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NOTES ON THE USE OF VIRTUAL POPULATION ANALYSIS FOR STOCK ASSESSMENT OF THE MACKEREL ICEFISH, *CHAMPSOCEPHALUS GUNNARI* (LÖNNBERG, 1906) IN SUBAREA 48.3 FOR THE 1990/91 AND 1991/92 SEASONS

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Abstract

Following on from the apparent failure of the CCAMLR Working Group on Fish Stock Assessment (WG-FSA) to satisfactorily assess in 1991 the status of the *Champsocephalus gunnari* population in Subarea 48.3 using VPA, attempts were made to re-work the analysis using Laurec-Shepherd and ADAPT tuning techniques, from 1991 back to 1977. The predicted age structure, dominated in recent years by the 1987 year-class (1 year olds in 1988), was quite robust, despite the use of various combinations of survey and CPUE indices for tuning. According to the VPA the population in 1991/92 was composed of a large proportion of 5 year olds, which was not observed during the survey on *Falklands Protector* in January 1992. Breakdown in the credibility of the VPA results in most recent years is attributed to the invalid assumption of constant M and contradictions in the input data. A conservative approach to management for 1992/93 is recommended, based on the results of surveys by *Falklands Protector* in 1990/91 and 1991/92.

Résumé

Suite à l'apparente incapacité du Groupe de travail de la CCAMLR chargé de l'évaluation des stocks de poissons (WG-FSA) à évaluer proprement en 1991 le statut de la population de *Champsocephalus gunnari* par la VPA dans la sous-zone 48.3, de nouvelles tentatives d'analyse ont été effectuées par les techniques d'ajustement Laurec-Shepherd et ADAPT, en remontant de 1991 à 1977. La structure d'âge prévue, dominée ces dernières années par la classe d'âge 1987 (âgés d'un an en 1988) était assez robuste, en dépit d'une ajustement effectué par plusieurs combinaisons d'indices de campagnes d'évaluation et de CPUE. D'après la VPA, la population de 1991/92 comportait une proportion importante d'individus de 5 ans, ce qui n'avait pas été observé lors de la campagne du *Falklands Protector* en janvier 1992. La baisse de crédibilité des résultats de la VPA de ces dernières années est attribuée à l'hypothèse invalide d'un M constant et aux contradictions dans les données d'entrée. Pour 1992/93, une approche conservative de gestion, fondée sur les résultats des campagnes d'évaluation du *Falklands Protector* de 1990/91 et 1991/92, est recommandée.

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Резюме

В связи с тем, что на совещании WG-FSA в 1991 г. не удалось удовлетворительно оценить состояние популяции *Champsocephalus gunnari* в Подрайоне 48.3 с использованием VPA, были предприняты попытки усовершенствовать анализ, используя методы настройки Лорека-Шеперда и ADAPT за период 1977-1991 гг. Прогнозируемая возрастная структура, в которой в последние годы преобладал годовой класс 1987 г. (однолетние особи в 1988 г.), была довольно устойчива несмотря на то, что при настройке использовались различные комбинации съемочных индексов и индексов CPUE. Судя по результатам анализа VPA популяция в 1991/92 г. содержала большую долю пятилетних особей, которая не наблюдалась в ходе съемки судна *Falklands Protector* в январе 1992 г. Неудача расчетов VPA за самые последние годы объясняется неправильным предположением о постоянной величине M и противоречиями в вводных данных. На основании результатов съемок судна *Falklands Protector*, проведенных в 1990/91 и 1991/92 гг., рекомендуется применить предохранительный подход к управлению промыслом в 1992/93 г.

Resumen

Luego del malogrado esfuerzo del Grupo de Trabajo para la Evaluación de las Poblaciones de Peces de la CCRVMA, por evaluar satisfactoriamente el estado de la población de *Champsocephalus gunnari* en la Subárea 48.3 en 1991 mediante el VPA, se trató de volver a aplicar el análisis utilizando las técnicas de ajuste de Laurec-Sheperd y ADAPT desde 1991, en regresión, hasta 1977. La distribución de edades prevista, la cual ha sido dominada por la clase del año 1987 (ejemplares de 1 año en 1988) fue muy abundante, a pesar de la utilización de distintas combinaciones de índices y de CPUE de prospecciones para el ajuste. De acuerdo al VPA, la población de 1991/92 estuvo compuesta en su mayoría de ejemplares de 5 años, lo que no se vio en la prospección del *Falklands Protector* realizada en enero de 1992. La baja credibilidad del VPA experimentada en los últimos años se atribuye al supuesto inválido de una M constante y a contradicciones en los datos de entrada. Se recomienda por tanto un planteamiento de gestión conservador durante la temporada 1992/93, basado en los resultados de las prospecciones del *Falklands Protector* en 1990/91 y 1991/92.

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1. INTRODUCTION

Attempts were made at the 1991 meeting of the CCAMLR Working Group on Fish Stock Assessment (WG-FSA-91) to assess the status of the *Champsocephalus gunnari* population in Subarea 48.3 using virtual population analysis (VPA). Two assessment papers were presented (Gasiukov, 1991; Parkes, 1991) which showed highly divergent stock sizes, largely due to differences in the use of tuning data. Two VPA runs were made at WG-FSA-91, using the Laurec-Shepherd tuning method (MAFF DFR VPA version 2.1), which followed the same general trends of the two assessments above (SC-CAMLR-X, 1991).

Despite the huge difference between estimates of the overall stock size in 1990/91, all of these VPAs indicated that the biomass that year was dominated by 4 year old fish. Negligible catch was reported for 1990/91, hence projections to 1991/92 predicted that the somewhere in the region of 40 to 50% of the fishable biomass (age 2+*) would be composed of 5 year olds. Accordingly, TAC levels based on fishing mortality $F_{0.1}$ were proposed under the assumption that these fish would form a considerable proportion of the catch. The observed age distribution from a stock assessment survey in Subarea 48.3 in January 1991 (Everson *et al.*, 1992a), however, did not confirm the age distribution estimated by the VPA for that year (Figure 1). Concern was expressed at WG-FSA-91 that the large biomass of 5 year olds predicted by the VPA for 1991/92 might be an artefact of the analysis. In the absence of this year class, the TAC would be extracted from the younger, less abundant year classes, with potentially catastrophic effects on a population already apparently under considerable stress (Everson *et al.*, 1991; Kock *et al.*, 1992). Concerns over the credibility of the VPA and resulting uncertainties in the estimation of total stock size lead to the closure of the fishery for *C. gunnari* in Subarea 48.3 for the 1991/92 season (CCAMLR, 1991).

A stock assessment survey of the same design as that in January 1991 was undertaken by the RV *Falklands Protector* in January 1992 (Everson *et al.*, 1992b). Figure 2 compares predictions of age structure in 1992 from VPAs presented to the working group in 1991 (age 2+) with that observed during this survey. The samples taken during the survey were dominated by 2 and 3 year old fish, with 5 year olds comprising less than 5% of the fishable population biomass. Assuming the survey provided a representative sample of the population, it appears that the VPAs presented to and performed at WG-FSA-91 provided a misleading representation of the current structure of the *C. gunnari* population in Subarea 48.3.

Closure of the fishery in 1991/92 resulted in no commercial catch in the most recent year, and hence no terminal Fs for the VPA. This report presents notes on a reworking of the VPA runs made at WG-FSA-91. Forwards projections to 1991/92 were made in an attempt to reconcile the estimated population structure with that observed during the UK stock assessment surveys of the last two years.

2. MATERIALS AND METHODS

Two VPA programs were used: MAFF DFR VPA version 2.1 (MAFF 1988) using the Laurec-Shepherd tuning module, written in Fortran, and a version of ADAPT VPA translated from APL and Fortran versions (authored by V.R. Restrepo and J.E. Powers) into Pascal by Dr K. Patterson (for algorithms see Gavaris, 1988).

2.1 Input Data

Input data were the same as those used at WG-FSA-91, except where indicated below.

2.1.1 Natural Mortality

Natural mortality M was fixed at 0.48 throughout the analyses. The absolute value of M was not thought to be of major concern since the initial purpose of the exercise was to compare the outputs of various runs rather than produce a definitive VPA result.

