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Stock assessment of trevally (*Caranx georgianus*) in TRE 7

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1. EXECUTIVE SUMMARY

The research reported in this document was part of a study conducted by NIWA for the Ministry of Fisheries under contract TRE9701. This report summarises the input data available for the stock assessment, describes the development of a stock assessment model to analyse these data, and presents the results of a preliminary stock assessment of TRE7.

Input data used in the modelling included catch history, CPUE indices, trawl survey indices, and proportion-at-age data. In addition to the reported QMS landings, allowance was made for mortality due to discarded fish, recreational catch, customary catch, and non-reported catch in the development of a catch history for modelling. Both unstandardised and standardised CPUE indices were fitted in the model. Both series were taken from the single trawl trevally fishery and covered the periods 1978 to 1997 and 1990 to 1997 respectively. Proportion-at-age data was available for the 1997–98 fishing year. These data were examined for spatial, temporal, and fishing method differences in selectivity. Although spatial and temporal differences in size and age distribution were evident in the data, it was decided to model the fishery with a single selectivity pattern. Proportion-at-age for ages 3 to 19 with a plus group at age 2 were fitted in the model. Estimates of 1 and 2 year old fish were available for 1986 to 1996 from the west coast North Island trawl surveys and were fitted in the model with relatively high *c.v.*s so as to down-weight their influence relative to the other input data.

The trevally fishery was modelled using a separable Sequential Population Analysis. The model assumed an initial equilibrium age structure, and catches were taken using the Baranov catch equation. The model was implemented using AD Model Builder software. Weights were assigned to each data set at values that represented the levels of confidence in the various data sets. An estimate of the confidence came from a consideration of both the estimated variance and possible bias inherent in the data.

Simulated data were used to estimate confidence limits for the results. Several sources of uncertainty were included in the procedure. A number of sensitivity analyses were carried out to examine the sensitivity of the model results to alternative model assumptions. Yield per recruit analysis was carried to obtain equilibrium yield estimates.

There is considerable uncertainty over biomass and yield estimates in the assessment. This uncertainty arises from a number of sources including uncertainty over the input data sets used to tune the model, the input parameters (in particular M), the model structure, and the harvest rates. Despite the uncertainty, it appears that the stock is still in the fishing down phase and is still well above B_{may}. Recent catch levels and the current TACCs appear sustainable and will allow the stock to remain above a size that will support the MAY.

2. INTRODUCTION

The research reported in this document was part of a study conducted by NIWA for the Ministry of Fisheries under contract TRE9701. The first two objectives of the contract included the collection and analysis of length and age composition data from the commercial TRE 7 fishery (Walsh *et al.* 1999), and the analysis of commercial catch and effort data from that fishery (Francis *et al.* 1999). No quantitative assessment of the trevally stocks has previously been carried out, so the aim of this part of the study was to develop a model to analyse these data and to subsequently carry out a stock assessment. The objectives of this part of the study were:

1. to develop a stock assessment model for TRE 7;

2. to carry out a stock assessment for TRE 7, including the estimation of biomass and sustainable yield if a relative abundance index is available.

This report summarises the input data available for the stock assessment, describes the development of a stock assessment model to analyse these data, and presents the results of the 1999 stock assessment of TRE 7.

3. MODEL INPUTS

3.1 Catch history

The catch history of the trevally fishery was described in detail by James (1984) and Francis *et al.* (1999). Both stated that the reported catches before 1970 underestimate the true catches of trevally due to large-scale discarding of fish. There has also been a recreational and customary catch as well as an illegal or non-reported catch. In the development of a catch history for modelling, allowance has been made for mortality due to discarded fish, recreational catch, customary catch, and non-reported catch. The following values for each type of catch were reached by consensus within the Inshore Working Group.

James (1984) obtained estimates of the rate of discards from experienced trawl fishermen and concluded that before 1955 more than 50% of the trevally caught was dumped. His estimates for discards over the subsequent years were 30% by 1960, 10% by 1965, dropping to zero by 1970. He reported the mortality of discarded trevally as ranging from 20% to 80%, and for his work assumed a mortality of 50%. James's figures on discards and mortality of discards were used to estimate the tonnage of dead discarded fish (Table 1).

Estimates of the number of trevally harvested by recreational fishers for TRE 7 were 62000 fish in the 1993–94 survey and 65000 fish in the 1996 survey, with the latter representing an estimated harvest of 69 t or 5% of the total catch (Annala *et al.* 1999). For modelling, recreational catches were assumed to be 70 t since 1970. Recreational catches were assumed to decline linearly from 70 t in 1970 to 14 t (20% of the 1970 level) by 1944 (*see* Table 1).

Customary Maori catches of 15 t, 10 t, and 12 t, were assumed for the periods 1944 to 1959, 1960 to 1979, and 1980 onwards respectively (*see* Table 1).

Allowance has also been made for non-reported catches (i.e., catches which have been landed but not reported in the log book system). The level of non-reporting is unknown, but as for the snapper assessment (Annala *et al.* 1999) a level of 20% before 1986 and 10% from 1986 onwards was assumed for the assessment (*see* Table 1).

The estimated total catch given in Table 1 was used for the modelling.

3.2 Catch-at-age data

On the basis of historical fishing patterns, the TRE 7 fishery was sampled during the peak season (October-May) and off-peak season (June-September), and for two methods (pair-trawl and single trawl) (Walsh *et al.* 1999). Length data were firstly scaled up to the weight of the landing and secondly up to the commercial catch for each method/time period before being examined for differences. Length composition was similar for single and pair trawl and, because pair trawl accounted for only 2% of the total, data from both methods were combined. Temporal differences in the length composition for single trawls were found between peak and off peak seasons, and spatial (north/south) differences were found within the peak season (Walsh *et al.* 1999). Proportionally fewer larger fish were taken during the off-peak period and in the south of the sampling area. If spatial and temporal patterns persist in future sampling some consideration may need to be given to modelling these differences explicitly. However, for the current assessment the length distributions were combined using the proportional commercial catch as a weighting factor (Figure 1).

