the case of VPA.

Various extensions to the dynamic model are introduced in an attempt to reduce the difference between dynamic model and VPA biomass estimates in Division 1.6 . In general, the incorporation in the dynamic model of time lag effects (in the net growth function) and increased efficiency factors (in the catching operation) yield no obvious improvement in agreement between dynamic model and VPA results. In addition, the effect of allowing the ratio of the biomass at the start of the given CPUE series to the carrying capacity (y_1/K) to assume values other than unity is examined. Results indicate that this extended model does not appear to have any advantages over models applied earlier which assumed $y_1=K$. The seemingly insignificant improvements obtained suggest that the original dynamic model nearly fully exploits the information content of the data and that the introduction of further parameters can cause the sum of squares surface to become very flat in the vicinity of the minimum that is sought in the fitting procedure. Dynamic model fits using the Shepherd surplus production form (which incorporates a skewness parameter) are performed on the catch-effort data. The ratio of the biomass at MSY to the carrying capacity (y_{MSY}/K) is shown to be very poorly determined by the catch-effort data (the average coefficient of variation of estimates is 30%). Results indicate that the Shepherd model is a suitable, though not necessarily superior, alternative to the Schaefer and Fox dynamic models.

Possible extensions and amendments to the dynamic models are suggested. These include the use of Clark's bioeconomic model to review the $f_{0,1}$ strategy with regard to economic optimality, and the replacement of the traditional Schaefer and Fox forms with a more generalized surplus growth function. Also proposed are an examination of the effects of changes in mesh size (on both catchability and growth parameters) and an adjusted dynamic model calculational procedure in which catches are 'discounted'. More appropriate weighting procedures for catch-effort model fits are suggested and lastly, an analysis of vessel power factors is advised.

1 INTRODUCTION

1.1 A review of previous methods used by ICSEAF for hake resource management

Although Cape hake have been fished since the turn of the century, it was only after 1962 that particularly heavy exploitation of the hake resources commenced as foreign vessels started operations in southern African waters. In 1966 the Division of Sea Fisheries initiated a research programme, concentrating on the collection of catch and effort statistics (Botha, 1980). These data revealed increasing catches accompanied by decreasing catch rates. Mounting concern about the depletion of the hake resources led to the establishment in 1972 of the International Commission for the South East Atlantic Fisheries (ICSEAF).

At its first two meetings (1972 and 1973) the ICSEAF Scientific Advisory Council (SAC) concentrated its attention on yield per recruit analyses for the hake resources, and the short and long term effects on yield of various net mesh sizes. As a result of these calculations, a minimum mesh size of 110mm was adopted by the Commission in 1973 and implemented on 1 January 1975.

In 1974 and 1975 the ICSEAF SAC began to investigate steady-state production models as a means of estimating maximum sustainable yield (MSY); both Schaefer and Fox forms were considered and the Gulland effort-averaging procedure used in calculating results. However, no Commission decisions on hake quotas were made until 1976 when recommendations of the SAC based on the Fox model (using the Gulland procedure) were adopted, and implemented for the 1977 season. Although it is not clear from reports (ICSEAF, 1976) why the Fox form was preferred, it is conceivable that plots of catch per unit effort (CPUE) against effort were considered to indicate a degree of concavity, so that the exponential form proposed by Fox (1970) was thought to be more appropriate than the linear Schaefer (1954) form. This Fox-Gulland method continued to be the basis for quota recommedations up to and including the 1983 ICSEAF Meeting.

In 1982 the ICSEAF Standing Committee on Stock Assessment (ICSEAF, 1983b) noted that Fox-Gulland model fits to plots of CPUE versus effort showed a general bias trend towards underestimating CPUE during the declining phases of these fisheries, and overestimating it in the recovery phases (the case for Division 1.5 is illustrated in Figure 1.1; the plot for Divisions 1.3 + 1.4 showed similar features).

Initially, several possible reasons for such biases were advanced by the Stock Assessment Committee, namely the effects of mesh regulations, the effects of the environment on availability, and low recruitment in recent years.

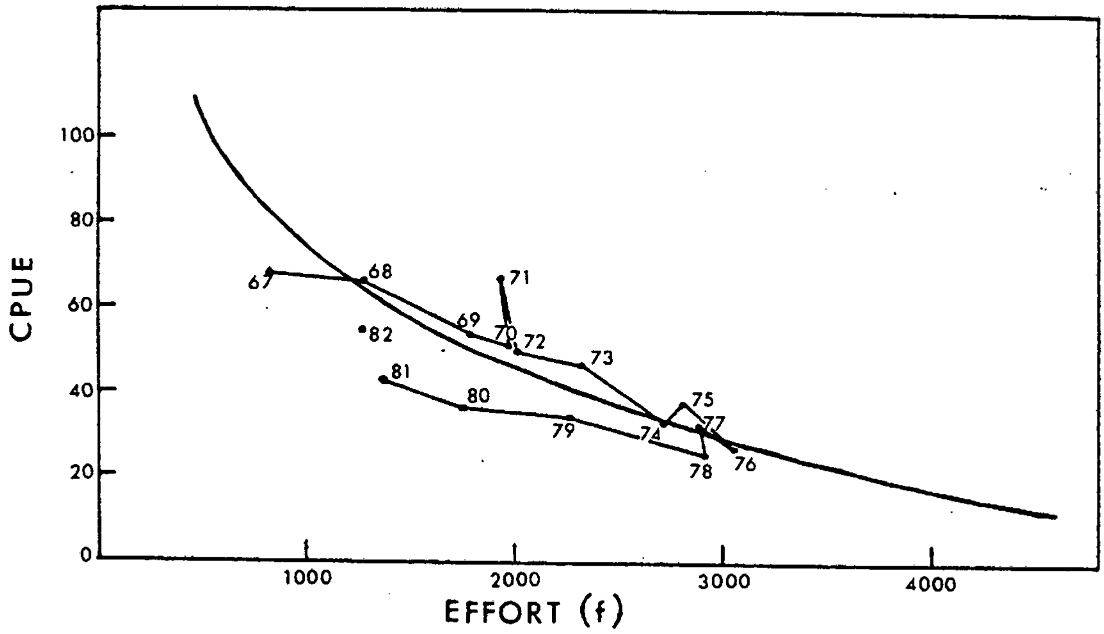


Figure 1.1 : Cape hakes in Division 1.5 - Plots of the observed CPUE versus effort statistics for 1967-1982 and the regression line fitted to the data series using the Fox model [redrawn from ICSEAF (1983b)]. Effort on the horizontal axis represents the average of the value in that year and the preceding two years as used in Gulland's calculational procedure.

The particular motivation for the investigations reported in this thesis was the hypothesis that the major cause of the abovementioned discrepancies was instead violation of the steady-state assumption upon which model-implementation up to that stage had been based. The dynamic catch-effort model developed here was first reported to the 1983 ICSEAF Meeting. Other authors also suggested alternative methods of incorporating dynamic aspects, which attempted (to varying degrees) to avoid the continuous equilibrium approximation in estimating the parameters and variables on which quota recommendations were based. Since 1984, the catch limit recommendations of the ICSEAF SAC have been based on an average of the results of three such methods, namely, those of Butterworth and Andrew (1984), Lleonart, Salat and Roel (1985) and Babayan _et_ _al_. (1985).

This study serves to review the Butterworth and Andrew (1984) dynamic model in detail. Results obtained using this model are compared to those of the pure steady-state approach, and of the Gulland method previously used by ICSEAF. The shortcomings of these latter approaches are discussed and various extensions to the original Butterworth and Andrew model are examined critically.

1.2 Outline of thesis

First a short biological description of the two hake species (namely, Merluccius capensis and Merluccius paradoxus) found off coast of southern Africa is given. The historical background of the fisheries in the four ICSEAF divisions (see Chapter 2) is then reviewed briefly and the objectives of fishery management defined. A description of the catch-effort data used in subsequent calculations follows.

The next two chapters consider the assumptions and equations upon which various surplus production models are based. The original steady-state model previously used by ICSEAF for management has resulted in serious discrepancies between model predictions and data. Biases caused by the continuous equilibrium assumption are considered, and Gulland's method of averaging effort data (used inter alia in an attempt to compensate for such biases) is examined. Discrete versions of the dynamic Schaefer and Fox models are then introduced. These models (fitted to catch-effort data using nonlinear minimization procedures) are used to provide predictions of future biomass (as well as CPUE and quota) values.

The following chapter concerns taking into account the effects of uncertainties which can seriously influence the outcome of management decisions. Consequently, the bases for various more conservative catch limit recommendations for management purposes are suggested. A description of the statistical procedures employed to determine the precision with which the model parameter and yield values are estimated is given.

The results obtained using the various models and data from the four ICSEAF divisions are then listed and compared. A historical examination of the accuracy of model projection capabilities is used to comment upon the efficacy of the Schaefer and Fox dynamic models. In addition, biomass estimates provided by the traditional Virtual Population Analysis (VPA) procedure are compared to those of the dynamic models for Division 1.6 .

Certain extensions to the dynamic model are introduced in an attempt to reduce apparent differences between dynamic model and VPA biomass estimates which are evident for Division 1.6 . In addition, dynamic model fits using the Shepherd surplus production form (which incorporates a skewness parameter) are performed on the catch-effort data. Lastly, further possible developments and amendments to the dynamic models are suggested.

1.3 Basic conventions

Most of the conventions used in this thesis are explained in the text. A few of the more common ones are outlined briefly here. In some cases a ^ is used to indicate that a parameter or variable has been estimated (for example, $\hat{y}$ denotes the estimated biomass). Unless indicated otherwise, the current year (that is, the year following the last in the series of available catch-effort data, usually 1985) will be denoted by an asterisk (for example, y^* will refer to the current biomass). The term 'significant' is used only in the sense of 'statistically significant at the 5% level'.

In this study, the precision with which quantities (especially management-related variables such as MSY's or quotas (Total Allowable Catches - TAC's) under particular harvesting strategies) are estimated will be emphasized. This involves calculation of the associated coefficient of variation (c.v.) estimates as follows:

$$\text{coefficient of variation} = \frac{\text{standard error}}{\text{mean}}$$

(these values are sometimes expressed as a %). Semi-arbitrarily, such c.v. estimates will be termed 'acceptable' if they are less than 20% (in discussions on the adequacy of available data to provide an 'acceptable' estimate of a particular quantity using a particular model).

For objective function minimizations, the NAG (see Note (1)) routine, E04FDF, was chosen. Results were checked using an alternative minimization routine, MINIM (see Note (2)). The BMDP statistical package, BMDP5D was employed for normal probability plots (see Note (3)).

Note (1) This NAG (National Algorithms Group Ltd., Oxford, 1983) routine uses a quasi-Newton type method (see Gill and Murray, 1978).

Note (2) MINIM is a minimization routine based on the simplex method (Nelder and Mead, 1965). It was programmed by D.E. Shaw of the CSIRO Division of Mathematics and Statistics (P.O. Box 218, Lindfield, Australia) and amended by R.W.M. Wedderburn of the Rothamsted Experimental Station, Harpenden, Hertfordshire, England.

Note (3) Biomedical Computer Programs (published by University of California Press, Berkeley, 1983).

2 BIOLOGICAL AND HISTORICAL BACKGROUND

2.1 Hake biology

Two hake species, namely Merluccius capensis Castelnau and Merluccius paradoxus Franca, known collectively as the Cape hakes, are taken by the fishery off southern Africa. A third species, M. polli Cadenat, is also taken in waters off northern South West Africa, Angola and further north, but it is not a 'Cape' hake and therefore will not form part of this thesis. Although originally regarded as subspecies of M. merluccius by many authors (Franca, 1962; van Eck, 1969), M. paradoxus and M. capensis are now recognized as full species (Inada, 1981). Aspects of the general taxonomy, anatomy, biology and distribution of adult Cape hakes have been discussed in detail by Botha (1980) and Inada (op. cit.).

M. paradoxus and M. capensis are similar, but they can be distinguished by the colour of their gill tubercles, the number of vertebrae (van Eck, 1969) and the shape of their otoliths (Botha, 1971). Inada (1981) proposes ranges for the number of vertebrae, namely, 49-53 for M. capensis and 54-58 for M. paradoxus. These do not differ significantly from ranges previously suggested by Franca (1954) and Pshenichnyy and Assorov (1969).

There are also other subtle differences in shape, in colouration and in eye size which, although not as definitive, permit an experienced worker to separate the species at a glance. M. paradoxus tends to be a longer, thinner fish with proportionately larger eyes than M. capensis. In addition, the dorsal parts tend to be blacker in M. paradoxus and more coppery in M. capensis. In South West African waters the edge of the anal fin is white in M. capensis and black in M. paradoxus. This distinctive criterion is absent in the stocks south of the Orange River mouth, where both species have dark anal fins and in the vicinity of the Orange River it cannot be reliably used to separate the two species. The morphological difference of the white anal fin in M. capensis north of the Orange River suggests that there are two distinct stocks, but as yet no measurable genetic differences between them have been observed (R. Leslie, SFRI, pers. commn).

Inada (1981) describes the geographical distribution of Cape hake. He concludes that the distribution is influenced by the cold, north-flowing Benguela Current along the west coast and is limited by the warm, south-flowing Mozambique Current along the east coast. According to Inada (op. cit.), shallow-water Cape hake (M. capensis) inhabit waters from just north of Bahio de Farto (±12°S) off Angola on the west coast to East London on the south-

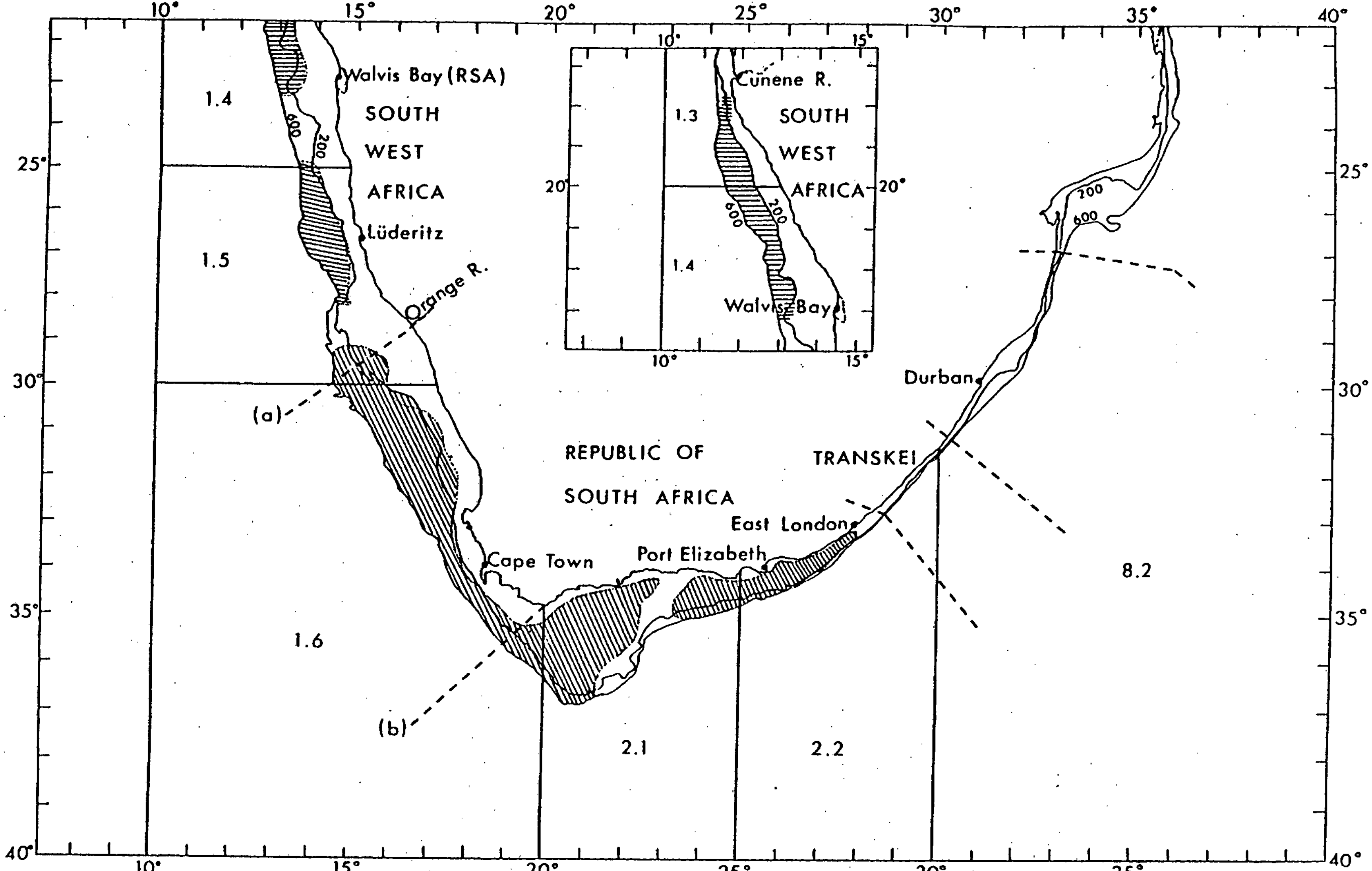


Figure 2.1 Map showing the major hake trawling grounds (shaded areas), the ICSEAF division boundaries and the 200 and 600 m depth contours off southern Africa (based on unpublished SFRI and ICSEAF statistics). The boundaries marked (a) and (b) refer to the domestically applied boundaries of Division 1.6 and the adjoining divisions.

east coast of southern Africa. They are found on the continental shelf, usually in depths of less than 440 m. M. capensis longer than 50 cm generally inhabit the 220-440 m depth range, whereas those shorter than 40 cm are distributed in depths shallower than 220 m. The maximum numerical abundance of M. capensis occurs at a depth of 150 m (with optimum temperature of 8,75°C) (Botha, 1980).

Deep-water Cape hake (M. paradoxus) are known to inhabit waters from Cape Frio (18°S) to Port Elizabeth (Quero, 1973) along the slope of the continental shelf. They are found more offshore than the shallow-water Cape hake, being distributed mainly between 150 and 640 m, although Inada (1981) states that they occur to at least 850 m off the Agulhas Bank and Botha (1980) gives a maximum depth of 920 m. Fishes longer than 50 cm inhabit waters deeper than 400 m and comprise maturing schools, whereas fishes between 20 and 40 cm are found in the 260-400 m depth range (Botha, op. cit.). The maximum numerical abundance of M. paradoxus occurs at 330m (and 8,11°C) (Botha, op. cit.).

From catch statistics it has been established for both species that there is some correlation between fish size and water depth. Within each species, the smaller hake inhabit shallower waters than the larger individuals and hence, although there is intermixing of the species in intermediate waters in the depth range of 200-400 m (Inada, 1981), the adults of the two species do not commonly mix (Badenhorst, 1984). In the overlap area where larger M. capensis have been found to coexist with small M. paradoxus (Botha, 1980), research studies have shown that interbreeding does not occur (Jones and MacKie, 1970) and that the species retain their specific integrity by spawning at different depths (Botha, 1973).

The above species and fish size stratification by depth partially breaks down in the waters off South West Africa possibly as a result of the narrower continental shelf in some parts and the extralimital occurrence of M. paradoxus. Although there is still a tendency for fish size to increase with depth, there is a much wider size range at depth and reports of large M. paradoxus and small M. capensis in the same trawl are not unusual (R. Leslie, SFRI, pers. commn).

The age composition and the distribution of the two species largely determine their fishing mortality rates, and therefore the fisheries in the various divisions differ substantially. Although both species are caught commercially in Division 1.6, the major impact has been on M. paradoxus, which constitutes 95,2% of the catch by numbers and 87,1% by mass (Botha, 1980). In South West African waters, M. paradoxus are far less abundant, especially north of Walvis Bay, and M. capensis is the dominant species (70% by mass) (Payne, in prep.). Similarly, according to unpublished Sea Fisheries catch statistics, M. capensis constitute at least 60% by mass of the catches made by the inshore fishery in Divisions 2.1 + 2.2 .

Since factories and fishermen do not differentiate between the two hake species in commercial catches, most of the data available are for both species combined. Current stock assessment models and the resulting management implications are therefore based on this single species assumption.

Although growth patterns of hake differ between areas, species and sexes, hake generally exhibit slow uniform growth throughout their life span. This is illustrated in Figure 2.2 where length-at-age curves are plotted using the von Bertalanffy growth equation as presented by Leslie (1985) for both species combined in ICSEAF Divisions 1.6 and 2.1 + 2.2:

Division 1.6: $$l_t = 125,4\ (1 - e^{-0,113(t\ -\ 0,0396)})$$

Divisions 2.1 + 2.2: $$l_t = 167,3\ (1 - e^{-0,0798(t\ +\ 0,378)})$$

where l_t = total hake length in cm

and t = time (age in years).

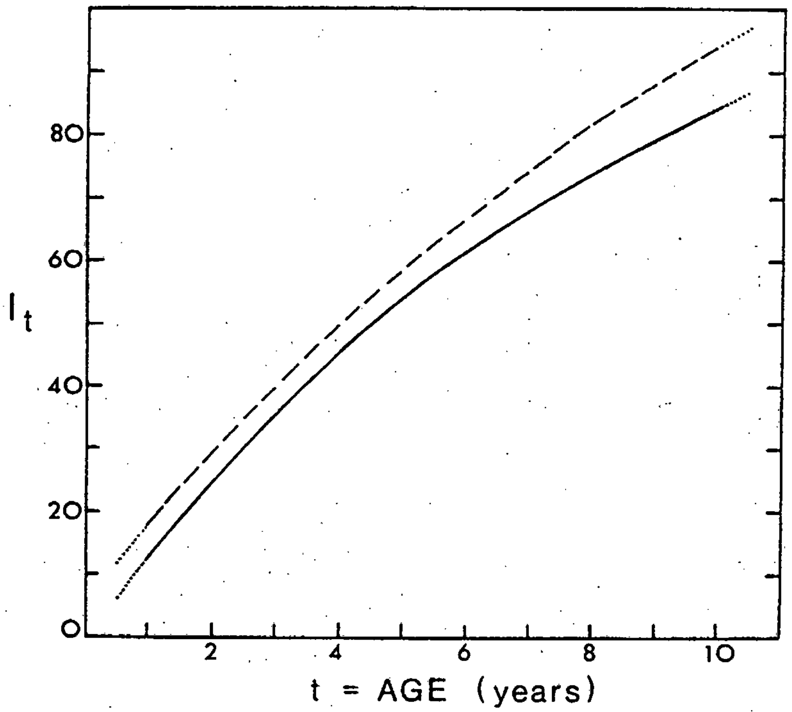


Figure 2.2: Length-at-age curves for hake in ICSEAF Divisions 1.6 (solid line) and 2.1 + 2.2 (dashed line).

Research studies have shown that males grow more slowly than females and that life expectancy is longer for females. Quero (1973) recorded a maximum length of 120 cm. Botha's observations on the growth rate and the maturity of both species have shown that, in Division 1.6, 50% sexual maturity is reached at lengths of approximately 48 cm in the case of female hake and 37 cm in the case of male hake (Botha, 1980). Using the length-at-age curve corresponding to this division in Figure 2.2, these lengths correspond to 50% sexual maturity at an age of 4,3 years for female hake and 3,1 years for male hake.

It is generally assumed that increased fishing rates or favourable environmental conditions tend to result in density-dependent increases in the growth rates of fish populations and/or decreases in the age and length at maturity as a natural means of promoting recovery. Such observations on the whitefish populations in Canada were documented by Healey (1975). Non-uniformities in the growth rates and age at maturity of Cape hake stocks in different areas can therefore be expected. From Figure 1.2 it can be seen that the growth rate of Cape hake on the South-east Coast appears to be faster in the early stages of development than that of hake in Division 1.6, although statistical tests of the significance (or otherwise) of the differences have yet to be carried out. Dissimilarities such as these in the reproductive and growth biology of the species in Divisions 2.1 + 2.2 could be attributed to the heavy exploitation of the stock in the mid-seventies (Payne, in prep.).

Spawning behaviour appears to differ substantially between regions. In Divisions 1.3 + 1.4, where M. capensis is the dominant species, a gonad study made by Assorov and Berenbeim (1983) indicates that spawning appears to be from July to December. On the other hand, Cape hake spawning data for the West Coast indicate a two-phase spawning period extending from November to March (Botha, 1980). The main spawning period occurs in November-December and is followed by a smaller less intense one in February-March, the latter spawning peak being sustained mainly by M. paradoxus (Assorov and Kalinina, 1979). There are also indications that some spawning activity takes place throughout the year and that the same fish can spawn more than once during each spawning season (Botha, op. cit.). In Divisions 2.1 + 2.2 studies by Payne (in prep.) also show that spawning can take place throughout the year, but that a peak is reached in spring and early summer (August/September until the end of the year). Thereafter it appears to decrease in intensity, reaching a minimum during the winter months of June and July.

The low occurrence of spawning fish in commercial catches made with bottom trawls is consistent with the general belief that spawning hake rise off the seabed to spawn in midwater (Botha, 1980).

Recruitment, which is the process by which juvenile fish join the fishable stock, depends on many factors. These include minimum mesh size regulations and the fact that, in both species, small hake generally inhabit shallower waters than do larger fish, gradually migrating into deeper water as they mature. As a result, recruitment is influenced by the age at which these migrations take place and, in the case of M. capensis, the minimum depth at which the trawlers operate.

Hake are carnivorous in general, but their food preferences change during growth. Results of studies off the South West African coast show that the major food organisms for juvenile hake in this area are planktonic organisms such as crustaceans (particularly euphausids), small fish (mainly myctophids) and cephalopods (Assorov and Kalinina, 1979). As the fish length increases, so the predominance of euphausids in the hake diet declines and fish become the major component of the diet of older hake. Feeding intensity drops significantly from October to December (during the spawning period) and is high from January to May (Chłapowski, 1977).

Cannibalism in Cape hake starts with fish of 40 cm and over and increases with size, hake becoming a principal food item in fish over 50 cm long (Chłapowski, 1977 and Preński, 1980a). Hake are cannibalized at a high rate from age 0 to 4, naturally the rate decreasing with age. By the age of 5 cannibalism has almost ceased. Studies of Cape hake off the coast of South West Africa have shown that large M. capensis are highly cannibalistic and that juvenile hake may make up over 50% of the diet of individuals of the same species larger than 60 cm (Macpherson, 1980 and Preński, op. cit). This high rate of cannibalism can partly be attributed to factors such as high population density and a coincidence in time and place of juvenile and adult hake (Lleonart et al., 1983). Therefore from just south of Walvis Bay northward, where there are fewer M. paradoxus, the incidence of 'true cannibalism' (that is, one species of hake eating the same species) would be expected to be higher. In the South African waters this proportion of hake in the diet of the same species may differ, because although small M. paradoxus do form a large part of the diet of large M. paradoxus, the large M. capensis eat mainly small M. paradoxus (Botha, 1980), which is not true cannibalism. Small M. capensis are protected from large M. paradoxus by geographical distribution.

Botha (1980) states that hake do not appear to be major predators of any other commercially exploited fish. Neither does the stock seem to be threatened by predators and it experiences little competition for food or living space. Changes in the hake population size are thus unlikely to markedly effect other fish species that are at present commercially exploited.

In practice, after the pelagic larval stage, hake descend to the bottom. However, migrations do take place for the purpose of spawning or feeding. At night they move vertically away from the seabed to feed and they return to the seabed during the day (Inada, 1981). Most vessels fish only during daylight when the fish are concentrated near the seabed and when the catch rates are generally higher. From catch records of vessels fishing throughout 24 hours it would seem that catch rates increase to a maximum at midday and decrease to a minimum at midnight (Jones, 1974). Botha (1980) confirms this rise off the seabed at night.

2.2 Historical background of the hake fishery

The ICSEAF convention area is, for statistical purposes, divided into two major regions, Zone I and Zone II. The former lies off the coast of South West Africa and comprises Divisions 1.3, 1.4 and 1.5, excluding a small area south of the Orange River (Figure 2.1). This small area is assigned to Zone II, which is formed mainly by Divisions 1.6, 2.1 and 2.2 and which is situated off the coast of South Africa.

Catch statistics are submitted in terms of either landed or nominal weight. The landed weight refers to the weight of the cleaned or processed fish whereas the nominal weight is an estimate of the weight of whole fish actually taken from the sea. It is calculated from the landed (headed/gutted) weight by means of a conversion factor of 1,46 (Chalmers, 1976). Future references to catches in this thesis always refer to nominal weight.

Hake has been fished commercially since the late nineteenth century. Catch figures for the South African fishing industry (Table 2.1) show that hake catches increased steadily from 1 000 metric tons in 1917 to 21 100 tons prior to the onset of World War II. After the war catches rose to 72 thousand tons in 1950 and, by 1961, catches of 148,7 thousand tons had been recorded. Until then only South African trawlers were exploiting the hake resource and their fishery was mainly restricted to the grounds in the vicinity of the Cape Peninsula (Jones, 1974).

After 1962 participation by distant-water trawlers from several foreign nations increased. ICSEAF (1978) gives 1962 as the start of foreign fishing effort in Division 1.6 with a total of 3,6 thousand metric tons being caught by the foreign fleet. The increase in both domestic and

Year	Catch
1917	1,0
1918	1,1
1919	1,9
1920	-
1921	1,3
1922	1,0
1923	2,5
1924	1,5
1925	1,9
1926	1,4
1927	0,8
1928	2,6
1929	3,8
1930	4,4
1931	2,8
1932	14,3
1933	11,1
1934	13,8
1935	15,0
1936	17,7
1937	20,2
1938	21,1
1939	20,0
1940	28,6
1941	30,6
1942	34,5
1943	37,9
1944	34,1
1945	29,2
1946	40,4
1947	41,4
1948	58,8
1949	57,4
1950	72,0
1951	89,5
1952	88,8
1953	93,5
1954	105,4
1955	115,4
1956	118,2
1957	126,4
1958	130,7
1959	146,0
1960	159,9
1961	148,7
1962	147,6
1963	169,5
1964	162,3
1965	203,3
1966	195,0
1967	194,1
1968	175,0
1969	206,8
1970	170,3
1971	236,5
1972	295,3
1973	235,2
1974	223,9
1975	163,4
1976	201,1
1977	138,0
1978	144,5
1979	144,2
1980	149,1
1981	134,6
1982	131,8
1983	114,9
1984	126,8

Table 2.1 : Total (RSA and foreign) hake catches for ICSEAF Division 1.6 (1917-1966) and Divisions 1.6, 2.1 and 2.2 (1967-1982) in thousands of metric tons. Trawling is known to have taken place in Divisions 2.1 + 2.2 during the period 1963-1966, but the catches made at that time were relatively small and have not been included in this table. Calculation of the catch data for 1917-1954 was based on historical records of landed catches published by Chalmers (1976). Since it is known that much discarding of small hake took place in the South African fishery during these years these figures were increased by 39% in accordance with a decision reached and published in ICSEAF (1978). The same procedure was used to account for discarding in RSA catches from 1955 to 1971. From 1972 onwards catches have not been adjusted because the commercial fishery began to find a market for the smaller fish and the catch rate decline dictated their retention. Corrected catch figures for 1955-1980 were obtained from ICSEAF (1985b). Data for 1981-1984 are based on unpublished SFRI and ICSEAF statistics.

foreign fishing effort was accompanied by an expansion of the area fished, and the trawling fleet soon fished virtually the whole of the continental shelf off the coast of South West Africa and South Africa as far east as East London (Jones, 1974). The bulk of the catch is taken by South African, Soviet and Spanish trawlers. The relative catches taken by the various fishing nations in selected years are given in Table 2.2 and the domestic and foreign catches off the South African and South West African coasts for all years are listed in Tables 2.3a and 2.3b.

After South Africa's introduction of a 200-nautical mile fishing zone on 1 November 1977, the hake fishery off South Africa reverted to an almost exclusively local one as it had been before 1962. In 1983, only 4 400 metric tons of hake were taken by foreign trawlers in South African waters as opposed to their 182,3 thousand tons in 1972 (Table 2.3b). However, total catches of Cape hake were not reduced in the same proportion because much of the foreign effort was diverted to South West African waters where, because of the uncertain political status, the 200-nautical mile fishing zone has not yet been enforced.

The Cape hake fishery is the largest in the world (Inada, 1981). In 1965, catches of Cape hakes alone accounted for 33% of the total world hake catch. This proportion rose to 41% in 1973 (Botha, 1980) and has since remained fairly constant. Statistics published in F.A.O. (1984) give the percentage of Cape hakes in the world hake catch in 1983 as 40% .

Hake is the dominant species in South African trawl catches. The SFRI Annual Report for 1984 states hake as constituting 73,6% by landed mass of the total demersal catch made by the South African trawling industry during that year (Marine Development Branch, 1984). Table 2.6 gives these annual percentages for the period 1978-1984. The foreign plus domestic hake catch for the total convention area in 1983 was approximately 450 thousand metric tons (ICSEAF Stat. 1985).

From Figure 2.3 it can be seen that the South African domestic catch has not changed much over the past 30 years. Although total catch figures for Divisions 1.6, 2.1 and 2.2 reflect a large peak in the mid-seventies followed by a substantial reduction, catches made by the local industry remained remarkably stable though, as discussed below, the catch rate dropped severely.

During the mid to late 1970s, catch rates for hake in the various ICSEAF divisions dropped to their lowest recorded levels as a result of an apparent sustained low recruitment of juveniles to the population and, in particular, heavy exploitation partly because of a substantial escala-

COUNTRY	YEAR						
	1977	1978	1979	1980	1981	1982	1983
Bulgaria	14071	8754	8187	152	-	1322	4667
Cuba	7900	9245	2986	56	-	263	15318
France	1016	3493	807	-	-	-	-
GDR	4923	4825	3703	3215	261	1147	2275
GFR	7222	10506	6112	-	-	-	-
Ghana	33	117	59	982	-	-	-
Iraq	-	-	9648	205	2	2	2
Israel	4000	6400	6570	7174	6149	4197	4610
Italy	4502	4670	1123	52	-	-	-
Japan	35494	13576	7873	4894	4285	3732	3859
Poland	35525	30306	25543	2453	4383	187	726
Portugal	15750	14881	12816	10116	14178	12111	17581
Rumania	2440	3666	4373	852	274	6221	7300
RSA	101583	143115	153200	150241	143905	156858	137619
Spain	141082	133408	116348	91494	135051	139099	130354
USSR	222156	133290	94584	46190	33943	114093	135013
Zaire	510	-	-	-	-	-	-
TOTAL	598207	520252	453932	318076	342431	439232	459324

Table 2.2 : *M. capensis* and *M. paradoxus* catches in metric tons by nation and year for the whole convention area (GDR = German Democratic Republic; GFR = German Federal Republic). Statistics are as given in F.A.O. (1981 and 1984).

Year	Domestic	Foreign	Total
1962	-	-	-
1963	-	-	-
1964	-	47 600 (100)	47 600
1965	-	192 600 (100)	192 600*
1966	10 900 (3,5)	301 700 (96,5)	312 600*
1967	1 300 (0,3)	393 100 (99,7)	394 400
1968	1 300 (0,2)	629 100 (99,8)	630 400
1969	1 400 (0,3)	525 300 (99,7)	526 700
1970	2 700 (0,4)	624 500 (99,6)	627 200
1971	6 100 (1,0)	589 200 (99,0)	595 300
1972	5 100 (0,6)	815 000 (99,4)	820 100
1973	4 500 (0,7)	663 400 (99,3)	667 900
1974	4 400 (0,9)	504 900+ (99,1)	509 300+
1975	5 600 (1,2)	482 500 (98,8)	488 100
1976	6 100 (1,1)	573 400 (98,9)	579 500
1977	3 300 (0,8)	431 900 (99,2)	435 200
1978	2 100 (0,6)	380 200 (99,4)	382 300
1979	1 300 (0,4)	301 000 (99,6)	302 300
1980	4 300 (2,7)	156 300 (97,3)	160 600
1981	8 300 (4,0)	200 200 (96,0)	208 500
1982	29 800 (9,7)	278 400 (90,3)	308 200
1983	27 030 (8,0)	312 100 (92,0)	339 100

Table 2.3a Nominal Cape hake catches by flag group for SWA (ICSEAF Divs 1.3, 1.4 and 1.5) in metric tons. Figures in parenthesis show the percentage of total catch. Statistics for 1962-1981 come from the South African Fishing Industry Handbook and Buyer's Guide (1985). Figures in disagreement with data from ICSEAF (1985b) are marked with an * . A + indicates that erroneous data have been amended. The statistics for 1982-1983 were calculated from ICSEAF Stat. (1984 and 1985).

Year	Domestic	Foreign	Total
1962	102 300 (95,9)	4 400 (4,1)	106 700*
1963	98 900 (77,9)	28 000 (22,1)	126 900*
1964	102 200 (80,0)	25 500 (20,0)	127 700*
1965	99 600 (58,1)	71 700 (41,9)	171 300*
1966	113 300 (63,9)	63 900 (36,1)	177 200*
1967	115 400 (59,5)	78 700 (40,5)	194 100
1968	115 100 (65,8)	59 900 (34,2)	175 000
1969	101 000 (48,8)	105 800 (51,2)	206 800
1970	91 700 (53,9)	78 600 (46,1)	170 300
1971	105 300 (44,5)	131 200 (55,5)	236 500
1972	113 000 (38,3)	182 300 (61,7)	295 300
1973	128 600 (54,7)	106 600 (45,3)	235 200
1974	113 500 (50,7)	110 400 (49,3)	223 900
1975	93 400 (57,2)	70 000 (42,8)	163 400
1976	107 900 (53,6)	93 200 (46,4)	201 100
1977	94 300 (68,3)	43 700 (31,7)	138 000
1978	135 300 (93,6)	9 200 (6,4)	144 500
1979	139 600 (96,8)	4 600 (3,2)	144 200
1980	138 000 (92,6)	11 100 (7,4)	149 100
1981	127 700 (93,2)	9 300 (6,8)	137 000
1982	127 100 (94,7)	7 100 (5,3)	134 200
1983	110 400 (96,2)	4 400 (3,8)	114 800

Table 2.3b Nominal Cape hake catches by flag group for RSA (ICSEAF Divs 1.6, 2.1 and 2.2) in metric tons. Figures in parenthesis show the percentage of total catch. Statistics for 1962-1980 come from the South African Fishing Industry Handbook and Buyer's Guide (1985). Figures in disagreement with data from ICSEAF (1985b) are marked with an *. The statistics for 1981-1983 were calculated from ICSEAF Stat. (1983, 1984 and 1985).

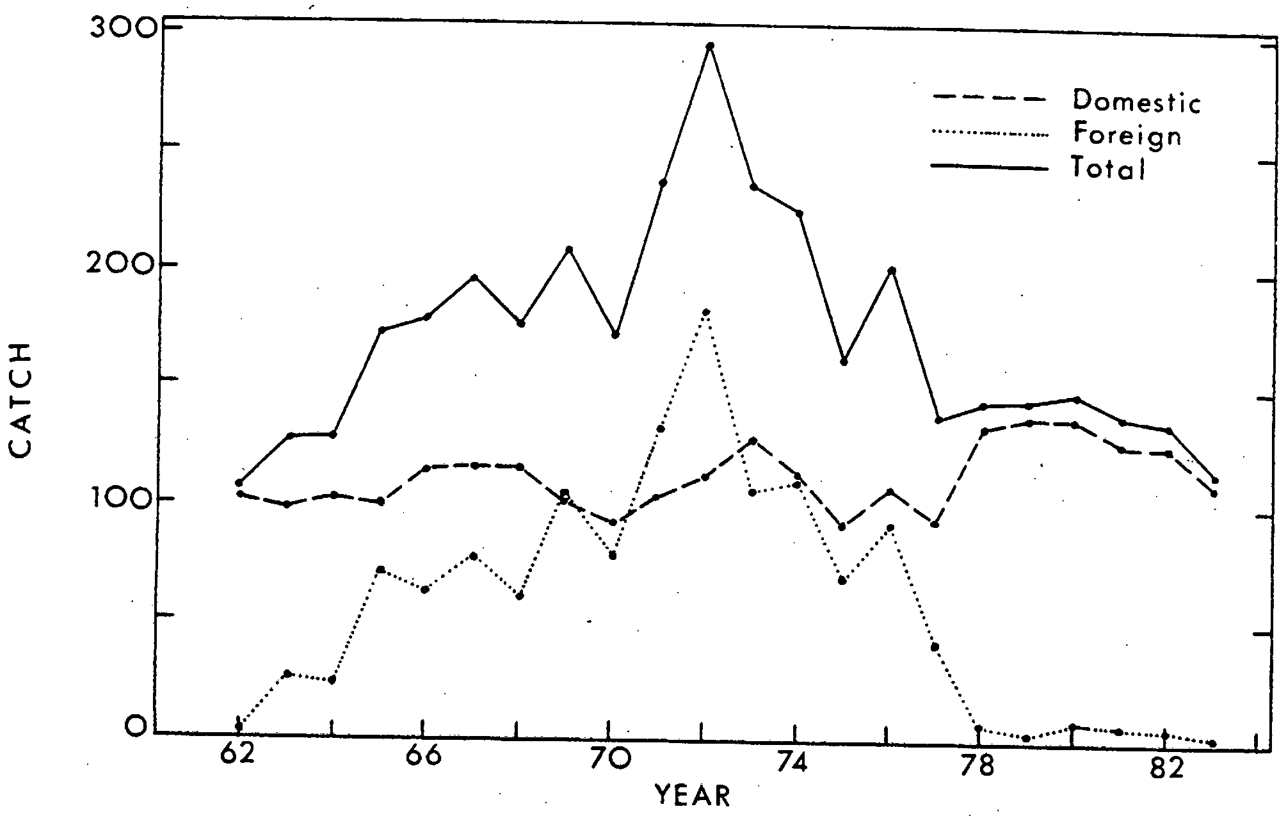


Figure 2.3: Domestic, foreign and total catches in thousands of metric tons for ICSEAF Divisions 1.6, 2.1 and 2.2 (Zone II). This graph has been based on data presented in Table 2.3b. Values for the period 1962-1966 should be viewed with caution.

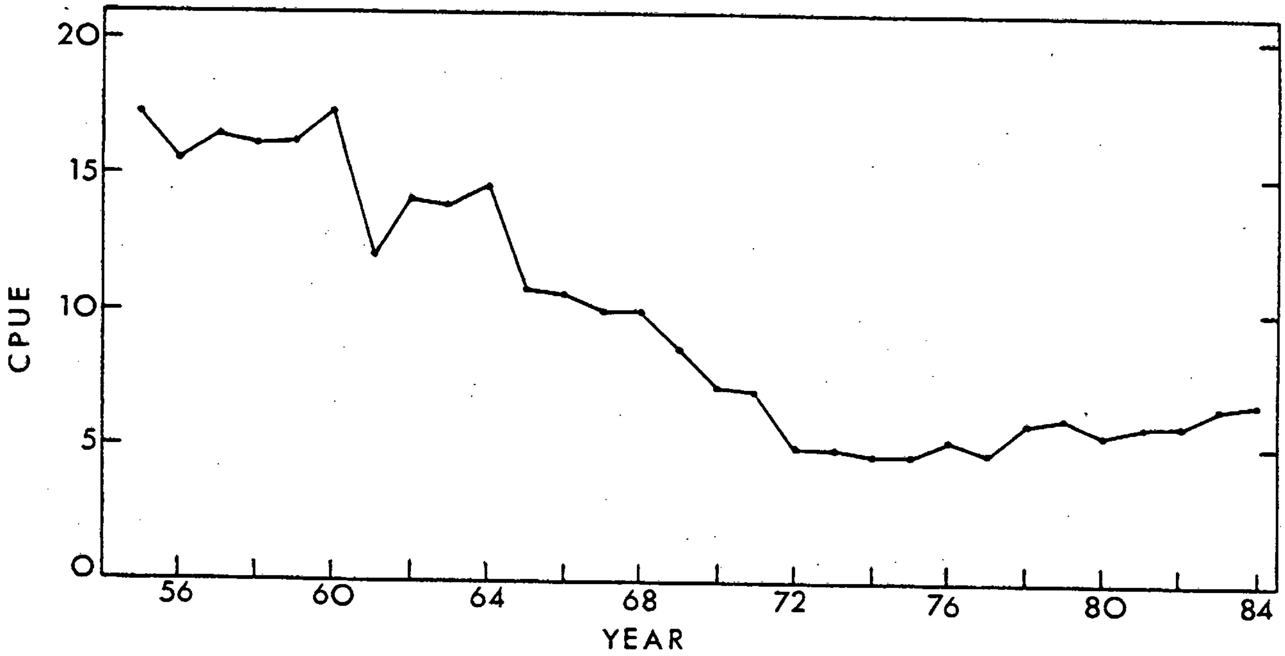


Figure 2.4: CPUE trend (in metric tons per South African standard trawler day) for ICSEAF Division 1.6 .

tion in foreign fishing in the early 1970s (see Chapters 8 and 9). This trend in CPUE values for ICSEAF Division 1.6 is illustrated in Figure 2.4. The catch rate decrease, together with an increase in fishing costs, particularly fuel and wages, seriously affected the profitability of the local hake industry which may have been running at a loss in the mid-seventies (R. Bross, pers. commn).

By this time work on stock assessment and population dynamics had already commenced. In 1966, the Division of Sea Fisheries, under the Department of Industries, had initiated a research programme, giving priority to the collection and compilation of reliable catch and effort statistics.

This was followed by the establishment of ICSEAF (the International Commission for the South East Atlantic Fisheries) in 1972 as a result of mounting concern about the depletion of hake stocks following increased exploitation in the area. Priority was given to stock assessment, and management concentrated on reducing effort on the heavily exploited stocks. An internationally recognized minimum mesh size of 110 mm was implemented on 1 July 1975 (Sea Fisheries Branch, 1980). Prior to that, South African deep-sea trawlers had used a mesh size of 102 mm. An inspection scheme for hake fishing was also initiated (1975) and a catch quota of an initial 700 thousand metric tons for the whole convention area (but subdivided between Zones I and II) was introduced into the fishery by ICSEAF on 1 January 1977 (Sea Fisheries Branch, 1981b).

Table 2.4 gives the ICSEAF catch quota recommendations from 1977 to 1985 for Zones I and II. Since 1978, quotas for Zone II have been set by the South African authorities after taking cognizance of ICSEAF recommendations. The historical deep-sea, inshore and foreign quota allocations for this region are detailed in Table 2.5.

Subsequent quota advice seemingly aimed at assuring an increase in stock abundance, principally by maintaining annual catches below current sustainable yields, generally adopting a $f_{0.1}$ strategy to do so. Current CPUE values and stock-size estimates indicate that these measures have been largely successful in countering the earlier apparent overexploitation of the stocks, and a biologically optimal exploitation (MSY) appears close to being (or has already been) achieved (see Chapter 8).

Year	Zone I (SWA)	Zone II (RSA)
1977	536 000 (81,2)	164 000 (84,1)
1978	480 300 (79,6)	147 700 (97,8)
1979	415 900 (72,7)	150 000 (96,1)
1980	320 000 (50,2)	112 000 (133,1)
1981	211 841 (98,4)	140 000 (96,1)
1982	352 000 (87,6)	127 700 (103,2)
1983	413 000 (82,1)	115 200 (99,7)
1984	413 000 (77,5)	129 000 (98,3)
1985	429 000 (-)	126 000 (-)

Table 2.4: ICSEAF recommendations (1977-1985) relating to the regulation of total Cape hake catches in metric tons. Statistics were obtained from ICSEAF (1976-1984). Figures in parenthesis show the percentage of the recommendation actually caught.

Year	Deep-sea	Inshore	Foreign	Spare	Global	%	
1978	113,50	5,00	6,50		125,00	115,6	(1)
1979	135,00	5,00	7,00	3,00	150,00	96,1	
1980	134,85	7,00 + 2,00	10,20 + 2,00		152,00	98,1	(2) (3)
1981	135,30	7,00 + 2,00	10,40	1,00	153,70	89,1	(3)
1982	119,15	9,00	7,85		136,00	98,7	
1983	105,00	8,00	7,00		120,00	95,7	
1984	111,65	9,35	7,00		128,00	99,1	
1985	114,15	9,35	7,00		130,50	-	

Table 2.5: Quota figures (in thousands of metric tons) as set by the RSA authorities for ICSEAF Divisions 1.6 and 2.1 + 2.2 . The last column shows the percentage of the quota landed and was calculated using the nominal catches given in Tables 3.3 and 3.4 . Quota figures were obtained from Annual Reports 46-52 of the Director of Sea Fisheries or the Chief Director of the Marine Development Branch and from SFRI records.

Note (1) The quota for South African vessels was filled by the end of October and a small additional quota was granted to extend to the end of the year.

(2) Taiwan was granted a quota of two thousand metric tons after initial quota allocations had been made.

(3) The inshore quota was raised from seven to nine thousand metric tons when it became clear that the deep-sea quota would not be filled.

Year	% hake	RSA quota
1978	71,6	152,000
1979	68,7	169,000
1980	70,8	165,750
1981	73,3	158,358
1982	75,0	151,097
1983	69,5	139,924
1984	73,6	147,924

Table 2.6 : A comparison of the percentage nominal weight of hake in demersal landings of the RSA commercial trawling industry with RSA quotas in thousands of metric tons for Zones I and II during the period 1978-1984. The figures for the percentage hake in demersal catches were obtained from Annual Reports 46-52 of the Director of Sea Fisheries or the Chief Director of the Marine Development Branch. The RSA quota figures are based on quotas listed for the domestic trawls in Table 2.5 and increased by the RSA Zone I quotas published in the Reports of the Meetings of the Scientific Advisory Council and the Standing Committee on Regulatory Measures in ICSEAF (1978-1984)

2.3 Objectives of fishery management

The ultimate objective of fisheries scientists is to provide scientific advice for management which should ultimately maximize benefits (for the moment benefits may be considered equivalent to yield) without impairing future prospects of exploiting the fishery. Beyond this stage, management is carried out by fisheries administrators. For operational purposes, this objective needs more specific definition; correspondingly the terms 'overfishing' or 'overexploitation', frequently used to describe fisheries, are not in themselves very clear or helpful without more detailed specification. For the purposes of this thesis, overfishing is interpreted in the purely biological sense to mean the reduction by fishing of the stock to below the level providing maximum sustainable yield (MSY), where MSY is the largest average catch that can continuously be taken from a stock.

Theoretically, by controlling the amount of fishing and the size of the fish that may be caught, the stock size can be adjusted and overfishing avoided. An understanding of the dynamics of the fish population is therefore necessary and this can be expressed in terms of models which estimate stock size and yield of the fishery for particular levels of effort. On the basis of such research, management policies can be framed for the regulation of the fishery. These include the establishment of annual catch quotas, sometimes referred to as Total Allowable Catches (TAC's), and the enforcement of scientifically based minimum mesh size regulations. However, the viability of such mesh size controls as a management tool in the hake fishery is open to conjecture owing to the apparent low survival rate of hake passing through the meshes of the trawl nets (R. Leslie, SFRI, pers. commn).

The overall objective of fishery scientists may differ from that of fishermen who might choose to maximize their profits immediately. So ideally, for optimal management of the stocks, economic, social and political factors should be incorporated in the models. For example, costs could be related to fishing effort so as to indicate how profitable different equilibrium levels of fishing effort would be. However, once economic factors are introduced, the term 'overfishing' needs to be generalized to include fishery revenue and cost factors. At present, such analyses cannot be performed because of the unavailability of suitable data.

Since environmental fluctuations can cause the stock size to vary, allowance for a safety factor is advocated when setting quotas. Management recommendations for Cape hake have generally been based on the $f_{0,1}$ procedure outlined by Gulland and Boerema (1973). It is an ad hoc procedure which aims to keep the stock slightly above MSY level as a buffer against fluctuations. Gordon's equilibrium economic factor stock model (Clark, 1976) suggests that in many cases this procedure will tend to provide better economic returns. Details of the $f_{0,1}$ procedure are given in Chapter 8.

3 DATA

3.1 Stock divisions

The ICSEAF convention area is divided into four main regions for the purposes of hake stock assessment (see Figure 2.1). These are Divisions 1.3 + 1.4, Division 1.5, Division 1.6 and Divisions 2.1 + 2.2 . In the absence of any definitive results on stock identity, the ICSEAF division boundaries have for convenience been taken to represent stock boundaries. Divisions 1.3 + 1.4 have been combined because evidence points to CPUE trends with time which are similar for these two areas, but which differ from that for Division 1.5 ; Divisions 2.1 + 2.2 were not split because in Division 2.2 relatively small catches were reported and the distribution of these catches did not extend far into this region (A.I.L. Payne, SFRI, pers. commn). In the four ICSEAF regions (from now on termed divisions) two hake species, *M. paradoxus* and *M. capensis*, are caught (though in different proportions). Because landing statistics do not distinguish between these two species, *M. paradoxus* and *M. capensis* [which have similar appearance (van Eck, 1969) and growth rates (Botha, 1971)] are treated as a single unit stock in each particular division.

3.2 Description of data

Three main types of data are available from the commercial fisheries. These are the catch (C), fishing effort (E) and biological characteristics of the catch (for example, length and age structure). Catch per unit effort (CPUE) statistics are calculated from catch and effort data. These data are utilized by the production models described in Chapters 4 and 5, whereas biological statistics are employed by alternative stock assessment procedures such as Virtual Population Analysis (see Chapter 9).

Because the precision of estimates of parameters of production models developed in later chapters depends largely on the length of the time series of historical data, catch-effort statistics have been collected from as early in the history of each of the fisheries as possible. These statistics are available for hake fisheries in the abovementioned four divisions for most of the period of exploitation, except as hereafter mentioned. Although Cape hake in Division 1.6 have been fished since the turn of the century, comprehensive catch and effort data are only available from 1955 for this region; catches in earlier years were small (see Table 2.1). The more northern grounds (Divisions 1.3 + 1.4 and 1.5) were virtually unfished by South African or foreign vessels until 1965, and it was only subsequently that fishing in the Lüderitz and Walvis Bay vicinities escalated rapidly. Therefore catch-effort statistics for these grounds are available only from this date. Similarly in Divisions 2.1 + 2.2, the data records only go back to 1967 when heavy exploitation of the hake resource began, though some inshore catches of M. capensis had been made by the sole fishery in earlier years.

The nominal catch, (standard) effort and CPUE data series used in analyses in subsequent chapters are presented in Tables 3.1 - 3.4 . The data values have been taken from ICSEAF (1985b), with some minor adjustments for Divisions 1.6 and 2.1 + 2.2 (R. Leslie and A.I.L. Payne, SFRI, pers. commn). The 1984 figures have been estimated on the basis of the figures for the first half of the year only and will be subject to later revision. Effort values were calculated on the basis of the catch and CPUE values as will be described in the sections hereunder.

Where unspecified in following chapters, catch, effort and CPUE units for the graphs and tables correspond to the units given in Tables 3.1 - 3.4 .

3.2.1 Catch data

Catch is the weight (or, in the case of other fisheries, sometimes number) of fish removed from the population by fishing. In Chapter 2 it was noted that catch statistics are usually reported in tonnes actual (landed) weight. Because the fish are headed and gutted before being weighed, these figures have been converted to tonnes whole (nominal or live) weight by multiplying by a factor of 1,46 (Chalmers, 1976). References to catch in this thesis will refer to nominal weight. From length, weight and otolith samples of the catch, the age composition by number of the catch can be determined by means of conversion tables (that is, age-length keys). [The percentage age structure by number of catches in Division 1.6 is given in Chapter 9 (see Table 9.1).]

Hake landing statistics by division are submitted to ICSEAF by all the major participating fishing nations. In the past some countries, notably South Africa, have discarded small hake, but this practice was considerably reduced by 1974. If discarding is unaccounted for in landed catch figures, nominal catch values and the proportion of the younger age groups in the catch may well be underestimated in earlier years. In an attempt to account for discarding in RSA catches, nominal catch values for Divisions 1.6 and 2.1 + 2.2 prior to 1972 were increased by 39% in accordance with a decision reached at the 1977 ICSEAF Meeting and published in ICSEAF (1978).

3.2.2 Effort data

Fishing effort is extremely difficult to quantify and control as it depends on many factors which are constantly undergoing change. These include the fleet composition, the efficiency of the various vessels and crews, and the introduction of new technology and fishing aids. The distribution of effort between various fishing grounds is also affected by factors such as distance from port, abundance of other species and their market demand.

In all divisions except Division 1.6, trawler hours are used to quantify actual effort. Trawler hours is a measure of the time during which the trawl nets are on the bottom. However, in Division 1.6, effort is measured in terms of (standard) trawler days (referring to the number of days a trawler spends on a fishing ground). Standard days is an appropriate index for Division 1.6 because little or no steaming time is involved (that is, the trawler leaves port and fishes virtually immediately) and night trawling is rare. However, its use implicitly assumes that the fraction of the day for which trawler nets are down has been constant over the history of the fishery.

The standard fishing effort of a vessel is defined as the product of its fishing power and the actual effort expended (that is, the number or hours or days it spent fishing). Fishing power is defined as the catch taken from a given density of fish per unit of fishing time (Gulland, 1969). It differs according to vessel category and gear and depends to a large extent on the characteristics of the vessel such as its tonnage and horsepower. The process of converting actual effort to standard effort will be referred to as 'standardization'. The effort data listed in Tables 3.1 - 3.4 have been standardized in this manner (that is, they are in terms of standard effort). They also refer only to 'hake-directed' effort (see discussion in Section 3.2.3).

Vessels in the hake fishery are categorized into tonnage classes as follows (ICSEAF Stat. 1984):

CODE (v)	GRT CATEGORY
2	0 - 49,9
4	50 - 149,9
5	150 - 499,9
6	500 - 999,9
7	1000 - 1999,9
8	2000 - Plus
0	Unknown
9	Research vessel

(GRT = gross registered tons).

Trawlers in the hake fishery are classified as OTB-v where OTB stands for otter trawler, bottom, and v refers to the tonnage class (as given above).

For the South African fishery, rather crude power factors were calculated during the early 1970s on the basis of the method of Beverton and Holt (1957). A hypothetical 400 GRT side trawler was allocated a power factor of 1 (that is, a South African standard hour refers to fishing effort equivalent to an hour of a 400 ton OTB-5 side trawler. For simplification of calculations, the fleet (ignoring the few very small vessels) was divided into three major categories with the following power factors allocated to each (A. Badenhorst, SFRI, pers. commn):

CODE	GRT	POWER FACTOR
F	300- 600	1,14
G	600-1000	2,00
H	± 1700	2,80

[Note that although the 300-600 GRT class includes the standard 400 ton vessel so that a power factor of 1 might be expected, a larger factor is used to allow for the fact that the mean catching power of the vessels in this group is slightly greater than that of a standard 400-ton side trawler. This average was evaluated by first assigning power factors on a finer scale from a CPUE versus GRT regression fit.]

It is evident that the above power factor allocation may not be adequate to reflect the true relative performance of the vessels in the fleet precisely; further research is needed on this topic (see Section 11.7).

A different approach has been used for Spanish effort calculations with the overall CPUE being 'standardized' first (see Section 3.2.3) and standard effort data being calculated therefrom. However, it should be noted that the standardization method adopted is at basis equivalent to that used for South African data (see Appendix 3.1) .

The combined (standard) effort of a fleet is calculated as the sum of the standardized efforts of the individual vessels assuming they have been fishing alone. Similarly total (standard) effort for the fishery is the sum of (combined) effort exerted by all the participating fleets.

However total effort data for the fisheries under consideration often cannot be compiled because few fleets have reported catch and effort statistics over the whole period of the fishery. Consequently, total effort estimates are often based on catch rate information from only one or two national series. Such catch rate values are divided into the corresponding total catches to provide total effort estimates. Biases in total effort estimates may therefore result from biases in CPUE measures, which are discussed in the following section.

3.2.3 Catch per unit effort (CPUE)

As has been mentioned above, although average annual CPUE figures should in principle be calculated from the total catch and effort statistics for the fishery, in practice CPUE is usually obtained from data from some part of the fishery, and total effort then estimated from this.

Because hake catches can form part of a multispecies fishery and trawlers may be able to direct their effort on preferred species to a certain extent, it is necessary that hake CPUE estimates be based only on that part of the fleet's fishing effort which is directed towards hake (directed effort), and the quantity of hake caught (directed catch) during that period. The catch-effort returns submitted by skippers of South African trawlers specify the species upon which they were focussing their effort, and this information is used to define 'directed' in the calculation of directed catch and effort. The Spanish operation on the other hand is entirely directed towards hake, so no adjustments of this nature are needed.

South African combined annual CPUE values are based on directed catch data and directed standard effort values (standardized to OTB-5 units by means of power factors - see Section 3.2.2):

$$\overline{(C/E)}^{S}_{i} = \frac{\sum_{v=F}^{H} C^{v}}{\sum_{v=F}^{H} Pf_{v} \, . \, E^{v}} \qquad (3.1)$$

where v refers to a particular vessel code

C^{v}_{i} is the catch of code-v vessels in the year i

E^{v}_{i} is the <u>actual</u> effort expended by code-v vessels in the year i

and $Pf_{v} . E^{v}_{i}$ is the corresponding <u>standard</u> effort in OTB-5 units.

However, in Spanish calculations, the OTB-7 category is used as the standard unit and the CPUE index for any particular year i is calculated as follows (ICSEAF, 1985b):

$$\overline{(C/E)}_i^{7} = \frac{\sum_{v=5}^{8} \left[[(C/E)_i^{v} \cdot C_i^{v}] / \bar{u}^{v} \right]}{\sum_{v=5}^{8} C_i^{v}} \cdot \bar{u}^{7} \qquad (3.2)$$

where v refers to a particular vessel OTB category ($v = 5,\ldots,8$)

$\bar{u}^{v}$ are the mean CPUE values for the OTB-v class over the years 1976 - 1981

and $(C/E)_i^{v}$ is the CPUE (in terms of <u>actual</u> effort) for the year i and OTB-v category.

It can be seen that separate CPUE indices are found for each of the different vessel categories and then, using such values in the equation (3.2), an annual catch rate (in terms of standard effort) is determined. Although this approach differs from that used for South African CPUE statistics, it is shown in Appendix 3.1 that this method is based essentially on the power factor concept.

Tables 3.1 - 3.4 list CPUE values obtained in this manner and total effort estimates based thereon. Abbreviations have been used for the effort units, namely, ESP OTB-7 t/h for the Spanish (OTB-7) trawler tons per hour and ZAF t/std day (or ZAF t/h) for the South African (OTB-5) tons per standard day (or hour) fished.

In the next chapter the method suggested by Gulland (1961) for analysis of catch-effort data will be considered. This approach may compensate to some extent for estimation errors occurring as a result of making the steady-state assumption in the production model analysis, and requires average effort values over a certain period. The basis for calculating this average effort value, f, is discussed in Chapter 4, but for convenience, the values used in the assessments that follow are listed in Tables 3.1 - 3.4 .

In order to maintain a long time series, statistics have been restricted to Spanish (OTB-7) data in Divisions 1.3 + 1.4, to pooled Spanish (OTB-7) and South African (OTB-5) data in Division 1.5, and to South African (OTB-5) data only in Divisions 1.6 and 2.1 + 2.2. In the case of Division 1.5, the 1972 CPUE values were considered to provide a valid reflection of the ratio in power factors for the dominant vessel categories in the two national fleets considered, and therefore that year was used as the reference (or base) value (ICSEAF, 1985b) in pooling the data.

In Divisions 2.1 + 2.2, although catch values for 1967 and 1968 were reported, corresponding CPUE values were unavailable. The 1967 and 1968 catch rates have been assumed as equal to the 1969 CPUE value of 1,28 because during that period the vessels were taking relatively small catches from a virtually virgin stock and any differences from this value are likely to have been small.

CPUE statistics are frequently used by fishery scientists to estimate changes in (hake) population biomass. Calculations in Chapters 4 and 5 are based on this assumption that CPUE is proportional to stock abundance, that is, $(C/E)=q.y$ where q is the catchability coefficient and y is the stock biomass.

There are many limitations and potential biases to this index of abundance. The theoretical basis for a linear relation of CPUE to abundance rests upon assumption of a uniform random distribution of fish and/or fishing effort over the whole range of fish stock. Although hake do not shoal (except occasionally at very early ages), they are often found preferentially in certain areas and hence their distribution cannot be considered to be uniform. Once one fishing vessel has detected hake in a certain area, other vessels are directed there and hence need to apply less 'effort' to catch the same quantity of fish. Therefore, although by definition effort will be correctly estimated, in reality, particularly if effort is measured in standard day units, such 'co-operative' nonrandom search can result in underestimated effort values and therefore overestimated CPUE indices (which may fail to give adequate indications of a stock decrease). On the other hand, fish may be frightened and dispersed by heavy exploitation and this would have the reverse effect.

Further, a steady increase in the fishing efficiency not properly allowed for in the power factor evaluation could lead to an increased catch without a corresponding change in the (apparent) effort values, and the population abundance would be overestimated. CPUE can also be influenced by the weather conditions (only where effort is measured in standard day units) and the behaviour of fish, so that the (C/E)=q.y relation will be subject to (random) error.

Biases in the CPUE index could also be caused by the fact that initially fishing took place near the shore, but as the fishery expanded, the vessels moved into deeper waters. If effort is measured in standard days, this would ultimately lead to an underestimation of catch rate values because proportionately more of the time away from port would have been required to steam to the fishing grounds. However, this unit of effort is only used for Division 1.6, and any bias that may exist is thought to be rather insubstantial as trawlers generally commence fishing shortly after leaving port.

Despite these possible problems, for the remainder of this thesis the assumption that the CPUE values listed in Tables 3.1 - 3.4 are proportional to the corresponding hake stock biomasses will be made (or if not, specific mention will be made of that fact).

During this chapter care has been taken always to specify whether reference to standard or actual effort is being made; however, all future references to effort in this thesis will be in the sense of standard effort.

Year	Total catch ('000 t)	CPUE (ESP OTB-7 t/h fished)	Total effort (OTB-7 hours fished)	$\bar{f}_{3y}$
1965	93,5	1,780	52 528	
1966	212,4	1,310	162 137	
1967	195,0	0,910	214 286	142 984
1968	382,7	0,960	398 646	258 356
1969	320,5	0,880	364 205	325 712
1970	402,5	0,900	447 222	403 358
1971	365,6	0,870	420 230	410 552
1972	606,1	0,720	841 806	569 753
1973	377,6	0,570	662 456	641 497
1974	313,8	0,450	697 333	733 865
1975	309,4	0,420	736 667	698 819
1976	369,8	0,420	880 476	771 492
1977	277,5	0,491	565 173	727 439
1978	258,1	0,437	590 618	678 756
1979	172,3	0,407	423 342	526 378
1980	90,5	0,450	201 111	405 024
1981	92,1	0,555	165 946	263 466
1982	176,4	0,539	327 273	231 443
1983	215,8	0,587	367 632	286 950
1984*	198,5	0,636	312 107	335 671

1984* - provisional data from CPUE values for January-June.

Table 3.1: Total catch and CPUE data, and total effort estimates obtained therefrom for the Cape hake stock in Divisions 1.3 + 1.4 .

Year	Total catch ('000 t)	Pooled CPUE index (+)	Total standard effort (+)	$\bar{f}_{3y}$
1965	99,7	2,10	47 476	
1966	122,2	2,47	49 474	
1967	199,4	1,36	146 618	81 189
1968	247,7	1,32	187 652	127 914
1969	206,2	1,08	190 926	175 065
1970	224,7	1,03	218 155	198 911
1971	229,7	1,34	171 418	193 500
1972	214,0	1,00	214 000	201 191
1973	290,3	0,94	308 830	231 416
1974	195,5	0,66	296 212	273 014
1975	178,7	0,76	235 132	280 058
1976	209,7	0,54	388 333	306 559
1977	157,7	0,65	242 615	288 693
1978	124,2	0,51	243 529	291 493
1979	130,0	0,69	188 406	224 850
1980	70,1	0,70	100 143	177 359
1981	116,4	0,84	138 571	142 373
1982	131,8	0,82	160 732	133 149
1983	123,3	0,96	128 438	142 580
1984*	121,4	1,01	120 198	136 456

1984* - provisional data from CPUE values for January-June.

(+) calculated from Spanish OTB-7 and South African OTB-5 statistics (see text)

Table 3.2: Total catch and CPUE data, and total effort estimates obtained therefrom for the Cape hake stock in Division 1.5 .

Year	Total catch ('000 t)	CPUE (ZAF t/ std day)	Total effort (ZAF standard days)	$\bar{f}$ (+) 4/3y
1955	115,4	17,31	6 667	
1956	118,2	15,64	7 558	
1957	126,4	16,47	7 675	
1958	130,7	16,26	8 038	7 484
1959	146,0	16,26	8 979	8 062
1960	159,9	17,31	9 237	8 482
1961	148,7	12,09	12 299	9 639
1962	147,6	14,18	10 409	10 231
1963	169,5	13,97	12 133	11 020
1964	162,3	14,60	11 116	11 490
1965	203,3	10,84	18 755	13 103
1966	195,0	10,63	18 344	15 087
1967	176,7	10,01	17 652	16 467
1968	143,6	10,01	14 346	17 274
1969	165,1	8,62	19 153	17 374
1970	142,5	7,23	19 710	17 715
1971	202,0	7,09	28 491	20 425
1972	243,9	4,90	49 776	32 659
1973	157,8	4,97	31 751	36 672
1974	123,0	4,65	26 452	35 993
1975	89,6	4,66	19 227	25 810
1976	143,4	5,35	26 804	24 161
1977	97,5	4,84	20 145	22 059

Table 3.3: Total catch and CPUE data, and total effort estimates obtained therefrom for the Cape hake stock in Division 1.6 .

Table 3.3 continued.

Year	Total catch ('000 t)	CPUE (ZAF t/ std day)	Total effort (ZAF standard days)	$\bar{f}_{4/3y}$ (+)
1978	101,7	5,90	17 237	21 395
1979	90,4	6,13	14 747	17 376
1980	101,5	5,50	18 455	16 813
1981	99,5	5,81	17 126	16 776
1982	85,0	5,87	14 480	16 687
1983	73,7	6,52	11 304	14 303
1984*	83,6	6,67	12 534	12 773

1984* - total South African catch + estimated foreign catch.

(+) 1955 - 1971 $\bar{f}_{3y}$

1972 - 1984 $\bar{f}_{4y}$

Year	Total catch ('000 t)	CPUE (ZAF t/h fished)	Total effort (ZAF standard hours)	$\bar{f}_{3y}$
1967	17,39	1,28(+)	13 586(+)	
1968	31,37	1,28(+)	24 508(+)	
1969	41,70	1,28	32 578	23 557
1970	27,80	1,22	22 787	26 624
1971	34,50	1,14	30 263	28 543
1972	51,40	0,64	80 313	44 454
1973	77,40	0,56	138 214	82 930
1974	100,90	0,54	186 852	135 126
1975	73,80	0,37	199 459	174 842
1976	57,70	0,40	144 250	176 854
1977	40,47	0,42	96 357	146 689
1978	42,76	0,41	104 293	114 967
1979	53,83	0,46	117 022	105 891
1980	47,57	0,44	108 114	109 809
1981	35,14	0,40	87 850	104 328
1982	46,83	0,51	91 824	95 929
1983	41,17	0,48	85 771	88 482
1984*	43,15	0,55	78 455	85 350

1984* – total South African catch + estimated foreign catch.

(+) assumed (see text)

Table 3.4: Total catch and CPUE data, and total effort estimates obtained therefrom for the Cape hake stock in Divisions 2.1 + 2.2 .

Appendix 3.1

The equivalence of Spanish pooled CPUE evaluations and a power factor formulation

In Section 3.2.3 the following formula [equation (3.2)] was given for the calculation of Spanish CPUE data:

In any particular year i,

$$\overline{(C/E)}_i^7 = \frac{\sum_{v=5}^{8} \left[[(C/E)_i^v \, . \, C_i^v] / \bar{u}^v \right]}{\sum_{v=5}^{8} C_i^v} \, . \, \bar{u}^7$$

where v refers to a particular vessel OTB category ($v = 5,\ldots,8$)

$\bar{u}^v$ are the mean CPUE values for the OTB-v class over the years 1976 - 1981

and $(C/E)_i^v$ is the CPUE for the year i and OTB-v category.

Assuming that:

(i) the CPUE corresponding to OTB-v vessels is

$$(C/E)_i^v = C_i^v / E_i^v$$ (that is, E_i^v is actual effort and does not incorporate power factor adjustments)

(ii) the power factors for OTB-v class vessels are given by

$$Pf_v = \bar{u}^v / \bar{u}^7$$

and (iii) $C_i^7 / E_i^7 = C_i^v / [Pf_v . E_i^v]$ for $v \neq 7$, or

$$C_i^v = [Pf_v . E_i^v . C_i^7] / E_i^7$$

(that is, relative catch rates of different vessel categories remain the same from year to year) it follows that in any particular year i,

$$\frac{\sum_{v=5}^{8}\left[\, [(C/E)_i^v \,.\, C_i^v\,] \,/\, \bar{u}^v \,\right]}{\sum_{v=5}^{8} C_i^v} \,.\, \bar{u}^7$$

$$= \frac{\sum_{v=5}^{8} [\bar{u}^7/\bar{u}^v].[C_i^v/E_i^v].C_i^v}{\sum_{v=5}^{8} C_i^v}$$

$$= \frac{\sum_{v=5}^{8} [1/Pf_v].[(Pf_v\,.E_i^v\,.C_i^7)/E_i^7].[C_i^v/E_i^v]}{\sum_{v=5}^{8} [Pf_v\,.E_i^v\,.C_i^7] \,/\, E_i^7}$$

$$= \frac{[\,C_i^7/E_i^7\,] \sum_{v=5}^{8} C_i^v}{[\,C_i^7/E_i^7\,] \sum_{v=5}^{8} Pf_v \,.\, E_i^v}$$

$$= \frac{\sum_{v=5}^{8} C_i^v}{\sum_{v=5}^{8} Pf_v \,.\, E_i^v}$$

which is equivalent to the formula used for the calculation of South African CPUE data [equation(3.1)]. In other words, equation (3.2) used to evaluate the pooled Spanish CPUE index is equivalent to a power factor formulation, with the power factors given by the ratio of the average catch rates of different vessel classes over the period 1976 - 1981.

4 STEADY-STATE PRODUCTION MODELS

4.1 Production models

In the next few chapters, production models using accumulated annual catch and effort data are developed as a means of explaining and understanding the past and present condition of the hake fishery and predicting its future. Of great importance is the evaluation of sustainable yields and quota levels and the effect of changes in the pattern of fishing as a result of regulatory measures. The mathematical models used for such evaluations can only be developed through an extensive analysis and understanding of the fundamental relationships between population size, fishing intensity and catch.

For the purposes of this analysis, the hake population in each particular ICSEAF division is regarded as a separate closed unit stock. The size of each stock can be described in two ways, namely, in terms of numbers or, in terms of biomass. Although some immigration and emigration must take place between the stocks, the relative magnitude of these effects is hopefully not very large and therefore these movements between the stocks have been ignored.

The stock is also affected by other inflows and outflows. Stock biomass is increased by the recruitment of new individuals to the population and the tissue growth of individuals present within the system. On the other hand, natural mortality and fishing mortality reduce stock biomass. The above dynamical effects depend on various factors such as the age and sex structure of the population and its geographical distribution, food availability, environmental variations and the stock size itself. Thus the ecosystem within which the commercial fisheries operate is complex, making the effects of fishing intensity on stock size and catch difficult to estimate.

Production models, however, ignore these individual processes, taking into account only two basic quantities, namely, the population biomass (y) and the catch (C), which are related to the fishing effort (E) and the net natural rate of increase.

It is assumed that the basic principle of density-dependent population growth applies, often enabling the species to adapt to changes in fishing intensity. Stock production models assume that for any particular set of environmental conditions, the population has a definite potential rate of increase which depends only on the existing stock size. That is, in the absence of exploitation,

$$dy/dt = f(y)$$

where dy/dt is the rate of change of population biomass and $f(y)$ is called the 'net growth rate function' or 'surplus production function'.

Simple forms of the net growth rate function must exhibit certain basic features. At low levels of stock size, the biomass growth rate is small. This rate increases with the stock level until it reaches a maximum. Thereafter it begins to decrease again until it becomes zero when the carrying capacity is reached. This limiting size is determined by factors such as the amount of space and food resources available. In this analysis two versions of the net growth rate function, $f(y)$, have been used. These forms, introduced by Schaefer (1954) and Fox (1970), are as follows:

(i) Schaefer: $f(y) = y.(1 - y/K)$ (4.1)

(ii) Fox: $f(y) = y.(1 - \ln(y)/\ln(K))$ (4.2)

[Note: If $f(y)$ is written in the form $f(y) = y.g(y)$, $g(y)$ is termed the specific rate of natural growth. In the Schaefer model $g(y)$ is a linear function of the biomass. However, for some stocks it has been observed that the data fell on a curve that was concave upward (Cadima, 1978) and in such cases the exponential Fox function may be more appropriate. The choice of $g(y)$ depends on the stock in question and a comparison of the fits of these two models to Cape hake data in Divisions 1.3 to 2.2 is made in Chapter 8.]

4.2 Equilibrium catch

Fishing has the effect of diminishing the increase in stock which would occur at the existing level of population if no fishing were taking place. Mathematically this can be expressed as:

$$dy/dt = f(y) - dC/dt \qquad (4.3)$$

where dC/dt = rate of catching which depends on the stock size, y, and the fishing effort, E.

When the rate of catching is exactly equal to the natural rate of increase (that is, $dy/dt = 0$) the stock size remains unaltered. In this case, the biomass produced over and above that which would keep the population biomass constant in the presence of natural mortality alone is regarded as a 'surplus' which can be harvested by the fishing industry. The fishery is then said to be in equilibrium for that level of population and fishing effort. The annual catch made under such conditions is called the equilibrium catch (or yield), and the size of population at which the equilibrium catch may be maximized is referred to as the MSY level. This point corresponds to the level where the absolute rate of natural growth is greatest, that is, where f(y) is a maximum. This position is given by

$$\left.\frac{df}{dy}\right]_{y=y_{MSY}} = 0 \ .$$

By controlling the amount of fishing, management can attempt to regulate the stock size, y, to produce such maximum yields.

4.3 Description of the steady-state model

Rather than the differential equation form (4.3), the discrete equivalent,

$$y_{i+1} = y_i + r.y_i.f(y_i) - C_i \qquad (4.4)$$

is used in this thesis

where y_i = biomass at the start of year i

C_i = catch in year i

r = intrinsic growth rate

and K = carrying capacity.

The steady-state (s-s) model is based on the assumption of an equilibrium situation in each year, that is,

$$y_i = y_{i+1}$$

which allows a very simple method of estimating the parameters of the model.