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* here and below, "age 2+" means "age ≥2"

2.1.2 Survey Indices

The method of standardising the survey indices to account for variations in the commercial catch between the 'birthday' at the start of the split-year and the time of the survey used in Parkes (1991) (equation 1) was criticised at WG-FSA-91, because it included values of different dimensions. For the month of the start of the survey t (July = month 1, August = month 2 etc.), and known catches C in month i, the number of fish N of age a on 1 July was approximated to:

$$N_a = N_{at} \bullet e^{\left(\frac{t-1}{12}M\right)} + \sum_{i=1}^{t-1} C_{ai} \bullet e^{\left(\frac{i-1}{12}M\right)} \qquad (1)$$

This would be valid if N were considered to be an absolute measure of abundance, however it is generally regarded to be a relative index I, such that:

$$I_{survey} = q \bullet N_{survey} \qquad (2)$$

where q is the catchability. Equation (1) then becomes:

$$I_a = I_{at} \bullet e^{\left(\frac{t-1}{12}M\right)} + q_a \sum_{i=1}^{t-1} C_{ai} \bullet e^{\left(\frac{i-1}{12}M\right)} \qquad (3)$$

The application of equation 3 in Parkes (1991) assumed that q was 1 (i.e., equation (1)), however, the Laurec-Shepherd tuned VPA provides estimates of predicted q_a from the series of survey indices I_a, which can be used to re-estimate values of I_a from equation (3). In running Laurec-Shepherd tuned VPAs for this report this procedure was iterated until the values of q_a and, therefore estimated abundance, stabilised.

Additional VPA runs were performed with 'raw' unstandardised survey indices for comparison with the results of those tuned using standardised indices. Raw and standardised survey abundance indices are given in Tables 2(a) and 2(b). The age distribution from the US/Polish survey in 1987/88 has been slightly amended since that presented in Parkes (1991), following the discovery of a small error in the allocation of ages 2 and 3 in the age/length key used previously (Basson *et al.*, 1989).

2.1.3 Effort Indices

VPA runs tuned to indices of CPUE used at WG-FSA-91 (Gasiukov, 1990 and 1991) were performed for comparison with the performance of survey tuning. An attempt was also made to combine the raw survey and standardised CPUE indices in one index to allow their use in a single run of the MAFF VPA. Using both survey and CPUE indices in one VPA run at WG-FSA-91 proved to be impossible, due to the absence of a CPUE index for 1991 (SC-CAMLR, 1991). A more recent version of the MAFF VPA is understood to have been written, which allows specification of separate weights for estimation of mean ln q from different tuning indices (allowing specific down-weighting of a dummy value of CPUE for 1991), however, this version was not available at the time of writing.

A standardised, combined index was simply derived as follows:

For years y and ages a with both survey indices I_{ay} and CPUE indices U_{ay}, the combined index A_{ay} was estimated as:

$$A_{ay} = \left(\frac{I_{ay}}{\overline{I_a}} + \frac{U_{ay}}{\overline{U_a}} \right) \bullet \frac{1}{2} \qquad (4)$$

where $\overline{I_a}$ is the mean survey index at age a over all years and $\overline{U_a}$ is the mean CPUE index at age a over all years.

For years with survey indices only:

$$A_{ay} = \frac{I_{ay}}{\overline{I_a}}$$

and for years with CPUE indices only:

$$A_{ay} = \frac{U_{ay}}{\overline{U_a}}$$

Equation 4 assumes equal weighting between the two indices in years when they are both available. The indices used here are shown in Table 2(c).

2.1.4 Bottom Row (Terminal Age) Fs

These are calculated in the MAFF VPA as a fixed proportion of the mean of Fs from a specified number of younger Fs for that year. The default is one times the mean of the four younger Fs (i.e., for *C. gunnari* age 1 to 6+ this represents the mean of ages 1 to 4). The bottom row Fs for the MAFF VPA runs presented here were calculated as the mean of ages 2 to 4. The bottom row Fs in the ADAPT program were population weighted averages of all younger Fs, except for the final year, which was based on the selection pattern, averaged over the four most recent years.

2.2 VPA RUNS

Several VPA runs were performed for comparison, using both Laurec-Shepherd and ADAPT tuning techniques.

2.2.1 MAFF VPA, Using Laurec-Shepherd Tuning

Survey indices were prepared for Laurec-Shepherd tuning in both raw, unstandardised form and standardised according to the method described in Section 2.1. The calculation of predicted q was either weighted by the inverse variance of the survey estimates, as in Parkes (1991), or it was unweighted. The details of inputs to individual runs are given in Table 2.

2.2.2 ADAPT VPA (Pascal Version)

Raw survey indices and standardised indices of fishing effort (Gasiukov, 1990 and 1991) were used both separately and in the same run for tuning the ADAPT VPA. Details of the inputs are also provided in Table 2. The indices were input as two fleets in the ADAPT3 run and as one combined index in the ADAPT4 run (as for run MAFF6). Initial estimates of population size in the final year for the ADAPT tuning were taken from a Laurec-Shepherd tuned VPA run with the same input data. The ADAPT procedure was constrained by limiting the possible difference between this initial estimate and the new estimate produced by minimising the sum of squared differences between observed and predicted abundance (Gavaris, 1988). In practice this constraint was set at different levels for each set of input data to assess whether the ADAPT procedure had genuinely converged or had simply reached its limits. Diagnostics from each iteration of each run were available to monitor the progress of the analysis.

3. RESULTS OF THE VPAS

3.1 MAFF VPA Runs

The outputs from the various MAFF VPA runs described in Table 2 are summarised in Tables 3 to 8. Total biomass (age 2+) is shown in Figure 3. Of the runs tuned to survey indices only (1 to 4) all show similar patterns of dynamics with the population in the most recent years dominated by the year class spawned in late 1985/86, recruiting as 1 year olds in 1987/88. The relative strength of the year class varies between runs, being particularly strong in run MAFF1. MAFF3 is similar to run 1 in Parkes (1991). The overall biomass is slightly larger, but the revision of the standardisation method and difference in calculation of bottom row Fs have had little effect on the dynamics of the population. The effect of using the standardised survey indices with equal weighting (run MAFF4) was to greatly reduce the overall estimated abundance due to higher q values, however, the standard errors on the predicted values of ln q were the largest of the survey tuned runs by a large margin, indicating an unreliable result.

The run tuned to CPUE (MAFF5) resulted in a much larger estimated population size in recent years (up to 1990) than the survey tuned runs. The population was again heavily dominated by the year class recruiting as 1 year olds in 1987/88. Combination of the two indices in the final Laurec-Shepherd tuned VPA (run MAFF6) resulted in an abundance estimate in between runs MAFF2 and MAFF5. It was, however, much closer to the former than the latter, due to the lack of a CPUE index for the most recent year of the VPA (1991). Some weighting factor could be introduced into equation 4 to adjust the balance of influence between the two indices if required. The fishable biomass in 1990/91 was again dominated by 4 year olds, as with all of the Laurec-Shepherd tuned VPA runs.

Age distributions of the biomass, projected to 1991/92 (age 2+) from runs 1 to 5 are illustrated in Figure 6, along with the age distribution from the *Falklands Protector* survey in January 1992. The population structure predicted by the VPA appears to be fairly robust with a variety of inputs. Comparison of these predictions with the observed age distribution highlights the same problem as illustrated in Figure 2. The large proportion of 5 year olds consistently predicted by the VPA was not observed during the survey.

3.2 ADAPT Runs

ADAPT runs 1 to 4 provided no satisfactory results. The constraint was set to its maximum possible value (initial estimate ±99%), however, in all cases one or more of the age groups reached their limit of abundance, indicating that the procedure was unable to converge. Diagnostics of runs ADAPT1 and ADAPT2 are presented in Table 9 as an illustration. These tables show the abundance (numbers of fish) by age group in the projected year (1992 for ADAPT1 and 1991 for ADAPT2).

The failure of the ADAPT to produce reasonable estimates for age group 2 in the projected year is understandable, due to the uncertainty associated with the estimate of recruitment (1 year olds) in the final year of the VPA. Table 9a, however, shows that run ADAPT1 was aiming to produce estimates in excess of double those produced by Laurec-Shepherd tuning (abundance + step) and similarly predicted a large proportion of 5 year olds in 1991/92.

Table 9b shows that run ADAPT2 (tuned to effort indices) produced estimates of abundance for ages 2 and 3 within the set limits, however, age group 4 reached the lower limit of its permitted range. The initial estimates for ADAPT2 came from MAFF5 (Table 7). It appears from Table 7 that the 1987 year class (4 year olds in 1991) was probably over estimated by MAFF5, and ADAPT2 would have reached a more sensible result had it not been constrained by the lower limit for this age group. A further ADAPT run was performed (ADAPT5), with a more appropriate starting estimate and limits for the 1987 year class. This run succeeded in converging within its limits and the results are shown in Table 10, with residuals plotted in Figure 5. No attempt was made to re-run the analysis following the masking of outlying residuals.

Total biomass (age 2+) from runs MAFF5 and ADAPT5, both tuned using the standardised effort data from Gasiukov (1990 and 1991) is compared in Figure 6. ADAPT5 produced much lower estimates of abundance in the most recent years than MAFF5. The picture of year class strength, however, is consistent with other runs, and projections from the end of the VPA again predict a high abundance of 4 year olds in 1990/91, and hence 5 year olds in 1991/92.

