INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

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THE USE OF SPAWNING STOCK BIOMASS ESTIMATES DERIVED FROM EGG SURVEYS AS INDICES FOR TUNING SEPARABLE VPA ASSESSMENTS.

C. D. Darby
Ministry of Agriculture, Fisheries and Food.
Fisheries Laboratory
Pakefield Road, LOWESTOFT, Suffolk
United Kingdom.

Abstract

The ICES Mackerel Working Groups 'tune' Western Mackerel (*Scomber scombrus* L., I.C.E.S Divisions VI, VII, and VIIIa&b) VPA's by minimising the residuals between the VPA generated spawning stock biomasses (SSBs), and SSB estimates derived from triennial international egg surveys of the spawning grounds. This paper describes the results of an investigation into the influence of bias in the egg survey estimates of SSB on the minima achieved by the tuning procedure. It is assumed that the egg surveys generate SSB totals which are all either over or under estimating the population SSB exploited by the fishery (the tuned VPA SSB for the same year) by a constant proportion. It treats the SSB values derived from the surveys as indices of the population SSB abundance, a similar approach to that used when tuning VPA's to fleet CPUE indices by *ad hoc* methods. The results suggest that the Western Mackerel egg surveys over estimate the biomass exploited by the fishery. A 10% reduction of all the egg survey estimates produces a 30% reduction in the sum of squares between the survey and VPA values. In addition, two Working Group modifications to the assessment data sets are examined in the context of their influence on the minima achieved by the tuning process.

Introduction

When the virtual population analysis equations are applied to catch-at-age data they produce a family of equally valid solutions for fishing mortality and population abundance-at-age. In order to differentiate between them, stock assessment procedures use independent estimates of either population abundance or the fishing mortality to which the stock is subjected. The majority of important demersal species assessments use fishing mortality estimates obtained by applying models such as *ad hoc* tuning (Pope & Shepherd 1985), ADAPT (Gavaris 1988), or XSA (Shepherd 1992) to catch per unit effort data obtained from prosecuting fleets. For pelagic shoaling species assessments, the derivation of reliable fleet effort data is a more complex problem. Interactions between catch and effort indices require analyses which mimic those used for predator - prey studies. Effort has to be subdivided between search and handling times, and both carrying capacity and information exchange between individuals within a fleet can influence the assessment (Gulland 1983). In order to overcome this complexity, the majority of pelagic assessments carried out by the International Council for the Exploration of the Seas (I.C.E.S) Working Groups are adjusted to fit indices of fishing mortality derived from tagging returns (Hamre 1980), population abundance estimates derived from acoustic surveys (Anon 1993), or spawning stock estimates obtained from plankton surveys (Lockwood *et al* 1981a). This paper examines a procedure used for tuning to spawning stock biomass and presents a procedural modification that could be applied to other assessments of this type.

The Western Mackerel Stock assessment.

The Mackerel Working Group 'tune' Western Mackerel (*Scomber scombrus* L., I.C.E.S Divisions VI, VII, and VIIIa&b) VPA's by adjusting the F-at-age values for the final year and oldest age (terminal F's) to achieve the best fit between the spawning stock biomasses (SSBs) generated by the VPA, and SSB estimates derived from triennial egg surveys of the spawning grounds (Anon 1991). The F values are generated by applying a separable model for fishing mortality and selection-at-age (Pope and Shepherd 1982) to the total international catch in numbers for age groups 0 - 11. Selection on the oldest age, defined by F-at-age divided by F on a reference age, is held constant (1.0) to produce a flat exploitation pattern for the older ages of the assessment (5 - 11). Tuning is achieved by adjusting the terminal F on the reference age (5) until the sum of squares of the residuals between the two estimates for SSB, for the years in which surveys were prosecuted, are minimised (Figure 1). A time series weighting is applied such that the selection pattern used for each tuning iteration is an average of the values for selection in the last six years of the assessment. The model assumes that there have been no significant changes to the selection pattern during the period of the assessment.

A modification to this approach was applied by the 1991 Mackerel Working Group (Appendix 1 in Anon (1991)). This incorporated the concurrent minimisation of (1) the residuals between the separable VPA estimates for log catch and log catch data, (2) the residuals between logarithms of the two series of estimates of SSB and (3) the separably generated estimates of recruitment and independent recruitment indices (log values). The results of the minimisation produced final year F-at-age and population-at-age values which were similar to those achieved using the tuning procedure.

Both of these techniques assume that the procedures used for deriving the egg survey SSBs produce estimates of the true total population spawning stock biomass. If there are any unknown procedural biases in the collection of data or calculations, the VPA assessments will be tuned towards them. An alternative method for tuning the assessment is to use the estimates as indices of the true population SSB. Egg survey SSB indices can therefore be linked to the stock SSB by a "catchability" or bias parameter similar to that which links log values of CPUE-at-age and log population-at-age within the fleet tuning approach. The "catchability" parameter (λ) for the Western Mackerel egg survey series can be estimated by finding the value that minimises

$$\sum [SSB_{VPA} - \lambda\, SSB_{SURVEY}]^2$$

where λ is a constant across surveys. It is therefore a procedural effect, not a year effect.

Method

VPA SSBs for the years 1972 - 1990 were generated using a range of values for terminal F (0.25 - 0.6) within a separable VPA. The assessment was performed using the Lowestoft VPA 3.1 assessment suite and the stock data files created by the 1991 Mackerel Working Group (Anon 1991). The values presented in the results are the raw VPA outputs. The estimates of recruits, stock numbers and spawning stock biomasses have not been adjusted for the lack of convergence in the younger ages of the most recent years.