If it is assumed that CPUE is proportional to biomass:

i.e. $$(C/E)_i = q.y_i \qquad (4.5)$$

where q = catchability coefficient

then, in the steady-state situation, equations (4.1) and (4.2) can be rewritten in the following forms (see

Appendix 4.1):

(i) Schaefer: $(\hat{C/E}) = \alpha - \beta.E$ (4.6)

$$\text{where } \alpha = q.K \text{ and } \beta = q^2.K/r$$

(ii) Fox: $(\hat{C/E}) = \alpha'.e^{-\beta'.E}$ (4.7)

$$\text{where } \alpha' = q.K \text{ and } \beta' = (q/r).\ln(K)$$

From equations (4.6) and (4.7) formulae for MSY, E_{MSY} and y_{MSY} can be derived (see Appendix 4.2):

(i) Schaefer: $MSY = \alpha^2/4\beta$ or $r.K/4$ (4.8)

$E_{MSY} = 0,5\alpha/\beta$ or $0,5\ r/q$ (4.9)

$y_{MSY} = K/2$ (4.10)

(ii) Fox: $MSY = (\alpha'/\beta').e^{-1}$ or $r.K.e^{-1}/\ln(K)$ (4.11)

$E_{MSY} = 1/\beta'$ or $r/(q.\ln(K))$ (4.12)

$y_{MSY} = K.e^{-1}$ (4.13)

In both models the proportion of y_{MSY} to K is fixed. For the Schaefer model, MSY is attained when the population is exactly half its maximum size (K), that is K/2, whereas for the Fox model MSY corresponds to a biomass of approximately $e^{-1}.K$ ($\doteq$ 0,368K).

The Fox exponential relationship in equation (4.7) can be transformed to the following linear form:

$$\ln(\hat{C/E}) = \alpha' - \beta'.E \qquad (4.14)$$

Estimates for the parameters α, β, α', β' and thence for MSY were obtained by performing functional regressions (see Appendix 7.2) on the observed $(E_i, (C/E)_i)$ data pairs in the case of the Schaefer model and the $(E_i\ , \ln(C/E)_i)$

data pairs for the Fox model. The results of these regressions are listed in Tables 8.1 - 8.8. Estimated sustainable yield curves relating the equilibrium yield, C, to fishing effort, E, under the steady-state assumption are illustrated for Division 1.6 in Figure 4.1. Such curves give an indication of MSY as well as the sensitivity of the resource to overexploitation (that is, the extent to which sustainable yields are reduced if effort exceeds the MSY level).

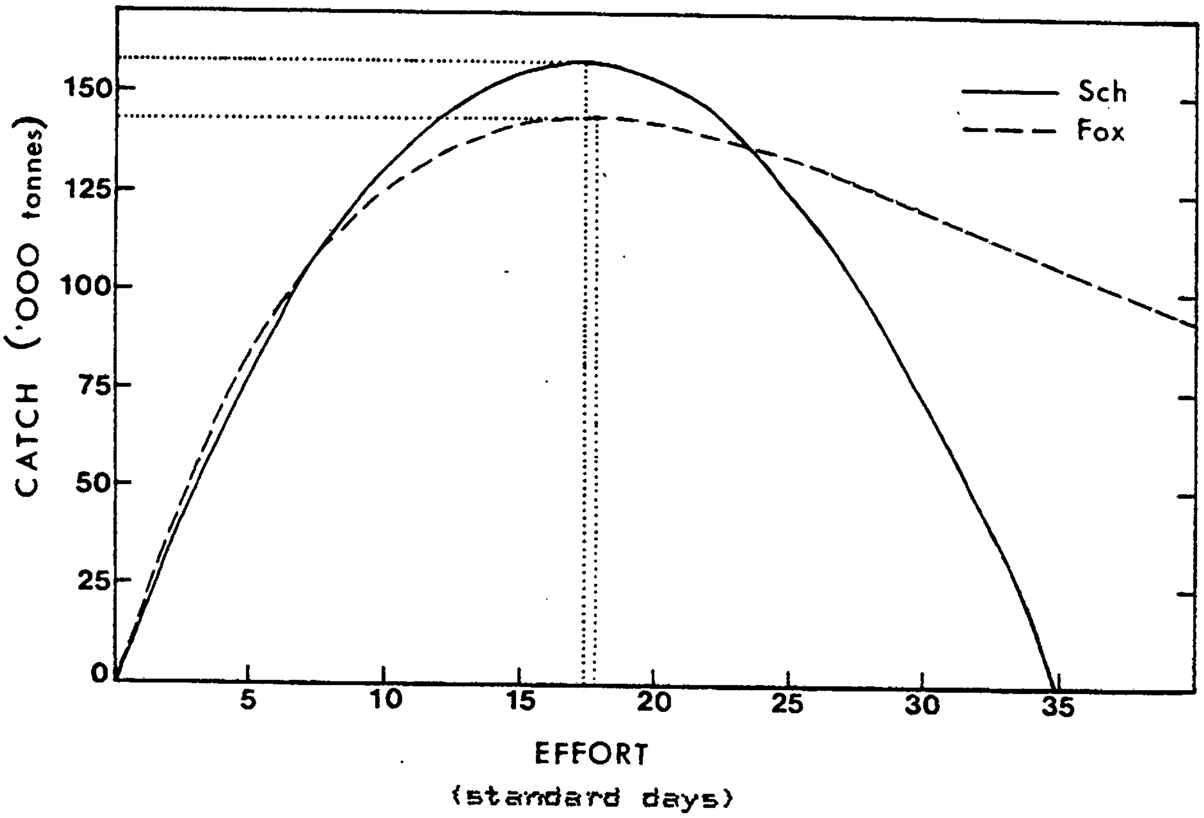


Figure 4.1: Catch-effort curves for the Schaefer and Fox models using α and β values obtained by functional regression on data from Division 1.6.

4.4 Shortcomings of the general production model

In this section some of the problems associated with stock production models and the steady-state estimation technique of the previous section are highlighted. These shortcomings have led to various modifications to the basic Schaefer and Fox models and these are discussed briefly.

The mathematics involved in the rearranging and solving of simultaneous equations to obtain equations (4.8) to (4.13) is conveniently straightforward once the steady-state assumption is made, and the need to estimate r, K , q or the stock size separately is avoided. However, in certain circumstances, this assumption can lead to the MSY and other estimates being substantially biased, as is discussed in detail in Section 4.5 . Use of positively biased MSY estimates could have dangerous consequences because constant catches above MSY will lead to extinction of the stock within a finite period.

Also the parameters estimated in the minimization (fitting) procedure (namely α, β and thence MSY) give no indication of the magnitude of parameters r and K. In other words, in the case of the Schaefer model where MSY = r.K/4, the estimated MSY could represent the combination of either a large r and small K or a small r and large K. This could have serious implications for the fishery since if r is large, a catch exceeding MSY could lead to a large biomass reduction. However, if r is small, the effect of a similar excess catch on the stock size would not be as great.

The most basic assumption of the stock production models is that the natural rate of increase of fish population is a function of the stock biomass alone (equation (4.3)). Whilst this assumption makes the model attractively simple, at the same time it implies certain assumptions about the fish population which are to some degree unrealistic and which, if the degree of departure from reality is sufficiently great, limit the usefulness of the model.

A major criticism is that such models ignore the fundamental biological processes (see Section 4.1) which increase and reduce biomass. Various authors have proposed other models which might more accurately reflect biological behaviour. For example, the most basic stock production models assume that the natural rate of increase responds immediately to changes in population density. This means that delayed effects of changes in the stock size on the natural rate of increase, such as the effects of the time lag between spawning and the recruitment into the catchable stock, are ignored.

In an attempt to correct for such time lags, Walter (1973) introduced his delay-differential equation based on the fact that the rate of change of biomass is likely to be determined by the current population and the population at some time T previously. In the simplest case, Walter considered the biomass at only one time delay:

$$g(y) = \frac{1}{y}\frac{dy}{dt} = r \,.\, [1 - a_1 . y(t) - a_2 . y(t-T)]$$

where y(t) is the current biomass

y(t-T) is the biomass at some time T previously

and r, a_1 and a_2 are constants fitted by regression.

The above is a specific example of a general limitation of the standard stock production model which is that it assumes that the natural increase in stock size is independent of the age composition of the population.

In addition, environmental factors (which affect recruitment, survival growth and catchability) can cause changes in the rate of increase that would occur under average environmental conditions. Therefore, it must be assumed in the application of these basic production models that the effect of environmental factors on recruitment, survival and growth are random (or at least they are not correlated with population changes due to changes in fishing effort), so that they are 'averaged out' in the fitting procedure. The consequences of random environmental effects for harvesting strategies based on the deterministic production model are discussed by, for example, Beddington and May (1977).

Aside from these general concerns, the specific functional forms for f(y) quoted previously (Schaefer and Fox) can be generalized. One such model is that of Pella and Tomlinson (1969) which includes both the Schaefer and Fox models as special cases. An additional parameter p is added to the functional form as follows:

$$dy/dt = r.y\,[1 - (y/K)^p].$$

By an appropriate choice of p, the yield curve can be skewed in either direction. This aspect is discussed further in Chapter 10.

Further, MSY is not necessarily the most appropriate management parameter to be estimated from a production model. It is felt by many that a fishery is an economic enterprise and that it should be analyzed as such (Gordon, 1954 and Walter, 1981). This would require the determination of a maximum economic yield as opposed to a maximum biological yield. Since future catches are worth less now than present catches, they should be accordingly discounted (Clark, 1976). Further discussion of this topic is given in Chapter 11.

4.5 The effects of a disequilibrium situation on the estimates of the steady-state model

Catch and effort statistics for the hake stocks in Divisions 1.3 to 2.2 (Tables 3.1 - 3.4) all indicate substantial declines in CPUE (and hence in biomass) over much of the history of these fisheries. In a declining stock, where the CPUE values show a downward trend with time, catches comprise not only the surplus production (sustainable yield), but also the biomass reduction. Since the steady-state assumption effectively considers the catches to be entirely net growth, one might expect MSY to be overestimated in this situation .

A justification for the direction of this bias is given in Figure 4.2 and discussed in detail in Appendix 4.3 . For a declining stock, the E_i value in an observed $(E_i, (C/E)_i)$ data pair will represent not the effort required to maintain the stock at that biomass level (and that C/E value), but the larger effort required to take the additional catch that leads to the decrease in stock biomass. In other words, it overestimates the effort required to keep the population in an equilibrium situation.

The observed data points in Figure 4.2 thus tend to be moved to the right of the true equilibrium C/E versus E relationship (line AB) and consequently, the apparent relationship (line CD) also lies to the right. In the case of the Schaefer model, MSY $(= \alpha^2/[4\beta])$ is given by half the area of the triangle formed by the line, $C/E = \alpha - \beta.E$, and the axes in Figure 4.2 . It follows, therefore, that the apparent MSY will be an overestimate of the true MSY. A similar argument holds for the Fox model (see Appendix 4.3) .

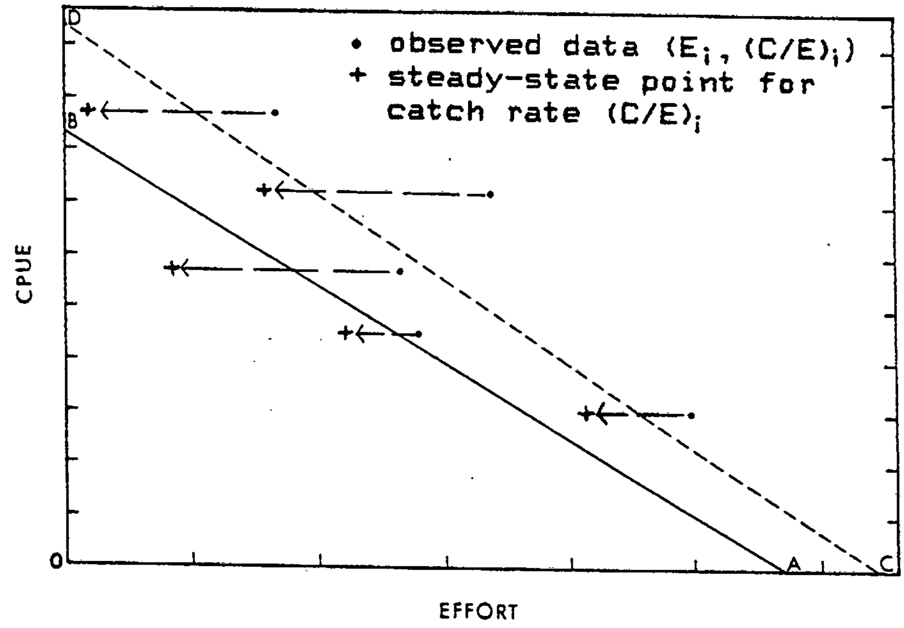


Figure 4.2

4.6 Gulland's equilibrium approximation method

A widely used method of correcting for disequilibrium is the method of effort averaging which was first outlined by Gulland (1961) and more fully explained in Gulland (1969). In any one year, the catch and CPUE will be related not only to the effort in that year, but also to the effort in several preceding years. This fact is taken into consideration by using an alternative value for effort, f, in equations (4.6) and (4.7). Gulland defined f as a moving average of the effort in the current and immediately preceding (n-1) years. That is,

$$f = (\sum_{j=1}^{n} E_{i-j+1}) / n \qquad (4.15)$$

where n is average number of years that an individual fish spends susceptible to the fishery. Gulland (1969) justifies this approach as follows:

The size of a particular year-class which has been in the fishery for n years will be determined by a factor equal to $\exp[-(\sum_{i=1}^{n} F_i)]$ where F_i is the fishing mortality in year i (i = 1,...n). This size is the same as if the year-class had been subject to a constant fishing mortality of $\sum_{i=1}^{n} F_i / n$. Therefore, the total CPUE for all ages will be related to some weighted average of the fishing effort. If this average effort, f, is taken over a period equal to the average duration of life in the exploited phase, then the relation between f and CPUE will approximate that between E and CPUE in the steady-state.

Parameters for the steady-state model are generated as in Section 4.3, but using values of f rather than E for the functional regression (see Appendix 7.2). This particular approach is termed the Gulland Functional Regression (GFR) method.

In calculating the average effort, f, for the stocks under consideration in this thesis, the period n was taken to be 3 for all divisions except Division 1.6 . For this latter division, the choice of n was based on the percentage catch-at-age structure (by number) given in Table 9.1. Exploited age groups were taken to be those contributing more than 10% by numbers to the total catch. Evaluation of the mean number of exploited age groups shows a reduction from 4 (for the period 1967-1972) to 3 (for the period 1973-1984), even though an associated decrease in the age at first capture had also occurred. Although this justifies a value of n = 4 until 1973 and 3 thereafter, for the purposes of this analysis it was decided to keep the analysis procedure consistent with that used previously by the Sea Fisheries Research Institute (Cape Town) and n was taken to be 4 until 1971 and 3 for the rest of the data series.

The initial decline in CPUE in a fishery is usually associated with a period of increasing effort. Similarly, increases in CPUE occur following effort reduction programmes. Even if no relationship exists between catch and the measure of effort (E) used, the procedure of regressing (C/E) against E can also lead to spurious relationships. This is because E is contained in both variables, and so there is an inevitable tendency towards negative correlation. Originally it was thought that by increasing the number of years in the moving average for effort as in Gulland's approach, such an effect would be nullified. However, Roff and Fairbairn (1980) show that any improvement may well be destroyed by false relationships caused by high positive serial correlations of effort with time (as when the fishery developed) and by negative correlations of catch rate with time (as when stock size numbers were reduced). Therefore, the steady-state assumption, even in a time-average sense, can lead to biased results in the sustainable yield curve estimation.

4.7 Concluding remarks

If the assumptions underlying the production model adequately describe the actual laws under which the fishery operates, then the data of a commercial fishery should be well fitted by the model. However, in reality, fish stocks are unlikely to behave exactly as indicated by the simple models described in this chapter. Even unexploited hake stocks are subject to continual changes over time which can cause fluctuations in stock size and age composition which, in turn, directly affect recruitment, natural mortality and growth rates. The importance of such variations will depend on their magnitude and the size structure of the stock.

In addition, it has been shown that analysis on the basis of the steady-state approximation of an exploited stock that is not in (or close to) equilibrium over its history can render biased results. These could deviate so widely from the actual values for the stock that it would become dangerous to manage a fishery using these results. To compensate for such biases, modifications to the estimation procedure that allow the steady-state assumption to be avoided have been introduced. These are discussed in detail in Chapter 5.

Appendix 4.1

Derivation of the Schaefer and Fox models

(i) Schaefer model:

The rate of change of biomass with respect to time can be related to the growth and catch rates by the following relation (see equation (4.3)):

$$dy/dt = r.y.(1-y/K) - dC/dt .$$

The steady-state assumption, $dy/dt = 0$, implies

$$dC/dt = r.y.(1-y/K)$$

i.e. equilibrium yield is reached when the catch and biomass growth rates are equal.

By integrating over a one-year interval, (0,1), and assuming y to be constant throughout this period, the catch, C, is given by:

$$C = r.y.(1-y/K) \tag{A4.1.1}$$

Assuming $(C/E) = q.y$, the substitution of $y = (C/E)/q$ into equation (A4.1.1) yields the following expression for (C/E):

$$(C/E) = q.K - (q^2.K/r).E .$$

This can be simplified to

$$(C/E) = \alpha - \beta.E \qquad \text{where } \alpha = q.K$$

$$\text{and} \quad \beta = q^2.K/r$$

(ii) Fox model:

As in (i), an expression for C can be obtained:

$$C = r.y.(1-\ln(y)/\ln(K)) \tag{A4.1.2}$$

By substituting $y = (C/E)/q$ into equation (A4.1.2),

$$(C/E) = q.K.e^{-(q/r).\ln(K).E} .$$

This can be written as

$$(C/E) = \alpha'.e^{-\beta'.E} \qquad \text{where } \alpha' = q.K$$

$$\text{and} \quad \beta' = (q/r).\ln(K).$$

Appendix 4.2

Derivation of MSY values

(i) **Schaefer model**:

(a) Equation (4.6), $C/E = \alpha - \beta.E$, can be rewritten as

$$C = \alpha.E - \beta.E^2 \tag{A4.2.1}$$

Differentiating the above gives $dC/dE = \alpha - 2\beta.E$ and hence the effort value needed to obtain MSY can be evaluated:

$$dC/dE = 0 \Rightarrow E_{MSY} = \alpha/(2\beta) \tag{A4.2.2}$$

$$= r/(2q) \tag{A4.2.3}$$

since $\alpha = q.K$ and $\beta = q^2.K/r$.

(b) By substituting this value for E_{MSY} into equation (A4.2.1),

$$C_{MSY} = \alpha^2/(4\beta) \tag{A4.2.4}$$

$$= r.K/4 \tag{A4.2.5}$$

(c) The differentiation of equation (A4.1.1),

$$C = r.y.(1 - y/K)$$

gives $dC/dy = r.(1 - 2y/K)$.

$dC/dy = 0$ when $y = K/2$ and hence MSY occurs when

$$y_{MSY} = K/2 \tag{A4.2.6}$$

(ii) <u>Fox model</u>:

(a) From equation (4.7), $C/E = \alpha'.e^{-\beta'.E}$,

it follows that $C = \alpha'.E.e^{-\beta'.E}$ (A4.2.7)

By a process similar to the one for the Schaefer model,

$$dC/dE = \alpha'.e^{-\beta'.E}.[1 - \beta'.E] .$$

Sustainable catch is maximized when

$$E_{MSY} = 1/\beta' \quad (A4.2.8)$$

$$= r/(q.\ln(K)) \quad (A4.2.9)$$

since $\alpha' = q.K$ and $\beta' = q.\ln(K)/r$.

(b) By substitution into equation (A4.2.7),

$$C_{MSY} = (\alpha'/\beta').e^{-1} \quad (A4.2.10)$$

$$= [r.K/\ln(K)].e^{-1} \quad (A4.2.11)$$

(c) Differentiating equation (A4.1.2),

$$C = r.y.(1-\ln(y)/\ln(K))$$

gives $dC/dy = r.[\ln(K)-1-\ln(y)]/\ln(K)$.

$$dC/dy = 0 \Rightarrow \ln(y) = \ln(K) - 1$$

and therefore $y_{MSY} = K.e^{-1}$ (A4.2.12)

Appendix 4.3

An example showing how bias arises in the estimation of MSY for a fishery with a declining biomass if the continuous equilibrium approximation is made

(i) Schaefer model:

The equilibrium CPUE versus E relationship is given by $(C/E) = \alpha - \beta.E$. In the continuous equilibrium approximation the parameters α and β can be obtained by linearly regressing the observed (C/E) values against E. For a declining stock (induced by exploitation), the E_i value in an observed $(E_i , (C/E)_i)$ data pair will represent not the steady-state effort required to maintain the stock at that biomass level and that CPUE value, but the larger effort which is required to take the additional catch that leads to the biomass decrease. The associated steady-state (s-s) effort values are calculated using the procedure described below.

Let C_i^{obs} = observed catch in year i

E_i^{obs} = observed effort in year i

and $(C/E)_i^{obs}$ = observed CPUE in year i.

Assuming (i) $y_{i+1} = y_i + r.y_i.(1 - y_i/K) - C_i^{obs}$

and (ii) $(C/E)_i^{obs} = q.y_i$, (see Note (1))

it follows

$$(C/E)_{i+1}^{obs} = (C/E)_i^{obs} + r.(C/E)_i^{obs}.[1-(1/\{q.K\}).(C/E)_i^{obs}] - q.C_i^{obs} .$$

This can be rewritten as

$$(C/E)_{i+1}^{obs} = q.K-(q^2.K/r).[E_i^{obs} + \{[(C/E)_{i+1}^{obs} - (C/E)_i^{obs}]/(C/E)_i^{obs}\}]$$

Since $(C/E)_{i+1}^{obs} = q.K - (q^2.K/r).E_i^{s-s}$ (see equation(4.6)) it can be deduced that

$$E_i^{s-s} = E_i^{obs} + [1/q].[\{(C/E)_{i+1}^{obs} - (C/E)_i^{obs}\}/(C/E)_i^{obs}]$$

(see Note (2)).

True E values were estimated for Divisions 1.3 + 1.4 for the period 1971 to 1975 and are shown in Figure A4.3.1 . The value of q used corresponds to the q value of 0,000466 given by the dynamic Schaefer model fit to the data in Divisions 1.3 + 1.4 (see Table 8.1).

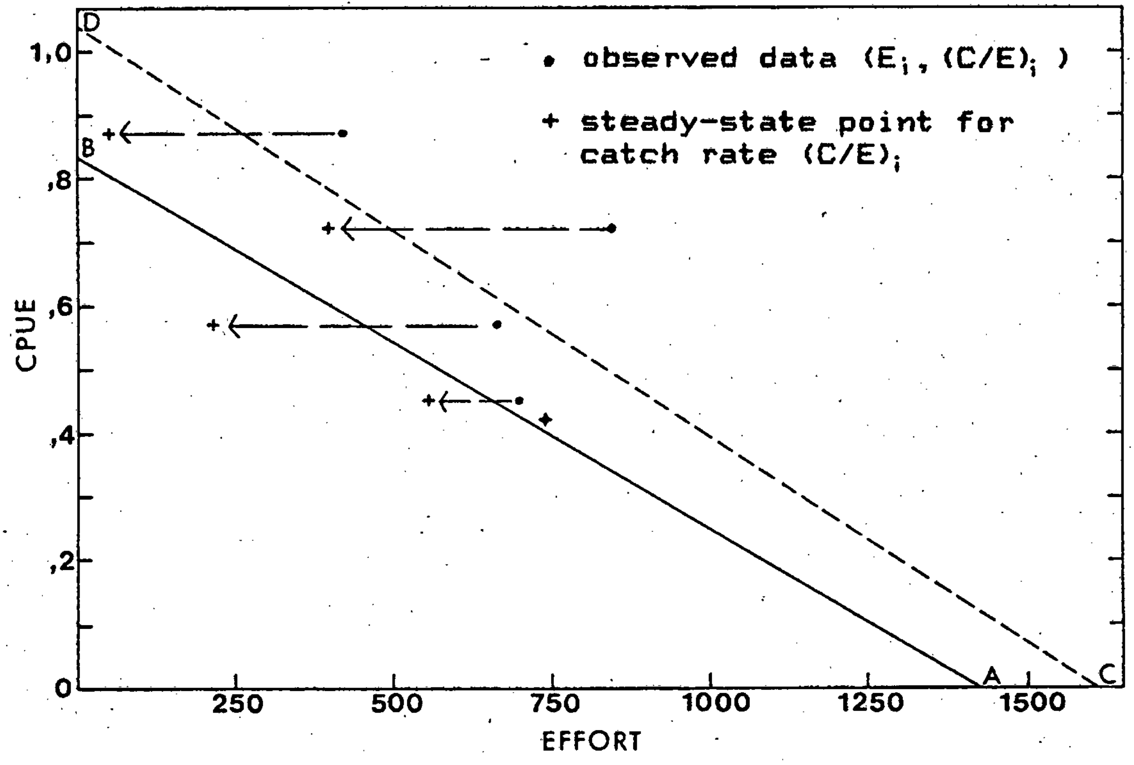


Figure A4.3.1: A plot of the steady-state (solid line) and the apparent (dashed line) C/E versus E relations for the Schaefer model obtained by linearly regressing the (E,(C/E)) data pairs for Divisions 1.3 + 1.4 for the period 1971 to 1975.

The observed $(E_i, (C/E)_i)$ data pairs tend to be moved to the right of the steady-state values and similarly, the apparent C/E versus E relationship (line CD) also lies to the right of the steady-state relationship (line AB).

Referring to the results in Figure A4.3.1, it can be seen that since

(i) MSY $= \alpha^2/(4\beta)$

and (ii) area of triangle OAB = 0,5 OA.OB $= \alpha^2/2\beta$,

it follows that MSY = (area OAB)/2 .

If the observed values for effort are used, the apparent MSY (= 0,5 x area OCD) will be an overestimation of the true MSY. The data under consideration yielded an apparent MSY estimate of 418 thousand metric tons which, as expected, was much higher than the unbiased MSY estimate of 297 thousand metric tons for that data set.

(ii) <u>Fox model</u>:

The CPUE versus effort relationship, $C/E = \alpha'.e^{-\beta'.E}$, can be rewritten as $\ln(C/E) = \ln(\alpha') - \beta'.E$ where α' and β' are estimated using a linear regression on the observed $(E_i, \ln(C/E)_i)$ data pairs.

As in the case of the Schaefer model in (i), the steady-state effort values were calculated on the basis of the assumptions:

$$\text{(i)}\quad y_{i+1} = y_i + r.y_i.[1-\ln(y_i)/\ln(K)] - C_i^{obs}$$

and (ii) $(C/E)_i^{obs} = q.y_i$ (see Note (1)).

It follows that

$$(C/E)_{i+1}^{obs} =$$

$$((C/E)_i^{obs} + r.(C/E)_i^{obs}.(1-\ln[\{(C/E)_i^{obs}/q\}]/\ln(K)) - q.C_i^{obs}$$

which can be rewritten as

$$\ln[(C/E)_{i+1}^{obs}/q] =$$

$$\ln(K)-[q.\ln(K)/r].[E_i^{obs}+(\{(C/E)_{i+1}^{obs}-(C/E)_i^{obs}\}/(C/E)_i^{obs})/q]$$

and hence

$$(C/E)^{obs}_{i+1} =$$

$$q.K.\exp\{-(q.\ln(K)/r).[E^{obs}_{i} + [\{(C/E)^{obs}_{i+1} - (C/E)^{obs}_{i}\}/(C/E)^{obs}_{i}]/q]\}.$$

Since $(C/E)^{obs}_{i+1} = q.K.\exp[-(q.\ln(K)/r).E^{s-s}_{i+1}]$

(see equation (4.7))

it can again be deduced that

$$E^{s-s}_{i} = E^{obs}_{i} + [1/q].[\{(C/E)^{obs}_{i+1} - (C/E)^{obs}_{i}\}/(C/E)^{obs}_{i}]$$

(see Note (2)).

True E values for Divisions 1.3 + 1.4 (1971-1975) were estimated by the above procedure using the q value of 0,000407 given by the dynamic Fox model fit to the data for that region (see Table 8.2).

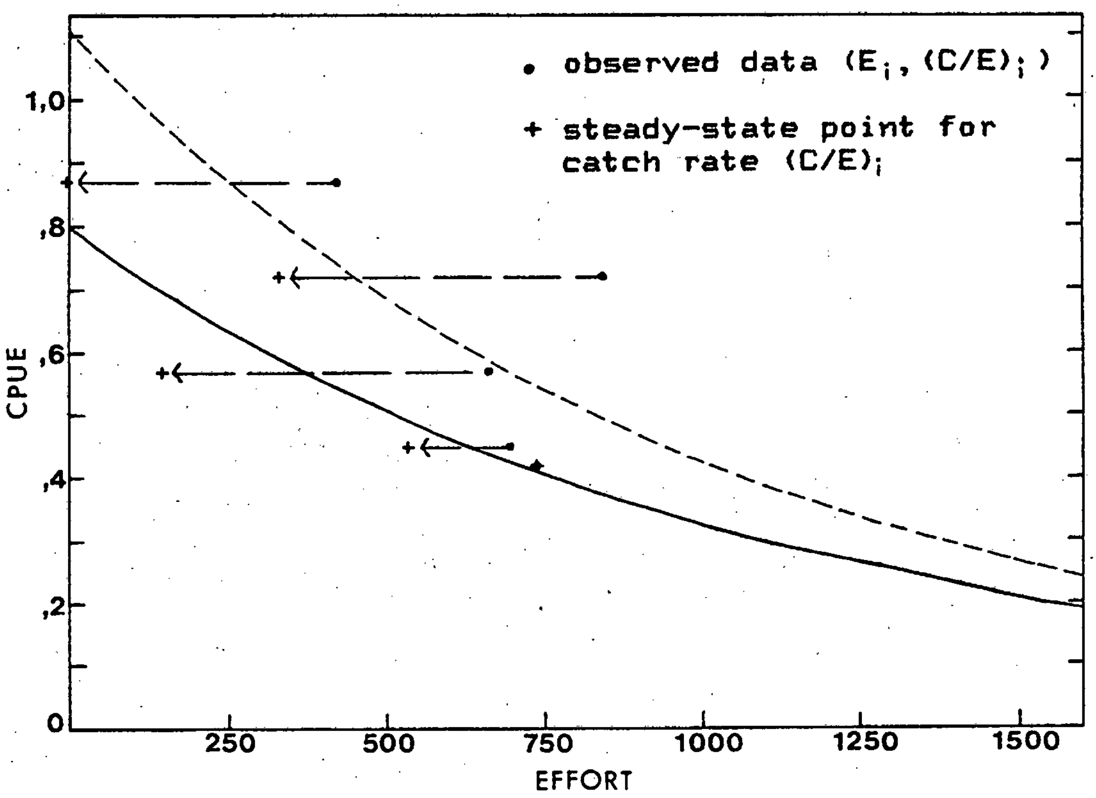


Figure A4.3.2: A plot of the steady-state (solid line) and the apparent (dashed line) C/E versus E relations for the Fox model for Divisions 1.3 + 1.4 for the period 1971-1975.

Referring to Figure A4.3.2 it can be seen that since

$$\text{(i)} \quad MSY = (\alpha'/\beta').e^{-1}$$

and (ii) area under the curve $= \int_0^A \alpha'.e^{-\beta'.E} dE$

$$= -(\alpha'/\beta').[e^{-A.\beta'} - 1]$$

$$= \alpha'/\beta' \quad \text{as } A \to \infty \quad ,$$

it can be deduced that $MSY = e^{-1}$ X (area under the curve).

($e^{-1} \doteq 0,368$).

Hence, the observed effort values cause MSY to be overestimated. This was confirmed by an analysis of data from Divisions 1.3 + 1.4 (1971-1975). The unbiased MSY value yielded was 326 thousand metric tons as opposed to an apparent MSY of 427 thousand metric tons.

Correspondingly, for a stock where the biomass is increasing because catches are below sustainable yields, points on the (E,(C/E)) plot would tend to lie to the left of the steady-state relationship and MSY would be underestimated.

Note (1) For algebraic simplicity, this form of the CPUE proportional to biomass assumption is used. It differs slightly from the form utilized for the dynamic models in Chapter 5, namely,

$$(C/E)^{obs}_i = q.(y_i + y_{i+1})/2 .$$

Note (2) Due to statistical fluctuations a negative E^{s-s} value may occur.

5 DYNAMIC MODELS

5.1 Introduction

Although the assumption of an equilibrium situation makes the steady-state model very simple and easy to apply, it can lead to positively biased results if CPUE results show a declining trend with time. In this chapter, dynamic models which allow for the non-equilibrium nature of the data are developed.

One such model used by ICSEAF has been constructed by Lleonart, Salat and Roel (1985). It is based on the catch-effort equation and introduces a new parameter inertia to represent the stock's resistence to adapt to a new exploitation pattern. The method is described briefly in Appendix 5.1 and the results are compared with those of the dynamic model developed below.

5.2 Description of the dynamic model used

The dynamic model is based on the same equations as the steady-state model in Chapter 4. That is,

$$y_{i+1} = y_i + G(y_i) - C_i \qquad (5.1)$$

where $G(y_i)$ is the net growth function of the form:

(i) Schaefer: $G(y) = r.y.(1-y/K)$ (5.2)

(ii) Fox: $G(y) = r.y.(1-\ln(y)/\ln(K))$ (5.3)

[Note that in the case of the Fox model, $(1/y).G(y)$ diverges as $y \rightarrow 0$ and therefore r may no longer be interpreted as an intrinsic growth rate.]

If $G(y_i) = C_i$, the fishery would be in equilibrium and the models discussed in Chapter 4 would be applicable. However, in a heavily exploited fishery this is unlikely to be the case as the losses due to fishing will exceed the net growth.

It is assumed that the expected catch rate, $(\hat{C/E})$, is proportional to the mid-year biomass:

$$(\hat{C/E}) = q.(y_i + y_{i+1}) / 2 \qquad (5.4)$$

For the steady-state formulations, sustainable yield curves were determined by equations (4.6) and (4.7) where α, β, α' and β' were obtained using functional regressions on catch and effort data.

For comparative results from the dynamic model, these parameters of the sustainable yield curve were obtained using the following relations (see Appendix 4.1).

(i) Schaefer: $\alpha = q.K$ $\qquad \beta = q^2.K/r$ (5.5)

(ii) Fox: $\alpha' = q.K$ $\qquad \beta' = q.\ln(K)/r$ (5.6)

5.3 Criteria used for obtaining the 'best' fit

Using the above model, it was necessary to provide catch limit recommendations which were based on only the 'best' estimates of the parameters involved. The aim, therefore, was to determine parameters (for example, r, K and q) such that the observed catch-effort data 'best' fit the values predicted by the model.

This was achieved using the NAG routine, E04FDF, which determines the unconstrained sum of squares minimum of m continuous nonlinear functions of n parameters. The problem can be expressed as follows:

If m = number of years in the data series

n = number of parameters ($n < m$)

and $\underline{X} = (X_1, X_2, ..., X_n)^T$

where X_i are the parameters to be estimated, then

$$\text{minimize } SS = \sum_{i=1}^{m} [f_i(\underline{X})]^2 \qquad (5.7)$$

(The functions $f_i(\underline{X})$ are termed residuals).

The routine requires that the user specifies the sum of squares function, SS, and initial estimates for the parameter values. From these a sequence of points is generated which is intended to converge to a local (and hopefully a global) minimum of SS.

The criterion adopted for determining the 'best' fit by the model to the observed catch and effort data was based on an approach proposed by Kirkwood (1981). On the basis of a model similar to that of Poisson-distributed catches (for which the square root transformation ensures asymptotic normality), he suggested that an appropriate choice for the residual function would be:

$$f_i(\underline{X}) = [\sqrt{C_i} - \sqrt{\hat{C}_i}] \tag{5.8}$$

Since annual variation is most easily conceptualized in terms of catch rate, this residual function has been recast in that form. This involves a weighted difference between square roots of observed and expected catch rates (the weighting is related to the effort applied):

$$f_i(\underline{X}) = \sqrt{E_i} \cdot (\sqrt{C/E_i} - \sqrt{(\widehat{C/E})_i}) \tag{5.9}$$

This residual is also used as the basis to estimate the coefficient of variation in subsequent analyses (see Chapter 7).

5.4 Specification of variables

Initial runs of the minimization routine used the parameters r, q and K. However, estimates of r were observed to be positively correlated with those of q and negatively correlated with those of K. The replacement of these original parameters with the parameters r, α (= q.K) and MSY (MSY = r.K/4 for the Schaefer model and MSY = $r.K.e^{-1}/\ln(K)$ for the Fox model) proved to be more appropriate.

To maintain a small number of parameters it was also assumed that the stock was at carrying capacity level (y_1 = K) at the start of the data series (that is, assuming little exploitation of the fishery prior to this date). For Divisions 1.3 + 1.4, 1.5 and 2.1 + 2.2 this assumption appears to be well founded since the data series used for this analysis commence only a few years after fishing in these regions began (see Tables 3.1, 3.2 and 3.4). Also, during those initial years of expansion of the fishery, catches were relatively small. On the other hand, for Division 1.6, this assumption may be more questionable since it is known that substantial trawls were being made prior to the start of the data series (see Tables 2.1 and 3.3).

The assumption y_1 = K does avoid the domain y > K where the behaviour of the surplus production function, G(y), is unsatisfactory in certain respects (see Chapter 10). If y_1 is unconstrained, the sharp decline in CPUE values for the first few years of each data series results in the fitting procedure assuming values of y_1 greater (and sometimes much greater) than K to take advantage of the unrealistically large negative values of G(y) in that domain. However, the rapid drop in CPUE values for the initial few years of each data series does not necessarily represent a proportional reduction in the stock size. Rather, it is suspected that large initial CPUE values (with smaller fisheries at that time) may be reflections of first fishing out some localized high density concentrations.

Therefore y_1 was fixed essentially to prevent it from exceeding K. Alternatively (as is investigated in Chapter 10), y_1 could have been freed and a semi-arbitrary number of data values at the start of the data series dropped.

Even in the absence of fishing, a stock will not necessarily be either at the instantaneous or average K level at any particular time. For example, random environmental fluctuations can cause variations in K. However, the above approach assumes that such variation is small compared to the substantial reduction in stock size over the course of the fishery.

5.5 Discussion

In constructing the above dynamic model, a compromise between realism and precision had to be reached. The above models could be made more complex by introducing additional parameters, however usually this leads to other problems. Using the CPUE data to fit additional parameters would probably lead to less predictive precision. Alternatively, other parameters could be introduced if their values were estimable from different independent data sets, but such data are not available.

As discussed in Section 2.3, the function of fisheries scientists is often to provide scientific advice for management with the objective of ultimately maximizing yield without impairing future exploitation of the fishery. It is therefore of interest to use the steady-state and dynamic models (in Chapters 4 and 5) to effect such management objectives so that management recommendations can be made according to fixed scientific procedures. In Chapter 6 such procedures are developed and the problems which are frequently encountered by fisheries management are described.

Appendix 5.1

An alternative dynamic model developed by Lleonart, Salat and Roel (1985)

Dynamic models can be described as models 'with a memory' in the sense that they take into consideration the more or less recent history of the fishery to explain the current situation. One such dynamic model has been developed by Lleonart, Salat and Roel (1985). It is based on the discrete form of the classical equilibrium production model, but requires the introduction of a new parameter called 'inertia' which provides for the abovementioned memory by representing the stock's resistance to adapt to a new exploitation level. A stock with 0 inertia would always be in equilibrium whereas a stock with inertia of 1 remains constant irrespective of changes in the exploitation pattern (Lleonart <u>et</u> <u>al</u>., 1985).

The traditional steady-state model assumes the equilibrium situation (inertia = 0) for fitting the curve, but uses the assumption that CPUE is constant (equivalent to an inertia of 1) for quota calculation. The dynamic model of Lleonart <u>et</u> <u>al</u>. uses the same inertia values for fitting the curve and for obtaining projections for quota estimation.

It is assumed that the annual catch and effort data are not in equilibrium and do not lie on the equilibrium curve. Schaefer and Fox model fits are calculated by means of a linear functional regression on CPUE versus effort data, adopting estimates for α, β and the inertia parameter which provide the closest fit to the data (that is, the fit with the highest correlation coefficient).

The results of the model presented by Lleonart <u>et</u> <u>al</u>. for ICSEAF Divisions 1.3 + 1.4 and Division 1.5 are compared with those of the dynamic model of equation (5.1) [termed the Butterworth/Andrew model] in Table A5.1.1 .

The attraction of this dynamic approach is that it needs only three parameters and it is conceptually easy to understand and apply to the data (Lleonart <u>et</u> <u>al</u>., 1985).

DIVISION METHOD	1.3 + 1.4		1.5	
	Q_{MSY}(85)	$Q_{0,1}$ (85)	Q_{MSY}(85)	$Q_{0,1}$ (85)
Butterworth/Andrew a) Schaefer b) Fox	 266 324	 239 253	 187 213	 168 166
Lleonart <u>et</u> <u>al</u>. a) Schaefer b) Fox	 298 309	 277 259	 173 165	 164 146

Table A5.1.1 Catch level estimates for hakes in ICSEAF Divisions 1.3 + 1.4 and 1.5 (ICSEAF, 1985b).

6 A BASIS FOR MANAGEMENT RECOMMENDATIONS

6.1 Introduction

Management is the process of making decisions relating available resources to desired objectives (ACMRR, 1980). It is often a complex undertaking involving the pursuit of varied and sometimes conflicting objectives - biological, economic, social, political and otherwise.

Effective fishery management depends on an accurate definition of the limits of the resource. However, this is not an easy condition to fulfil since the reaction of the fish stocks to exploitation and management is difficult to predict with great precision.

Despite this fact, the fishery management process is structurally the same as other forms of management. It consists of the following activities: the setting of objectives, the definition of boundaries, the collection of data, the transformation of data into information, the formulation and execution of policies and the evaluation of results.

Any exploited fish stock forms part of a complex ecosystem which is continuously changing as a result of many factors. Only one of these factors, predation by man, can be controlled to any significant degree by fishery management. If such control is possible at all, it must be implemented through control of the activities of the fishermen.

Fisheries policies are therefore designed to regulate fishing so as to effect changes in the fish population and/or catch. These changes should be preferable to those obtained if fishing took place without the intervention of management. In general, a 'preferable' fishing pattern is difficult to determine quantitively or objectively as it is a function of a great many factors.

Agreement on quota levels is often more easily reached if it is based on objective scientific advice about the state of the fish stocks. This is usually provided by fisheries biologists. To understand how such regulations can influence fish population size and yield, the outcome of changes in the intensity of fishing on the fish population (and vice versa) must be examined. This analysis is usually performed in quantitative terms. Projection models are useful in this respect as results of different fishing strategies can easily be compared. In addition, such models can help clarify the steps that are needed to attain certain objectives.

If production models (see Chapter 4) are to be suitable for management they should be easily understandable to decision makers and should realistically describe and predict to an acceptable degree of precision events surrounding the particular fish stock concerned. In addition they should make low demands in data and analysis (Gulland and Boerema, 1973). Both the steady-state and dynamic models described in Chapters 4 and 5 satisfy this condition in that they require only catch and effort data for their implementation. These are relatively easy and cheap to obtain as opposed to biological data (such as catch-age structure, natural mortality rates, growth rates etc).

6.2 Choice of a suitable management objective

Effective management necessitates the establishment of clear objectives. To achieve such objectives, regulations must be introduced which should be kept as simple as possible so as to be both efficient and enforcible.

A common and traditional objective of management has been the biological one of MSY, that is, the greatest yield that can be removed from a stock each chosen time period (usually taken to be one year) without impairing the capacity of the resource to renew itself. Thus MSY has been used as a reference point for management purposes to describe the maximum potential productivity of a stock in terms of catch and is usually associated with an exploitation policy, f_{MSY}, that is required to hold the stock at that level of productivity (ACMRR, 1980).

Production models are therefore mostly concerned with estimating MSY, the associated steady-state fishing effort and the corresponding stock biomass, y_{MSY} (in terms of a relative if not absolute index). If the fish stock has been driven below this biomass level associated with MSY, then, by limiting the fishing intensity, average catch rates can be increased and the stock returned to MSY level.

Objectives must also be realistic. During early stages in the development of a fishery, as the fish population is reduced from its initial size, the catch may rise well above the MSY level. However, this initial period during which surplus catches are available cannot continue indefinitely. Once it is over, such surplus catch will no longer be available and it is unlikely that the fishery will ever be restored to the maximum historical levels of production.

MSY is, however, not necessarily the best management objective. A major problem of its use as a management criterion is that often MSY estimates are blindly accepted as being correct without taking into account the assumptions made to reach those estimates. The steady-state and dynamic models described in previous chapters offer a simplified description under average conditions of events occurring in the sea. In reality, the situation is far more complex. MSY is therefore not a static parameter as often it is assumed to be. In fact it is as dynamic in nature as the fish populations it attempts to estimate (ACMRR, 1980).

There are many sources of stock size variation other than exploitation. The most important of these is environmental perturbation which causes variations in recruitment. Since adverse environmental conditions can cause large reductions in stock biomass, biologists would choose to manage the stock at some catch (or effort) level below the level associated with MSY so as to keep the stock somewhat above its MSY level and to reduce the probability of a collapse of the resource.

Gulland and Boerema (1973) present a method to choose such a level which is easy to apply and furthermore, which does not differ too radically from MSY. This '$f_{0,1}$' procedure is described in section 6.3.1(iii). Another advantage of this method is that in a steady-state context (that is, ignoring dynamic effects and discounting), the corresponding effort level $E_{0,1}$ differs from E_{MSY} in the direction of the effort level associated with maximum profit (Clark, 1976). Therefore often $E_{0,1}$ represents a greater profit than would E_{MSY}. This feature of the model will be discussed further in Chapter 11.

In the following section, the formulae for three different management strategies are developed; the results of these applied to the hake stocks under consideration for the years following 1984 are listed in Tables 8.1 - 8.8 .

6.3 Catch limit recommendations

All catch limit recommendations have been based on the following prescription as indicated in ICSEAF (1983b):

$$Q = (\hat{C/E}).\hat{E}_t \qquad (6.1)$$

where Q = the catch limit for a particular harvesting strategy, for example, Q_{MSY} (corresponding to an 'f_{MSY}' strategy)

$\hat{E}_t$ = corresponding estimate of effort (that is, target effort) for the selected objective, for example, E_{MSY} for an MSY objective and $\widehat{(C/E)}$ = estimate of expected CPUE for the year for which the catch limit is to be set.

Three possible forms of catch limit recommendations are described for both the steady-state (s-s) and dynamic models. They are as follows:

(i) the catch that would maintain the stock at its present (1985) biomass, Q_{s-s}

(ii) the catch that would eventually result in the harvesting of the maximum sustainable yield, Q_{MSY}

(iii) the catch advocated by the $f_{0,1}$ procedure, $Q_{0,1}$ (see Section 6.3.1(iii))

In this analysis the following notations have been used:

$x = x_{obs}$, the observed value of x

$E(x) = x_{exp}$, the expected (true) value of x which is never known

$\hat{x} = \hat{x}_{exp}$, the estimate of the expected value of x.

Sometimes x is used to denote E(x). Where possible confusion may arise, the alternative notations x_{obs} and x_{exp} are used to differentiate between the two variables.

6.3.1 Steady-state models

In the case of the steady-state models, average effort values as prescribed by Gulland have been used (see equation (4.15)). The expected catch rate, $\widehat{(C/E)}$ is assumed to be the same as that of the most recent year (1984), $(C/E)^{*}_{obs}$. This principle has been applied by the Standing Committee for Stock Assessment of the ICSEAF Scientific Advisory Council in the past (ICSEAF, 1984a).

Using equation (6.1), values for Q_{s-s}, Q_{MSY} and $Q_{0,1}$ can be calculated:

(i) $Q_{s-s} = (C/E)^*_{obs} . E_{s-s}$ and therefore

(a) Sch: $$Q_{s-s} = (C/E)^*_{obs} . (1/\beta) . [\alpha - (C/E)^*_{obs}] \qquad (6.2)$$

where E_{s-s} was calculated using f^* in the steady-state relation: $(C/E)^* = \alpha - \beta . f^*$

(b) Fox: $$Q_{s-s} = (C/E)^*_{obs} . (-1/\beta') . \ln[(1/\alpha') . (C/E)^*_{obs}] \qquad (6.3)$$

where calculations of E_{s-s} were based on the relationship: $(C/E)^* = \alpha' . e^{-\beta' . f*}$

(ii) $Q_{MSY} = (C/E)^*_{obs} . E_{MSY}$ and therefore

(a) Sch: $$Q_{MSY} = (C/E)^*_{obs} . [0,5 \alpha / \beta] \qquad (6.4)$$

(b) Fox: $$Q_{MSY} = (C/E)^*_{obs} . [1/\beta'] \qquad (6.5)$$

(iii) The marginal yield, dC/dE, is defined as the increase in total yield achieved by adding one extra unit of effort. In other words, it is the slope of the tangent to the curve of catch against effort (Gulland, 1968). From the catch-effort equations given in equations (4.6) and (4.7) it can be seen that the marginal yield is a decreasing function of effort, with a maximum at the virgin stock (zero effort) position and decreasing to zero at the level where MSY is attained. The $f_{0,1}$ policy as described by Gulland and Boerema (1973) is to fish at an effort level where the marginal yield is one tenth of the value of dC/dE at the origin. As can be seen from Figure 6.1, this effort level will be less than that corresponding to MSY. The equilibrium catch level corresponding to this strategy, $C_{0,1}$ and the constant level of effort, $E_{0,1}$, applied under this strategy are derived in Appendix 6.1. They are as follows:

(a) Schaefer:

$$E_{0,1} = 0,9\ E_{MSY}$$

$$= 0,9\ [\alpha/2\beta] \qquad (6.6)$$

$$C_{0,1} = 0,99\ (\alpha^2/4\beta) \qquad (6.7)$$

$$= 0,99\ C_{MSY}$$

(i.e. the expected catch under such a strategy once equilibrium is reached would be 99% of the MSY)

(b) Fox:

$$E_{0,1} \doteq 0,782\ E_{MSY} \qquad (6.8)$$

$$= 0,782\ (1/\beta')$$

$$C_{0,1} \doteq 0,972\ (\alpha'/\beta').e^{-1} \qquad (6.9)$$

$$= 0,972\ C_{MSY}$$

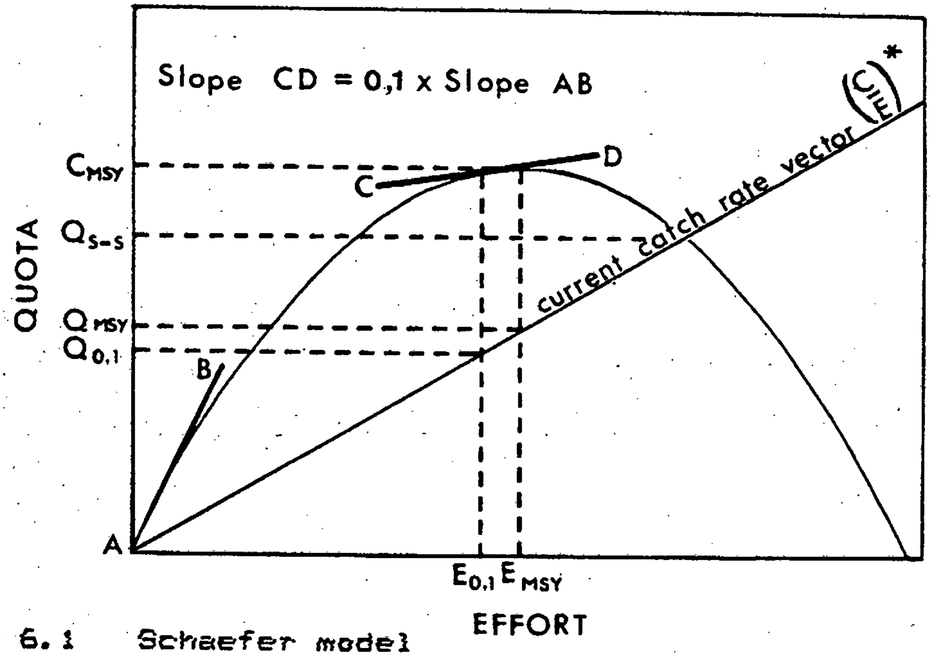


Figure 6.1 Schaefer model

The expected catch rate for the year in question (1985) is estimated by the current catch rate (that is, the observed catch rate for 1984) and is denoted by $(C/E)^*_{obs}$. Using this value together with $E_{0,1}$ or E_{MSY}, management can then fix the quota (for 1985) on the basis of the formula:

$$Q_{0,1} = (C/E)^*_{obs} . E_{0,1}$$

Interpreting this graphically, the catch level, $Q_{0,1}$, which will cause the stock to move towards the equilibrium condition associated with such a chosen objective is determined by the intercept of the effort ordinate prescribed by the $f_{0,1}$ management objective and the catch rate vector (see Figure 6.1).

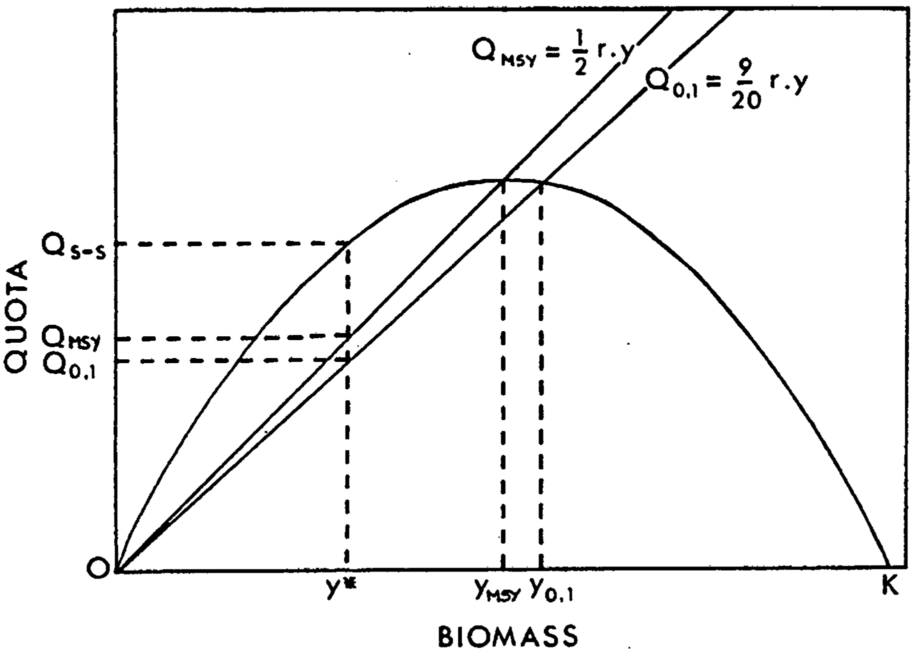


Figure 6.2 Schaefer model.

As can be seen from Figure 6.2, the $f_{0,1}$ procedure is a more cautious approach and will lead to the equilibrium population biomass being greater than that associated with MSY, namely, y_{MSY}. In the Schaefer model this corresponds to a biomass 'safety factor' of 10% and in the Fox, 24%. The calculation of these 'safety factors' is given in Appendix 6.2.

The $f_{0,1}$ management objective recommended here has no strict biological or economic basis. It simply establishes a criterion for a position probably closer to bioeconomic optimality than that of MSY, about which fishery managers can agree in principle and which they can easily understand.

6.3.2 Dynamic models

In the case of the dynamic models, the (estimated) expected catch rate can be estimated from stock projections based on the assumption that the expected CPUE is proportional to the mid-year biomass:

$$\widehat{(C/E)}_i = \hat{q}.\ (\hat{y}_i + \hat{y}_{i+1})\ /\ 2$$

(see equation (5.4)).

As in equations 6.3.1(i) - (iii), catch limits for the year (i+1) are calculated as follows:

(i) Sch: $Q_{s-s}(i+1) = r.y_{i+1}.(1-y_{i+1}/K)$ (6.10)

Fox: $Q_{s-s}(i+1) = r.y_{i+1}.(1-\ln(y_{i+1})/\ln(K))$ (6.11)

(ii) $Q_{MSY}(i+1) = \widehat{(C/E)}_i\ .E_{MSY}$ which gives

(a) Sch: $Q_{MSY}(i+1) = [q.(y_i + y_{i+1})/2].\ [0,5\ r/q]$

$$= 0,5\ r.(y_i + y_{i+1})/2 \qquad (6.12)$$

(see equations (5.4) and (4.9)). Similarly,

(b) Fox: $Q_{MSY}(i+1) = [q.(y_i + y_{i+1})/2].\ [r/(q.\ln(K))]$

$$= (r/\ln(K)).((y_i + y_{i+1})/2) \qquad (6.13)$$

(see equations (5.4) and (4.12)).

(iii) $Q_{0,1}(i+1) = \widehat{(C/E)}_i\ .E_{0,1}$. Therefore

(a) Sch: $Q_{0,1}(i+1) = [q.(y_i + y_{i+1})/2].[0,9\ E_{MSY}]$

$$= 0{,}9\ Q_{MSY}(i+i)$$

$$= 0{,}9\ [0{,}5\ r.(y_i + y_{i+1})/2]$$

$$= 0{,}45\ r.(y_i + y_{i+1})/2 \qquad (6.14)$$

$$\text{(b) Fox:}\quad Q_{,0,1}(i+1) = [q.(y_i + y_{i+1})/2].[0{,}782\ E_{MSY}]$$

$$= 0{,}782\ Q_{MSY}(i+1)$$

$$= 0{,}782\ (r/\ln(K)).(y_i + y_{i+1})/2 \qquad (6.15)$$

[Note: To facilitate calculation of the above equations, $\widehat{(C/E)}_i$ rather than $\widehat{(C/E)}_{i+1}$ has been used. While ideally the use of the latter would be more preferable, its calculation requires y_{i+1} and would therefore need an iterative procedure. As current biomass rates of change are not large, differences should not be substantial. Further, this enables a more direct comparison of catch limits with those evaluated on the steady-state basis of the previous section.]

Since E_{MSY} is based on a fit to data for a period of years, it therefore, to a certain extent, 'averages out' data fluctuations. However, in the case of the steady-state model, the $(C/E)^*_{obs}$ component of the formula is based on data for only one year. A potential advantage of the dynamic model is that it allows an estimate of CPUE in the most recent year, $\widehat{(C/E)}^*$, which is dependent on more than a single year's data. This produces catch limit recommendations which, in principle, are less subject to fluctuations.

6.3.3 Catch limits expressed as a proportion of the current stock size

The above f_{MSY} and $f_{0,1}$ management recommendations were given in the form of catch limits (Q). Since the dynamic models provide estimates of the parameters r, q, and K as well as those for the sustainable yield curves (that is, α and β), recommendations can alternatively be expressed as a proportion, h, of the current stock size appropriate to harvest under the specified policy. For example,

$$h_{MSY} = Q_{MSY} / [(y_i + y_{i+1})/2]$$

The following table gives a summary of the Schaefer and Fox formulae derived for h_{MSY} and $h_{0,1}$ using equations (6.10) - (6.15).

	SCHAEFER	FOX
h_{MSY}	0,5 r	r/ln(K)
$h_{0,1}$	0,45 r	0,7815 r/ln(K)

The appropriate values obtained using the parameters calculated for the best fits of the dynamic Schaefer and Fox models to the data are shown in Table 8.5. These values of h could then be used to obtain catch limit recommendations based on independent methods of estimating current stock size such as VPA (see Chapter 5).

6.4 Uncertainty

Uncertainty is an important feature of fisheries management. Since it is impossible to eliminate such uncertainty from fish stock assessment, good management strategies must take such uncertainty into account. The following discussion on causes of uncertainty and methods of dealing with it is based primarily on Walters (1984).

A major cause of uncertainty is environmental fluctuations whose effects on the fish population are not (as yet) predictable. Perturbations such as these can cause large year to year variations in the mortality rate between spawning and the recruitment of juveniles into the system. Such recruitment variation is primarily driven by marine climate factors such as upwelling patterns.

In comparison with the pelagic fish populations such as the anchovy and pilchard stocks, hake have a longer life span and therefore the stocks consist of more year-classes. This to a certain extent provides security against environmental fluctuations as their effect is dampened when the total stock biomass is considered. However, random and cyclic environmental perturbations can still cause a large amount of variation around predicted yields (see Figures 10.15 - 10.18) and stock size and could result in unintended substantial resource depletion. Therefore the results of the steady-state models together with the short and long term stock size projections for the dynamic models should be interpreted in the light of unpredictable and possibly major fluctuations as a result of environmental uncertainty.

Randomness can easily be incorporated into the production models by introducing a random perturbing factor. The frequency and magnitude with which this factor operates can be evaluated from the past history of the fishery. This method should, however, be used with caution as most fishery data records are not extensive and future environmental conditions may not necessarily mimic those of the past.

As soon as random factors are included in production models, predictions can no longer apply to one specific year, but to one of many possible years that could follow. However, the probability of a particular outcome can be estimated by running a simulation model many times, thereby obtaining a number of predictions for each particular year. By calculating the number of times such an event occurs in, for example, 1000 random trials, the distribution of such predictions could then be examined and the probability of a particular outcome estimated. This method of assigning odds to various outcomes is termed Monte Carlo modelling (see Chapter 7). Statistics such as the probability of collapse of the fishery or the probability of obtaining a particular level of yield in any one year under a given level of fishing effort can then be calculated.

When low population sizes occur, neither bad fisheries management nor unpredictable environmental events can necessarily be held solely responsible for the stock biomass decline. Usually this state is the result of a combination of such factors. Thus management policies which do not reduce the fishing intensity at low population sizes take risks as low abundance levels can be decreased even further by adverse environmental conditions. It is therefore important that decision makers have a clear understanding of this fact so that they appreciate the need to detect any variation in the population without delay and to respond rapidly to it. Their management policies must be updated regularly so as to ensure that the state of the stock remains as near as possible to that required by management objectives.

A second form of uncertainty exists in the formulation of models and the determination of their parameters. The effectiveness of production models depends on the accuracy of the assumed model and the precision with which its parameters can be estimated. Even if the 'correct' production functions are fitted to the data, errors can occur in the estimation of their parameters. Sometimes these are due to large measurement errors, but more often there has simply not been enough variation in stock sizes and policies over time to allow accurate estimation. That is, often it is found that data can equally well be described by a variety of parameter combinations.

Furthermore, models cannot account for all factors that influence stock size and production. Their validity could be seriously affected by parameters excluded from the model which could cause changes in the stock size and catch.

Usually, the only data sets with information about variation in stock sizes are those from the early part of fishery development when variables change rapidly. Owing to uncertainty most fishery management tends to adopt a conservative fishing policy where development proceeds cautiously and stock sizes remain near equilibrium. They assume the 'best' current model is correct, waiting for environmental fluctuations to tell them more about how the system responds to variations.

Walters (1984) recommends instead the use of experimental management policies which would provide information about the system under more extreme conditions than would arise naturally or through conservative policies. Ideally, these probing experiments should be interspersed with longer periods of cautious management. Small probing tests are unfavourable since they deteriorate short term performance without substantially providing new information for parameter estimation. He summarizes good management as that which operates within the 'safe' limits of variation whilst at the same time encourages variation that could be informative by more markedly increasing the precision of parameter estimates.

6.5 Economic considerations

So far, only the biological objectives associated with the f_{MSY} and $f_{0,1}$ strategies have been discussed. However, other considerations should be taken into account when managing a marine resource. Where, for example, the current catch is producing a stock decline, fishermen may be unconcerned, feeling perhaps that in times of low abundance of a particular resource they could fish several alternative stocks or take other employment as an alternative means of income. In situations where the current catch just keeps the stock at a low level without allowing any increase, the fishermen may well prefer to maintain current catches and incomes, rather than accept a smaller present catch and income on the expectation of future increases, because of the time-discounting effect (Clark, 1976).

In the above instances, to these fishermen, the biological optimum would not economically be the most desirable.

Therefore, although in theory the f_{MSY} and $f_{0.1}$ strategies might appear to be effective and appropriate means of controlling the resource, in practice, in times of low or declining stock size, management agencies might have difficulty in implementing the quota reductions that such strategies indicate, especially when the fishermen's livelihoods are at stake.

An analysis of the economic situation can be made by transforming Schaefer and Fox production curves to revenue curves and then relating them to cost curves to determine the most profitable level of fishing. An adequate representation of all the economic factors would require transformations involving many parameter estimates. These would further complicate the dynamic models which are already quite complex and fairly imprecise. However, despite their inaccuracy, these expansions could help conceptualize the likely results of economic pressures. The inclusion of economic variables is dealt with in greater detail in Chapter 11.

Although historically fishery management has primarily focussed on the biological aspects of the fisheries and has been mainly concerned with the protection and conservation of fish stocks, it is now apparent that if fisheries are to contribute fully to society, then social, economic, political and environmental factors must be included in the management process. Greater consideration of the people involved in or affected by the fishery is necessary. Fishery management is now not necessarily only concerned with the application of restrictive (regulatory) measures. Its scope is wider and includes a strong role in planning and executing fishery development.

6.6 Discussion

Uncertainty is one of the most important factors in fisheries analysis, causing problems when trying to assess what has happened historically and what might occur in the future. It is therefore necessary to deal with unpredictable variation as it arises by working within the constraints of available facilities and developing efficient processing systems to ensure that results are speedily produced.

At present, yearly catch quota limits in conjunction with minimum mesh size regulations have been used in the management of the southern African hake populations. An alternative method of controlling the fishery would be through the introduction of effort restrictions. However, fishing effort is a function of the number of vessels and their power/efficiency, and although it might be possible to place limitations on the number of ships operating per year, problems arise when trying to quantify and control power. Therefore although catch limit policies are less stable against fluctuations than effort limitation policies, they are easier to monitor and apply.

The application of a complex mathematical model to fisheries data is often taken to imply a greater reliability of the answer (for example, quota) obtained than is justified by the (lack of) quantity and (poor) quality of the input data; quoting only a single number can produce a misleading impression. It is therefore also desirable to include not only the best estimates of parameters from the model applied to the data, but also to give a quantitative indication of the reliability of such estimates. For this reason, methods have been applied in the following analyses to provide coefficient of variation (standard error/mean) values for parameter estimates for both the dynamic models and the GFR approach. These procedures are described in the following chapter. Suggestions as to how such information might be incorporated in catch limit recommendations are made in Chapter 8.

Appendix 6.1

Equilibrium catch and effort levels corresponding to an $f_{0,1}$ strategy.

(i) Schaefer model:

In equilibrium,

$$C = \alpha . E - \beta . E^2$$

$$\Rightarrow \quad dC/dE = \alpha - 2\beta . E \ .$$

Therefore $dC/dE\Big]_{E=E_{0,1}} = \alpha - 2\beta . E_{0,1}$

and $dC/dE\Big]_{E=0} = \alpha$.

The $f_{0,1}$ policy corresponds to fishing at an effort level where

$$dC/dE\Big]_{E=E_{0,1}} = 0,1 \ dC/dE\Big]_{E=0} \ .$$

Therefore $\alpha - 2\beta . E_{0,1} = 0,1\,\alpha$

and $E_{0,1} = 0,9 \ (\alpha/2\beta)$.

Since $E_{MSY} = \alpha/(2\beta)$ (see equation (4.9))

$$E_{0,1} = 0,9 \ E_{MSY} \qquad \text{(A6.1.1)}$$

Under such a strategy, at equilibrium,

$$C_{0,1} = E_{0,1} . (\alpha - \beta E_{0,1})$$

$$= 0,9 \ (\alpha/2\beta).[\alpha - \beta. \ 0,9 \ (\alpha/2\beta)]$$

$$= 0,99 \ (\alpha^2/4\beta)$$

where $C_{0,1}$ = quota corresponding to an $f_{0,1}$ strategy once the stock has reached its equilibrium value.

Since $C_{MSY} = \alpha^2/(4\beta)$ (see equation (4.8)), it follows that

$$C_{0,1} = 0{,}99\ C_{MSY}.$$

(ii) <u>Fox model</u>:

In equilibrium,

$$C = \alpha'.E.e^{-\beta'E}$$

$$dC/dE\Big] = \alpha'.e^{-\beta'.E}.[1 - \beta'.E]$$

$$dC/dE\Big]_{E=E_{0,1}} = \alpha'.e^{-\beta'.E_{0,1}}.[1 - \beta'.E_{0,1}]$$

$$dC/dE\Big]_{E=0} = \alpha'.$$

As in section (i), $E_{0,1}$ is determined as follows:

$$dC/dE\Big]_{E=E_{0,1}} = 0{,}1\ dC/dE\Big]_{E=0}$$

$$\therefore\ \alpha'.e^{-\beta'.E_{0,1}}.[1 - \beta'.E_{0,1}] = 0{,}1\,\alpha'.$$

Letting $x = \beta'.E_{0,1}$

$$\therefore\ e^{-x}.[1 - x] = 0{,}1$$

$$\therefore\ 1 - x - 0{,}1\ e^{-x} = 0\ .$$

Using the Newton-Raphson iterative procedure, an estimate of $x \doteqdot 0{,}782$ is obtained. Therefore

$$E_{0,1} \doteqdot 0{,}782\ (1/\beta') .$$

Since $E_{MSY} = (1/\beta')$ (see equation (4.12)), it follows that

$$E_{0,1} \doteqdot 0{,}782\ E_{MSY} \qquad (A6.1.2)$$

Similarly the equilibrium quota under such an $f_{0,1}$ strategy can be determined:

$$C_{0,1} = \alpha'.E_{0,1}\ .e^{-\beta'.E_{0,1}}$$

$$\doteqdot \alpha'.0{,}782\ (1/\beta').e^{-\beta'.0{,}782\ (1/\beta')}$$

$$= 0{,}782\ e^{-0{,}782}\ .(\alpha'/\beta') .$$

Since $C_{MSY} = (\alpha'/\beta').e^{-1}$ (see equation (4.11))

$$C_{0,1} \doteqdot 0{,}782\ e^{-0{,}782+1}\ .C_{MSY}$$

$$= 0{,}972\ CMSY .$$

Appendix 6.2

Formulae for catch quotas under a $f_{0,1}$ strategy.

(i) Schaefer model:

To approach $f_{0,1}$, Figure 6.1 indicates the calculation of quotas on the following basis:

$$Q_{0,1} = E_{0,1} \,.\, (C/E)^{*} \qquad \text{(see equation (6.1))}$$

$$= E_{0,1} \,.\, q \,.\, y^{*} \qquad \text{(see equation (4.5))}$$

$$= 0{,}9\ E_{MSY} \,.\, q.\ y^{*} \qquad \text{(see equation (A6.1.1))}$$

$$= 0{,}9\ [\ r\ /\ (2q)\ ] \,.\, q \,.\, y^{*} \qquad \text{(see equation (4.9))}$$

$$= 0{,}9\ \ r \,.\, (y^{*}\ /\ 2)\ \ .$$

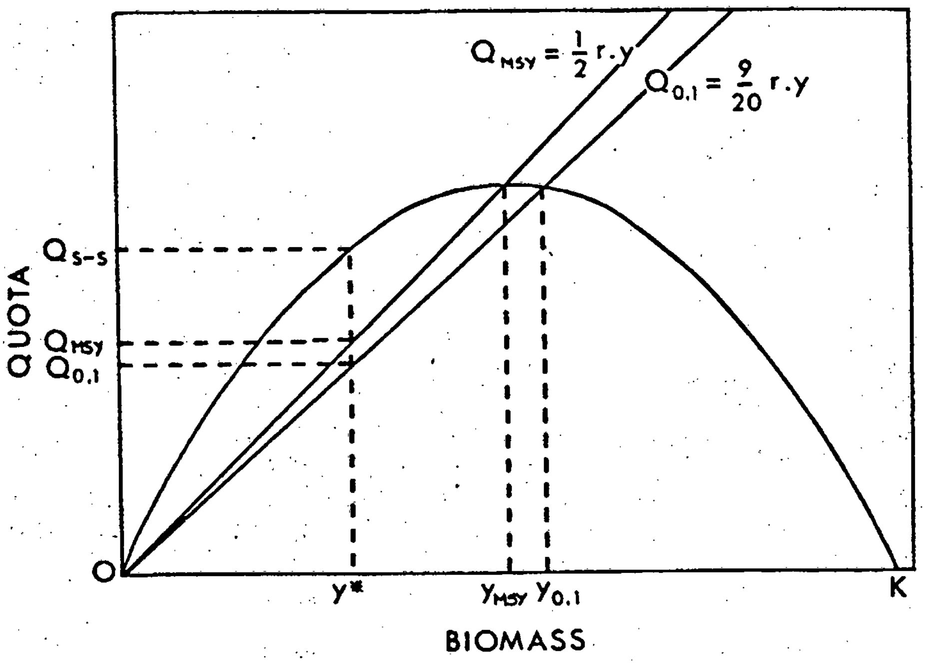


Figure A6.2.1 Schaefer model.

Assuming $y_{0,1}$ is the biomass level obtained at equilibrium under this strategy, it follows that

$$0{,}9\ (r/2)\ .\ y_{0,1} = r\ .\ y_{0,1}\ .\ (\ 1 - y_{0,1}/K\ )$$

which implies $y_{0,1} / K = 11/20$

or eqivalently $y_{0,1} = 1{,}1\ (K/2)$.

Since $y_{MSY} = K / 2$ (see equation (4.10))

it follows that $y_{0,1} = 1{,}1\ y_{MSY}$.

Therefore, this policy corresponds to employing a 10% 'safety factor'. That is, the equilibrium population biomass will be 10% greater than y_{MSY} as is illustrated in Figure A6.2.1 .

(ii) Fox model:

Similarly,

$$Q_{0,1} = E_{0,1}\ .\ (C/E)^{*} \qquad \text{(see equation (6.1))}$$

$$= E_{0,1}\ .\ q\ .\ y^{*} \qquad \text{(see equation (4.5))}$$

$$\doteqdot 0{,}782\ E_{MSY}\ .\ q\ .\ y^{*} \qquad \text{(see equation (A6.1.2))}$$

$$= 0{,}782\ [\ r/(q.\ln(K))\ ]\ .\ q\ .\ y^{*} \qquad \text{(see equation (4.12))}$$

$$= 0{,}782\ [\ r/\ln(K)\ ]\ .\ y^{*}\ .$$

Assuming equilibrium occurs where $y = y_{0,1}$,

$$0{,}782\ [r/\ln(K)].y_{0,1} \doteqdot r.y_{0,1}.(1 - [\ln(y_{0,1})/\ln(K)])$$

i.e. $0{,}782 \doteqdot \ln(K) - \ln(y_{0,1})$

and $\therefore$ $y_{0,1} \doteqdot K\ .\ e^{-0{,}782}$.

Since $y_{MSY} = K \cdot e^{-1}$ (see equation (4.13))

it follows that $y_{0,1} \doteqdot e^{-0,782+1} \cdot y_{MSY}$

$$\doteqdot 1,244\ y_{MSY}$$

Therefore, such a management strategy corresponds to a 24% 'safety factor'.

7 ESTIMATES OF PRECISION

7.1 Introduction

In the previous chapter the sources of various uncertainties involved in managing a fishery were discussed. These included bias arising from errors in the assumed model and the lack of precision of estimates of management variables (for example, quotas) caused by (non-systematic) errors in the observations (for example, CPUE as an index of stock biomass). The 'quality' of such estimates is in some sense inversely proportional to the sum of these two errors combined. In this chapter the 'quality' of the parameter estimates provided by the prescribed steady-state and dynamic models is evaluated by assuming zero model error and by calculating the precision of the estimates using the statistical procedures described below.

7.2 Steady-state models

Estimates of precision were obtained using the Monte Carlo bootstrap approach presented by Efron (1982). For the statistical details of this bootstrap approach see Appendix 7.1 . From the set,

$$S = \{(f_i, (C/E)_i) : i = 1 \ldots m\},$$

(m = the number of years in the data series)

a new data set,

$$S' = \{(f_j, (C/E)_j) : j = 1 \ldots m\} \qquad (7.1)$$

is created by random sampling with replacement from the original set S of observed data pairs. From the set S' parameters such as α and MSY can be calculated as described in Chapters 4 and 5. By repeating this procedure a large number of times , N such data sets S' can be generated. In this analysis, a value of N = 1000 was used. Each repetition yielded new estimates of the various parameters and these were grouped into sets, for example,

$$T = \{\alpha_k : k = 1 \ldots N\}, \qquad (7.2)$$

From these parameter sets, the following statistics were calculated:

(i) Standard error: $$\text{s.e.} = \frac{\sigma}{\sqrt{N}} \qquad (7.3)$$

where the variance, $\sigma^2 = \frac{1}{N-1}\left[(\sum_{k=1}^{N} \alpha_k^2) - \frac{1}{N} (\sum_{k=1}^{N} \alpha_k)^2 \right]$

(ii) Using this estimate of the standard error, the coefficient of variation (c.v.) can be determined:

$$\text{c.v.} = \frac{\sigma}{\bar{\alpha}} \tag{7.4}$$

where the mean of α, $\bar{\alpha} = \frac{1}{N} [\sum_{k=1}^{N} \alpha_k]$.

(iii) 95% and 68% confidence limits were calculated from the 1000 parameter estimates in the sets T after ordering as follows (Buckland, 1984):

$$95\% \text{ limits: } (,975\alpha_{25}+,025\alpha_{26};\ ,025\alpha_{975}+,975\alpha_{976}) \tag{7.5}$$

$$68\% \text{ limits: } (,84\alpha_{160}+,16\alpha_{161};\ ,025\alpha_{840}+,84\alpha_{841}) \tag{7.6}$$

Thus, by drawing a sample and calculating its statistics over and over again, a frequency distribution can be built up. This distribution will then closely approximate the bootstrap estimate of the probability distribution. The attraction of this bootstrap method is that it does not require a known functional form for the probability distribution of the residuals in the regression. The particular bootstrap procedure outlined here is described by Efron (1982) as being a cautious approach. In Appendix 7.2 an alternative bootstrap procedure is presented, the results of which are compared with those of the original Efron (1982) method in Table 8.10.

7.3 Dynamic models

Although the approach outlined in Appendix 7.2 could have been adopted for the analysis of dynamic model estimates, a different procedure was used. The Monte Carlo technique was again employed to calculate sample statistics, but this time the weighted residuals were assumed to be distributed normally with zero mean and variance σ^2 estimated by:

$$\sigma^2 = SS / (m - n_p) \tag{7.7}$$

where n_p = the number of parameters estimated. In the case of the dynamic models, three parameters (r, α and MSY) were estimated and therefore a bias correction factor $m \rightarrow m-3$ was assumed. These correction factors were based on a similar adjustment used for linear regression models with n_p parameters. Later the model was extended to include a fourth parameter, y_1/K and in this case the correction factor became $m-4$.

In place of set, $S = \{(C_i, (C/E)_i) : i = 1,...m\}$, N (= 1000) 'pseudo' data sets,

$$S' = \{(C_i, (C/E)'_i) : i = 1,...m\} \qquad (7.8)$$

were fitted such that

$$\sqrt{(C/E)'_i} = \sqrt{(\widehat{C/E})_i} + \varepsilon_i$$

$$\text{where} \qquad \varepsilon_i \text{ from } N(0, \sigma^2/\hat{E}_i) \qquad (7.9)$$

$$\text{and} \qquad \hat{E}_i = C_i / (\widehat{C/E})_i .$$

[It must be noted that time ordering within the sets S' is preserved here.]