4. DISCUSSION OF THE VPA RESULTS

All of the VPA runs presented in this document show inconsistencies between the age structure for 1991/92 and that observed during the UK survey in Subarea 48.3 in January 1992. It is not expected that these two independent estimates should coincide completely, however, had a TAC been set for 1991/92 based on the assumption that the VPA results were reliable, the fishery would have probably targeted 2 and 3 year old fish, due to the apparent absence of the predicted abundance of 5 year olds. This could have had a potentially catastrophic effect on the population, which was already under stress according to the results of the 1990/91 UK survey (Everson *et al.*, 1992a; Everson *et al.*, 1991 and Kock *et al.*, 1992). The decision taken by CCAMLR to close the *C. gunnari* fishery in Subarea 48.3 for the 1991/92 season appears to have been vindicated by the results of the recent UK survey (CCAMLR, 1991; Everson *et al.*, 1992b).

The reasons for this discrepancy are uncertain, however, a number of possible sources are potentially responsible. The VPA assumes constant M both between years and between ages over the period of the analysis. This assumption is almost certainly violated to some extent in all fish populations, however, both UK and Soviet surveys in Subarea 48.3 during 1989/90 and 1990/91 revealed that there had been a massive reduction in the standing stock of *C. gunnari* between these two seasons, in the absence of commercial fishing (SC-CAMLR, 1991).

The UK survey results between 1989/90 and 1990/91 can be used to estimate values of total mortality Z by year and age class using Baranov's method (Baranov, 1914), where:

$$Z = -\ln\left(\frac{N_{(a+1,y+1)}}{N_{a,y}}\right) \qquad (5)$$

The results are presented in Table 11. Given the large uncertainty associated with survey abundance estimates, this method should only be employed with caution, however, it is worth investigating. There has been virtually no reported catch of *C. gunnari* in Subarea 48.3 in 1990/91 and 1991/92, hence these values of Z could be considered to be indicative of either natural mortality or a loss of fish from the area by some other mechanism such as migration. Whatever the mechanism, assuming the fish will not return at some future time, they can be considered to be lost to the fishery. This could therefore be represented in the assessment as an increase in M for that particular period. These results are clearly not particularly reliable, although the values for 3, 4 and 5 year olds in 1991 and 4, 5 and 6 year olds in 1992 are reasonably consistent, and they do serve to emphasise the magnitude of the change in apparent mortality. Changes in M were not taken into account in the VPA and may therefore represent one explanation of its failure to produce credible results for the most recent years.

There may also be problems with the catch at age data itself. The tendency for *C. gunnari* in years of high abundance to aggregate in age specific groups has been reported (Kock, 1979; Parkes *et al.*, 1990). Given the likelihood that the commercial fishery exploits aggregations as they are encountered, the exploitation pattern in a given year may depend more upon which aggregations are encountered rather than the selectivity of the trawl. During the UK survey in January 1990, for instance, commercial trawlers were observed exploiting an aggregation to the north west of South Georgia, which was sampled and found to consist almost exclusively of 3 year old fish. No length distribution from the commercial fishery was available for that period. It was necessary to use information from samples collected during the survey to produce an *ad hoc* commercial length and age distribution for the catch-at-age in that year (Parkes, 1991). Other aggregations were encountered during the same survey, however, which apparently consisted almost exclusively of 2 year olds, calling into question the validity of the assumed age distribution of the catch in that year. Similarly in other years the assumed commercial age distribution will depend upon where the length and age samples were taken from, in comparison to the actual distribution of the fishery.

The overall length distributions for the surveys are calculated by weighting samples from individual stations by the catch rate. In order for this distribution to be representative of the population in years when aggregations are encountered, it must be assumed that the catch rates encountered at the aggregations are proportional to the abundance and the length frequency samples taken are representative of the whole aggregation. The degree to which this is true is unknown, hence the overall length distribution may contain unknown bias. This may be true for the 1989/90 survey at least in terms of the proportions of 2 and 3 year olds. Unfortunately insufficient fine-scale catch and biological data is currently available through CCAMLR to investigate this further.

No aggregations were encountered during the surveys of the following two seasons hence they probably do not suffer from the same problem. It is possible that the 4 and 5 year old fish predicted by the VPA in 1990/91 and 1991/92 respectively were aggregated into patches which were missed by the surveys. There is evidence, however, from other sources that the drop in abundance between 1989/90 and 1990/91 indicated by the surveys was genuine. Commercial trawlers failed to locate any viable concentrations of *C. gunnari* in Subarea 48.3 in December/January 1990/91 and acoustic surveying between and around sampling stations during both the 1990/91 and 1991/92 did not detect any fish concentrations.

The 'background count' of *C. gunnari* biomass outside the aggregations during the 1989/90 *Hill Cove* survey was of the order of 7 600 tonnes. This indicates that there may be a 'sink' effect which draws fish spread out over the shelf in towards these areas of high abundance. The hypothesis that the 1990/91 and 1991/92 surveys missed aggregations, which were present on the shelf, suggests that the observed standing stock represented this 'background count'. Assuming the observed ratio between the background biomass and aggregated biomass in January 1990, for the two proceeding surveys to have failed to detect the aggregated biomass, the total biomass in 1990/91 and 1991/92 would have to have been of the order of 400 000 tonnes, which seems unlikely. The more plausible scenario is that the fall in standing stock indicated by the surveys is genuine and needs to be taken into account in the assessment.

5. ASSESSMENT FOR 1991/92

The VPA has apparently broken down in the most recent years due to conflicting information in the input data. It is therefore necessary to devise an alternative method of assessing the current status of the fishery and the potential effect of setting a TAC for 1992/93.

One approach is to use the results of the two most recent surveys, which show a reasonably consistent picture of total biomass, and project forwards to 1992/93 and 1993/94, assuming either no catch (maintenance of the current closure) or a catch based on a target F, such as $F_{0.1}$, in 1992/93. Projected recruitment of 1 year olds was input as a mean value with a log-normal error. Mean recruitment and the variance of $\log_e$ recruitment were taken from the VPA between 1977 and 1986, prior to the period where the analysis apparently broke down. These parameters were very consistent between runs and were taken from the MAFF6 run (898 000 individuals and 0.45 respectively). Annual recruitment, R was generated independently for each year on each run as follows:

$$R = \overline{R} \bullet e^{\left(x - \frac{\sigma^2}{2}\right)} \quad (6)$$

where $\overline{R}$ = mean recruitment
$X = \sqrt{\sigma^2} \bullet Z$
σ^2 = variance of $\log_c$ recruitment
Z = normal (0,1) random variable

The value of σ^2 was well within the range of values listed for other marine species (Beddington and Cooke, 1983). Each projection was run 500 times to simulate recruitment uncertainty and 95% confidence limits. The results of all projections are presented in Table 12 and Figure 7.

The survey biomass estimate from January 1991 (with 1 year olds in 1991 replaced by the simulated value) was projected forwards one year and compared to the survey result in January 1992. The projected biomass of 2 to 6 year olds in 1992 was higher than that estimated from the survey, largely due to the size of the 2 year old age class. This may be an indication that the recruitment of 1 year olds in 1991 was lower than estimated using mean recruitment from the early part of the VPA. The 1992 survey estimate was then projected forwards 2 years, with the 1 year olds being replaced by a simulated value, firstly with no fishing in 1992/93 and then assuming a catch at the $F_{0.1}$ level, calculated under the same assumptions used in Parkes (1991) and at WG-FSA-91 ($F_{0.1} = 0.39$, with knife edge selection at age 2).

In the absence of fishing the mean biomass was projected to grow to about 137 000 tonnes (95% confidence limits L_1 = 62 700, L_2 = 277 000) by 1993/94, with a healthy increase in the biomass of 4 and 5 year olds.

The $F_{0.1}$ catch level in 1992/93 was estimated to be in the region of 24 000 tonnes (95% confidence limits L_1 = 15 200, L_2 = 43 600), however, about 50% of this was composed of 2 year olds and was thus highly dependent on the estimated recruitment of 1 year olds in 1991/92. The mean recruitment from the VPA was estimated over a period when the fishery was generally in a more healthy state than it appears to be at present. Any projections relying heavily on this mean recruitment should therefore be treated with caution. Following this catch in 1992/93 the biomass was projected to grow to about 111 000 tonnes (95% confidence limits L_1 = 49 400, L_2 = 241 000) in 1993/94. The lower limit of the 95% confidence interval on the total biomass, however, was lower in 1993/94, following the catch, than it was in 1992/93.