The I.C.E.S program used by the 1991 Working Group and the Lowestoft program used in this analysis differ in their method of calculation for the weights at age of the plus group. The I.C.E.S. program uses the stock and catch weights for the first age in the plus group as weights for the whole plus group (i.e. age 12 weights for a 12+ group). The Lowestoft program calculates plus group specific stock and catch weight values. These are weighted averages (weighted by catch numbers-at-age) of the catch or stock weights supplied for all plus group ages. When the numbers at age in the plus group are significant, this causes discrepancies between the spawning stock biomasses calculated by the two programs. The Western Mackerel plus group populations are relatively small and the minor differences in total spawning stock biomasses between the two assessment procedures are not considered to have influenced the conclusions drawn from the results. It should be noted that when tuning to SSB surveys the calculation method will become a significant determinant if a large number of ages are concatenated into the plus group.

For each assessment the total sum of squares (SSQ) was calculated from the residuals between the VPA SSB estimates generated by each terminal F and the egg survey estimates adjusted by a range of λ values. Total SSQ values were tabulated and examined for minima.

Working group customisation of the assessment data sets.

During the development of the Western Mackerel assessment series, two significant alterations to assessment parameters have been made by Working Groups.

In 1980 the second research vessel survey in the plankton survey series (M.A.F.F. RV Cirolana 4/80) reported significantly lower catches of eggs than would have been anticipated from the distributions of egg production with time observed during 1977 and 1983 (Anon 1984). This was thought to have been caused by an unidentified, gear related, problem in the sampling procedure (Anon 1984). The estimate of egg numbers derived from the 4/80 survey was rejected by the 1984 Working Group and the total numbers of eggs produced during May estimated using linear interpolation between the cruises adjacent to 4/80. Figure 2, taken from Anon (1984) illustrates the adjustment to the egg survey data. The original 1980 SSB can be derived from the total production estimate of 1.48×10^{15} eggs (Lockwood *et al*, 1981b) and linear interpolation with the data in Table 3.3 of Anon (1991). The 1984 Working Group alteration to the survey series produced an increase in the 1980 estimate of SSB from 2.20×10^6 to 2.73×10^6 tonnes.

In 1986 a relatively low abundance of eggs was recorded on the spawning grounds (Anon 1987a). Stock surveys indicated that density dependent effects were implicated for the relatively abundant 1984 year class (6.9 billion recruits, 4.9 billion 2 group). The mean length of two year old fish recorded on the spawning grounds in 1986 was 3 cm smaller than that recorded for 1985. The Working Group discussed the effect on the maturity ogive and reduced the maturity of the 2 year old fish from 60% to 20% (Anon 1987b). This has not been repeated for other abundant year classes. The 1981 year class had 6.9 billion recruits and the 1989 year class was predicted to have been 7.0 billion recruits (Anon 1991).

The influence of both Working Group alterations on the fit of the tuned VPA model SSBs to the survey results was examined, initially by varying terminal F alone (λ=1.0), and then using the interaction between λ and terminal F.

Results

Variation in terminal F (λ=1.0)

Figure 3 illustrates the effect of changes to terminal F, on the time series of spawning stock biomass generated by the VPA. The egg survey estimates are plotted for comparison. They include the 1980 value before alteration by the Working Group. It is evident that 'realistic' variation in the value of terminal F, will only generate significant alterations to VPA spawning stock biomasses after 1982. . Prior to this year the convergence of the VPA calculations ensures that the VPA generated SSBs are robust with regard to the input terminal F. An examination of the residuals between the survey estimates and VPA SSB's, illustrated by Figure 3, reveals that the reduction in the sum of squares shown in Figure 1, results primarily from alterations to the fit of the VPA to the last three surveys. The contribution to the sum of squares by the 1977 and 1980 surveys (for each 1980 scenario) can be considered significant but relatively constant.

The figure demonstrates that, if the separable VPA model holds for this stock and it is assumed that the catches and egg surveys are measuring the same population, the egg surveys undertaken during 1977 and 1980 appear to have over-estimated the exploited spawning stock biomass. It is also clear that the estimate of SSB from the 1980 egg surveys which include the Cirolana 4/80 cruise, provides a better fit to the VPA SSBs than the Working Group value which excludes it.

A comparison between Figures 3 & 4 illustrates the effect of the Working Group alteration to the maturity of the 2 year old fish in 1986. The result of the change is to significantly decrease the spawning stock biomass estimated by the VPA for that year. This results in a minor alteration to the value of terminal F providing the optimum fit from 0.3 (60% maturity, Figure 5) to the Working Group optimum F of 0.275 (20% maturity, Figure 1) and a decrease in reference $Fbar_{(4-8)}$ from 0.4 to 0.3.

The interaction between λ and terminal F.

Figures 6 presents a contoured surface of the SSQ calculated using a range of input terminal F values for the separable VPA and λ, the proportion by which the egg surveys are scaled. A reference point on the SSQ's surface is provided by plotting the range over which the values calculated by the Working Group are situated (i.e. λ=1.0 F=0.25 - 0.3). This corresponds to the range of SSQ values plotted in Figure 1. The cross on the line is situated at the 1991 Working Group optimum value for terminal F.

The contours of Figure 6 clearly demonstrate that a better fit between the two sets of data is achieved at λ = 0.9 (a 10% reduction of the survey SSB estimates) or less, and a terminal F value for the reference age in the separable VPA of F = 0.35. The SSQ minimum at these parameter values is 43% lower than the value achieved at the Working Group solution (628019 ⇒ 269044, Table 1). The highlighted contour level demonstrates the 95% confidence interval about the minimum. This is calculated by a reworking of the maximum likelihood (M.D.Nicholson pers.comm.), such that

$$SSQ @ 95\% = SSQ\ minimum \times e^{\Psi_2/n}$$

where Ψ_2 is the Chi squared parameter with 2 degrees of freedom, at the 95% level and n is the number of data points (5). The SSQ value at the 95% level of confidence is 8.92 E+5. The SSQ total obtained by the Working Group falls within the 95% level of confidence surrounding the new minimum.

Figure 7 illustrates the fit of the scaled survey points (SSB * λ = 0.9) to the biomasses generated by the optimum VPA solution.

The 1980 egg survey SSB estimate.