By fitting the prescribed dynamic model to each of N (= 1000) such data sets S', parameter sets (see equation (7.1)) could be constructed from which standard error and coefficient of variation estimates could be obtained and confidence intervals evaluated. It should be noted that since the catch, C, appears to be reasonably well-determined, the approach assumes that variations in CPUE account for any disagreement between the data and the assumed model.

If this model appropriately describes the observed data, the weighted residuals should be:
(i) normally distributed
(ii) random (uncorrelated) and
(iii) homoscedastic (for maximum likelihood estimation).

To test these conditions, a χ^2 test, a runs test and a test for significant slope in a linear regression of the modulus of the weighted residuals against E, respectively, were performed. The results of these tests are listed and discussed in Chapter 8.

[Note that the Efron (1982) method which was employed for evaluating the precision of static model estimates (see Section 7.2) could not be used for the dynamic models because of the time ordering of the newly created sets S']

7.4 Discussion

The results of these methods of estimating precision are discussed in Chapter 8 and the c.v. values obtained are listed (see Tables 8.1 - 8.10). The c.v. values for MSY and $Q_{0,1}$ estimates (for both the Schaefer and Fox models) using the GFR approach calculated by the bootstrap procedure given in Appendix 7.2 (see equation (A7.2.5)) and Efron's 'more cautious' approach (see Section 7.2) are compared in Table 8.10 . From these results it is evident that although the results of the two procedures are similar, they are by no means identical with the procedure in equation (A7.2.4) often yielding larger values.

Appendix 7.1

The Monte Carlo bootstrap method as presented by Efron

The bootstrap method described here was introduced by Efron (1979). It is a simple nonparametric method which can be used to estimate the sampling distribution of a statistic of interest, say α, where α depends on a known random sample $\underline{X} = (X_1,\ldots X_N)$ from an unknown probability distribution F.

The method of attaching a standard error to some parameter value, say $\hat{\alpha}$, using observed data $\underline{x} = (x_1,\ldots x_n)$ where $\hat{\alpha}$ is a specified random variable depending on both the random sample $\underline{X}$ and the unknown distribution F is given below.

Assume independent identical sampling from a completely unspecified population distribution F. The bootstrap estimate of standard error for $\hat{\alpha}$ denoted by $\sigma_B(\hat{\alpha})$ is as follows:

(i) Let $\hat{F}$ be the sample probability distribution of the data,

$\hat{F}$: probability mass $1/n$ at each observed x_i

$(i = 1,\ldots n)$.

(ii) Let $\underline{X}^* = (X^*_1,\ldots X^*_n)$ be a random 'bootstrap sample' of size n drawn from F and let $\underline{x}^* = (x^*_1,\ldots x^*_n)$ be the observed bootstrap values where the values of $\underline{X}^*$ are selected with replacement and equal probability from the set $(x_1,\ldots x_n)$. That is,

$$X^*_i = x^*_i$$

$$X^*_i \ \text{iid} \ \hat{F} \quad (i = 1,\ldots n)$$
$$\sim$$

(iid = independently identically distributed).

Also let $\hat{\alpha}^* = \hat{\alpha}(X_1^*, \ldots X_n^*)$ where $\hat{\alpha}^*$ is the statistic depending on the bootstrap sample and the sample probability distribution $\hat{F}$.

(iii) The bootstrap estimate of the standard error is:

$$\sigma_B(\hat{\alpha}) = \sqrt{\mathrm{var}_*(\hat{\alpha}^*)}$$

where $\mathrm{var}_*(\hat{\alpha}^*)$ indicates the variance of $\hat{\alpha}^*$ under the probability prescription (ii), with $\hat{F}$ fixed at its observed value in (i).

In other words, the bootstrap estimate of $\sigma_B(\hat{\alpha})$ is simply the standard deviation of the quantity of interest, $\hat{\alpha}(X_1, \ldots X_n)$ if the unknown distribution F is taken equal to the observed distribution $\hat{F}$.

As direct theoretical calculation of $\sigma_B(\hat{\alpha})$ is usually impossible, other methods must be used to calculate the bootstrap distribution. One such method is the Monte Carlo simulation which yields a quick approximation and is easy and fast to implement on a computer.

A large number N of independent repetitions of step (ii) are performed yielding N observed bootstrap samples, say $\underline{x}_1^*, \ldots \underline{x}_N^*$ and their corresponding $\hat{\alpha}^*$ values, $\alpha_1^*, \ldots \alpha_N^*$. Then the bootstrap estimate of the standard error is approximated by the sample standard deviation:

$$\sigma_B(\hat{\alpha}) = \sqrt{\frac{1}{N-1} \cdot \left[\sum_{j=1}^{N} \left(\hat{\alpha}_j^* - \frac{1}{N} \cdot \sum_{j=1}^{N} \hat{\alpha}_j^*\right)^2\right]}$$

Efron (1981) compared the bootstrap approach to other genuinely nonparametric methods such as the jackknife. He reported that "it performs best since it is the nonparametric maximum likelihood estimate of the standard error". It was therefore chosen for the analysis of certain static model parameter estimates as it seemed more widely applicable and more dependable than other alternatives.

Appendix 7.2

Considerations on bootstrapping a functional regression

In situations where both variates (X and Y) are subject to error of measurement and/or inherent variability, it has been suggested (Ricker, 1973) that a functional regression is usually more suitable than conventional linear regression methods. However, problems arise when attempting to extend Efron's (1982) standard bootstrap procedure for a predictive regression (sampling with replacement from the residuals) to the case of a functional regression. Where both variates are subject to measurement error, it is possible to obtain a least squares estimate of the functional regression by estimating the ratio λ where λ is the true variance of Y at a given (true) value of X to the true variance of X at a given Y. In practice, usually the required ratio, λ, cannot be obtained from the data alone (Ricker, op. cit.). Therefore, where an objective estimate of λ is unavailable, a further assumption must be made.

For simplicity, let x and y represent the quantities as measured from their means, that is, $x = X - \bar{X}$ and $y = Y - \bar{Y}$. Then an estimate of m is required for the relation:

$$y = m.x \qquad \text{(A7.2.1)}$$

Using the functional regression method m is estimated as follows:

$$m^2 = \frac{\sum_{i=1}^{n} y_i^2}{\sum_{i=1}^{n} x_i^2} \; ; \qquad \frac{m}{|m|} = \frac{\sum_{i=1}^{n} x_i y_i}{\left|\sum_{i=1}^{n} x_i y_i\right|} \qquad \text{(A7.2.2)}$$

for the observed data set $\{(x_i, y_i): i = 1,\ldots n\}$.

In addition, it is assumed that λ is made equal to the ratio of the total variances of the sets of x_i and y_i observations, that is, $\lambda = m^2$ (cf. Ricker (1973) equation (28)). The maximum likelihood estimate of the 'true' data pair (x_i, y_i) corresponding to the observed pair $(\tilde{x}_i, \tilde{y}_i)$ is therefore:

$$\tilde{x}_i = \frac{1}{2}(x_i + y_i/m)$$

$$\tilde{y}_i = m.\tilde{x}_i = \frac{1}{2}(y_i + m.x_i) \qquad \text{(A7.2.3)}$$

On the basis of these values for $\tilde{x}_i$ and $\tilde{y}_i$ and the fact that the ratio of the variance of the true error value to the variance of the estimated error is $\sqrt{2}$, residuals for the variates can be evaluated:

$$\varepsilon_i^x = \sqrt{\frac{n}{n-2}} \cdot \sqrt{2} \cdot (x_i - \tilde{x}_i)$$

$$\varepsilon_i^y = \sqrt{\frac{n}{n-2}} \cdot \sqrt{2} \cdot (y_i - \tilde{y}_i) \qquad \text{(A7.2.4)}$$

[Note that a correction factor of $\sqrt{\frac{n}{n-2}}$ was used as two parameters were estimated for the functional regression.]

Using values of ε^x and ε^y obtained by random sampling with replacement from the sets,

$$\{\varepsilon_i^x : i = 1,\ldots n\} \text{ and } \{\varepsilon_i^y : i = 1,\ldots n\},$$

a new set $\{(X_i^*, Y_i^*) : i = 1,\ldots n\}$ is generated where

$$X_i^* = \bar{X} + \tilde{x}_i + \varepsilon^x \qquad \text{(A7.2.5)}$$

and $$Y_i^* = \bar{Y} + \tilde{y}_i + \varepsilon^y.$$

The above process is repeated a large number N times, thereby creating N such sets of (X_i^*, Y_i^*) values from which estimates of parameters such as α^* can be obtained. These parameter estimates can be grouped together in sets, such as,

$$T_k = \{\alpha_k^* : k = 1,\ldots N\}$$

(see equation (7.2)) and by this Monte Carlo bootstrap procedure, the required sample statistics can be evaluated.

Simulation tests, although not exhaustive as yet, indicate that the above procedure works reasonably well, even for λ values differing quite substantially from m^2.

8 RESULTS AND DISCUSSION

8.1 Presentation of results

In the past few chapters, various methods for fitting catch-effort data were described, namely the Gulland Functional Regression (GFR) approach (Appendix 7.2), two versions of the conventional (that is, predictive) linear regression method (Chapter 4) and the dynamic model approach (Chapter 5). The linear regression models were fitted using the same minimization criterion involving square roots as were the dynamic models (specified in equation (5.9)) so that the results of these approaches could be directly compared. Using each of these four methods, catch and effort data for the four ICSEAF Divisions under consideration were fitted using both the Schaefer and Fox forms given in equations (4.6) and (4.7). The results are listed in Tables 8.1 – 8.8 . In these tables the CPUE and effort units are the same as those given in Tables 3.1 – 3.4 .

In the case of the conventional linear regression method, two sets of data pairs were fitted, namely

$$\{(E_i, (C/E)_i : i = 1,\ldots n\}$$

and $$\{(f_i, (C/E)_i : i = 3/4,\ldots n\}$$

where f_i is Gulland's average effort value as given in equation (4.15). The results using these two sets are shown under 'Square Root Minimization' in Tables 8.1 – 8.8 with the headings 'S-state' and 'Gulland' respectively. Conventional linear regressions which use the latter data set will be referred to as Gulland Square Root Minimization (GSRM) fits. This data set was also used for the GFR method. The Schaefer and Fox forms for the GSRM and GFR approaches were therefore as follows:

$$\text{(i) Schaefer:} \quad \widehat{(C/E)} = \alpha - \beta . f$$

$$\text{(ii) Fox:} \quad \widehat{(C/E)} = \alpha' . e^{-\beta' . f}$$

It should be noted that in the case of the steady-state (s-s) and GSRM models, the bias correction factor for σ is taken to be $\sqrt{\frac{m}{m-2}}$ since only two parameters, α and β are estimated (see section 7.3).

For the steady-state models the ratios of current biomass (y^*) to the carrying capacity (K) or MSY biomass level (y_{MSY}) were estimated on the basis of relative CPUE values and refer to 1984 values (in effect, a mid-year average). However, for the dynamic (sometimes termed 'DSRM') models the current biomass level was taken to be that at the start of 1985.

Catch limits (such as $Q_{0,1}$) beyond 1985 could only be estimated by the dynamic models. These together with estimates for $Q_{0,1}(86)$ are also listed in Tables 8.1 - 8.8 . Results for Q_{s-s} and Q_{MSY} apply to 1985. Using equation (5.1) to predict future biomass levels, dynamic model estimates of the average annual increase rate (a.i.r.) of the stock over the period 1985 - 1986 under the specified harvesting strategy were calculated. Three cases are shown, corresponding to the best estimates of $Q_{0,1}$ for 1985 and 1986 and for 90% and 80% of those values.

In addition, the corresponding probability (p.dec.) that at the start of 1987 the stock would have declined (and would also be below y_{MSY}) under such catch regimes for 1985 and 1986 was calculated. This was done using estimates of the catch limits based on a best fit to the original data. Using Monte Carlo simulations (such as those described in Section 7.3), 1000 pseudo data sets were constructed to which dynamic model parameters (such as r', K' and q') were fitted. From each of these simulations an estimate of the current biomass level (for this analysis, y'_{85}) was obtained and these values together with the dynamic parameter estimates and fixed catch limit values for future years ($Q_{0,1}(85)$ and $Q_{0,1}(86)$ as calculated from the original data set) were used to provide a projection of the future stock size. The probability of decline estimate was determined as the proportion of these 1000 simulations for which a downward trend was indicated (that is, for which, $y'_{87} < y'_{85}$).

The estimates given in Tables 8.1 - 8.8 are the 'best estimates' on the basis of the minimization procedures prescribed in Chapter 5. Also given (in parenthesis) in Tables 8.1 - 8.8 are the coefficient of variation (c.v.) values for the dynamic and GFR model 'best estimates'. For the dynamic model c.v. values, the Monte Carlo procedure described in Section 7.3 was used, whereas the bootstrap approach of Appendix 7.2 was employed for the GFR procedure. These 'best estimates' may differ from the means and/or medians of the parameter distributions produced by such Monte Carlo procedures because of effects arising from nonlinear parameter combinations, the use of $\hat{E}_i$ rather than E_i for residual weighting in the dynamic model and the distribution skewness (in respect of medians). In practice, however, such differences are very small (that is, typically less than 2%), suggesting that bias in the original estimation procedure is similarly of little consequence.

The estimates of the dynamic Schaefer and Fox model parameters for calculating the harvestable portions (see Section 6.3.3) of the hake stocks in the four ICSEAF divisions are listed in Table 8.9. The c.v. estimates are indicated in parenthesis.

Table 8.10 gives a comparison of the c.v. estimates for the Gulland Functional Regression MSY and $Q_{0,1}$ (85) values (for both the Schaefer and Fox models). Two different c.v. estimation procedures were used, namely the Efron (1982) procedure described in Section 7.2 and the alternative bootstrap procedure given in Appendix 7.2 . The results of the two procedures are similar, though by no means identical, and in many cases (and especially with regard to MSY) the latter procedure provided larger c.v. estimates, despite being termed 'more cautious' (though not in respect of this specific comparison) by Efron.

In Figures 8.1 - 8.8 plots of the observed CPUE trends with time are compared to expected CPUE trends given by dynamic and GFR model fits to the catch-effort data in each division. These are shown for both the Schaefer and Fox models.

Figures 8.9 - 8.12 show dynamic Schaefer and Fox model estimates of both historic and projected absolute biomass values. The biomass levels were projected 10 years forward under a $Q_{0,1}$ harvesting strategy as evaluated using the Fox model. The vertical bars represent the historical annual catches and $Q_{0,1}$ catch projections for the Fox model over the next 10 years.

Plots of the probability that the true $Q_{0,1}$ value is less than a particular catch limit value are shown in the form of ogives. These probabilities were calculated for both the GFR and dynamic methods (for both the Schaefer and Fox forms) using Monte Carlo estimates of $Q_{0,1}$(85) obtained by simulations as descibed above. The results for all four divisions are illustrated in Figures 8.13 - 8.16 .

8.2 Comparison of models

An index of the relative goodness of fit of the various models to the catch-effort data within each division is provided by the estimate of the standard deviation of the weighted residuals, σ, shown in Tables 8.1 - 8.8 . Note that all σ values shown incorporate ad hoc adjustments for bias (see Section 7.3). A summary of these σ values is given in the following table:

DIVISION	MODEL	Standard deviation, σ		
		S-state	GSRM	Dynamic
1.3 + 1.4	Schaefer	2,58	1,91	,945
	Fox	2,56	1,95	,937
1.5	Schaefer	1,88	1,22	,921
	Fox	1,84	1,27	,981
1.6	Schaefer	3,50	1,72	,814
	Fox	1,98	1,49	,689
2.1 + 2.2	Schaefer	1,05	,793	,660
	Fox	,982	,710	,602

Without exception, the fit improves when moving from the steady-state to the GSRM and then to the dynamic model approach. Relative change values show an average improvement in σ values of 30% for the GSRM model and 55% for the dynamic model when compared to the traditional s-s method. In all divisions except Divisions 2.1 + 2.2 the dynamic model σ values were substantially (over 50%) lower than their s-s counterparts. Although comparative σ values could not be calculated for the GFR formulation, plots of the observed CPUE time series and the expected CPUE series predicted by the dynamic and GFR formulations clearly indicate an improved fit of the dynamic model over that of the GFR formulation (Figures 8.1 - 8.8). [Well illustrated also are the low CPUE values recorded in all ICSEAF divisions during the mid to late 1970s (refer to Chapter 2).]

In Chapter 7.3 it was noted that if the model (and estimation technique) appropriately describes the data, the weighted residuals should be normally distributed, random and homoscedastic. The P (probability) values given in Tables 8.1 - 8.8 for the GSRM and dynamic model fits correspond to the probability that, under corresponding null hypotheses, results 'as bad as or worse than' those obtained, would be achieved.

χ^2 tests for normality were not very powerful because of the small number of points in the data sets under consideration (particularly in Divisions 2.1 + 2.2). However, as can be seen from the following table, in all cases the P values were not significant at the 5% level, thereby indicating consistency with the assumption of a normal distribution of weighted residuals in terms of this test. It is noticeable nevertheless that, with the exception of Divisions 2.1 + 2.2, P values for the GSRM fits are markedly smaller than for the dynamic model fits.

DIVISION	MODEL	P values (normal.)	
		GSRM	Dynamic
1.3 + 1.4	Schaefer	,248	,752
	Fox	,248	,752
1.5	Schaefer	,317	,403
	Fox	,127	,752
1.6	Schaefer	,105	,721
	Fox	,198	,721
2.1 + 2.2	Schaefer	,724	,317
	Fox	,480	,248

Because of the lack of power of the χ^2 test for the data considered, this aspect was also investigated using BMDP normal probability plots produced by the statistical package, BMDP5D. A description of the procedure together with the results obtained for the GSRM and dynamic models (both Schaefer and Fox) in all four divisions is given in Appendix 8.1 . Inspection of these plots is not suggestive of any marked deviation from normality, except perhaps in Divisions 2.1 + 2.2 for the GSRM approach.

To test for randomness a runs test was performed. The results are summarized below:

DIVISION	MODEL	P values (random)	
		GSRM	Dynamic
1.3 + 1.4	Schaefer	,004	,066
	Fox	,004	,358
1.5	Schaefer	,052	,646
	Fox	,052	,358
1.6	Schaefer	,4x10^{-4}	,063
	Fox	,4X10^{-4}	,063
2.1 + 2.2	Schaefer	,010	,145
	Fox	,010	,145

At the 5% level, in all divisions except Division 1.5 (where P = ,052) residuals for the GSRM model fits did not satisfy the runs test for randomness by a large margin. This result is a consequence of the general bias trend in Gulland model fits (noted in Chapter 1) of underestimating CPUE during the declining phases of these fisheries, and of overestimating it in the recovery phases. On the other hand, as is reflected by the improved fits in Figures 8.1 - 8.8, in all cases the dynamic model fits pass the test (although it should be noted that for both models in Division 1.6 and the Schaefer model in Divisions 1.3 + 1.4, this is only by a small margin - see also Section 8.4). In general, the P values for most of the dynamic model fits are relatively small (on average, 23%). This could be the result of CPUE fluctuations arising not only from sampling variation (the basis of equation (5.8)), but also from environmental changes affecting catchability. Such environmental changes would, plausibly, show a degree of positive serial correlation and could be the cause of the low P values for the runs test for Divisions 1.3 + 1.4 and 1.6. (However, less plausibly, this line of argumentation requires the postulate of negative serial correlation effects for Division 1.5).

To test for homoscedacity (constant variance), the moduli of the weighted residual values were regressed against the corresponding effort data, and the regression lines fitted were then tested for significantly non-zero slope. The table below presents a summary of the results of these tests:

DIVISION	MODEL	P values (homosced.)	
		GSRM	Dynamic
1.3 + 1.4	Schaefer	,214	,541
	Fox	,456	,643
1.5	Schaefer	,132	,651
	Fox	,532	,552
1.6	Schaefer	,002	,006
	Fox	,421	,335
2.1 + 2.2	Schaefer	,023	,113
	Fox	,175	,138

At the 5% level there was a significant departure from homoscedacity for the Schaefer model in Division 1.6 (for both GSRM and dynamic models) and similarly, for the Schaefer model in Divisions 2.1 + 2.2 (GSRM method only).

However, in all other cases the P values were consistent with the assumption of homoscedacity. In most cases P values were larger for the dynamic compared to the GSRM model fits.

From the abovementioned results it therefore appears that, in general, the GSRM and dynamic model fit residuals satisfy the conditions for normality, randomness and homoscedacity, and that these conditions are better satisfied in the case of the dynamic model fits.

From the σ values listed in Tables 8.1 - 8.8, it appears that there is little to choose from between the Schaefer and Fox model fits to the data. This is contrary to what might have been expected in view of the apparent concavity of the C/E versus E plots in the initial stages of the fisheries (see Chapter 1). Dynamic correction factors are probably not the root cause of this, because the same effect shows for the GSRM method. The reason is more likely to be the relatively lower weighting accorded the initial points in the data series both through the square root transformation and use of E as a weighting factor.

In all divisions with one minor exception (that is, the Schaefer model MSY and $Q_{0,1}$(85) estimates for Division 1.6 where the s-s values are less than the Gulland estimates), comparative estimates of sustainable catches and quota levels decrease when moving from the s-s to the Gulland to the dynamic approaches. As is evident from the table below, dynamic model estimates of MSY were on average 17% less than those calculated using the GSRM technique. Therefore, as expected (see Section 4.5), the s-s assumption results in positively biased MSY values. A comparison of the GSRM and dynamic model estimates for MSY and $Q_{0,1}$(85) is given in the table below:

DIVISION	MODEL	MSY		$Q_{0,1}$ (85)	
		GSRM	Dynamic	GSRM	Dynamic
1.3 + 1.4	Schaefer	337	263	405	239
	Fox	353	249	465	253
1.5	Schaefer	189	175	222	168
	Fox	188	162	225	166
1.6	Schaefer	164	139	155	93,7
	Fox	148	123	115	89,5
2.1 + 2.2	Schaefer	62,3	52,8	77,1	50,9
	Fox	60,1	51,8	72,1	53,8

A comparison of these $C_{0,1}(85)$ values indicates that, on average, dynamic model estimates of $C_{0,1}(85)$ are approximately 32% less than those obtained using the GSRM method.

Use of the GFR rather than the GSRM procedure reduces average differences in MSY and $C_{0,1}(85)$ estimates compared to those of the dynamic models to approximately 10% in both cases. Large discrepancies (greater than 10%) in $C_{0,1}(85)$ remain only for Divisions 1.3 + 1.4 (a reduction 24% and 23% for the Schaefer and Fox models respectively) and for Division 1.5 (where a reduction of 14% is evident for the Schaefer model). These large reductions are however compensated by dynamic model $C_{0,1}(85)$ estimates for Divisions 2.1 + 2.2 being slightly higher than those evaluated using the GFR approach. This leads to the lowish average reduction quoted above.

The smaller differences between GFR and dynamic model $C_{0,1}(85)$ values may be attributed to the fact that the functional regression gives relatively greater weight to the points at the start of the data series (which generally have high CPUE values). This results in larger estimates of the pristine CPUE, α , thereby implying that the current stock level corresponds to a greater proportional decline than is the case for dynamic models. When catch limits are evaluated this aspect tends to compensate for the smaller MSY values indicated by the dynamic models.

The precision with which MSY, $C_{0,1}(85)$, r, K and q values are estimated is represented by their respective coefficient of variation values listed in the following table:

DIVISION	MODEL	Dynamic model c.v. estimates				
		MSY	$C_{0,1}$	r	K	q
1.3+1.4	Schaefer	,055	,124	,163	,115	,149
	Fox	,055	,125	,125	,094	,130
1.5	Schaefer	,049	,132	,205	,161	,203
	Fox	,049	,135	,148	,132	,179
1.6	Schaefer	,070	,170	,270	,232	,237
	Fox	,043	,113	,128	,100	,134
2.1+2.2	Schaefer	,064	,173	,259	,264	,272
	Fox	,052	,159	,159	,172	,216
AVERAGE	Schaefer	,060	,150	,224	,193	,215
	Fox	,050	,133	,140	,124	,165

The c.v. values tended to be smallest for MSY, larger for $Q_{0,1}$(85) and greatest for r, K and q. In particular, c.v. estimates for the $Q_{0,1}$(85) values were, on average, 2,5 times greater than the corresponding MSY estimates. However, in general, the $Q_{0,1}$(85) c.v. estimates were still within an acceptable range (that is, less than 18%) thus indicating a fair degree of precision.

The average c.v. values for MSY and $Q_{0,1}$(85) estimates obtained using the GFR and dynamic models are compared in the table below:

MODEL	Average c.v. value	
	MSY	$Q_{0,1}$(85)
GFR	6,8%	11,6%
Dynamic	5,5%	14,1%

From the figures given above it can be seen that for the dynamic model compared to the GFR model, precision is greater for the MSY estimates, but less for the $Q_{0,1}$(85) estimates. However, the difference in these average c.v. values is small. It therefore appears that despite changing from a two-parameter (GFR) to a three-parameter (dynamic) model, there is little loss in precision of the estimate of the operative management variable, $Q_{0,1}$(85).

Figures 8.9 - 8.12 illustrate dynamic model biomass trends for both the Schaefer and Fox models. In all four divisions historical biomass estimates of the Fox model are higher than those corresponding to the Schaefer model. In addition, biomass trends are positive for the most recent years and suggest that the stocks have entered a recovery phase. This would be a consequence of strict catch limits since the late 1970s having kept harvests below sustainable yield levels (see Section 8.6).

Table 8.9 gives the estimates (together with c.v. values) of the dynamic Schaefer and Fox model parameters for calculating the harvestable proportions, h, (corresponding to particular harvesting strategies such as $f_{0,1}$ or f_{MSY}) of the hake stocks in the various divisions. These results were used to obtain a weighted average h value which could be used as an alternative means of providing catch limit recommendations. This topic is discussed in greater detail in the next section.

8.3 Catch limit recommendations

In Section 8.2 dynamic model fits to the catch-effort data were shown to be superior to those obtained using the GFR and other continuous equilibrium approaches. It therefore seems appropriate to base catch limits recommendations on the dynamic model procedure. Any differences between the Schaefer and Fox models were marginal. However, in most cases the latter form provided a slightly better fit (that is, lower σ values and higher P values in tests on the weighted residuals - see tables of Section 8.2), and therefore it appears reasonable (and consistent) to use the Fox model when making recommendations.

It also seems wise to employ a more conservative procedure where there are less appropriate fits to the data or where fits are based on fewer data points. To cater for such uncertainties, a fraction, λ, of the standard error (s.e.) of the quota estimate can be subtracted as follows:

$$Q_{0,1} \rightarrow Q_{0,1} \left[1 - \lambda \text{ c.v.}(Q_{0,1})\right] \qquad (8.1)$$

An adjustment of this type seems appropriate in that for poorer fits or cases where there are insufficient data and/or large inherent variances (and therefore less adequate estimates), the c.v. will be greater.

At the 1983 meeting of the International Whaling Commission (IWC) this method was adopted and a value of $\lambda = 1$ chosen for the evaluation of catch limits for southern hemisphere minke whales (I.W.C., 1984).

The choice of a value for λ appears to be a subjective one, reflecting the degree of conservatism considered appropriate. However, as a guideline, the p. dec. estimates in Tables 8.1 - 8.8 can be used. These estimates represent the probability of the stock declining from 1985 to 1987, provided also the stock level is below MSY level in 1987. The latter specification was included to provide for cases where the stock starts above the MSY level and a decline per se may not necessarily be undesirable (for example, in Divisions 2.1 + 2.2). Estimates of p.dec. for the Schaefer and Fox models in all divisions were in the range 0 - 18% under a $Q_{0,1}$ regime. However, under $0,9Q_{0,1}$ this range was reduced to 0 - 4% . A 10% reduction in $Q_{0,1}$ corresponds to a range of about 0,6 - 0,9 of the c.v. values for the $Q_{0,1}$ estimates from the dynamic models for the various divisions. A choice of $\lambda = 0,5$, say, would therefore achieve a marked reduction in the chance of stock decline without being unnecessarily conservative.

Adopting a value of $\lambda = 0,5$ would mean roughly that values are used which are twice as likely to be below the actual value as above it. This procedure when compared to the use of the best estimate (which is approximately equally likely to be above as below the actual value) clearly reflects a more cautious approach.

Although results for the dynamic Fox model in Division 1.6 show p. dec. values of zero under a $\theta_{0,1}$ strategy so that a downward adjustment of that catch limit on the basis of equation (8.1) might seem unnecessary, a more cautious approach nevertheless seems appropriate since that stock is at a much lower proportion of the MSY level than are the other stocks considered here (this is reflected by the y^*/y_{MSY} values in Tables 8.1 - 8.8). In addition, in Chapter 9 it shall be seen that VPA results indicate more pessimistic biomass values and trends than the dynamic catch-effort models. On this basis, the employment of a λ value greater than zero would be appropriate for all the divisions considered.

The following table gives catch limit recommendations based on the dynamic Fox model and a value of $\lambda = 0,5$ for all divisions. Figures in parenthesis indicate corresponding estimates based on the GFR (Fox model) approach. The resultant recommendations do not differ greatly except in the case of Divisions 1.3 + 1.4 where the GFR approach yields a value 26% larger than does the dynamic model method.

DIVISION	Catch limit ('000 t)	
	1985	1986
1.3 + 1.4 1.5 1.6 2.1 + 2.2	237 (299) 155 (165) 84 (88) 47 (43)	241 159 90 50

In Section 6.3.3 an alternative means of expressing catch limits as a proportion (h) of the current stock size appropriate to harvest under a specified regime was discussed. The appropriate harvestable proportions for both the Schaefer and Fox models and for all four divisions under consideration are shown in Table 8.9. These results have been pooled by averaging after weighting with a factor inversely proportional to the squared standard errors (see weighted averages in Table 8.9) . The standard error of such average values ($\overline{s.e.}$) is estimated from the standard error estimates for the four separate divisions $(\overline{s.e.})_k$ using the formula:

$$\overline{s.e.} = \left[\sum_{k=1}^{4} \frac{1}{(s.e.)^2} \right]^{-\frac{1}{2}} \qquad (8.2)$$

A justification for this formula is given in Appendix 8.2 . The pooled estimates are h = 0,215 (c.v. = 0,108) for the Schaefer model and h = 0,217 (c.v. = 0,079) for the Fox model, both for an f_{MSY} harvesting strategy.

The values of h may be used to obtain catch limit recommendations based on independent methods of estimating current stock size such as trawl surveys or VPA (described in Chapter 9). For example, the VPA ($M = 0{,}3$) estimate of 1984 mid-year biomass for Division 1.6 is 154 thousand metric tons (see Table 9.3). For example, for an $f_{0,1}$ harvesting strategy, the Fox model (incorporating the procedure of deducting half a standard error in estimating h as above) provides the following catch limit recommendation for Division 1.6:

$$\text{Catch limit (Division 1.6)} = h_{0,1} \cdot y_{\text{mid-year}(1984)}\ \text{(VPA)}$$

$$= 0{,}170 \times 154$$

$$= 26 \text{ thousand metric tons.}$$

This quantity is far less than that indicated above using the dynamic model alone. The reduction is partly an appropriate response to the lower biomass indicated by the VPA compared to the dynamic model calculations. However, if such lower biomass values are indeed more realistic, estimates of r (and, accordingly, h) from the catch-effort data alone would be likely to be negatively biased and higher estimates of h than those shown in Table 8.9 might be more appropriate.

8.4 Accuracy of CPUE projections

In this section the efficacy of the dynamic Schaefer and Fox models is examined by considering how accurately these models predict future CPUE trends. The accuracy of such projections was tested by running programs for the dynamic Schaefer and Fox models using only the catch-effort data up to a certain year (for example, 1971) and estimating the model parameters therefrom. These parameters were then used to project 'future' CPUE trends until 1984 using the actual catches taken from the stock in subsequent years (for example, after 1971).

Figures 8.17 - 8.24 show a comparison of predicted and observed CPUE trends for all four ICSEAF divisions.

Forward projections of the CPUE values for one, two and three years were calculated and compared to the actual observed values. The differences were expressed as a relative error (r.e.) where

$$\text{r.e.} = \frac{(C/E)^{\text{projected}} - (C/E)^{\text{observed}}}{(C/E)^{\text{observed}}} \qquad (8.3)$$

The results are illustrated in Figures 8.25 - 8.33. The plots of predictions one year in the future also show a one standard error (s.e.) estimate for the projections. The standard errors were calculated on the basis of the following error model:

$$\sqrt{(C/E)}_i = \sqrt{(\hat{C/E})}_i + \varepsilon_i \qquad (8.4)$$

where ε_i is from $N(0, \sigma^2/E_i)$ (see section 7.3) .

From the two sets of figures referred to above, it can be seen clearly that over the last two years (that is, from 1982) CPUE predictions have been reasonably accurate with errors of no greater than 12% for one-year projections.

If the above error model is appropriate, the statistics (termed 'standardized weighted residuals')

$$\varepsilon^*_j = \frac{[\sqrt{(C/E)}_j - \sqrt{(\hat{C/E})}_j]}{[\sigma/\sqrt{E_j}]} \qquad (8.5)$$

where j refers to the year for which the CPUE projection is made,

would be expected to be normally distributed with unit standard deviation.

A χ^2 test for such normality yielded the following probability values:

DIVISION	MODEL	Probability
1.3 + 1.4	Schaefer	,527
	Fox	,094
1.5	Schaefer	,273
	Fox	,094
1.6	Schaefer	,054
	Fox	,168
2.1 + 2.2	Schaefer	$,5 \times 10^{-3}$ *
	Fox	,001 *

(* indicates that the tests may be unreliable because of the short data series used in the test).

The χ^2 test for normality therefore does not yield significant results, except in Divisions 2.1 + 2.2 where, as indicated, the results should be treated with caution because of the short data series involved. For Divisions 1.3 to 1.6, however, it can be concluded that results are consistent with the hypothesis that these standardized weighted residuals are normally distributed with unit standard deviation.

Similarly, a runs test was used to test for randomness of the ε_j^*. It produced the following results:

DIVISION	MODEL	Probability	
1.3 + 1.4	Schaefer	,061	
	Fox	,422	
1.5	Schaefer	,789	
	Fox	,789	
1.6	Schaefer	,066	
	Fox	,006	
2.1 + 2.2	Schaefer	,751	*
	Fox	1,0	*

Here again, results for Divisions 2.1 + 2.2 should be treated with caution. However, results supported the assumption of a random distribution, except in the case of the Fox model in Division 1.6 where results were significantly at variance with this assumption. The Schaefer model for this division also provided a result only marginally not significant.

It is interesting to note that the above tests produced results that were similar to those obtained for the weighted residuals in Section 8.2 . In both cases it appears that even the dynamic models (particularly for Division 1.6) cannot entirely adequately describe the history of the fisheries. In Figures 8.1 - 8.8 (and especially Figures 8.5 - 8.6 for Division 1.6) it can be seen that biases are occurring (that is, there are periods of consistent over- and underestimation of CPUE values). This could be a reflection of inappropriate allowances for discarding in earlier records. Although catch data for Divisions 1.6 and 2.1 + 2.2 prior to 1972 have been adjusted (ICSEAF 1978) in an attempt to account for discarding (see Chapter 3), the accuracy of such adjustments is questionable. It therefore seems that there is more in the data than the dynamic model can explain. However, it is not immediately apparent whether it is the model that is inadequate or the data that is inaccurate.

8.5 Historical precision of parameter estimates

Time series for values of the Schaefer and Fox model parameters r, q, K, MSY and α (= q.K) were assessed using only the catch-effort data up to the year in question. Results are illustrated in Figures 8.33 - 8.40 together with 95% confidence limits for these estimates for certain years during the history of these fisheries. These confidence intervals were calculated using the Monte Carlo method descibed in Section 7.3 together with a NAG minimization procedure. In many cases the estimated distributions appeared to be markedly skew and even when near-symmetric, distribution tails were much more pronounced than for a normal distribution.

Negative values (and confidence limits) for the parameters considered are unrealistic and, for simplicity, were taken as being equal to zero in the plotting of Figures 8.33 to 8.40 .

From these figures it can be seen that only the parameter α was reasonably well determined at an early stage, the other four parameters showing large fluctuations over the initial period of each fishery. [Note that the confidence intervals shown on the graphs for α may give a false impression of poor precision since the horizontal axis is not at $\alpha = 0$.]

For Divisions 1.3 + 1.4 (see Figures 8.33 - 8.34) and Division 1.6 (see Figures 8.37 - 8.38) Schaefer and Fox parameter estimates appear to be well stabilized since 1977. Similarly, in Division 1.5 (see Figures 8.35 and 8.36) and in Divisions 2.1 + 2.2 (see Figures 8.39 and 8.40) this stabilization occurred after 1979. As can be seen from these figures, only after the initial stages of the fisheries in each division did the estimates for r and MSY (see their confidence limits) become significantly greater than zero. In other words, confidence intervals for the parameter estimates have only recently decreased to levels which are consistent with confirmation of the existence of a density-dependent response by the population. The above comments apply particularly to the Fox model in Division 1.6 (see Figure 8.38) where the MSY estimate was effectively zero or negative for the years 1965 to 1975 .

It is apparent that until the CPUE declines were halted, these confidence intervals for r and MSY frequently overlap zero. This can be attributed to the fact that model fits to the CPUE declines cannot effectively distinguish the removal of accumulated stock from surplus production. An increasing trend in CPUE values over a few years is needed before this can be done. This provides a good illustration of the contention of Walters (1984) that data contrasts are essential for effective determination of key population dynamics parameters and for management of resources. Future 'probing experiments' to produce further data contrasts may well prove desirable for these hake stocks.

8.6 Summary and concluding remarks

In all divisions there was a substantial improvement in fit to the catch-effort data when the dynamic model (as opposed to the GFR, steady-state or GSRM formulations) was used. Tests for randomness, normality and homoscedacity of the weighted residuals were not entirely convincing since they were, in general, based on a relatively short data series and therefore were not very powerful. However, in most cases the P values for the dynamic model residuals were larger than those for the GSRM model, and in only one case of a dynamic model fit did they indicate significant discrepancies from the required conditions of normality, randomness and homoscedacity.

As expected, dynamic model MSY and $Q_{0,1}(85)$ estimates were less (on average, 17% and 32%) than those obtained using the GSRM approach. However, in general, the differences between dynamic and GFR model MSY and $Q_{0,1}(85)$ estimates were smaller (on average, approximately 10% in both cases), although some large discrepancies were still evident. The c.v. estimates indicate a high degree of precision for the dynamic model MSY (on average, 5%), but less for $Q_{0,1}(85)$ (on average, 14%) estimates, and still less in the case of the r, q and K estimates (on average, 18%) . Since the c.v. estimates for $Q_{0,1}(85)$ values were all less than 18%, these estimates still lie within an acceptable range of precision. This range of precision is identical to that for the GFR approach and therefore the need of the dynamic model to estimate three rather than two parameters does not lead to a loss of precision.

There appeared to be little to choose between the Schaefer and Fox models. However, since in most divisions the Fox model reflected a marginal improvement in fit, this model is suggested as the more appropriate basis for catch limit recommendations.

Although biomass estimates for recent years evaluated by the dynamic models are fairly optimistic (indicating recovery of the stocks) for all four ICSEAF division combinations considered, it is possible that the increasing CPUE trends upon which these assessments are based could be reflecting (at least in part) a few good year classes only rather than sustained recovery of the stocks. For example, large proportional catches of juvenile fish have been reported (for example, in Division 1.6 , see Table 9.1) and concern has been expressed that this apparently favourable recruitment is rapidly being exposed to heavy exploitation. Only future catch and effort values and catch-at-age data will allow determination of whether this is the case or not. Therefore, the dynamic model assessments should be treated with caution, especially when making catch limit recommendations.

To cater for these uncertainties, it was suggested that more appropriate (that is, conservative) catch quota values could be obtained by subtracting a fraction of the standard error from the $Q_{0,1}$ estimate. Alternatively, if current biomass estimates are available from other estimates (for example, VPA or trawl surveys), the dynamic model analysis provides an estimate of the appropriate biomass fraction to harvest. For an f_{MSY} strategy, the average fraction for the four stocks analyzed using the Fox model is 0,217 .

An analysis of the accuracy of CPUE projections showed that for the initial period of the fisheries when consistently declining CPUE trends were evident, confidence intervals for r and MSY often overlapped zero. This was caused by the minimization routine frequently choosing to explain the historical catches as much more the removal of accumulated stock than the harvesting of surplus production. However, during the past decade, increasing CPUE trends have been reported and these data contrasts have enabled the models to better estimate surplus production and so to provide results which demonstrate a statistically significant density-dependent response by the population. Relative error calculations over the history of the fisheries indicate relatively accurate CPUE predictions, with errors of less than 12% for the one-year projections since 1982 for all divisions considered.

These results lead to the conclusion that the dynamic model approach is an improvement over that of the traditional steady-state models (such as the GFR method). Bias is reduced without an accompanying loss of precision, and the unrealistic continuous equilibrium assumption of the steady-state models is avoided.

METHOD PARAMETER	FUNCTIONAL REGRESSION	SQUARE ROOT MINIMIZATION		
	Gulland	Gulland	S-state	Dynamic
α β	1,078 (,083) ,000975(,172)	0,952 0,000674	0,852 0,000448	1,250 (,049) 0,00148(,084)
E_{MSY} $E_{0,1}$	553 (,111) 498 (,111)	707 636	952 856	421 (,053) 379 (,053)
CPUE(84)-obs. CPUE(84)-exp.	0,64 0,75 (,065)	0,64 0,73	0,64 0,71	0,64 0,63 (,137)
y^*/K y^*/y_{MSY}	0,590 (,082) 1,180 (,082)	0,668 1,335	0,746 1,492	0,517 (,086) 1,034 (,086)
MSY ('000 t)	298 (,086)	337	406	263 (,055)
$Q_{steady\text{-}state}$ Q_{MSY} ('000 t)	288 (,099) 352 (,111)	299 450	307 605	263 (,053) 266 (,124)
$Q_{0,1}$ (85) ('000 t) $Q_{0,1}$ (86)	316 (,111)	405	545	239 (,124) 247 (,122)
$Q_{0,1}$ a.i.r.% p.dec.%				1,3 (,837) 10,2
$0,9Q_{0,1}$ a.i.r.% p.dec.%				3,0 (,390) 1,1
$0,8Q_{0,1}$ a.i.r.% p.dec.%				4,8 (,275) 0,1
r q K				0,392 (,163) ,000466 (,149) 2683 (,115)
y (mid-84)				1354 (,116)
No. data pts Wt. residuals σ P: normal P: random P: homosced.	18	18 1,91 0,248 0,004 0,214	20 2,58	20 0,945 0,752 0,066 0,541

Table 8.1 Cape hake stock in Divisions 1.3 + 1.4: parameters for Schaefer model fits (period: Gulland 1967-1984, others 1965-1984). Figures in parenthesis show coefficients of variation.

METHOD / PARAMETER	FUNCTIONAL REGRESSION	SQUARE ROOT MINIMIZATION		
	Gulland	Gulland	S-state	Dynamic
α	1,207 (,143)	1,026	0,925	1,270 (,051)
β	0,00152 (,171)	0,00107	0,000795	0,00188 (,067)
E_{MSY}	660 (,177)	935	1258	533 (,068)
$E_{0,1}$	516 (,177)	731	983	416 (,068)
CPUE(84)-obs.	0,64	0,64	0,64	0,64
CPUE(84)-exp.	0,73 (,074)	0,72	0,72	0,61 (,138)
y^*/K	0,527 (,136)	0,620	0,687	0,486 (,077)
y^*/y_{MSY}	1,432 (,136)	1,685	1,868	1,320 (,077)
MSY ('000 t)	293 (,085)	353	428	249 (,055)
$Q_{steady\text{-}state}$	269 (,105)	284	300	237 (,035)
Q_{MSY} ('000 t)	420 (,177)	595	800	324 (,125)
$Q_{0,1}$ (85) ('000 t)	328 (,177)	465	625	253 (,125)
$Q_{0,1}$ (86)				256 (,118)
$Q_{0,1}$ a.i.r.%				-1,2 (-,407)
$Q_{0,1}$ p.dec.%				0,8
$0,9Q_{0,1}$ a.i.r.%				0,4 (1,31)
$0,9Q_{0,1}$ p.dec.%				0,1
$0,8Q_{0,1}$ a.i.r.%				2,1 (,305)
$0,8Q_{0,1}$ p.dec.%				0
r				1,74 (,125)
q				,000407 (,130)
K				3124 (,094)
y (mid-84)				1497 (,100)
No. data pts	18	18	20	20
Wt. residuals				
σ		1,95	2,56	0,937
P: normal		0,248		0,752
P: random		0,004		0,358
P: homosced.		0,456		0,643

Table 8.2 Cape hake stock in Divisions 1.3 + 1.4: parameters for Fox model fits (period: Gulland 1967–1984, others 1965–1984). Figures in parenthesis show coefficients of variation.

METHOD PARAMETER	FUNCTIONAL REGRESSION	SQUARE ROOT MINIMIZATION		
	Gulland	Gulland	S-state	Dynamic
α	1,685 (,078)	1,545	1,381	1,954 (,060)
β	,00392 (,158)	,00316	,00222	,00544 (,097)
E_{MSY}	215 (,092)	244	311	179 (,050)
$E_{0,1}$	194 (,092)	220	280	161 (,050)
CPUE(84)-obs.	1,01	1,01	1,01	1,01
CPUE(84)-exp.	1,15 (,053)	1,11	1,11	1,04 (,167)
y^*/K	0,599 (,077)	0,654	0,731	0,556 (,101)
y^*/y_{MSY}	1,199 (,077)	1,307	1,463	1,112 (,101)
MSY ('000 t)	181 (,059)	189	215	175 (,049)
$Q_{steady\text{-}state}$	174 (,075)	171	169	173 (,044)
Q_{MSY} ('000 t)	217 (,092)	247	314	187 (,132)
$Q_{0,1}$ (85) ('000 t)	196 (,092)	222	282	168 (,132)
$Q_{0,1}$ (86)				176 (,122)
$Q_{0,1}$ a.i.r.%				-0,1 (-10,7)
p.dec.%				12,6
$0,9Q_{0,1}$ a.i.r.%				2,5 (,571)
p.dec.%				1,8
$0,8Q_{0,1}$ a.i.r.%				5,0 (,337)
p.dec.%				0,1
r				0,603 (,205)
q				,00168 (,203)
K				1162 (,161)
y (mid-84)				619 (,148)
No. data pts	18	18	20	20
Wt. residuals				
σ		1,22	1,88	0,921
P: normal		0,317		0,403
P: random		0,052		0,646
P: homosced.		0,132		0,651

Table 8.3 Cape hake stock in Division 1.5: parameters for Schaefer model fits (period: Gulland 1967–1984, others 1965–1984). Figures in parenthesis show coefficients of variation.

METHOD PARAMETER	FUNCTIONAL REGRESSION	SQUARE ROOT MINIMIZATION		
	Gulland	Gulland	S-state	Dynamic
α β	2,092 (,150) 0,00441 (,154)	1,786 0,00350	1,640 0,00288	1,984 (,071) 0,00451 (,075)
E_{MSY} $E_{0,1}$	227 (,156) 177 (,156)	286 223	348 272	222 (,077) 173 (,077)
CPUE(84)-obs. CPUE(84)-exp.	1,01 1,15 (,066)	1,01 1,11	1,01 1,16	1,01 0,96 (,185)
y^*/K y^*/y_{MSY}	0,483 (,142) 1,312 (,142)	0,565 1,537	0,616 1,674	0,495 (,093) 1,346 (,093)
MSY ('000 t)	174 (,056)	188	210	162 (,049)
$Q_{steady-state}$ Q_{MSY} ('000 t)	167 (,077) 229 (,156)	164 288	170 351	153 (,030) 213 (,135)
$Q_{0,1}$ (85) ('000 t) $Q_{0,1}$ (86)	179 (,156)	225	274	166 (,135) 169 (,122)
$Q_{0,1}$ a.i.r.% p.dec.%				-2,0 (-,232) 1,6
$0,9Q_{0,1}$ a.i.r.% p.dec.%				0,2 (3,24) 0,9
$0,8Q_{0,1}$ a.i.r.% p.dec.%				2,4 (,341) 0
r q K				2,15 (,148) ,00132 (,179) 1497 (,132)
y (mid-84)				724 (,131)
No. data pts Wt. residuals σ P: normal P: random P: homosced.	18	18 1,27 0,127 0,052 0,532	20 1,84	20 0,981 0,752 0,358 0,552

Table 8.4 Cape hake stock in Division 1.5: parameters for Fox model fits (period: Gulland 1967-1984, others 1965-1984). Figures in parenthesis show coefficients of variation.

METHOD / PARAMETER	FUNCTIONAL REGRESSION	SQUARE ROOT MINIMIZATION		
	Gulland	Gulland	S-state	Dynamic
α	18,18 (,069)	12,71	14,36	19,08 (,043)
β	0,524 (,121)	0,247	0,330	0,653 (,065)
E_{MSY}	17,4 (,067)	25,8	21,8	14,6 (,053)
$E_{0,1}$	15,7 (,067)	23,2	19,6	13,2 (,053)
CPUE(84)-obs.	6,67	6,67	6,67	6,67
CPUE(84)-exp.	11,49 (,057)	9,56	10,22	7,13 (,181)
y^*/K	0,367 (,069)	0,525	0,465	0,391 (,139)
y^*/y_{MSY}	0,734 (,069)	1,050	0,929	0,781 (,139)
MSY ('000 t)	158 (,064)	164	156	139 (,070)
$Q_{steady\text{-}state}$	147 (,055)	163	155	133 (,116)
Q_{MSY} ('000 t)	116 (,067)	172	145	104 (,170)
$Q_{0,1}$ (85) ('000 t)	104 (,067)	155	131	93,7 (,170)
$Q_{0,1}$ (86)				101,8 (,185)
$Q_{0,1}$ a.i.r.%				6,7 (,577)
$Q_{0,1}$ p.dec.%				4,3
$0,9Q_{0,1}$ a.i.r.%				9,1 (,454)
$0,9Q_{0,1}$ p.dec.%				1,5
$0,8Q_{0,1}$ a.i.r.%				11,4 (,385)
$0,8Q_{0,1}$ p.dec.%				0,3
r				0,433 (,270)
q				,0148 (,237)
K				1286 (,232)
y (*mid*-84)				480 (,209)
No. data pts	27	27	30	30
<u>Wt. residuals</u>				
σ		1,72	3,50	0,814
P: normal		0,105		0,721
P: random		$0,4\times10^{-4}$		0,063
P: homosced.		0,002		0,006

Table 8.5 Cape hake stock in Division 1.6: parameters for Schaefer model fits (period: Gulland 1958-1984, others 1955-1984). Figures in parenthesis show coefficients of variation.

METHOD / PARAMETER	FUNCTIONAL REGRESSION	SQUARE ROOT MINIMIZATION		
	Gulland	Gulland	S-state	Dynamic
α	21,85 (,128)	18,17	15,18	20,62 (,043)
β	0,0562 (,111)	0,0451	0,0330	0,0615 (,038)
E_{MSY}	17,8 (,111)	22,2	30,3	16,3 (,038)
$E_{0,1}$	13,9 (,111)	17,3	23,7	12.7 (,038)
CPUE(84)-obs.	6,67	6,67	6,67	6,67
CPUE(84)-exp.	10,66 (,065)	10,21	10,04	7,04 (,148)
y^*/K	0,305 (,122)	0,367	0,439	0,353 (,084)
y^*/y_{MSY}	0,830 (,122)	0,998	1,194	0,958 (,084)
MSY ('000 t)	143 (,058)	148	169	123 (,043)
$Q_{steady\text{-}state}$	141 (,051)	148	166	123 (,048)
Q_{MSY} ('000 t)	119 (,111)	148	202	115 (,113)
$Q_{0,1}$ (85) ('000 t)	92,8 (,111)	115	158	89,5 (,113)
$Q_{0,1}$ (86)				94,9 (,113)
$Q_{0,1}$ a.i.r.%				5,1 (,237)
$Q_{0,1}$ p.dec.%				0
$0,9Q_{0,1}$ a.i.r.%				6,6 (,196)
$0,9Q_{0,1}$ p.dec.%				0
$0,8Q_{0,1}$ a.i.r.%				8,2 (,171)
$0,8Q_{0,1}$ p.dec.%				0
r				1,42 (,128)
q				,0117 (,134)
K				1764 (,100)
y (mid-84)				602 (,096)
No. data pts	27	27	30	30
Wt. residuals				
σ		1,49	1,98	0,689
P: normal		0,198		0,721
P: random		$0,4\times10^{-4}$		0,063
P: homosced.		0,421		0,335

Table 8.6 Cape hake stock in Division 1.6: parameters for Fox model fits (period: Gulland 1958-1984, others 1955-1984). Figures in parenthesis show coefficients of variation.

METHOD / PARAMETER	FUNCTIONAL REGRESSION	SQUARE ROOT MINIMIZATION		
	Gulland	Gulland	S-state	Dynamic
α β	1,226 (,083) ,00634 (,147)	0,800 ,00257	0,749 0,00192	1,025 (,097) ,00497 (,180)
E_{MSY} $E_{0,1}$	96,7 (,082) 87,0 (,082)	156 140	195 175	103 (,105) 92,8 (,105)
CPUE(84)-obs. CPUE(84)-exp.	0,55 0,68 (,070)	0,55 0,58	0,55 0,60	0,55 0,55 (,199)
y^*/K y^*/y_{MSY}	0,449 (,081) 0,897 (,081)	0,687 1,374	0,734 1,468	0,552 (,130) 1,104 (,130)
MSY ('000 t)	59,2 (,076)	62,3	73,0	52,8 (,064)
$Q_{steady\text{-}state}$ Q_{MSY} ('000 t)	58,6 (,070) 53,2 (,082)	53,6 85,7	57,0 107	52,2 (,058) 56,6 (,173)
$Q_{0,1}$ (85) ('000 t) $Q_{0,1}$ (86)	47,9 (,082)	77,1	96,5	50,9 (,173) 52,7 (,152)
$Q_{0,1}$ a.i.r.% p.dec.%				-0,3 (-5,24) 18,1
$0,9Q_{0,1}$ a.i.r.% p.dec.%				2,5 (,824) 4,0
$0,8Q_{0,1}$ a.i.r.% p.dec.%				5,4 (,485) 0,6
r q K				0,698 (,259) ,00338 (,272) 303 (,264)
y (*mid*-84)				162 (,298)
No. data pts <u>Wt. residuals</u> σ P: normal P: random P: homosced.	16	16 0,793 0,724 0,010 0,023	18 1,05	18 0,660 0,317 0,145 0,113

Table 8.7 Cape hake stock in Divisions 2.1 + 2.2: parameters for Schaefer model fits(period: Gulland 1969-1984, others 1967-1984). Figures in parenthesis show coefficients of variation.

METHOD / PARAMETER	FUNCTIONAL REGRESSION	SQUARE ROOT MINIMIZATION		
	Gulland	Gulland	5-state	Dynamic
α	1,270 (,130)	0,974	0,909	1,101 (,091)
β	,00847 (,134)	0,00596	0,00487	,00782 (,112)
E_{MSY}	118 (,132)	168	205	128 (,118)
$E_{0,1}$	92,3 (,132)	131	160	100 (,118)
CPUE(84)-obs.	0,55	0,55	0,55	0,55
CPUE(84)-exp.	0,62 (,057)	0,59	0,62	0,54 (,183)
y^*/K	0,433 (,121)	0,565	0,605	0,498 (,109)
y^*/y_{MSY}	1,177 (,121)	1,536	1,645	1,355 (,109)
MSY ('000)	55,2 (,061)	60,1	68,6	51,8 (,052)
$Q_{steady-state}$	54,4 (,065)	52,7	56,7	48,9 (,026)
Q_{MSY} ('000 t)	65,0 (,132)	92,2	113	68,8 (,159)
$Q_{0,1}$ (85) ('000 t)	50,8 (,132)	72,1	88,2	53,8 (,159)
$Q_{0,1}$ (86)				54,0 (,133)
$Q_{0,1}$ a.i.r.%				-3,0 (-,172)
$Q_{0,1}$ p.dec.%				2,7
$0,9Q_{0,1}$ a.i.r.%				-0,1 (-12,0)
$0,9Q_{0,1}$ p.dec.%				0,6
$0,8Q_{0,1}$ a.i.r.%				2,8 (,385)
$0,8Q_{0,1}$ p.dec.%				0
r				2,42 (,159)
q				,00326 (,216)
K				338 (,172)
y (mid-84)				165 (,203)
No. data pts	16	16	18	18
Wt. residuals				
σ		0,710	0,982	0,602
P: normal		0,480		0,248
P: random		0,010		0,145
P: homosced.		0,175		0,138

Table 8.8 Cape hake stock in Divisions 2.1 + 2.2: parameters for Fox model fits (period: Gulland 1969-1984, others 1967-1984). Figures in parenthesis show coefficients of variation.

	Schaefer (r)	Fox (2r/ln(K))
Division 1.3 + 1.4	0,392 (0,163)	0,432 (0,136)
Division 1.5	0,603 (0,205)	0,588 (0,164)
Division 1.6	0,433 (0,270)	0,380 (0,141)
Division 2.1 + 2.2	0,698 (0,259)	0,831 (0,183)
Weighted average	0,455 (0,108)	0,452 (0,079)
Weighted average less [(s.e.)/2]	0,430	0,434
Proportional harvest ~ f_{MSY} : h_{MSY}	0,215	0,217
Proportional harvest ~ $f_{0,1}$: $h_{0,1}$	0,193	0,170

Table 8.9 Estimates of dynamic Schaefer and Fox model parameters for calculating the harvestable portions of the hake stocks in the various ICSEAF divisions. Figures in parenthesis indicate coefficients of variation.

Division	Model	c.v. [MSY]		c.v. [$Q_{0,1}$(85)]	
		Efron 1982	Equ. (A7.2.5)	Efron 1982	Equ. (A7.2.5)
1.3 + 1.4	Schaefer	0,069	0,086	0,085	0,111
	Fox	0,062	0,085	0,149	0,177
1.5	Schaefer	0,052	0,059	0,067	0,092
	Fox	0,051	0,056	0,128	0,156
1.6	Schaefer	0,058	0,064	0,095	0,067
	Fox	0,051	0,058	0,143	0,111
2.1 + 2.2	Schaefer	0,069	0,076	0,172	0,082
	Fox	0,071	0,061	0,224	0,132

Table 8.10 Comparison of the coefficient of variation (c.v.) estimates for the MSY and $Q_{0,1}$(85) estimates in the Schaefer and Fox models using the Gulland Functional Regression approach for Efron's bootstrap procedure (see Section 7.2) and for the bootstrap procedure suggested in equation (A7.2.5) .

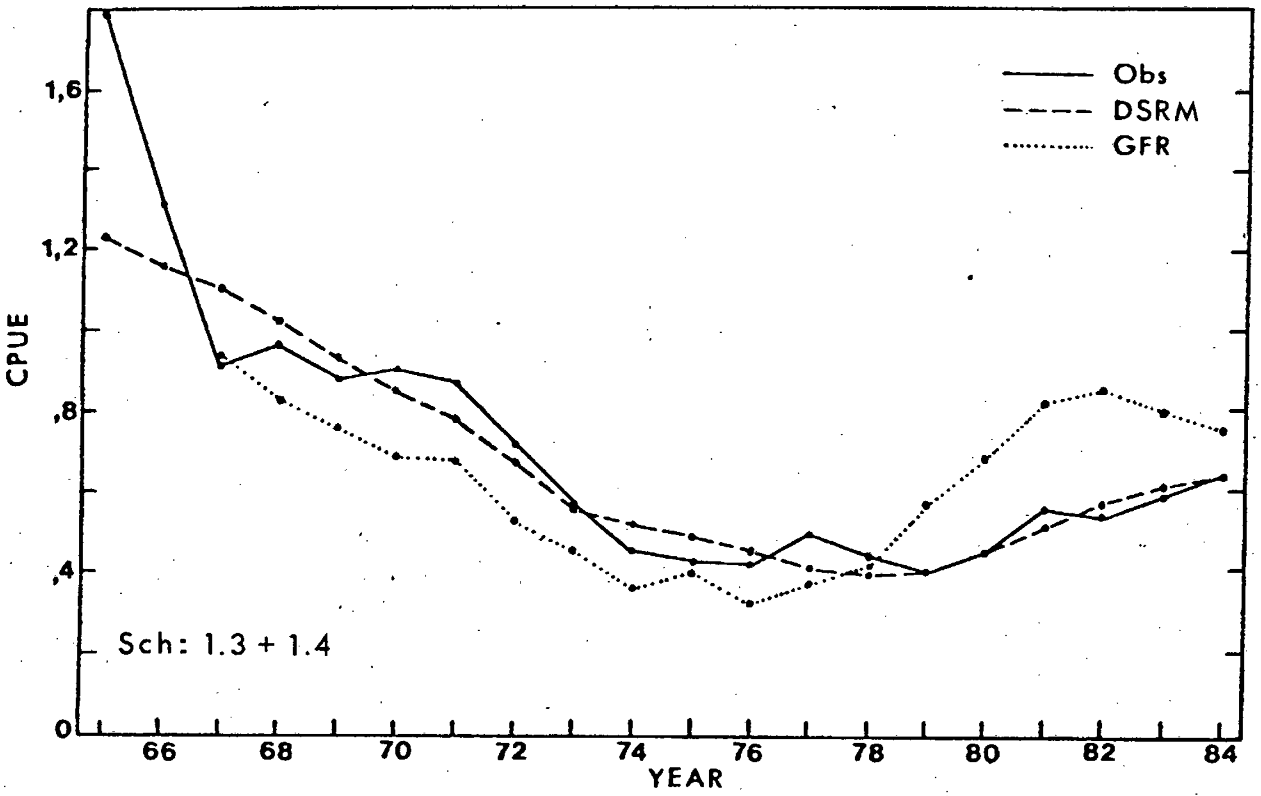


Figure 8.1 Schaefer model.

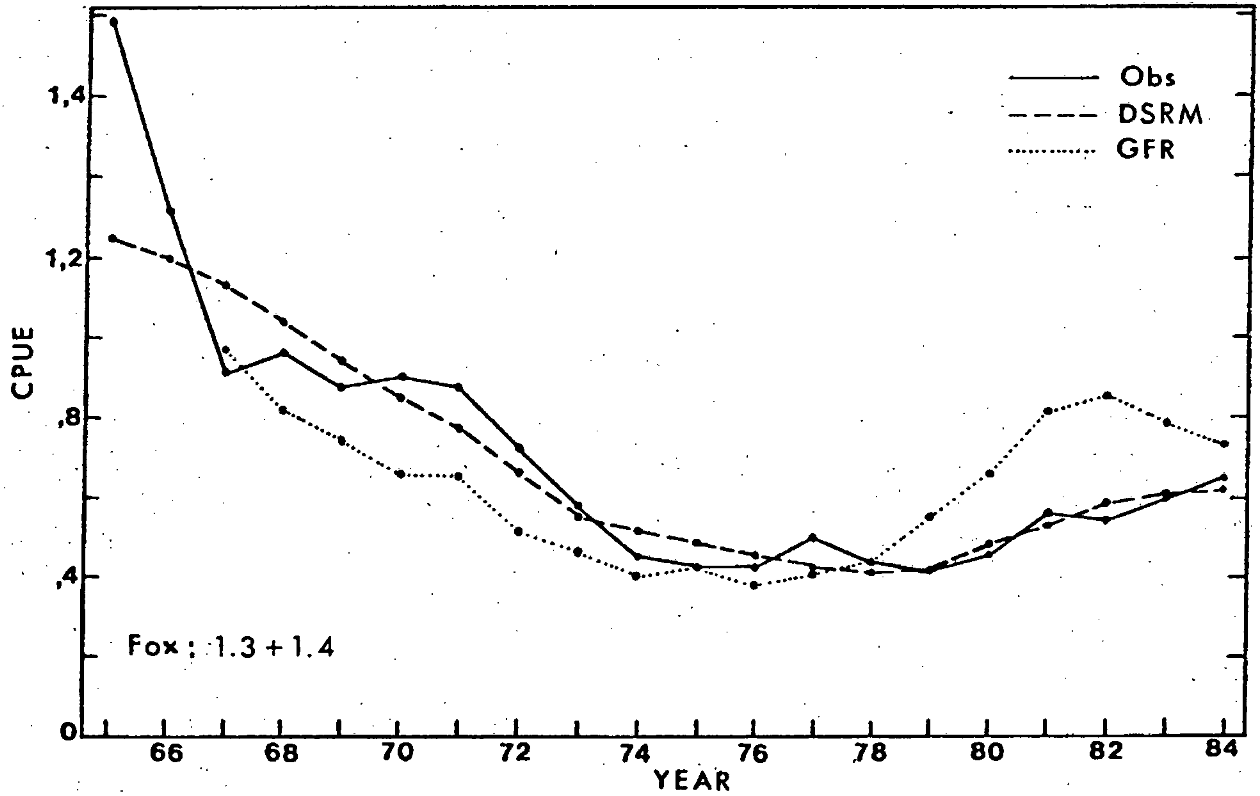


Figure 8.2 Fox model.

Figures 8.1 - 8.2: Divisions 1.3 + 1.4 . Plots of the observed CPUE time series (solid line) are compared to the expected CPUE series for the dynamic model (dashed line) and the GFR method (dotted line).

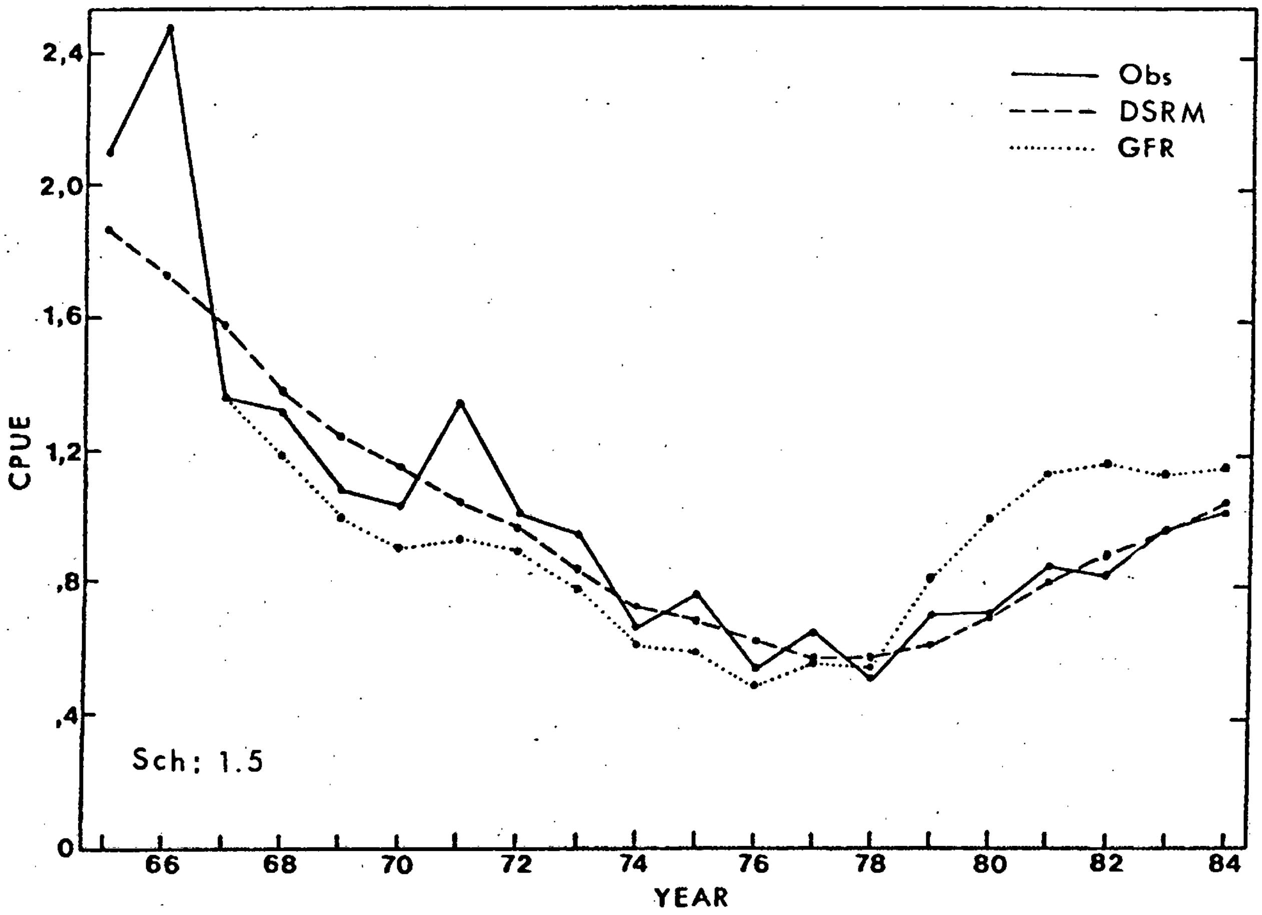


Figure 8.3 Schaefer model.

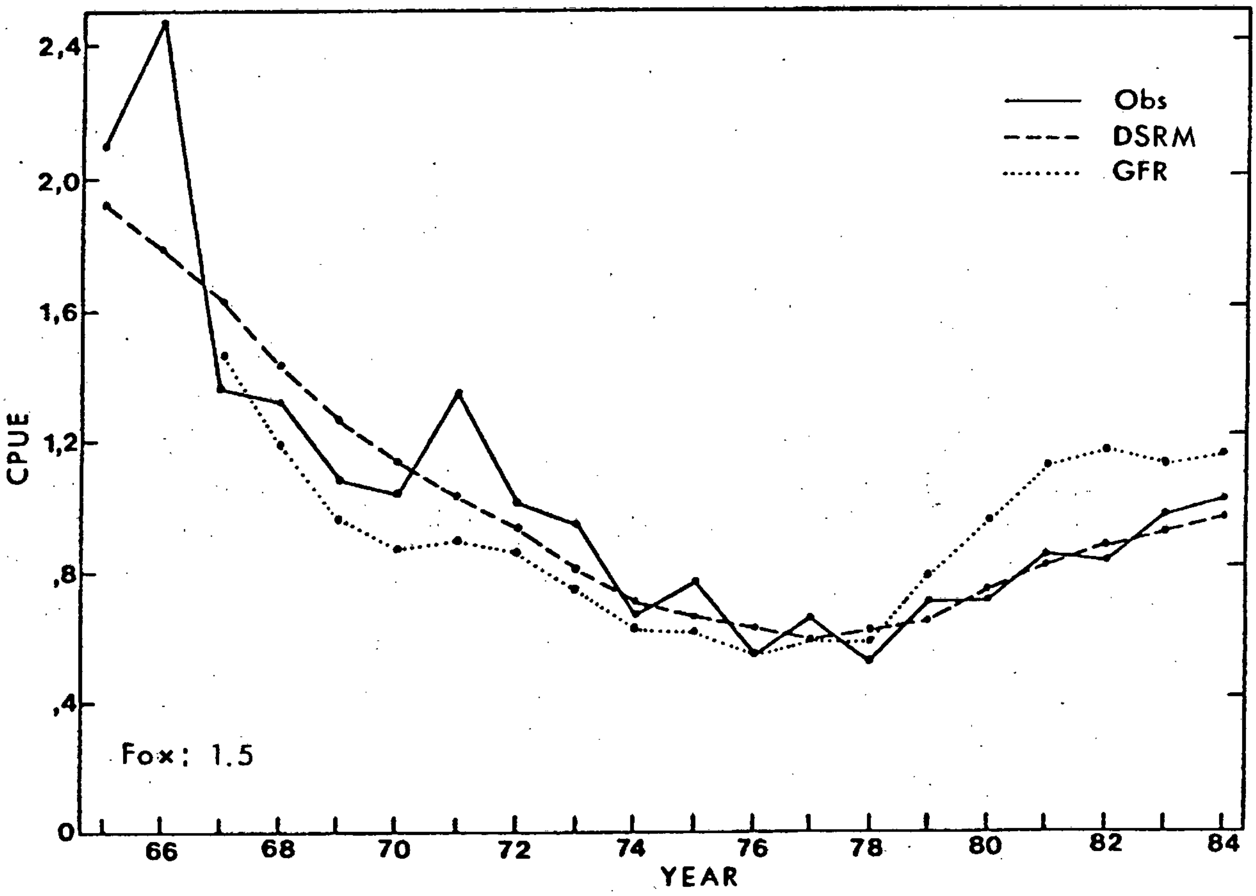


Figure 8.4 Fox model.

Figures 8.3 - 8.4: Division 1.5 . Plots of the observed CPUE time series (solid line) are compared to the expected CPUE series for the dynamic model (dashed line) and the GFR method (dotted line).

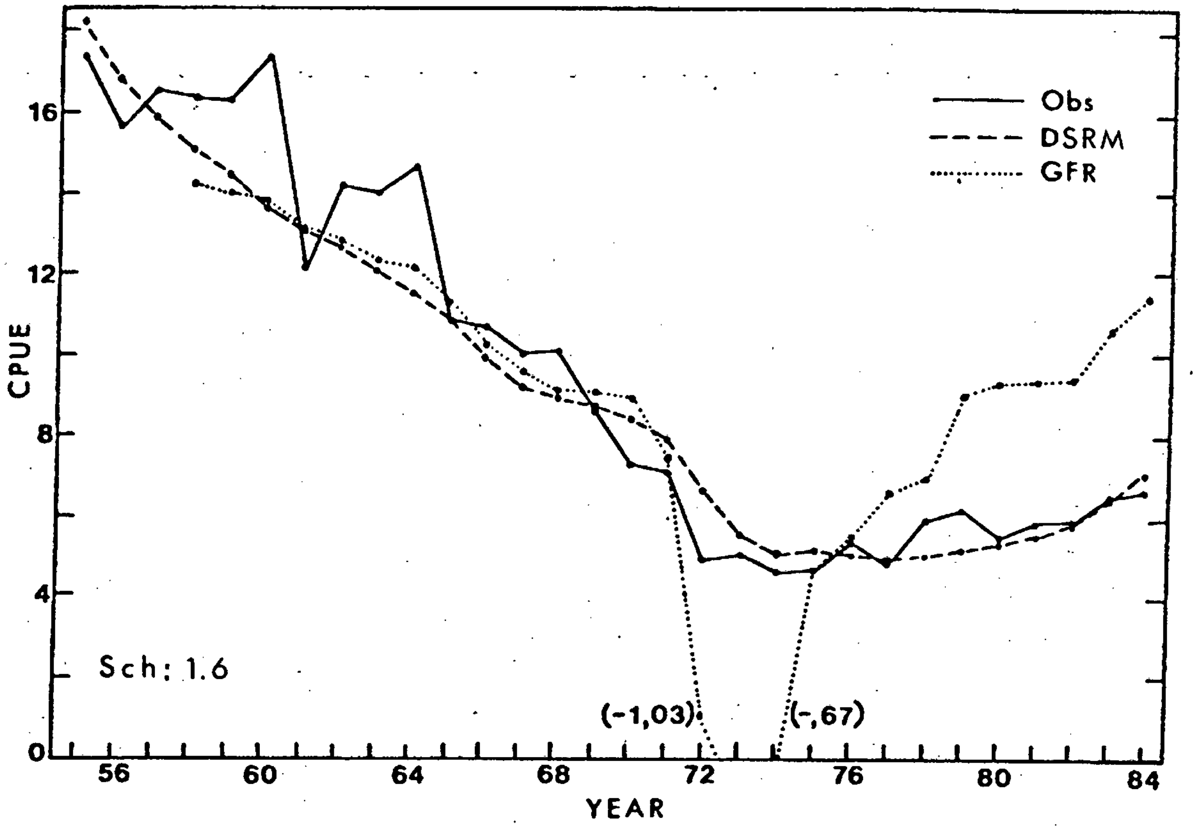


Figure 8.5 Schaefer model.

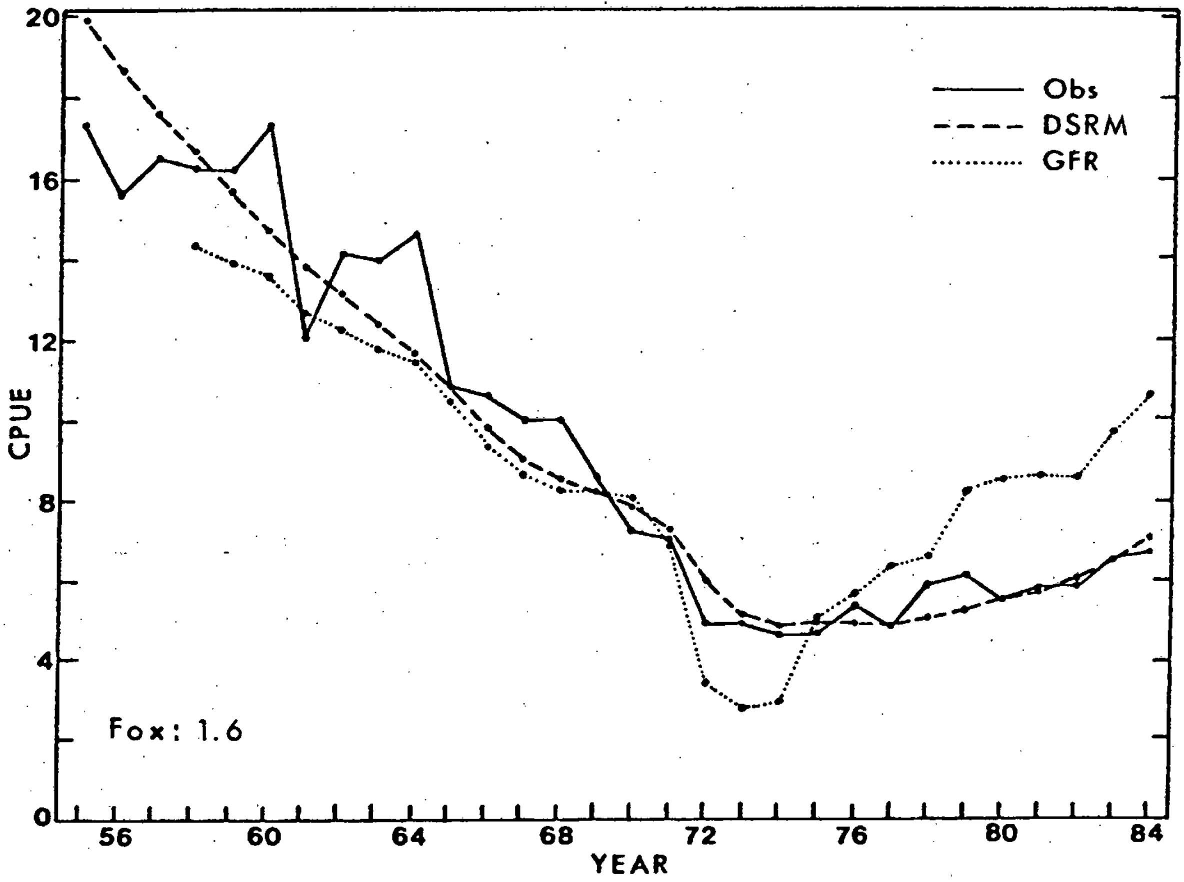


Figure 8.6 Fox model.