Scaled numbers at length were converted to catch-at-age via an age-length key. The age-length key, which comprised 378 otoliths collected from spatially diverse pair and single trawl landings, was obtained during January and February 1998. This key is assumed representative of the age composition of the entire TRE 7 stock. The scaled numbers at length and numbers at age are shown in Figure 1 and the proportion at age in Table 2. Between-reader variability increased in older ages and so a plus group was arbitrarily assigned at age 20.

3.3 Natural mortality

James (1984) estimated total mortality of trevally caught by research trawl in the western Bay of Plenty using catch curve analysis. He obtained estimates ranging from 0.61 to 0.76 for younger fish (ages 0–6), 0.03 for older fish (ages 7–34) and 0.3 for the oldest fish (ages 35–46). James ascribed the high Z in the early ages to a high fishing mortality in recent years and considered that values for the older ages constituted estimates of natural mortality (M). A further analysis based on the range 6 to 43 years yielded an estimate of 0.06. In his yield per recruit analysis, James (1984) assumed a value of 0.03 for all ages up to 34, and a value of 0.3 thereafter. Annala *et al.* (1999) considered that the value of 0.03 was likely to be conservative. They provide an estimate of M using the equation $M = \log_e 100/\text{maximum age}$. Using a maximum age of 45 years, M was estimated to be 0.1.

It was beyond the scope of this study to revisit the estimate of M from the earlier studies. A value of 0.03 appears to be very low compared to other species found in New Zealand waters, whereas a value of 0.1 is clearly inconsistent with the estimates from James. A recent unpublished estimate of M based on catch curve analysis for snapper, a species with similar growth characteristics and slightly longer lifespan than trevally, equalled 0.075 (*in* Annala *et al.* (1999). Based on the available data at the time, a value of M of 0.1 was chosen for all ages and years for the base case assessment. Sensitivity tests were conducted using values of 0.05, 0.075, and 0.15, which were thought to encompass the range of likely values. It should be emphasised that M is not well known, and may also vary with age, which could have quite serious implications for the modelling work.

3.4 Weight at age

Weight at age was calculated from the age length key by converting length to weight using the length-weight coefficients given in Annala *et al.* (1999), and then calculating the mean weight for each age class and the plus group. The corresponding mean weight at age is given in Table 2.

3.5 CPUE data

Catch per unit effort (CPUE) indices were calculated for the trevally fishery by Francis *et al.* (1999). Because of changes in the recording forms three separate time periods were analysed: 1974–85, 1983–89, and 1989–97. Unstandardised indices were calculated for each of these periods for single trawlers, small pair trawlers, and large pair trawlers (where data were available). Francis *et al.* (1999) concluded that single trawlers were the most consistent vessel class throughout the time period, with relatively stable amounts of effort between 1980 and 1997. Indices for small pair trawl and large pair trawl were available only for the periods from 1973–74 to 1993–94 and from 1976–78 to 1984–85 respectively.

For a particular method, the CPUE indices were similar for the years of overlap between the periods suggesting that they could be used as a single series. The data for single trawl were therefore combined into a single series by averaging the indices between the series in the years of overlap (Table 3).

After the analysis was completed it was realised that these unstandardised indices were on the log scale. A sensitivity analysis was carried out using the back-transformed CPUE indices to determine the effect of this on the model results.

Standardised CPUE indices were also calculated separately for the target snapper and trevally single trawl fisheries from 1989–90 to 1996–97 (*see* Table 3) (Francis *et al.* 1999). Because there were a large number of zero tows in the snapper target fishery, only the standardised series based on the trevally fishery was fitted in the model,

3.6 Trawl survey data

Estimates of 1 and 2 year old trevally biomass were calculated for the west coast North Island spring trawl surveys by Morrison & Stevenson (unpubl. results), and are given in Table 4. It is suspected that catchability of trevally may not be constant from year to year, but may be affected by factors such as temperature and water clarity (Annala *et al.* 1999, Francis *et al.* 1999). Therefore, these estimates should be regarded as uncertain. To account for this uncertainty, the trawl pre-recruit biomass estimates were converted to numbers and fitted in the model with relatively high *c.v.*s.

4. STOCK STRUCTURE

Little is known of stock structure in trevally. Tagging in the Bay of Plenty and Hauraki Gulf suggested some movement of trevally along the northeast coast of the North Island (Gilbert 1988). Differences in growth rates between TRE 1 and TRE 7 appear slight (James 1984, Walsh *et al.* 1999) and are not sufficient to suggest that the stocks are separate (Gilbert 1988). James (1984) and Walsh *et al.* (1999) found significant differences in size and age distribution between different parts of TRE 7. However, these are not large enough to warrant separate stock status, and electrophoretic studies by Gauldie & Johnston (1980) suggest that trevally along the west coast of the North Island probably belong to one stock. For the stock assessment, it has therefore been assumed that fish from the west coasts of the North and South Island form a single stock.

5. MODEL SPECIFICATION

5.1 Model specification

The trevally fishery was modelled using a separable Sequential Population Analysis (sSPA) (Fournier & Archibald 1982, Hanchet *et al.* 1998). The overall sSPA model approach is essentially the same as that used in recent stock assessments of southern blue whiting (Hanchet 1998a) and gemfish (Hurst *et al.* 1998). However, because there was only one year of catch-at-age data, an initial equilibrium age structure was assumed (following Hanchet 1998b).