Figures 3 and 4 illustrate that, with hind-sight, the original 1980 spawning stock biomass estimate provides a better estimate of the 1980 VPA SSB than the 1984 Working Group alteration. Figure 8 presents the SSQ surface generated when the 1980 value is set to the original estimate. The pattern of contours is similar to that derived in the previous simulation. The optimum fit is again achieved at λ = 0.9 and a terminal F value of 0.35. At these values the SSQ have been reduced from 628,019 (λ = 1.0, F = 0.275 the Working Group optimum) to 31,914 (λ = 0.9, F = 0.35) a reduction by a factor of 95% and the broad double minimum apparent in Figure 6 is eliminated. Clearly the fit to the egg survey SSB indices is improved dramatically. The contour line equivalent to the 95% confidence interval is highlighted on the figure at SSQ = 1.06 E +5.

Figure 9 illustrates the fit of the scaled survey points to the optimum assessment. Table 2 presents the SSQ values.

The sensitivity of the assessment to maturity at age.

If the 1980 SSB estimate is set to that recommended by the 1984 Working Group, and the percentage maturity of the 2 year old fish in 1986 set to 60%, the SSQ surface plot for the simulations is similar to that for 20% maturity. The surface minimum occurs at a egg survey scaling of $\lambda = 0.9$ and as anticipated from the results illustrated by Figures 3 and 4 the terminal F value is slightly higher at 0.38. The reference mean F ($Fbar_{(4-8)}$) for the terminal year is increased from 0.39 to 0.43. These results demonstrate that the 1991 assessment is relatively insensitive to variations in the maturity of 2 year old fish in 1986. The robustness is primarily due to the presence of the 1989 egg survey SSB which restrained the level of terminal F in the optimum fit. Without the 1989 survey the current assessment would be extremely sensitive to the maturity of the abundant year classes.

The influence of the alterations to maturity on the value of terminal F may not seem too damaging for the 1991 assessment but the result must be considered in the context of past and future assessments. Figures 3 & 4 illustrate that the fit to the egg survey SSB estimates achieved by the 1987, 1988 and 1989 assessments could have been extremely sensitive to the alteration in the maturity of two year old fish in 1986. If the 1989 egg survey is ignored, Figure 3 shows that the optimum terminal F appears to be 0.3, in Figure 4 the terminal F would be $\cong$ 0.4. In 1992 the abundant 1989 and 1991 year classes could dominate the population structure and spawning stock biomass. Both recruitments are predicted to be equivalent in magnitude to the 1984 year class. If the 1993 Working Group uses the standard maturity-at-age ogive, used in the VPA for all years except 1992, significant errors may be introduced into the tuning process.

Discussion

This study has established that the application of a bias or "catchability" parameter to the spawning stock biomasses recorded by the Western Mackerel egg surveys can improve the fit to a "tuned" separable VPA. Assessments tuned by varying the bias parameter (λ) and the terminal F on the reference age have achieved sum of square totals which are reduced 43% when compared to the results achieved by the 1991 assessment Working Group (Anon 1991).

The minima in the sum squares at $\lambda = 0.9$ suggests that the procedures used for calculating the SSB estimates are consistently over estimating the spawning stock exploited by the fishery by 10%. Lockwood *et al* (1981a) estimated errors of +30% and -20% for the total egg production in 1977. The errors have not been carried through to the spawning stock abundance, but if they are of similar magnitude they would explain the size of the discrepancy between the VPA and egg survey SSB's but not the apparent bias towards over estimation. Possible explanations for the values of $\lambda < 1.0$ are:

1) The catches are derived from only part of the population measured by the egg survey.

The fleets may be exploiting a different spatial distribution to that examined by the egg surveys. If the catch is derived from high density schools situated within a low density background abundance. The catches would reflect the abundance within patches. The egg surveys are representative of the overall population abundance. This difference in the populations perceived by the methods could be compounded by aggregation on the spawning grounds after migration.

Modest under or over reporting of catches, an incorrect estimate of M or errors in the percentage maturity at age for important age groups could all lead to values for λ which are less than 1.0.

2) If it is thought that the catches reported by the fleet are drawn from the same population as that covered by the egg surveys, then :

$$SSB_{VPA} = \lambda \, SSB_{SURV} = \lambda \, \frac{\text{Eggs in the sea}}{\text{Eggs per fish}} \, C$$

C is representative of the sex ratio and the average weight of a female on the spawning grounds.

For set values of eggs in the sea and stock weights etc., values of $\lambda < 1$ indicate that the number of eggs produced per fish is under-estimated by the fecundity analysis and processes such as indeterminate spawning may be taking place. If $\lambda > 1$ the number of eggs produced per fish is over-estimated and this would indicate a reduction in fecundity due to atresia etc.

In all of the simulations examined during this investigation, the SSB derived from the 1980 egg surveys which included the Cirolana 4/80 survey, provide the best estimate of the converged VPA biomasses. The fit to the survey estimates achieved by the 1991 Working Group can be improved by 95% when the original survey value is used in conjunction with the bias parameter.

If the 4/80 survey value is revised to the original value recorded in 1980 (Lockwood *et al*, 1981b), further lines of investigation may lead to the cause of the absence of eggs in May 1980. Anon (1984) reported that the low abundance of eggs in the plankton samples was not confined to Mackerel. If gear failure could be excluded as a cause, this may indicate that the bimodal distribution was environmentally induced. Future Working Groups should seriously consider whether to reverse the decision to reject the 4/80 survey made by the 1984 Working Group and tune with the original 1980 SSB estimate.

Density dependent effects on growth and maturity have been implicated within this stock. Predictions for population parameters in the terminal years, derived by tuning VPA's using SSB estimates, can be extremely sensitive to these effects. In order to reduce the sensitivity of the method to this parameter, there is a requirement for direct estimation of the maturity-at-age in each year that the egg surveys are collected. As soon as possible this should be augmented by a description of the relationship between population density and both mean length at age and maturity at age. It may be possible to estimate maturity as a function of length rather than age. The statement recorded in Anon (1991) that " in the absence of evidence to the contrary the maturity of 2 year old fish is assumed to be 60%", requires experimental verification.