Figures 8.5 - 8.6: Division 1.6. Plots of the observed CPUE time series (solid line) are compared to the expected CPUE series for the dynamic model (dashed line) and the GFR method (dotted line).

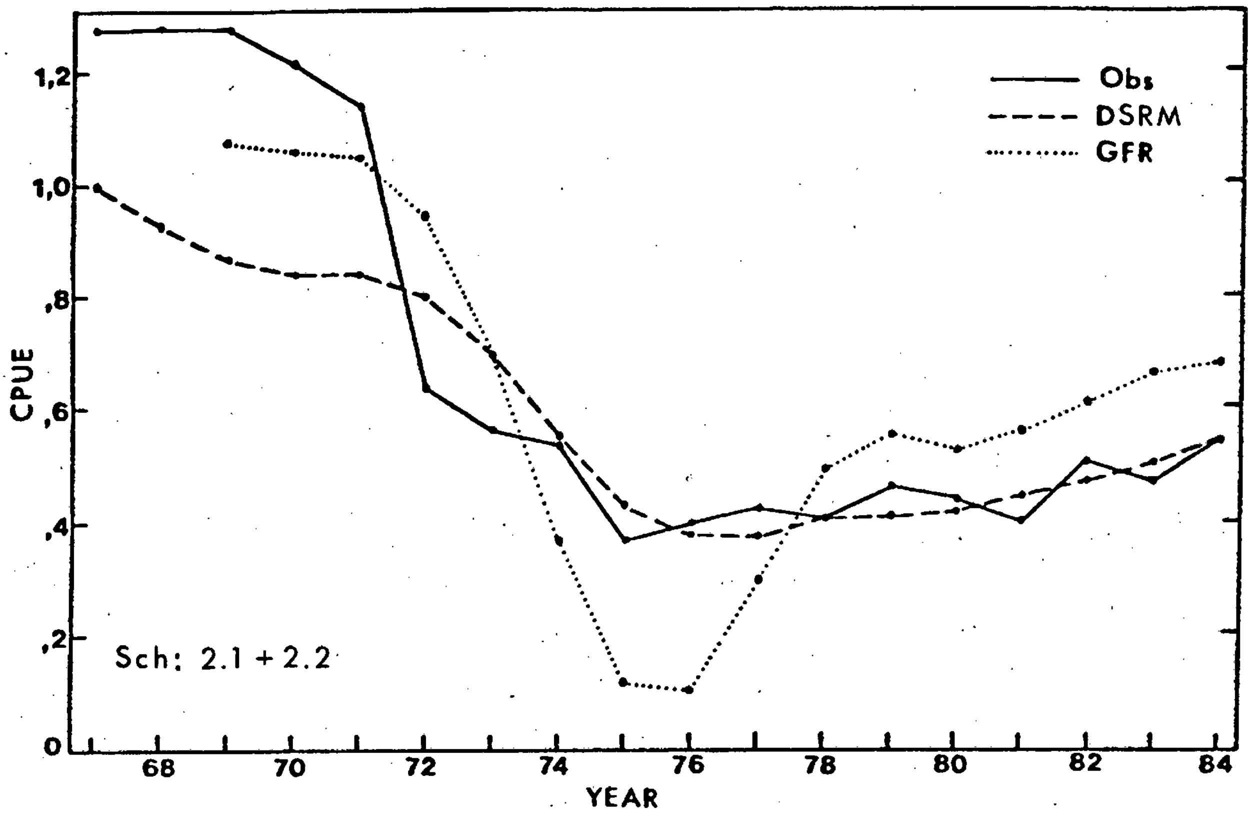


Figure 8.7 Schaefer model.

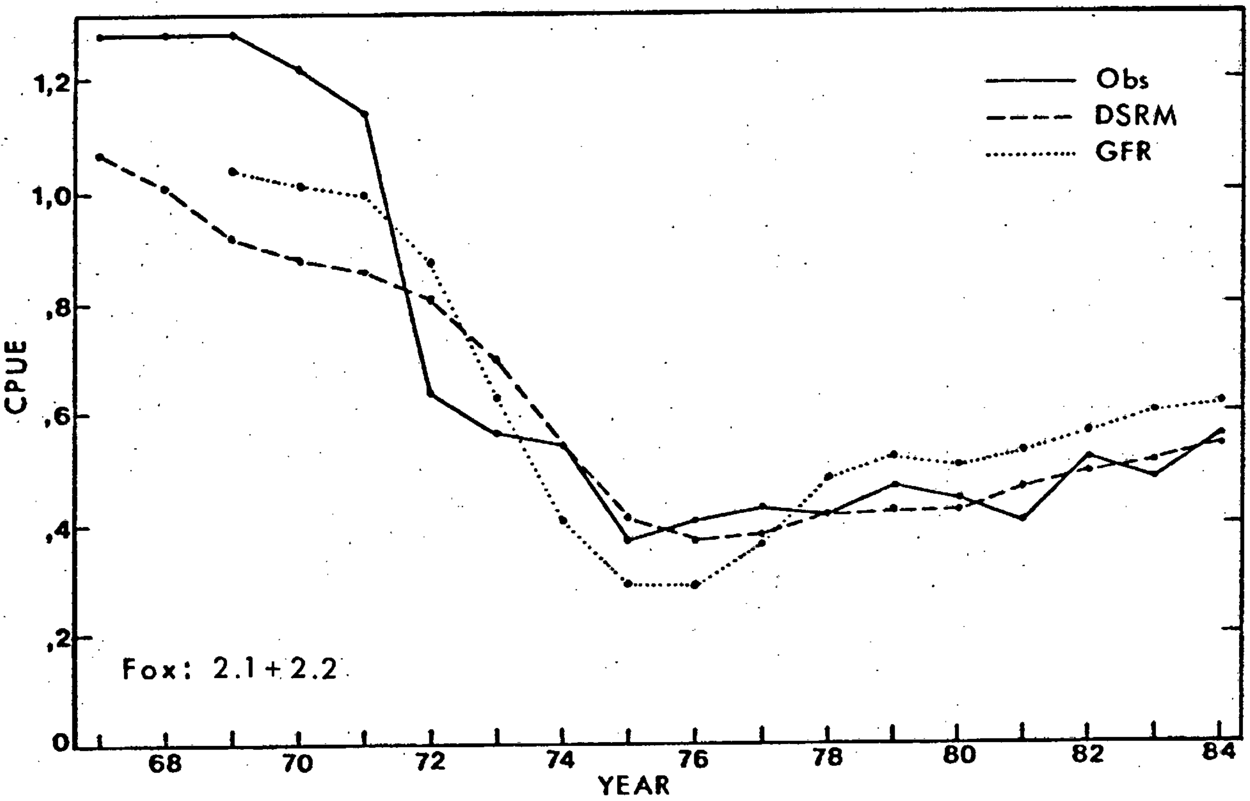


Figure 8.8 Fox model.

Figures 8.7 - 8.8: Divisions 2.1 + 2.2 . Plots of the observed CPUE time series (solid line) are compared to the expected CPUE series for the dynamic model (dashed line) and the GFR method (dotted line).

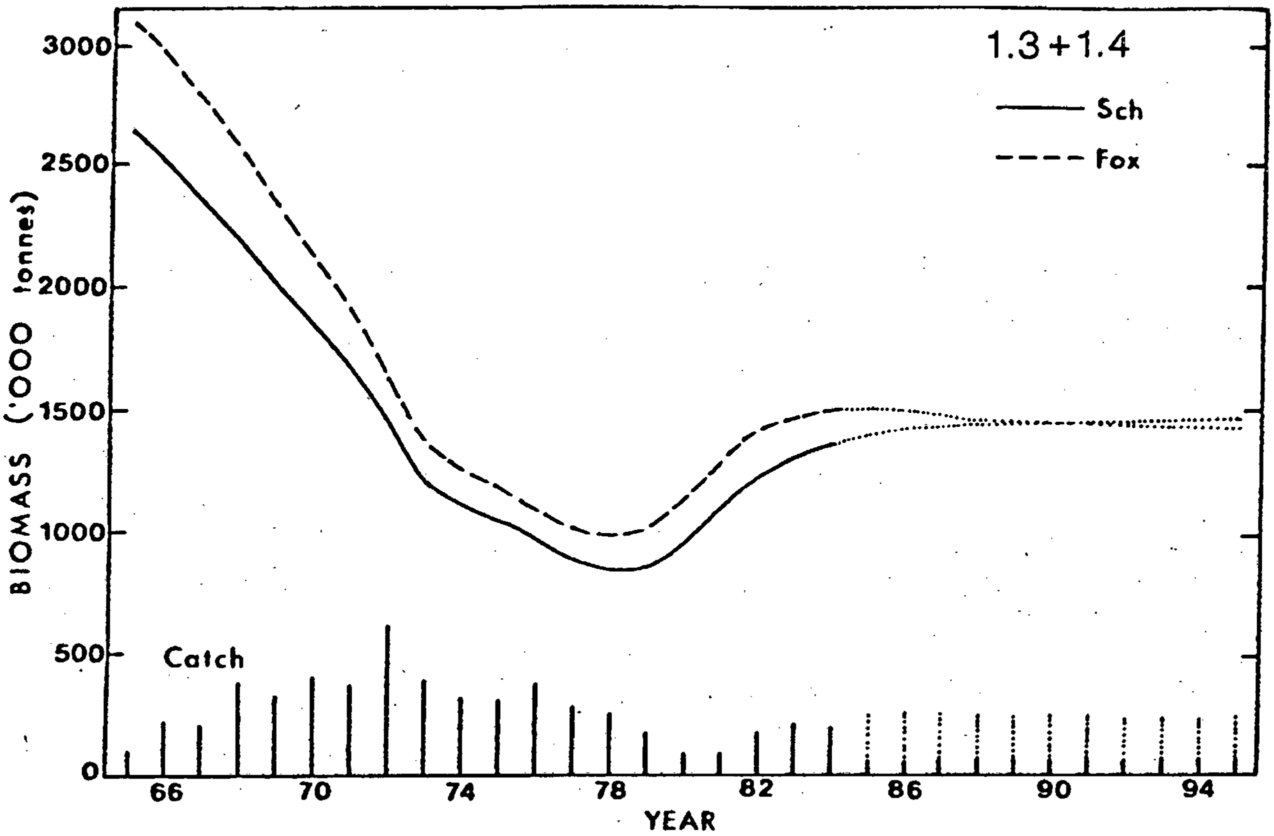


Figure 8.9 Divisions 1.3 + 1.4

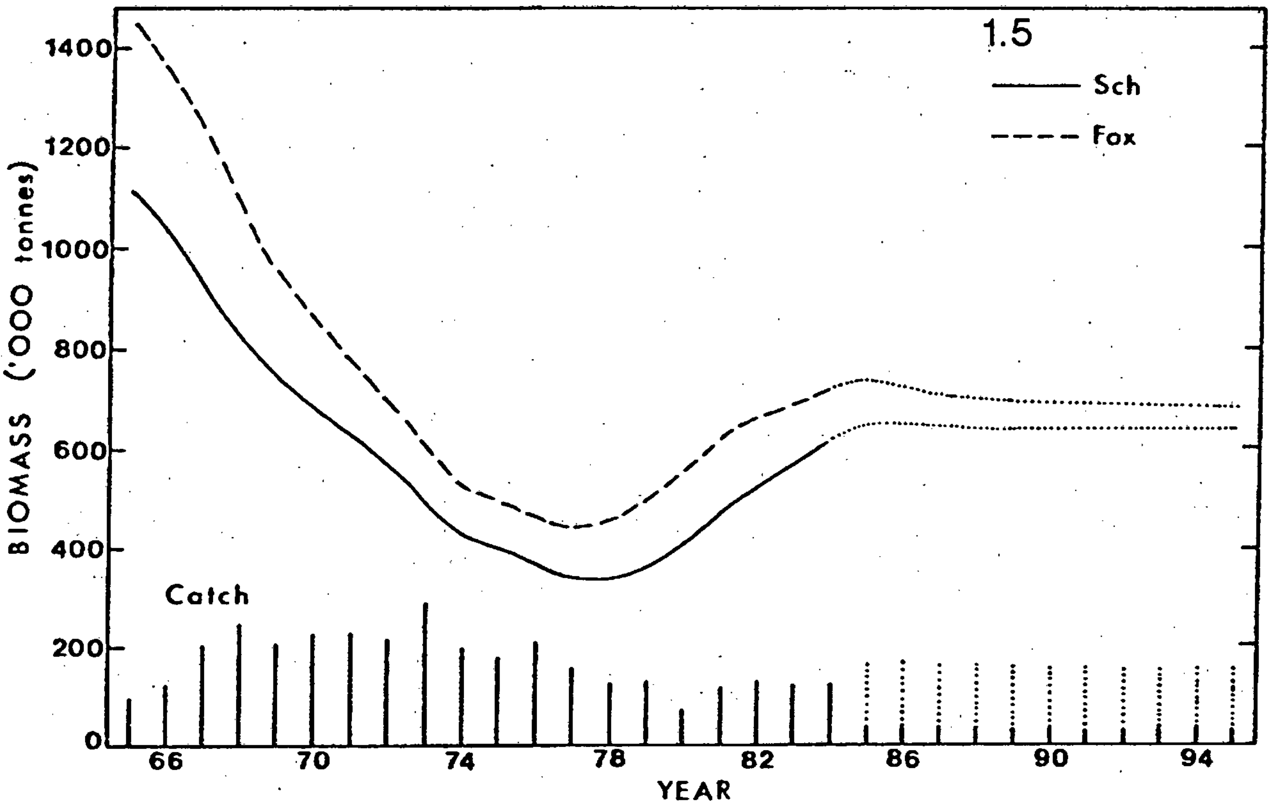


Figure 8.10 Division 1.5

Figures 8.9 – 8.10 : Biomass estimates using the dynamic Schaefer model (solid line) are compared with those from the dynamic Fox model (dashed line), and ten-year biomass projections under a $Q_{0,1}$ harvesting strategy (dotted lines) are shown for both models. Historical annual catches are indicated by solid vertical bars and the $Q_{0,1}$ projections for the next ten years by dotted vertical bars.

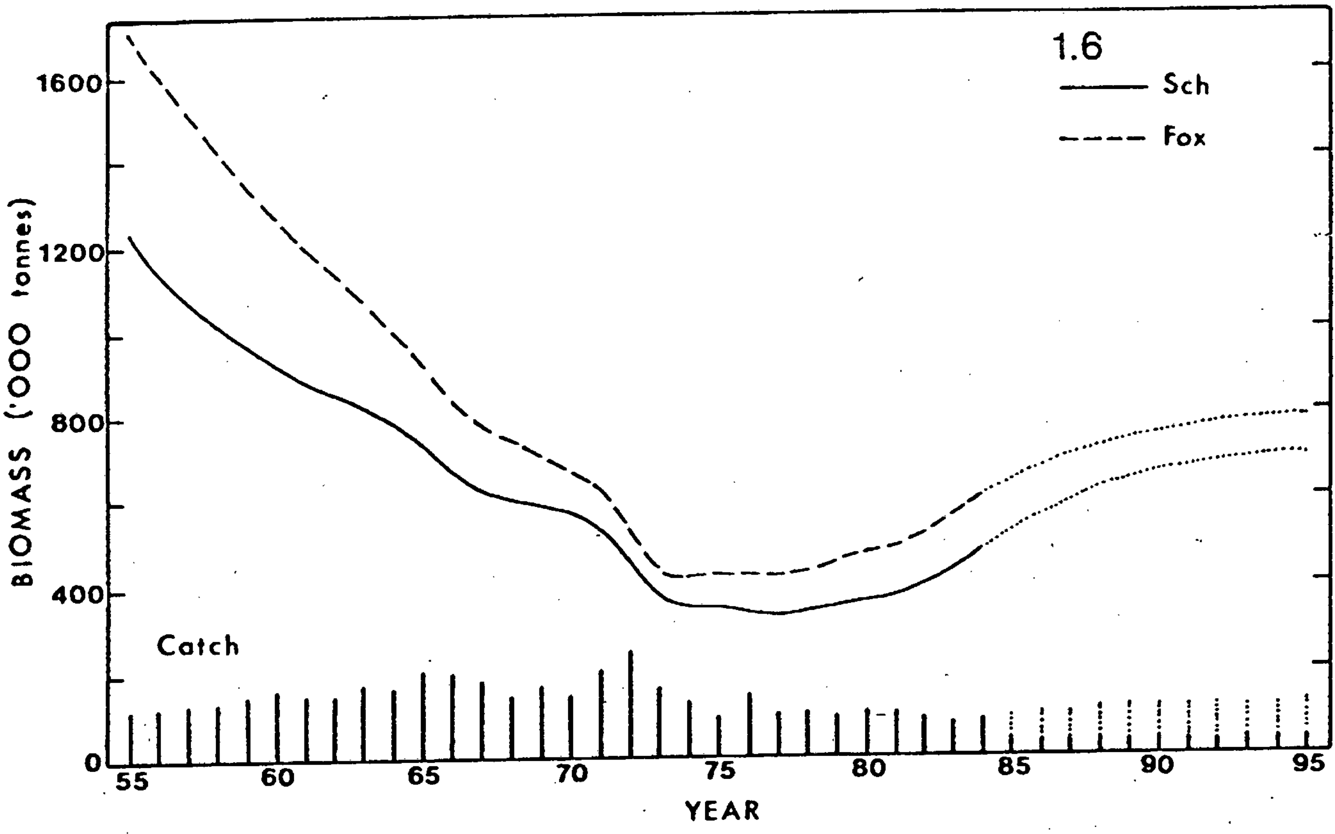


Figure 8.11 Division 1.6

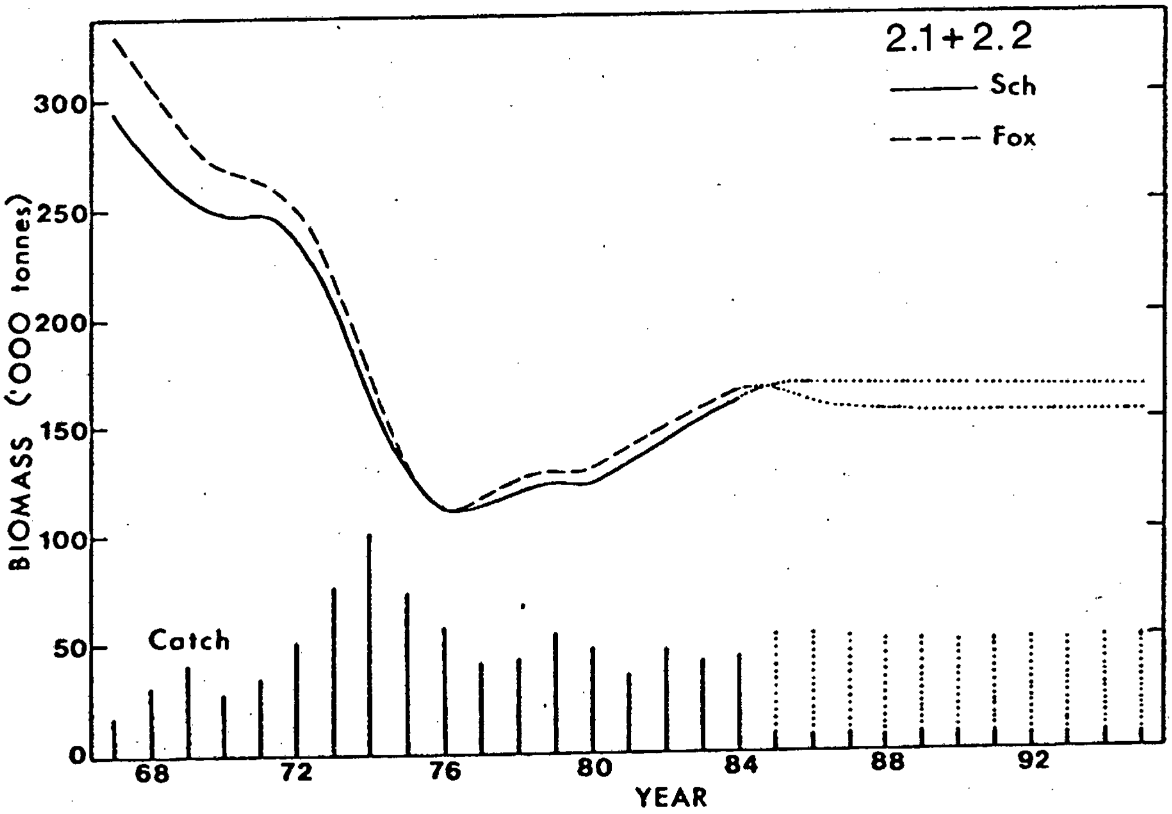


Figure 8.12 Division 2.1 + 2.2

Figures 8.11 - 8.12 : Biomass estimates using the dynamic Schaefer model (solid line) are compared with those from the dynamic Fox model (dashed line) and ten-year biomass projections under a $Q_{0,1}$ harvesting strategy (dotted lines) are shown for both models. Historical annual catches are indicated by solid vertical bars and the $Q_{0,1}$ projections for the next ten years by dotted vertical bars.

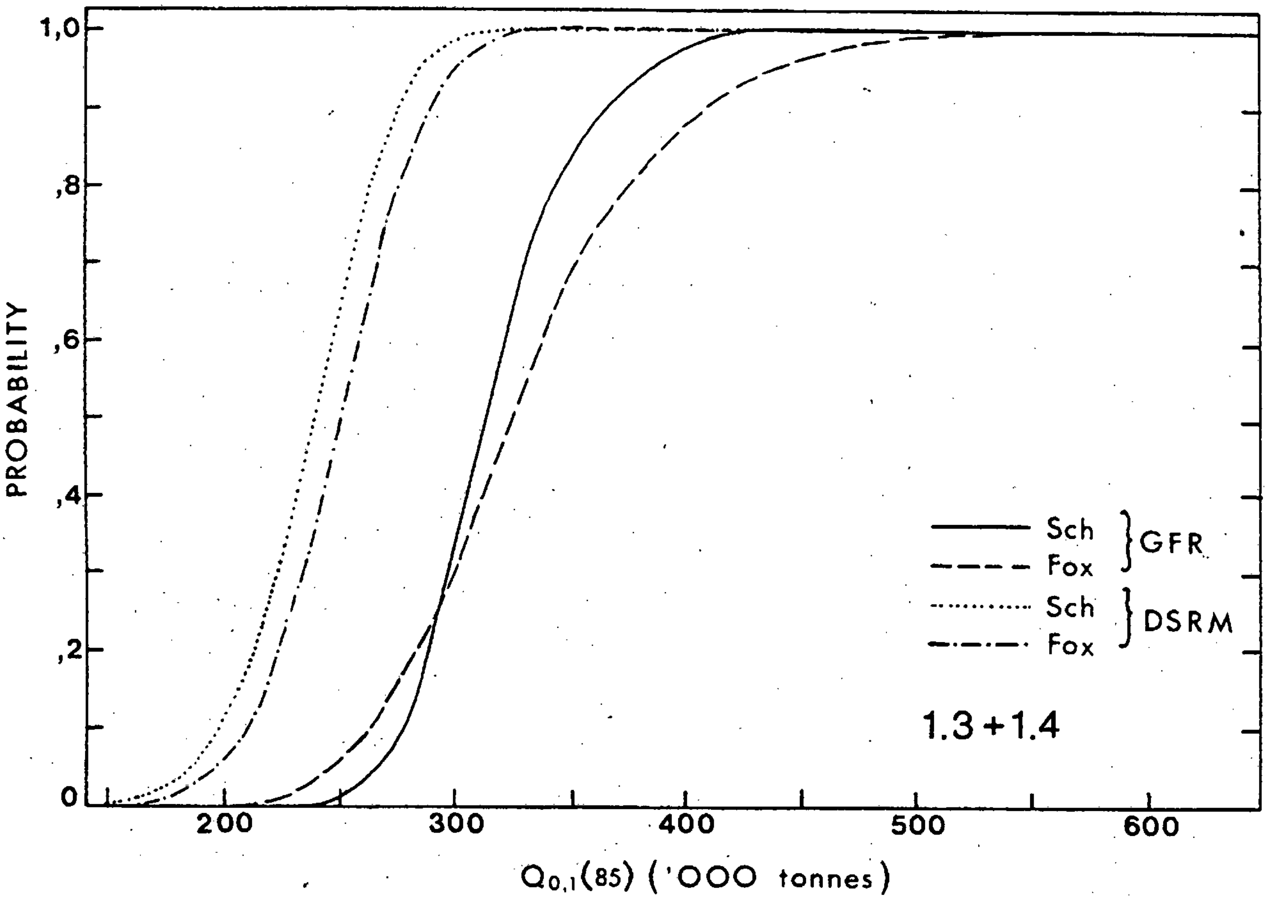


Figure 8.13 Divs 1.3+1.4

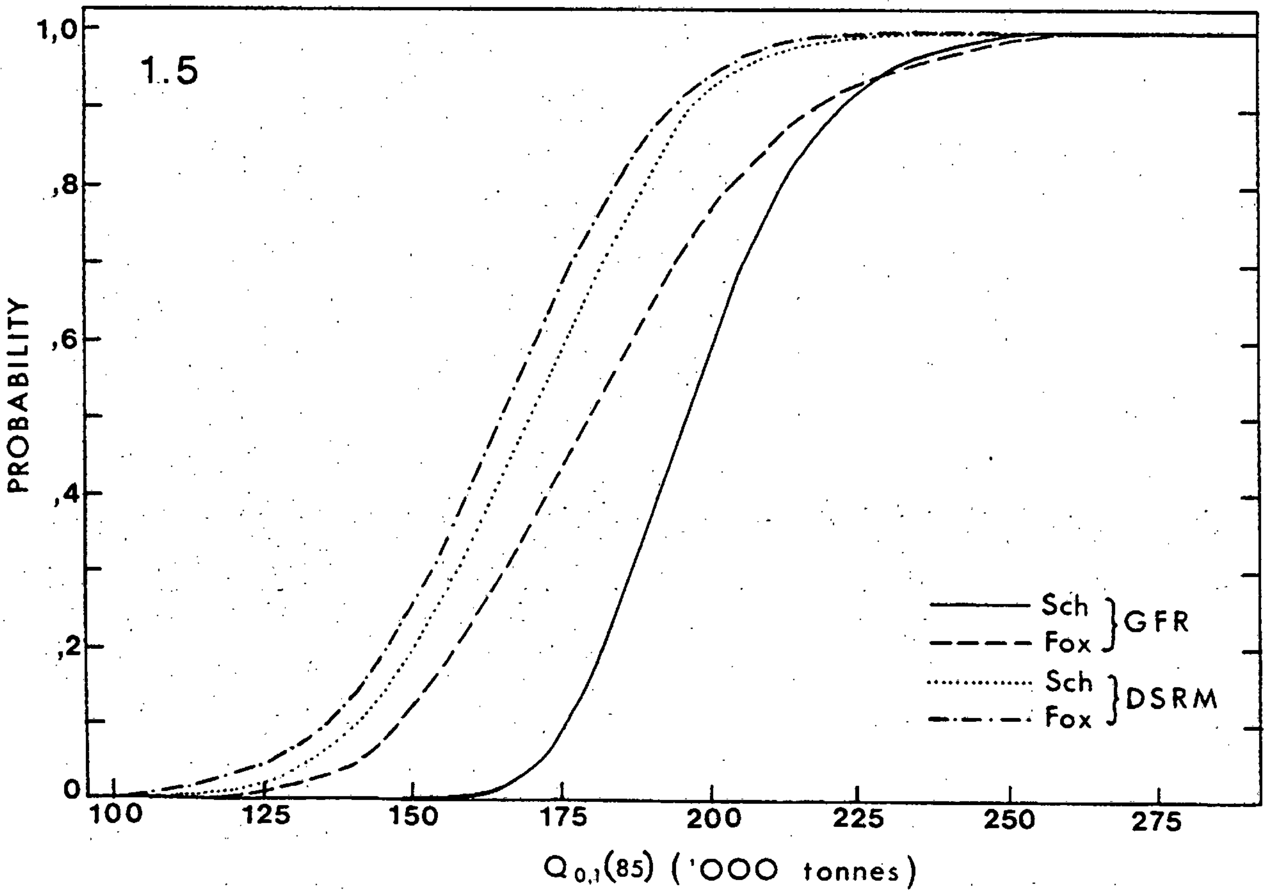


Figure 8.14 Division 1.5

Figures 8.13 – 8.14: Plots of the probability that the actual value of $Q_{0,1}(85)$ is less than the value indicated are shown for the Schaefer (solid line) and Fox (dashed line) GFR methods and the Schaefer (dotted line) and Fox (dash-dotted line) DSRM models.

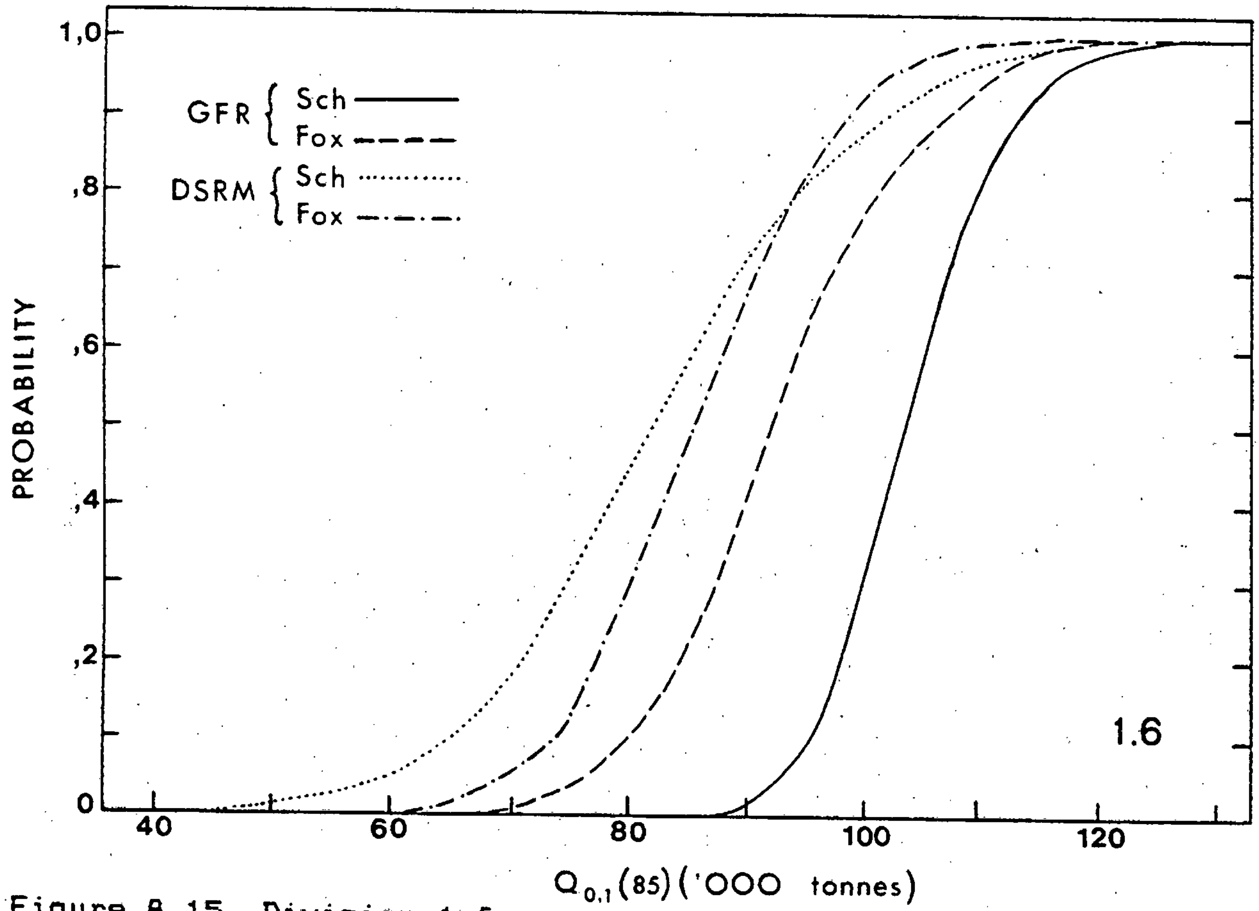


Figure 8.15 Division 1.6

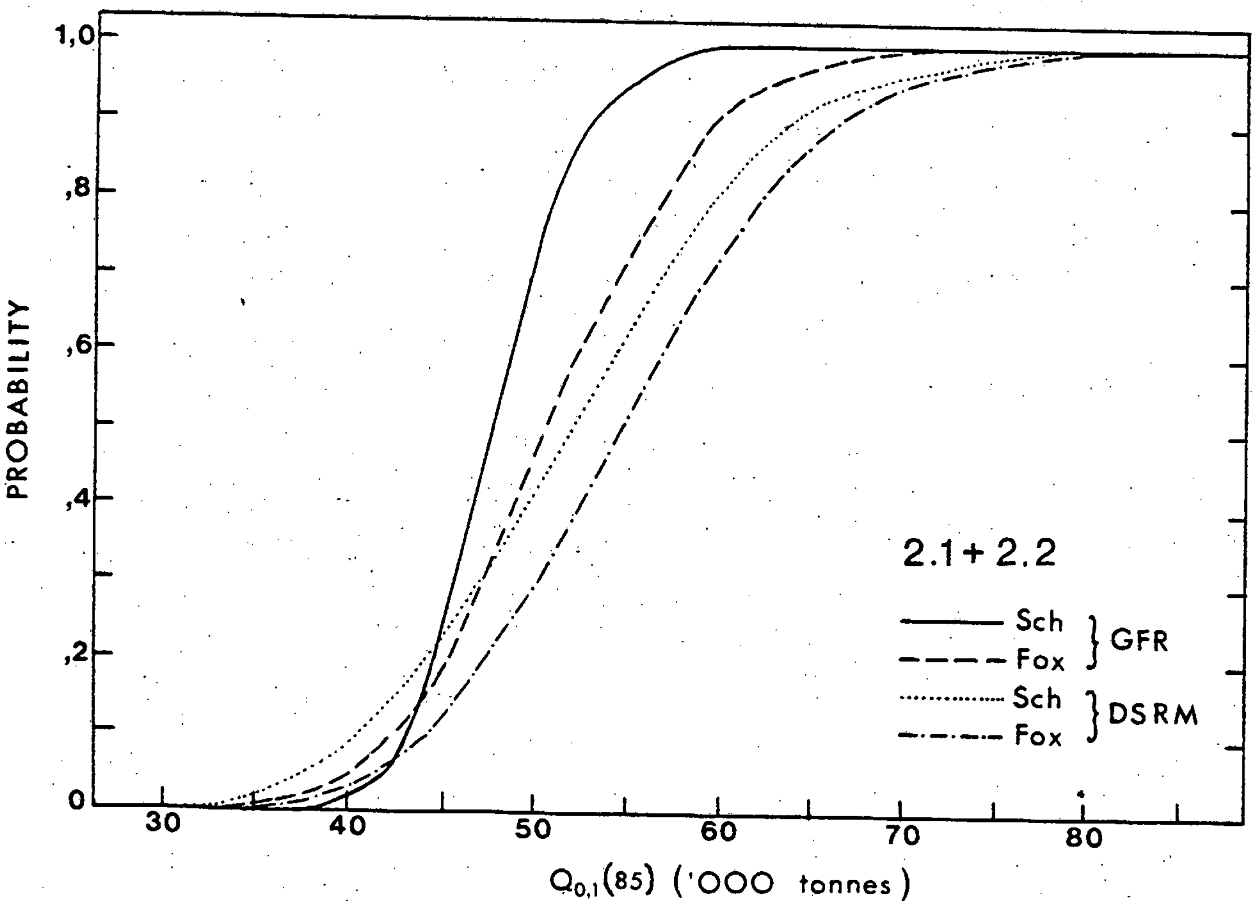


Figure 8.16 Divs 2.1+2.2

Figures 8.15 – 8.16: Plots of the probability that the actual value of $Q_{0,1}(85)$ is less than the value indicated are shown for the Schaefer (solid line) and Fox (dashed line) GFR methods and the Schaefer (dotted line) and Fox (dash-dotted line) DSRM models.

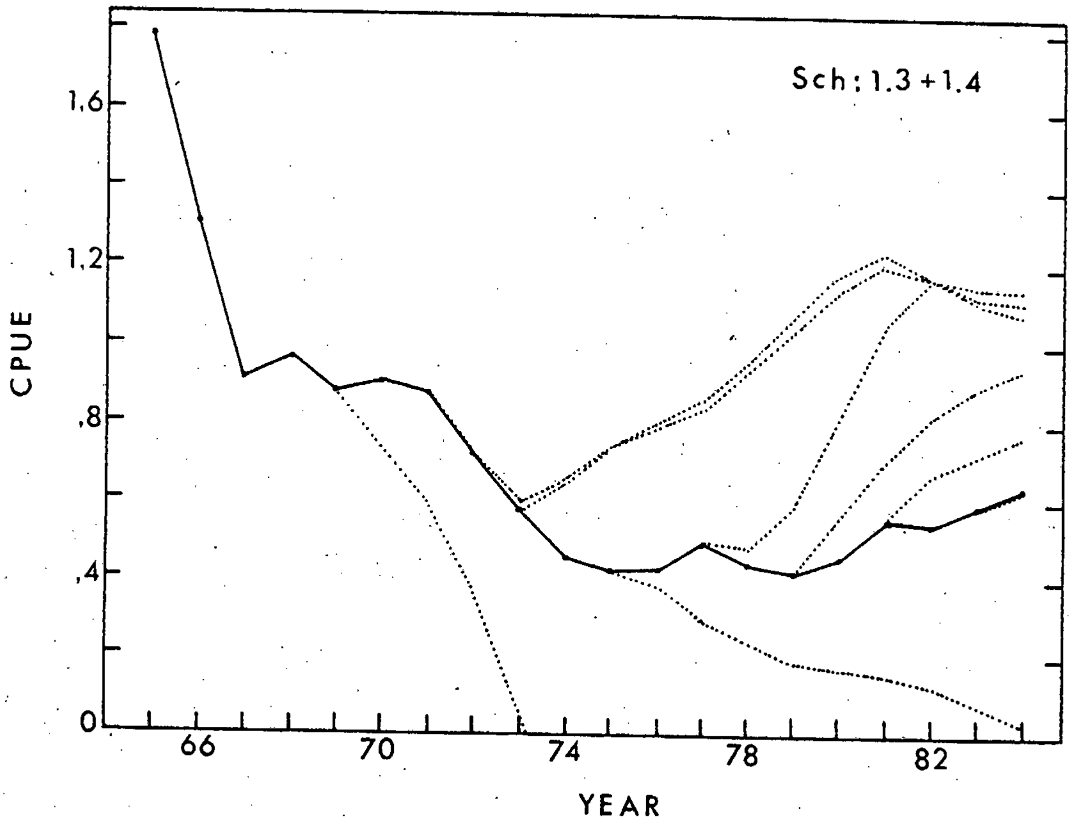


Figure 8.17: Schaefer Model

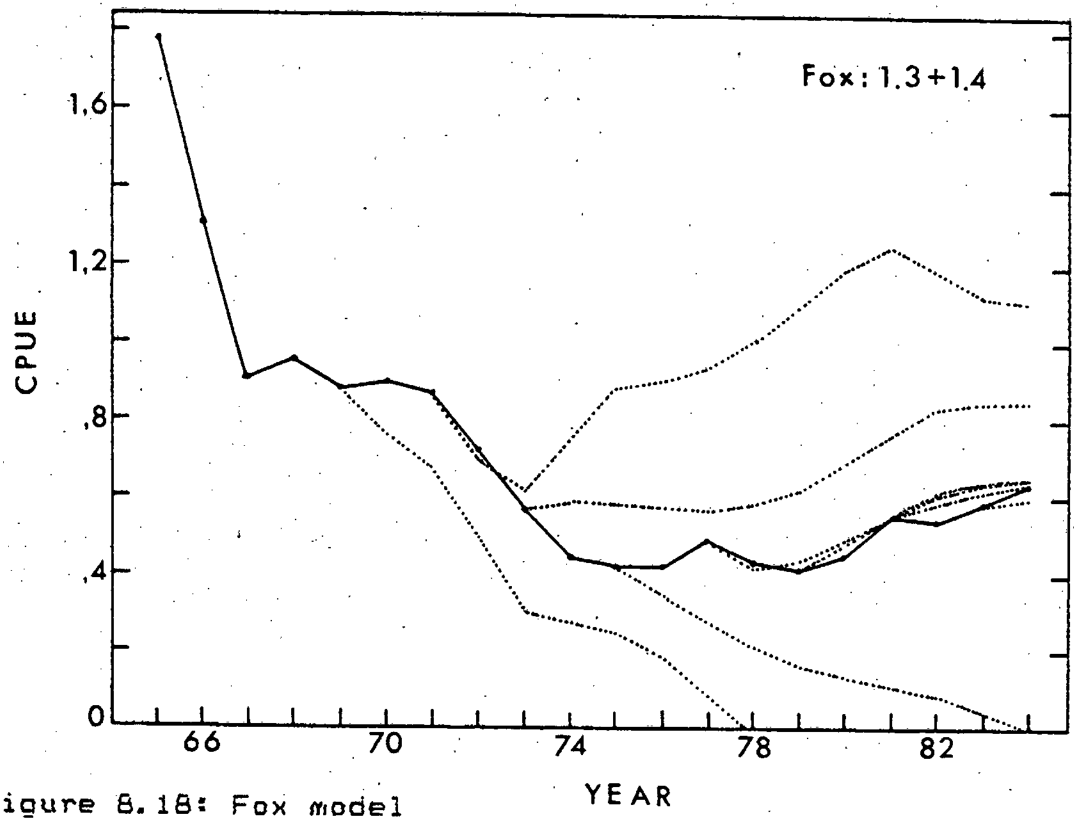


Figure 8.18: Fox model

Figures 8.17 - 8.18 : Dynamic model CPUE projections (in metric tons per Spanish OTB-7 trawler hour) for Divisions 1.3 + 1.4 taking into account catch-effort data only up to the year in question. The solid line indicates the observed time series and the dotted lines represent the model predictions at various times taking future catches to be those actually made.

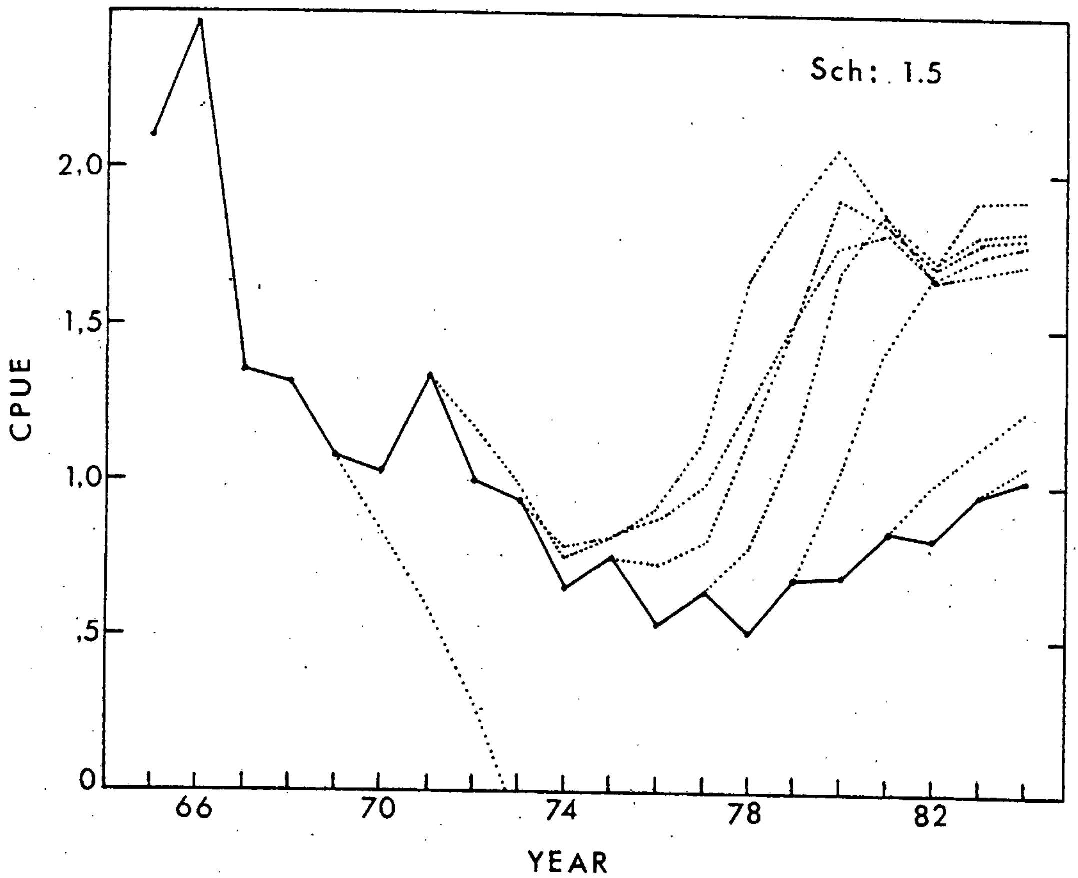


Figure 8.19: Schaefer Model

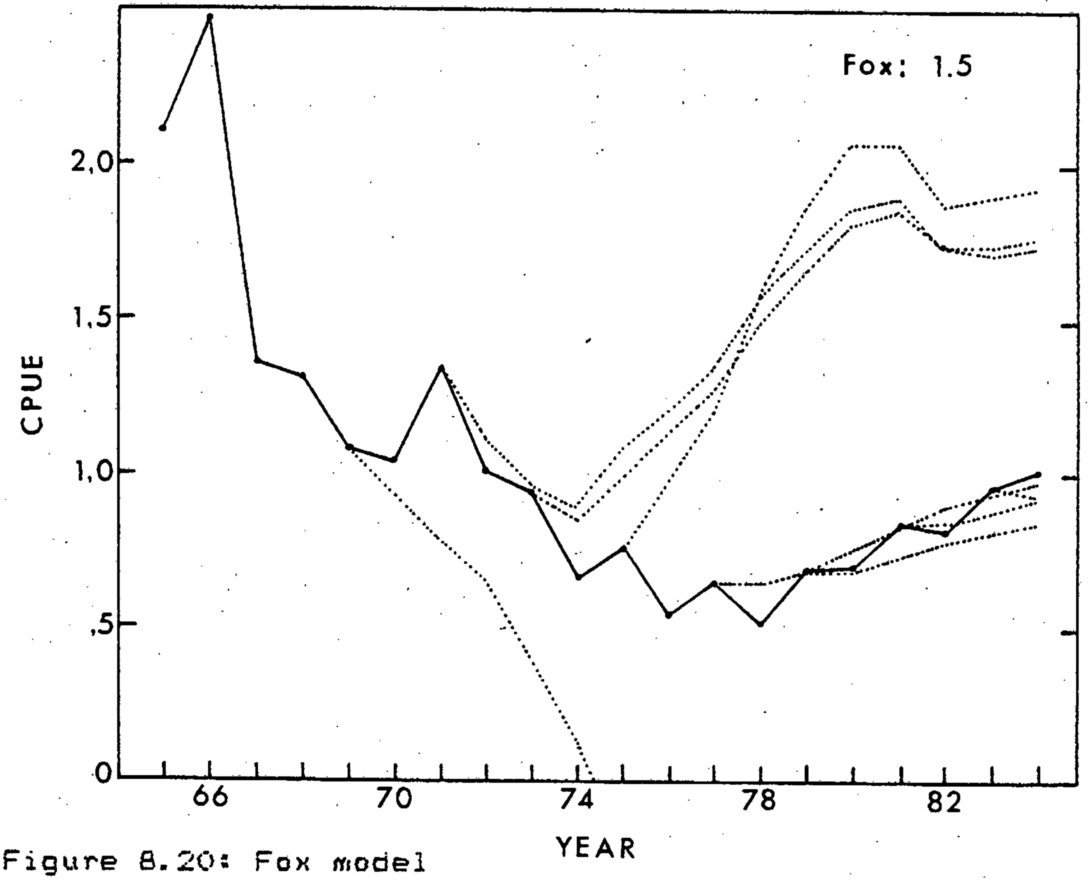


Figure 8.20: Fox model

Figures 8.19 - 8.20 : Dynamic model CPUE projections (in metric tons per Spanish OTB-7 trawler hour) for Division 1.5 taking into account catch-effort data only up to the year in question. The solid line indicates the observed time series and the dotted lines represent the model predictions at various times taking future catches to be those actually made.

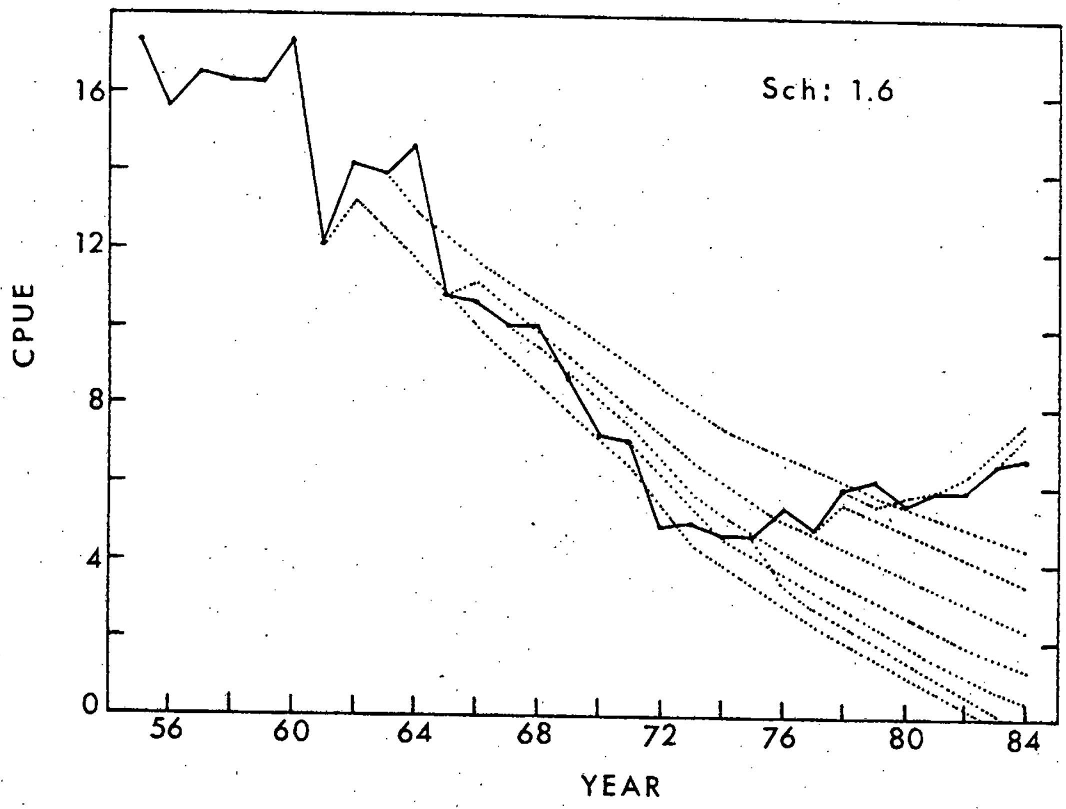


Figure 8.21: Schaefer Model

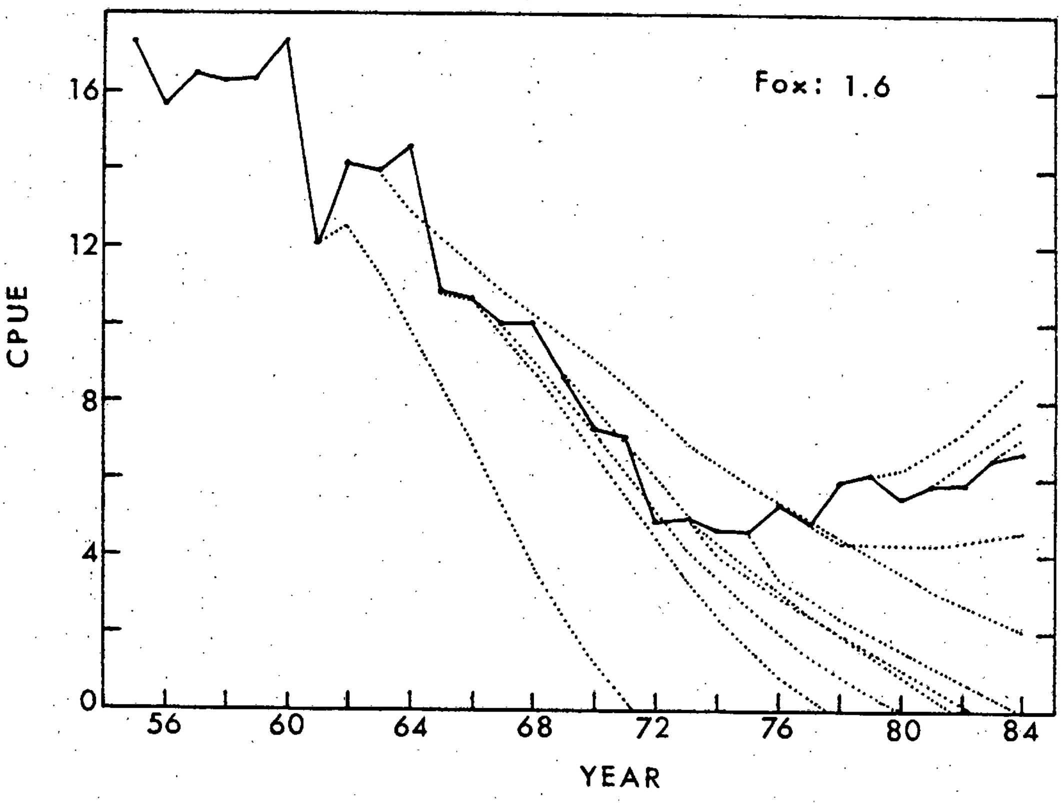


Figure 8.22: Fox model

Figures 8.21 - 8.22 : Dynamic model CPUE projections (in metric tons per South African standard trawler day) for Division 1.6 taking into account catch-effort data only up to the year in question. The solid line indicates the observed time series and the dotted lines represent the model predictions at various times taking future catches to be those actually made.

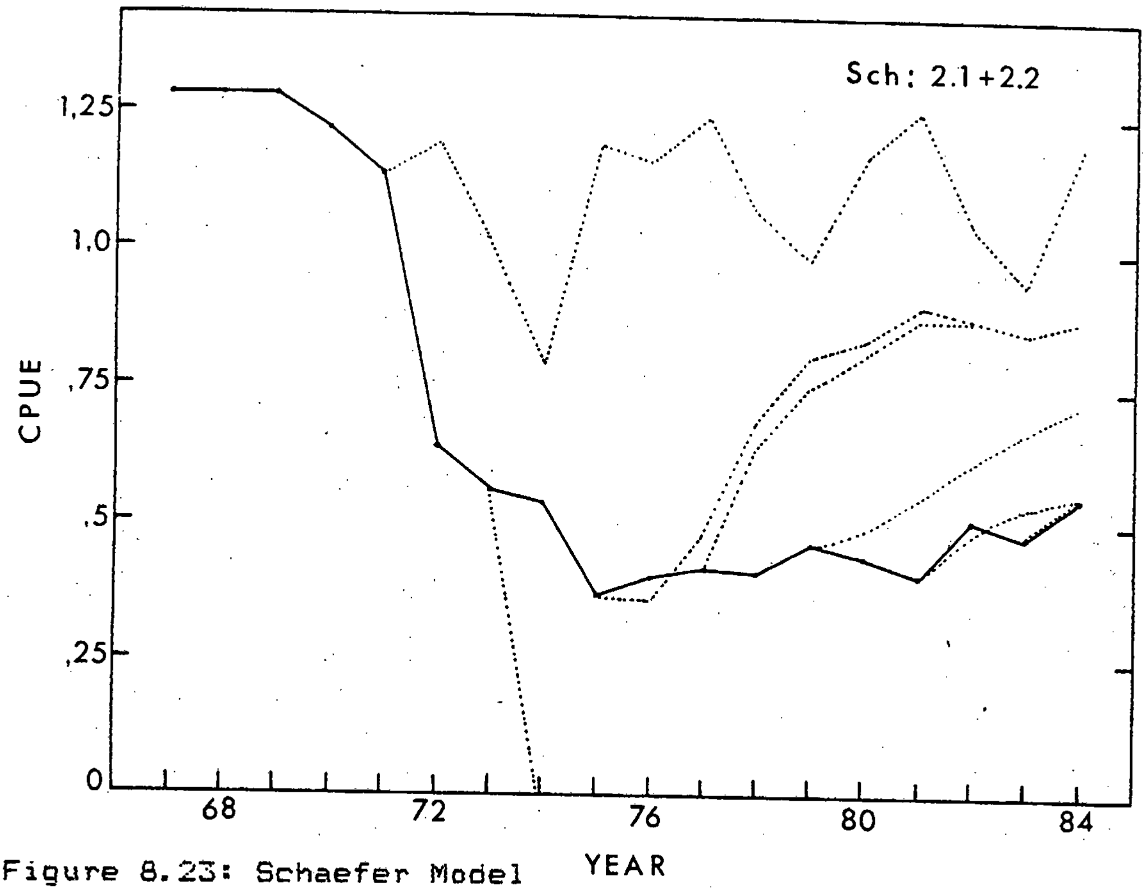


Figure 8.23: Schaefer Model

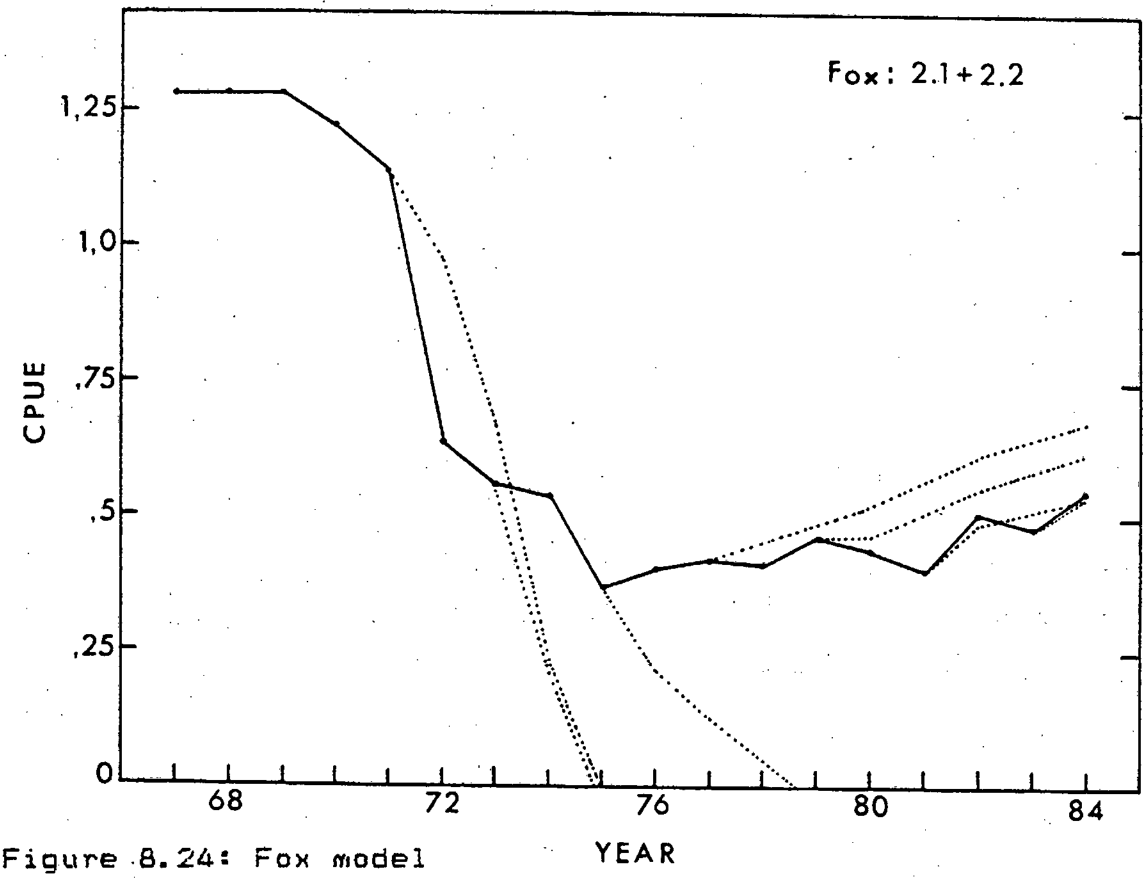


Figure 8.24: Fox model

Figures 8.23 – 8.24 : Dynamic model CPUE projections (in metric tons per South African standard trawler hour) for Divisions 2.1 + 2.2 taking into account catch-effort data only up to the year in question. The solid line indicates the observed time series and the dotted lines represent the model predictions at various times taking future catches to be those actually made.

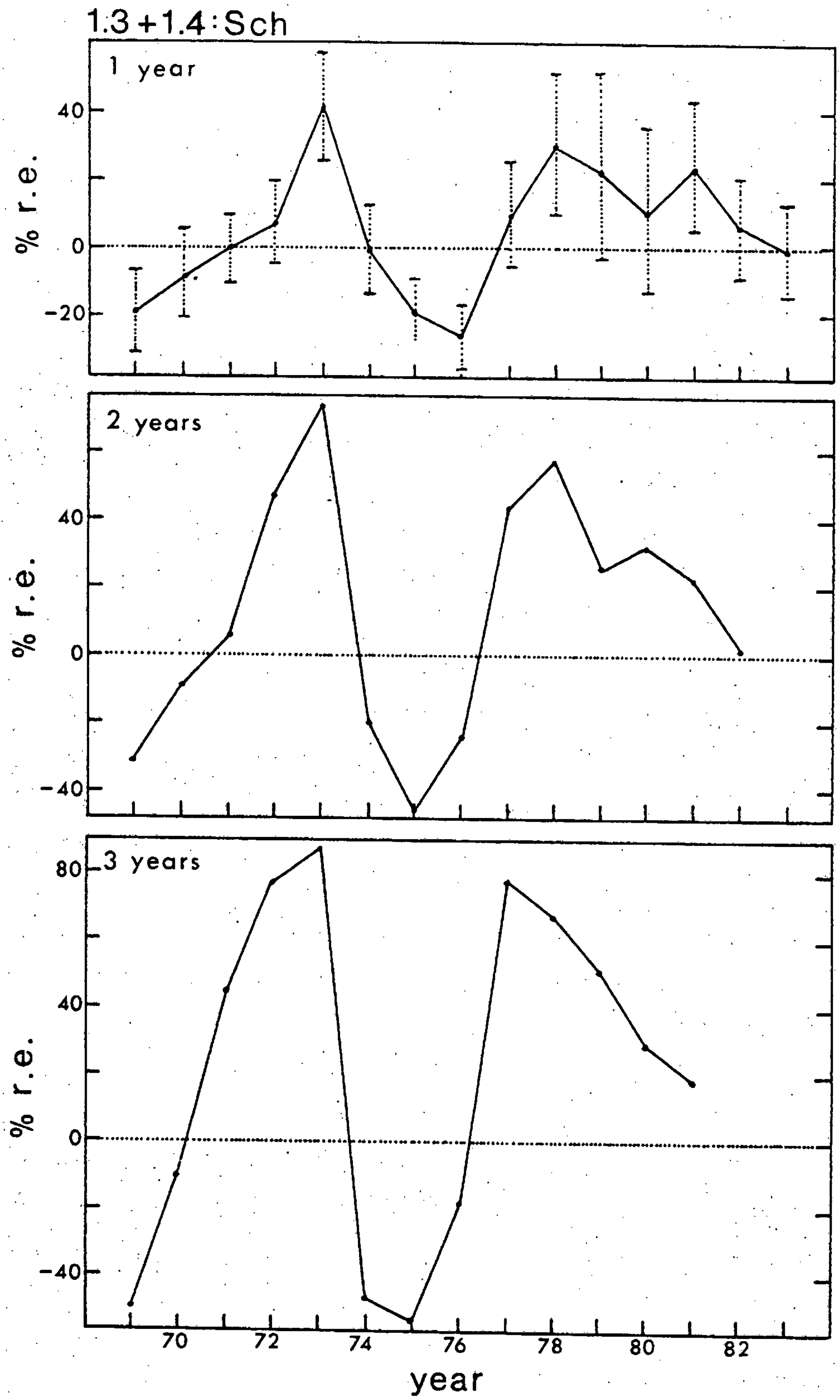


Figure 8.25 Divisions 1.3 + 1.4: Relative accuracy of CPUE projections made as indicated in Figure 8.17 (Schaefer model) for periods one, two and three years in advance. The error bars shown for one-year projections represent the estimated magnitude of one standard error for the projected CPUE value.

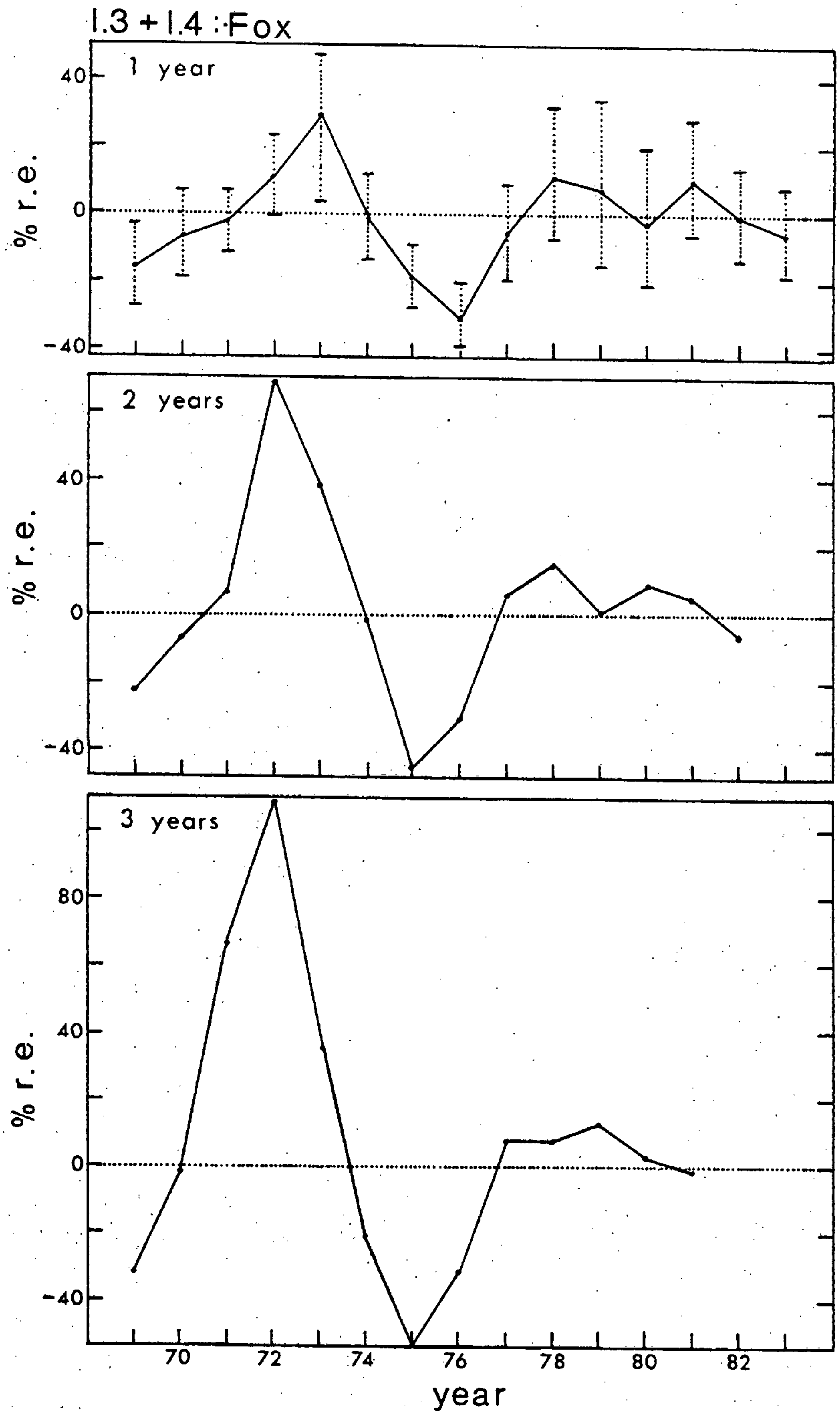


Figure 8.26 Divisions 1.3 + 1.4: Relative accuracy of CPUE projections made as indicated in Figure 8.18 (Fox model) for periods one, two and three years in advance. The error bars shown for one-year projections represent the estimated magnitude of one standard error for the projected CPUE value.

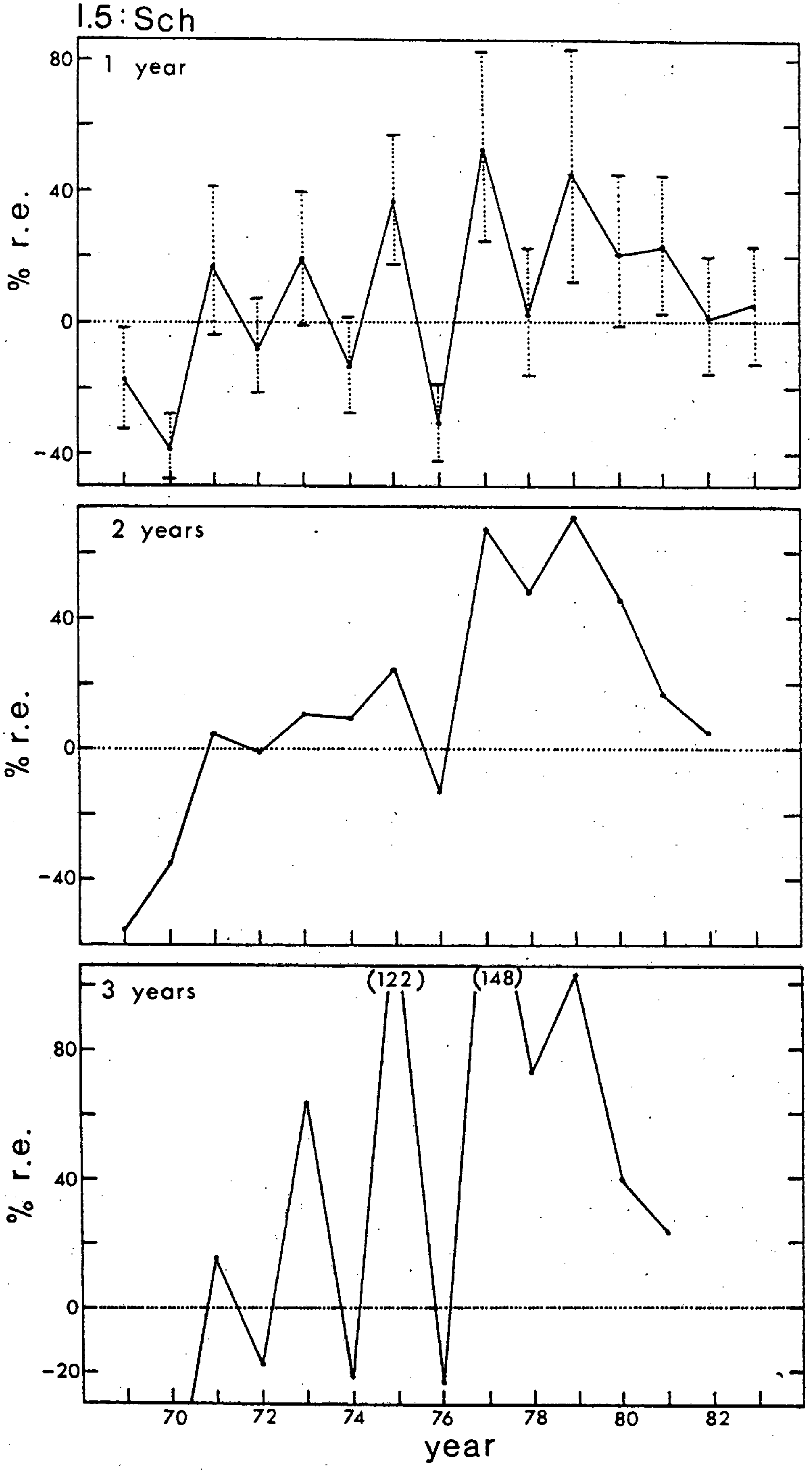


Figure 8.27 Division 1.5: Relative accuracy of CPUE projections made as indicated in Figure 8.19 (Schaefer model) for periods one, two and three years in advance. The error bars shown for one-year projections represent the estimated magnitude of one standard error for the projected CPUE value.

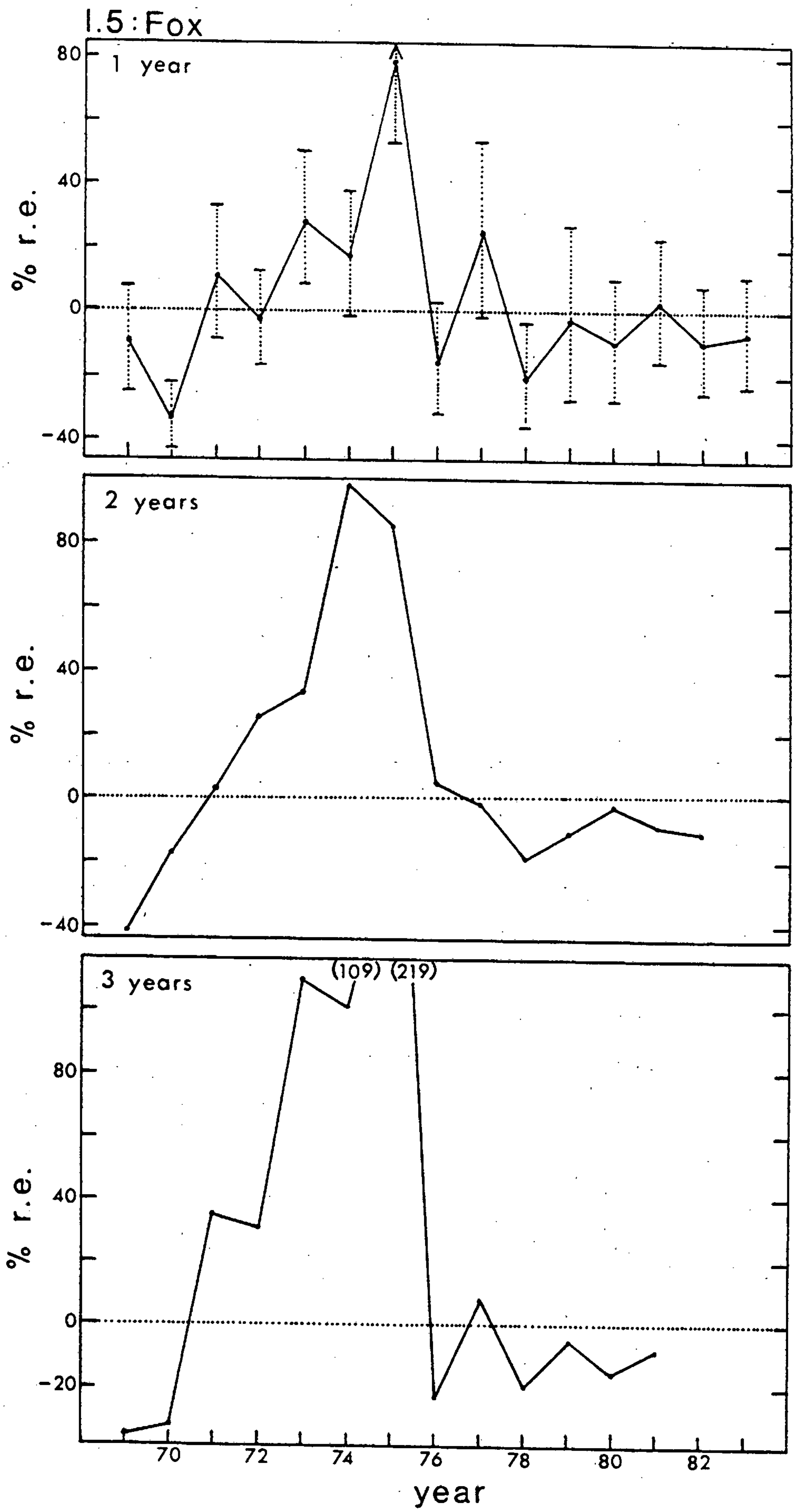


Figure 8.28 Division 1.5: Relative accuracy of CPUE projections made as indicated in Figure 8.20 (Fox model) for periods one, two and three years in advance. The error bars shown for one-year projections represent the estimated magnitude of one standard error for the projected CPUE value.