Given the uncertainty surrounding the current status of and future recruitment to the *C. gunnari* fishery in Subarea 48.3, a conservative approach to management is appropriate in the immediate future. The wisdom of re-opening the fishery and setting a TAC in 1992/93 is questionable. A more prudent policy would be to maintain the current closure until the degree of uncertainty in the stock status is reduced. In the event that a TAC is considered appropriate, the lower 95% confidence limit given above (15 200 tonnes) is likely to allow the stock a reasonable chance of recovery over the next few years. The proportion of 2 year olds in the projected catch in 1992/93 at this level is reduced to about 25%, thus relying less heavily on the assumed recruitment of 1 year olds in 1991/92.

6. SUMMARY

1. Attempts were made to run a satisfactory VPA on *C. gunnari* in Subarea 48.3 using Laurec-Shepherd and ADAPT tuning techniques, from 1991 back to 1977.

2. Various combinations of survey and CPUE indices were used.

3. The VPA does not account for the massive decline in population size detected by the surveys between 1989/90 and 1990/91 in the absence of fishing.

4. According to the VPA the population in 1991/92 was composed of a large proportion of 5 year olds, which was not observed during the survey on *Falklands Protector* in January 1992.

5. Breakdown in the credibility of the VPA results in most recent years is attributed to the invalid assumption of constant M and contradictions in the input data.

6. A conservative approach to management for 1992/93 is recommended, based on the results of surveys by *Falklands Protector* in 1990/91 and 1991/92.

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Table 1: Data inputs into VPA runs.

Run Code	Period	Source of Catch-at-Age	Source of Mean Weight at Age	M	Tuning Indices	Weighting of Mean in q
MAFF1	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Raw survey indices	Inverse variance of surveys
MAFF2	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Raw survey indices	Equal weighting
MAFF3	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Standardised survey indices	Inverse variance of surveys
MAFF4	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Standardised survey indices	Equal weighting
MAFF5	1977 to 1990	WG-FSA-91	WG-FSA-91	0.48	Fishing effort indices	Equal weighting
MAFF6	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Combination of fishing and raw survey indices	Equal weighting
ADAPT1	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Raw survey indices	--
ADAPT2	1977 to 1990	WG-FSA-91	WG-FSA-91	0.48	Fishing effort	--
ADAPT3	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Raw survey indices and fishing effort	--
ADAPT4	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Combination of fishing effort and raw survey indices	--
ADAPT5	1977 to 1990	WG-FSA-91	WG-FSA-91	0.48	Fishing effort adjusted starting value	--

Table 2: Tuning data for VPAs.

2(a) unstandardised survey indices
MAFF1 and MAFF2

Year	Effort	1	2	3	4	5	6+
1987	100	17265	298562	181115	15760	1831	257
1988	100	18858	36456	52004	5248	570	202
1989	100	364220	57940	29350	15696	2156	663
1990	100	93622	721231	164021	10382	760	1688
1991	100	190078	53809	42303	17741	1039	343

2(b) standardised survey indices with inverse variance weighting
Final iteration, MAFF3

Year	Effort	1	2	3	4	5	6+
1987	100	20361	386123	393315	19685	2952	436
1988	100	27444	40603	250980	17764	21182	5841
1989	100	464062	230921	104067	23952	18234	3958
1990	100	114350	880914	200336	12681	928	2061
1991	100	241636	68574	54401	22570	1324	437

2(c) standardised survey indices with equal weighting
Final iteration, MAFF4

Year	Effort	1	2	3	4	5	6+
1987	100	21581	558201	442349	24449	4824	747
1988	100	33312	80530	298979	51662	64483	17630
1989	100	476836	987750	122175	39959	54354	11220
1990	100	114350	880914	200336	12681	928	2061
1991	100	241636	69391	54571	22642	1332	439

2(d) combined survey and effort indices
MAFF6; ADAPT4

Year	Effort	1	2	3	4	5	6+
1981	100	1869.8	8558.9	2827.3	1985.3	1554.8	2464.6
1982	100	21280.3	17080.3	9720	25026.5	19051.3	33089.6
1983	100	25825.8	16851.1	12112	19269.2	16264	27478.7
1984	100	7496.2	20577.4	7222.9	7961.6	1311.5	411.5
1985	100	5377.2	13945.1	13715.7	7748.6	1092.3	3809.2
1986	100	10319.3	8619.6	3500.2	8119.7	2798.2	1075.9
1987	100	2706.7	8783.6	18601.3	8681.1	9053	3503.2
1988	100	3931.3	960.7	5616.6	8040.9	16145.9	19625
1989	100	21038.1	4982.9	2739.5	9163.5	21177	17410.5
1990	100	4292.8	16304.9	21237.5	7217.3	3501.3	13412.1
1991	100	13893.7	2303.5	4511.9	13683.3	8173.4	5439.3

Table 3: Output: run MAFF1.

Table 3a: Fishing Mortality F at age (Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0112	0.0002	0	0.0012	0.0195	0.0572	0.1694	0.0049	0.0367	0.0846	0.0095	0.0768	0.0166	0
2	0.0136	0.9682	0.0334	0.1226	0.5333	0.2685	0.5092	0.8977	0.0569	0.0618	0.8211	0.2928	0.2612	0.0402	0.0032
3	2.8582	0.3615	0.0285	0.1615	0.1823	0.271	1.4655	1.4773	1.0712	0.1933	1.1724	1.1619	0.9779	0.116	0.0052
4	4.0118	0.8608	0.0346	0.4592	0.1085	0.4226	0.9637	2.5751	0.8839	0.1383	0.2175	0.6374	0.6427	0.8855	0.0006
5	2.2945	0.7302	0.0322	0.2478	0.2747	0.3207	0.9794	1.652	0.6816	0.133	0.737	0.6974	0.6281	0.3479	0.003
+gp	2.2945	0.7302	0.0322	0.2478	0.2747	0.3207	0.9794	1.652	0.6816	0.133	0.737	0.6974	0.6281	0.3479	0.003

Table 3b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189300	328747	684480	1260337	2267894	826719	586741	791778	1348092	756022	107093	1140116	174089	138022	463068
2	32614	117135	201166	423476	779875	1401621	501660	342878	413609	830065	450978	60894	698788	99762	83996
3	209650	19909	27526	120387	231796	283120	663053	186557	86460	241786	482837	122775	28115	333012	59296
4	228126	7443	8582	16555	63384	119529	133604	94762	26349	18328	123318	92511	23772	6543	183502
5	41615	2555	1947	5130	6472	35189	48470	31539	4465	6737	9877	61391	30262	7735	1670
+gp	4957	1400	1312	3255	4309	25674	16597	6311	1339	1307	1642	16714	6084	3762	835

Table 3c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5012	9384	19629	35701	65590	23397	17977	26119	38698	23066	3075	30292	4909	4337	13429
2	2471	9570	16511	34332	64553	113532	43990	32373	33981	72483	37060	4631	56398	8972	7453
3	32348	3312	4600	19873	39067	46694	118387	35864	14463	42990	80790	19010	4620	60981	10713
4	59151	2081	2410	4592	17952	33128	40087	30614	7407	5476	34675	24071	6565	2013	55712
5	15996	1059	811	2109	2717	14458	21559	15104	1861	2984	4117	23679	12389	3529	752
+gp	2602	793	746	1828	2471	14407	10082	4128	762	791	935	8805	3402	2344	513
age 2+	112568	16815	25078	62734	126760	222219	234105	118083	58474	124724	157577	80196	83374	77839	75143
Total	117580	26199	44707	98435	192350	245616	252082	144202	97172	147790	160652	110488	88283	82176	88572

Table 4: Output: run MAFF2.