This study has demonstrated the use of a bias or "catchability" parameter which links indices of population or spawning stock biomass to the "true" population or biomass. The procedure can significantly improve the fit between indices and assessment results. However, it has only been applied to the 1991 (final year of data 1990) assessment for the stock. The over estimation bias estimated for the Western mackerel egg surveys, falls within the range of the known procedural biases (atresia, indeterminate spawning etc.): values outside the range should be treated with caution. Retrospective studies examining the robustness of the estimate of catchability should be carried out in order to ascertain the long term value of the technique. The study should also consider other parameters which have a significant bearing on the conclusions drawn from the results. The technique is straight forward to use and may be useful with other assessment procedures or stocks.

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Figure 1.

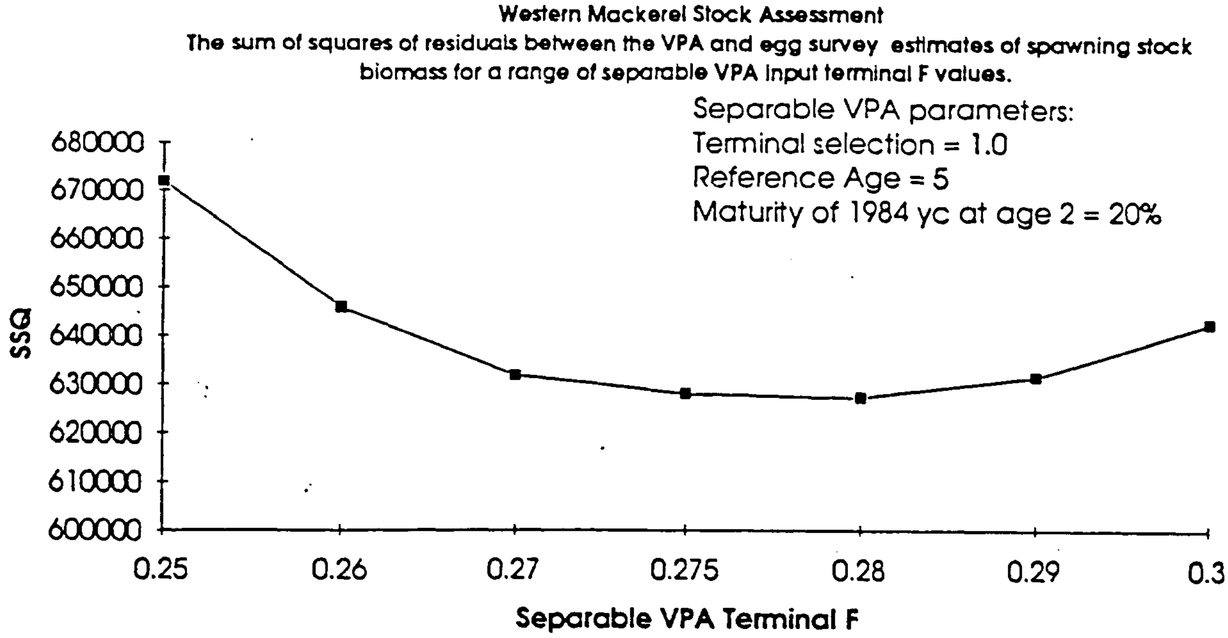

Figure 2. The Western Mackerel egg production curves for 1977, 1980 and 1993. Illustrating the alteration made by the 1984 Working Group to the 1980 series.

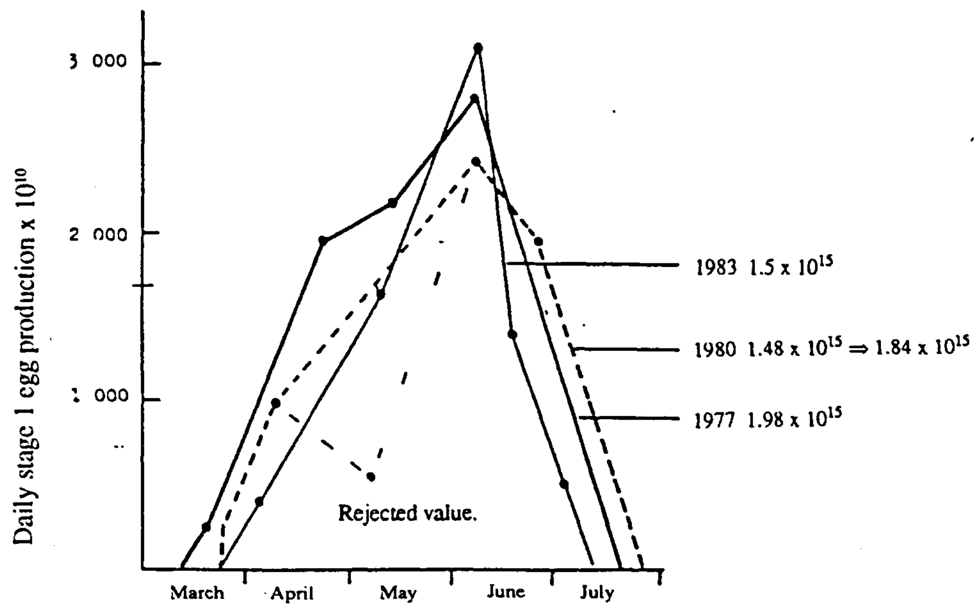

Figure 3.