The model developed to analyse the fishery is an extension of the approach outlined by Fournier & Archibald (1982). Errors associated with the observed catch, the proportion-at-age, fishing effort and pre-recruit biomass estimates are all explicitly considered in the model. The fits to the total catch and the catch-at-age data are kept separate following Fournier & Archibald (1982), which has allowed incorporation of variability into the age determination process. The catch is taken throughout the year with a peak in the summer months during the spawning season, so the Baranov catch equation was used. Although several fishing methods have been used in the trevally fishery, currently the main fishing method is single trawl. During the last two seasons less than 5% of the catch was taken by pair trawl (Francis *et al.* 1999, Walsh *et al.* 1999). Furthermore, catch-at-age sampling during 1997–98 suggested that the single trawl and small pair trawl methods take very similar sized fish. Therefore, it has been modelled as a single method fishery.

The form of the catch equations used in the model is given by the following relationships.

$$C_{ij} = \frac{F_{ij}}{Z_{ij}}\left[1 - \exp(-Z_{ij})\right]N_{ij}w_j$$

$$Z_{ij} = F_{ij} + M$$
$$N_{i+1,j+1} = \exp(-Z_{ij})\ N_{ij}$$
$$N_{i+1,a} = \exp(-Z_{i,a-1})N_{i,a-1} + \exp(-Z_{ia})N_{ia}$$

where,

i	indexes year,
j	indexes age class,
a	is the number of age classes,
C_{ij}	is the catch (in weight) of age class *j* fish in year *i*,
F_{ij}	is the instantaneous fishing mortality rate for age class *j* in year *i*,
M	is the instantaneous natural mortality,
Z_{ij}	is the instantaneous total mortality rate for age class *j* during the fishing period in year *i*,
N_{ij}	is the number of age class *j* fish in the population at the beginning of year *i*,
w_j	is the weight of fish in age class *j*.

Initial conditions

The initial age structure is assumed to be:

$$N_{0j} = R_0 \exp^{-M(j-1)} \qquad \text{for } 1 \leq j \leq a\text{-}1$$

and for the plus group

$$N_{0j} = R_0 \exp^{-M(a-1)} / (1 - \exp^{-M}) \qquad \text{for } j = a$$

where,

$$R_0 = R.\overline{N}_{i1}$$

where, log*R* is a scalar estimated by the model,

$$\log \overline{N}_{i1} = \sum_{i=Ryrs}^{i=nyrs-3} \log N_{i1} \,/\, (nyrs - 3 - Ryrs + 1)$$

where, *Ryrs* is the first year where year class strength is estimated, and *nyrs* is the number of years in the model.

Regression approach and objective functions

Fishing mortality is treated as a function of the observed fishing effort ($\widetilde{E}_i$), catchability (*q*), and age-specific selectivity (s_j). Examination of the proportion-at-age data suggested that the fish were fully selected at age 4 (*see* Table 2). Therefore, selectivity of age 3 fish was estimated and older fish were assumed to be fully selected. When proportion-at-age data for more years become available this assumption can be tested. The relationships describing observed fishing effort, expected fishing effort (E_i), and fishing mortality are:

$$E_i = \widetilde{E}_i \exp(d_i^E)$$

and $$F_{ij} = q s_j \widetilde{E}_i$$

where, d_i^E represent deviations in the effort-fishing mortality relationship, and q is an abundance scalar.

Following Fournier & Archibald (1982), we assume that the age-composition samples adhere to a multinomial sampling distribution and that annual total catch estimates are independent and log-normally distributed. The negative of the log-likelihood function for the catch-at-age model is then

$$-n_i \widetilde{p}_{ij} \ln p_{ij} + \sigma_C \sum_i \left(\ln(\widetilde{C}_i) - \ln(C_{i\cdot})\right)^2 + \sigma_E \sum_i (d_i^E)^2$$

where n_i is the sample size, $\widetilde{p}_{ij}$ and p_{ij} are the observed and predicted proportion of fish of age j in year i respectively. $\widetilde{C}_i$ is the observed catch in year i, and σ_C and σ_E are standard deviations for catch and effort which are described below.

Additional components were added to the negative of the log-likelihood function to tune the model to the trawl survey estimates of 1 and 2 year old fish and the standardised CPUE index. The trawl survey estimates were assumed to represent indices of recruitment and modelled as estimates of 3 year old fish of the appropriate year class.

The standardised CPUE index was fitted as an index of mid-season biomass.
The model estimates of mid-season biomass (B_i) are:

$$B_i = \sum_j s_j w_j \exp(-0.5 Z_{ij}) N_{ij}$$

The following terms are added to the negative of the log-likelihood function:

$$\sigma_F \sum \left(\ln(\widetilde{F}_i) - \ln(q_F B_i)\right)^2 + \sigma_T \sum \left(\ln(\widetilde{T}_{i-2}) - \ln(q_T N_{i3})\right)^2 + \sigma_U \sum \left(\ln(\widetilde{U}_{i-1}) - \ln(q_U N_{i3})\right)^2$$

where:

σ_F σ_T σ_U	are the standard deviations of the CPUE index, and trawl survey indices of 1 and 2 year olds respectively
$\widetilde{F}_i$	is the CPUE index for each year
$\widetilde{T}_{i-2}$ $\widetilde{U}_{i-1}$	are the trawl survey indices of 1 and 2 year olds in years i - 2 and i - 1 respectively
T_i U_i	are the estimates of 3 year olds

q_F q_T q_U are the abundance scalars

The model was implemented using AD Model Builder software (Fournier 1994), which gave simple and ready access to minimisation routines, and provided the ability to estimate the variance-covariance matrix for all dependent and independent parameters of interest. The parameters being estimated when minimising the negative log-likelihood function are ln(N_{i1}), d_i^E, logR, s_j, q, q_F, q_T, and q_U. The first two groups of parameters are estimated in the model as a vector of deviations from a common mean and constrained so that they sum to zero.