Table 4a: Fishing Mortality F at age (MAFF output Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0112	0.0002	0	0.0012	0.0196	0.0575	0.1786	0.0051	0.0378	0.0899	0.0213	0.1209	0.0313	0
2	0.0136	0.9685	0.0334	0.1227	0.5337	0.2686	0.5113	0.9057	0.0604	0.0643	0.8591	0.3151	0.7082	0.0657	0.0061
3	2.8584	0.3617	0.0285	0.1616	0.1824	0.2713	1.467	1.4935	1.0962	0.2069	1.2613	1.3156	1.1274	0.4767	0.0085
4	4.012	0.8611	0.0346	0.4595	0.1086	0.423	0.9659	2.5936	0.9135	0.1441	0.2365	0.7636	0.8834	1.3159	0.003
5	2.2947	0.7304	0.0322	0.2479	0.2749	0.321	0.9814	1.6661	0.7014	0.1405	0.7857	0.7981	0.9064	0.6196	0.0059
+gp	2.2947	0.7304	0.0322	0.2479	0.2749	0.321	0.9814	1.6661	0.7014	0.1405	0.7857	0.7981	0.9064	0.6196	0.0059

Table 4b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189266	328554	684062	1259483	2267011	824119	583570	753795	1297820	734238	101027	513483	112791	73883	307084
2	32602	117114	201046	423218	779346	1401075	500051	340915	390134	798957	437499	57141	311040	61846	44309
3	209646	19901	27513	120313	231636	282797	662716	185572	85283	227262	463591	114659	25801	94794	35837
4	228124	7441	8577	16547	63339	119430	133404	94570	25789	17632	114345	81263	19037	5171	36415
5	41614	2555	1946	5127	6467	35161	48409	31420	4374	6401	9447	55850	23432	4869	858
+gp	4957	1400	1311	3253	4306	25653	16576	6287	1312	1242	1571	15206	4711	2368	429

Table 4c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5011	9379	19617	35676	65564	23324	17880	24866	37255	22402	2901	13643	3181	2322	8905.45
2	2471	9568	16501	34311	64510	113487	43849	32188	32052	69766	35952	4345	25104	5562	3932
3	32348	3311	4598	19860	39040	46641	118327	35675	14267	40407	77570	17753	4240	17359	6475
4	59151	2080	2409	4590	17939	33101	40027	30552	7250	5268	32152	21144	5257	1591	11056
5	15995	1059	810	2108	2715	14446	21532	15047	1823	2835	3938	21542	9592	2221	386
+gp	2602	792	745	1827	2469	14395	10070	4112	747	751	894	8010	2634	1475	264
age 2+	112567	16810	25063	62696	126673	222070	233805	117574	56139	119027	150506	72794	46827	28208	22113
Total	117578	26189	44680	98372	192237	245394	251685	142440	93394	141429	153407	86437	50008	30530	31018

Table 5: Output: run MAFF3.

Table 5a: Fishing Mortality F at age (MAFF output Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0112	0.0002	0	0.0012	0.0196	0.0575	0.1788	0.0051	0.0378	0.0916	0.0165	0.2365	0.0182	0
2	0.0136	0.9685	0.0334	0.1227	0.5337	0.2686	0.5112	0.9053	0.0604	0.064	0.8622	0.3226	0.5032	0.1418	0.0035
3	2.8584	0.3617	0.0285	0.1616	0.1824	0.2713	1.467	1.4933	1.0952	0.2071	1.2514	1.3293	1.1837	0.2753	0.0193
4	4.012	0.861	0.0346	0.4595	0.1086	0.423	0.9659	2.5932	0.9132	0.1438	0.2369	0.7482	0.9099	1.5577	0.0015
5	2.2947	0.7304	0.0322	0.2479	0.2749	0.321	0.9814	1.6658	0.7009	0.1404	0.7835	0.8	0.8663	0.6591	0.0082
+gp	2.2947	0.7304	0.0322	0.2479	0.2749	0.321	0.9814	1.6658	0.7009	0.1404	0.7835	0.8	0.8663	0.6591	0.0082

Table 5b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189267	328558	684070	1259502	2267031	824149	583702	753156	1303047	732554	99163	661075	60706	126617	336023
2	32603	117114	201049	423223	779358	1401087	500070	340997	389739	802192	436458	55988	402366	29652	76939
3	209646	19901	27513	120315	231639	282804	662724	185583	85333	227018	465592	114033	25091	150530	15923
4	228124	7441	8577	16547	63340	119432	133409	94574	25795	17661	114194	82428	18675	4753	70727
5	41615	2555	1946	5127	6467	35162	48410	31422	4376	6405	9464	55757	24137	4652	619
+gp	4957	1400	1311	3253	4306	25654	16576	6287	1313	1243	1574	15180	4853	2262	310

Table 5c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5011	9379	19617	35677	65565	23324	17884	24845	37405	22350	2847	17564	1712	3979	9744.67
2	2471	9568	16501	34311	64511	113488	43851	32195	32020	70049	35867	4257	32474	2667	6827
3	32348	3311	4598	19861	39040	46642	118328	35677	14275	40364	77905	17656	4123	27565	2877
4	59151	2080	2409	4590	17939	33101	40029	30553	7252	5277	32109	21447	5157	1463	21473
5	15995	1059	810	2108	2715	14446	21532	15048	1824	2837	3945	21506	9881	2122	279
+gp	2602	792	745	1827	2469	14395	10070	4112	747	752	896	7997	2713	1410	190
age 2+	112567	16810	25063	62697	126674	222072	233810	117585	56118	119279	150722	72863	54348	35227	31646
Total	117578	26189	44680	98374	192239	245396	251694	142430	93523	141629	153569	90427	56060	39206	41391

Table 6: Output: run MAFF4.

Table 6a: Fishing Mortality F at age (MAFF output Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0112	0.0002	0	0.0012	0.0196	0.0577	0.1839	0.0052	0.0384	0.0943	0.0264	0.2787	0.0998	0
2	0.0136	0.9686	0.0334	0.1228	0.534	0.2687	0.5123	0.9095	0.0624	0.0654	0.8819	0.3343	0.9769	0.1735	0.0204
3	2.8585	0.3617	0.0285	0.1617	0.1825	0.2715	1.4678	1.5018	1.1087	0.2148	1.3044	1.422	1.2774	0.9294	0.0241
4	4.0121	0.8612	0.0346	0.4596	0.1086	0.4233	0.9671	2.603	0.9293	0.1471	0.2479	0.8351	1.1187	2.1739	0.0076
5	2.2948	0.7305	0.0322	0.248	0.275	0.3212	0.9824	1.6732	0.7116	0.1446	0.8114	0.8638	1.1243	1.0923	0.0174
+gp	2.2948	0.7305	0.0322	0.248	0.275	0.3212	0.9824	1.6732	0.7116	0.1446	0.8114	0.8638	1.1243	1.0923	0.0174

Table 6b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189249	328458	683853	1259058	2266570	822803	582048	733938	1276133	722118	96451	415789	52471	23903	262146
2	32597	117103	200987	423088	779083	1400802	499237	339974	377862	785538	430000	54311	250590	24570	13386
3	209645	19898	27507	120276	231556	282635	662548	185073	84719	219670	455289	110153	24057	58374	12782
4	228123	7440	8575	16543	63316	119381	133305	94474	25506	17299	109655	76440	16443	4150	14260
5	41614	2554	1946	5126	6465	35147	48379	31360	4329	6231	9241	52955	20520	3324	292
+gp	4957	1400	1310	3252	4305	25643	16565	6275	1299	1209	1536	14417	4125	1617	146

Table 6c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5011	9376	19611	35664	65551	23286	17833	24211	36632	22032	2769	11047	1480	751	7602.25
2	2470	9567	16496	34300	64488	113465	43778	32099	31044	68595	35336	4130	20225	2210	1188
3	32347	3310	4597	19854	39026	46614	118297	35579	14172	39057	76181	17055	3953	10689	2309
4	59150	2080	2408	4589	17933	33087	39998	30521	7170	5169	30833	19889	4541	1277	4329
5	15995	1058	810	2108	2714	14440	21518	15018	1804	2760	3852	20425	8401	1516	131
+gp	2602	792	745	1827	2468	14389	10063	4104	739	731	875	7595	2307	1007	90
age 2+	112564	16807	25056	62678	126629	221995	233654	117321	54929	116312	147077	69094	39427	16699	8047
Total	117575	26183	44667	98342	192180	245281	251487	141532	91561	138344	149846	80141	40907	17450	15649

Table 7: Output: run MAFF5.

Table 7a: Fishing Mortality F at age (MAFF output Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0111	0.0002	0	0.0012	0.0188	0.0539	0.0996	0.0035	0.0265	0.0271	0.0047	0.0562	0.0117	
2	0.0137	0.9649	0.0332	0.1217	0.5277	0.2671	0.4852	0.8174	0.0318	0.0437	0.5228	0.0829	0.1198	0.029	
3	2.8592	0.3646	0.0283	0.1602	0.1807	0.2668	1.4475	1.3077	0.855	0.1025	0.6784	0.4718	0.1768	0.0477	
4	4.0193	0.8622	0.0349	0.4561	0.1075	0.4176	0.9368	2.3754	0.6346	0.0947	0.1042	0.229	0.1385	0.071	
5	2.2974	0.7382	0.0322	0.2507	0.2719	0.3172	0.9565	1.5002	0.5071	0.0803	0.4351	0.2613	0.1451	0.0492	
+gp	2.2974	0.7382	0.0322	0.2507	0.2719	0.3172	0.9565	1.5002	0.5071	0.0803	0.4351	0.2613	0.1451	0.0492	