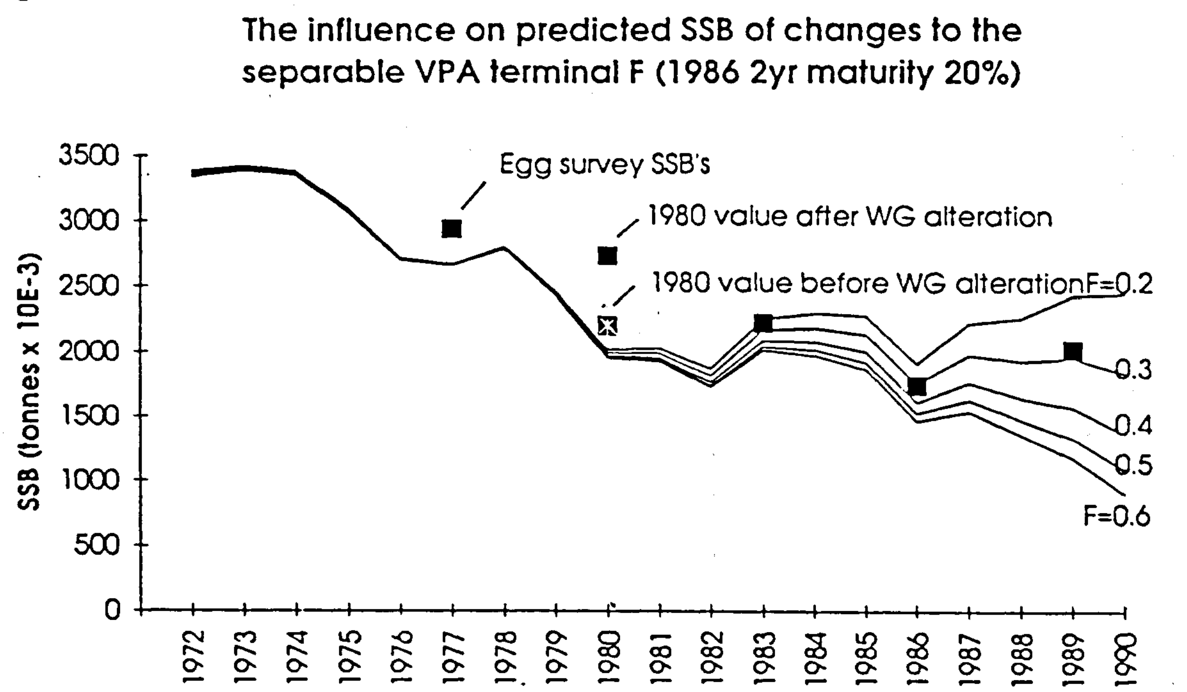

Figure 4.

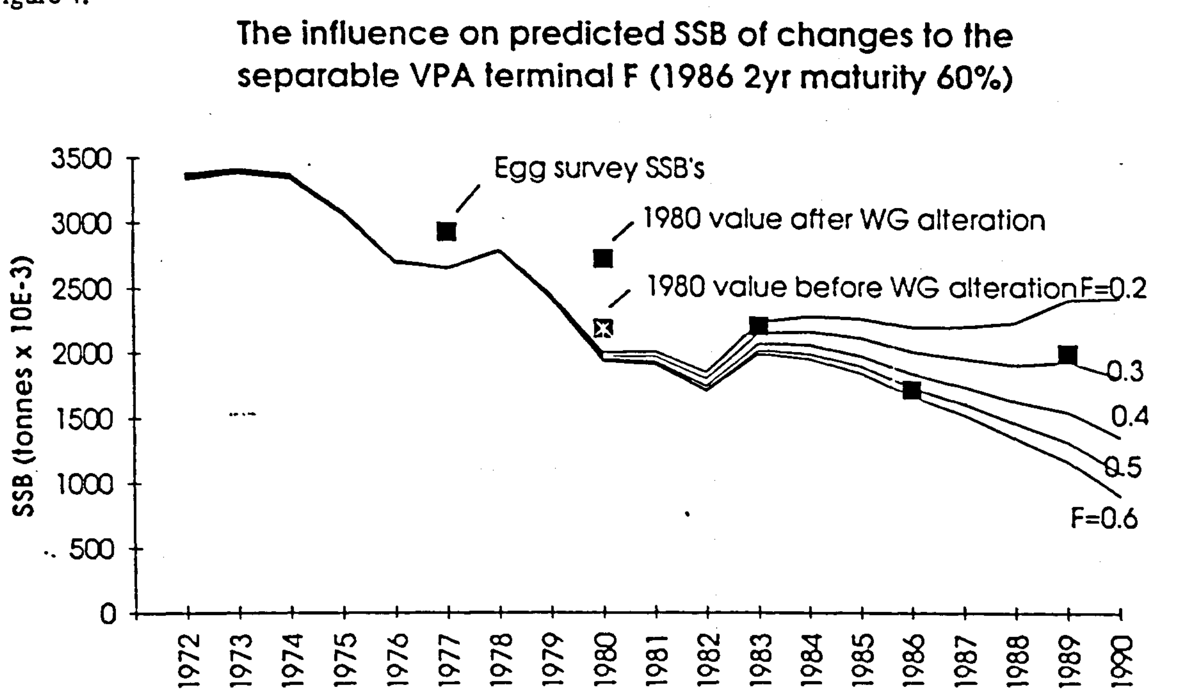

Figure 5.

Western Mackerel Stock Assessment
The sum of squares of the residuals between the VPA and egg survey estimates of spawning stock biomass for a range of separable VPA input terminal F values.