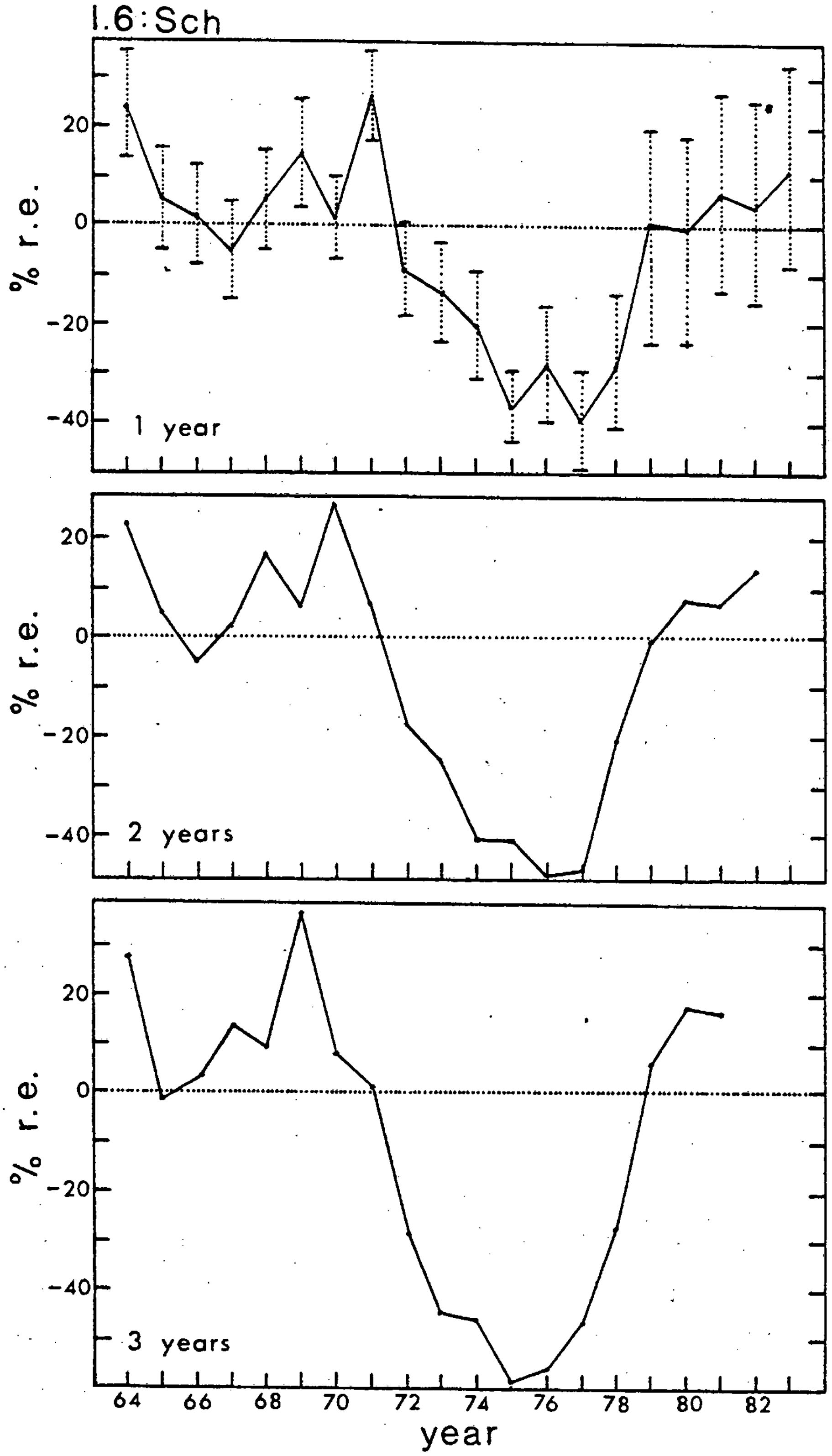


Figure 8.29 Division 1.6: Relative accuracy of CPUE projections made as indicated in Figure 8.21 (Schaefer model) for periods one, two and three years in advance. The error bars shown for one-year projections represent the estimated magnitude of one standard error for the projected CPUE value.

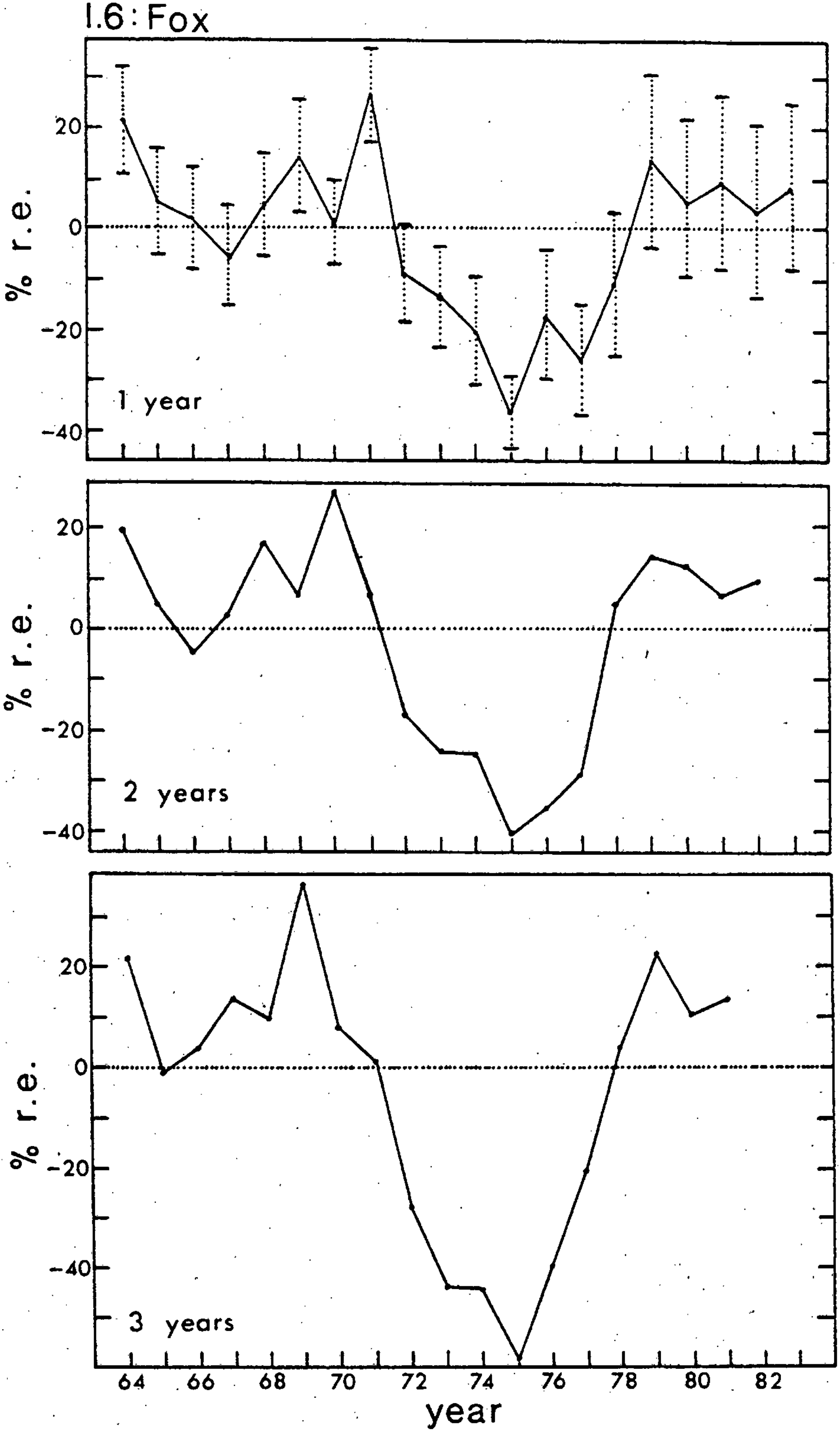


Figure 8.30 Division 1.6: Relative accuracy of CPUE projections made as indicated in Figure 8.22 (Fox model) for periods one, two and three years in advance. The error bars shown for one-year projections represent the estimated magnitude of one standard error for the projected CPUE value.

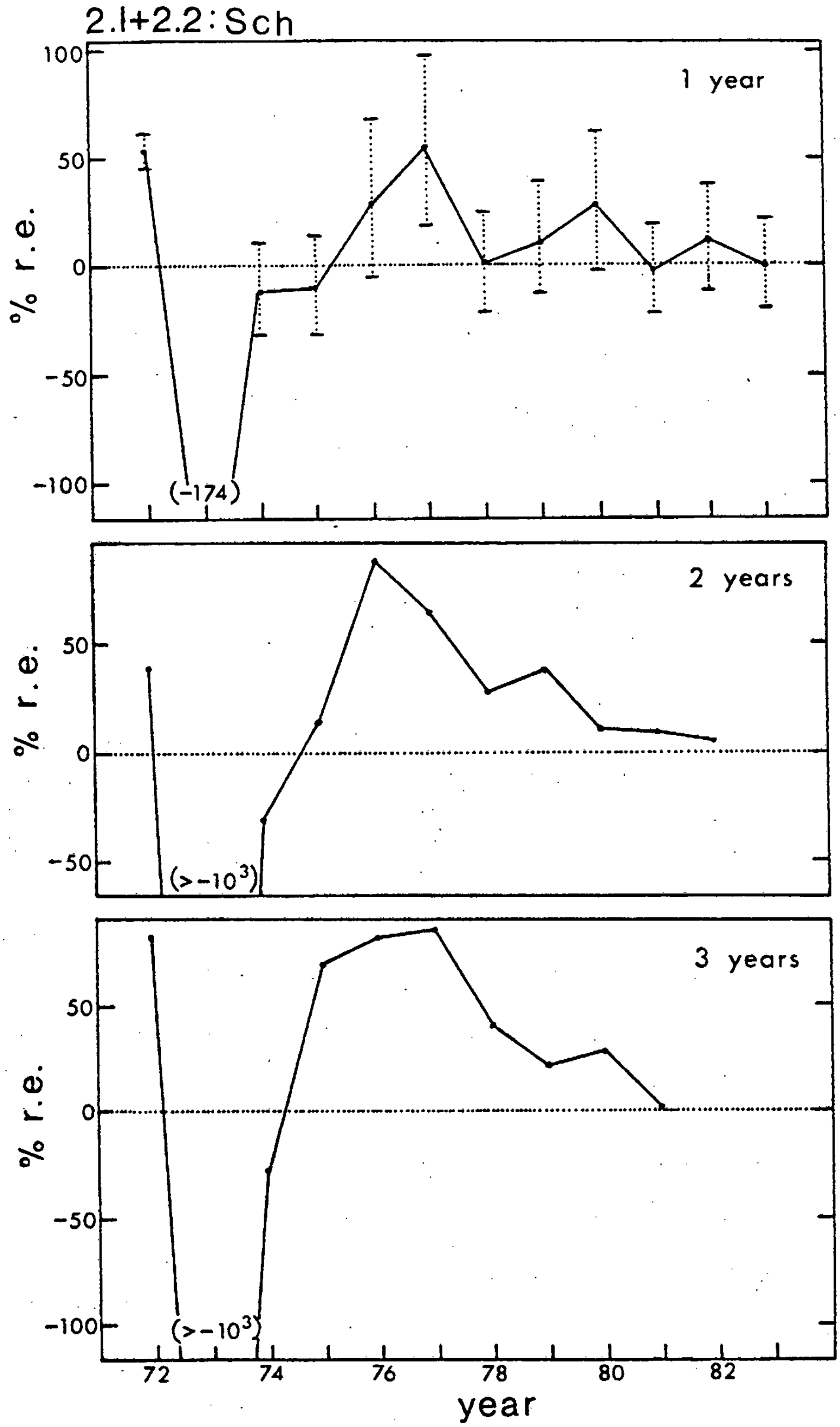


Figure 8.31 Divisions 2.1 + 2.2: Relative accuracy of CPUE projections made as indicated in Figure 8.23 (Schaefer model) for periods one, two and three years in advance. The error bars shown for one-year projections represent the estimated magnitude of one standard error for the projected CPUE value.

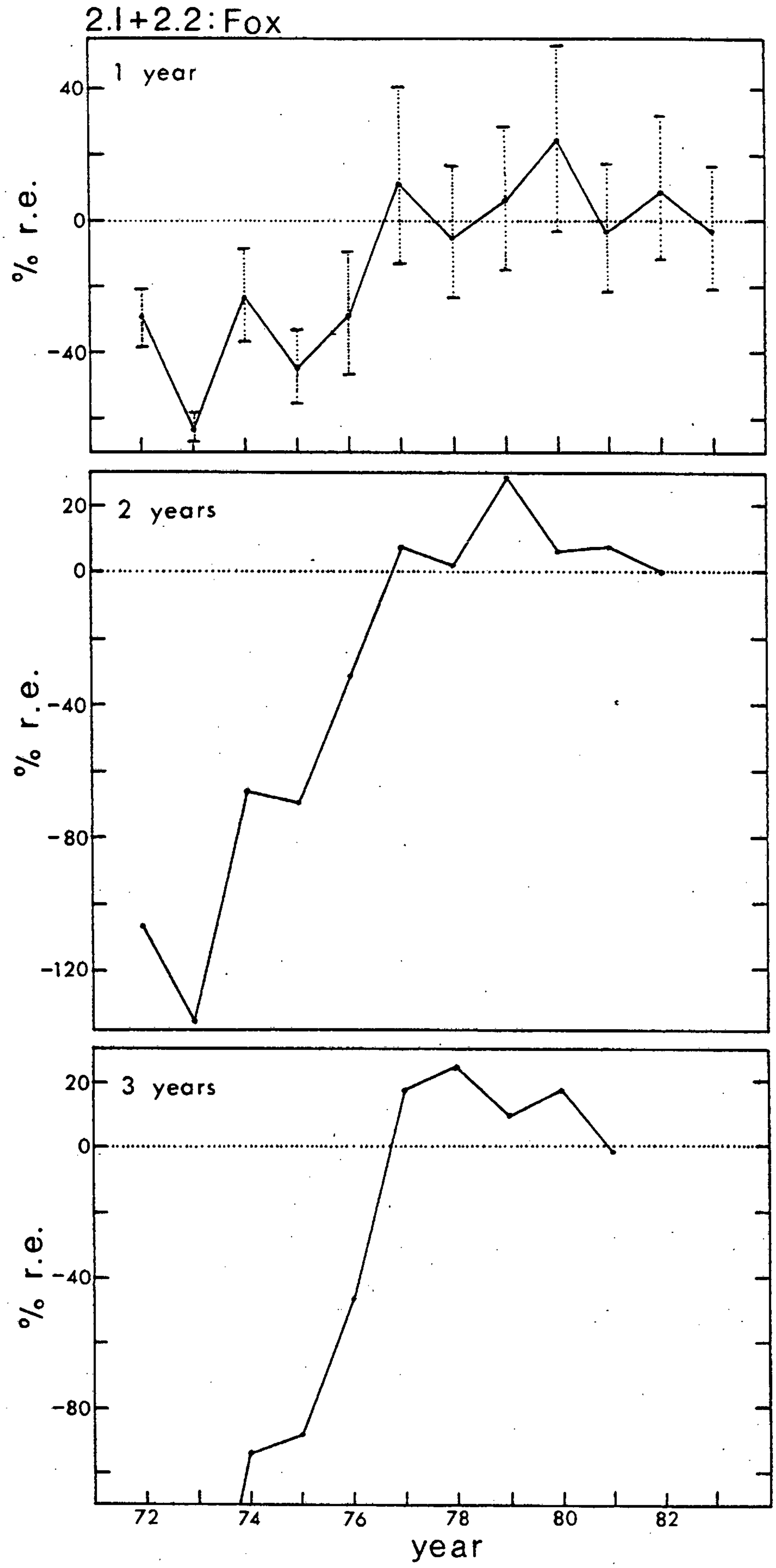


Figure 8.32 Divisions 2.1 + 2.2: Relative accuracy of CPUE projections made as indicated in Figure 8.24 (Fox model) for periods one, two and three years in advance. The error bars shown for one-year projections represent the estimated magnitude of one standard error for the projected CPUE value.

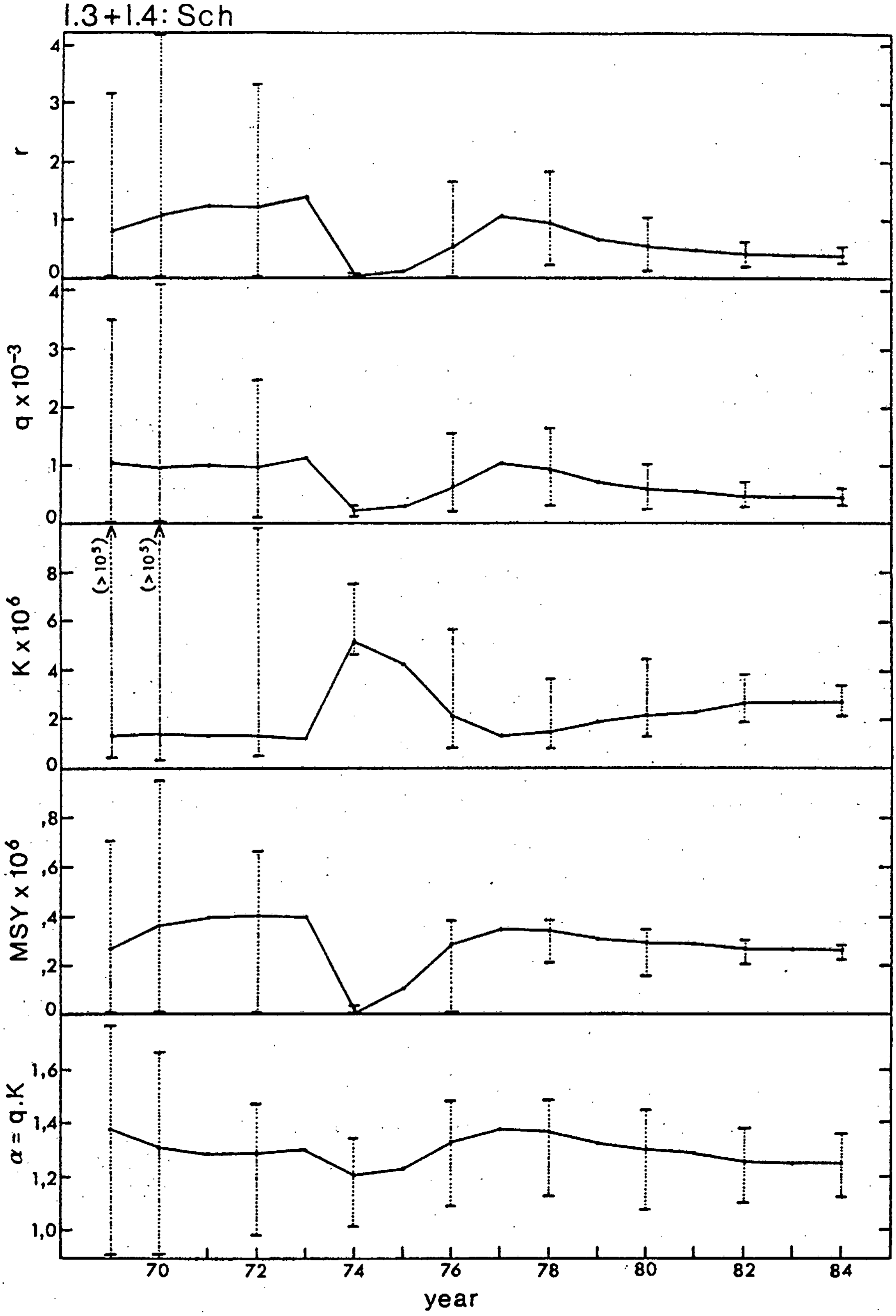


Figure 8.33: Divisions 1.3 + 1.4. Time series of estimates of calculated Schaefer model parameters r, q, K, MSY and α. The error bars shown represent 95% confidence intervals.

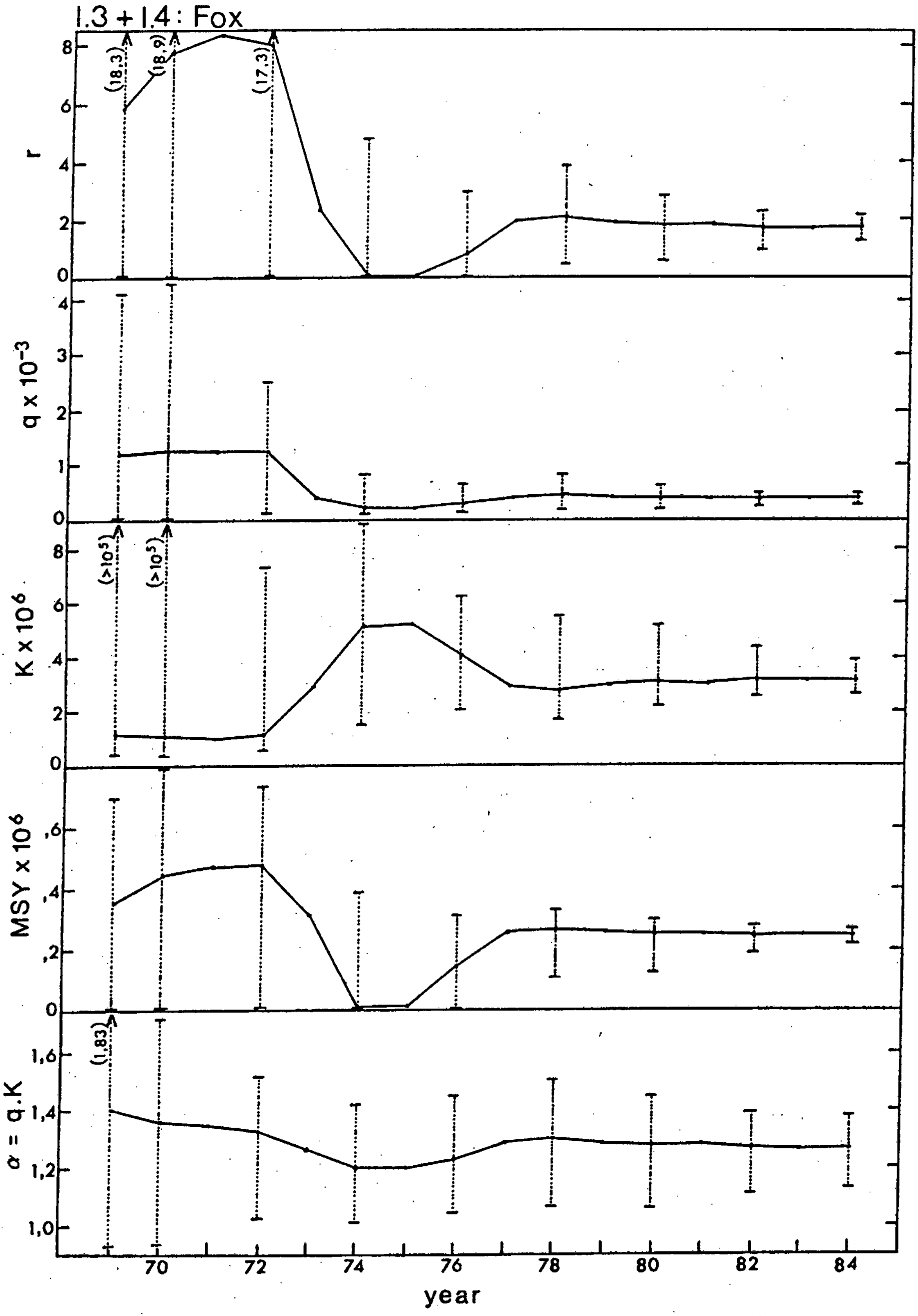


Figure 8.34: Divisions 1.3 + 1.4. Time series of estimates of calculated Fox model parameters r, q, K, MSY and α. The error bars shown represent 95% confidence intervals.

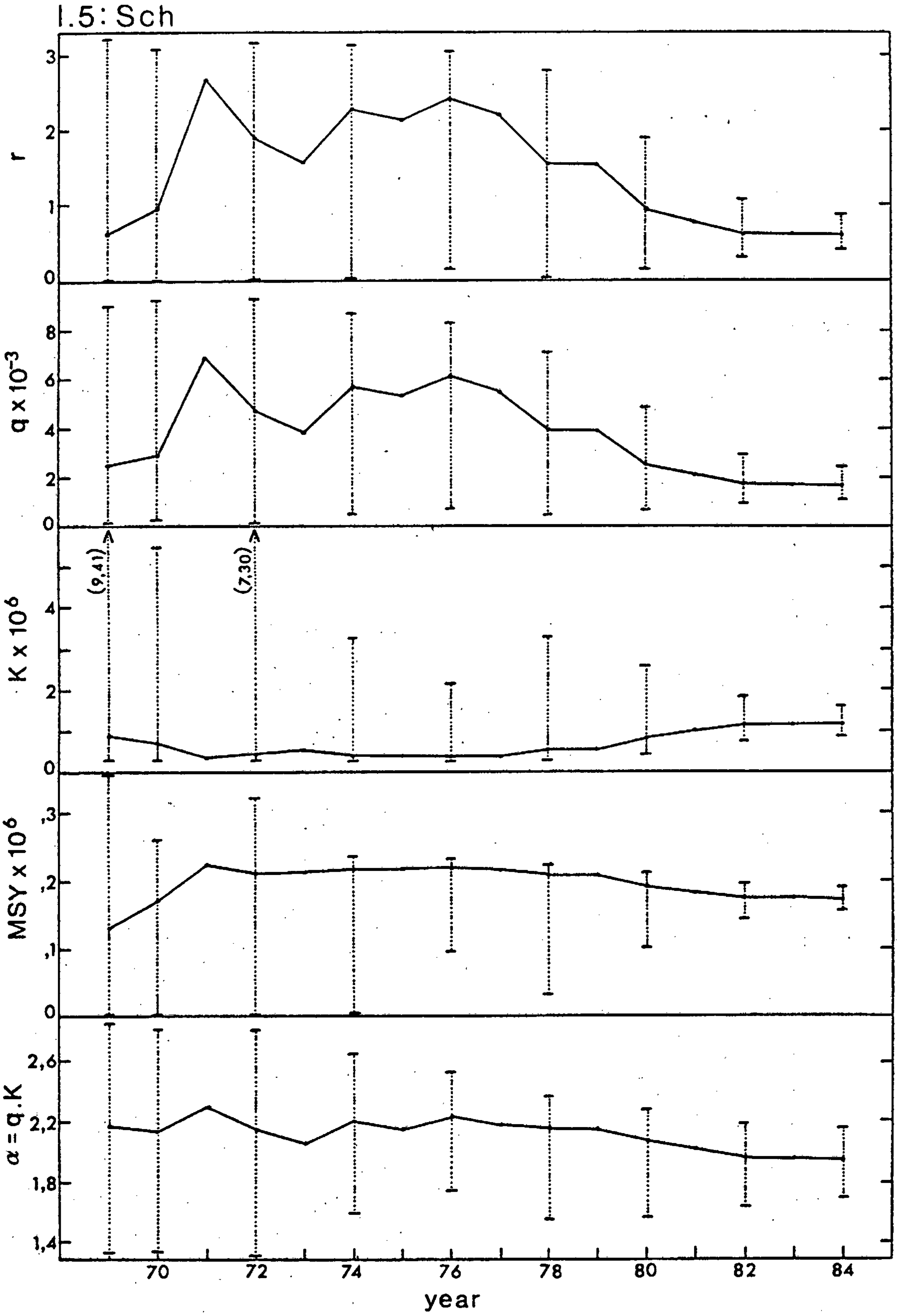


Figure 8.35: Division 1.5 . Time series of estimates of calculated Schaefer model parameters r, q, K, MSY and α . The error bars shown represent 95% confidence intervals.

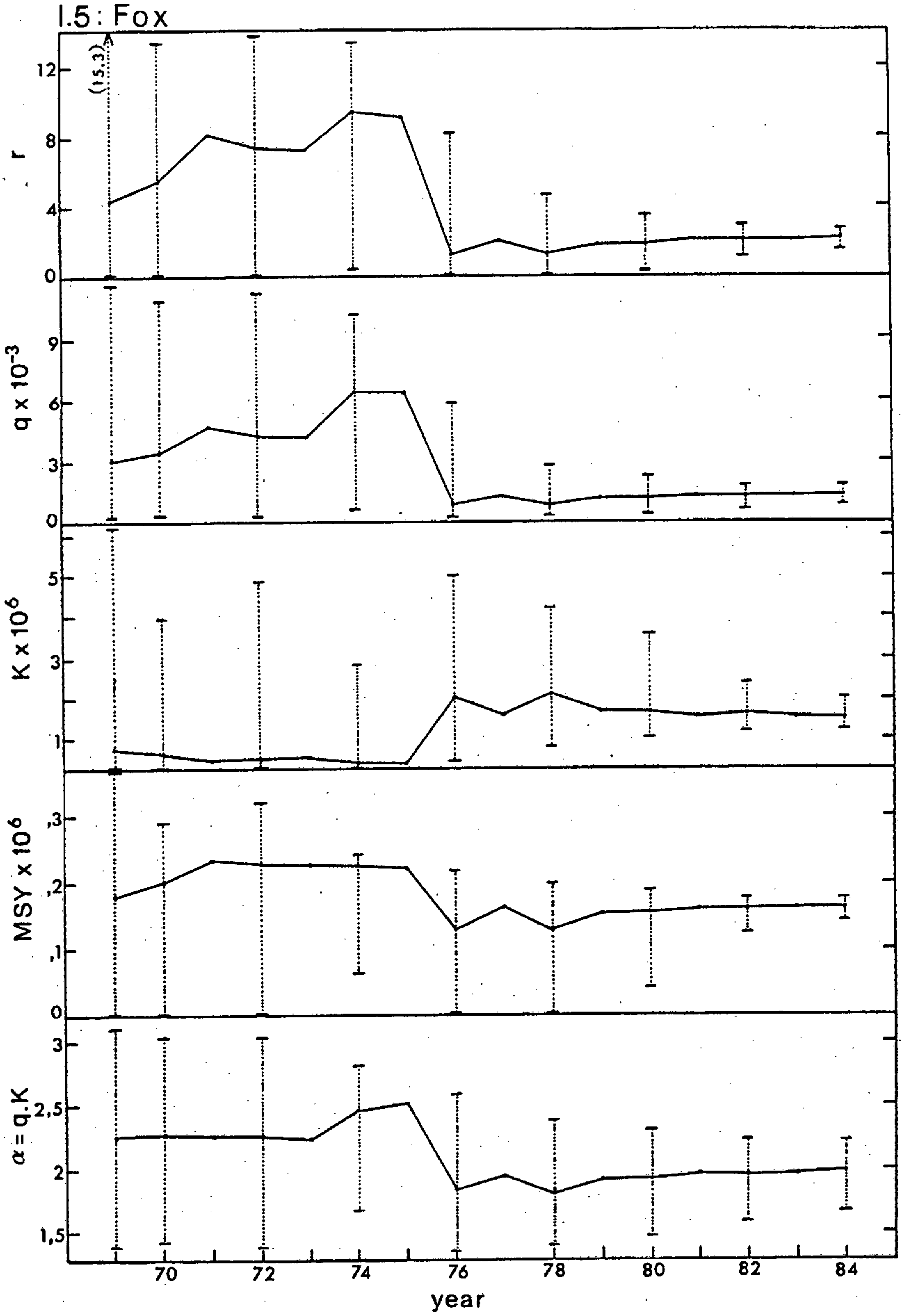


Figure 8.36: Division 1.5 . Time series of estimates of calculated Fox model parameters r, q, K, MSY and α. The error bars shown represent 95% confidence intervals.

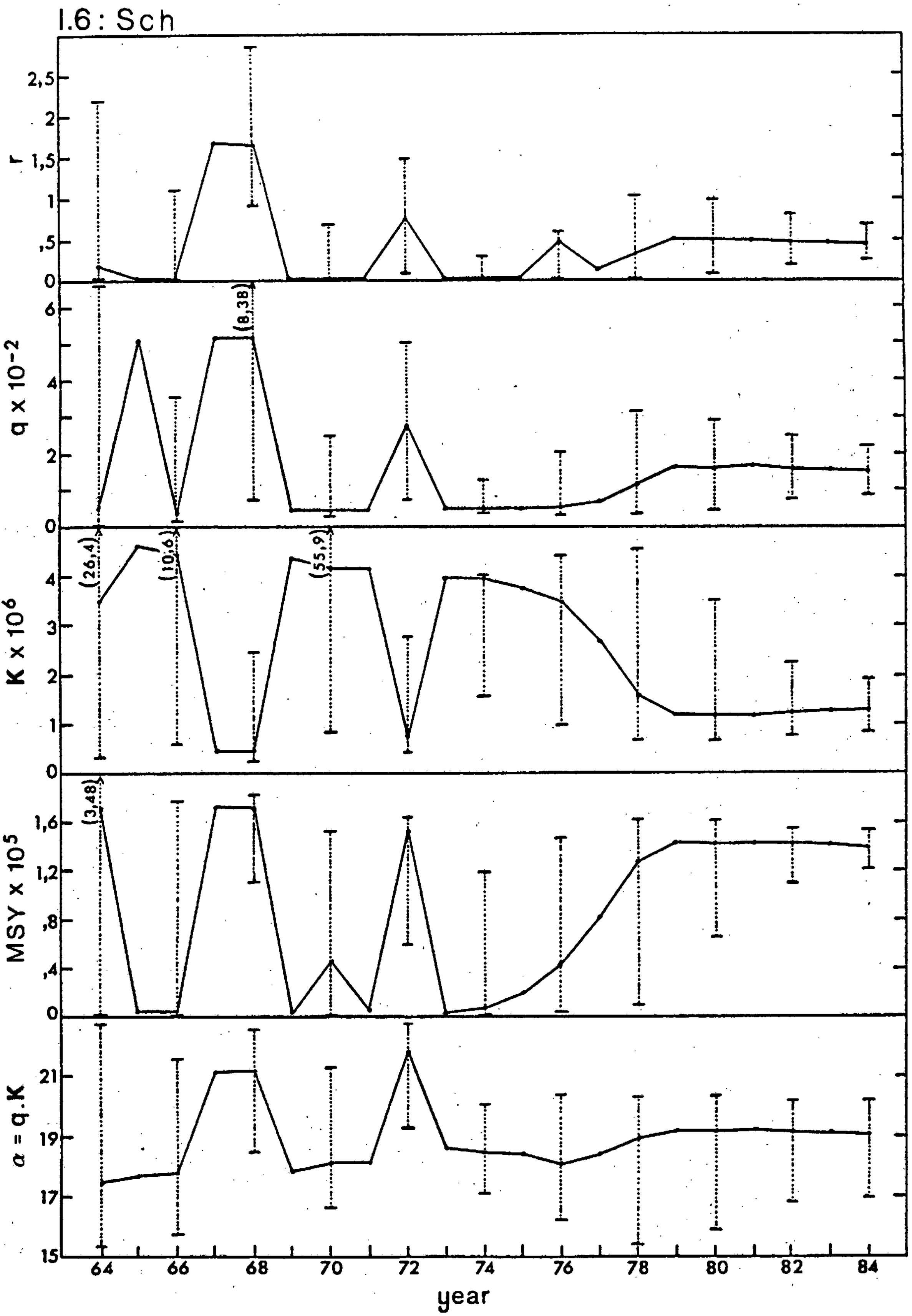


Figure 8.37: Division 1.6 . Time series of estimates of calculated Schaefer model parameters r, q, K, MSY and α. The error bars shown represent 95% confidence intervals.

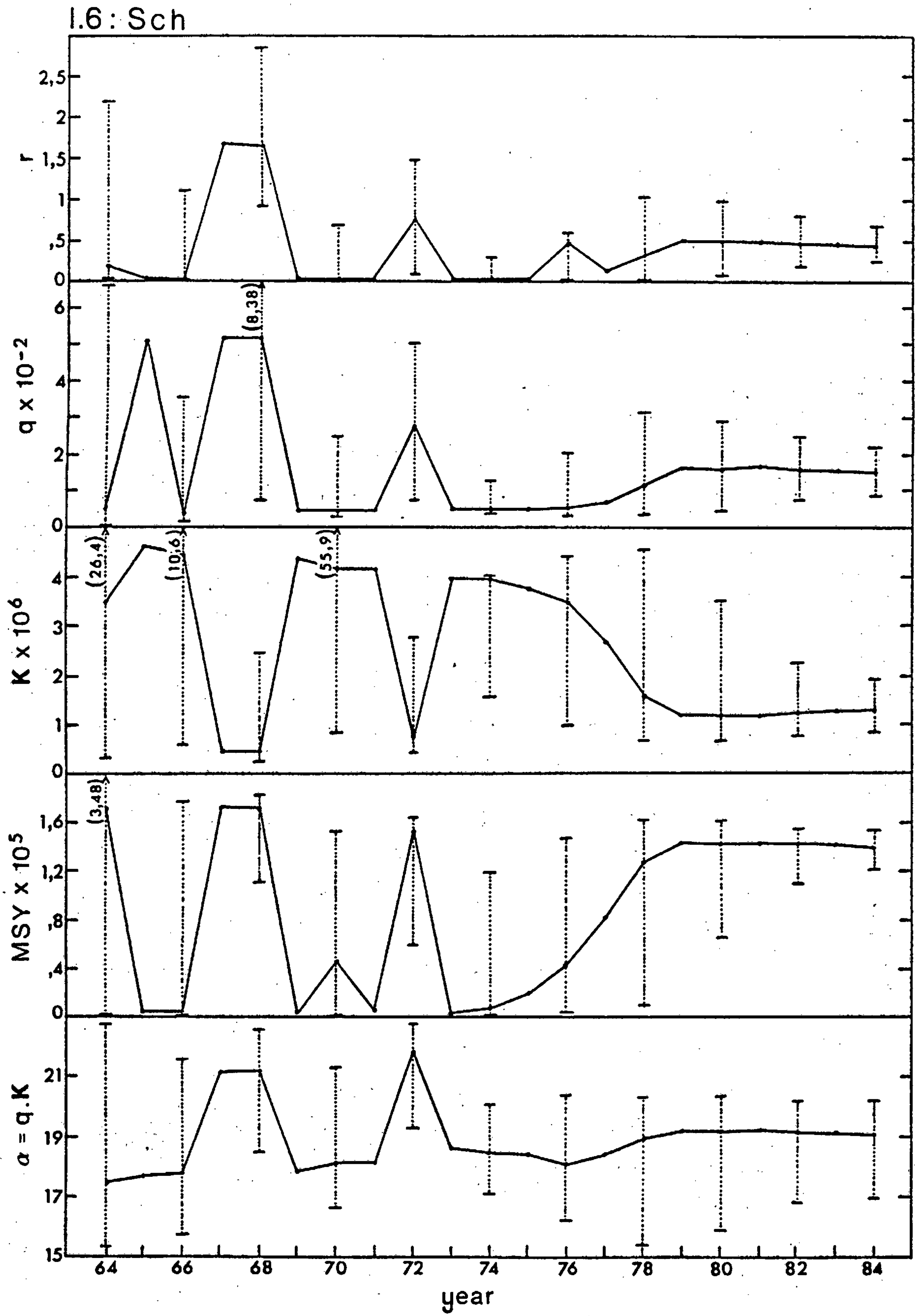


Figure 8.37: Division 1.6 . Time series of estimates of calculated Schaefer model parameters r, q, K, MSY and α . The error bars shown represent 95% confidence intervals.

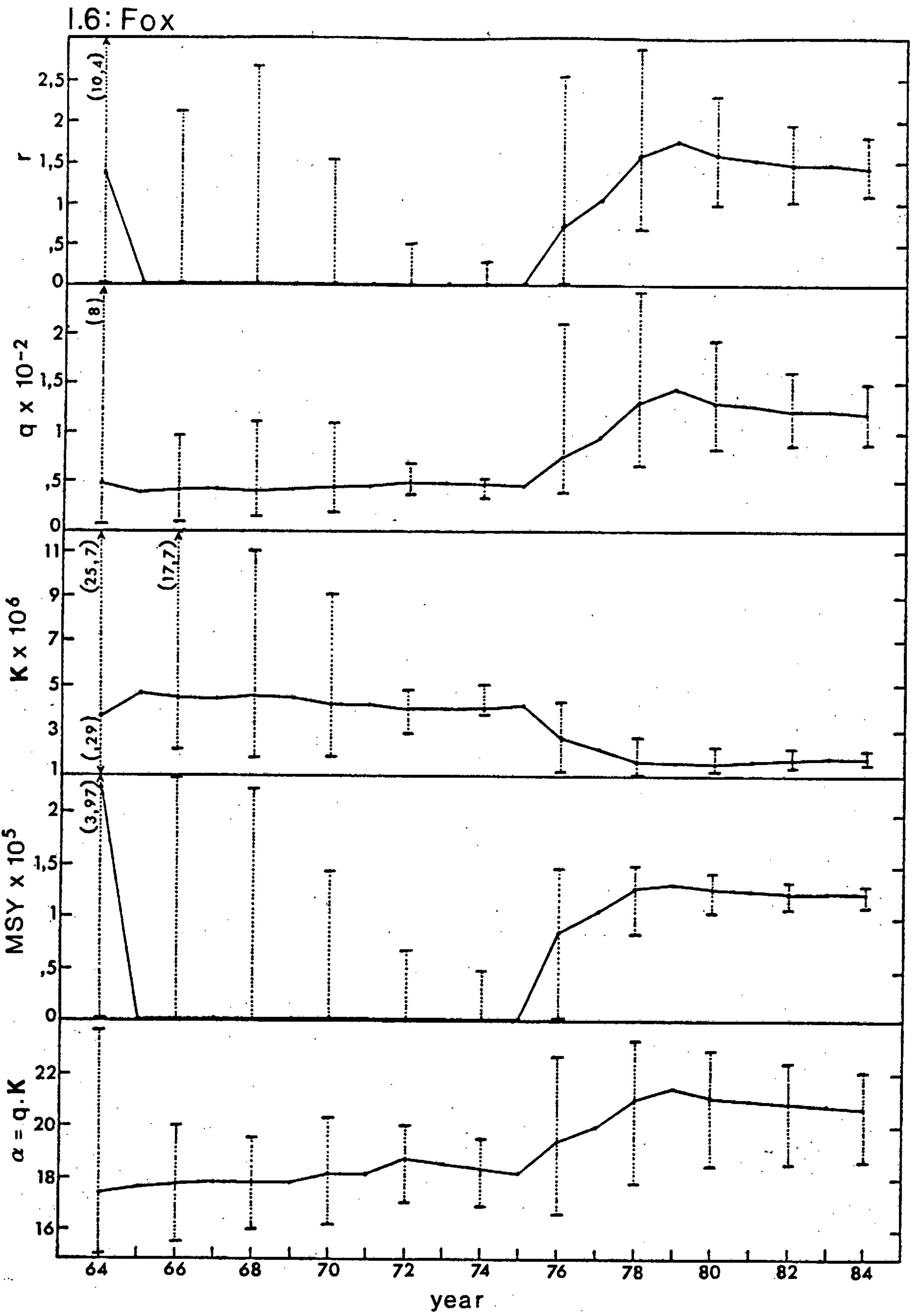


Figure 8.38: Division 1.6 . Time series of estimates of calculated Fox model parameters r, q, K, MSY and α. The error bars shown represent 95% confidence intervals.

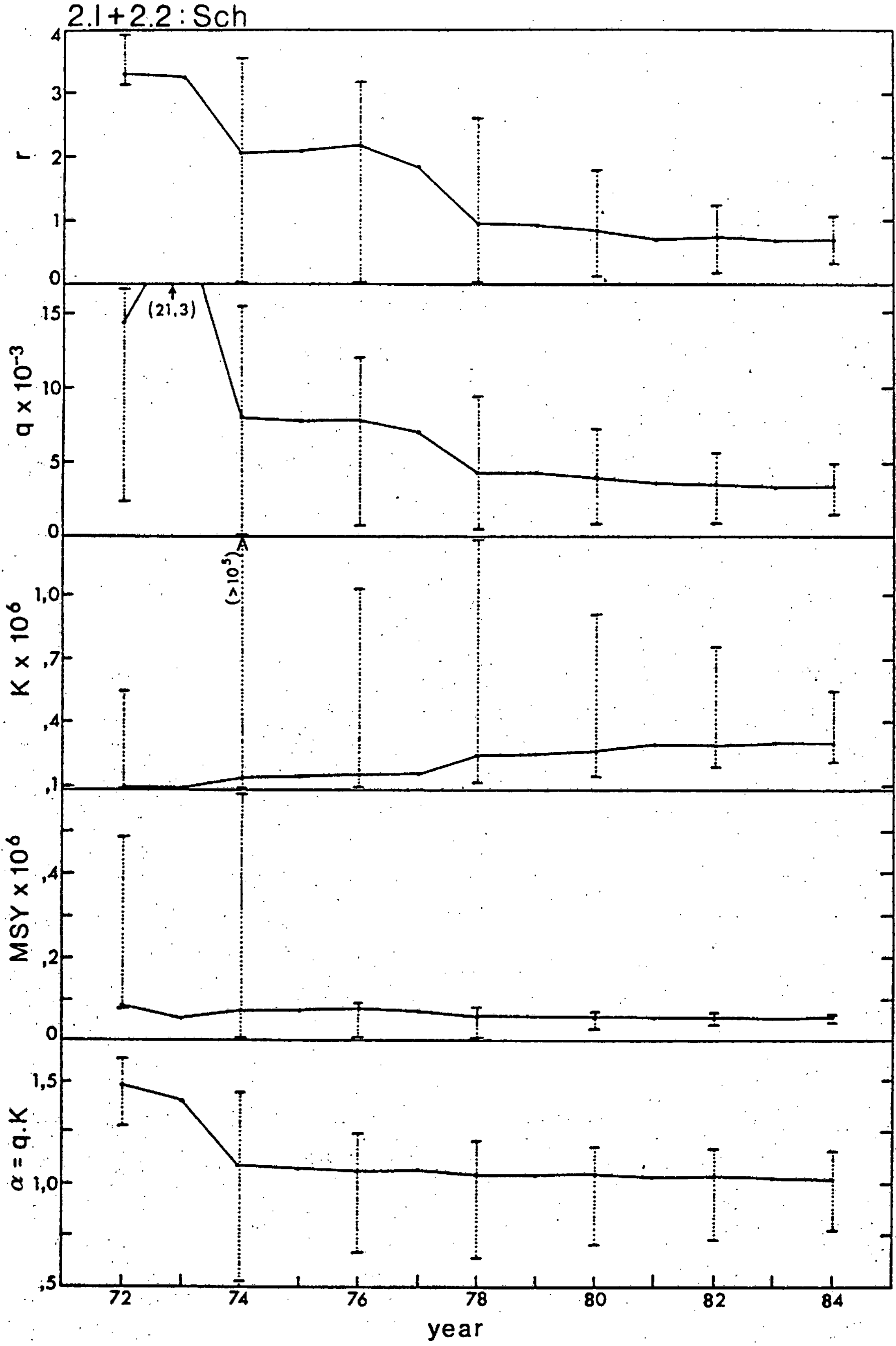


Figure 8.39: Divisions 2.1 + 2.2. Time series of estimates of calculated Schaefer model parameters r, q, K, MSY and α. The error bars shown represent 95% confidence intervals.

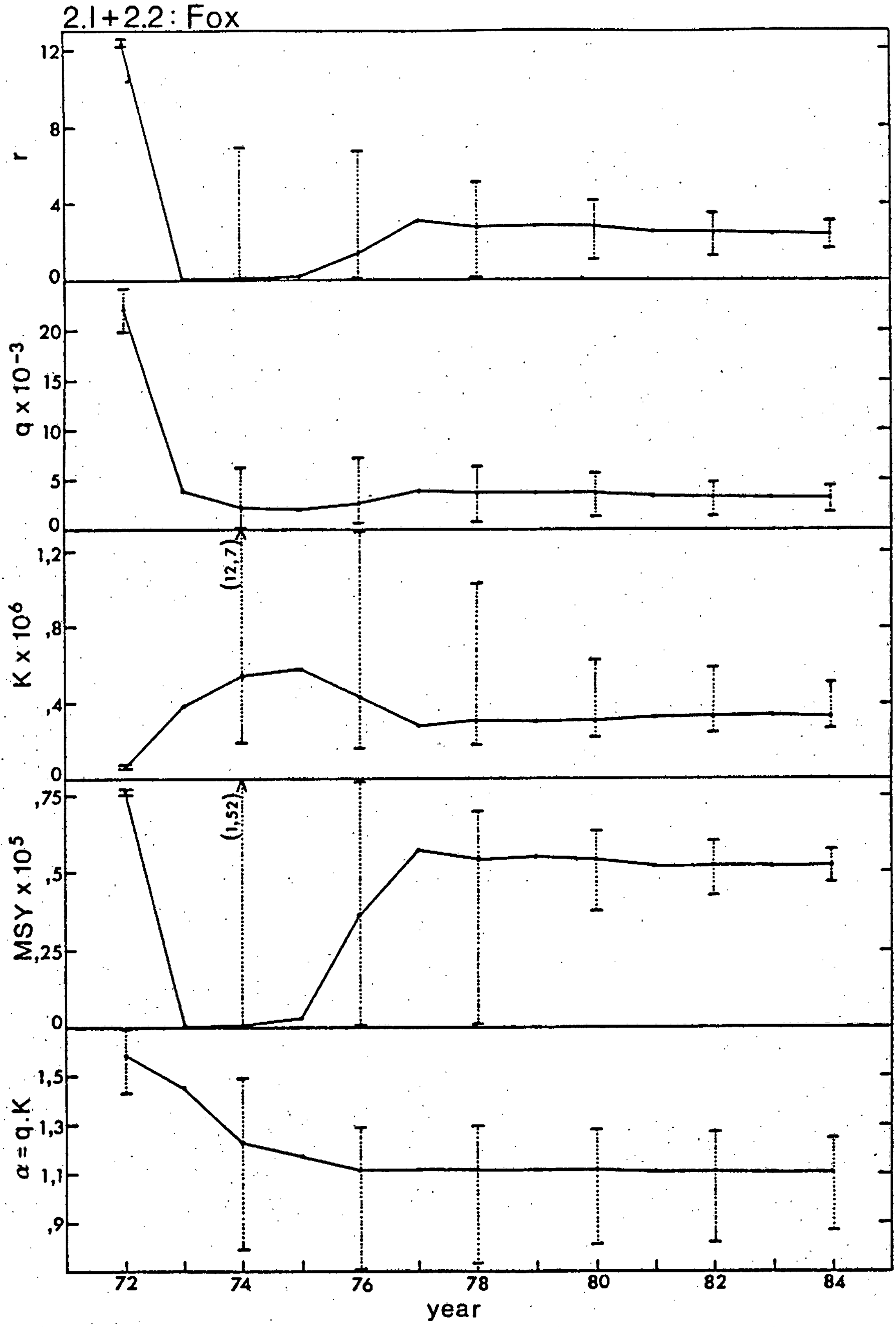


Figure 8.40: Divisions 2.1 + 2.2. Time series of estimates of calculated Fox model parameters r, q, K, MSY and α. The error bars shown represent 95% confidence intervals.

Appendix 8.1

BMDP normal probability plots

To test for normality of the weighted residuals in the dynamic model fits to the catch-effort data, χ^2 tests were performed and the results listed in Tables 8.1 - 8.8 (see Section 8.2).

A far simpler and more effective means of detecting non-normality is to use normal probability plots such as those produced by the BMDP statistical package, BMDP5D.

These show the observed weighted residual values (ordered) along the horizontal axis against their expected normal values (based on the rank of the observation) along the vertical axis (see Note (1)). If the data are from a normal distribution, the resultant line would be straight, except for random fluctuations.

BMDP normality plots were produced for the weighted residuals obtained from runs of the Gulland square root minimization (GSRM) and dynamic square root minimization (DSRM) models. These are illustrated in Figures A8.1.1 to A8.1.16. Residuals from a normal distribution would lie on the line indicated by the symbol /.

Generally the residuals for the dynamic model fits appear slightly more consistent with this straight line than those for the GFR approach. Only for the latter approach in Divisions 2.1 + 2.2 do there seem to be largish discrepancies.

Note (1) Let $x_1, x_2, \ldots x_j, \ldots x_N$ represent the weighted residual values after ordering from smallest to largest where the subscript, j is the rank order of the value and N is the total number of observations. The expected normal value for the relative rank (j out of N) is estimated by $\phi^{-1}[p]$, the standard normal value corresponding to the probability $p = (3j - 1)/(3N + 1)$.

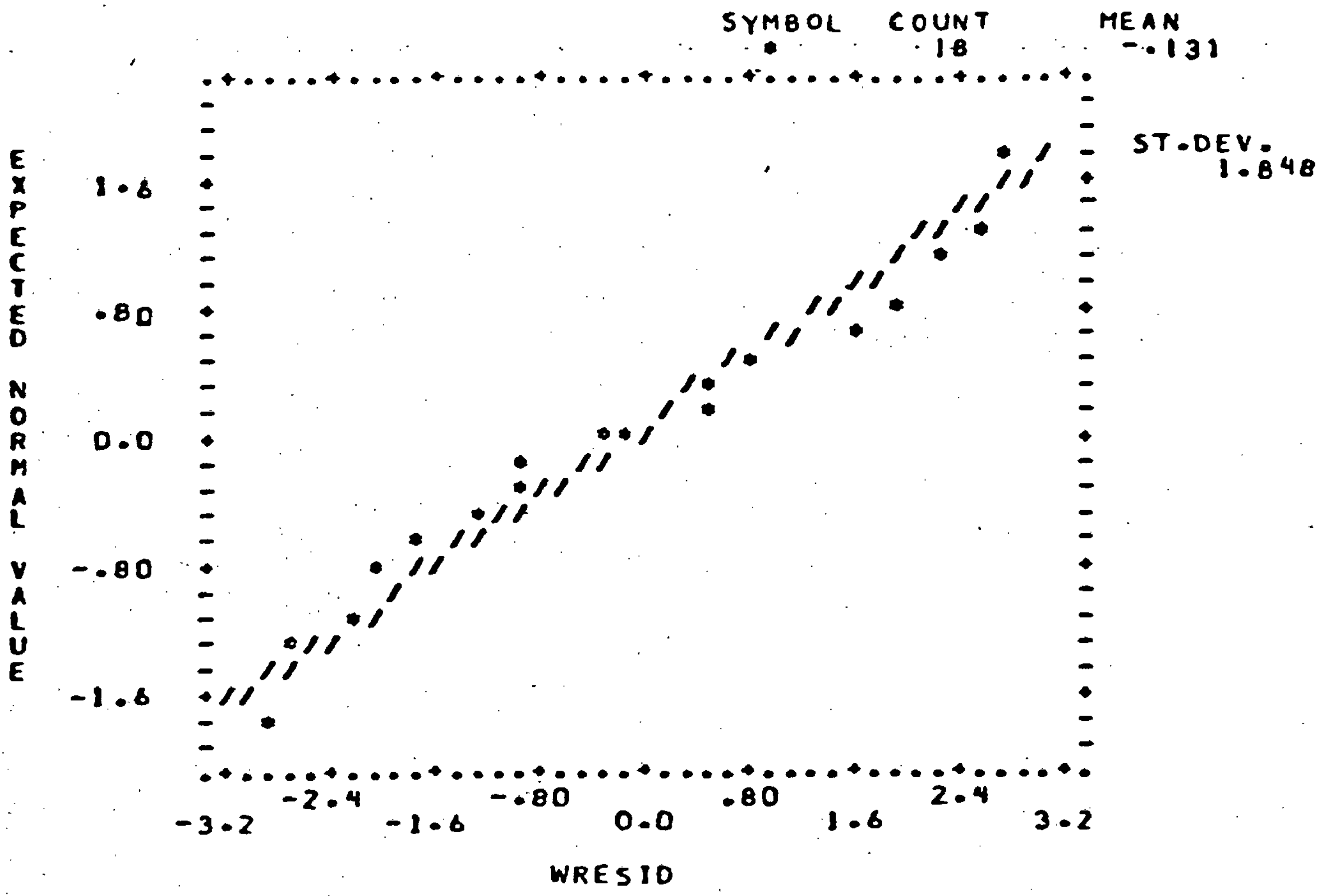


Figure A8.1.1 : Divs 1.3 + 1.4 . Schaefer model using the Gulland square root minimization (GSRM) method.

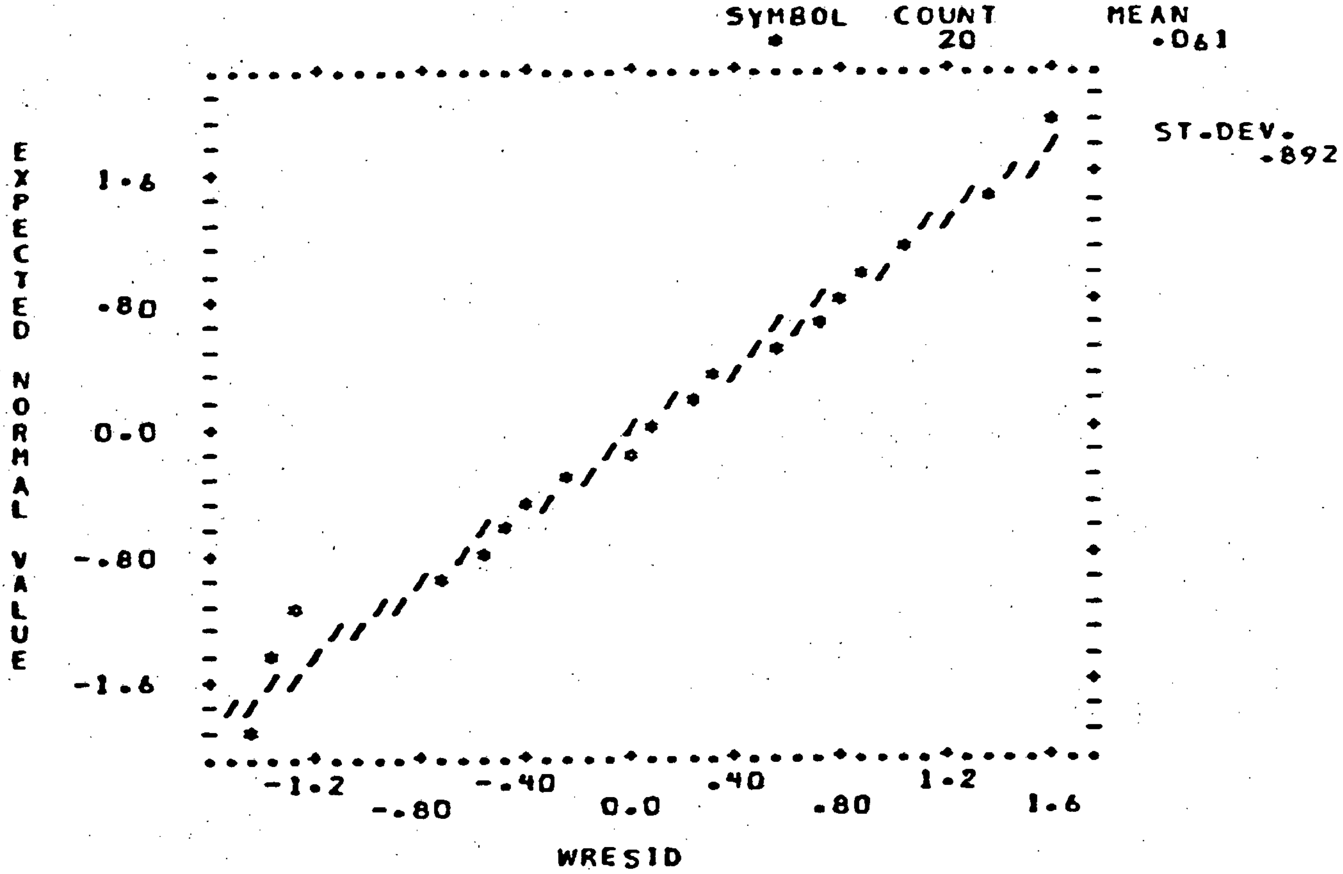


Figure A8.1.2 : Divs 1.3 + 1.4 . Schaefer model using the dynamic square root minimization (DSRM) method.

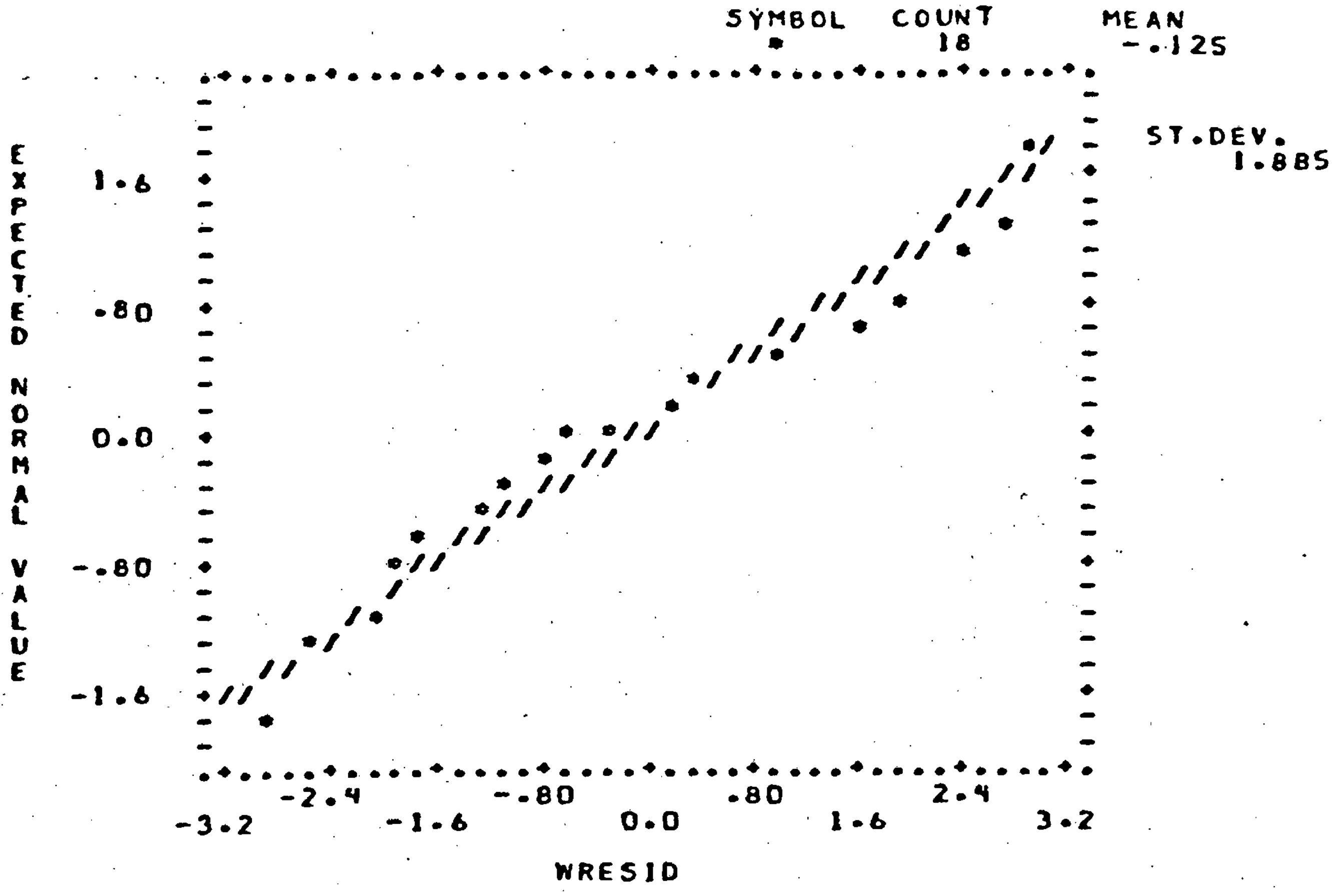


Figure A8.1.3 : Divisions 1.3 + 1.4 . Fox model using the GSRM method.

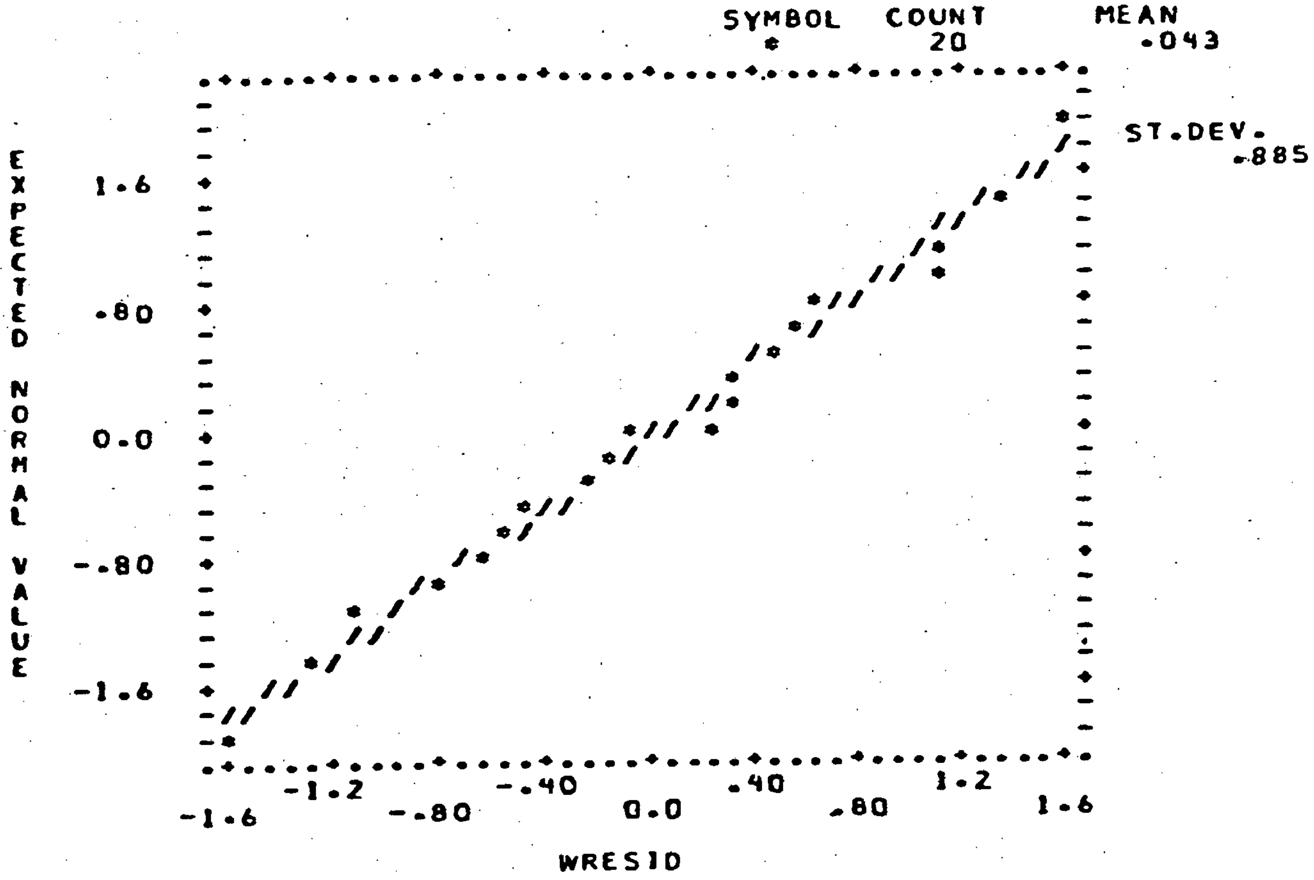


Figure A8.1.4 : Divisions 1.3 + 1.4 . Fox model using the DSRM method.

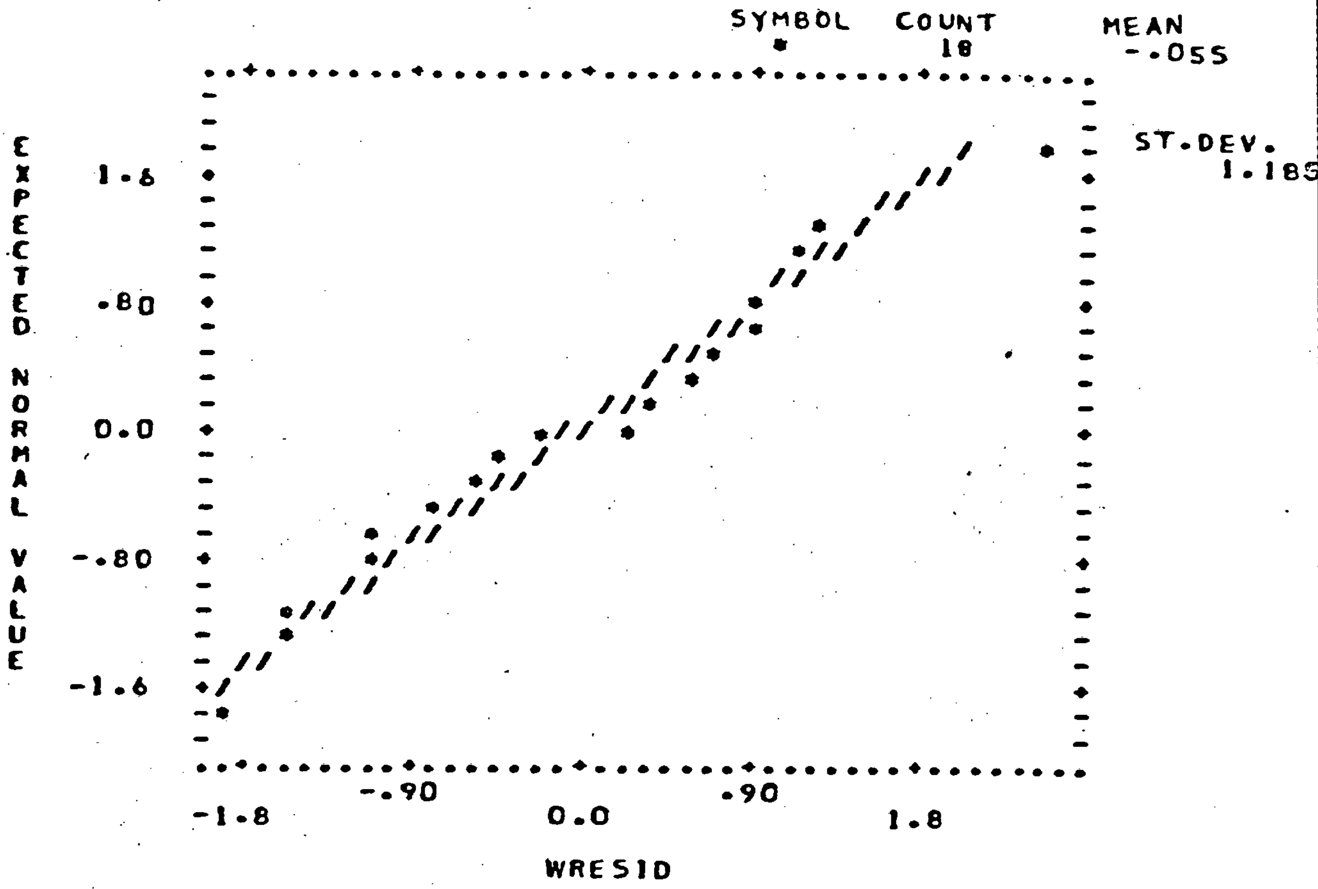


Figure A8.1.5 : Division 1.5 . Schaefer model using the GSRM method.

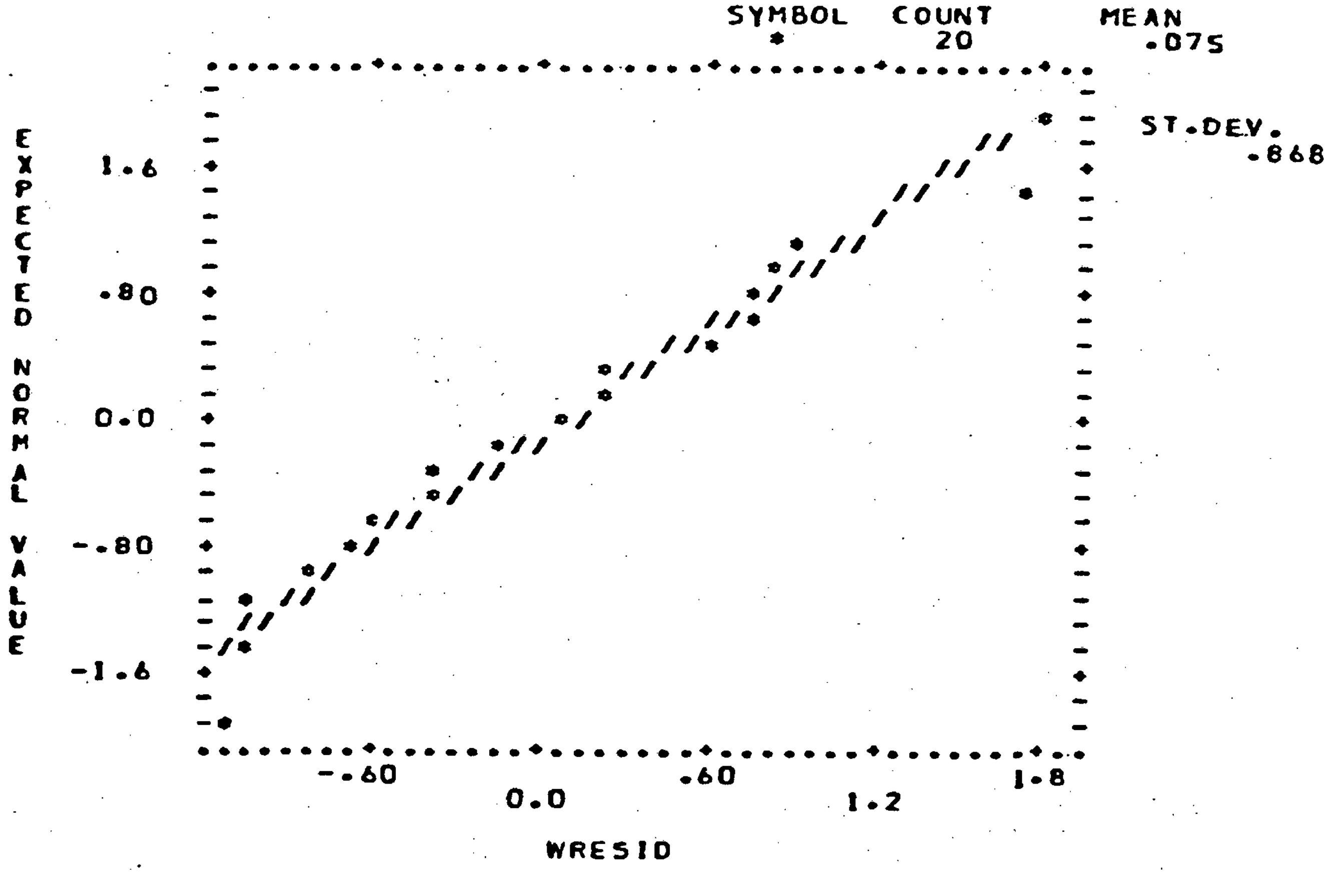


Figure A8.1.6 : Division 1.5 . Schaefer model using the DSRM method.

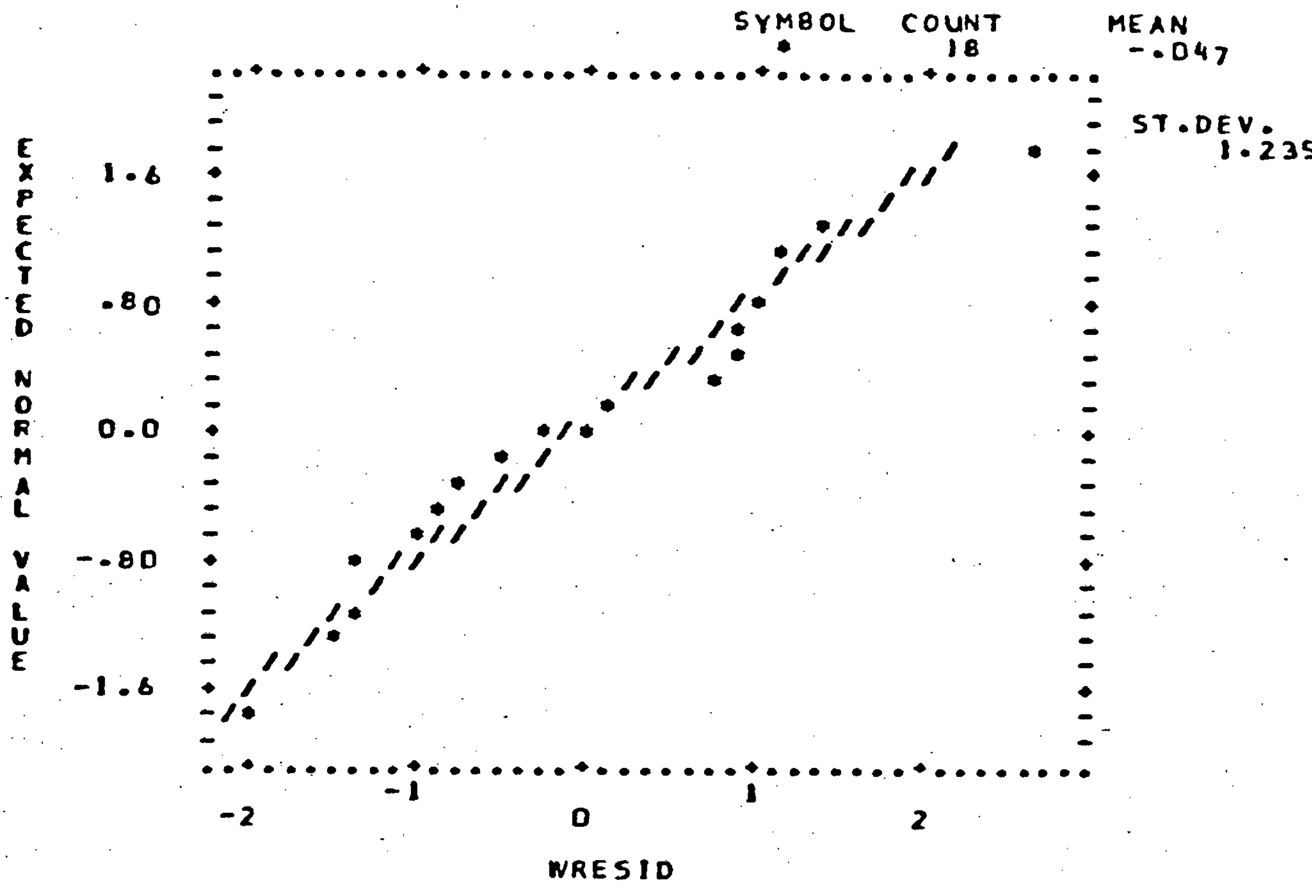


Figure A8.1.7 : Division 1.5 . Fox model using the GSRM method.

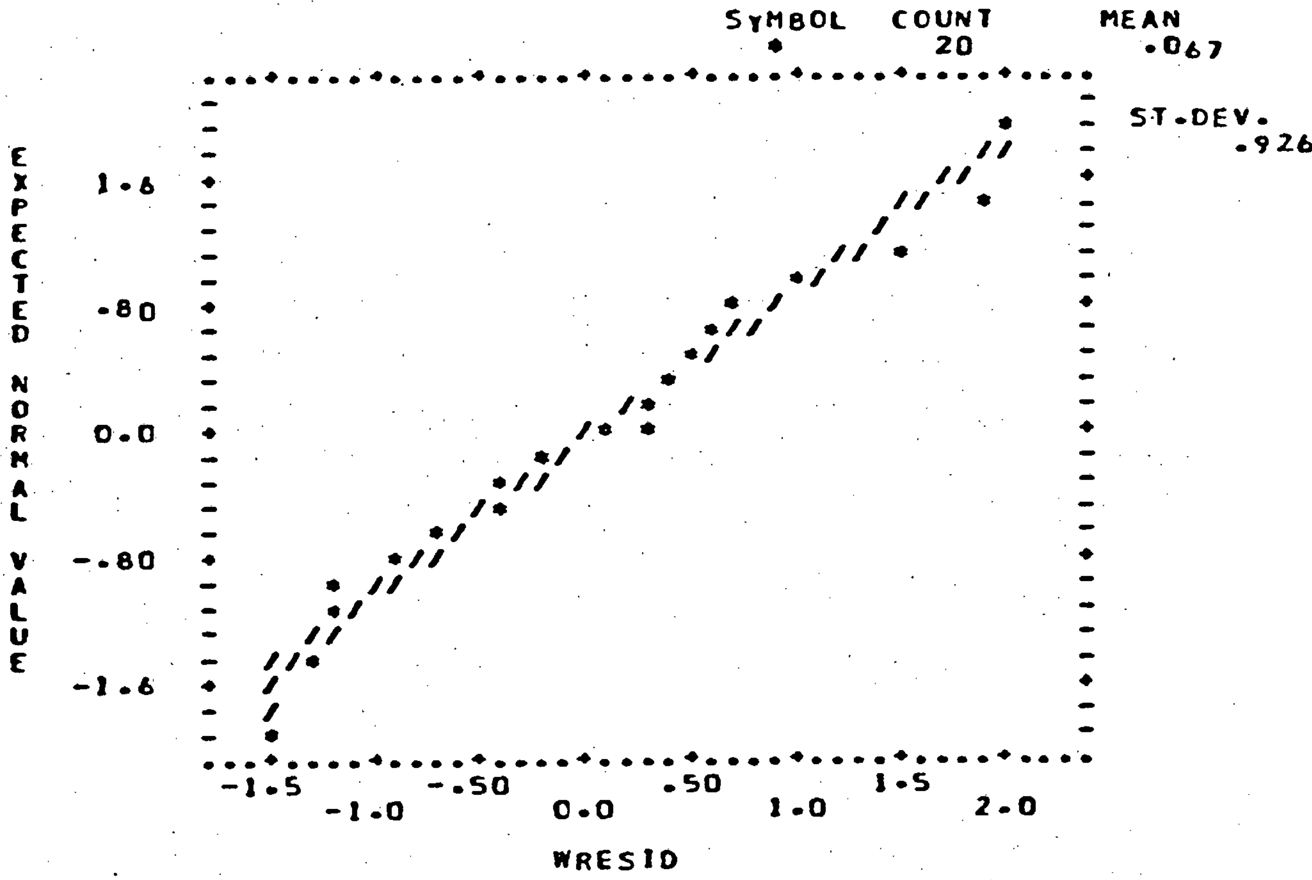


Figure A8.1.8 : Division 1.5 . Fox model using the DSRM method.