Table 7b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189707	331067	689494	1270696	2278520	858280	622322	1304431	1887491	1041284	325409	2323563	235716	981493	
2	32386	117387	202601	426579	786285	1408197	521190	364892	730619	1163835	627487	195972	1431084	137889	
3	209631	19768	27676	121275	233714	287043	667111	198526	99701	437933	689347	230198	111619	785586	
4	228061	7434	8495	16648	63933	120715	136025	97074	33222	26237	244595	216452	88864	57873	
5	41598	2535	1942	5076	6529	35529	49198	32985	5585	10898	14768	136369	106520	47875	
+gp	4955	1390	1308	3221	4347	25922	16846	6600	1675	2115	2456	37127	21415	23283	

Table 7c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5023	9450	19772	35994	65897	24290	19067	43031	54182	31770	9343	61735	6647	28463.3	
2	2454	9590	16628	34583	65084	114064	45703	34451	60026	101628	51565	14902	115501	12401	
3	32345	3288	4625	20019	39390	47341	119111	38165	16678	77864	115344	35642	18343	143855	
4	59134	2078	2386	4618	18108	33457	40814	31361	9339	7839	68776	56319	24541	17809	
5	15989	1051	809	2087	2741	14597	21883	15797	2327	4827	6156	52599	43607	21839	
+gp	2601	786	744	1809	2493	14546	10234	4317	954	1279	1398	19559	11974	14506	
age 2+	112523	16793	25192	63116	127816	224005	237745	124091	89324	193437	243239	179021	213966	210410	
Total	117546	26243	44964	99110	193713	248295	256812	167122	143506	225207	252582	240756	220613	238873	

Table 8: Output: run MAFF6.

Table 8a: Fishing Mortality F at age (MAFF output Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0112	0.0002	0	0.0012	0.0196	0.0574	0.1734	0.0051	0.0371	0.0849	0.0183	0.0624	0.0171	0
2	0.0138	0.9682	0.0334	0.1226	0.5332	0.2685	0.5096	0.9018	0.0584	0.0632	0.8362	0.2942	0.574	0.0323	0.0033
3	2.8617	0.3665	0.0285	0.1615	0.1823	0.271	1.4652	1.4807	1.0839	0.1992	1.2214	1.22	0.9868	0.3361	0.0041
4	4.022	0.8658	0.0352	0.4592	0.1085	0.4226	0.9635	2.571	0.8899	0.1412	0.2257	0.7039	0.7235	0.9055	0.0019
5	2.2992	0.7411	0.0324	0.2526	0.2747	0.3207	0.9794	1.6512	0.6774	0.1345	0.7611	0.7394	0.7614	0.4246	0.0031
+gp	2.2992	0.7411	0.0324	0.2526	0.2747	0.3207	0.9794	1.6512	0.6774	0.1345	0.7611	0.7394	0.7614	0.4246	0.0031

Table 8b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189301	328758	684483	1260391	2268091	826174	585116	774641	1319370	747083	106679	597966	212866	134033	359725
2	32247	117136	201173	423478	779908	1401743	501323	341872	403017	812292	445447	60638	363316	123752	81528
3	209586	19681	27526	120391	231797	283140	663128	186351	85857	235233	471841	119442	27957	126636	74140
4	228038	7414	8442	16555	63387	119530	133617	94804	26231	17972	119269	86073	21819	6449	55995
5	41588	2528	1930	5043	6472	35191	48470	31546	4485	6666	9656	58891	26347	6549	1613
+gp	4954	1386	1300	3200	4309	25675	16597	6312	1346	1293	1606	16033	5297	3185	807

Table 8c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5012	9385	19629	35702	65595	23382	17927	25554	37873	22793	3063	15887	6003	4212	10432
2	2444	9570	16511	34332	64556	113541	43961	32278	33111	70931	36606	4611	29323	11129	7234
3	32338	3274	4600	19873	39067	46698	118400	35825	14363	41824	78951	18494	4594	23189	13395
4	59128	2073	2371	4592	17953	33129	40091	30627	7374	5370	33537	22396	6026	1984	17000
5	15985	1048	804	2074	2717	14458	21559	15108	1869	2953	4025	22715	10786	2987	726
+gp	2601	784	739	1797	2471	14407	10082	4129	766	782	914	8446	2962	1984	496
age 2+	112496	16749	25025	62668	126764	222233	234093	117967	57483	121860	154033	76662	53691	41273	38851
Total	117508	26134	44654	98370	192359	245615	252020	143521	95356	144653	157096	92549	59694	45485	49283

Table 9a: Diagnostics from ADAPT run 1.

Iteration 1
Sum of Squares Before = 16.1489719
Sum of Squares After = 7.69898365

Age	Step	Abundance	Lower	Upper
2	758927.1	511994.7	56888.3	511994.7
3	68532.9	48967.7	5440.9	48967.7
4	61048.2	39522.2	4391.4	39522.2
5	-8464.519	13974.22	4487.748	40389.74

Iteration 2
Sum of Squares Before = 7.6989
Sum of Squares After = 7.6371

Age	Step	Abundance	Lower	Upper
2	479375.0	511994.7	56888.3	511994.7
3	87561.4	48967.7	5440.9	48967.7
4	90385.9	39522.2	4391.4	39522.2
5	18317.84	32292.07	4487.748	40389.74

Iteration 3
Sum of Squares Before = 7.6989
Sum of Squares After = 7.6247

Age	Step	Abundance	Lower	Upper
2	401364.3	511994.7	56888.3	511994.7
3	90106.2	48967.7	5440.9	48967.7
4	97896.9	39522.2	4391.4	39522.2
5	18243.62	40389.74	4487.748	40389.74

Iteration 4
Sum of Squares Before = 7.6247
Sum of Squares After = 7.6247

Age	Step	Abundance	Lower	Upper
2	421498.4	511994.7	56888.3	511994.7
3	90550.2	48967.7	5440.9	48967.7
4	98327.9	39522.2	4391.4	39522.2
5	11522.07	40389.74	4487.748	40389.74

Table 9b: Diagnostics from ADAPT run 2.

Iteration 1
Sum of Squares Before = 2.4797
Sum of Squares After = 2.0307

Age	Step	Abundance	Lower	Upper
2	114988.7	213126.1	23680.7	213126.1
3	72360.4	147940.3	16437.8	147940.3
4	-1092739.0	91727.6	91727.6	825548.1
5	-33484.48	6585.022	6585.022	59265.2

Iteration 2
Sum of Squares Before = 2.0307
Sum of Squares After = 1.7111

Age	Step	Abundance	Lower	Upper
2	102845.7	213126.1	23680.7	213126.1
3	-142262.0	16437.8	16437.8	147940.3
4	-51958.0	91727.6	91727.6	825548.1
5	8077.638	14662.66	6585.022	59265.2

Iteration 3
Sum of Squares Before = 1.7111
Sum of Squares After = 1.4163

Age	Step	Abundance	Lower	Upper
2	-41128.5	171997.6	23680.7	213126.1
3	43415.7	59853.5	16437.8	147940.3
4	-88923.5	91727.6	91727.6	825548.1
5	-3257.323	11405.34	6585.022	59265.2

Iteration 4
Sum of Squares Before = 1.4163
Sum of Squares After = 1.3283

Age	Step	Abundance	Lower	Upper
2	-65508.9	106488.7	23680.7	213126.1
3	17594.5	77447.9	16437.8	147940.3
4	-61969.6	91727.6	91727.6	825548.1
5	1087.835	12493.17	6585.022	59265.2

Table 9b (continued)

Iteration 5
Sum of Squares Before = 1.3283
Sum of Squares After = 1.2975

Age	Step	Abundance	Lower	Upper
2	-13089.2	93399.5	23680.7	213126.1
3	-14931.7	62516.2	16437.8	147940.3
4	-44679.8	91727.6	91727.6	825548.1
5	-296.8229	12196.35	6585.022	59265.2

Iteration 6
Sum of Squares Before = 1.2975
Sum of Squares After = 1.2926

Age	Step	Abundance	Lower	Upper
2	-7697.1	85702.4	23680.7	213126.1
3	7268.0	69784.2	16437.8	147940.3
4	-50192.0	91727.6	91727.6	825548.1
5	-225.2508	11971.1	6585.022	59265.2

Iteration 7
Sum of Squares Before = 1.2926
Sum of Squares After = 1.2904

Age	Step	Abundance	Lower	Upper
2	-1700.9	84001.6	23680.7	213126.1
3	-4586.5	65197.7	16437.8	147940.3
4	-45321.2	91727.6	91727.6	825548.1
5	103.072	12074.17	6585.022	59265.2

Table 10: Output: run ADAPT5.