5.2 Weightings

It was not possible to estimate the various standard deviations (σ_F, σ_T, σ_U) so they were fixed at values that represented our levels of confidence in the various data sets. A convenient way to do this was in terms of weights where $w_x = \sigma_x^{-2}$, for each variate *x*, and the corresponding *c.v.*s are given for each dataset considered. An estimate of the confidence came from a consideration of both the estimated variance and possible bias inherent in the data. Where appropriate, weights can be assigned different values between years.

To allow for some uncertainty in the annual catch, a weight equivalent to a *c.v.* of 5% was given to each year's catch.

Weights were assigned to the proportion-at-age based on the sample size in a multinomial distribution.

Sample size (ss) $= \dfrac{1-p}{cv^2 * p}$, where p = proportion at age and cv = *c.v.* of age class

The precision of data collected from this fishery suggests a sample size of over 100 (equivalent to a *c.v.* of 20%) is warranted for the stronger well determined year classes (*see* Figure 1). However, the standard multinomial sampling process is not robust to violations of assumptions (Fournier & Archibald 1982). A number of factors, including ageing error, sampling bias, and non-conformity with the model assumption of separability, would all lead to the sample size being inflated relative to the true deviations of predicted versus observed proportions-at-age. The sample size was therefore reduced to 100 in the model.

A weight of 2 (equivalent to a *c.v.* of 50%) was used for each trawl survey data point which is consistent with the *c.v.*s from the surveys (*see* Table 4). There is no reason to believe that the biomass was better estimated in any of the years, so the indices were given equal weighting for each year.

A weight of 5 (equivalent to a *c.v.* of 32%) was used for the unstandardised CPUE series. The standardised CPUE indices estimated by the general linear model were considered to be more reliable than the unstandardised indices by the Working Group and were given a weight of 10 (equivalent to a *c.v.* of 22%).

5.3 Estimation of confidence intervals

Simulated data were used to estimate confidence limits for the results. Several sources of uncertainty were included in the procedure. The individual otolith length-age data within individual years were resampled (with replacement) and then scaled up to catch-at-age using the weighted length frequency of the catch for that year. (Uncertainty in the weighted numbers at length was not included because these appeared to be reasonably well determined for most length classes.) Uncertainty in the two trawl survey indices, the standardised and unstandardised CPUE data, and the annual catch was captured by assuming the data were log-normally distributed with *c.v.s* of 50%, 50%, 22%, 32%, and 5%, respectively. For each of the 500 bootstrap runs data were randomly selected from each distribution. The percentile method was used to estimate confidence intervals (Effron 1981): the estimate of the 90% confidence interval was computed as the 5th and 96th points in the set of bootstrap estimates after sorting them into ascending order.

5.4 Sensitivity analysis

A number of sensitivity analyses were carried out to examine the sensitivity of the model results to alternative model assumptions. These included the relative weightings given to the catch-at-age, CPUE, and trawl survey data, the value used for M, and the number of recruitments (N_{i1}) being estimated. A sensitivity analysis was also carried out using the back-transformed CPUE indices to determine the effect of this on the model results (*see also* Section 3.5).

Details of the input parameters for the base case and sensitivity runs are given in Table 5.

5.5 Yield estimates

A yield per recruit analysis was carried out using the same parameters as those used in the base case assessment to obtain equilibrium yield estimates. Selectivity of 3 year olds was assumed to be 0.08 to be consistent with the estimate from the model. The results of the yield per recruit analysis are given in Table 6. MAY represents the equilibrium yield under a $F_{0.1}$ fishing policy (Annala *et al.* 1999). All calculations were made under the assumption of no stock-recruit relationship.

6. RESULTS

6.1 Biomass estimates

The results of the base case assessment suggest a steady decline in biomass through the 1960s and 1970s followed by a levelling off during the 1980s and 1990s (Figure 2, Table 7). The slight dip and increase in biomass in the past five years is a result of recruitment in those years being estimated in the model. The model is unable to fit the steep increase in the early part of the unstandardised CPUE index series or the standardised CPUE index (*see* Figure 2). (Note the back-transformed unstandardised CPUE indices were a lot more variable than the $\log_{10}$CPUE indices shown in the figures.) The model estimates good recruitment in 1998 (the 1995 year class) and a low selectivity (0.08) of these 3 year old fish. However, these two parameters are strongly negatively correlated (r = -0.8) and are poorly estimated by the model. When more years of proportion-at-age data are available and fitted in the model the selectivity and the size of recruiting year classes should be better estimated.

The median biomass trajectory and 90% confidence intervals are shown in Figure 3. These suggest a reasonably high level of uncertainty in the assessment. The median bootstrap biomass trajectory was considerably lower than the trajectory from the base case assessment.

The sensitivity of the results to changes in the input parameters is summarised in Table 8. The assessment was sensitive to most parameters investigated. When one or 10 year classes were estimated in the model the estimated historical and current biomasses were lower than in the base case (Figure 4). When 10 year classes were estimated in the model, there was a better fit to the trawl survey indices, but a poorer fit to the CPUE indices and the proportion-at-age (Figure 5). When only one year class was estimated in the model, there was a better fit to the CPUE indices but a worse fit to the trawl survey indices and the proportion-at-age (Figure 6).

The results were also sensitive to the weighting (sample size) used for the proportion-at-age data (Figure 7, Table 8). When the age data were given more weight (ss = 200), historical and current biomass were lower and the diagnostic fits similar to the base case (Figure 8). When the age data were downweighted (ss = 10), or not fitted at all (ss = 0), historical and current biomass were considerably higher (Figure 8). The model also estimated the 1994 and 1995 year classes to be large (because of the high trawl survey index of 2 year olds in 1996) and this resulted in a large increase in biomass in the final year (Figure 9). This large increase is probably an artefact of the model. If the CPUE index had extended into 1998 at the existing 1997 level the biomass would probably have remained more constant.