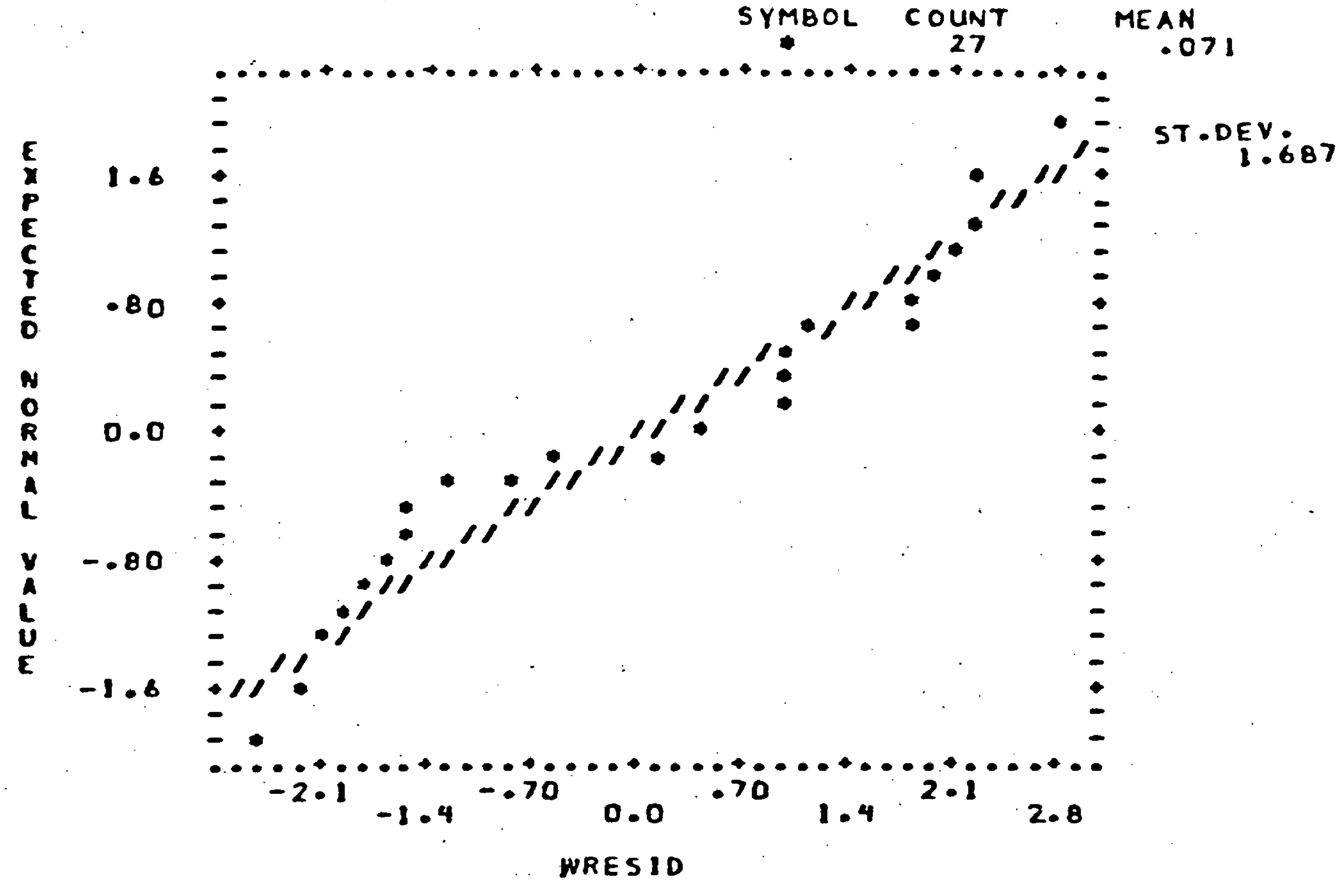


Figure A8.1.9 : Division 1.6 . Schaefer model using the GSRM method.

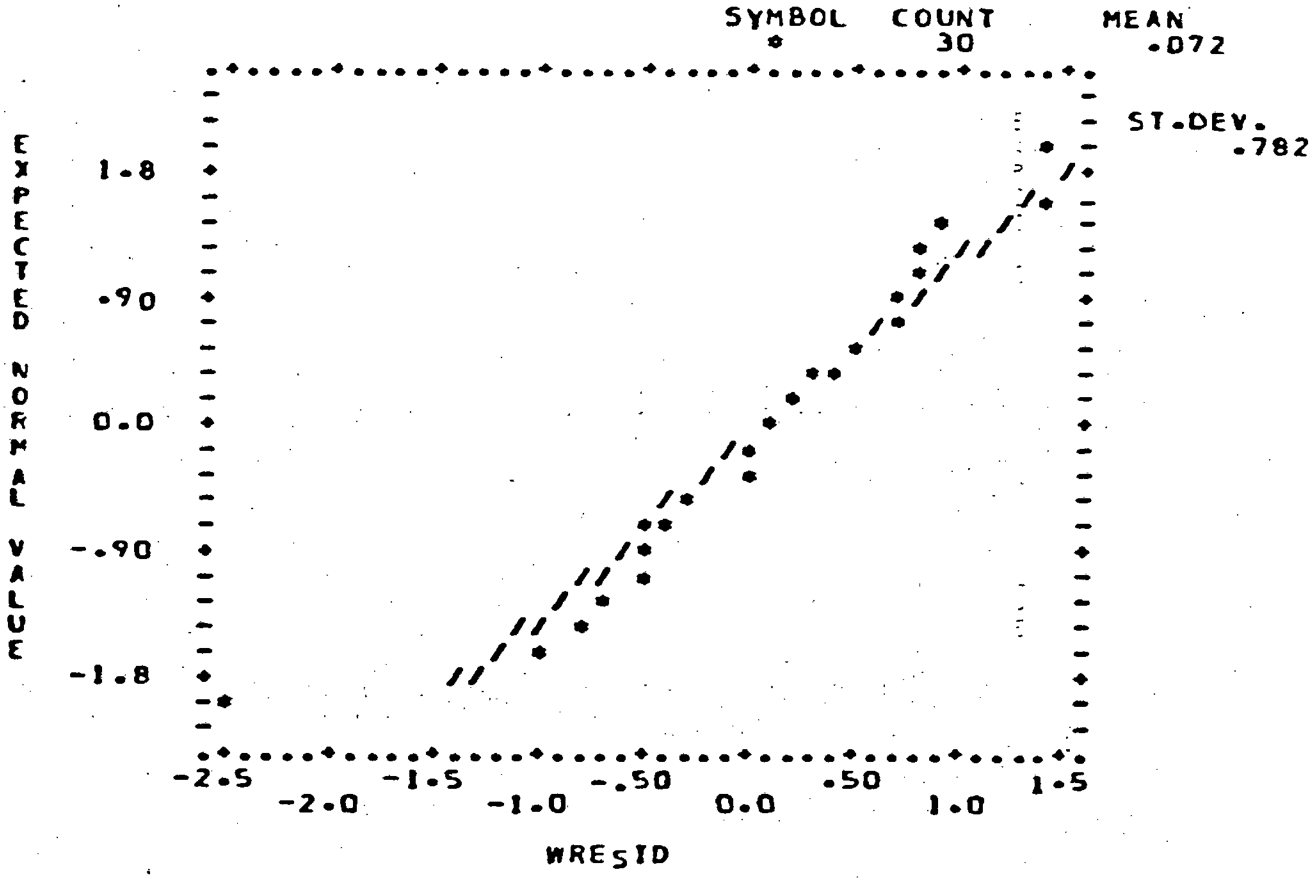


Figure A8.1.10 : Division 1.6 . Schaefer model using the DSRM method.

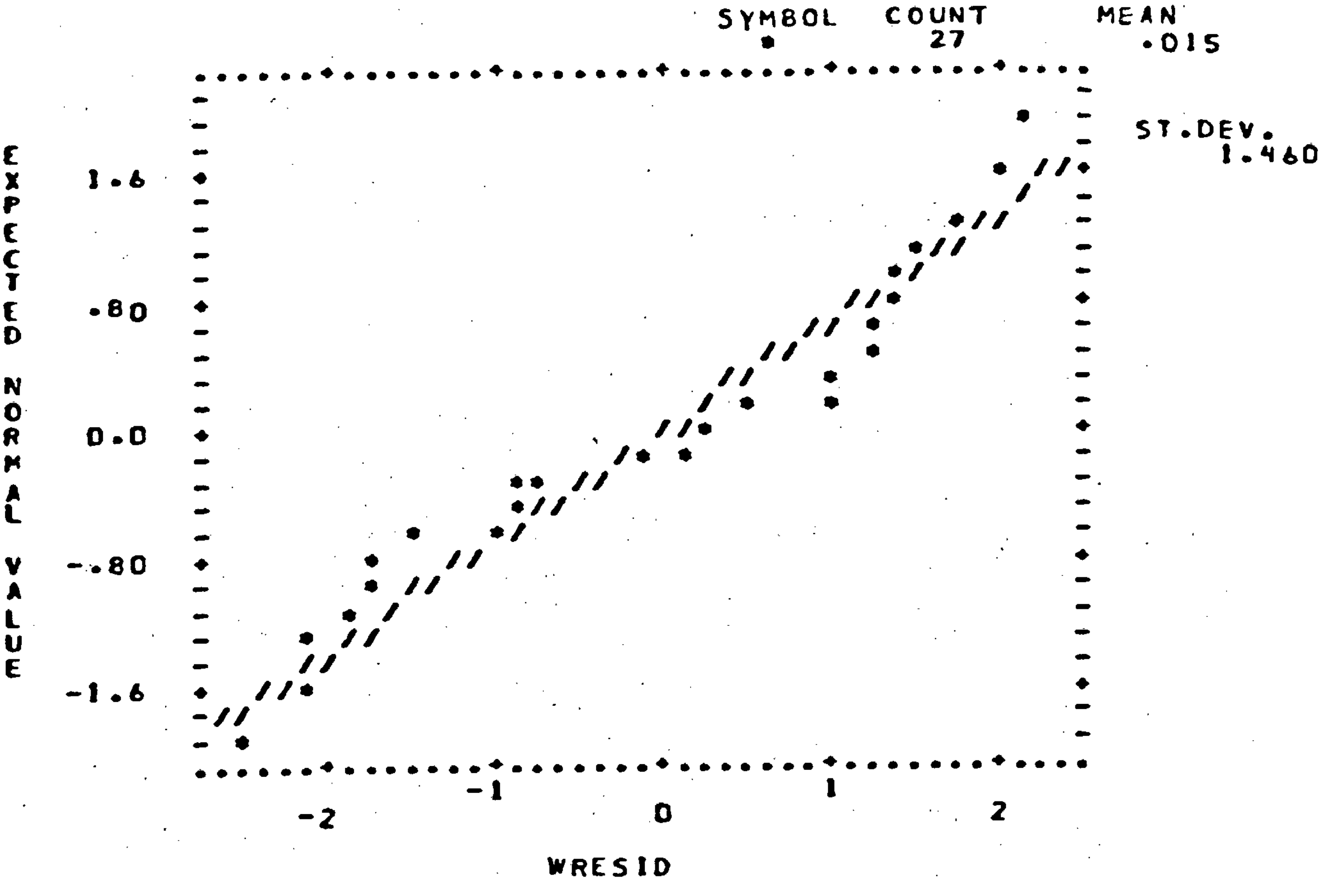


Figure A8.1.11 : Division 1.6 . Fox model using the GSRM method.

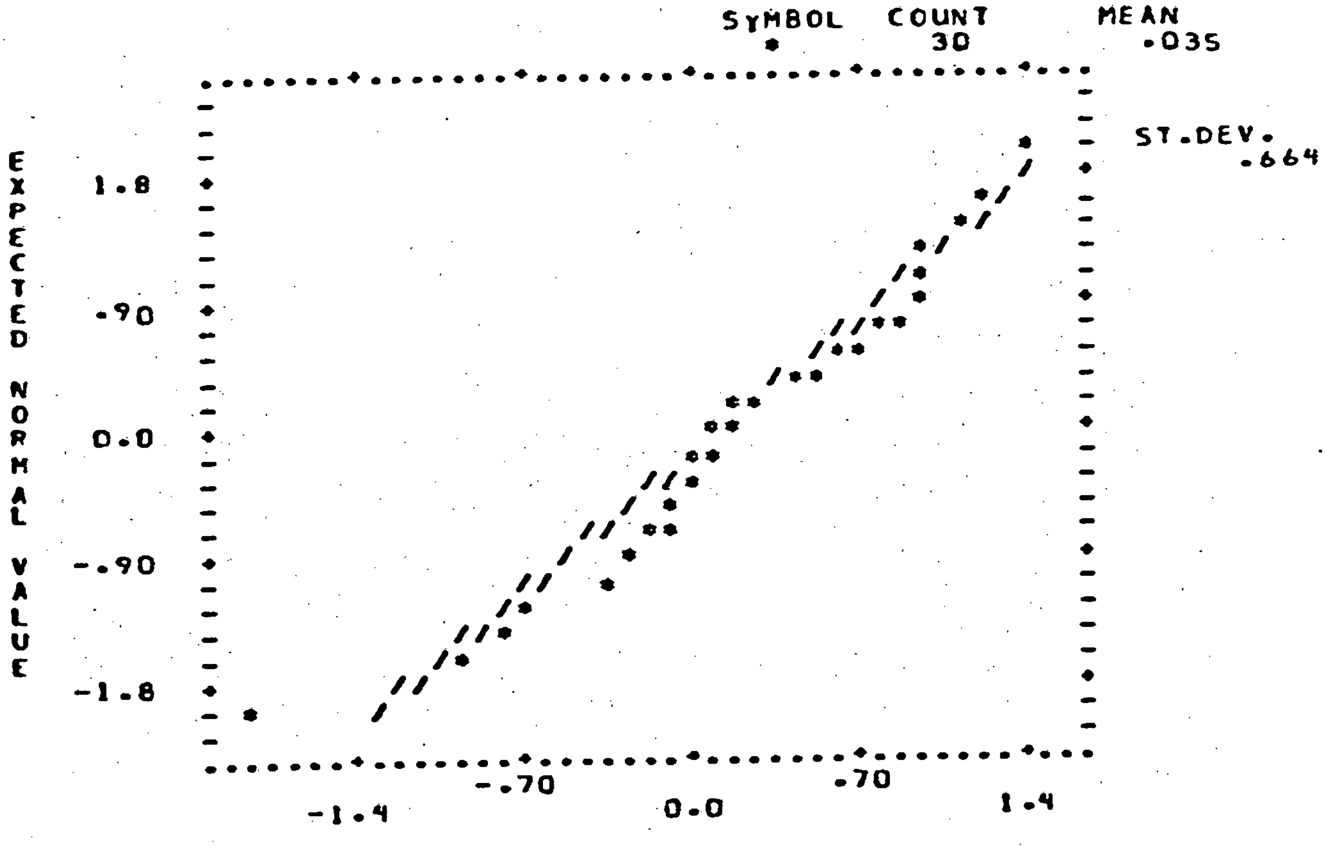


Figure A8.1.12 : Division 1.6 . Fox model using the DSRM method.

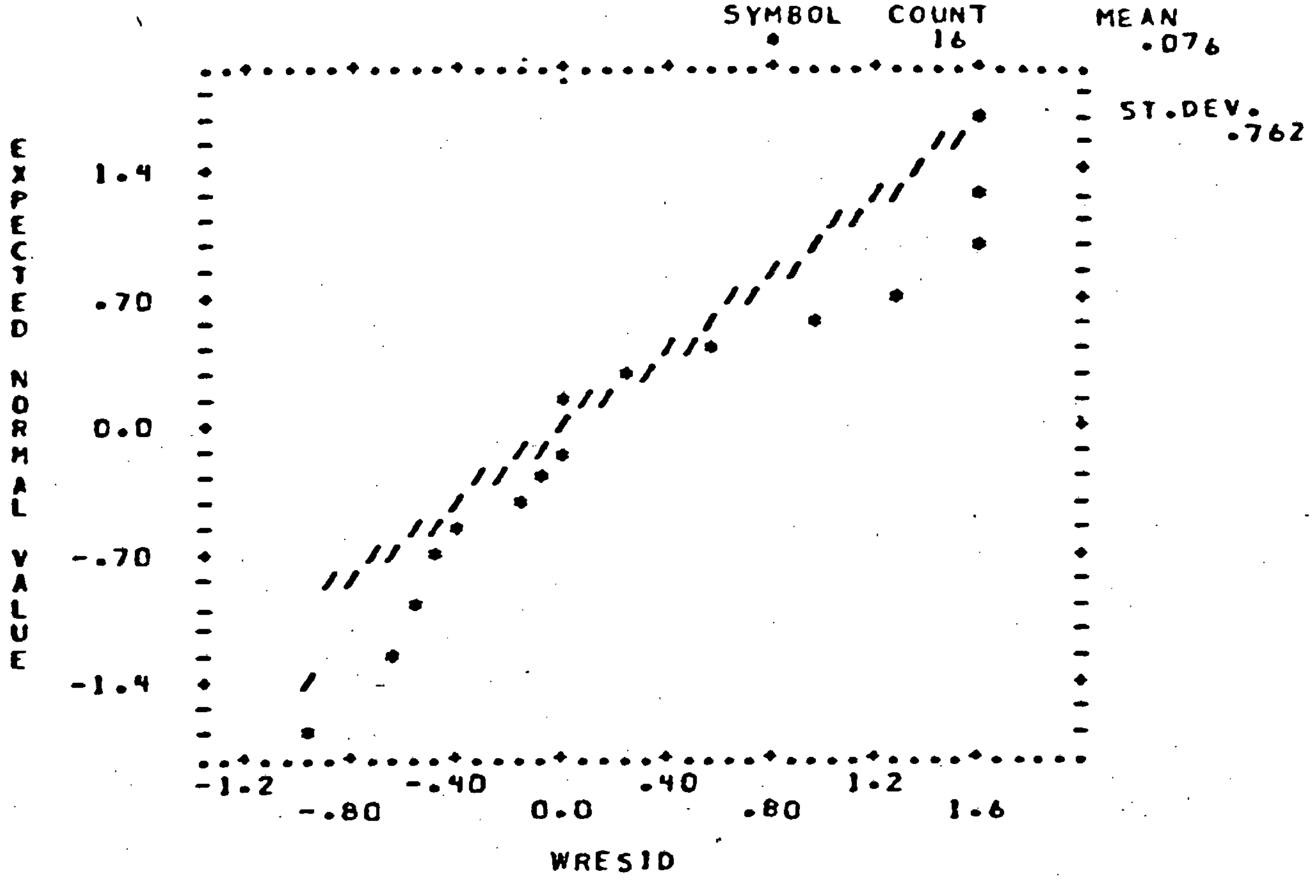


Figure A8.1.13 : Divisions 2.1 + 2.2 . Schaefer model using the GSRM method.

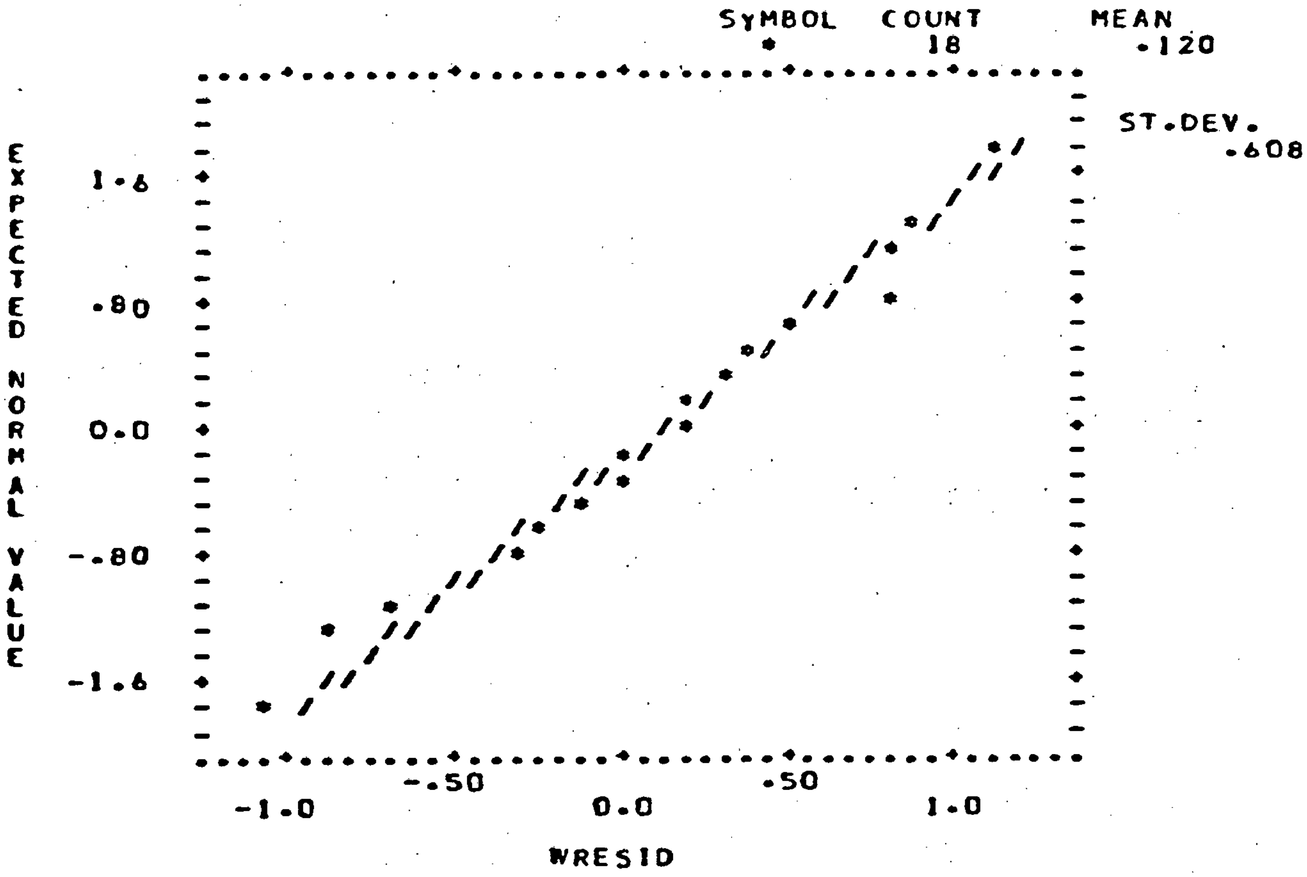


Figure A8.1.14 : Divisions 2.1 + 2.2 . Schaefer model using the DSRM method.

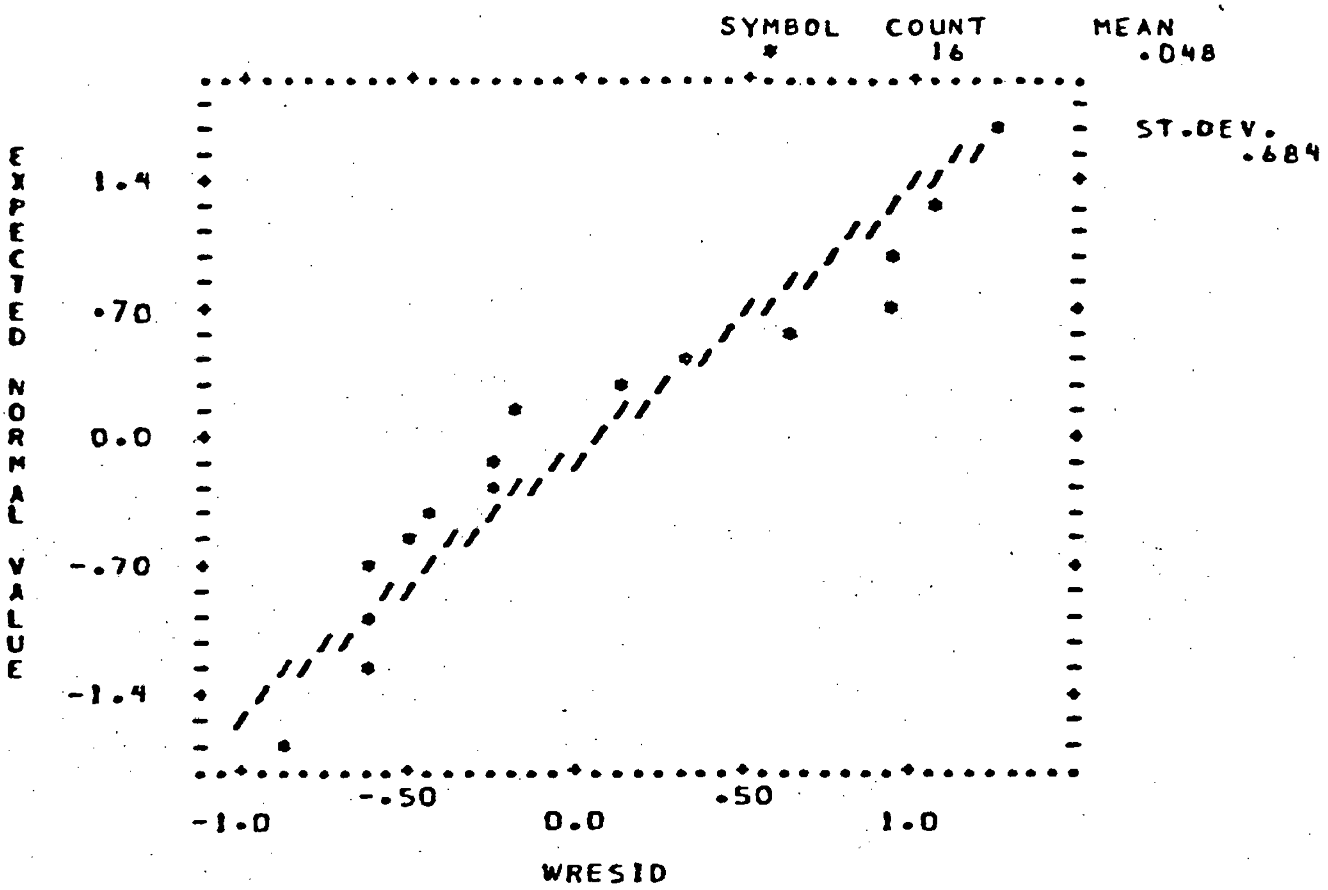


Figure A8.1.15 : Divisions 2.1 + 2.2 . Fox model using the GSRM method.

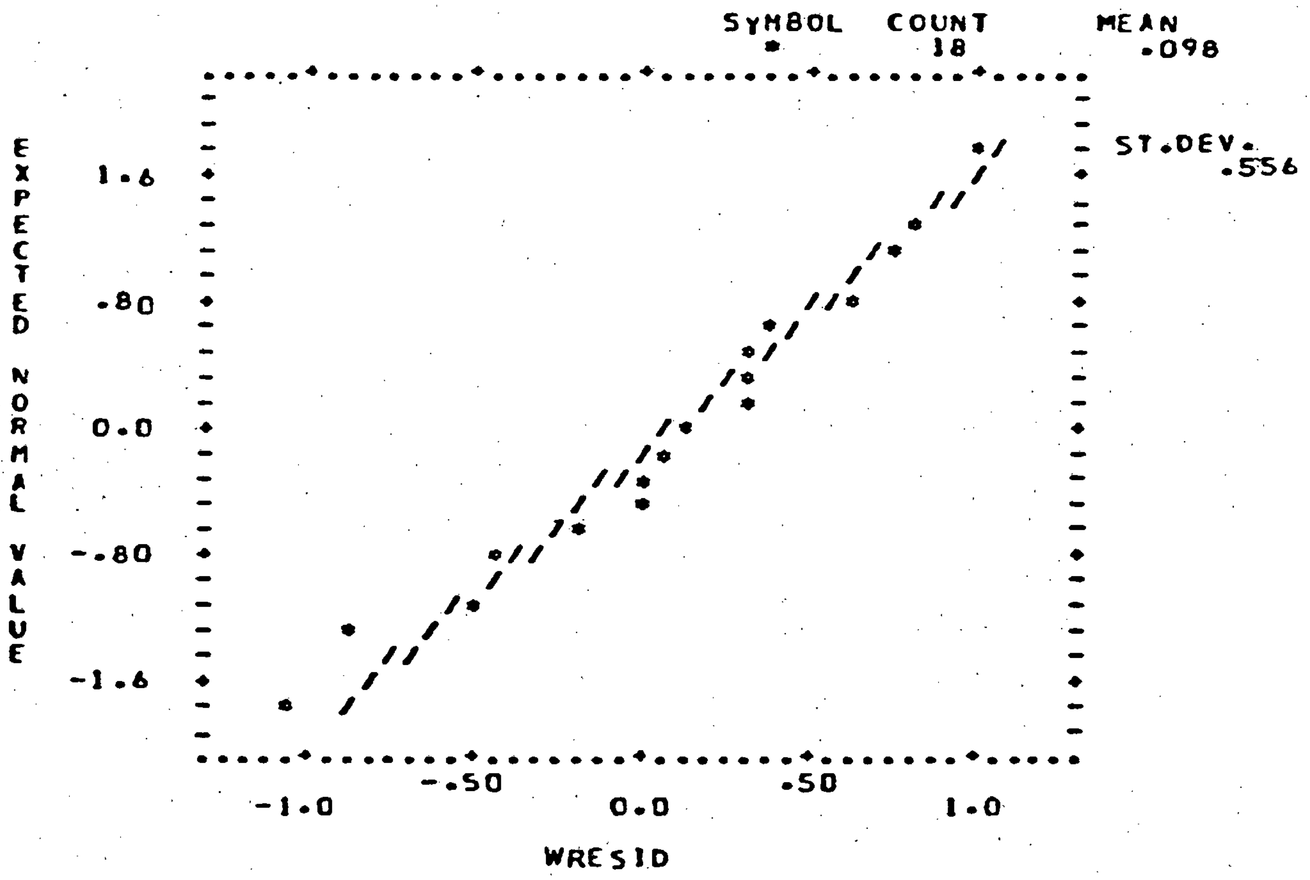


Figure A8.1.16 : Divisions 2.1 + 2.2 . Fox model using the DSRM method.

Appendix 8.2

A justification of the formula used to calculate the standard error of an inverse-variance weighted average

The weighted average intrinsic growth rate, $\bar{r}$, in the Schaefer model for the four separate hake stocks under consideration, was determined using the formula:

$$\bar{r} = \sum_{i=1}^{4} w_i \, . \, r_i \qquad \text{(A8.2.1)}$$

where r_i is the intrinsic growth rate corresponding to a particular stock i

and w_i is the associated weighting factor.

These weighting factors were determined using the variances (var) of the r_i values as follows:

$$w_i = \frac{[1/\mathrm{var}(r_i)]}{\sum_{j=1}^{4} [1/\mathrm{var}(r_j)]} \qquad \text{(A8.2.2)}$$

(that is, weighting proportional to inverse variance).

Provided the r_i estimates are uncorrelated (that is, covariance$(r_i, r_j)=0$ for $i \neq j$), it follows from equation (A8.2.1) that

$$\mathrm{var}(\bar{r}) = \sum_{i=1}^{4} w_i^2 \, . \, \mathrm{var}(r_i).$$

This implies that

$$\mathrm{var}(\bar{r}) = \sum_{i=1}^{4} \left[\frac{1}{\mathrm{var}(r_i)}\right]^2 . \left[\sum_{j=1}^{4} \frac{1}{\mathrm{var}(r_j)}\right]^{-2} . \, \mathrm{var}(r_i)$$

$$= \left[\sum_{j=1}^{4} \frac{1}{\mathrm{var}(r_j)}\right]^{-2} . \left[\sum_{i=1}^{4} \frac{1}{\mathrm{var}(r_i)}\right]$$

$$= \left[\sum_{j=1}^{4} \frac{1}{\mathrm{var}(r_j)}\right]^{-1} .$$

Since $\mathrm{var}(\bar{r})=[\mathrm{s.e.}(\bar{r})]^2$ and $\mathrm{var}(r_j)=[\mathrm{s.e.}(r_j)]^2$, equation (8.2) for $\bar{r}$ or similarly any other parameter follows immediately:

$$(\mathrm{s.e.}(\bar{r})) = \left[\sum_{j=1}^{4} \frac{1}{[\mathrm{s.e.}(r_j)]^2}\right]^{-\frac{1}{2}} .$$

9 VIRTUAL POPULATION ANALYSIS (VPA)

9.1 Introduction

The dynamic catch and effort models given in Chapter 5 are two of many means of stock biomass estimation. Alternative methods use data obtained from tagging, acoustic and aerial surveys and egg and larval sampling to estimate stock abundance. In this chapter the VPA method of biomass estimation is discussed and the results obtained using this assessment technique are compared with those of the dynamic models for Division 1.6 . Further aspects of the dynamic models are investigated as a result of the discrepancy between biomass estimates for the two methods.

9.2 The underlying principles of VPA

VPA is a major method of current and historic biomass estimation from catch statistics. Fry (1957) introduced the term 'virtual population' to describe the total number of fish belonging to a particular year-class present in the water at any given time that are destined to be captured in that year and in all subsequent years. Gulland (1965) took this idea further, developing the technique now known as VPA.

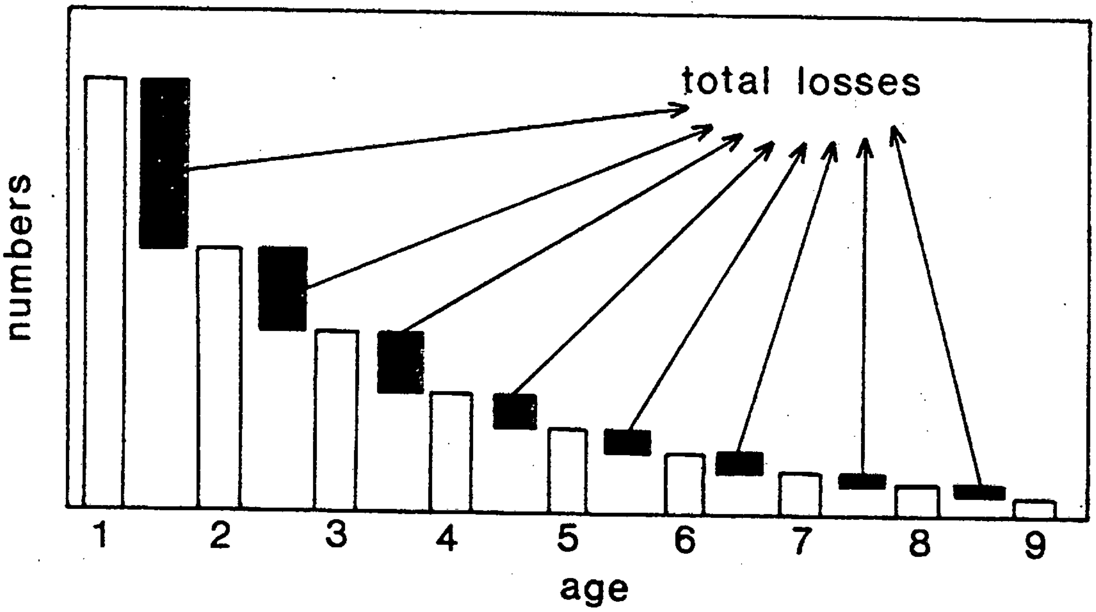


Figure 9.1: The total number of individuals removed throughout the life of a year-class must equal the total number of individuals initially present in that year-class.

Assuming that hake spawn annually during a discrete breeding season, the population will be composed of a number of cohorts or year-classes, each of which is the product of one breeding season. The size of the cohort at the age at which it joins the adult stock is called the recruitment or year-class strength.

If the total number of fish removed from a year-class during its entire exploited phase can be determined, then estimations of the original number of individuals in that year class can be obtained. During the interval of time under consideration, fish can either be caught, die of natural causes or survive to the beginning of the next period. See Figure 9.1 .

VPA is a stepwise procedure of estimating the population size and the rate of fishing mortality for each age in the stock using past years' catch-at-age information and taking into account natural losses. Although the method is valid for all catch data, the estimates of F provided by VPA will be more precise if a large proportion of the total removals are due to fishing.

9.3 Method of solution

For simplicity, the basic concepts and methods for the case of a single cohort are first developed.

Let N_i = number of fish of age i at the start of the year

C_i = number of fish caught of age i during the year

F_i = fishing mortality applied to age class i

and M = natural mortality which is assumed to be constant for all years and ages (see Appendix 9.1 for discussion on M).

Assuming that each age group, i, in the fish stock is subject to a certain steady cause of mortality, it is generally assumed that the rate of change of age group size in numbers with respect to time, dN_i/dt, will be proportional to the number of fish present. The constant of proportionality is called the total mortality, Z_i, which is a combination of natural and fishing mortality (that is, $Z_i = M + F_i$). dN_i/dt can then be expressed as follows:

$$dN_i/dt = Z_i . N_i = -(M+F_i).N_i(t) .$$

Therefore if the number of fish present at time t = 0 is N_i, by integating over the time period (0,t), the decline in numbers with age can be represented by an exponential curve,

$$N_{i+1}(t) = N_i . e^{-(F_i+M)t}$$

and therefore over a period of one year,

$$N_{i+1} = N_i . e^{-(F_i+M)} \qquad (9.1)$$

Similarly, the catch rate by numbers is given by:

$$dC_i/dt = F_i . N_i \; .$$

It is assumed that fishing is a continuous process, taking place uniformly throughout the year. By integrating over the period (0,1) and using equation (9.1) it follows that the number caught over a period of one year is

$$C_i = N_i . F_i . (1-e^{-(F_i+M)})/(F_i+M) \qquad (9.2)$$

Equations (9.1) and (9.2) are combined to give

$$N_{i+1}/C_i = [(F_i+M).e^{-(F_i+M)}]/[F_i . (1-e^{-(F_i+M)})] \qquad (9.3)$$

To start the analysis one needs an estimate or guess of the fishing mortality rate of the age group of the oldest fish captured in the cohort, F_t (t here is the last or 'terminal' age of a year-class for which catch data is available). It can be seen from Figure 9.2 that, in general, this amounts to estimating F values for the last row and the last column of the F matrix. Allowance has to be made for the disappearance of older age classes caused by heavy exploitation. From the estimates of F_t values for N_t can be calculated using equation (9.2).

With estimates for N_i, C_{i-1} and M available, it is possible to use equation (9.3) to solve for F_{i-1}. As this formula does not yield an analytic solution for F_i, VPA estimates are obtained by referring to tables or by solving iteratively. Once F_{i-1} is known, the numbers in that age

ages / years	I	II	III	IV	V	VI	VII	VIII
i	F_1^i	F_2^i	F_3^i					F_8^i
i+1		F_2^{i+1}						
			F_3^{i+2}					
				F_4^{i+3}				
					F_5^{i+4}			
						F_6^{i+5}		
i+6							F_7^{i+6}	
y								F_8^y

Figure 9.2: The F matrix with the fishing mortality rate values for different ages and year-classes set off in boxes. F_i^y is the fishing mortality for age i in year y.

group, N_{i-1}, can be obtained from equation (9.1). In turn, equation (9.3) can then be used to obtain F_{i-2} and so on, proceeding backwards in time from the oldest to the youngest ages in the cohort (see Figure 9.3 for method of solution).

Up to this point only the calculations for a single cohort have been considered. However, in the real situation this procedure must be repeated for all year-classes present in the population, thereby yielding initial F_i^y estimates for all age groups and year-classes under consideration.

By repeating the whole of the above procedure again, these initial estimates for F_i^y can be improved upon. These calculations require estimates of F_t which are not computable by equations (9.1), (9.2) and (9.3). Initially, these values are guessed. In subsequent iterations, values for F_t are estimated using the techniques described below.

Pope's method of 'cohort analysis' (1972) is an alternative simplified approach to VPA. It provides an approximation to VPA which has been shown to have an accuracy of approximately 5% for values of M less than 0,3 and F less than 1,2 (Pope, 1972). Cohort analysis is described in detail in Appendix 9.3 .

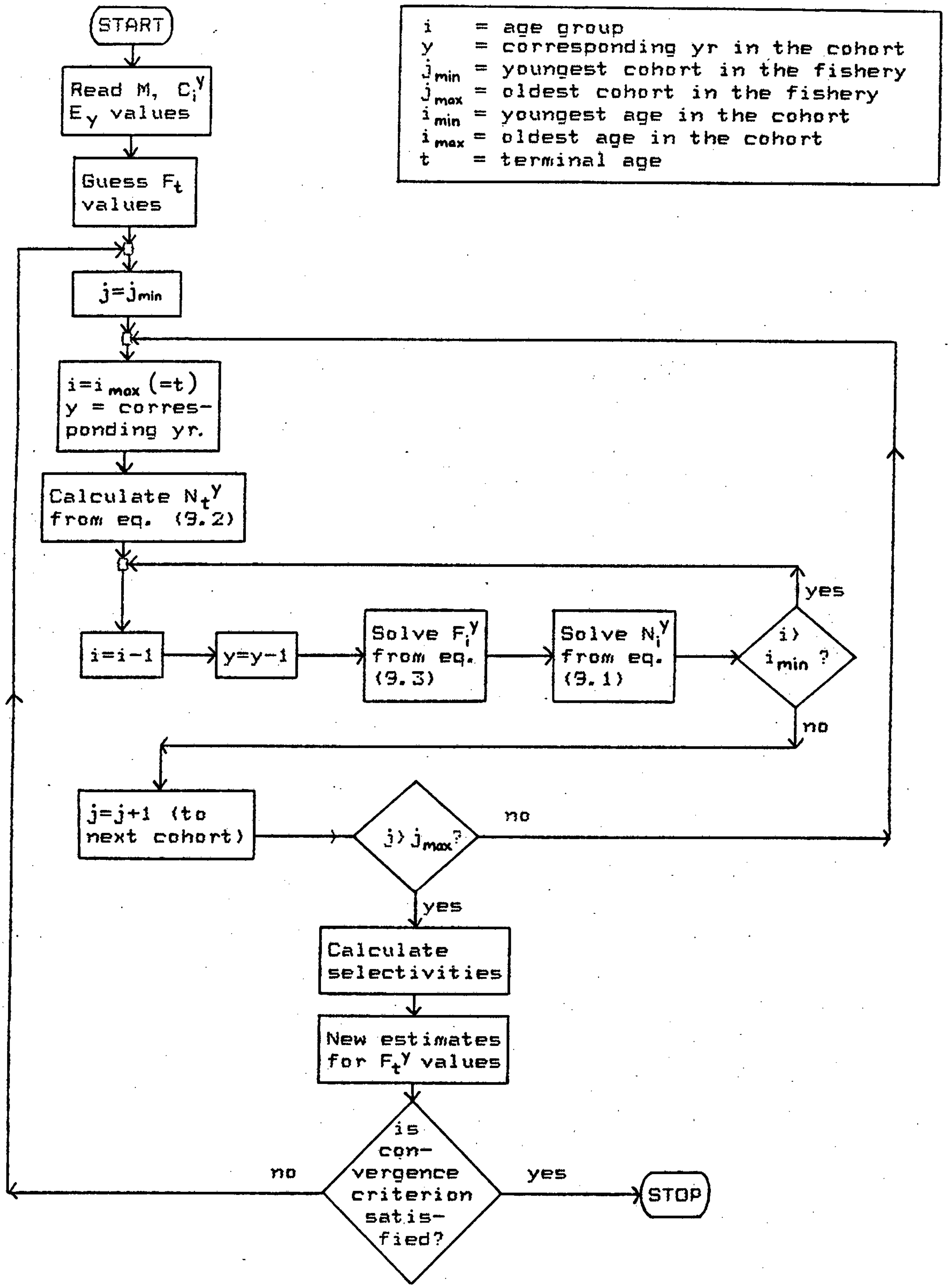


Figure 9.3 VPA method of solution.

9.4 Selectivity factors

Selectivity (or partial recruitment) factors determine the size composition of any catch from a population of given age structure.

The total fishing effort exerted on a stock changes from year to year as a result of changes in fleet size, fishing power or other factors. Even within a single year, however, a given level of fishing effort does not bring about the same rate of fishing mortality for all age groups (that is, year-classes) in a fishery. The size composition of any catch will in part be determined by two factors: the mesh size of the net and the size composition of the fish which may vary over their geographical distribution. For a given size composition, the effect of mesh size will be that the larger fish will tend to be subjected to a greater fishing mortality than the smaller ones which may escape through the meshes of the net.

For any year y, the overall fishing mortality, $\bar{F}_y$, is given by

$$\bar{F}_y = q.E_y \qquad (9.4)$$

where q = catchability coefficient (which can be obtained from regression on earlier years' data)

and E_y = effort in year y.

A selectivity factor, S_i, is introduced to account for the variation in F between age classes as follows:

$$F_i^y = S_i.\bar{F}_y \qquad (9.5)$$

(Note that $F_i^y = S_i.\bar{F}_y$ can be expressed as

$$F_i^y = S_i'.\bar{F}_y' \qquad \text{where } S_i' = \alpha.S_i$$

$$\bar{F}_y' = (1/\alpha).\bar{F}_y$$

and α is some constant.

Therefore equation (9.5) only defines S_i and $\bar{F}_y$ up to normalization constants.)

It follows from equation (9.4) that $F_i^y = S_i.q.E_y$ (9.6)

Using equations (9.2) and (9.5), the catch rate for year y of fish of age i can be represented by the following equation:

$$dC_i^y/dt = F_i^y.N_i^y$$

$$= S_i \bar{F}_y .N_i \quad . \qquad (9.7)$$

Similarly the rate of change of population size is

$$dN_i/dt = -(M + S_i.F_i^y).N_i^y \quad .$$

The use of selectivity factors can be illustrated by the following simple example. Take a population with, say, 5 age classes and an overall fishing mortality, $\bar{F} = 0,25$.

Age class	0	1	2	3	4
N_i	2000	1000	500	200	100

Introducing a selectivity factor, S_i such that $F_i = \bar{F}.S_i$, the number of fish of age i caught is determined using equation (9.7) .

Age class	0	1	2	3	4
N_i	2000	1000	500	200	100
S_i	0	0,25	0,5	1,0	1,0
$\bar{F}$	0,25	0,25	0,25	0,25	0,25
dC_i/dt] Δt small	0	62,5	62,5	50	25

In the above example, the graph of selectivity, S_i, versus age has been approximated by a step function as shown in Figure 9.4 .

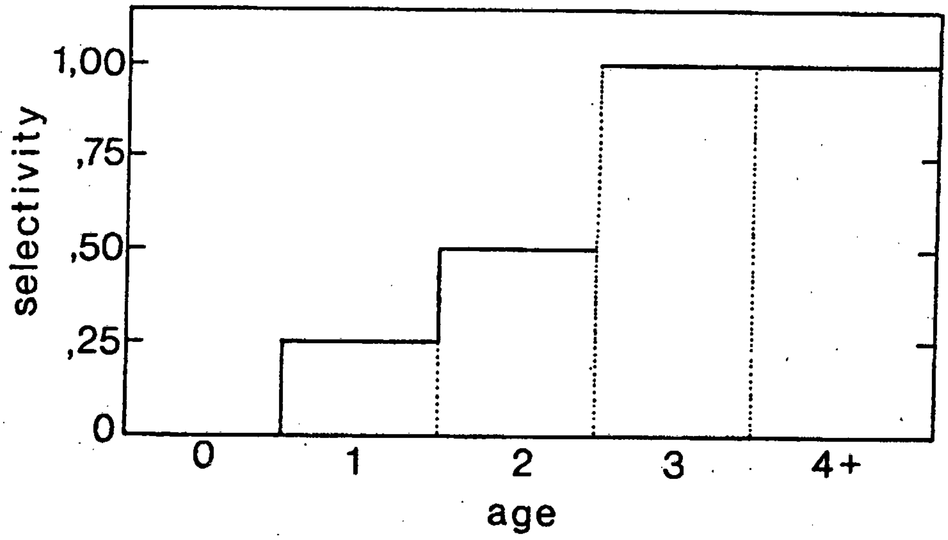


Figure 9.4

In any given year, within any two age groups we see that

$$F_i^y / F_{i+1}^y = (q.S_i.E_y) / (q.S_{i+1}.E_y)$$

$$= S_i / S_{i+1} .$$

That is, assuming constant age-specific selectivities in this manner means that the ratio of the fishing mortalities of age i to age i+1 remains constant from one year to the next although total effort and therefore actual levels of F_i may change.

Therefore, for any given year, ideally,

$$(F_1^y / S_1) = \ldots (F_i^y / S_i) = \ldots (F_{imax-1}^y / S_{imax-1}) = (F_{imax}^y / S_{imax}) \qquad (9.8)$$

where imax = oldest age of fish caught,

and therefore $S_i = S_{imax} . [F_i^y / F_{imax}^y]$.

It is assumed that the oldest age is fully selected because of mesh size. That is,

$$S_{imax} = 1 .$$

(Note that for simplicity this argument has ignored the effect of emigration. See Appendix 9.4 .)

It follows that $S_i = F_i^y / F_{imax}^y$ (9.9)

F_i^y values may vary from year to year and thus the F_i^y and F_{imax}^y values are averaged over the whole data period so as to smooth out any fluctuations in the S_i values. This amounts to summing the F_i^y values in the various columns of the F matrix. Therefore, the selectivity values for all ages are estimated using the formula:

$$S_i = \sum_{k=0}^{imax-1} F_i^{y^*-k} \Big/ \sum_{k=0}^{imax-1} F_{imax}^{y^*-k} \qquad (9.10)$$

where y^* is the most recent year in the data series.

9.5 Terminal F values for the oldest age-classes

The VPA procedure requires an estimate of the fishing mortality rate for the oldest age-class in each cohort, F_{imax}^y.

This is equivalent to calculating values for the last column of the F matrix where all cohorts are assumed to have been fully recruited. From equation (9.8) it can be seen that

$$F_{imax}/S_{imax} = F_i/S_i \; .$$

The selectivity-at-age can be represented by the following diagram.

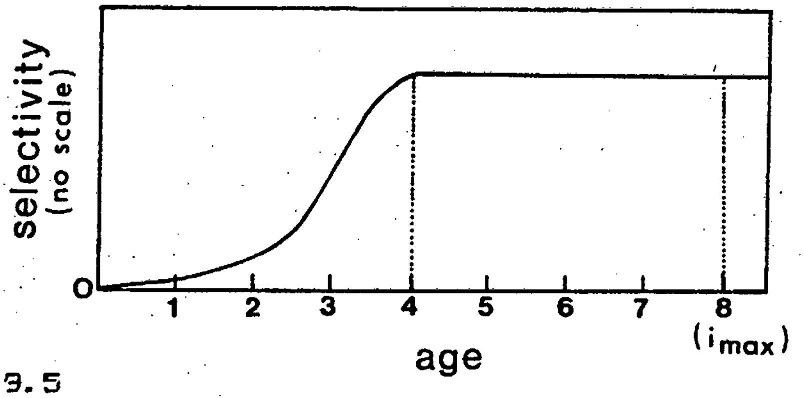


Figure 9.5

To account for fluctuations, and at the same time to avoid any major variations between age groups, an average of the (S_i/F_i) values for the (imax-5) oldest age groups was taken. The terminal fishing mortality prescription for the oldest age-classes was therefore:

$$(F^{y}_{imax}/S_{imax}) = (\sum_{i=4}^{imax-1} [F^{y}_{i}/S_{i}])/(imax-4) \qquad (9.11)$$

Using the assumption, $S_{imax} = 1$, this can be simplified to

$$F^{y}_{imax} = (\sum_{i=4}^{imax-1} [F^{y}_{i}/S_{i}])/(imax-5) \qquad (9.12)$$

9.6 Estimates for F for the most recent year

Nearly all cohorts present in the population during the most recent year covered by the data will not have reached age i_{max} and therefore require the treatment described below.

Assuming that selectivity patterns remain unchanged from year y-1 to year y and using equation (9.6), it follows that:

$$F^{y}_{i}/F^{y-1}_{i} = [q.S_{i}.E_{y}]/[q.S_{i}.E_{y-1}]$$

$$= E_{y}/E_{y-1}$$

and hence $$F^{y}_{i} = [E_{y}/E_{y-1}].F^{y-1}_{i} \qquad (9.13)$$

That is, F_i values can be allocated for the most recent year by proportion to those from the previous year. Then if y* corresponds to the most recent year and y is any previous year, F^{y*}_{i} is given by

$$F^{y*}_{i} = E_{y*}.(F^{y}_{i}/E_{y}) \qquad (9.14)$$

To reduce the effect of data fluctuations, an average over a number of previous years may be taken. Equation (9.13) can be generalized to the following:

$$F^{y*}_{i} = E_{y*}.[\sum_{k=1}^{5} (F^{y*-k}_{i}/E_{y*-k})]/5 \qquad (9.15)$$

Cases of zero catches of age i are omitted from the average. Although selectivity-at-age values are likely to vary from year to year, it is desirable to mimimise bias from possible long term trends in catchability, q. Taking the average over the last 5 years as in equation (9.15) is tantamount to assuming that no marked trends in q (or in the selectivity pattern with age) have occurred over that period.

9.7 Precision of VPA

Many of the inaccuracies of VPA stem from imperfect input data on natural mortality, catch numbers-at-age and weight-at-age.

To estimate the stock size using the principles underlying VPA, reliable values for the rate of natural mortality, M, must be obtained. Over- or under-estimating M will have a large effect on absolute values such as those for F and stock size. Trends, however, will be affected to a lesser extent. Although M is assumed to be constant it is likely to vary during the lifespan of hake and from year to year. Ideally, an age-dependent M should be incorporated into the model, but it would be difficult to quantitatively apportion. The problem of what numerical value to use for M is discussed further in Appendix A9.1 .

There are also many problems in assessing the numbers caught of each age from total catch statistics owing to inaccuracies in catch estimates and the lack of knowledge about the age composition of the hake population and catches. These occur frequently because of the discarding of small hake (see Section 9.9).

In VPA, the problem of estimating the terminal F values cannot be solved at all precisely from the age structure information above (Pope and Shepherd, 1982). Further assumptions such as those used in equations (9.12) and (9.15) are needed.

In general as one moves back into the history of each cohort present in the stock there is a tendency for the F_i values to become increasingly less sensitive to the initial estimate of F_t, and hence any error in the estimates of F_i^y or N_i^y caused by error in the starting values will decrease steadily as back calculations proceed.

The largest errors from VPA are therefore likely to occur in the current and recently preceding years' biomass estimates. Unfortunately, it is these years where the highest accuracy is required if predictions for the size and composition of the stock in subsequent years are to be realistic. Predicted values should be treated with caution as the error in such estimates will increase steadily as one moves into the future.

9.8 Comparison of the VPA results with those of the dynamic Schaefer and Fox models

The VPA procedure developed in the previous sections was applied on the assumption that fishing took place uniformly throughout the year for all age groups.

Table 9.1 lists the catch-at-age data (expressed as a percentage by number of the total annual catch) used in the VPA calculations for Division 1.6 as provided by R. Leslie (SFRI, pers. commn). The data required to calculate VPA estimates for the other divisions were unavailable to the author at the time these calculations were carried out. The percentage catch-at-age data do not distinguish between 0 and 1 year olds and VPA calculations have assumed that all fish aged 1 year and younger belong to the 1 year old age group. Since it is known that the contribution of 0 year olds to the catch is extremely small, such a combination of 0 and 1 year olds is reasonable and should not significantly affect results.

Also given in Table 9.1 are the mid-year weights at time t, w_t, calculated using the following formula (see Appendix 9.2):

$$w_t = 0,0095 \left[125,4 \left(1 - e^{-0,113(t - 0,0396)}\right) \right]^{2,8852} \tag{9.16}$$

where t = time (in years).

The VPA estimates of fishing mortality-at-age, F_i^y and selectivity-at-age, S_i, for the case M = 0,3 are listed in Table 9.2 . In addition, the mid-year stock biomass and 0-group year class strength were estimated and these are given in Table 9.3 . From 0-group strength figures in this table it can be seen that the low 1972-1977 catch rates for Division 1.6 (Table 3.3) may not only have been caused by heavy exploitation, but may also be the result of a sustained low recruitment of juveniles over the period 1972-1975.

In Figure 9.6, mid-year biomass estimates obtained from the VPA analysis are compared with those provided by the Schaefer and Fox dynamic models for Division 1.6 . Three different values of M were used, namely, M = 0,2 , 0,3 and 0,4 , as these were considered to be representative of a reasonable possible range for M (see Appendix 9.1).

Both models indicate a decreasing trend in biomass until the mid-seventies. In the case of the dynamic models this trend continues until 1974, but VPA results show a curtailment of this decline only in 1976. The minimum biomass levels obtained using the VPA method were substantially lower than those indicated by dynamic model estimates. The subsequent recovery shown by the dynamic

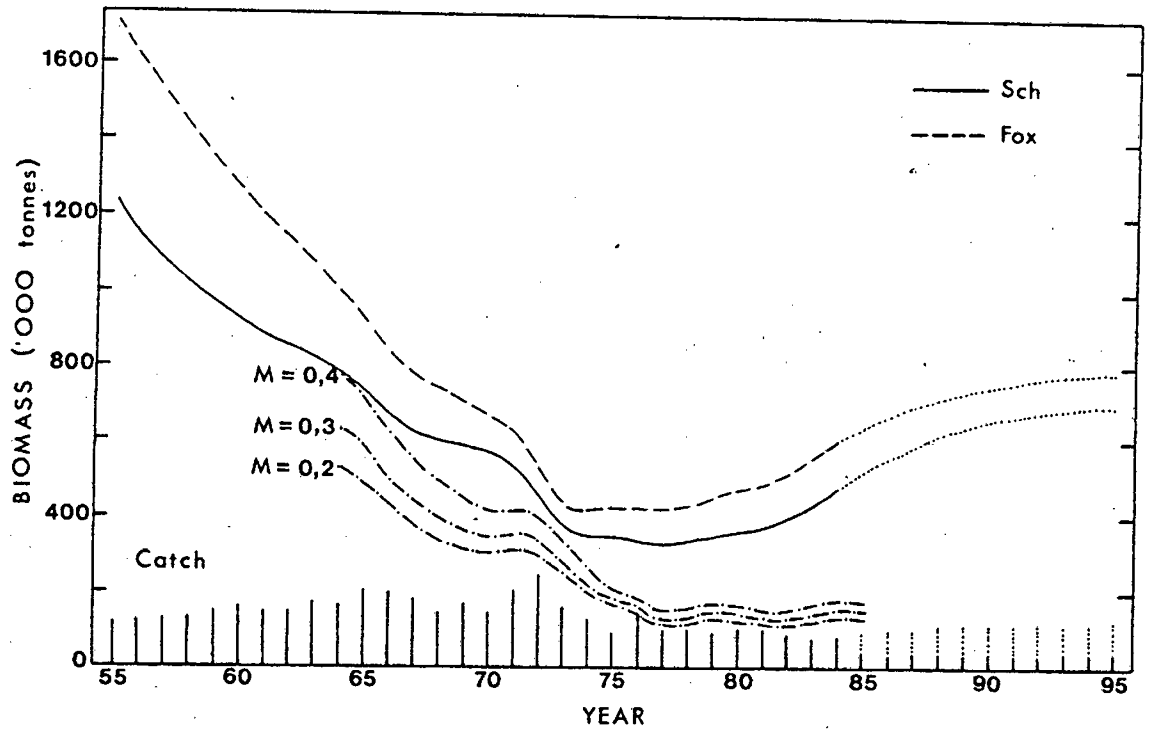


Figure 9.6: Biomass estimates for Division 1.6 using the dynamic Schaefer model (solid line) are compared with those from the dynamic Fox model (dashed line). In addition, 10-year biomass projections under a $Q_{0,1}$ harvesting strategy (dotted lines) are shown for both models. Historical annual catches are indicated by solid vertical bars and the Fox model $Q_{0,1}$ projections for the next 10 years by dashed vertical bars. VPA biomass estimates for three different values of natural mortality (M) are also shown (dashed-dotted lines).

models to begin in 1978, is not evident in the VPA results which show relatively insignificant changes from 1976 onwards. This is somewhat surprising as the dynamic model outputs are reflecting the CPUE increase over this period, and this is incorporated to some extent into the VPA through equation (9.15). These results therefore indicate that, in general, the biomass estimates and trends for Division 1.6 for the VPA model are smaller and time-delayed in comparison with the estimates of the dynamic models.

In the context of the assumptions made for these VPA calculations, the VPA biomass estimates over the last few years should be interpreted with caution.

9.9 Further considerations

The large discrepancy between the results obtained in Section 9.8 may possibly be attributed to two major factors, namely, discarding (rejection) and cannibalism.

It is known that many vessels discard the smaller fish in their catches. Investigations in 1966 showed that fish less than 40 - 45 cm long were frequently discarded and the proportion of discards could amount to 10 - 30% by weight of the total catch, or up to 50% by number (Jones, 1974). The size composition and numbers of fish discarded tend to fluctuate according to the market demand and with catch rates. In this analysis, revised total catch figures were used for Division 1.6 (see Chapter 3). Although these figures include an estimate of rejection, it is not known whether the revised values are an under- or overestimation of the true values. Such inaccuracies will affect biomass estimates obtained using the dynamic models and the VPA procedure. In addition, the VPA procedure also requires percentage catch-at-age information. If unreported rejection of juveniles has taken place then it is likely that in reality the proportion of younger age groups in the catch is greater than assumed here. This would alter the relative age structure of the population and the VPA biomass estimates based thereon. So it can be seen that where no (or inadequate) allowance is made for discarding, biomass estimates can be over- or underestimated and this could cause either greater or lesser agreement between the curves in Figure 9.6 .

Cannibalism is a prominent feature of the Cape hake populations and increases in areas of high population density and where there are individuals of different sizes in the same place and at the same time. Since a large proportion of the younger fish die as a result of cannibalism, the failure to include this factor in the VPA analysis means that the biomass of the younger age groups is underestimated.

Catch-at-age statistics given in Table 9.1 indicate a steady decrease in the proportion of adult individuals in hake catches since 1964, reflecting a higher average population age in the initial stages of the fishery. Since the rate of cannibalism of juvenile hake is dependent on the number of older (cannibalistic) individuals in the population, an effective M would be larger during this period. This would imply a much steeper decline of the graph of VPA biomass estimates in the 60's (see Figure 9.6) and hence better agreement with the dynamic Fox and Schaefer absolute biomass estimates during this period. However, the discrepancy between VPA and dynamic Fox and Schaefer model estimates in the later stages of the fishery cannot be accounted for by this argument. The inclusion of the effect of cannibalism in the VPA procedure has been examined by Lleonart, Salat and Macpherson (1985). Details are given in Appendix 9.5 .

YEAR	AGE								
	1	2	3	4	5	6	7	8	9
1964	0	3,11	7,24	11,91	17,36	24,75	20,28	10,02	5,32
1965	0	3,07	5,75	10,97	19,85	24,76	20,46	10,01	5,12
1966	0	0	12,68	21,37	30,21	19,29	12,07	3,52	0,86
1967	0	0	18,12	27,78	27,79	15,36	8,21	2,23	0,52
1968	0	0,34	19,55	27,97	26,36	14,04	8,38	2,71	0,64
1969	0	8,87	31,84	27,48	13,59	10,08	5,61	1,95	0,58
1970	2,08	15,70	30,78	24,17	12,49	8,18	4,39	1,65	0,56
1971	12,46	25,44	35,46	15,27	4,82	3,66	1,81	0,83	0,25
1972	10,16	37,52	32,55	13,20	3,49	1,80	0,89	0,28	0,11
1973	1,78	32,82	43,01	15,10	4,49	1,50	0,83	0,37	0,11
1974	0	18,30	44,68	22,35	8,16	3,12	2,41	0,63	0,34
1975	0	15,05	26,41	20,80	17,90	10,16	6,58	2,42	0,68
1976	6,05	31,83	34,80	16,32	5,56	3,67	1,61	0,17	0
1977	13,67	53,45	21,44	7,12	3,32	0,83	0,17	0	0
1978	7,22	71,59	15,15	3,87	1,58	0,49	0,10	0	0
1979	11,36	54,50	21,50	6,35	4,63	1,31	0,33	0,02	0
1980	5,58	47,17	28,85	11,19	4,76	1,70	0,54	0,16	0,05
1981	23,78	47,37	16,55	7,77	2,76	1,20	0,39	0,14	0,03
1982	35,06	46,51	11,01	3,96	2,23	0,89	0,26	0,06	0,02
1983	11,77	48,47	24,91	8,30	4,25	1,55	0,58	0,13	0,04
1984	9,22	46,84	26,49	10,56	4,43	1,67	0,54	0,21	0,03
Mid-season mass (g)	71	181	415	743	1148	1613	2121	2653	3197

Table 9.1: Percentage age structure by number of catches (including discards) of Cape hake in Division 1.6 .

YEAR	AGE									$\bar{F}_y$
	1	2	3	4	5	6	7	8	9	
1964	0	,01	,03	,08	,18	,43	,70	,57	,53	,53
1965	0	,01	,03	,09	,28	,64	1,29	1,73	1,08	1,08
1966	0	0	,09	,22	,53	,72	1,24	1,38	1,11	1,11
1967	0	0	,16	,32	,58	,67	,96	1,01	,95	,95
1968	0	,002	,13	,35	,51	,58	,85	,89	,83	,83
1969	0	,06	,36	,50	,50	,69	,93	,94	,90	,90
1970	,01	,07	,30	,55	,49	,70	,82	,90	,86	,86
1971	,06	,21	,60	,71	,57	,77	1,07	1,22	1,06	1,06
1972	,13	,48	,86	,94	,64	,83	,84	,91	,98	,98
1973	,02	,43	,80	,69	,54	,36	,63	,55	,64	,64
1974	0	,21	,85	,70	,55	,51	,79	,76	,78	,78
1975	0	,07	,25	,55	,78	,95	2,31	1,61	1,61	1,61
1976	,04	,43	1,00	1,14	1,42	2,51	2,81	2,81	0	2,81
1977	,07	,71	,75	,74	1,03	1,21	1,64	0	0	1,64
1978	,06	,95	,69	,42	,53	,60	,61	0	0	,84
1979	,08	,59	,60	,50	,87	,78	,73	,24	0	1,07
1980	,04	,60	,76	,78	,91	1,01	,95	1,07	1,22	1,22
1981	,16	,77	,71	,77	,72	1,08	1,23	1,34	1,30	1,30
1982	,28	,66	,50	,45	,67	,69	,97	,81	,95	,95
1983	,07	,41	,49	,48	,64	,72	,69	,98	,92	,92
1984	,10	,50	,51	,49	,64	,71	,75	,74	,90	,87
Selectivity by age	,049	,317	,464	,508	,601	,758	1,01	1,00	1,00	

Table 9.2: Fishing mortality values F (in yr^{-1}) from VPA for Division 1.6 . $\bar{F}_y$ obtained from equation (9.12) .

YEAR	Mid-year biomass ('000 t)	0 group strength (in millions)
1964	612	564
1965	533	582
1966	470	574
1967	417	656
1968	382	950
1969	353	1162
1970	351	1301
1971	356	771
1972	315	425
1973	252	481
1974	200	559
1975	170	725
1976	137	1029
1977	130	753
1978	143	611
1979	146	641
1980	136	857
1981	126	829
1982	135	590
1983	148	321
1984	154	-

Table 9.3: Biomass and year class strength estimates for Division 1.6 from VPA.

Appendix 9.1

The instantaneous coefficient of natural mortality, M

A9.1.1 Introduction

Natural mortality is defined as death caused by all factors, except fishing. A major cause of natural mortality within the hake population is cannibalism. Other factors include disease, old age, predation by other species and pollution. It would be desirable to distinguish quantitatively between these different causes of natural mortality and to quantify their effects on the stock so that the real situation can be more accurately reflected, thereby making fisheries management more effective.

This section has been included since, although the Schaefer and Fox models require only past catch and effort data, estimates of the instantaneous coefficient of natural mortality, M, must be provided for the Shepherd model and VPA procedure. The results of these latter two evaluations should therefore be viewed in the context of the problems inherent in assessing M.

Uncertainty about natural mortality has complicated hake stock assessment. Values assumed for M have varied in the past. These include the earlier estimates of M by Newman et al. (1976a, b and c) and Draganik (1976a) which were in the range 0,2 - 0,25. In 1979 Assorov and Shcherbich proposed revised natural mortality values of 0,42 for M. capensis and 0,5 for M. paradoxus in Zone I. Such values were considerably higher than earlier estimates and were not adopted for stock assessment purposes, although slightly increased values of 0,3 were used by authors such as Preński (1980b) and Davies et al. (1980).

In 1984, the ICSEAF Standing Committee on Stock Assessment decided that values of M falling between 0,3 and 0,4 would be regarded as being acceptable (ICSEAF, 1985a). Some researchers feel, however, that the actual value of M may be appreciably higher and, in the case of M. paradoxus in Divisions 2.1 + 2.2, this coefficient could be as high as 0,7 (Payne, in prep.).

Assessments in Chapter 9 and 10 assume M to be constant at 0,3 . This choice was made to be consistent with the 1984 ICSEAF decision noted above. In the case of the VPA procedure, assessments were repeated using values of 0,2 and 0,4 to provide some idea of the sensitivity of results to the value assumed for M. Since management decisions are generally based on stock trends rather than absolute values, the lack of a precise value of M may not severely handicap attempts to provide good management advice (ICSEAF, 1979).

A9.1.2 Variations in M with age and time

In reality, the assumption that M is constant with respect to age and time does not hold. M is dependent on the age of the fish, being higher for smaller younger fish (which are available to a broader range of predators) and for older less fit fish.

Of the density-dependent factors which naturally regulate the fish population size, quite possibly density-dependent mortality in the youngest age groups plays a major role in the hake populations. It has been noted that M appears to be inversely related to the rate of exploitation (ICSEAF, 1978). An increase in fishing intensity resulting in a decrease in population size, could be counteracted by a decrease in overall natural mortality. This is partly attributed to the likely proportional reduction in the number of older (cannibalistic) hake individuals. Studies by Preński (1978) in Divisions 1.4 and 1.5 indicated a heavy cannibalism rate by individuals greater than 60 cm in length. Smaller hake were found to constitute 90% of the total food consumed by such adults. Therefore, it can be hypothesized that M, particularly in younger fish, is closely dependent on the abundance of older fish (that is, fish longer than 60 cm) and the more abundant the latter, the higher the value of M. This theory would lead one to expect lower values of M in the middle stages of the fishery when the stocks were most heavily depleted. On the other hand, an increase in stock size following a reduction in fishing intensity (as a result of, for example, lower catch quotas or the introduction of fishing zones or increased mesh sizes) would be expected to indicate higher values of M for the most recent (and earliest) period of the fishery. M also depends on the predator populations other than man, which may adjust their intake of hake depending on its abundance and availability.

Although a production model which makes provision for a density-dependent M is likely to be a more realistic management tool, at present the information to estimate parameters quantifying such changes and hence to construct such a model is not available. Therefore, for the purposes of this assessment, M is assumed to be independent of age and stock biomass. Since most production models deal essentially with the exploitable part of the stock which is mainly beyond the young ages after which natural mortality rates decrease sharply, it may be reasonable to assume that M is constant for those fished ages. The probable density-dependent nature of M must, however, be kept in mind when drawing conclusions from Shepherd model and VPA results.

A9.1.3 Methods of estimating M and some results

Botha (1980) calculated values for M using a method originally developed by Rikhter and Efanov (1977). This method, which is based on the relationship between M and fish age at 50% sexual maturity, is given by the following formula:

$$M = 1,521 / (x^{0,70}) - 0,155$$

where x is the age in years at 50% sexual maturity
and M values throughout this thesis are quoted in units yr^{-1}.

Botha (1980) applied the above formula to data available for males and females of both species in Division 1.6. The M values he calculated are given below:

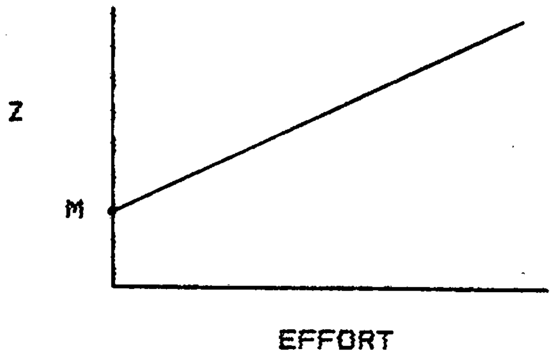
Species	Male	Female
M. capensis	0,42	0,33
M. paradoxus	0,44	0,34

Another method of natural mortality estimation is the analysis of the stomach contents of predators. Such estimates depend on the total consumption by predators, their abundance, diet composition and preferences and the abundance and suitability of prey. This approach is used in CVPA (described in Appendix 9.5).

As illustrated below, M can also be calculated from the linear regression of fishing effort on the total mortality coefficient, Z:

$$Z = F + M = q.E + M.$$

where M is the y intercept (E = 0).



Pauly (1980) introduced an alternative means of estimating M for any given fish stock by relating it to other easily estimable parameters, namely, the size of the fish as expressed by its value of W_∞ or L_∞ (given by the von Bertalanffy growth formulae in equations A9.2.2 and A9.2.3), the von Bertalanffy equation growth parameter K and T (the mean annual water temperature). Good estimates of these parameters have been calculated for most large exploited marine fish stocks (Pauly, op. cit.).

By obtaining regression equations in terms of weight:

$$\log \hat{M} = -,2107 - ,0824 \log W_\infty + ,6757 \log K + ,4627 \log T \qquad (A9.1.1)$$

and in terms of length :

$$\log \hat{M} = -,0066 - ,279 \log L_\infty + ,6543 \log K + ,4634 \log T \qquad (A9.1.2)$$

(where W_∞ is given in grams, L_∞ in cm and T in °C)

and by calculating their multiple and partial correlation coefficients, Pauly showed that the three variables, K, T and W_∞ or L_∞ significantly affect the value of M with K having the highest partial correlation with M.

Pauly also calculated the standard deviations of the log $\hat{M}$ values for equations (A9.1.1) and (A9.1.2). A typical range for M values for hake is 0,3 - 0,5 . For the lower extreme of this range the standard deviation of log $\hat{M}$ is 0,247 which corresponds to a coefficient of variation (c.v.) of 24,7% and a standard error (s.e.) of approximately 0,1 for the estimate of M. For the higher extreme, the corresponding values are very similar, namely, a standard deviation of 0,245 for log $\hat{M}$ and corresponding c.v. and s.e. values of 24,5% and approximately 0,1 respectively for M.

Table A9.1.1 gives estimates of M obtained using Pauly's (1980) formulae and data provided by various authors for the hake stocks in each of the divisions. It is notable that most of these estimates are nearer the higher than the lower end of the 0,3 - 0,5 range. This suggests that the 0,3 - 0,4 range currently considered acceptable by ICSEAF and the value of 0,3 used in this thesis may be somewhat too low.

AUTHOR, DATE and DIVISION				T=8,11		T=6,75		
	K	L_∞	W_∞	M_L	M_W	M_L	M_W	
Kolender 1975 (1.3 + 1.4)	,063 ,077	174,83 130,30	34509 15260	,40	,41	,38	,38	(Mc) (Mp)
Pozo 1976 (1.3 + 1.4)	,120	111,14	* 7594			,48	,49	(Mc)
Obregón 1980 (1.3 + 1.4)	,056	170,86	22280	,36	,37	,36	,38	
Isarev 1983 (1.3 + 1.4)	,085	134,53	17128	,41	,42	,42	,43	
Preński 1978 (1.4 + 1.5)	,106	125,20	13091			,45	,46	(Mc)
Botha 1971 (1.5 + 1.6)	,087	139,63	*14670	,42	,43	,42	,43	
Draganik 1976b (1.5 + 1.6)	,088	138,5	18270	,42	,43	,42	,43	
Botha 1970 (1.6)	,130	115,7	10748			,49	,48	(Mc)
Davies *et al.* 1980 (1.6)	,119	118,6	* 9160	,46	,48	,47	,48	
Payne *et al.* 1982 (1.6)	,134	114,0	* 8172	,48	,50	,49	,50	
Leslie 1985 (1.6)	,113	125,4	*10758	,45	,47	,46	,47	
Payne *et al.* 1984 (1.6, 2.1 + 2.2)	,086	144,8	*16292	,41	,42	,42	,43	
Kono 1980 (2.1 + 2.2)	,111 ,099	118,8 129,1	14160 17076	,44	,44	,46	,47	(Mc) (Mp)
Leslie 1985 (2.1 + 2.2)	,079	167,3	*24715	,40	,41	,40	,42	

Table A9.1.1 . Estimates of M obtained using Pauly's (1980) 'length' and 'weight' formulae (denoted by M_L and M_W respectively), and data provided by various authors. Values of T = 6,75 (for *M. capensis*) and T = 6,11 (for *M. paradoxus*) are used (Botha, 1980). A * indicates that the W_∞ values are calculated on the basis of Draganik's (1976b) length:weight relationship (see Appendix 9.2). Where values apply to only *M. capensis* or *M. paradoxus* this is correspondingly denoted by Mc or Mp after the results.

Appendix A9.2

Growth in length and weight

Growth is one of the main driving forces in the dynamics of a fish population. To reflect weight- or length-at-age measurements such as those required for Virtual Population Analysis (Chapter 9) and Pauly's method of estimating M (Appendix 9.1), fisheries scientists use simple growth equations. These are based on observed size-at-age data and are in mathematical forms which can be incorporated reasonably easily in expressions for yield. The equations for weight and length used in this analysis are described below.