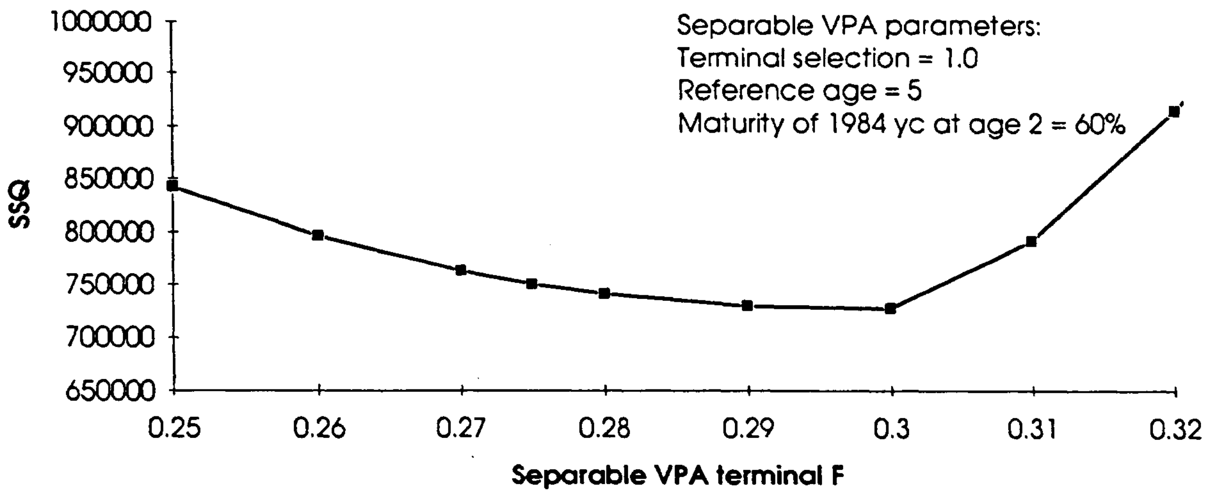

Figure 6. The sum of squares surface for the residuals between the SSB's generated by a separable VPA assessment with various terminal F values for the reference age, and egg survey SSB's scaled by λ, a procedural bias estimate. The 1980 egg survey SSB is set to the Working Group alteration.

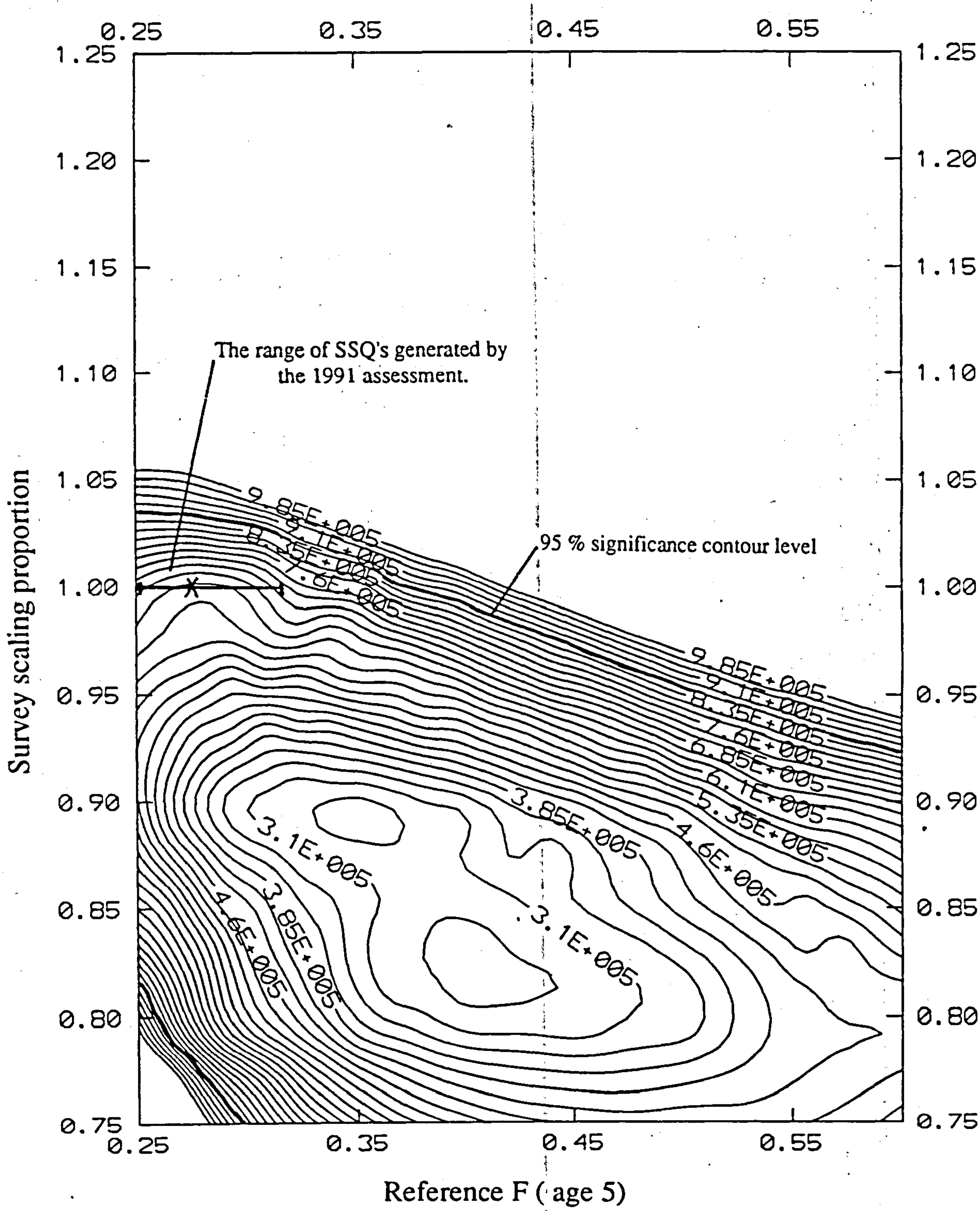

Figure 7. The fit between the scaled egg surveys and the optimum assessment with $\lambda = 0.9$ and the 1980 egg survey estimate set to the Working Group alteration.