The model results were also moderately sensitive to the *c.v.* used for the trawl survey index (Figure 10), and to M (Figure 11), but was not sensitive to the *c.v.* used for the CPUE indices (Figure 12). Lower biomass estimates resulted when the trawl or CPUE indices were not fitted in the model and at a lower value for M, and vice versa (Table 8).

When the back-transformed unstandardised CPUE indices were fitted in the model there was slight increase in virgin and current biomass.

6.2 Yield estimates

(a) Estimation of Maximum Constant Yield (MCY)

MCY was estimated from the equation MCY = 0.25 $F_{0.1}$ B_0 (Method 1, Annala *et al.* 1999). The value of $F_{0.1}$ was taken from the yield per recruit analysis (Table 6), and the estimate of B_0 from the assessment (Table 7). MCY equalled 3381 t (Table 9).

Estimates of MCY were very sensitive to the value of natural mortality but only moderately sensitive to the other parameters investigated (Table 10).

(b) Estimation of Current Annual Yield (CAY)

CAY was not estimated because no reliable estimates of current biomass were available.

(c) Other yield estimates and stock assessment results

(i) Maximum Sustainable Yield (MSY)

MSY was calculated as the maximum catch that could be sustained by the stock in equilibrium under a F_{max} fishing policy. MSY for the base case equalled 4200 t (Table 9). Estimates of MSY were very sensitive to the value of natural mortality but only moderately sensitive to the other parameters investigated (Table 10).

(ii) Maximum Average Yield (MAY)

MAY was calculated as the maximum catch that could be sustained by the stock under a $F_{0.1}$ fishing policy. MAY for the base case equalled 3970 t (Table 9). Estimates of MAY were very sensitive to the value of natural mortality but only moderately sensitive to the other parameters investigated (Table 10).

7. DISCUSSION

The results presented in this report, which represent the first quantitative assessment of trevally stocks, should be regarded as very uncertain. The uncertainty in the assessment arises from a number of sources, including uncertainty over the input data sets used to tune the model (in particular the CPUE and trawl survey indices); the input parameters (in particular the natural mortality rate and the weight at age); the model structure (including selectivity assumptions); and the harvest rates which have been calculated under the assumption of no stock-recruit relationship.

The unstandardised CPUE indices show little contrast over the 20 year period apart from a slight increase in the early years. The indices for the first three years had wide 95% confidence intervals (Francis *et al.* 1999). Indices with wide confidence intervals or calculated from low sample sizes could be downweighted in future assessments. Both indices are noisy, perhaps reflecting changes in availability of trevally to the trawl rather than changes in abundance. If the high between-year variability does not appear to smooth out over time, it may be necessary to consider incorporating other environmental factors into the standardised CPUE analysis as recommended by Francis *et al.* (1999).

The trawl survey abundance estimates of 1 and 2 year olds were variable, and were therefore assigned high *c.v.*s, so as to have low weighting in the model. It appears that they may be monitoring year class strength because there was agreement in some years between the survey data and the proportion-at-age (*see* Figure 5). However, more years of ageing data are required before this relationship can be confirmed, and it is recommended that the low weighting be retained in the short term.

The current model was set up to represent a single method fishery with a single fishing selectivity, which probably oversimplifies reality. The proportion-at-age data should be examined each year for differences between fishing methods, and for spatial and seasonal patterns. If the fishing patterns differ between years, then consideration may need to be given to developing more complex models with different spatial, seasonal, or fishing method components.

Considerable uncertainty also surrounds the estimate of natural mortality for trevally. James (1984) estimated a natural mortality rate of 0.03 for ages 6 to 34 and of 0.30 thereafter from a catch curve analysis. In the current assessment, a value of 0.10 was used for all ages, based on the value given in Annala *et al.* (1999). Estimates of yield from the model appear to be very sensitive to the value used for M. It should be emphasised that M is not well known, and may vary with age, which could have serious implications for the modelling work. It is recommended that the estimate of M calculated by James (1984) be reviewed before the next assessment is carried out. Future assessments may need to model M as a function of age if a re-examination of his work confirms his earlier conclusions.

Lastly, harvest rates were calculated using yield per recruit analyses under the assumptions of no stock-recruit relationship, and without consideration given to appropriate levels of risk. It is recommended that stock-recruit relationships be explicitly considered both in the model and in the estimation of harvest rates in future assessments, and that harvest rates incorporating an appropriate level of risk are calculated (following Francis 1992).

8. MANAGEMENT IMPLICATIONS

There is considerable uncertainty over biomass and yield estimates in this assessment. The uncertainty in the assessment arises from a number of sources, including uncertainty over the input data sets used to tune the model, the input parameters (in particular M), the model structure, and the harvest rates (*see also* Section 7).

Despite the uncertainty, some general conclusions can be made regarding the stock status. Since 1970, total removals from the stock have averaged over 2500 t per year, with no apparent change in the CPUE. Although this is an aggregated semi-pelagic stock, where targeting could potentially mask a decline in abundance, Francis *et al.* (1999) were confident that trends in stock size should be detectable in the CPUE data. Furthermore, the landings from the fishery comprise a large number of age classes and a sizeable plus group, and the reported and estimated landings themselves have shown no decline. These more general indicators of stock status tend to support the results of the stock assessment.

The results of the assessment (including 90% confidence intervals and all sensitivity runs) suggest that the stock is still in the fishing down phase and well above B_{may} and B_{msy}. Yield estimates from the base case assessment (including 90% confidence intervals) and most of the sensitivity tests are higher than the recent total removals from the stock, which have averaged about 2200 t. It is considered therefore that recent catches are sustainable and will allow the stock to remain above a size that will support the MAY.