(i) It has been found that within any stage of a fish's life, weight varies as some power of length:

$$w = a.l^{b} \qquad (A9.2.1)$$

where w = weight in grams

l = length of fish in centimetres

and a and b are constants (b being approximately equal to 3).

For the purposes of this hake assessment the length : weight relationship of Draganik (1976b) is used:

$$w = 0{,}0095\ l^{2{,}8852} .$$

(ii) The model most frequently used to describe growth in length has been attributed to von Bertalanffy (1934). The von Bertalanffy growth function (VBGF) assumes that fish grow towards some theoretical maximum length or weight, and that the closer the length gets to the maximum the slower the rate of change of size. The VBGF equation for length is given by

$$l_t = L_\infty.[1-e^{-K.(t-t_0)}] \qquad (A9.2.2)$$

where l_t is the length of fish in cm at time t

L_∞ is the asymptotic length of fish in cm and K is the rate at which length approaches L_∞.

(See Note (1) for the derivation of equation (A9.2.2).)

The VBGF is a useful model since it fits most of the observed fish growth data and it can be incorporated readily into stock assessment models. A single model will not fit the growth curve from egg to old age, so different models apply to different stages of the growth curve. Usually it is only the adult fished population that is of interest.

From curves of length- and weight-at-age, L_∞, t_0 and K can be determined using regression techniques.

Payne et al. (1984) present a composite VBGF for Zone II based on South African age data drawn from the years 1968-1982. The relationship is:

$$l_t = 144,8\ [1 - e^{-0,08601(t\ +\ 0,3998)}]$$

However, since the Virtual Population Analysis discussed in this thesis only requires a VBGF for Division 1.6, the formula given by Leslie (1985) was used, namely,

$$l_t = 125,4\ [1 - e^{-0,113(t\ -\ 0,0396)}]$$

The weight of a fish is usually closely proportional to the cube of its length and so equation (A9.2.2) can also be expressed in weight:

$$w_t = W_\infty . \left[1 - e^{-K.(t - t_0)}\right]^3 \qquad (A9.2.3)$$

where w_t is the weight in grams at time t

and W_∞ is the asymptotic weight, corresponding to the asymptotic length, L_∞.

The constant, K, is as given in equation (A9.2.2).

Many problems in fishery assessment are essentially a matter of comparing weight gained by growth against that lost by natural mortality, and as a result most population analysis is concerned more directly with the growth rate of biomass rather than number of the population.

Note (1) The simplest derivation of the VBGF is that of Gulland (1969):

$$dl/dt = K.(L_\infty - l) .$$

Integration of the above equation yields

$$l = L_\infty - c.e^{-K.t} \qquad (A9.2.4)$$

where c is the constant of integration.

Let $l = 0$ at t_o, then $c = L_\infty . e^{K.t_o}$.

It follows from equation (A9.2.4) that

$$l_t = L_\infty . [1 - e^{-K.(t-t_o)}] .$$

Appendix 9.3

Cohort analysis

As in VPA, cohort analysis uses catch-at-age data and estimates of M and F_t to obtain estimates of F_i and N_i for each age of a year-class.

Pope's method is as follows:

Let N_i = number of fish of age i

C_i = number of fish caught of age i

and M = instantaneous rate of natural mortality.

Cohort analysis is based on the following two basic VPA equations:

$$N_{i+1} = N_i . e^{-(F_i + M)} \qquad (A9.3.1)$$

$$C_i = N_i . F_i . (1 - e^{-(F_i + M)})/(F_i + M) \qquad (A9.3.2)$$

Equation (A9.3.1) can be rewritten as

$$N_{i+1} . e^{M} = N_i . e^{-F_i}$$

which can be expressed as

$$N_{i+1} . e^{M} = N_i - N_i (1 - e^{-F_i}) .$$

Using equation (A9.3.2) this can be written as

$$N_{i+1} . e^{M} = N_i - [C_i . (F_i + M) . (1 - e^{-F_i})]/[F_i . (1 - e^{-(F_i + M)})] .$$

VPA assumes that, within any one age group, the decline in numbers due to fishing and natural mortality with time over one year can be represented by an exponential curve. In cohort analysis, the exponential curve is interrupted by a step function by assuming that all the catch for any particular age group is taken instantaneously in the middle of the time period under consideration (usually one year) and that only natural losses occur continuously on an exponential basis.

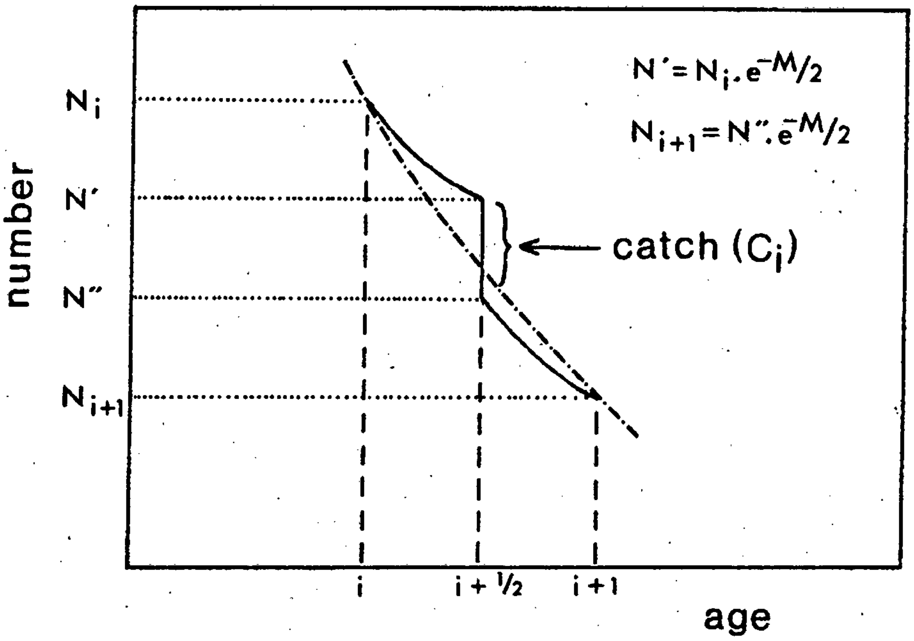


Figure A9.3.1: In cohort analysis a step function replaces the exponential curve (dotted) of VPA.

For values of $M < 0,3$ and $F_i < 1,2$, the function

$$[(F_i + M).(1-e^{-F_i})]/[F_i.(1-e^{-(F_i+M)})]$$

can be accurately approximated by $e^{M/2}$ (see Note (1)). It follows that

$$N_i = N_{i+1} . e^{M} + C_i . e^{M/2} \qquad (A9.3.3)$$

If all the catch were taken at the midpoint of the time period under consideration, then equation (A9.3.3) would be exact.

For the case $i = t$, making some assumption for N_{i+1} (or equivalently an assumption for F_t) and further knowing the values of C_i and M, one can use equation (A9.3.3) to obtain N_i and this in turn can be used to obtain N_{i-1} and so on proceeding backwards in time from the oldest to youngest ages. So, if one can determine the population size of the oldest age, by applying equation (A9.3.3) one can determine the size in numbers of successively younger age groups.

Equation (A9.3.1) can be rewritten as

$$F_i = \ln(N_i / N_{i+1}) - M .$$

Values of F_i can therefore be found for all age groups.

If the rate of fishing mortality is distributed uniformly throughout the year, more fish of any fully recruited age are caught during the first semester than the second. Therefore equation (A9.3.3) will tend to overestimate the N_i values, but only for a few percent for values of

$F < 1,2$ and $M < 0,3$.

As with VPA, the most recent set of F estimates and hence current population estimates are going to be the least accurate in the analysis, and Pope (1977) emphasizes that quota adjustments based on this type of analysis should account for the likely errors involved.

<u>Note</u> (1) Let $f(M,F) = (F+M).(1-e^{-F}) / [F.(1-e^{-(F+M)})]$.

If $e^{M/2}$ is an approximation of f(M,F), then the relative error (r.e.) is given by:

$$r.e. = f(M,F) / e^{M/2} - 1 \qquad (A9.3.4)$$

From the plot in Figure A9.3.2 it can be seen that the relative error increases as the values of F and M increase.

A Taylor expansion of the function $[f(M,F) / e^{M/2}] - 1$ as far as terms of the second order in M and F yielded the following:

$$f(M,F) / e^{M/2} - 1 = - [M.(M+2F)]/24 + \qquad (A9.3.5)$$

terms of the third and higher order in F and M.

Appendix 9.4

The effect of mesh size and emigration on selectivity

In Section 9.4 the effect of the mesh size of the net on selectivity was discussed. In principle, the mesh size determines the size composition of the catch, the larger fish being more vulnerable to the fishing nets than the smaller fish which pass through the meshes. This effect is illustrated graphically in Figure A9.4.1 where i_R is the age of full recruitment and i_{max} is the maximum age observed in the catch.

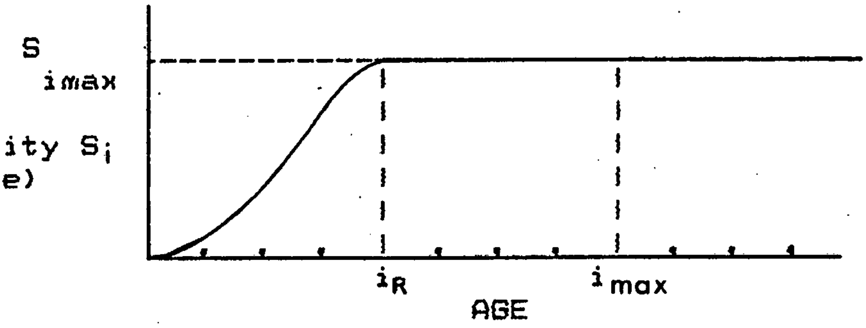


Figure A9.4.1

It is assumed that the oldest age is fully selected because of mesh size. That is, $S_{imax} = 1$. This defines the scale and removes any ambiguity from the definition of selectivity.

The size composition of hake is also known to vary over their geographical distribution. As hake mature, they tend to migrate to deeper waters and therefore various groups of hake may not inhabit the main fished area. This effect of emigration is roughly equivalent to apparent selectivity decreasing with age (see Figure A9.4.2).

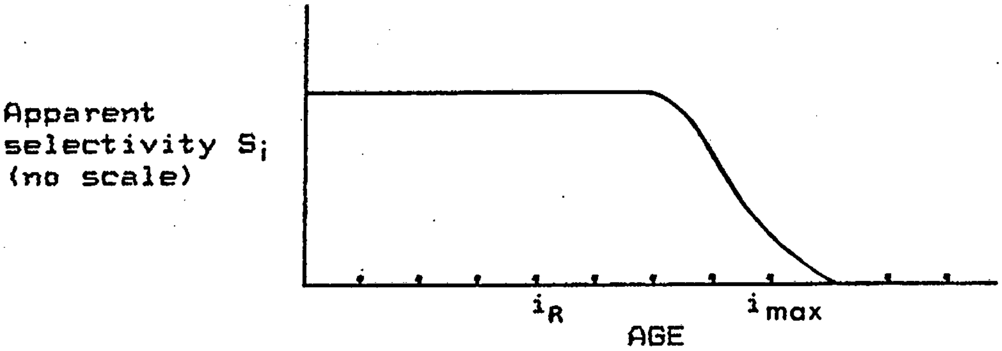


Figure A9.4.2

Taking both effects into account, the graph of selectivity with respect to age could exhibit the following behaviour.

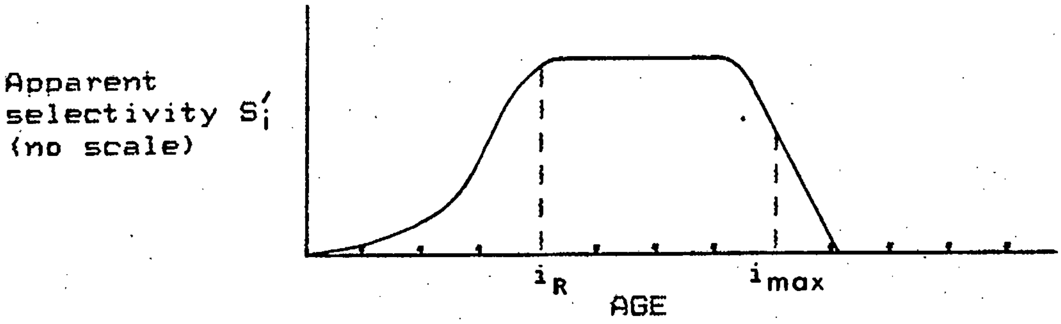


Figure A9.4.3

Mathematically, the rate of change of population size (in numbers) with respect to time when there is an emigration effect can be expressed as

$$dN^y_i \,/\, dt = -M.N^y_i - q.S_i.F^y.N^y_i - \tilde{E}_i.N^y_i \qquad (A9.4.1)$$

where $\tilde{E}_i$ denotes the per capita rate of population loss due to emigration.

The effects of emigration on selectivity are difficult to quantify and therefore, for convenience, they are ignored for the purposes of this analysis. However, emigration could be incorporated into the definition of M by rewriting equation (A9.4.1) as follows:

$$dN^y_i \,/\, dt = -M'_i.N^y_i - q.S_i.F^y.N^y_i$$

where $M'_i = M + \tilde{E}_i$.

Appendix 9.5

CVPA

The method of CVPA, applied to hake by Lleonart, Salat and MacPherson (1985), is an alternative method of stock biomass estimation which includes the effect of cannibalism. The natural mortality factor has two components. The first depends on cannibalism and the other, which is due to all other natural causes, remains constant. Since cannabilism varies greatly with age, the use of a model such as VPA which takes the age structure of the stock into account, is particularly appropriate.

The CVPA model was applied by Lleonart et al. (1985) to Cape hake in Division 1.5. Yearly catch-at-age data was available for this division and cannibalism was known to occur. The yearly diet of cannibalistic individuals and the number of individuals eaten at each age was estimated from stomach content analysis.

The CVPA results were compared to the those obtained using the standard VPA. Significant differences in values for population size-at-age and the coefficient of natural mortality were found between these two models. CVPA estimates of the total number of individuals were 1,44 times greater than those of VPA. The difference between the number of younger and older individuals was shown to be much greater than in VPA and as a consequence the population appears to be much younger. Biomass-at-age levels showed the same trend to a lesser degree. Therefore, by ignoring the effects of cannabilism, the standard VPA underestimates the values for the youngest age groups.

These considerations have a significant impact on the management of the Cape hake fishery in which there is a high rate of cannibalism. Management could to a certain extent limit the effect of the competition between fishing and cannibalism on the younger age groups by shifting the fishing pressure onto larger individuals. Lleonart et al. conclude that 'Regulating the mesh size would be likely to be much more effective than regulating total effort, because, even if effort increases, if that increase only affects the older age groups, which cannibalise the younger age groups, but which do not themselves suffer heavily from cannibalism (ages 5 to 7 in the present instance) it would be offset by the enhanced survival of younger individuals which as a result do not fall prey to cannibalism. '.

10 EXTENSIONS TO DYNAMIC MODEL

10.1 Introduction

In Chapter 9, VPA biomass estimates were compared with those of the Schaefer and Fox dynamic models for Division 1.6 and some large discrepancies were noted. In this chapter a number of possible biases in the existing dynamic production model are examined. Several extensions to this model are introduced in an attempt to achieve greater agreement with the magnitude and trend of biomass estimates produced using VPA.

Such extensions include the incorporation of a time delay in the net growth function as well as (undetected) increased efficiency in the catching operation. In addition, the effect of allowing y_1 to vary is also examined (up to this point, the initial biomass, y_1, has been assumed equal to the carrying capacity K). Finally, an alternative form of the net growth function which was introduced by Shepherd (1982) is described and applied to data from all four divisions.

10.2 The effect of time lags in the net growth function

A response delay was incorporated into the net growth function, G(y), and its effects on dynamic model biomass estimates were examined:

$$G(y_i) \rightarrow G(y_{i-T})$$

where T = time lag.

This aspect was introduced to allow the model to take some account of the period between spawning and recruitment to the fishery.

Earlier comparisons with VPA results for Division 1.6 do suggest that time lags may be playing a role. It then might follow that the instantaneous response in the net growth function assumed by the models considered above, could lead to overestimates of appropriate catch limits.

Schaefer and Fox models which incorporate such an effect have been fitted to the data for Division 1.6 . Results are shown in Figures 10.1 and 10.2 respectively. Non-integral time lags were simulated by linearly interpolating between biomass values:

$$y_{i-a} = (1 - a).y_i + a.y_{i-1} \qquad (10.1)$$

where $0 \leqslant a \leqslant 1$.

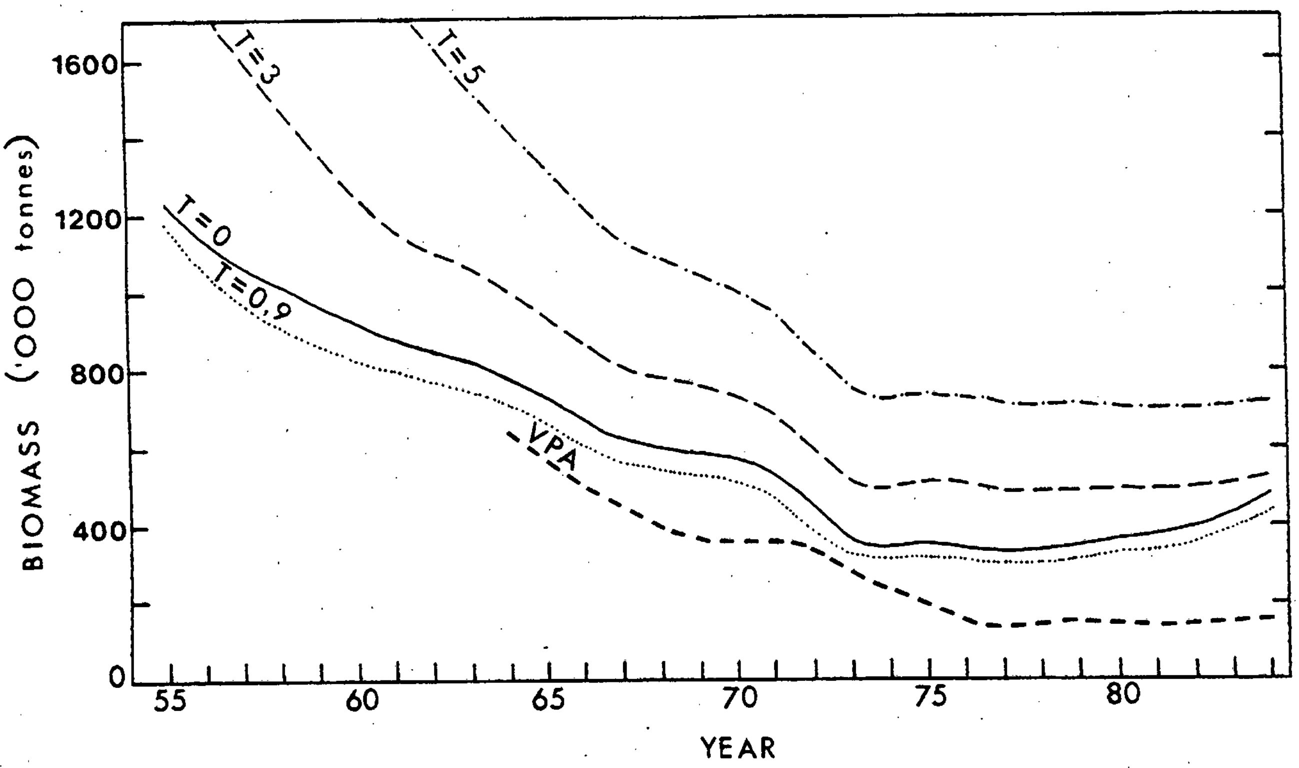


Figure 10.1: Schaefer model

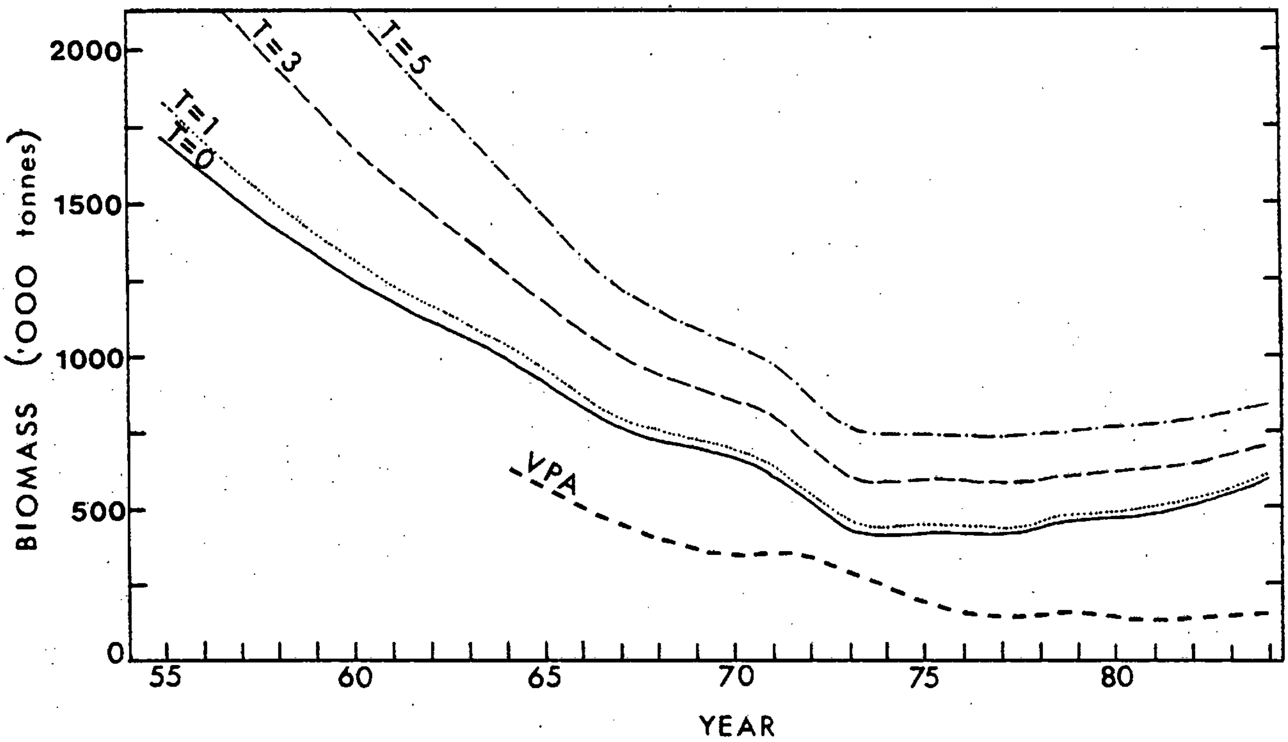


Figure 10.2: Fox model

Figures 10.1 - 10.2: Biomass trends for Division 1.6 for the Schaefer and Fox models where a time-lag of T years is incorporated in the surplus production function. The VPA biomass assessment for M = 0,3 is shown by the dashed line marked VPA.

The Schaefer model results in Figure 10.1 indicate that values of $T \leqslant 1$ year do provide a marginally improved agreement with the VPA estimates. However, the results for the Fox model (illustrated in Figure 10.2) show no improvement in agreement beween the two procedures; for all values of $T > 0$, the biomass curves are higher than the curve showing no time lag ($T = 0$), thus representing correspondingly larger discrepancies with VPA biomass estimates.

For large delays of approximately T greater than 3, there does appear to be some better agreement of trends with those of VPA for recent years (that is, not as large a rate of increase of biomass as for the case $T = 0$), but this is at the expense of a much greater difference in absolute biomass estimates.

Therefore, it can be concluded from analyses based on available catch and effort data, that the inclusion of time delays in the net growth function does not appear to account for the major inconsistency between the VPA and dynamic model estimates.

10.3 The effect of increased efficiency in the catching operation

The dynamic model is based on the assumption that the catch rate is proportional to biomass (equation (5.4)), that is,

$$y = (C/E)/q$$

where q is the catchability coefficient.

This can be rewritten as $C/y = q.E$

where E = actual effort.

If $E = P_f.E_N$

where P_f is the suitably averaged power factor of vessels active in the fishery (that is, relative efficiency)

and E_N is nominal effort measured in trawler hours,

it follows that $C / y = q.P_f.E_N$.

As can be seen from the above equations, the proportion of the accessible population caught per year is determined by changes both in nominal effort and in the efficiency of fishing vessels.

For this analysis, the ICSEAF figures for actual effort (which have been adjusted by ICSEAF to allow for power factors) are used. If, however, the power factors used in the calculation of actual effort have failed to account completely for a gradual steady increase in catching efficiency taking place over the past years, current CPUE estimates could reflect biomass values that are lower than dynamic model biomass estimates obtained in Chapter 8. Such lower values would be more consistent with VPA biomass estimates for Division 1.6 .

The associated revised model can be represented as follows:

$$C/y = q.P'_f.E = q.P'_f.P_f.E_N \qquad (10.2)$$

where P'_f is an adjustment to the existing averaged power factor incorporated to account for (undetected) increased efficiency.

A constant percentage increase (x) in the adjustment factor each year was introduced into the dynamic minimization procedure, that is,

$$(P'_f)_{i+n} = [1 + (x/100)]^n$$

where the adjustment factor is assumed to first come into play in year (i+1). Though x is defined as a percentage here, for clarity of meaning the % symbols will nevertheless be retained in the following text when quoting values of x.

Biomass estimates for Division 1.6 were evaluated, considering an (undetected) increase in efficiency over the last 10 and last 20 year periods for both the Schaefer and Fox models. The results are illustrated in Figures 10.3 - 10.6.

Schaefer and Fox model results indicate little improvement in agreement with VPA estimates for the 10 year period. For the 20 year period there is better agreement. In the case of the Schaefer model, consistency between biomass values improves when the adjustment factor has a value of up to 5% and is best when an increment of 3% is used. Fox model estimates lead to similar improvements over a large range of adjustment factor values, the optimum case being when the postulated undetected efficiency increase rate is 6% per year.

While these results are of interest, it would seem premature to use them in framing management action at this time. The first consideration should be a search for other

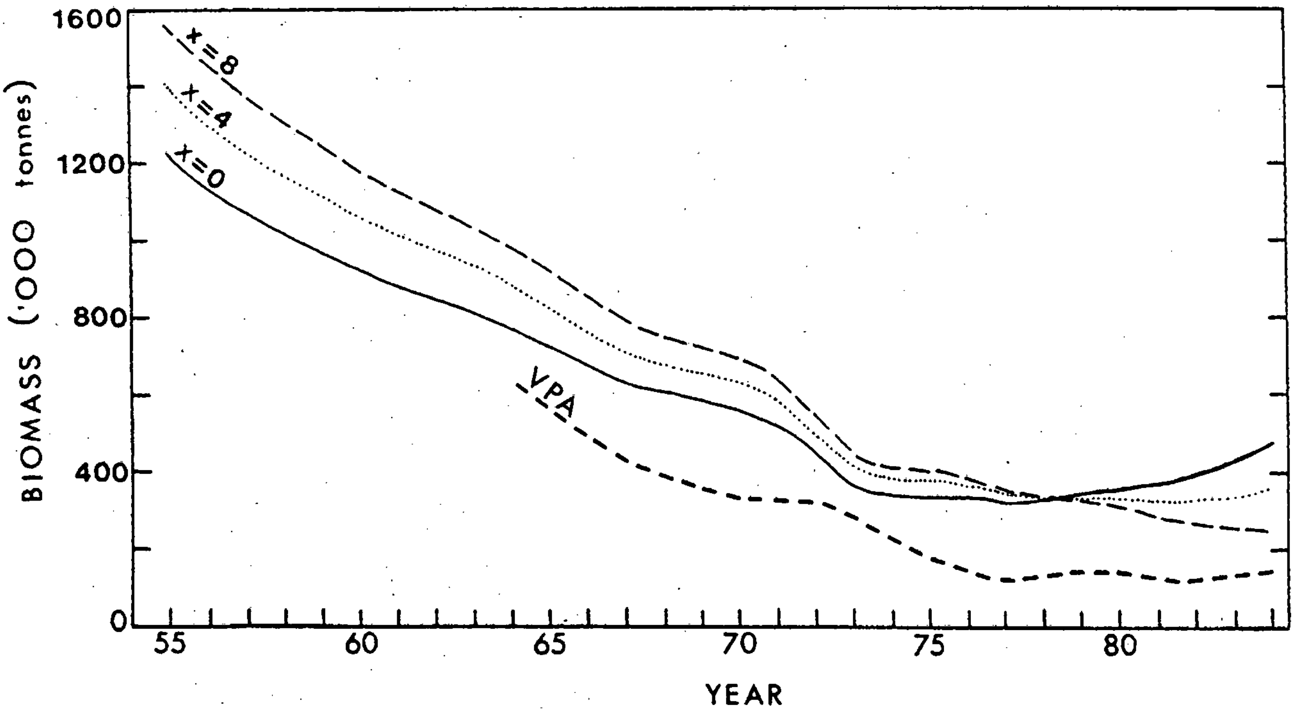


Figure 10.3: Schaefer model

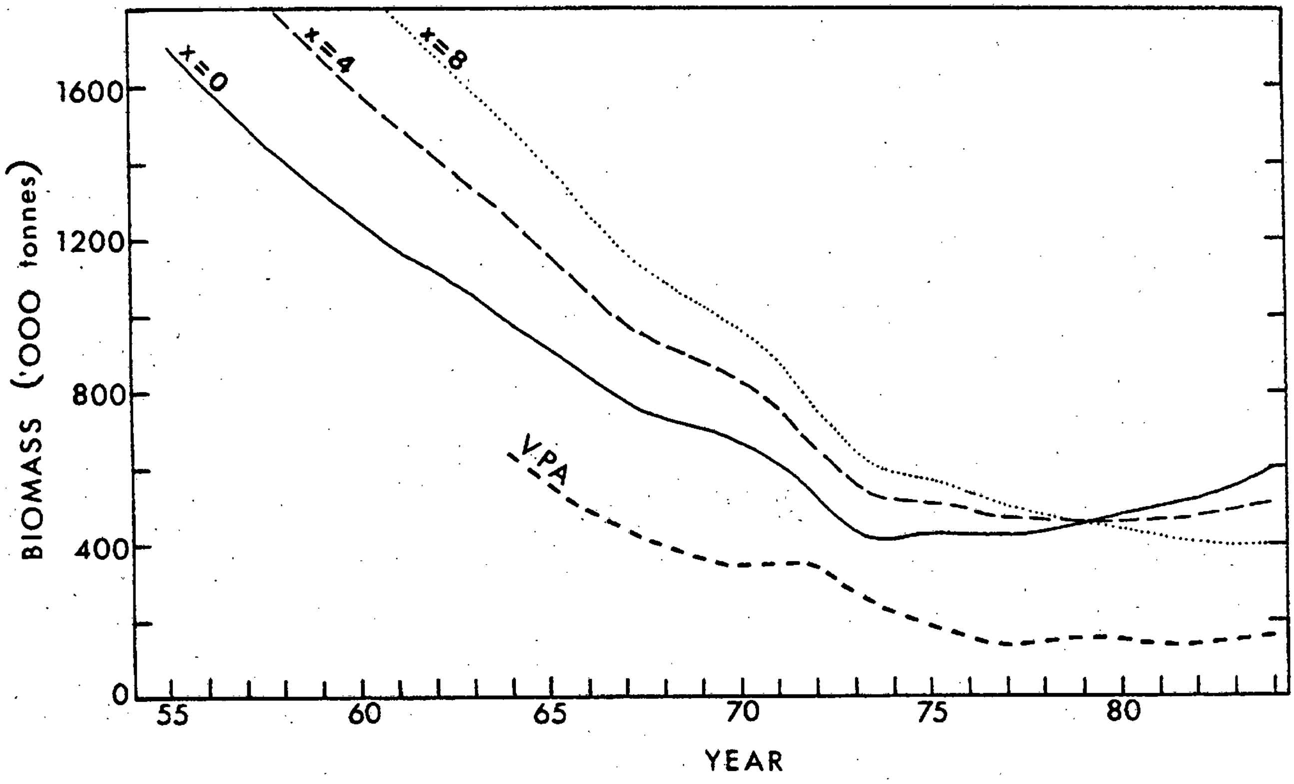


Figure 10.4: Fox model

Figures 10.3 - 10.4: Schaefer and Fox model biomass trends for Division 1.6 assuming that catching efficiency has increased (undetectedly) by x % per year over the past 10 years (that is, since 1974). The VPA biomass assessment for M = 0,3 is shown by the dashed line marked VPA.

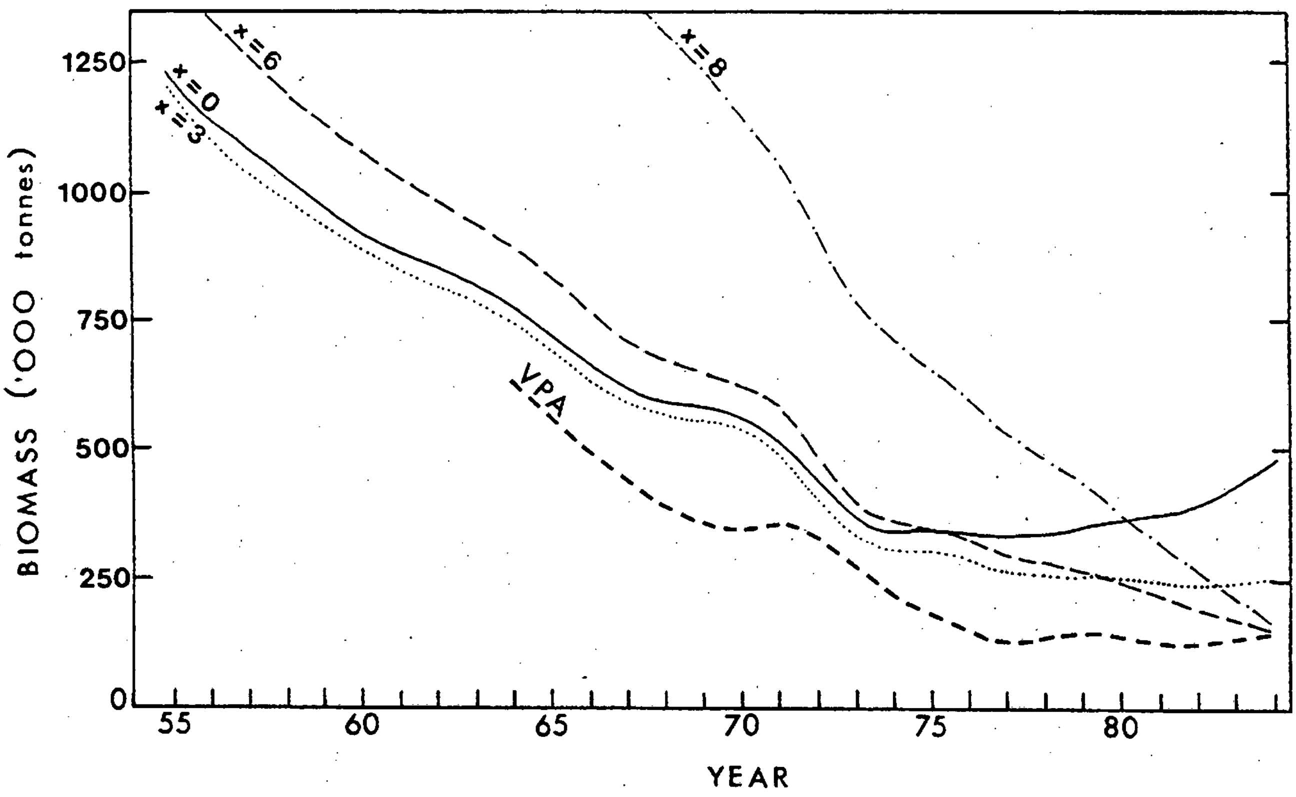


Figure 10.5: Schaefer model

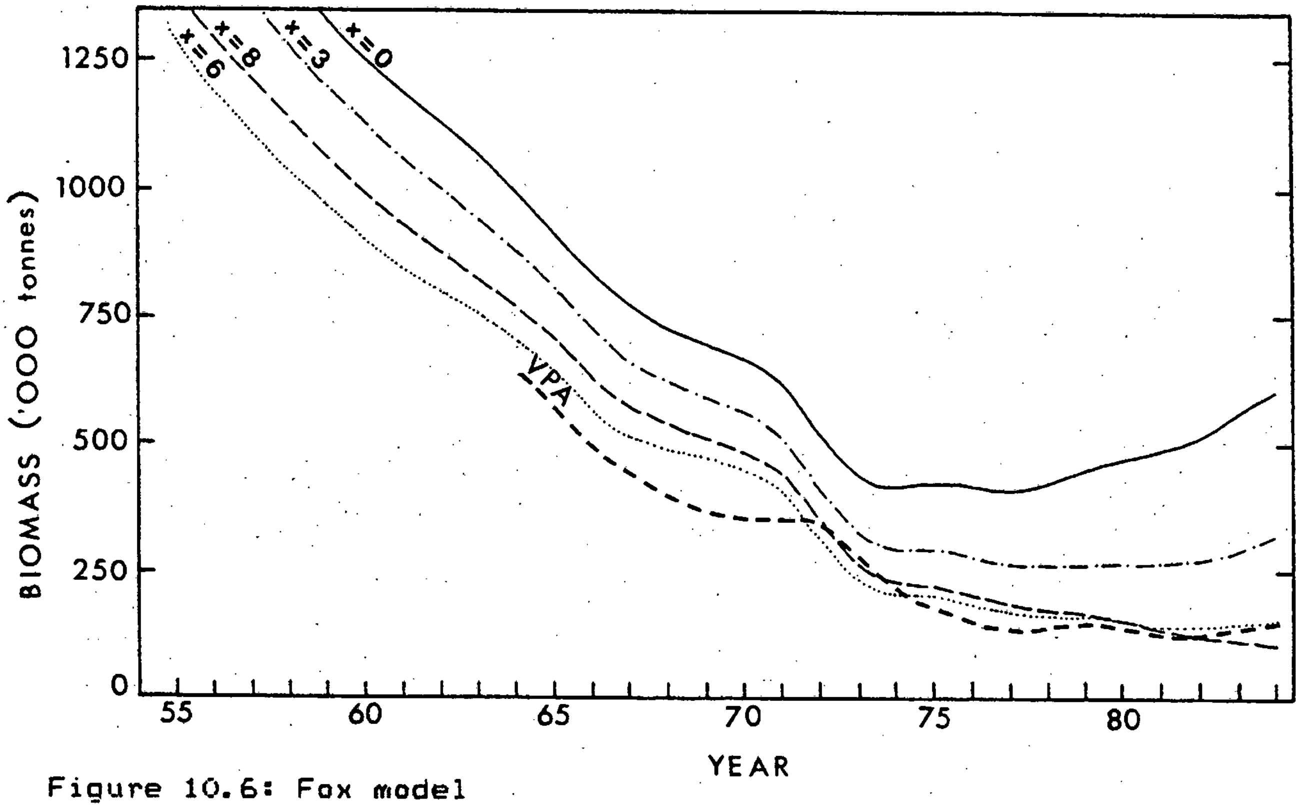


Figure 10.6: Fox model

Figures 10.5 - 10.6: Schaefer and Fox model biomass trends for Division 1.6 assuming that catching efficiency has increased (undetectedly) by x % per year over the past 20 years (that is, since 1964). The VPA biomass assessment for M = 0,3 is shown by the dashed line marked VPA.

evidence to independently quantify the 'undetected' efficiency increases postulated above. Such research might commence with a re-examination of previous power factor estimation calculations.

10.4 The effects of time delay and increased efficiency factors on estimates of sustainable yield and quotas

Originally, time delay and increased efficiency factors were incorporated in the dynamic models in an attempt to reduce differences between dynamic model and VPA estimates. However, of additional interest is the effect of such factors on the MSY and 1985 quota estimates. These effects are illustrated in Figures 10.7 - 10.10.

The incorporation of time lags in the dynamic model net growth equation resulted in changes in MSY that were relatively insignificant. In the case of the Schaefer model, a time delay of $T = 0,9$ provided optimal agreement between VPA and dynamic catch-effort model biomass estimates. This time delay corresponded to a 2,4% increase in MSY and a 4,7% decrease in $Q_{0,1}(85)$ when compared to values obtained when $T = 0$. In general, the trend was towards slightly lower MSY values as the time lag was increased (see Figure 10.7).

As shown in Figure 10.8, an increase in efficiency over the last 10 years had a similar effect on MSY. However, a slightly steeper and virtually linear decrease in MSY values with respect to the increase in efficiency was observed. An increase of $x = 4\%$ (per year) resulted in a 5% decrease in MSY for the Schaefer model, and correspondingly a 13% decrease for the Fox model.

Quite different MSY trends were observed when the efficiency increase was taken over the last 20 years. For the Schaefer model, MSY was seen to remain fairly constant for x values in the range 0 - 5% per year, after which it decreased sharply. On average, Fox model estimates showed quite a different trend, with MSY values rising slightly as the efficiency adjustment factor increased. The 'optimum' value (in respect of getting best agreement with VPA biomass records) of $x = 3\%$ for the Schaefer model resulted in no increase in MSY, whilst the corresponding x value of 6% for the Fox model led to a 7,4% increase.

The effect of increased efficiency over the last 10 years on 1985 quota values was also investigated (see Figure 10.10). $Q_{0,1}(85)$ values appear to decrease in an exponential-like fashion as the efficiency adjustment factor is increased. For the Schaefer model, an 'optimum' value of $x = 3\%$ yielded an 38% decrease in $Q_{0,1}(85)$, whereas, in the case of the Fox model with $x = 6\%$, the corresponding decrease was 40% .

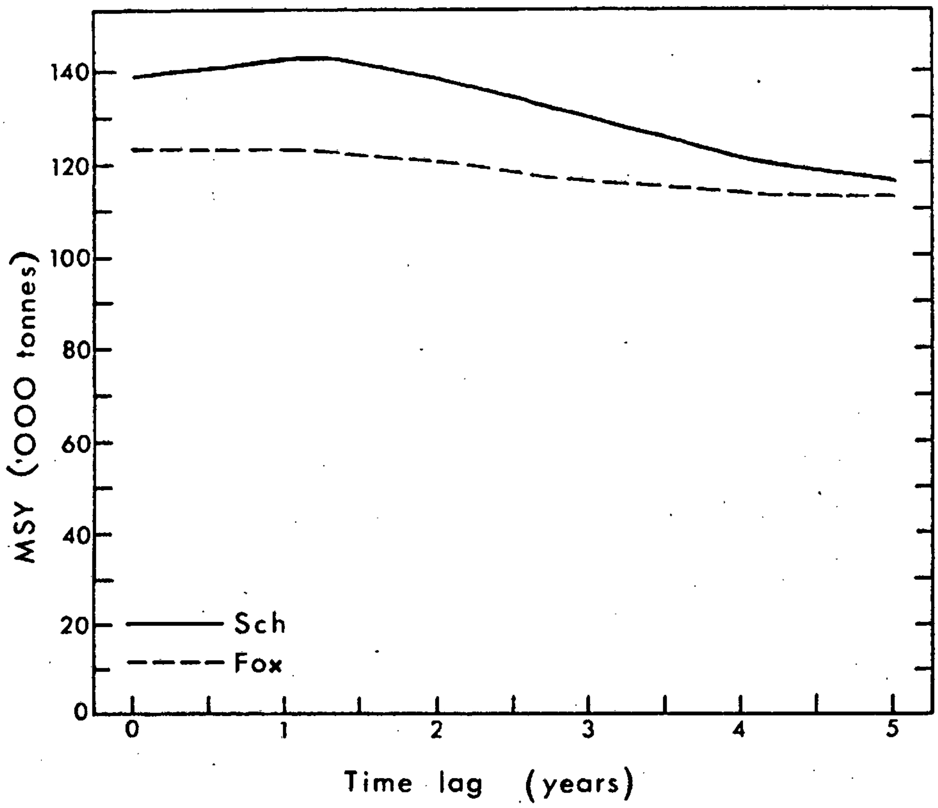


Figure 10.7: Schaefer and Fox model MSY estimates as a function of T for Division 1.6 where T is the time-lag (in years) that has been incorporated in the surplus production function.

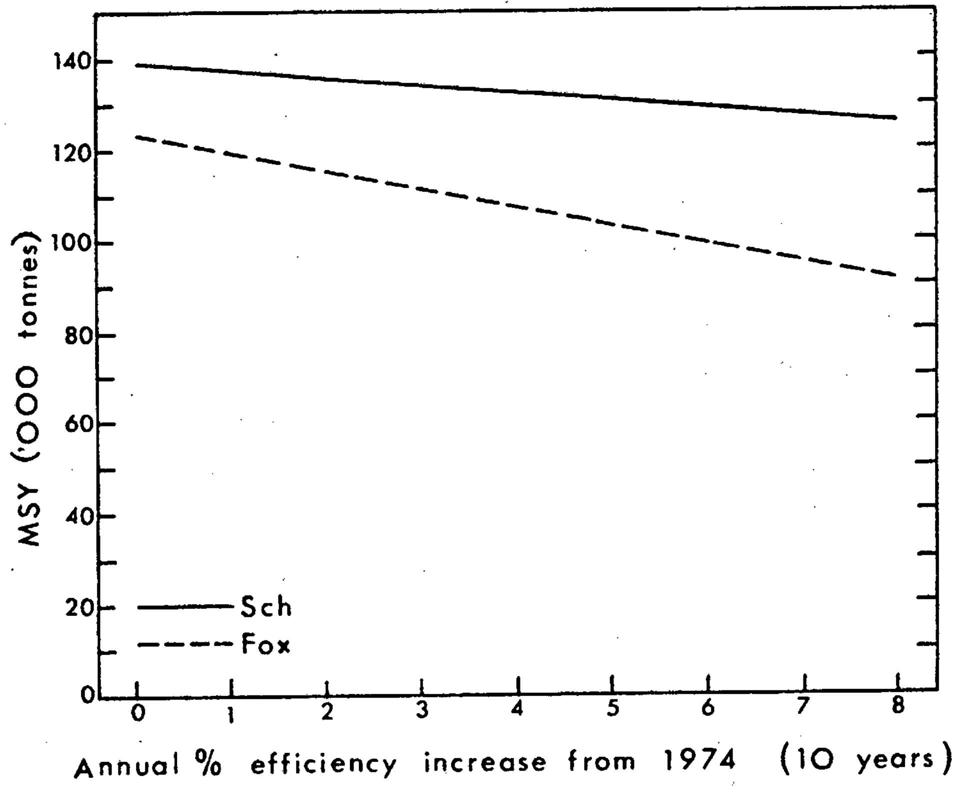


Figure 10.8: Schaefer and Fox model MSY estimates as a function of x for Division 1.6 where x is the percentage increase (undetetected) in catching efficiency per year over the past 10 years.

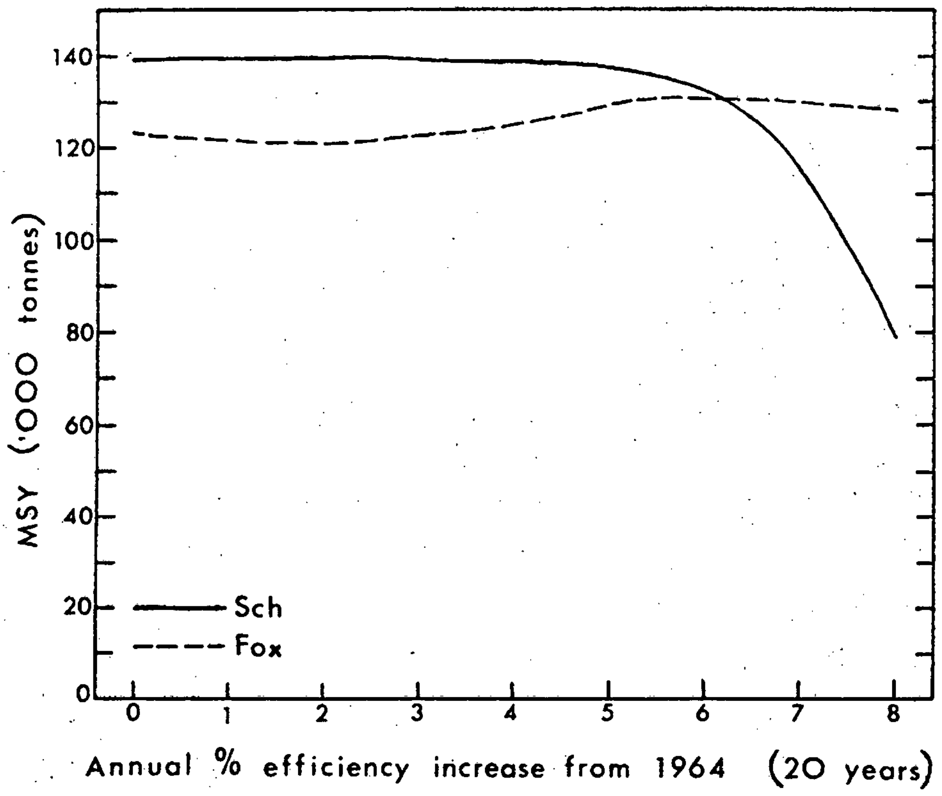


Figure 10.9: Schaefer and Fox model MSY estimates as a function of x for Division 1.6 where x is the percentage increase (undetetected) in catching efficiency per year over the past 20 years.

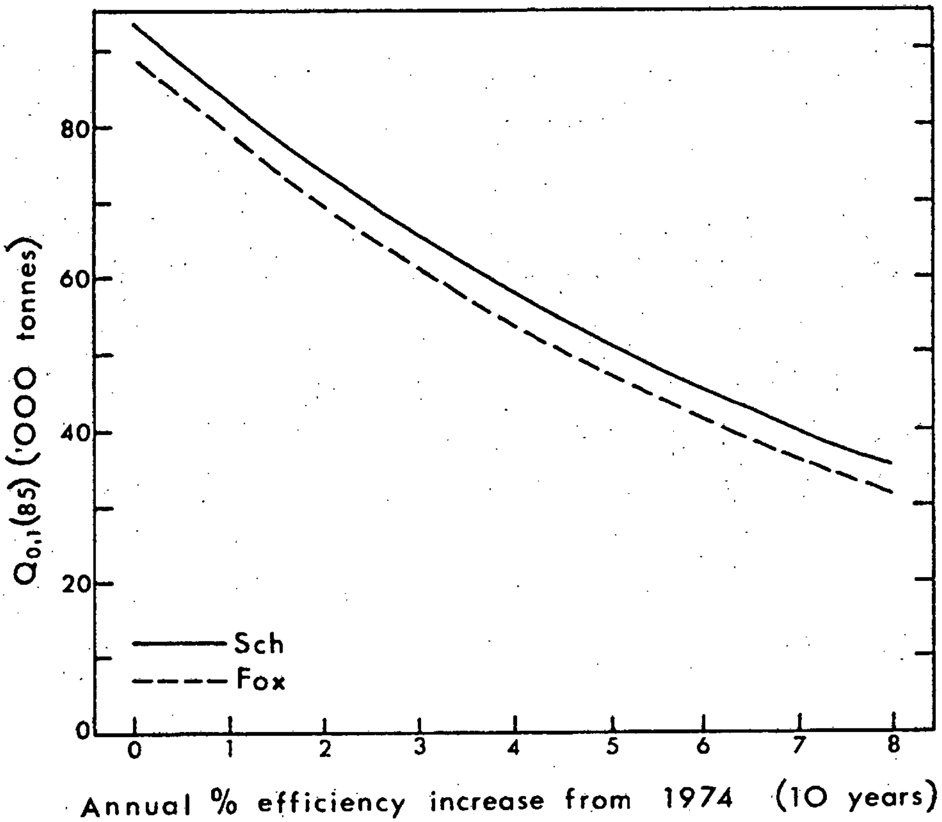


Figure 10.10: Schaefer and Fox model $Q_{0,1}$ estimates as a function of x for Division 1.6 where x is the percentage increase (undetetected) in catching efficiency per year over the past 10 years.

10.5 The effect of allowing initial biomass, y_1, to assume values other than the carrying capacity, K

In the initial runs of the dynamic model program, the constraint was set that the initial hake biomass present (that is, the biomass at the start of the CPUE series), y_1, was somewhat arbitrarily assumed equal to the carrying capacity, K. This is reasonable if the CPUE data series goes back to the start of the fishery or, alternatively, if catches before the start of the data series were relatively small (which is broadly the case for the stocks under consideration here). The effect of relaxing this assumption is now examined. However, as explained below, allowing y_1 to vary without any constraints can lead to unrealistic estimates for initial biomass.

Data series for all four ICSEAF divisions (see Tables 3.1 - 3.4) indicate very high CPUE values for the initial stages (typically the first 2 - 3 years) of the fishery and then substantially lower values thereafter. These large values at the start of the CPUE series (when the fisheries were small) do not necessarily indicate a proportionately higher stock size. They could rather be the result of the initial fishing out of high density regions. If there are no restrictions on y_1, the fitting procedure immediately sets $y_1 \gg K$ to account for the unrealistically large negative values of the growth function, G(y), needed to reproduce large declines in 'biomass' (corresponding to large CPUE drops), and therefore poor estimates of y_1 could be expected. Such results should be treated with caution.

To illustrate this problem, the following approach was adopted. A semi-arbitrary number of CPUE values at the start of each of the data series were ignored for the analysis and the value of y_1/K that allows for the best fit to the data was selected.

Results of runs of the Schaefer and Fox square root minimization procedures for $y_1 = K$ and for y_1/K set variable are given in Tables 10.1 - 10.4 . In the y_1/K variable case, the model was fitted to the whole of the data series as well as to the data series less the first n data pairs (where n = 1,...5). Minimizations were performed using the NAG minimization routine, E04FDF, and in all cases the results were checked using an alternative routine MINIM.

Coefficient of variation (c.v.) estimates were calculated using the same procedure described in Chapter 7. These are given for all parameter and variable estimates calculated using the full data series and for certain cases where n data pairs were dropped from the start of the data series. (Since the variance calculation method adopted uses considerable computer time, it would have been unrealistic to perform such calculations for the whole table.) For Divisions 1.3 to 1.6 a value of $n = 2$ was chosen since, in general, 'reasonable' (that is less than unity) y_1/K ratios resulted from these data sets. However, in Divisions 2.1 and 2.2, n was taken to be 5 since only in this case did y_1/K first fall to below 1.

From the y_1/K variable results given in the table below, it can be seen that in 6 (out of the 8) cases, y_1 was greater than K when the complete data set was used. However, in three of the abovementioned cases, the difference between the y_1/K estimates and unity is small and from the 95% confidence interval limits (listed in the table below) it can be seen that these differences are not statistically significant. A similar argument shows that even though both the Schaefer and Fox models in Divisions 2.1 and 2.2 show y_1 to be much greater than K, the corresponding 95% confidence intervals span unity and therefore the difference by which y_1/K is greater than 1 is also not statistically significant. Therefore only in the case of the Schaefer model in Divisions 1.3 + 1.4 is y_1/K (=2,28) significantly greater than 1. However, as soon as the first year (1965) is omitted from the data series, this ratio drops to below unity.

		y_1/K		
DIVISION	MODEL	Estimate	95% confidence int.	c.v.
1.3+1.4	Schaefer	2,28	(1,25 ; 3,18)	,22
	Fox	1,11	(0,58 ; 1,94)	,31
1.5	Schaefer	1,27	(0,70 ; 2,19)	,30
	Fox	0,95	(0,44 ; 1,84)	,37
1.6	Schaefer	1,03	(0,74 ; 1,76)	,23
	Fox	0,80	(0,60 ; 1,08)	,15
2.1+2.2	Schaefer	1,36	(0,42 ; 2,53)	,41
	Fox	1,96	(0,86 ; 3,85)	,36

To facilitate comparison of the constrained (y_1=K) and unconstrained (y_1/K variable) model estimates of the quantities MSY, $Q_{0,1}(85)$ and y^*/K, the relative changes in these values were calculated and expressed as percentages.

In the case of the MSY estimates, these differences were very small (less than 5% and on average 1,3%) for both the Schaefer and Fox models in all divisions. A comparison of the $Q_{0,1}$(85) estimates yielded similar results (that is, changes less than 5%) except in two cases, namely, the Schaefer model in Divisions 1.3 + 1.4 (where a relative change of 6% is evident) and for the Fox model in Divisions 2.1 + 2.2 (where the change was 13%).

The relative change in y^*/K values for these two cases was also rather larger with corresponding values of 6 and 10% being obtained. Also, in the case of the Fox model in Division 1.6, a largish absolute relative change of 7% was calculated for the y^*/K value. Since no obvious trends towards higher or lower MSY, $Q_{0,1}$(85) and y^*/K values were observed when y_1/K was unconstrained (that is, both negative and positive and generally fairly small relative changes were observed), it can be concluded that the removal of the $y_1=K$ constraint will cause only small changes in the estimates used for management decisions.

On the other hand, a comparison of the relative changes in precision associated with the MSY, $Q_{0,1}$(85) and y^*/K results (as determined by their c.v. estimates) reveals, in most cases, substantial differences between the precision of the constrained and unconstrained dynamic model results. Only in 6 (out of the 24) cases was the relative change found to be insubstantial (less than 5%) and in as many as 7 cases, the relative change exceeded 50% . Also, in one third of the cases, negative relative changes were evident and therefore no general conclusions could be reached with regard to increasing or decreasing trends in precision as a result of the removal of the $y_1=K$ constraint.

The c.v. estimates for the three quantities (MSY, $Q_{0,1}$(85) and y^*/K) were all less than 20%, except for $Q_{0,1}$(85) (y_1/K variable case) in Divisions 2.1 + 2.2 . It can therefore be concluded that, although letting y_1/K vary might result in c.v. estimates substantially different from the $y_1=K$ case, the overall precision with which these three quantities can be estimated is still within an acceptable range and therefore the use of the unconstrained model (as opposed to the $y_1=K$ model) is unlikely to have a substantial effect on resultant management recommendations.

It is also obvious from the results in Tables 10.1 - 10.4 that the exclusion of high CPUE values from the start of the data series has a definite effect on y_1/K estimates. In Division 1.3 + 1.4 and 1.5 this effect was to decrease y_1/K values. On the other hand, in Divisions 1.6 and 2.1 + 2.2 the reverse effect occurred, and in some cases relatively high estimates of y_1/K were obtained. As expected, in a few cases unrealistic y_1/K ratios occurred as a result of some high initial CPUE values.

A reasonable or biologically acceptable value of y_1/K can, as a rough guideline, be considered to be one where $y_1/K \leqslant 1$ (that is, one where $y_1 \leqslant K$). Runs of the Schaefer and Fox models for y_1/K variable and different data series (that is, for values of $n = 0,\dots5$) all yielded a reasonable y_1/K ratio for at least one data combination, except in the case of the Schaefer model for Division 1.6 where the minimum value of y_1/K was 1,01 . However, coefficients of variation for these estimates were in the range of 15 - 40%, suggesting that much variation in these estimates can be expected.

In summary, it can be concluded that this extended model does not appear to have any obvious advantages over models where $y_1=K$. In some cases, more biologically acceptable results were obtained, but there was no trend in these results and so no generalizations could be made. Since parameter and variable estimates important to management of the stocks remained essentially the same, the original three-parameter model may as well be retained for management advice.

Further refinements could, however, be made to the original model or fitting procedure. One such change would be to consider a constrained minimization where y_1/K is variable, but not greater than some fixed quantity. The latter would not necessarily be equal to 1. It could be a slightly higher amount (for example, 1,2) to allow for the fact that natural fluctuations might have seen the stock somewhat higher than its mean exploited level (K) when the fishery commenced.

A further extension to the fitting procedure is possible if there is some information on catches (but not effort) before the start of the data series used. The model could then take such catches into account, although the absence of corresponding effort information would mean that these catches affected the minimization criterion only indirectly.

DIVISIONS 1.3 + 1.4 : SCHAEFER MODEL							
	$y_1 = K$	y_1/K VARIABLE					
	65-84	65-84	66-84	67-84	68-84	69-84	70-84
y_1/K	1,00	2,28 (,217)	,973	,705 (,252)	,810	,831	1,02
MSY	263 (,055)	262 (,057)	261	273 (,091)	266	259	251
$Q_{0,1}$	239 (,124)	254 (,105)	240	226 (,134)	234	244	274
y*/K	,517 (,086)	,550 (,077)	,521	,472 (,162)	,501	,535	,615
K	2683 (,115)	2686 (,106)	2745	2820 (,144)	2736	2625	2392

DIVISIONS 1.3 + 1.4 : FOX MODEL							
	$y_1 = K$	y_1/K VARIABLE					
	65-84	65-84	66-84	67-84	68-84	69-84	70-84
y_1/K	1,00	1,11 (,311)	,803	,549 (,372)	,668	,731	,984
MSY	249 (,055)	250 (,059)	249	257 (,112)	251	248	256
$Q_{0,1}$	253 (,125)	265 (,186)	231	193 (,241)	213	239	313
y*/K	,486 (,077)	,505 (,146)	,444	,360 (,287)	,407	,460	,579
K	3124 (,094)	3101 (,108)	3285	3791 (,304)	3437	3106	2550

Table 10.1: Division 1.3 + 1.4 . Parameter estimates using Schaefer and Fox dynamic square root minimization procedures with y_1 = K and y_1/K variable. Figures in parenthesis indicate coefficients of variation. y* is the current biomass (that is, biomass at the start of 1985).

DIVISION 1.5 : SCHAEFER MODEL

	$y_1 = K$	y_1/K VARIABLE					
	65-84	65-84	66-84	67-84	68-84	69-84	70-84
y_1/K	1,00	1,27 (,298)	1,93	,612 (,231)	,592	,485	,579
MSY	175 (,049)	173 (,054)	181	185 (,071)	185	192	178
$Q_{0,1}$	168 (,132)	169 (,127)	169	156 (,130)	156	152	159
y*/K	,556 (,101)	,564 (,099)	,542	,492 (,154)	,491	,463	,521
K	1162 (,161)	1192 (,159)	1166	1252 (,165)	1253	1321	1174

DIVISION 1.5 : FOX MODEL

	$y_1 = K$	y_1/K VARIABLE					
	65-84	65-84	66-84	67-84	68-84	69-84	70-84
y_1/K	1,00	,946 (,370)	,666	,351 (,328)	,330	,246	,362
MSY	162 (,049)	162 (,051)	164	187 (,089)	190	206	178
$Q_{0,1}$	166 (,135)	163 (,189)	144	107 (,287)	105	96,1	115
y*/K	,495 (,093)	,486 (,164)	,426	,283 (+)	,273	,231	,320
K	1497 (,132)	1501 (,153)	1601	2173 (,266)	2245	2644	1901

Table 10.2: Division 1.5 . Parameter estimates using Schaefer and Fox dynamic square root minimization procedures with $y_1 = K$ and y_1/K variable. Figures in parenthesis indicate coefficients of variation. y^* is the current biomass (i.e. biomass at the start of 1985). A (+) indicates that the distribution for the parameter estimate evaluated by the bootstrap technique was extremely skew. The estimate is therefore probably severely biased and the coefficient of variation is an inappropriate measure of precision.

DIVISION 1.6 : SCHAEFER MODEL							
	$y_1 = K$	y_1/K VARIABLE					
	55-84	55-84	56-84	57-84	58-84	59-84	60-84
y_1/K	1,00	1,03 (,228)	1,01	1,08 (,211)	1,10	1,13	1,13
MSY	139 (,070)	139 (,064)	138	136 (,076)	134	133	132
$Q_{0,1}$	93,7 (,170)	93,7 (,153)	93,8	95,0 (,149)	96,8	99,3	103
y*/K	,391 (,139)	,392 (,119)	,395	,405 (,115)	,416	,432	,450
K	1286 (,232)	1297 (,209)	1309	1327 (,210)	1328	1322	1307

DIVISION 1.6 : FOX MODEL							
	$y_1 = K$	y_1/K VARIABLE					
	55-84	55-84	56-84	57-84	58-84	59-84	60-84
y_1/K	1,00	,796 (,152)	,793	,854 (,178)	,881	,906	,902
MSY	123 (,043)	128 (,042)	128	126 (,047)	125	124	123
$Q_{0,1}$	89,5 (,113)	86,0 (,113)	86,7	89,4 (,114)	91,9	95,0	97,9
y*/K	,353 (,084)	,328 (,099)	,332	,347 (,107)	,359	,374	,388
K	1764 (,100)	1699 (,103)	1696	1676 (,099)	1656	1628	1602

Table 10.3: Division 1.6 . Parameter estimates using Schaefer and Fox dynamic square root minimization procedures with $y_1 = K$ and y_1/K variable. Figures in parenthesis indicate coefficients of variation. y* is the current biomass (that is, biomass at the start of 1985).

DIVISIONS 2.1 + 2.2 : SCHAEFER MODEL

	$y_1 = K$	y_1/K VARIABLE					
	67-84	67-84	68-84	69-84	70-84	71-84	72-84
y_1/K	1,00	1,36 (,406)	1,47	1,61	1,62	2,00	,722 (,367)
MSY	52,8 (,064)	51,4 (,130)	50,7	51,1	52,3	53,7	53,2 (,168)
$Q_{0,1}$	50,9 (,173)	49,1 (,316)	49,7	53,0	58,2	61,4	56,7 (,249)
y*/K	,552 (,130)	,543 (,155)	,555	,586	,627	,645	,604 (,258)
K	303 (,264)	334 (,753)	359	368	368	390	402 (,364)

DIVISIONS 2.1 + 2.2 : FOX MODEL

	$y_1 = K$	y_1/K VARIABLE					
	67-84	67-84	68-84	69-84	70-84	71-84	72-84
y_1/K	1,00	1,96 (,364)	1,97	2,03	2,12	2,25	,589 (,419)
MSY	51,8 (,052)	52,8 (,142)	54,5	57,6	63,0	76,2	53,1 (,152)
$Q_{0,1}$	53,8 (,159)	60,7 (,301)	66,4	75,9	90,6	122	54,6 (,496)
y*/K	,498 (,109)	,548 (,121)	,580	,625	,680	,756	,492 (+)
K	338 (,172)	373 (,272)	375	376	381	405	481 (,458)

Table 10.4: Division 2.1 + 2.2 . Parameter estimates using Schaefer and Fox dynamic square root minimization procedures with $y_1 = K$ and y_1/K variable. Figures in parenthesis indicate coefficients of variation. y^* is the current biomass (i.e. biomass at the start of 1985). A (+) indicates that the distribution for the parameter estimate evaluated by the bootstrap technique was extremely skew. The estimate is therefore probably severely biased and the coefficient of variation is an inappropriate measure of precision.

10.6 The Shepherd parametrization of the surplus production function.

Previous dynamic model calculations were based on the Fox and Schaefer forms where y_{MSY} is a constant proportion of the carrying capacity, K. For the Schaefer model $y_{MSY}/K = 0,5$ and for the Fox model, 0,37. There is no firmly established reason why either of these proportions should necessarily be correct. In principle, any degree of skewness of the yield curve away from the symmetric Schaefer curve would be acceptable. However, predictions of models which are skewed further to the left than the Fox model should be treated with extreme caution because of the high relative depletion levels they would advocate.

The fitting procedure could, in principle, incorporate a skewness parameter in an appropriately chosen functional form for the surplus production function, G(y). In this section such a generalized form of the dynamic model is used to test whether the data contains sufficient information to determine the y_{MSY}/K ratio at an acceptable level of precision.

The net biomass growth (surplus production) function, G(y), is defined as the growth due to both individual fish growth and recruitment ('gross' growth), g(y), less losses to natural mortality:

$$G(y) = g(y) - M.y \qquad (10.3)$$

where y is the recruited population biomass

(g(y) is by definition non-negative).

One method of allowing MSY to be achieved at values that are not a fixed proportion of K was suggested by Pella and Tomlinson (1969). They prescribed the following formula for net biomass growth which does not separately distinguish the effects of growth and mortality:

$$G(y) = r.y.[1 - (y/K)^p] \qquad (10.4)$$

where r is the intrinsic growth rate (at least for cases with $p > 0$)

and K is the carrying capacity.

When p = 1, Pella-Tomlinson's model is equivalent to the Schaefer formula.

Shepherd (1982) criticized the Pella-Tomlinson form on the following grounds. For large biomasses ($y > K$), G(y) becomes negative. From equations (10.3) and (10.4) it follows that

$$g(y) = G(y) + M.y = (r + M).y - r.K^{-p}.y^{p+1}$$

Since g(y) is by definition non-negative, this relation requires M to be density-dependent and to increase for large biomasses. Strictly therefore, such a model can only be used in assessing populations if one is prepared to accept that natural mortality is density-dependent. However, for most heavily fished populations such as those considered here, y is less than K and therefore the poor behaviour of the model in the domain $y > K$ does not pose any real problems.

Shepherd (1982) suggests a more versatile general production model with a skewness parameter which allows for the achievement of MSY at values that are not a fixed proportion of K. In addition, this model has more realistic behaviour in the domain $y \to 0$ than the Fox model and in the domain $y \to K$ than the Pella-Tomlinson model. In the Shepherd parametrization,

$$G(y) = r'.y/[1 + (y/K')^{p}] - M.y \qquad (10.5)$$

where the parameters are defined as follows:

r' = intrinsic specific 'gross' biomass growth rate attainable only at very low biomasses (that is, before natural mortality is taken into account)

p = degree of compensation in the relationship

and K' = threshold biomass separating the region $y > K'$ (where density-dependent effects are dominant) from the region $y < K'$ (where the 'gross' growth rate is approaching its intrinsic maximum value).

Unlike the Pella-Tomlinson model, Shepherd's model does not require M to be density-dependent for appropriate behaviour in the region $y > K$.

It is desirable to rewrite the Shepherd form with parameters r and K having the same interpretation as those used in the Pella-Tomlinson model (and thence the Schaefer form). This was effected as follows:

Using the assumptions, $G(y) = 0$ at $y = 0$ and $y = K$

and $$(1/y)\, dG/dy \Big]_{y=0} = r$$

G(y) can be rewritten in terms of r and K. The substitution of

$$r' = M + r$$

and $$K' = K.(M/r)^{(1/p)},$$

into equation (10.5) yields

$$G(y) = \left[(M+r).y \;/\; [1+(r/M).(y/K)^{p}]\right] - M.y \qquad (10.6)$$

By differentiating the above formula, solutions for y_{MSY}/K and MSY can be found:

$$y_{MSY}/K = \left[(r-M-p.(M+r)+p.\sqrt{(1+p^2).(M+r)^2+2(M^2-r^2)}\,)/(2r)\right]^{(1/p)} \qquad (10.7)$$

$$MSY = (M+r).y_{MSY} \;/\; [1+(r/M).(y_{MSY}/K)^{p}] - M.y_{MSY} \qquad (10.8)$$

Since $$C = \left[(M+r).y/[1+(r/M).(y/K)^{p}]\right] - M.y$$

and $$C/E = q.y\,,$$

C can be expressed as follows:

$$C = q.K.E.\left[(1-(q/r).E)/(1+(q/M).E)\right]^{(1/p)} \qquad (10.3)$$

MSY and the effort level at which it is obtained can be evaluated by differentiating with respect to E :

$$E_{MSY} = (-A+\sqrt{A^2+4p^2.r.M}\,)/(2p.q) \qquad (10.10)$$

$$C_{MSY} = q.K.E_{MSY}.\left[(1-(q/r).E_{MSY})/(1+(q/M).E_{MSY})\right]^{(1/p)} \qquad (10.11)$$

where $A = M.(1+p) + r.(1-p)$.

$E_{0,1}$ and $Q_{0,1}$ (see Chapter 7) are determined by using the secant method of approximating roots to solve for X in

$$\left[10\left[1-(M+r).X/\{p.(M+X).(r-X)\}\right]\right]^{p}.M.(r-X) - r.(M+X) = 0$$

where $E_{0,1} = X/q$

and $$Q_{0,1} = q.K.E_{0,1}.\left[(1-(q/r).E_{0,1})/(1+(q/M).E_{0,1})\right]^{(1/p)}. \qquad (10.12)$$

The above Shepherd model formulae are now used as a basis for investigating an unrestricted y_{MSY}/K ratio.

The square root minimization procedure described in Chapter 5 was used to calculate 'best fit' estimates of the Shepherd model parameters for all four divisions, initially for various fixed values of p and then letting p vary. The value of M was taken to be 0,3 yr^{-1} for all calculations (see Appendix 9.1). These results are given in Tables 10.5 - 10.8 and coefficients of variation are given by figures in parenthesis. Biomass trends with time for various fixed values of the parameter p are illustrated in Figures 10.11 - 10.14 .

In all cases, the results listed were calculated using the same NAG routine, E04FDF, as described in Chapter 5. These results were checked using another minimization routine MINIM and no discrepancies were found. In many cases the r values were very poorly determined (see Appendix 10.1) and where this is the case, r estimates have been placed in parenthesis. To prevent the fitting procedure from estimating unrealistically high r values, it was decided to limit r to the range [0 ; 50] for the minimization.

In Divisions 1.3 + 1.4, 1.6 and 2.1 + 2.2, 'best fits' were achieved at low p values (0,962, 0,418 and 0,836 respectively) and hence low y_{MSY}/K ratios (0,362 , 0,279 and 0,139 respectively). The corresponding values obtained for Division 1.5 were p = 2,89 and y_{MSY}/K = 0,507 . The low p values obtained in all divisions except Division 1.5 may be attributed in part to the fact that the additional p parameter is used to try to fit the initial high observed CPUE values more closely. As is shown in Figures 10.11 - 10.14 this is reflected in the increasing biomass and decreasing MSY estimates (interpreting the fisheries' history more as the removal of accumulated stock and less as the harvesting of surplus production).

The σ values in Tables 10.5 to 10.8 were calculated as follows:

$$\sigma = \sqrt{SS / (m - n_p)}$$

where SS is the sum of squares minimum, m is the number of observations used in the fit and n_p is the number of parameters fitted (see equation (7.7)). The subtraction of n_p in the denominator is an ad hoc allowance for bias. This correction would be exact if the model was linear in the parameters estimated. Therefore, for p fixed $n_p = 3$, whereas for p set variable, $n_p = 4$. σ values calculated using p variable runs have been marked with an asterisk and should be multiplied by a factor of $\sqrt{\frac{m-4}{m-3}}$ before comparison with three-parameter models (such as Schaefer and Fox) is made.

From Tables 10.5 to 10.8 it can be seen that changes in the value of p produce relatively insignificant changes in σ. It therefore appears that the addition of the parameter p yields little improvement in the general fitting of the net growth function to past catch and effort data. In addition, a comparison of the sum of squares minima calculated using the Shepherd model (with p variable) to those obtained using the Schaefer and Fox dynamic models indicates that any improvements in fit by the Shepherd model are negligible.

The c.v. values were calculated (using the method described in Chapter 7) for all parameter and variable estimates for the p variable case listed in Tables 10.5 to 10.8. Of particular interest are the 95% confidence limits for y_{MSY}/K estimates which are given below:

	y_{MSY}/K		
DIVISION	Estimate	95% confidence interval	c.v.
1.3 + 1.4	0,36	(0,23 ; 0,62)	0,32
1.5	0,51	(0,29 ; 0,62)	0,15
1.6	0,28	(0,26 ; 0,41)	0,13
2.1 + 2.2	0,14	(0,09 ; 0,58)	0,60

In all divisions except perhaps Division 1.6 the y_{MSY}/K values appear to be very poorly estimated, and it can be concluded that the skewness of the Shepherd surplus production function (and hence probably that of any other surplus production functional form incorporating a skewness parameter) is very imprecisely determined by available data. Accordingly, estimates of the quantities associated with a bioeconomically optimal policy such as $f_{0,1}$ may not be determined very precisely (Butterworth _et al._, 1986a).

A good indication of how close the current biomass (y^*) is to the equilibrium biomass corresponding to the $f_{0,1}$ harvesting policy ($y_{0,1}$) is given by the ratio, $y^*/y_{0,1}$. These estimates together with the corresponding coefficients of variation are given in the following table:

DIVISION	$y^*/y_{0,1}$	c.v.
1.3 + 1.4	1,08	0,137
1.5	1,05	0,108
1.6	0,83	0,081
2.1 + 2.2	1,31	0,124

These figures indicate that for all divisions except Division 1.6 , the stocks have already attained their equilibrium levels under an $f_{0,1}$ strategy so that management's initial objective in restoring these stocks from previous depleted levels has virtually been achieved.

As can be seen from the above table, the c.v. estimates for $y^*/y_{0,1}$ range from 8 to 14% which indicates a more acceptable degree of precision than in the case of y_{MSY}/K where the c.v. estimates are on average 2,5 times larger. Similarly, the c.v. estimates associated with $Q_{0,1}$(85) (see Tables 10.5 - 10.8) are also relatively low (in the range 11 - 19%). So although it may be difficult to determine with confidence the position of y_{MSY} relative to K, the variables necessary for management purposes ($y^*/y_{0,1}$ and $Q_{0,1}$(85)) may be estimated with a far greater degree of precision.

It is also of interest to compare the c.v. estimates of the abovementioned variables with those of the Schaefer and Fox models (listed in Tables 8.1 - 8.8) where y_{MSY}/K is fixed. In these models, $y_{0,1}$ is a constant proportion of y_{MSY} and therefore the coefficients of variation for $y^*/y_{0,1}$ will be the same as those for y^*/y_{MSY}. In most cases, the Schaefer and Fox estimates of $y^*/y_{0,1}$ and $Q_{0,1}$(85) were relatively more precise. This is not surprising since, although the incorporation of the additional parameter (p) used in the Shepherd model leads to a decrease in bias, a corresponding loss of precision would generally be expected. However this is not always the case. In Division 1.6, Schaefer model c.v. estimates for $y^*/y_{0,1}$ and $Q_{0,1}$(85) are notably (at least 10%) greater than the corresponding Shepherd model estimates. In each division the proportional increase in c.v. for these management variables estimated using the Shepherd model over estimates using the Schaefer and Fox model was calculated. These proportions were then averaged over the four ICSEAF Divisions and the results are given in the following table:

Proportional increase (expressed as a %) of Shepherd model c.v.		
MODEL	$y^*/y_{0,1}$	$Q_{0,1}$(85)
Schaefer	4,97	0,54
Fox	26,06	10,55

A similar table below gives a comparison of the average percentage difference in the actual $y^*/y_{0,1}$ and $Q_{0,1}$(85) values of the Shepherd model over all four divisions:

Prop. incr. (expressed as a %) of Shepherd model parameter values		
MODEL	$y^*/y_{0,1}$	$Q_{0,1}$(85)
Schaefer	16,55	12,15
Fox	6,72	10,28

From these two tables it can be concluded that only the Fox model management variable estimates show a substantial increase in precision when compared to those of the Shepherd model. The average proportional increases in Shepherd model $Q_{0,1}$(85) estimates are slightly larger as a result of higher $y^*/y_{0,1}$ values (that is, the Shepherd model estimates the current state of the stock to be closer to or more in excess of $y_{0,1}$ than is the case for the Schaefer and Fox models, and therefore higher quotas are advocated). However, the average differences for the $y^*/y_{0,1}$ and $Q_{0,1}$(85) variables are still relatively insubstantial. In addition, the Shepherd model c.v. estimates for the the two management variables are within an acceptable range and are very similar overall to those of the Schaefer model which is considered to be a suitable model for management recommendation purposes by the ICSEAF Scientific Advisory Council. The Shepherd model can therefore be accepted as an appropriate model for management of the Cape hake stocks.