Table 10a: Fishing Mortality F at age

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.01	0.0002	0	0.0012	0.019	0.0581	0.163	0.0049	0.0354	0.0511	0.0194	0.0787	0.0172	
2	0.0092	1.0984	0.0299	0.1227	0.5135	0.2623	0.4925	0.9174	0.0544	0.0613	0.7771	0.1643	0.6246	0.0413	
3	2.8274	0.2317	0.0351	0.1432	0.1824	0.2558	1.3853	1.351	1.138	0.1837	1.1525	1.015	0.4056	0.3841	
4	4.1552	0.8204	0.0205	0.6029	0.0947	0.4242	0.8725	1.8852	0.6895	0.154	0.2048	0.6132	0.479	0.1959	
5	3.1714	0.9092	0.0298	0.1388	0.417	0.2717	0.9871	1.21	0.2563	0.0907	0.8769	0.6358	0.5867	0.2228	
+gp	3.1714	0.9092	0.0298	0.1388	0.417	0.2717	0.9871	1.21	0.2563	0.0907	0.8769	0.6358	0.5867	0.2228	

Table 10b: Stock number at age, start of year

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	175528	365897	683090	1299238	2317218	849700	578295	820957	1359158	782804	174179	562472	169960	422354	
2	47838	108613	224157	422616	803946	1432140	515871	337632	431601	836914	467546	102406	341365	97207	
3	209897	29329	22408	134618	231305	297698	681692	195073	83473	252933	487068	133008	53766	113108	
4	227137	7685	14394	13387	72185	119259	142638	105560	31261	16552	130250	95197	29826	22178	
5	38132	2204	2093	8727	4533	40632	48285	36885	9915	9707	8780	65669	31904	11431	
+gp	4545	1206	1414	5539	3014	29624	16529	7391	2980	1881	1457	17870	6398	5565	

Table 10c: Stock biomass at age with sop correction, start of year

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5090	10611	19810	37678	67199	24641	16771	23808	39416	22701	5051	16312	4929	12248	
2	3971	9015	18605	35077	66728	118868	42817	28023	35823	69464	38806	8500	28333	8068	
3	35473	4957	3787	22750	39091	50311	115206	32967	14107	42746	82314	22478	9086	19115	
4	64507	2183	4088	3802	20501	33870	40509	29979	8878	4701	36991	27036	8471	6299	
5	16054	928	881	3674	1908	17106	20328	15529	4174	4087	3696	27647	13432	4812	
+gp	2613	693	813	3185	1733	17034	9504	4250	1713	1082	838	10275	3679	3200	
age 2+	122617	17775.4	28174.1	68488.5	129960.05	237188	228365	110748	64695.7	122079	162646	95935.9	63000.8	41494.3	
Total	127707	28386.4	47983.7	106166	197159.37	261829	245135	134556	104111	144780	167697	112248	67929.6	53742.6	

Table 11: Estimates of Z from surveys using the Baranov method.

age in 1991 >>	2	3	4	5	6
Z 1990 to 1991	0.55	2.84	2.22	2.30	0.80
age in 1992 >>	2	3	4	5	6
Z 1991 to 1992	0.10	*	1.21	1.92	1.36

* N age 3 in 1992 > N age 2 in 1991.

Table 12: Projection results.

	Total Biomass (tonnes), age 2+, Subarea 48.3					
	1990/91 Survey	1991/92 Survey	1992/93 Projection	1993/94 Projection without catch	1992/93 Catch at $F_{0.1}$	1993/94 Projection With Catch
Upper 95%			154139	277226	43621	240564
Mean	22400 cv 16%	38000 cv 18%	87005	137350	24289	110791
Lower 95%			52065	62707	15175	49371

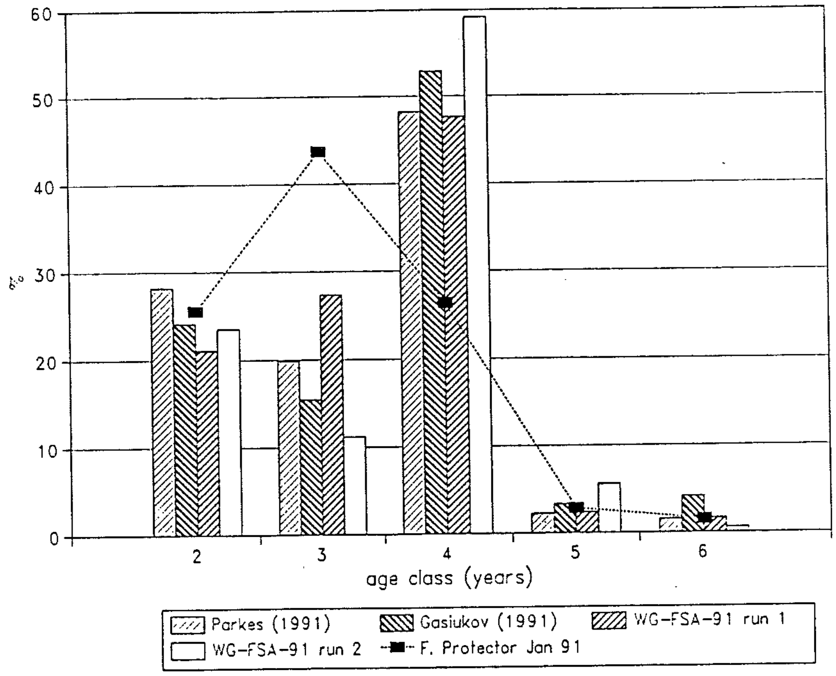

Figure 1: Age distribution of biomass (age 2+) - observed and estimated 1990/91.

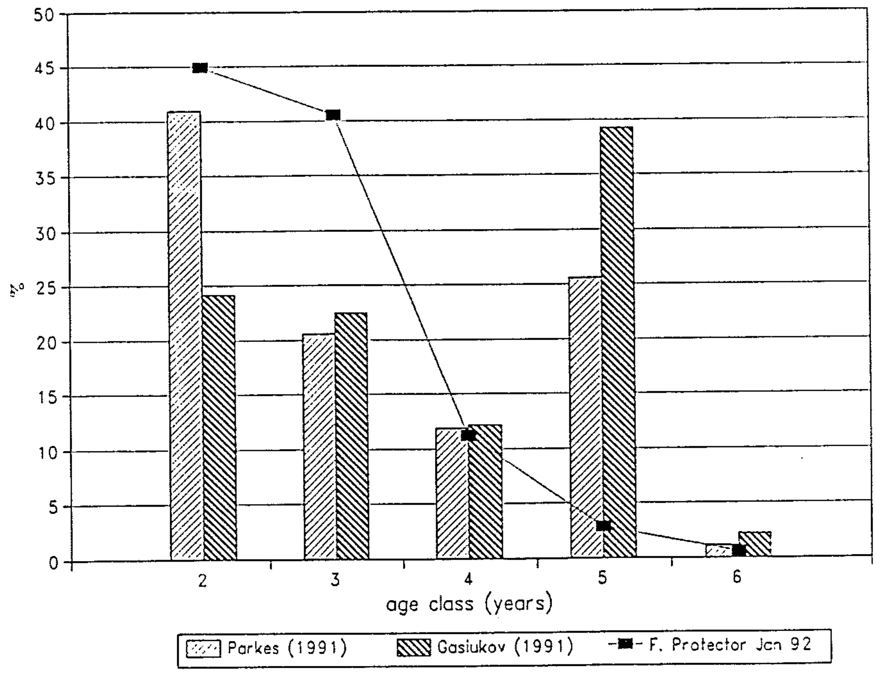

Figure 2: Age distribution of biomass (age 2+) - observed and predicted 1991/92.

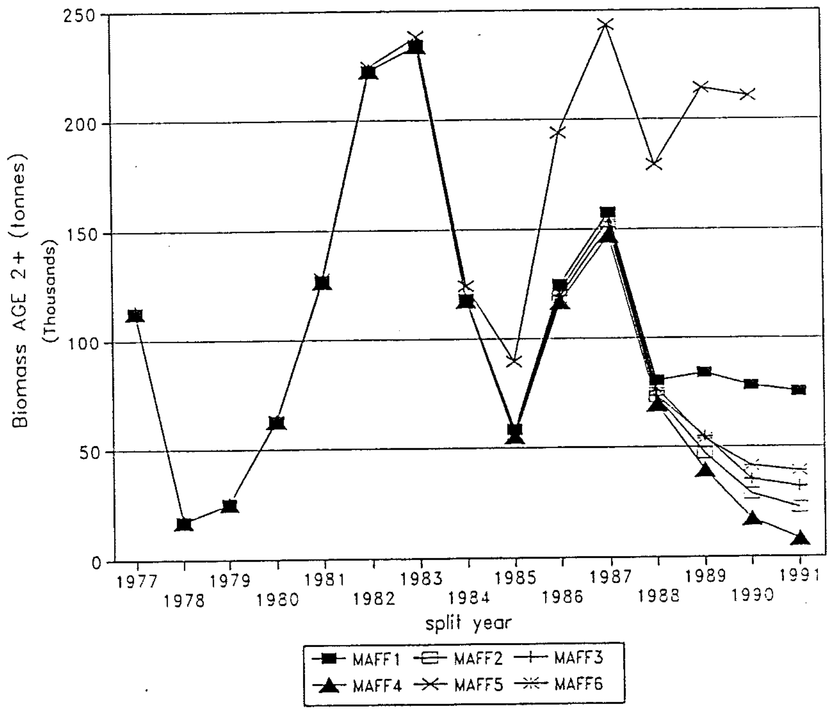

Figure 3: Comparison of VPA runs - total biomass age 2+.