The current TACC of 2153 t is also smaller than the MCY estimates and it is considered that commercial catches at this level are sustainable and will allow the stock to remain above a size that will support the MAY.

9. ACKNOWLEDGMENTS

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Table 1: Reported landings, and estimated dead discards, recreational catch, under-reported catch and total catch, in tonnes

Year	Reported landings	Estimated dead discards*	Under-reported catch†	Recreational catch‡	Customary take	Estimated total catch
1944	3	2	1	14	15	35
1945	3	2	1	16	15	37
1946	3	2	1	18	15	39
1947	14	7	3	20	15	59
1948	8	4	2	23	15	52
1949	7	4	1	25	15	52
1950	15	8	3	27	15	68
1951	36	18	7	29	15	105
1952	31	16	6	31	15	99
1953	103	52	21	33	15	224
1954	78	39	16	36	15	184
1955	138	69	28	38	15	288
1956	130	65	26	40	15	276
1957	296	148	59	42	15	560
1958	343	172	69	44	15	643
1959	351	176	70	46	15	658
1960	595	128	119	48	10	900
1961	471	101	94	51	10	727
1962	543	116	109	53	10	831
1963	662	142	132	55	10	1 001
1964	534	114	107	57	10	822
1965	544	117	109	59	10	839
1966	1 080	60	216	61	10	1 427
1967	1 493	83	299	64	10	1 949
1968	1 515	84	303	66	10	1 978
1969	1 322	73	264	68	10	1 737
1970	1 682	0	336	70	10	2 098
1971	2 037	0	407	70	10	2 524
1972	2 226	0	445	70	10	2 751
1973	2 320	0	464	70	10	2 864
1974	2 024	0	405	70	10	2 509
1975	1 598	0	320	70	10	1 998
1976	1 894	0	379	70	10	2 353
1977	2 113	0	423	70	10	2 616
1978	2 322	0	464	70	10	2 866
1979	2 600	0	520	70	10	3 200
1980	2 493	0	499	70	12	3 074
1981	2 844	0	569	70	12	3 495
1982	2 497	0	499	70	12	3 078
1983	2 165	0	433	70	12	2 680
1984	1 707	0	341	70	12	2 130
1985	1 843	0	369	70	12	2 294
1986	1 830	0	183	70	12	2 095
1987	1 626	0	163	70	12	1 871
1988	1 752	0	175	70	12	2 009
1989	1 665	0	167	70	12	1 914

1990	1 589	0	159	70	12	1 830
1991	2 016	0	202	70	12	2 300
1992	1 367	0	137	70	12	1 586
1993	1 796	0	180	70	12	2 058
1994	2 231	0	223	70	12	2 536
1995	2 138	0	214	70	12	2 434
1996	2 019	0	202	70	12	2 303
1997	1 844	0	184	70	12	2 110
1998	2 103	0	210	70	12	2 395

* Assuming the following discard rates: 50% from 1944 to 1959, 30% from 1960 to 1965, 10% from 1966 to 1969; and a 50% mortality rate on discarded fish (*after* James 1984).

† Assuming 20% overruns before 1986, and 10% overruns from 1986 onwards.

‡ Assuming a recreational catch of 70 t since 1970 reducing to 20% of that value in 1944.

Table 2: Proportion at age (and *c.v.*) and mean weight at age in the commercial fishery

Age (years)	Proportion at age	*c.v.*	Weight (kg)
1	0	0	0.040
2	0	0	0.240
3	0.093	0.14	0.469
4	0.170	0.13	0.790
5	0.089	0.22	0.948
6	0.024	0.45	1.063
7	0.026	0.42	1.229
8	0.081	0.22	1.261
9	0.096	0.2	1.350
10	0.047	0.26	1.468
11	0.066	0.21	1.581
12	0.066	0.21	1.892
13	0.070	0.22	1.803
14	0.017	0.4	2.188
15	0.020	0.35	2.588
16	0.013	0.39	3.287
17	0.010	0.4	3.290
18	0.017	0.34	3.180
19	0.016	0.35	2.831
20+	0.076	0.13	3.679

Table 3: Unstandardised $\log_{10}$ CPUE indices for single trawl, small pair trawl, and large pair trawl and standardised CPUE indices for tows targeting trevally and snapper in the single trawl fishery in TRE 7 (*after* Francis *et al.* 1999)

Year	Unstandardised			Standardised	
	Single trawl	Small pair trawl	Large pair trawl	Trevally	Snapper
1974	–	2.72	–	–	–
1975	–	2.77	–	–	–
1976	–	–	–	–	–
1977	–	2.92	3.04	–	–
1978	2.40	3.08	2.83	–	–
1979	2.56	2.98	3.21	–	–
1980	2.77	2.74	3.13	–	–
1981	3.05	2.71	3.10	–	–
1982	3.00	2.84	3.09	–	–
1983	2.97	3.00	3.24	–	–
1984	2.70	2.90	3.08	–	–
1985	2.76	2.96	3.05	–	–
1986	2.77	3.07	–	–	–
1987	2.50	3.24	–	–	–
1988	2.95	–	–	–	–
1989	2.87	–	–	–	–
1990	2.90	3.35	–	1.00	1.00
1991	2.95	3.18	–	1.06	0.73
1992	2.90	3.02	–	0.64	0.59
1993	2.79	2.93	–	0.41	0.55
1994	3.00	3.34	–	0.54	0.68
1995	2.90	–	–	0.92	0.65
1996	2.92	–	–	0.59	0.85
1997	2.76	–	–	0.64	1.03

Table 4: Estimated pre-recruit biomass and coefficient of variation (*c.v.*) for 1 and 2 year old trevally for FMA 9 (*after* Morrison & Stevenson unpubl. results)