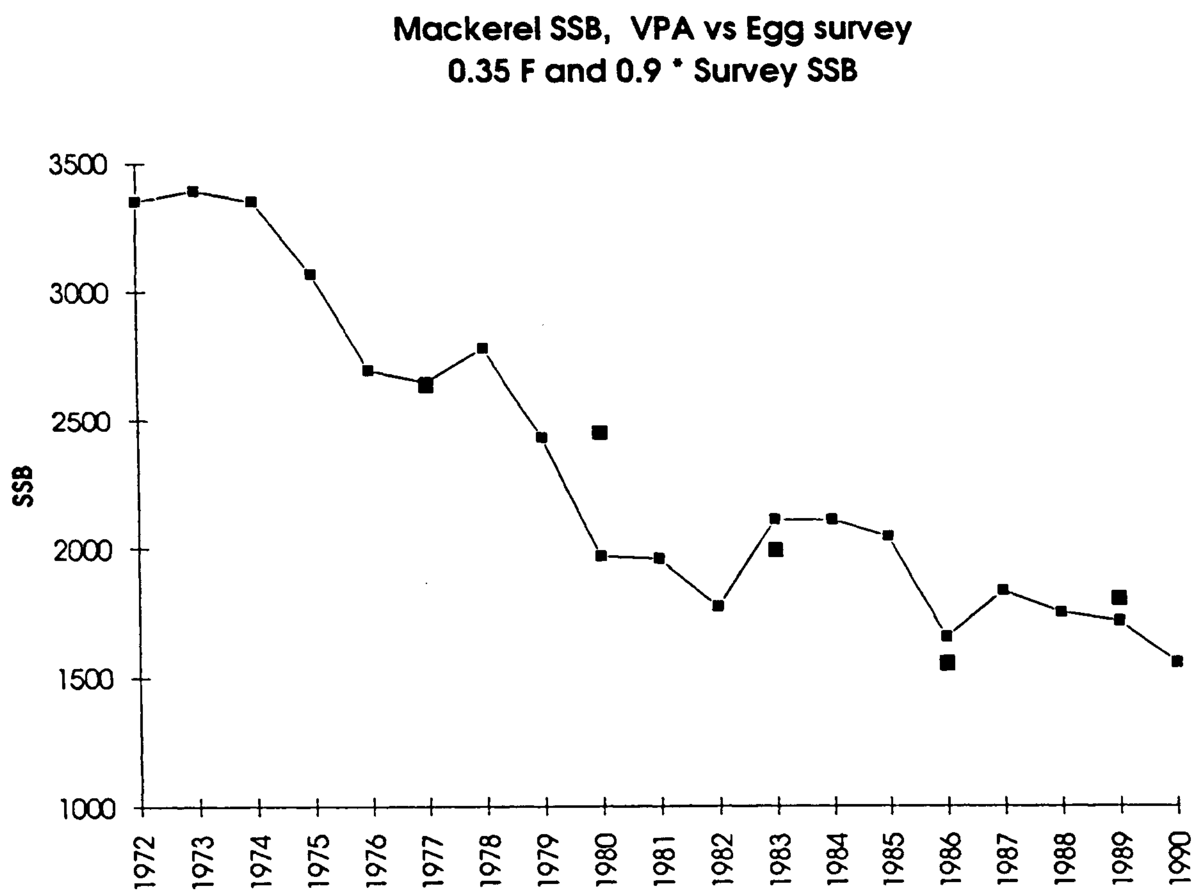

Figure 8. The sum of-squares surface for the residuals between the SSB's generated by a separable VPA assessment with various terminal F values for the reference age, and egg survey SSB's scaled by λ, a procedural bias estimate. The 1980 egg survey SSB is set to the original estimate.