A comparison with VPA biomass estimates for Division 1.6 (Figure 10.13) indicates no improvement in agreement between the two models when the value of p providing the sum of squares minimum ($p = 0,418$) for the Shepherd model was used. Values of p in the range 0,3 - 2,0 all indicated current biomass estimates which were substantially greater than those provided by the VPA procedure, although consistency between absolute VPA and dynamic Shepherd model biomass estimates improved considerably when the value of p was increased to 2,0 . However, the Shepherd model shows different recent biomass trends to those calculated using the VPA. This discrepancy appears to be the result of a conflict in the interpretation of increasing CPUE trends (which dominate production model fits) and decreasing mean catch-at-age trends (which dominate the VPA). The VPA is further confounded by the possibility of a change in selectivity pattern which cannot be independently quantified (Butterworth et al., 1986b).

Figures 10.15 to 10.18 show plots of the surplus production $G(y_i)$ as a function of biomass, y_i. The parameters used were determined by fits of the Fox, Schaefer and Shepherd functional forms to the data for all ICSEAF divisions. The approach adopted is set out in Appendix 10.2 . From a qualitative inspection of these plots, it is clear that while the data can determine a measure of scale (such as MSY), they contain relatively little information about the shape of $G(y)$ (see Butterworth et al., 1986a).

To summarize: the comparison of the Shepherd model results with those of the Schaefer and Fox models indicated improvements in fit (as reflected by the sum of squares minima or σ) and differences in values and precision of management variables that were insubstantial. The Shepherd model y_{MSY}/K values had relatively high c.v. estimates (on average 30%), thus indicating that the skewness parameter p could not be estimated with reasonable precision from the available data (given in Tables 3.1 - 3.4). However, c.v. estimates for $Q_{0,1}(85)$ values (the variable of primary concern to management) were much smaller (~ 15%), indicating that inability to estimate skewness precisely is not as critical as one might first think from an exploitation regulation standpoint. The actual values of estimated management variables (such as $Q_{0,1}(85)$ and $y^*/y_{0,1}$) and the precision with which these quantities were determined did not differ substantially from those of the Schaefer and Fox models, although the actual $Q_{0,1}(85)$ values in the case of the Shepherd model did tend to be slightly higher (by ~ 11%). This was partly attributed to the fact that the Shepherd model estimated the current states of the stocks to be closer to or more in excess of $y_{0,1}$ than did the Schaefer and Fox models. A comparison of biomass estimates provided by the Shepherd model (using the value of p providing the sum of squares minimum) with those of the VPA procedure for Division 1.6 indicated no improvement in agreement compared to the Schaefer and Fox models.

The Shepherd model was introduced as a means of incorporating a skewness parameter in the growth function. However, as indicated above, the available catch-effort data series proved inadequate to determine this parameter with reasonable precision. Further, any bias that might arise in estimates of management variables through fixing the skewness (such as in the Schaefer and Fox models) rather than treating it as an estimable parameter seems relatively small (~ 10%). Thus the Shepherd model appears to be a suitable, though not necessarily superior, alternative basis for management of the stocks under consideration.

DIVISIONS 1.3 + 1.4				DATA PERIOD: 1965-1984	
p value	p=0,3	p=0,5	p=1,0	p=2,0	p=,962 (,822) (best fit)
r	(50,0)	(49,2)	0,578	0,321	0,614 (1,55)
$q \times 10^{-3}$	0,233	0,366	0,402	0,456	0,400 (,206)
K	4833	3456	3166	2768	3182 (,175)
E_{MSY}	546	801	531	433	540 (,305)
$E_{0,1}$	379	481	423	391	426 (,121)
y^*/K	0,409	0,464	0,483	0,510	0,482 (,105)
y^*/y_{MSY}	1,34	1,83	1,31	1,06	1,33 (,289)
y_{MSY}/K	0,306	0,253	0,369	0,481	0,362 (,319)
y(mid-84)	1987	1590	1510	1380	1515 (,148)
$y_{0,1}$	2036	1363	1427	1462	1422 (,111)
MSY	188	256	249	263	249 (,089)
Q_{s-s} (85)	181	223	237	262	236 (,114)
Q_{MSY} (85)	252	466	322	272	327 (,304)
$Q_{0,1}$ (85)	175	280	257	246	258 (,150)
$Q_{0,1}$ (86)	175	277	258	253	260 (,137)
σ	1,31	0,945	0,940	0,947	0,969 *

Table 10.5: Parameters of Shepherd model fits (using the square root minimisation procedure) to hake catch-effort data for Divisions 1.3 + 1.4 . All biomass-type parameters are in '000 tonnes.

DIVISION 1.5 DATA PERIOD: 1965-1984

p value	p=0,3	p=0,5	p=1,0	p=4,0	p=2,89 (,389) (best fit)
r	(50,0)	(50,0)	0,874	0,507	0,478 (3,03)
$q \times 10^{-3}$	0,526	0,878	1,21	2,15	1,83 (,228)
K	3020	2083	1631	893	1081 (,235)
E_{MSY}	241	334	244	183	184 (,170)
$E_{0,1}$	167	200	184	173	170 (,062)
y^*/K	0,414	0,438	0,478	0,621	0,571 (,133)
y^*/y_{MSY}	1,36	1,73	1,42	1,11	1,12 (,166)
y_{MSY}/K	0,306	0,253	0,336	0,559	0,507 (,153)
y(mid-84)	1255	903	765	517	586 (,182)
$y_{0,1}$	1273	822	699	524	588 (,179)
MSY	117	154	161	196	184 (,071)
Q_{s-s} (85)	113	139	149	191	180 (,080)
Q_{MSY} (85)	159	264	224	203	197 (,173)
$Q_{0,1}$ (85)	111	159	170	193	182 (,140)
$Q_{0,1}$ (86)	110	159	171	206	191 (,125)
σ	1,40	1,10	1,00	0,940	0,940 *

Table 10.6: Parameters of Shepherd model fits (using the square root minimisation procedure) to hake catch-effort data for Division 1.5 . All biomass-type parameters are in '000 tonnes.

DIVISION 1.6 DATA PERIOD: 1955-1984					
p value	p=0,3	p=0,5	p=1,0	p=2,0	p=,418 (,507) (best fit)
r	(50,0)	2,18	0,516	0,388	19,6 (,715)
$q \times 10^{-3}$	7,15	10,4	12,1	15,4	10,1 (,163)
K	2612	2001	1715	1283	2054 (,113)
E_{MSY}	17,8	19,2	16,1	15,3	20,4 (,097)
$E_{0,1}$	12,3	13,2	13,0	13,7	13,3 (,047)
y^*/K	0,306	0,340	0,356	0,388	0,337 (,081)
y^*/y_{MSY}	1,00	1,14	0,943	0,831	1,21 (,120)
y_{MSY}/K	0,306	0,298	0,378	0,468	0,279 (,127)
y(mid-84)	791	663	590	474	676 (,103)
$y_{0,1}$	1100	830	783	663	836 (,097)
MSY	101	119	126	142	118 (,057)
C_{s-s} (85)	101	118	126	137	117 (,054)
C_{MSY} (85)	100	132	115	112	139 (,137)
$C_{0,1}$ (85)	69,7	90,5	92,6	100	90,3 (,114)
$C_{0,1}$ (86)	71,8	94,8	98,5	109	94,3 (,115)
σ	0,794	0,677	0,706	0,822	0,687 *

Table 10.7: Parameters of Shepherd model fits (using the square root minimisation procedure) to hake catch-effort data for Division 1.6 . All biomass-type parameters are in '000 tonnes.

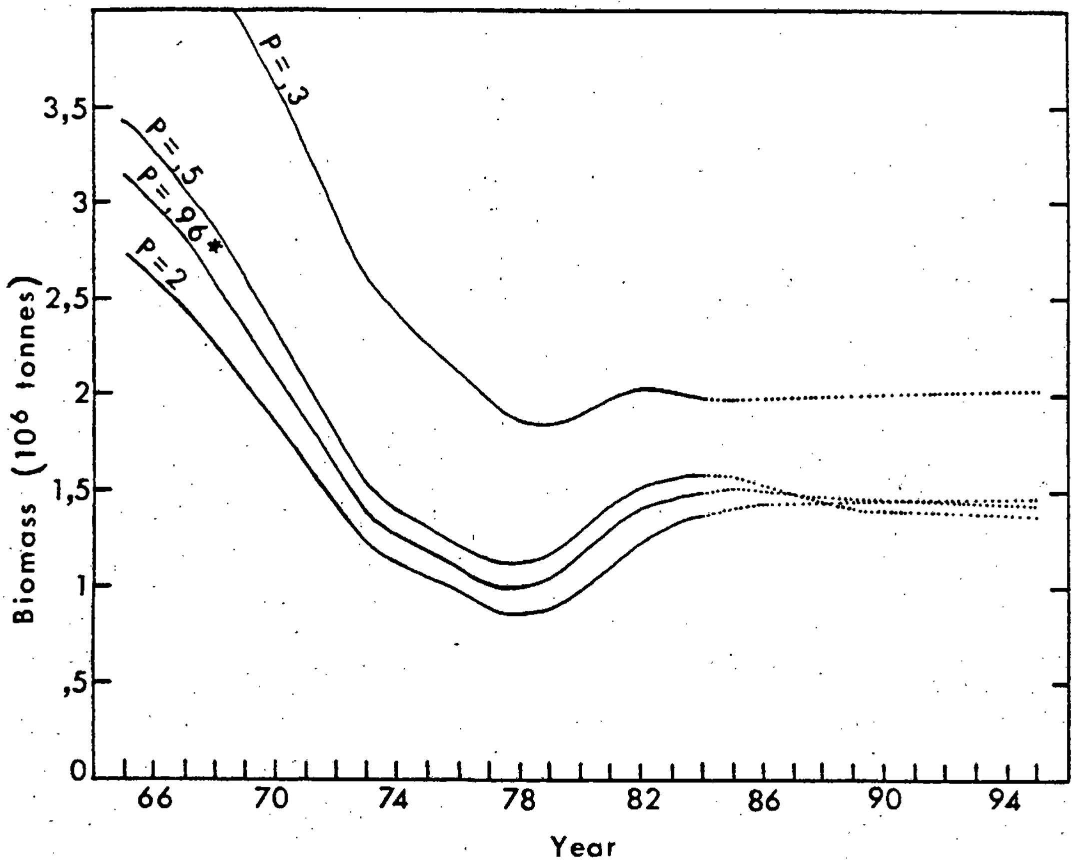


Figure 10.11: Divisions 1.3 + 1.4

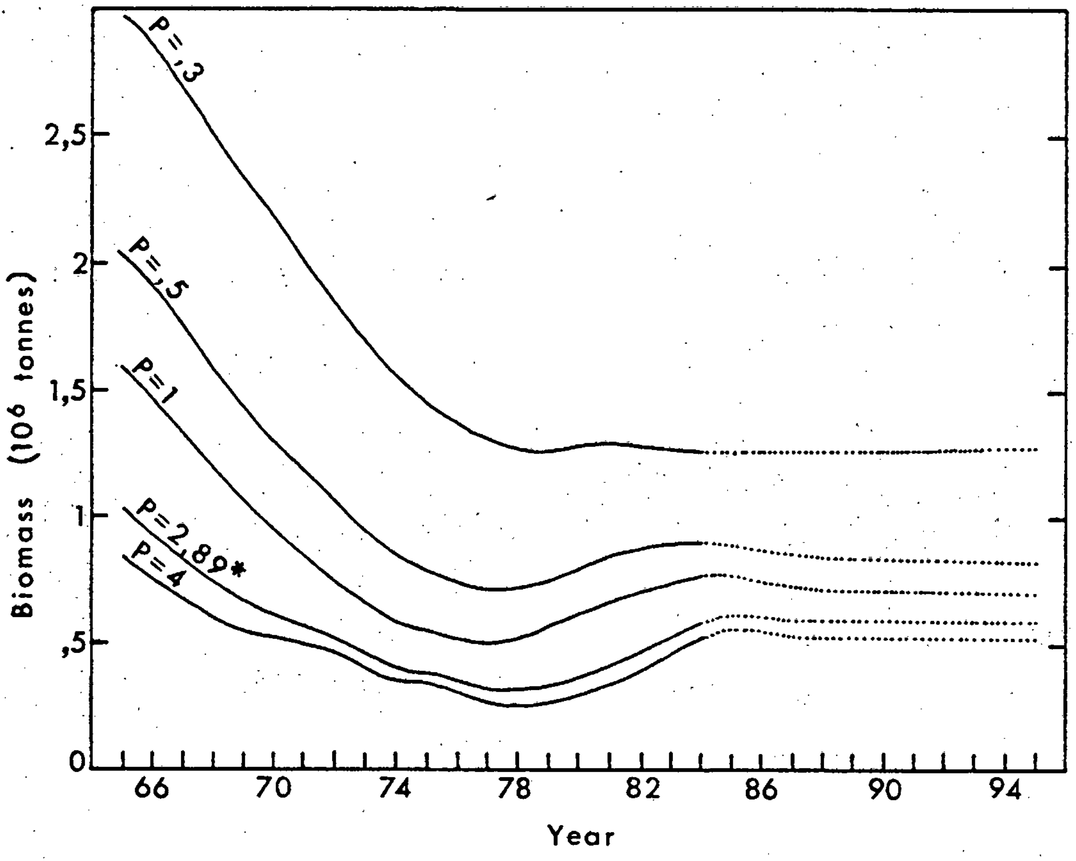


Figure 10.12: Division 1.5

Figures 10.11 - 10.12: Shepherd model biomass trend estimates (full line) and projections under a $F_{0,1}$ harvesting strategy (dotted lines) for various fixed values of the Shepherd model parameter p.

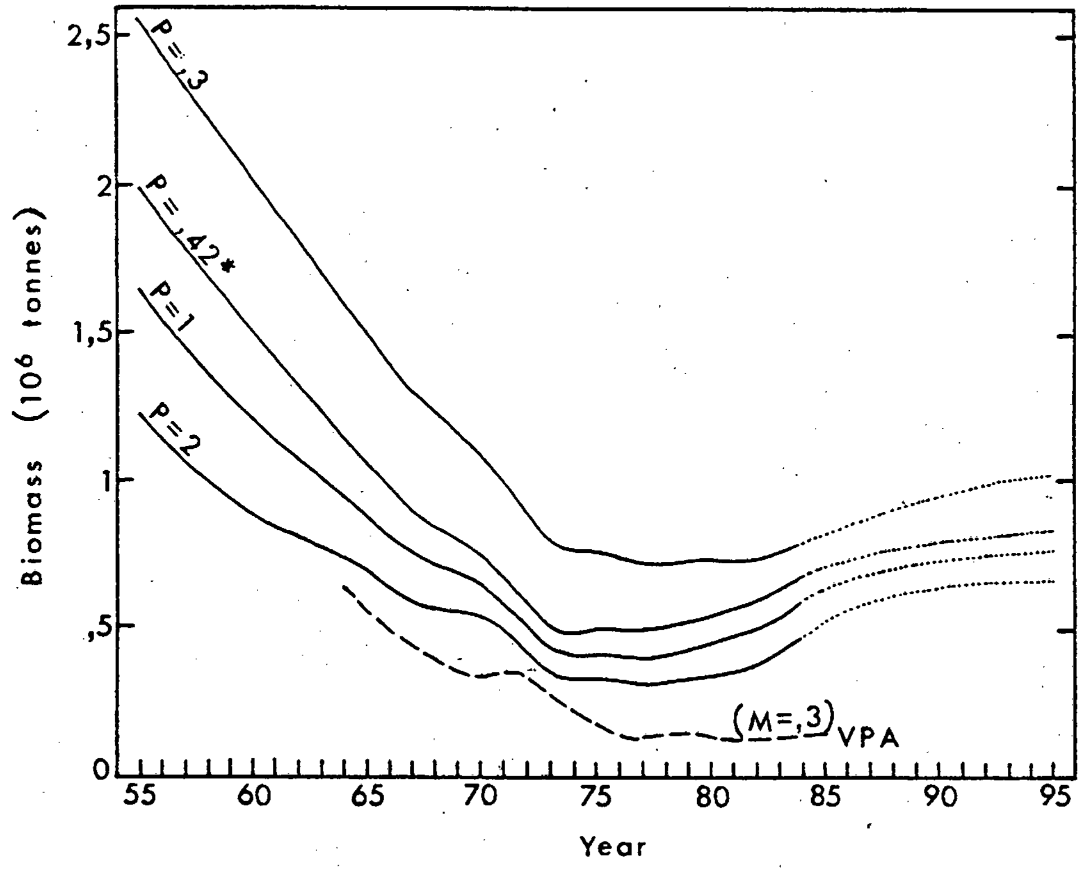


Figure 10.13: Division 1.6

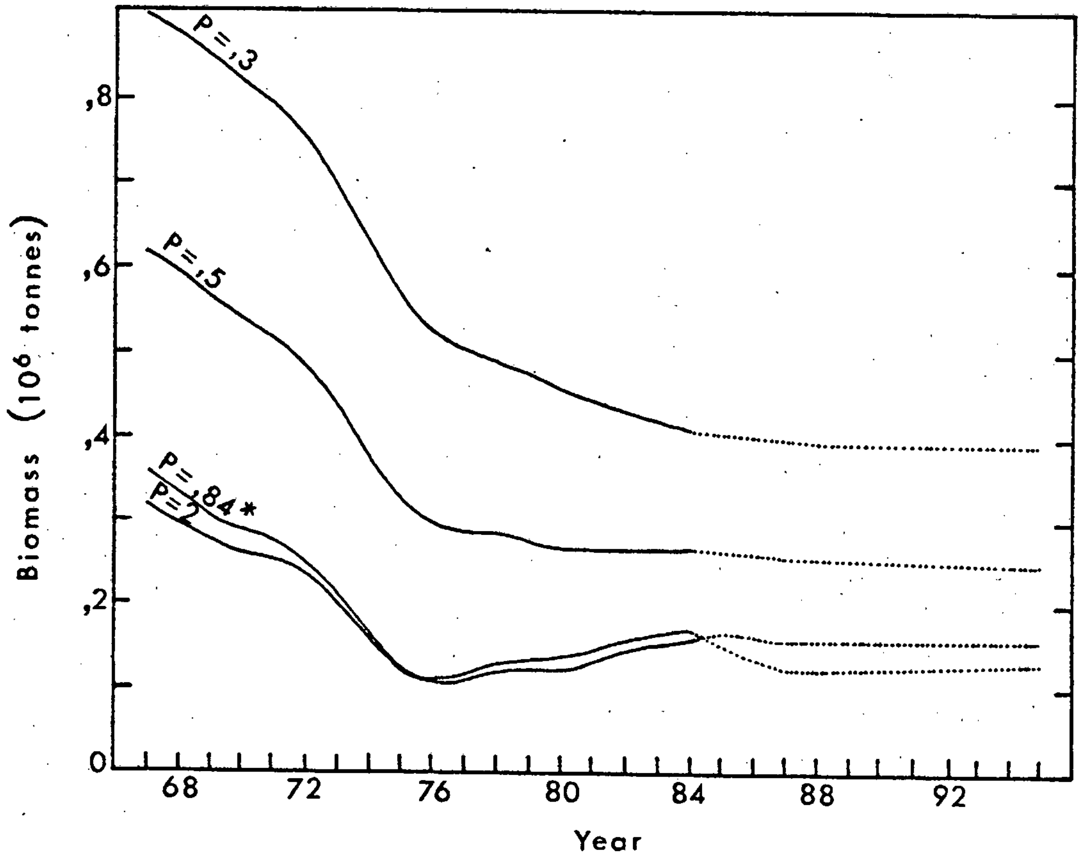


Figure 10.14: Divisions 2.1 + 2.2

Figures 10.13 - 10.14: Shepherd model biomass trend estimates (full line) and projections under a $F_{0,1}$ harvesting strategy (dotted lines) for various fixed values of the Shepherd model parameter p.

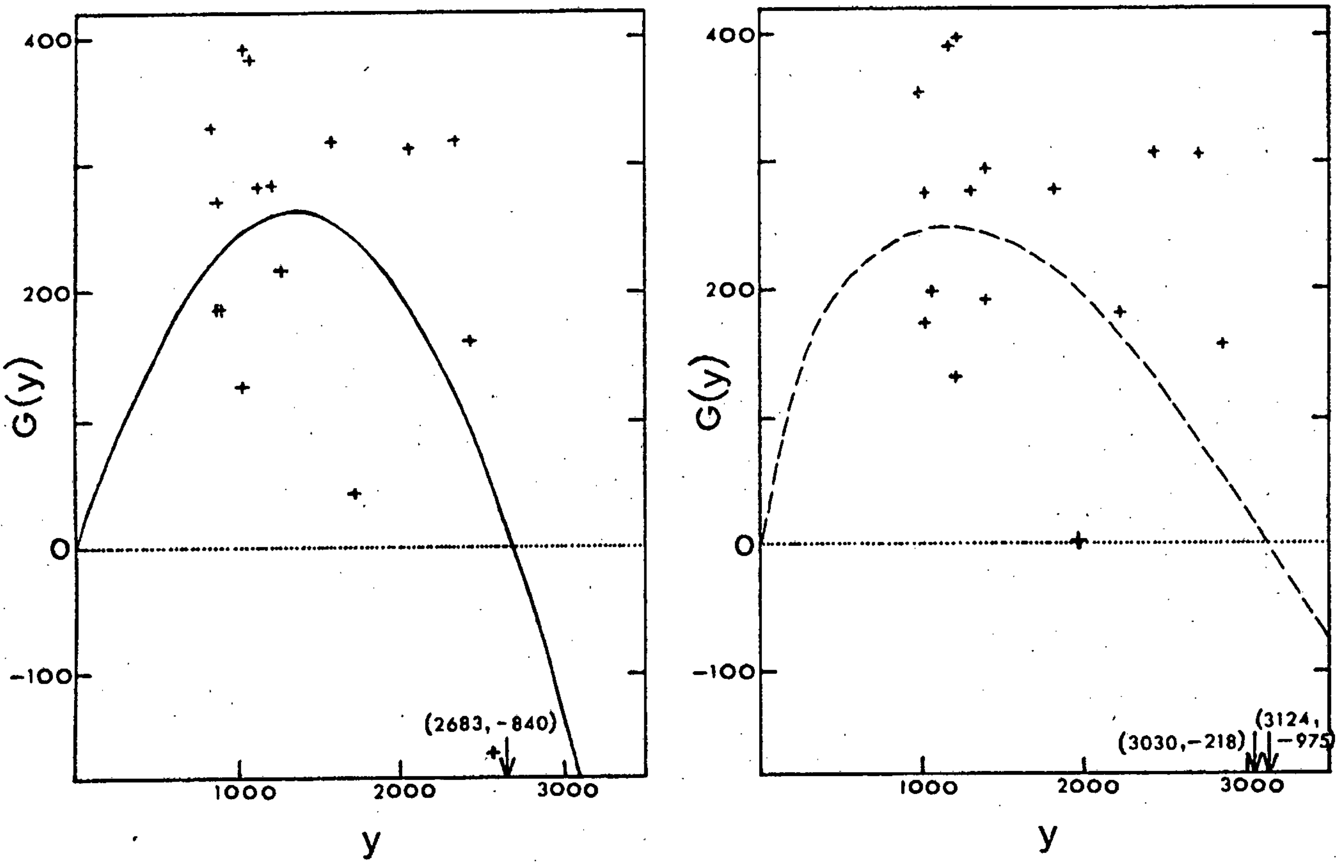


Figure 10.15a: Schaefer

Figure 10.15b: Fox

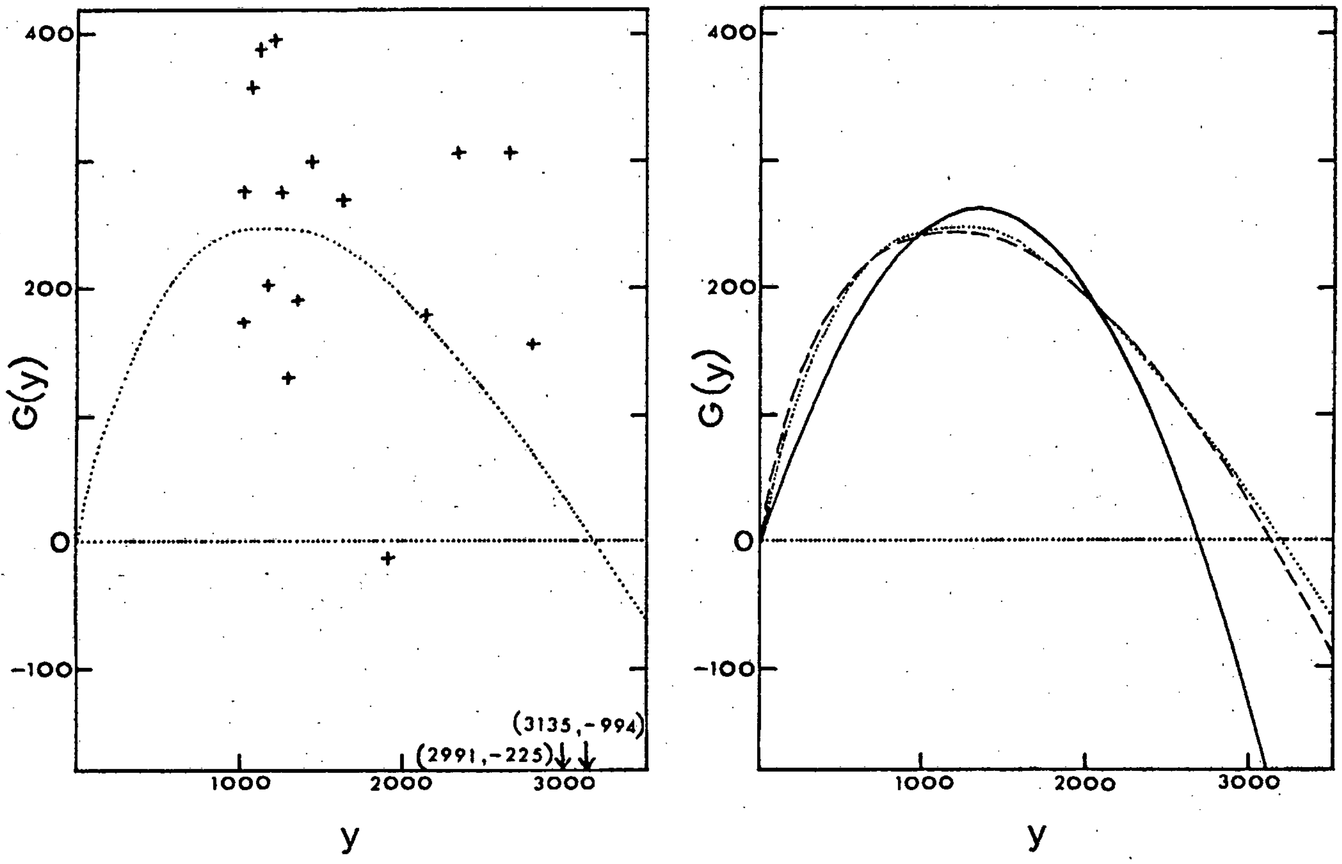


Figure 10.15c: Shepherd

Figure 10.15d: Comparison of the three models

Figs 10.15a-d: Divs 1.3 + 1.4 . All units are '000 tonnes

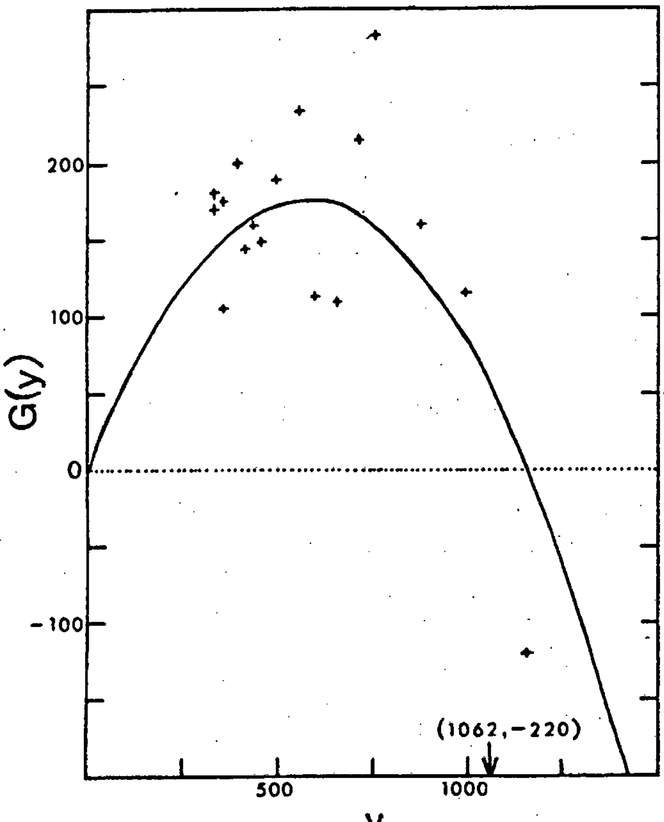


Figure 10.16a: Schaefer

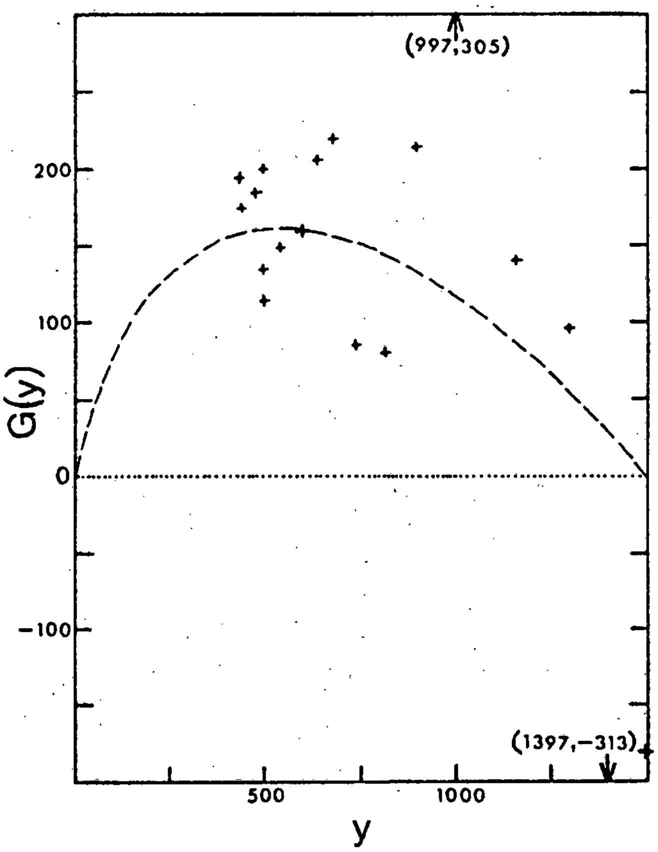


Figure 10.16b: Fox

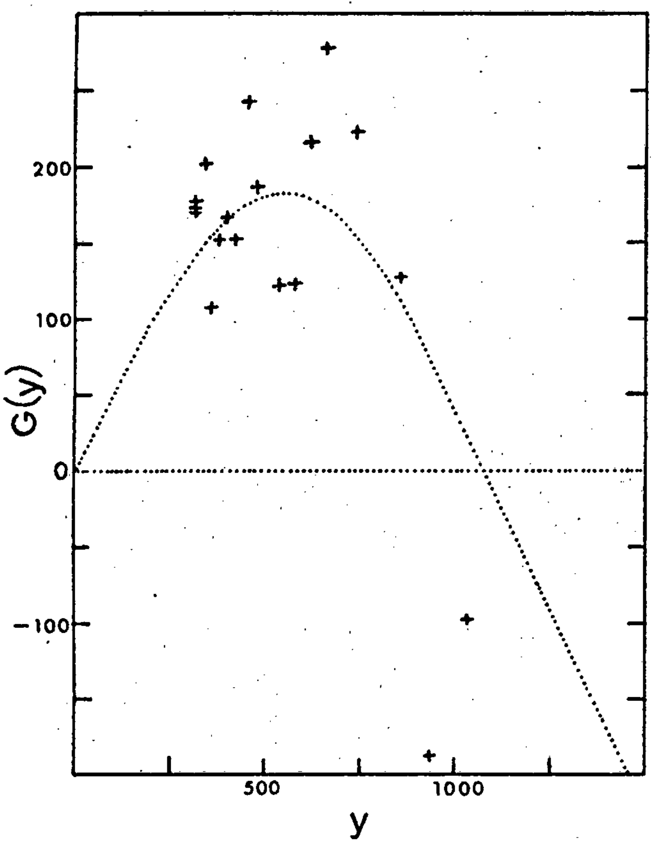


Figure 10.16c: Shepherd

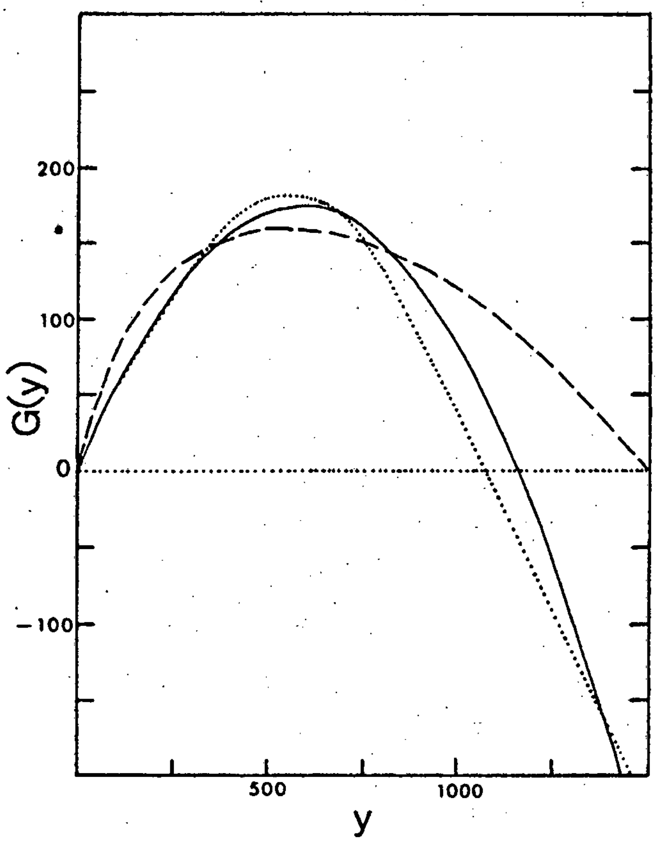


Figure 10.16d: Comparison of the three models

Figs 10.16a-d : Division 1.5 . All units are '000 tonnes

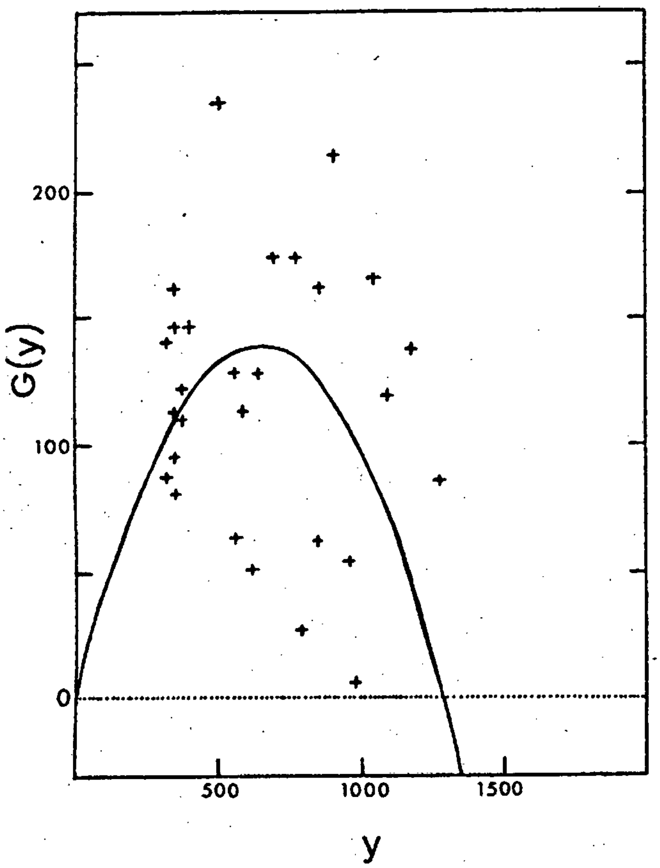


Figure 10.17a: Schaefer

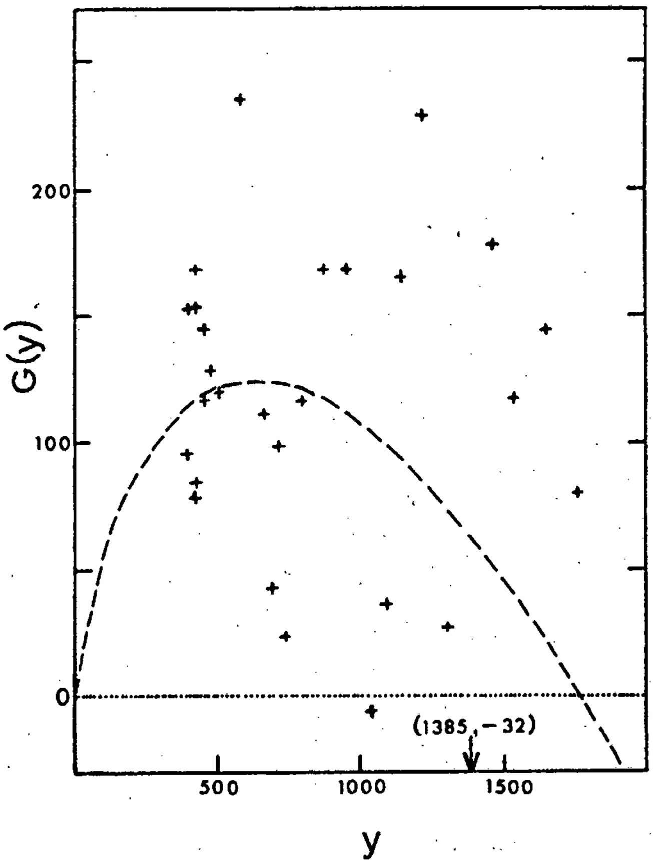


Figure 10.17b: Fox

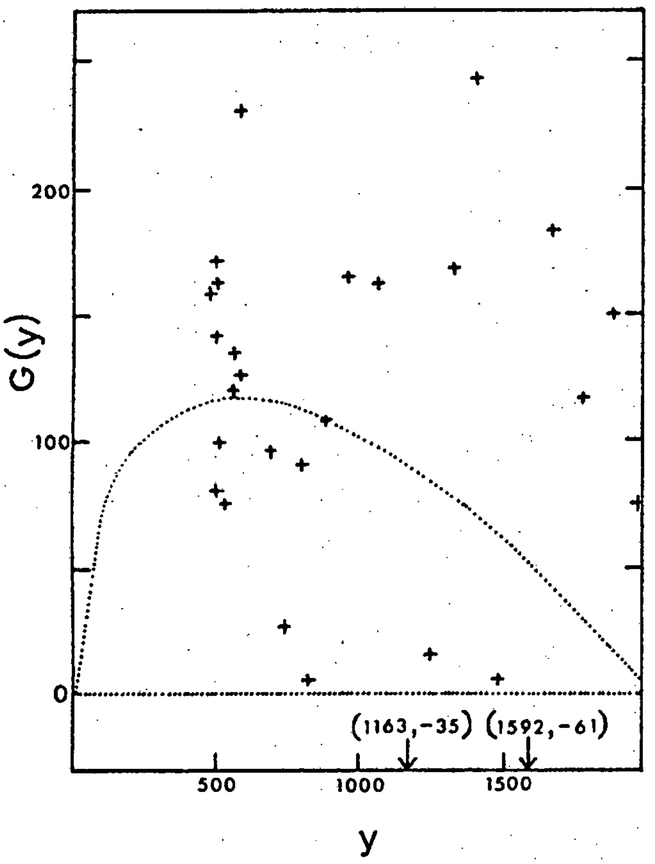


Figure 10.17c: Shepherd

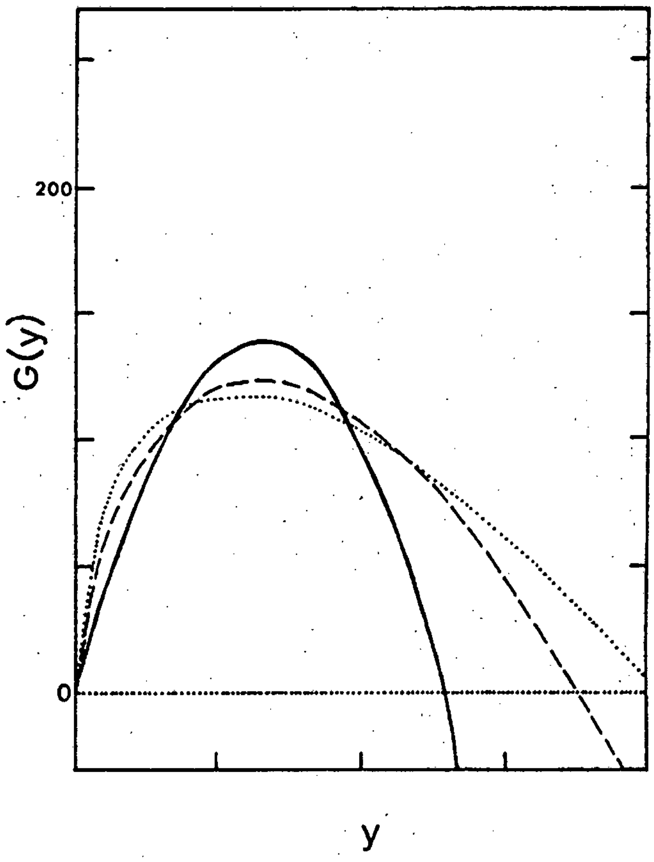


Figure 10.17d: Comparison of the three models

Figs 10.17a-d: Division 1.6 . All units are '000 tonnes

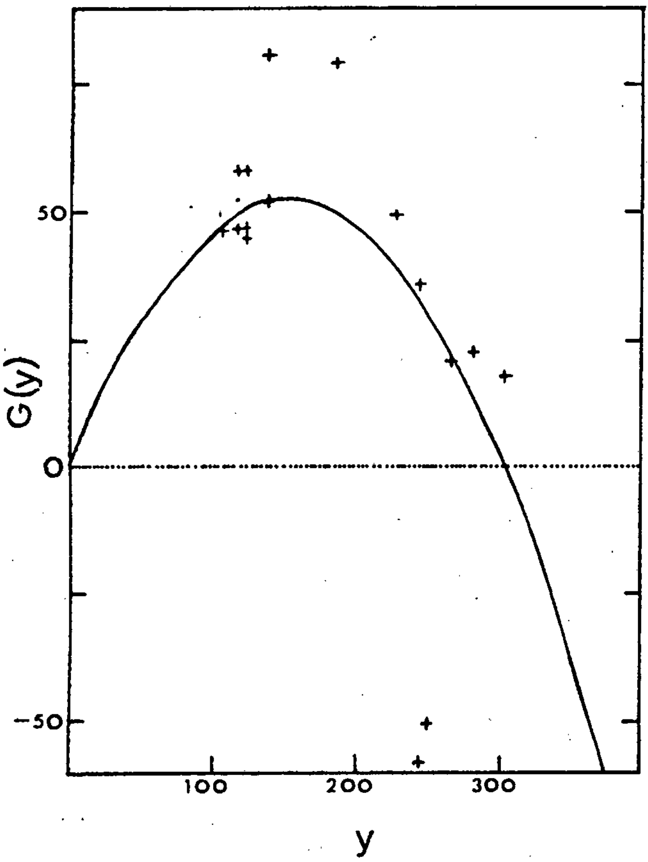


Figure 10.18a: Schaefer

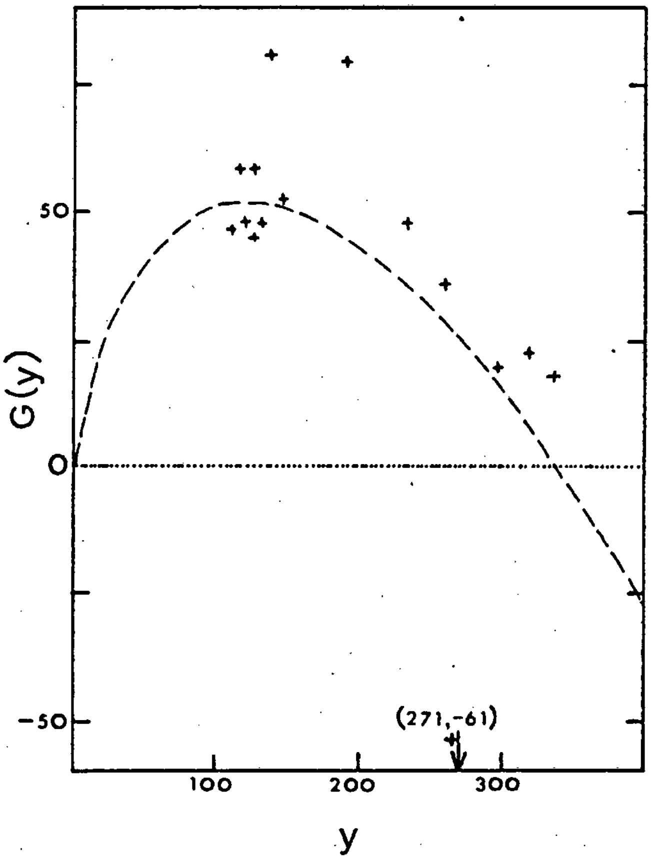


Figure 10.18b: Fox

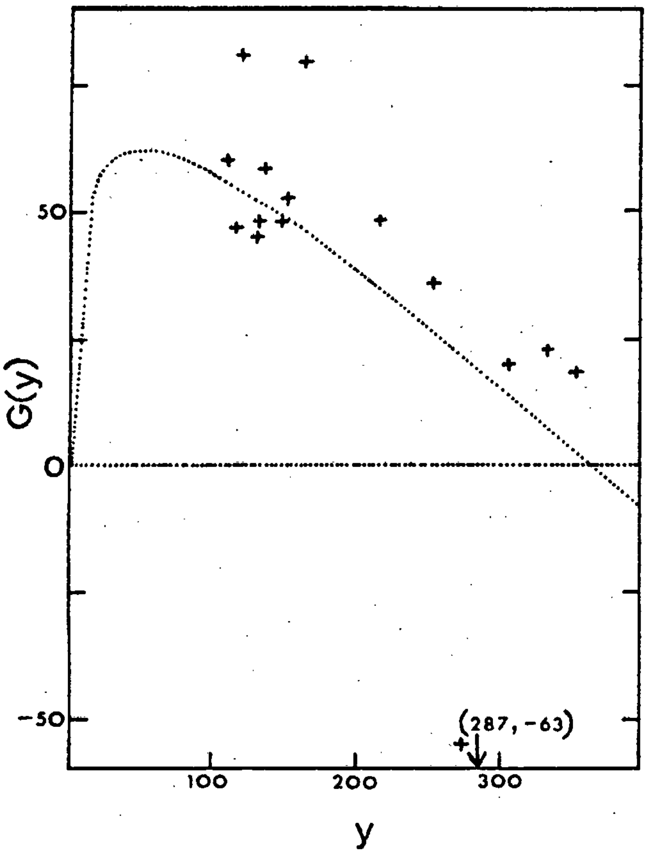


Figure 10.18c: Shepherd

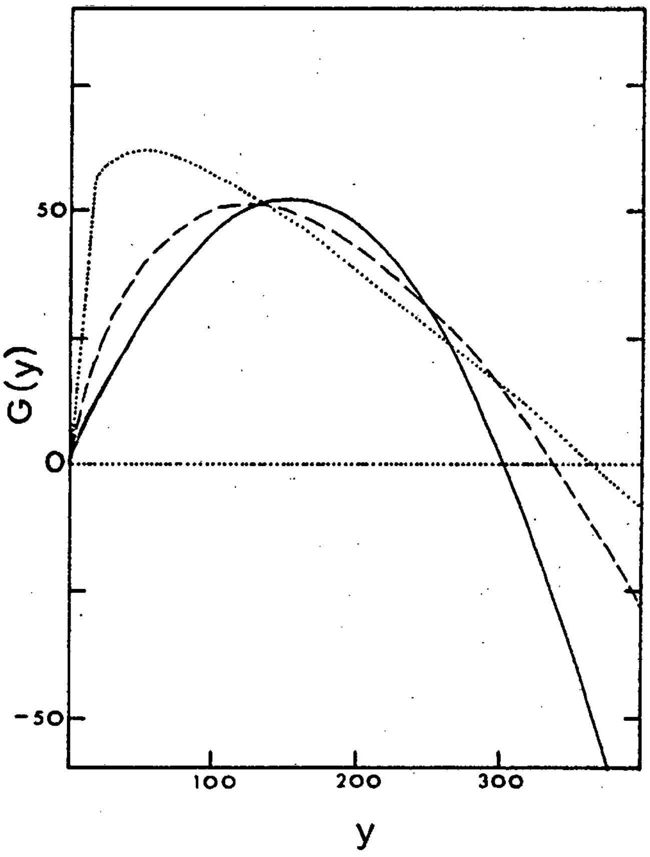


Figure 10.18d: Comparison of the three models

Figs 10.18a-d: Divs 2.1 + 2.2 . All units are '000 tonnes

10.7 Conclusion

The Shepherd model and extensions to the Schaefer and Fox dynamic models were introduced in an attempt to resolve the difference between dynamic model and VPA biomass estimates. Although, theoretically, the effects discussed in Sections 10.2 to 10.5 could be quantitatively estimated using the dynamic model minimization procedure, in practice, this is unlikely to prove a useful exercise. The seemingly insignificant results obtained could be attributed to the fact that the original three-parameter version of the dynamic model had relatively good fits, but once further parameters are introduced, the sum of squares surface becomes very flat in the vicinity of the minimum. This suggests that this model nearly fully exploits the information content of the catch and effort data.

In all cases the modified models showed no obvious improvement in agreement with VPA biomass estimates or superiority over the original models. Even the Shepherd dynamic model with variable p did not yield a substantial decrease in the sum of squares minima when compared to those of the Schaefer and Fox forms.

It therefore appears that further extensions or different parametrizations of the dynamic model may not lead to a significant improvement in results. However, a minimization procedure incorporating additional independent information in its criteria (for example, agreement with VPA trends) could provide insight concerning these extra features.

The opinion of some local researchers now (M. Bergh, D. Butterworth, pers. commn) is that the inconsistency between the VPA and dynamic model biomass estimates probably reflects more that there are problems with the VPA assessments rather than biases due to the simplistic nature of the production models. There are two main problem areas with VPA assessments. The first is the discarding of small fish. Total catch values have accounted for this to some extent, but discard patterns have varied over time so that the available catch-at-age statistics may not be representative. Secondly, cannnibalism acts in a density-dependent way, decreasing when the stock is fished down and increasing in periods of greater stock size. Hence, higher M values in earlier years would reflect larger biomasses than indicated by VPA and a correspondingly better agreement with production model results.

Appendix 10.1

Insensitivity of Shepherd surplus production function to value of r when r>>M

Consider the case where $0 < p < 1$ and the surplus production function is given by:

$$G(y) = \left[(M+r).y \ / \ [1+(r/M).(y/K)^{p}]\right] - M.y.$$

Assuming $r >> M$, then $(r/M).(y/K)^{p} >> 1$ unless y/K is very small. It follows that

$$G(y) \rightarrow \left[r.y \ / \ [(r/M).(y/K)^{p}]\right] - M.y \qquad (A10.1.1)$$

This can be simplified to $G(y) \rightarrow M.y\,[(y/K)^{-p} - 1]$ which is independent of the value of r.

[It should be noted that this form is very similar to the form adopted by the Pella-Tomlinson equation when the p (Pella-Tomlinson) is approximately equal to -p (Shepherd) and lies in the range [-1 ; 0]. In this limit, $y_{MSY}/K = [1-p]^{\frac{1}{p}}$ (Shepherd p), which is the reason why Tables 10.5 - 10.8 show near identical values of y_{MSY}/K for low p values with r approximately or set equal to 50 .]

It can be concluded from equation (A10.2.1) that changes in large values of r will have little effect on the general surplus production function.

Appendix 10.2

A description of the approach used for the graphical comparison of the best fits to the Schaefer, Fox and Shepherd models

The model used in this thesis is $y_{i+1} = y_i + G(y_i) - C_i$

where $G(y_i)$ has one of the following forms:

(a) Schaefer: $G(y_i) = r.y_i.(1 - y_i/K)$ (A10.2.1)

(b) Fox: $G(y_i) = r.y_i.(1 - \ln(y_i)/\ln(K))$ (A10.2.2)

(c) Shepherd: $G(y_i) = (M+r).y_i/[1+(r/M).(y/K)^p] - M.y$ (A10.2.3)

Using the dynamic formulations given in sections 5 and 10, best fits of the parameters (r, K, q and p) were calculated. These are given in Tables 8.1 - 8.8 and 10.5 - 10.8 . It was assumed there that the model was a precise fit and that any error was in the observed catch rates. Note that for these fits the expected catch rate is given by

$$(\hat{C/E})_i = q.(y_i + y_{i+1})/2 \qquad \text{(A10.2.4)}$$

An alternative approach is to assume that the observed $(C/E)_i$ is an exact index of y_i and that any error represents only and entirely fluctuation in $G(y_i)$ as given in equations (A10.2.1) to (A10.2.3) [see Note (1)].

To compare the Schaefer, Fox and Shepherd fits to the data, plots of surplus production, $G(y_i)$, as a function of biomass, y_i, were used.

The 'observed' $G(y_i)$ values were calculated using the formula given below:

$$G^{obs}(y_i) = y_{i+1} - y_i + C_i$$

where $y_{i+1} = [(C/E)_{i+1} + (C/E)_{i+2}]/(2q)$ (see Note (2))

(the q values used were those obtained from the previous fits to the Schaefer, Fox and Shepherd forms).

It follows that $G^{obs}(y_i) = [(C/E)_{i+2} - (C/E)_i]/(2q) + C_i$.

The 'expected' $G(y_i)$ values were calculated from equations (A10.2.1), (A10.2.2) and (A10.2.3) using the parameters (r, K and p) obtained by the best fit to the data.

Note (1) Ideally, the minimization program should have been rerun, taking this change into account by postulating a plausible distribution for the difference between $G^{obs}(y_i)$ and $G(y_i)$. However, since this will have a minor effect on numerical values, it has been ignored for the purposes of this thesis.

Note (2) This equation is not identical to the one used previously for relating catch rate and biomass (equation (A10.2.4)), but for practical purposes it can be assumed equivalent.

11 FURTHER CONSIDERATIONS

11.1 Introduction

There is considerable potential to extend the dynamic catch-effort models. This chapter reviews some of the possibilities. In cases where such analyses have already been carried out and reported elsewhere, the approaches employed and results obtained are described briefly. In other cases questions related to the fishery are posed and approaches that could be used to answer them suggested.

First economic aspects are discussed. Results in Chapter 8 indicate that following the mid-seventies slump, biomasses of the hake resources have increased and are near to reaching or have already reached $y_{0,1}$ equilibrium levels. It therefore appears that management's initial conservation objective has essentially been reached and it is now appropriate to consider whether the $f_{0,1}$ strategy is economically optimal. Consequently, an alternative approach using Clark's bioeconomic model to find the optimal harvesting policy as a function of the discount rate and price/cost ratio is described.

In this context, the shape of the surplus growth function near to y_{MSY} is particularly important. Graphs in Section 10.6 highlighted the need for a reassessment of various forms of the surplus growth function. Here, the appropriateness of more flat-topped curves than the Schaefer and Fox is considered.

The dynamic models used previously have been based on the assumption of constant catchability. Management imposed increased minimum mesh sizes on the hake fisheries in the mid 1970s in an attempt to improve catch rates and yields in the longer term. Such a change would be expected to change both catchability and the growth parameter r. An examination to test for the efficacy of this change in mesh size using the dynamic model is proposed.

In Chapter 9 large differences in dynamic model and VPA estimated biomass values and trends for Division 1.6 were evident. An adjusted dynamic model calculational procedure in which catch estimates are discounted is proposed. Such a discount factor would allow for the effects of growth and natural mortality that would have adjusted the biomass of fish caught had they not been removed from the stock, thereby possibly reducing discrepancies between VPA and dynamic model estimates. The impact of cannibalism on such analyses is also discussed.

Further considerations also include more appropriate weighting procedures for catch-effort model fits and an analysis of vessel power factors.

11.2 Economic considerations

Up to this point, management recommendations have been based predominantly on what is 'preferable' in a biological sense (that is, MSY or slight variants thereof). However, such recommendations may not necessarily be economically 'preferable' for the industry as a whole.

The $y^*/y_{0,1}$ estimates obtained for the four hake stocks under consideration are summarized in the following table (y^* refers to the estimated biomass at the start of 1985):

DIVISION	$y^*/y_{0,1}$	
	Schaefer	Fox
1.3 + 1.4	0,94	1,06
1.5	1,01	1,08
1.6	0,71	0,77
2.1 + 2.2	1,00	1,09

These results indicate that most stocks are close to attaining their equilibrium level under a $f_{0,1}$ strategy if they have not already done so. It therefore appears that management's initial conservation objective has virtually been achieved. The following question now arises: to what extent should the loss of catch (lower sustainable yields) at greater biomass levels be traded for higher catch rates? This goes beyond the purely biological regime and requires that economic factors also be considered.

The $f_{0,1}$ strategy is at best making an ad hoc allowance for this effect in the context of Gordon's static bioeconomic model (as well as keeping stock size above MSY level as a buffer against fluctuations). Therefore an examination of the appropriateness of the $f_{0,1}$ strategy and other management strategies now becomes of importance. Such an analysis has been published by Butterworth, Bergh and Andrew (1986b); the main points are summarized briefly below.

Clark (1976) extended Gordon's (1954) approach to cater for dynamic effects. The particular and important feature of his model was the incorporation of a discount factor to allow more appropriate comparison of the values of current and future economic returns.

Clark's solution for a differential equation surplus production model is readily adapted to the discrete formulation of the dynamic model given in Section 5.2. The biomass $(\tilde{y})$ at which the present value of future economic rent is maximized (the optimality criterion used) is given by the solution of the following equation:

$$\Delta = G'(\tilde{y}) + [\, G(\tilde{y})/\tilde{y} \,] \,/\, [\, q.\tilde{y}.p/c - 1 \,]$$

or

$$p/c = \left[\, 1 + \{[\, G(\tilde{y})/\tilde{y} \,] \,/\, [\, \Delta - G'(\tilde{y}) \,]\} \,\right] / \,(\, q.\tilde{y} \,) \tag{11.1}$$

where p = price of unit mass of fish harvested

c = cost of unit of effort used in harvesting

and Δ = annual discount rate.

For the Schaefer model $G(y) = r.y.(1-y/K)$ and therefore

$$p/c = \left[\, 1 + \{r(1 - \tilde{y}/K)/[\Delta - r(1-2\tilde{y}/K)]\} \,\right] / \,(q.\tilde{y}) \tag{11.2}$$

Under the $f_{0,1}$ harvest strategy concept, in the case of the Schaefer model,

$$y_{0,1} = 1,1\ K / 2$$

(see Appendix 6.2).

Therefore if the $f_{0,1}$ policy equilibrium biomass level $(y_{0,1})$ corresponds to the bioeconomic optimum in terms of Clark's model (that is, $y_{0,1} = \tilde{y}$) then

$$p/c = [1 + 0,9 \,/\, \{2(\Delta/r + 0,1)\}] \,/\, [q.K\ (1,1)/2] \tag{11.3}$$

Similar calculations to find the optimal harvesting policy as a function of the discount rate and price/cost ratio can be performed for the Fox model.

Immediate questions arise from the above equations. For example, what are appropriate values for p and c and what discount rate range is economically/politically desirable or acceptable? Little data on such economic factors are available, and investigation to determine them seems desirable. Butterworth, Bergh and Andrew (1986b) quote illustrative results assuming Δ = 5% and basing a p/c estimate on the assumption of zero profitability of the fishery at the lowest recorded catch rate. These suggest harvesting strategies in the range $f_{0,15}$ to $f_{0,33}$ might be more appropriate than the $f_{0,1}$ procedure.

A further important question is: how sensitive are the results obtained using the above analysis to CPUE trend fits by production models other than the Schaefer model, which have y_{MSY}/K not equal to 0,5 ? This could be investigated using the Shepherd model introduced in Chapter 10.

11.3 Further aspects of the shape of the surplus production function

Results in Chapters 8 and 10 suggest that the general scale of the surplus production function (indexed by, for example, the MSY estimate) is quite precisely determined by the dynamic catch-effort models. Coefficient of variation values for hake MSY estimates for the four divisions range over 4 - 7%. However, plots of the surplus production, G(y), against biomass (y) data (see Figures 10.15 to 10.18) indicate that the shape of the surplus production function is very imprecisely determined by the available data and may be more flat-topped than the Schaefer and Fox forms used. This aspect is particularly relevant when considering whether allowing biomass (and catch rate) to increase will result in drops in sustainable yield as large as that suggested by the traditional Schaefer and Fox models. This in turn will have important implications for the choice of bioeconomically optimal strategies.

To investigate this aspect, the following alternative form of the surplus production function was considered in Butterworth, Bergh and Andrew (1986b):

$$G(y) = \frac{r.K}{2\mu}\left[1 - \left[1 - \frac{2y}{K}\right]^{\mu}\right] \qquad (\mu > 0) \qquad (11.4)$$

[This form has $y_{MSY} = K/2$ whatever the value of μ . The Schaefer model is a special case of this form with $\mu = 2$. Values of $\mu > 2$ give curves more flat-topped than the Schaefer model.]

Results of fits of the dynamic catch-effort model using the above surplus production function (and various values of μ) to revised catch-effort data series (differing marginally from the data sets given in Tables 3.1 to 3.4) are given in Butterworth, Bergh and Andrew (1986b). The results for the four divisions were ambivalent with two values of $\mu > 2$ and two of $\mu < 2$ being obtained. In all cases the sum of squares of residuals (or alternatively σ) values appear to be relatively insensitive to the value of μ and large 95% confidence intervals were obtained. Only in Division 1.6 was the value of μ significantly greater than 2 at the 5% level.

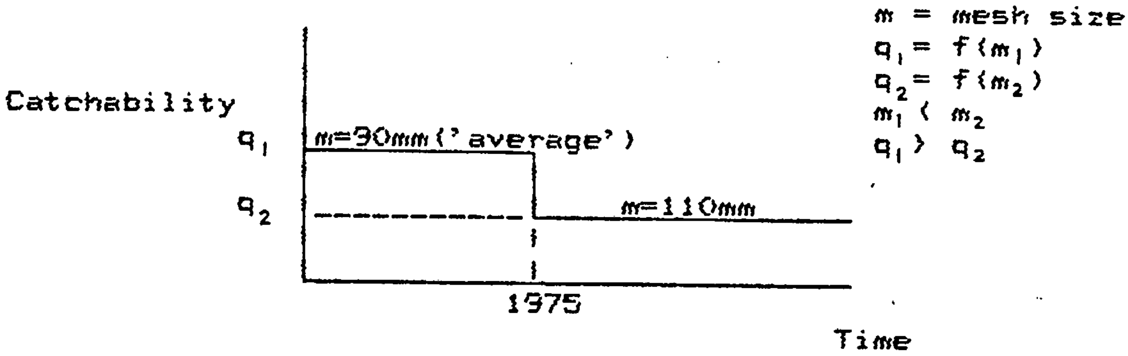
11.4 The effect of changes in catchability in the catching operation

Catchability is the fishing mortality on a stock generated by a unit of fishing effort. This has been denoted by q in the equation $F = q.E$. Dynamic model calculations (in previous chapters) have been based on the assumption of constant catchability over time. However, it is known that catchability is dependent on many variables (such as seasonal, physiological or behavioural changes or changes in the type or deployment of fishing gear).

For example, it would be expected that the catchability coefficient would have been greater in the initial stages of the fishery when the areas of local high density were the first to be exploited and reduced. This could account for the high CPUE values recorded in the early stages of exploitation which both the steady-state and dynamic models have problems fitting (see Figures 8.1 - 8.8). In addition, catch-at-age figures indicate an increase in the proportion of younger fish in catches in recent years which may also affect catchability/efficiency.

It has already been mentioned that catchability is likely to be a function of mesh size. During the years 1964 to 1973 fishing for hake in the divisions under consideration was conducted mainly by Japanese, South African, Spanish and Soviet trawlers. These vessels used nets with mesh sizes ranging from 70 to 120 mm, and therefore many problems arise when attempting to generalize on the effective mesh size of the whole fleet over this period (Newman _et al_., 1976c). However, it is known that from 1933 the South African fleet was restricted by local authorities to the use of a 102 mm mesh net (Newman, 1977). Mesh selection studies based on yield per recruit analyses (ICSEAF Report of the Second Regular Session, 1974) indicated that if all vessels adopted a minimum mesh size of 110 mm in place of 90 mm, long term increases in catch of the order of 5 - 13% could be obtained. This led to the introduction of mesh restrictions on 1 July 1975 to the entire international fishery when a minimum mesh size of 110 mm was implemented by ICSEAF (Newman, op. cit.).

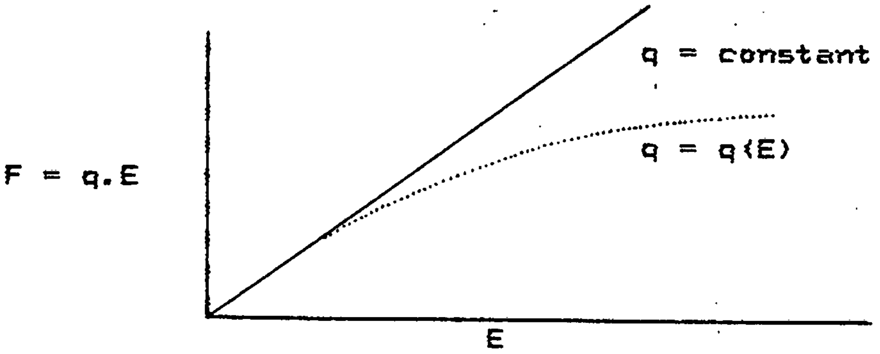
The following figure illustrates how catchability might be expected to have changed with the introduction of the 110 mm minimum mesh size regulation in 1975. In addition, the growth rate parameter r might be expected to increase to reflect the increased yield/recruit indicated for the larger mesh.



Analyses on a basis similar to those carried out in Chapter 10 could be undertaken to examine whether the catch-effort data reveal any significant change in q or r in 1975.

In addition, the effects of saturation (which could effectively lead to q being a function of E) should be considered. As the net fills, the meshes become blocked and the catchability of the fish trapped within the net increases. Accordingly, if there has been a trend towards haul times of increasing length, catchability could increase (and vice versa). Further, if such trends in haul times correlated (positively) with trends in total effort, q could be either an increasing or decreasing function of E. In other words, the relation between F and E could be respectively convex or concave.

On the other hand, as effort increases, the number of vessels in the fishery usually also grows and the chances of one vessel trawling over grounds covered by another shortly beforehand becomes greater. As the average time between hauls over the same ground decreases, the probability that the fish redistribute themselves by diffusion/migration (thus equalizing density over the whole area) drops. Hence the effective catchability for the second vessel will be less as it is trawling over a lower density than the first. This effect would result in q being a declining function of E as is illustrated below.



Addition of a further parameter to the model to represent such an effect, and determination of confidence limits for the estimate of that parameter, could be used to ascertain whether there is significant evidence for such effects playing a role.

11.5 The incorporation of a catch discount factor in dynamic model calculations

In Chapter 9 it was shown that VPA estimates for biomasses and biomass trends for Division 1.6 were smaller and more time delayed than corresponding estimates obtained using the dynamic models.

If annual catch values (Tables 3.1 - 3.4) used in the dynamic model fits were discounted as follows:

$$C \rightarrow \omega.C$$

that is, $y_{i+1} = y_i + G(y_i) - \omega.C_i$, (11.5)

then biomass estimates from the dynamic model fits would all be adjusted by the discount factor ω ($y_i \rightarrow \omega.y_i$). For $\omega < 1$, better agreement with the VPA biomass estimates might result.

There is a biological justification for such a discount factor which to a certain extent accounts for the combined effects of growth and natural mortality (mainly due to cannibalism); these would have adjusted the biomass of the fish caught between the time of capture and the end of the year had they not been removed from the population. Such a factor ω can be calculated for each year from age composition data (such as that given in Table 9.1) and weight-at-age relationships. From these ω values, an average ω value can then be obtained for the whole period. [Note that if values of ω greater than unity are obtained, biomass estimates from the dynamic model would be increased, augmenting rather than reducing the discrepancy with the VPA estimates.]

Using this approach, Butterworth and Andrew (1984) quote values of $\omega = 1,09$ for $M = 0,3$ yr^{-1} and $\omega = 1,04$ for $M = 0,4$ yr^{-1}. So in this case, introduction of this factor does not help remove the discrepancy in biomass estimates. However cannibalism is known to be an important natural mortality factor for the younger age classes, and indications are that M may be much higher than the values assumed above for younger hake (Lleonart, Salat and MacPherson, 1985). This would affect both ω as calculated above and VPA biomass estimates, so that not too much should be read into the difference in biomass estimates provided by VPA and dynamic catch-effort model approaches, at least until the influence of cannibalism on each has been assessed.

11.6 Weighting factors in criteria for fitting dynamic catch-effort models

The objective function minimized in fitting dynamic catch-effort models to hake catch and CPUE data is given in equation (5.9).

In fitting the models, C_i and E_i were (for simplicity and comparability with other analyses presented at ICSEAF) taken to be the total catch and calculated total effort for the division concerned. However, as is mentioned in Chapter 3, catch rate statistics from which effort values are calculated are usually based on information from only one of the national fleets participating in the fishery in that division.

A more appropriate weighting procedure statistically would be to use for E_i only the effort of the vessels providing the observed CPUE data, rather than the total effort calculated to have been used by all nations in making the total catch. In other words, C_i should refer to the catch of the nation whose CPUE data series is being used, rather than the total catch. This would make no difference to results if the nation whose catch rate data series is being employed had maintained a constant proportion of the total catch over the history of the fishery; however Butterworth, Bergh and Andrew (1986b) show that this proportion is often quite variable.

11.7 Power factor analyses

Fishing power, as defined in Chapter 3, is dependent on many factors such as the tonnage or horsepower of the vessel concerned. The quantification of such factors is not a simple process, but is absolutely necessary if precise effort estimates are to be obtained. At present, Spanish and South African effort data used have been standardized to OTB-7 and OTB-5 vessel units respectively. However, the power factors used to convert vessels from other classes to these categories have been estimated only very crudely (see Chapter 3). A detailed analysis of variance examination of catch rates as a function of vessel characteristics (such as tonnage, age of vessel and horsepower) to extract power factors for these fleets is an urgent necessity.

11.8 Conclusion

Of the various aspects suggested for further investigation, the most urgent would seem to be an examination of power factors. The interpretation of the current status of these fisheries as essentially recovered to equilibrium $y_{0,1}$ levels is crucially dependent on the recently increasing CPUE trends; these could be artefacts of inappropriate allowance for power factors as fleet composition has changed. As shown in Section 10.4, this aspect can affect the calculations for current appropriate catch levels quite markedly (see Figure 10.10). It would seem sensible to finalize any adaptions to the effort data base arising from such analyses prior to embarking upon more sophisticated model extensions, the results of which may well prove critically dependent on this aspect of the data.

12 CONCLUSIONS

The motivation for this study was evidence of increasing discrepancies between recent observed and model-predicted CPUE values for the hake fisheries in the ICSEAF convention area (for example, see Figure 1.1). Previously, the ICSEAF Scientific Advisory Council had been using a steady-state version of the Fox production model (incorporating Gulland's effort averaging procedure) to assess these stocks and make quota recommendations. It was hypothesized that the major cause of these discrepancies was the continuous equilibrium assumption made in those analyses, and that a dynamic version of the production model would provide a much improved fit to the data.

A particular concern pertaining to those ICSEAF analyses was the possibility of biases arising in sustainable yield estimates because of the failure to take dynamic effects into account. Downward CPUE trends have generally been observed for the major part of the histories of the hake fisheries in the four ICSEAF division combinations considered, and it was shown in Chapter 4 that under these circumstances the steady-state production model will tend to produce positively biased estimates of sustainable yield. While Gulland's procedure will compensate for this bias to some extent, it is not immediately clear whether it will tend to under- or over-correct.

Accordingly, this study has examined the performance of the discrete formulation of the dynamic version of the production model. Schaefer and Fox forms of this model were fitted (using nonlinear minimization procedures) to catch-effort data for these four divisions. In addition, coefficients of variation for the model parameter and yield values assessed were estimated using Monte Carlo simulation methods.

In all divisions the dynamic models provided substantially improved fits to the CPUE time series when compared to those obtained using the Gulland Functional Regression (GFR) or the steady-state formulations (this is particularly well illustrated by comparative plots of observed and model-predicted CPUE trends with time - see Figures 8.1 to 8.8). As expected, dynamic model MSY and $Q_{0,1}(85)$ estimates were less on average (by approximately 10% in both cases) than those resulting from the GFR procedure. Coefficient of variation (c.v.) estimates indicated a high degree of precision for the dynamic model MSY estimates (average c.v. = 5%), but less for $Q_{0,1}(85)$ estimates (average c.v. = 14%), and even less in the case of the r, q and K estimates (average c.v. = 18%) . By comparison, the GFR c.v. estimates for MSY and $Q_{0,1}(85)$

averaged 7% and 12% respectively. Although there appeared to be little to choose between the Schaefer and Fox models, in most divisions the Fox model reflected a marginal improvement in fit and therefore was preferred as a basis for catch limit evaluations.

Biomass estimates for recent years calculated using the dynamic models show fairly optimistic trends (indicating recovery of the stocks) for all four ICSEAF division combinations considered. However it is possible that the increasing CPUE trends upon which these assessments are based could be reflecting (at least in part) a few good year classes only, rather than sustained recovery of the stocks. Concern has been expressed that this apparently favourable recruitment is rapidly being exposed to heavy exploitation. The effects of uncertainties such as these as well as the effects of environmental variability can seriously affect the outcome of management decisions; caution should therefore be exercised when making catch limit recommendations. Various more appropriate (that is, conservative) approaches were advocated, and associated current catch limit recommendations evaluated. These include the Gulland and Boerema $f_{0,1}$ procedure, and an approach where the quota is reduced by a fraction of the standard error of the initial quota estimate. Alternatively, if current biomass estimates are available from other assessment methods, the dynamic model analysis provides an estimate of the appropriate biomass fraction to harvest. For an f_{MSY} strategy, the average fraction for the four stocks analyzed using the Fox model was 0,22 (with a c.v. of 8%).

The dynamic model was also employed to predict future biomass (as well as CPUE and quota) values. A historical examination of the accuracy of such biomass projections was used to comment upon the efficacy of the Schaefer and Fox dynamic models. For the initial period of the fisheries when consistently declining CPUE trends were evident, confidence intervals for the net growth rate parameter r and for MSY often overlapped zero. This was caused by the minimization routine frequently choosing to explain the historical catches as mainly the removal of accumulated stock rather than the harvesting of surplus production. However, during the past decade, increasing CPUE trends have been reported and the resultant data contrasts have enabled the models to better estimate surplus production and so to provide results which demonstrate a statistically significant density-dependent response by the population. Relative error calculations over the history of the fisheries indicated relatively accurate CPUE predictions, with errors of less than 12% for the one-year projections since 1982 for all divisions considered.

A comparison of dynamic model biomass estimates with those provided by the Virtual Population Analysis (VPA) procedure for Division 1.6 revealed large discrepancies in both recent trends and absolute values, with both being much lower in the case of VPA. In an attempt to resolve these differences, various extensions to the Schaefer and Fox dynamic models were introduced. The incorporation in the dynamic model of time lag effects (in the net growth function) and increased efficiency factors (in the catching operation) yielded no obvious improvement in agreement between dynamic model and VPA results. In addition, models where the ratio of the biomass at the start of the given CPUE series to the carrying capacity (y_1/K) was allowed to assume values other than unity, showed no superiority over models applied earlier which had assumed $y_1 = K$. The apparent failure of these extensions to lead to a significant improvement in agreement between results suggests inter alia that the original three-parameter version of the dynamic model (which provided relatively good fits) nearly fully exploits the information content of the catch-effort data, and that the introduction of further parameters can cause the sum of squares surface to become very flat in the vicinity of the minimum sought by the fitting procedure.

Further, dynamic model fits using the Shepherd surplus production form (which incorporates a skewness parameter) were performed on the catch-effort data and it was found that the sum of squares minima obtained from these fits were not substantially less than those obtained using the Schaefer and Fox forms. In addition, the ratio of the biomass at MSY to the carrying capacity (y_{MSY}/K) was shown to be very poorly determined by the catch-effort data (the average value for the four divisions being 0,32 and the average of the c.v. estimates being 30%). It was concluded that the Shepherd model was a suitable, though not necessarily a superior, alternative to the Schaefer and Fox dynamic forms.

Discrepancies between VPA and dynamic model biomass estimates are now felt to stem more probably from problems with the VPA assessments than biases due to the simplistic nature of the production models. The two major problem areas with VPA assessments appear to be making appropriate allowances for the discarding of small fish and the effects of cannibalism on natural mortality.

Possible future extensions and amendments to the dynamic models have also been suggested. These included the use of Clark's bioeconomic model to review the $f_{0,1}$ strategy (usually the basis for the ICSEAF Scientific Advisory Council's quota recommendations) with regard to economic optimality, and the replacement of the traditional Schaefer and Fox forms with more generalized surplus growth functions. Also proposed was an examination of whether the 1975 change in mesh size had an effect on either catchability or net growth parameters, and an adjusted dynamic model calculational procedure in which catches are 'discounted' to allow for individual growth and natural mortality corrections. More appropriate weighting procedures for catch-effort model fits have been suggested and lastly, an analysis of vessel power factors has been advised. Of the above aspects suggested for further investigation, the most urgent appears to be an examination of vessel power factor allocation.

The results of this study lead to the conclusion that the dynamic model approach is undoubtedly an improvement over that of the traditional steady-state models for assessing the hake resources in the ICSEAF convention area. The use of dynamic models can reduce bias without an accompanying loss of precision, so that the unrealistic continuous equilibrium assumption of the steady-state procedures can be avoided.

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