Survey	1 year olds		2 year olds	
	Biomass (t)	*c.v.* (%)	Biomass (t)	*c.v.* (%)
KAH8612	4.89	86	40.68	67
KAH8715	1.36	51	5.34	97
KAH8918	0.11	48	0.02	100
KAH9111	0.01	100	17.97	46
KAH9410	0.92	86	0.08	100
KAH9615	3.56	74	36.17	83

Table 5: sSPA model input parameters and sensitivity tests. NF, not fitted; BT, back-transformed

Parameter	Base case	Sensitivity
M	0.10	0.05, 0.075, 0.15
Weighting on proportion-at-age data	100	0, 10, 200
Proportion-at-age data	1998	NF
Unstandardised single trawl CPUE index	1978–1997	NF, BT
Unstandardised single trawl CPUE index *c.v.*	0.32	0.5
Standardised single trawl CPUE index	1990–1997	NF
Standardised single trawl CPUE index *c.v.*	0.22	0.5
Trawl survey 1+, 2+ indices	1986–1996	NF
Trawl survey *c.v.*	0.5	0.3
Number of year classes estimated	5	1, 10

Table 6: Estimates of equilibrium biomass and yields (as % B0) and $F_{0.1}$ harvest rates from a yield per recruit analysis

	B_{MSY} (%B_0)	MSY (%B_0)	B_{MAY} (%B_0)	MAY (%B_0)	$F_{0.1}$
M = 0.050	0.216	0.021	0.312	0.020	0.065
M = 0.075	0.189	0.029	0.306	0.028	0.092
M = 0.100	**0.127**	**0.039**	**0.292**	**0.037**	**0.126**
M = 0.150	0.072	0.066	0.261	0.059	0.225

Table 7: Biomass estimates from the base case assessment of TRE 7, with 90% confidence intervals. B, mid-season biomass

Parameter	B_0 ('000 t)	B_{1998} ('000 t)	B_{1998} (%B_0)	B_{1998} (%B_{msy})	B_{1998} (%B_{may})
Base case	107.3	73.4	68%	539%	234%
CI	73.5–116.7	35.5–86.4	48–74%	380–583%	165–253%

Table 8: Changes of selected parameter estimates as a result of alternative model assumptions. B, mid-season biomass

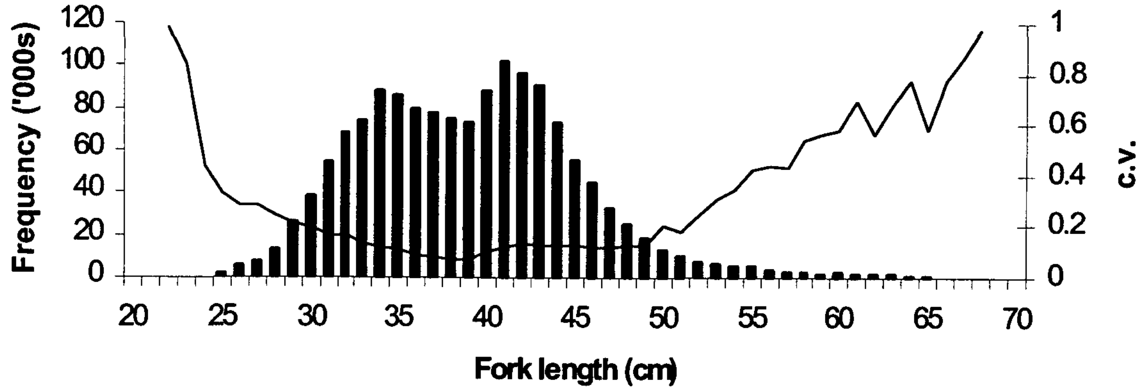
Parameter	B_0 ('000 t)	B_{1998} ('000 t)	B_{1998} ($\%B_0$)	B_{1998} ($\%B_{msy}$)	B_{1998} ($\%B_{may}$)
Base case	**107**	**73**	**0.68**	**539**	**234**
1 year class estimated	87	54	0.62	487	211
10 year classes estimated	82	38	0.46	362	157
No age data	142	173	1.22	957	416
Proportion-at-age sample size = 10	149	147	0.99	780	339
Proportion-at-age sample size = 200	82	44	0.53	421	183
No trawl indices	74	35	0.47	367	160
Trawl indices *c.v.* = 0.3	154	132	0.86	675	293
CPUE indices *c.v.* = 0.5	98	63	0.65	508	221
No CPUE indices	92	57	0.62	485	211
M = 0.05	85	32	0.38	176	122
M = 0.075	87	44	0.51	268	165
M = 0.15	108	77	0.71	990	273
Unstandardised CPUE indices back-transformed	116	83	0.72	563	245

Table 9: Yield estimates (t) from the base case assessment of TRE 7, with 90% confidence intervals

Parameter	MSY	MAY	MCY
Base case	4 186	3 971	3 381
CI	2 868–4 552	2 721–4 319	2 316–3 677

Table 10: Changes of yield estimates as a result of alternative model assumptions

Parameter	MSY (t)	MAY (t)	MCY (t)
Base case	**4 186**	**3 971**	**3 381**
1 year class estimated	3 410	3 235	2 754
10 year classes estimated	3 194	3 031	2 580
No age data	5 546	5 261	4 479
Proportion-at-age sample size = 10	5 794	5 497	4 680
Proportion-at-age sample size = 200	3 190	3 027	2 577
No trawl indices	2 901	2 752	2 343
Trawl indices *c.v.* = 0.3	5 998	5 690	4 844
CPUE indices *c.v.* = 0.5	3 824	3 627	3 088
No CPUE indices	3 589	3 405	2 899
M = 0.05	1 777	1 692	1 364
M = 0.075	2 523	2 436	1 997
M = 0.15	7 144	6 387	6 092
Unstandardised CPUE indices back-transformed	4 524	4 292	3 654