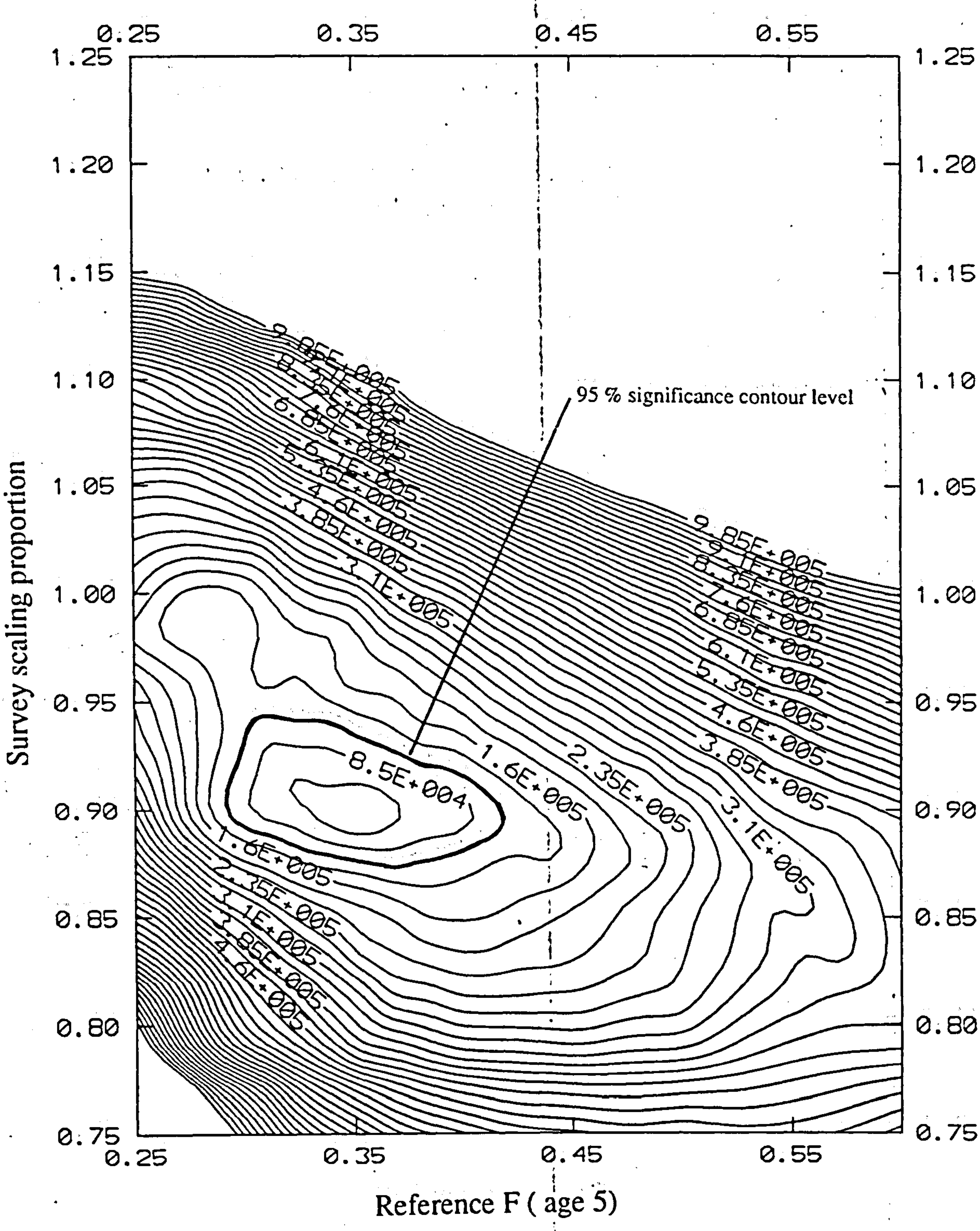

Figure 9. The fit between the scaled egg surveys and the optimum assessment with $\lambda = 0.9$ and the 1980 egg survey estimate set to the original estimate.

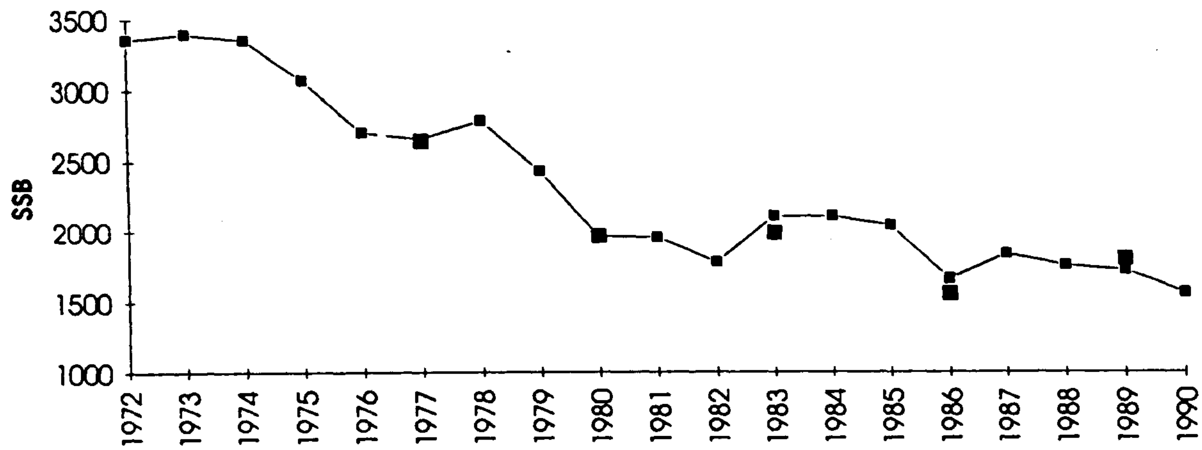

Table 1. The sum of squares of the residuals between egg survey and VPA estimates of total spawning stock biomass for the Western Mackerel
All surveys, W.G values for 1980 egg survey, 20%maturity on 1986 2 yr olds

		Terminal F for the Separable VPA											
		0.25	0.26	0.27	0.275	0.28	0.29	0.3	0.35	0.4	0.45	0.5	0.6
	0.75	1392229	1242902	1115988	1061068	1007772	916377	837921	585224	473439	433142	428951	472362
	0.8	967548	842920	738586	693879	651083	578828	518241	339541	281974	282925	311249	402403
Egg	0.9	539055	463825	404651	380370	358574	324599	299750	269044	319913	403360	496714	683354
Survey	1	671720	645888	631874	628019	627223	631528	642417	759705	919010	1084953	1243337	1525463
Scaling	1.05	948487	947354	955920	962278	971982	995427	1024185	1215470	1428993	1636184	1827083	2156952
	1.1	1365543	1389109	1420255	1436826	1457030	1499615	1546242	1811524	2079265	2327704	2551118	2928730
	1.2	2620524	2693488	2769794	2806791	2847995	2928860	3011225	3424501	3800678	4131613	4420057	4893155
	1.25	3458449	3556112	3654998	3702208	3753912	3853917	3954151	4441424	4871819	5244002	5564961	6085802

WG terminal F =0.275

Table 2. The sum of squares of the residuals between egg survey and VPA estimates of total spawning stock biomass for the Western Mackerel
All surveys, without WG correction to 1980, 20%maturity 1986 2yr olds

		Terminal F for the Separable VPA											
		0.25	0.26	0.27	0.275	0.28	0.29	0.3	0.35	0.4	0.45	0.5	0.6
	0.75	1521861	1367727	1236807	1180285	1125386	1030787	949126	683610	563813	517106	508909	545911
	0.8	1000580	870825	762218	715802	671296	595623	531617	339244	273131	267245	291296	375613
Egg	0.9	339421	258423	194442	168238	144519	106698	78003	31914	73169	148925	237471	416420
Survey	1	186799	154558	135202	129211	126278	126310	132926	233122	381744	539141	692184	965764
Scaling	1.05	301189	293326	296284	300399	307859	326818	351089	524427	726733	924951	1110242	1431137
	1.1	542714	559229	584500	598721	616575	654459	696386	942867	1198857	1437895	1655434	2023645
	1.2	1407165	1472438	1542334	1576768	1615408	1691145	1768382	2161148	2524506	2845185	3127220	3590063
	1.25	2030093	2119744	2211953	2256492	2305526	2400189	2495082	2960990	3378032	3739532	4053814	4563973