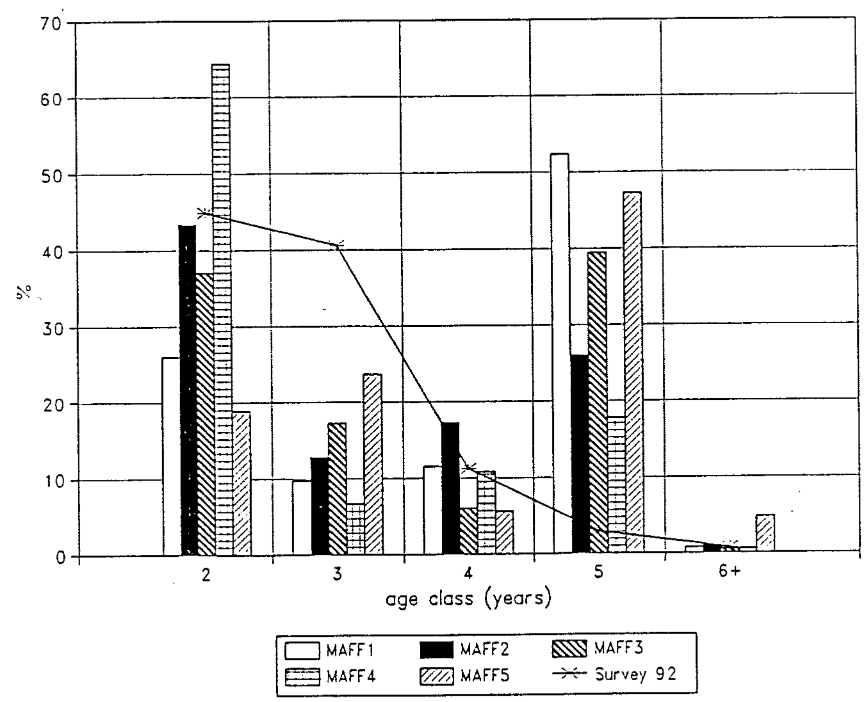

Figure 4: VPA projection and survey 1991/92. Age distribution of biomass (age 2+).

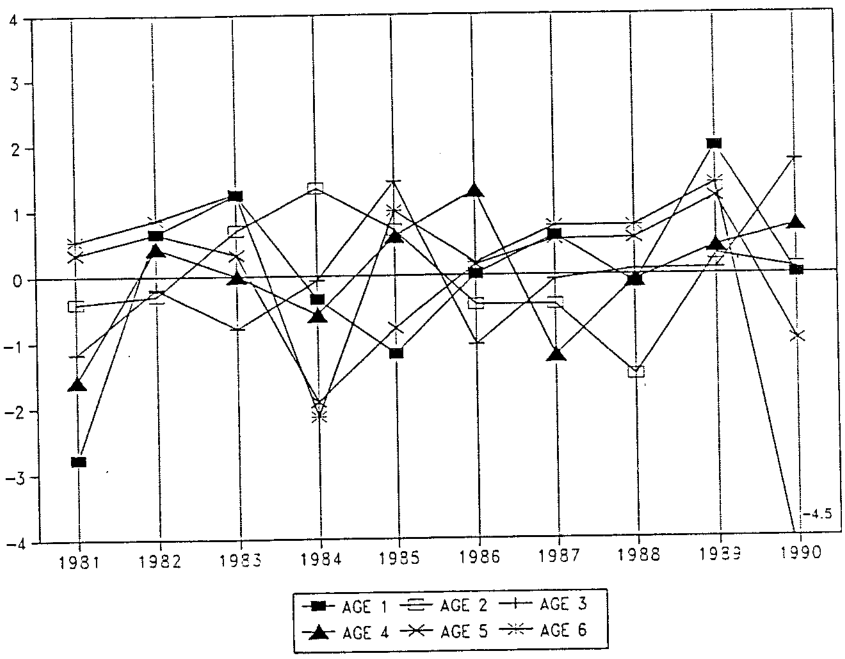

Figure 5: Log_e residuals from ADAPT run 5 (CPUE index).

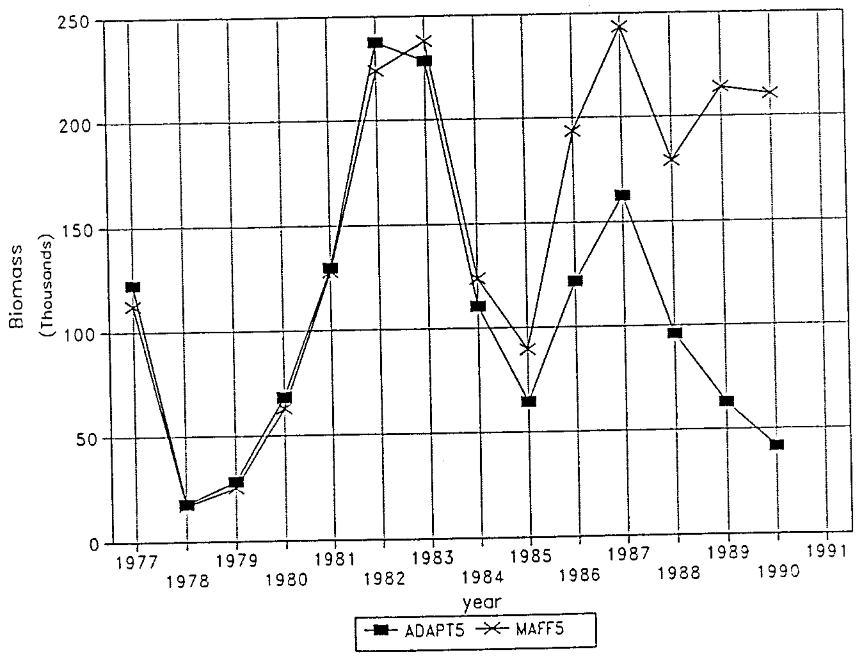

Figure 6: Comparison of results of runs MAFF5 and ADAPT5 (CPUE tuned - total biomass (age 2+).

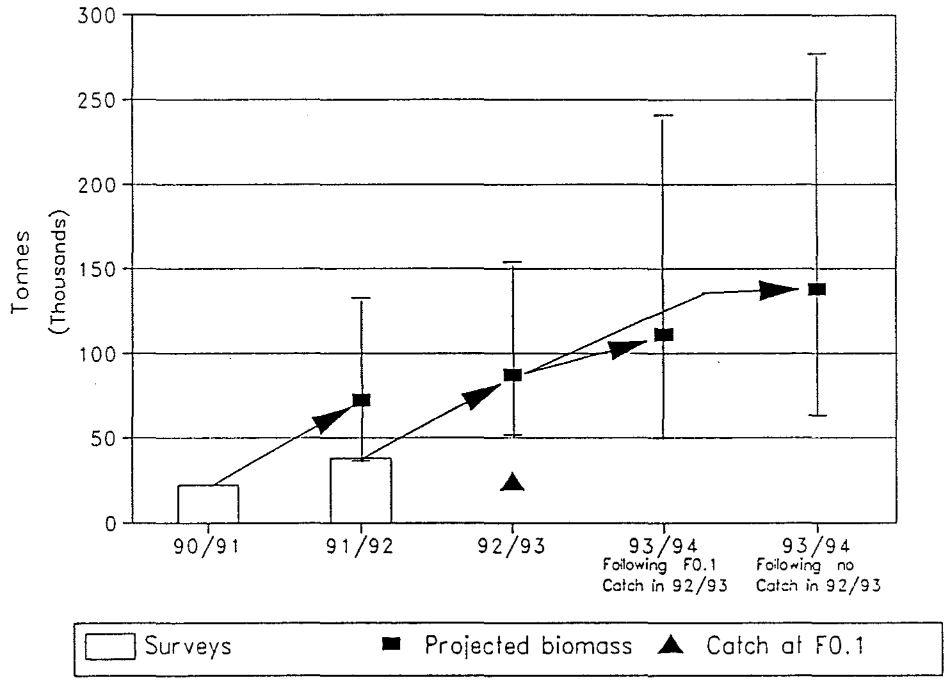

Figure 7: Projection scenarios with variable recruitment (total biomass age 2+).

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