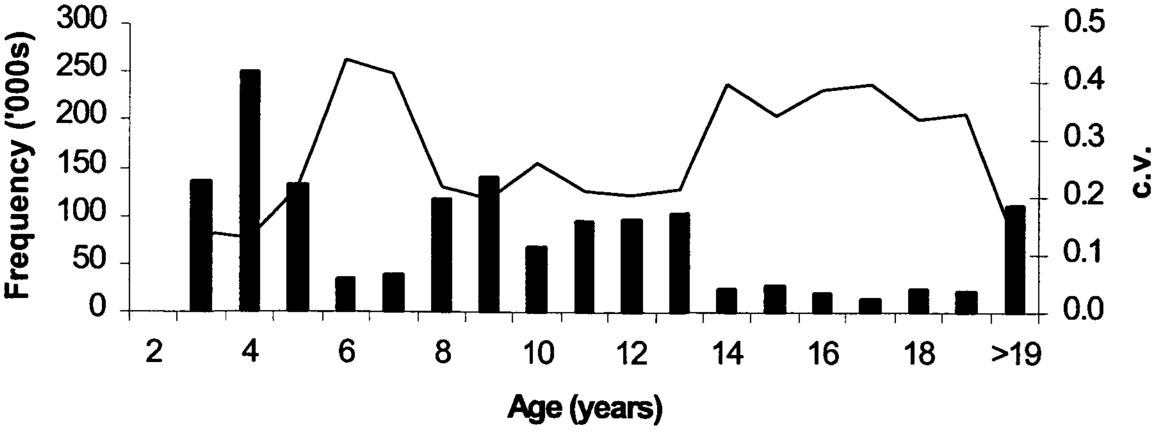


Figure 1: Weighted numbers at length and numbers at age (histograms) and *c.v.*s. (solid lines) from the combined single and pair trawl commercial fishery.

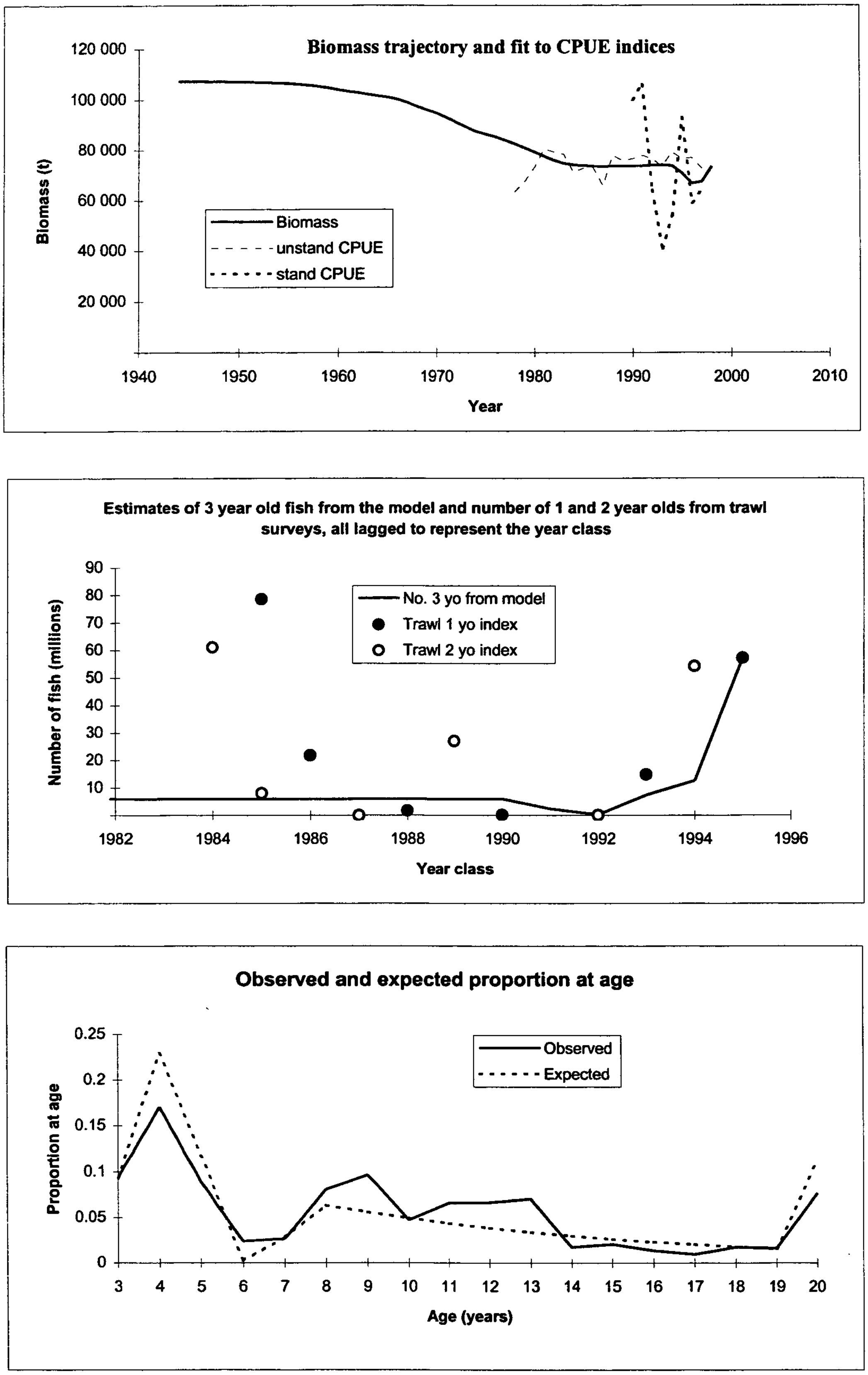


Figure 2: Diagnostic fits for the base case assessment for TRE7.

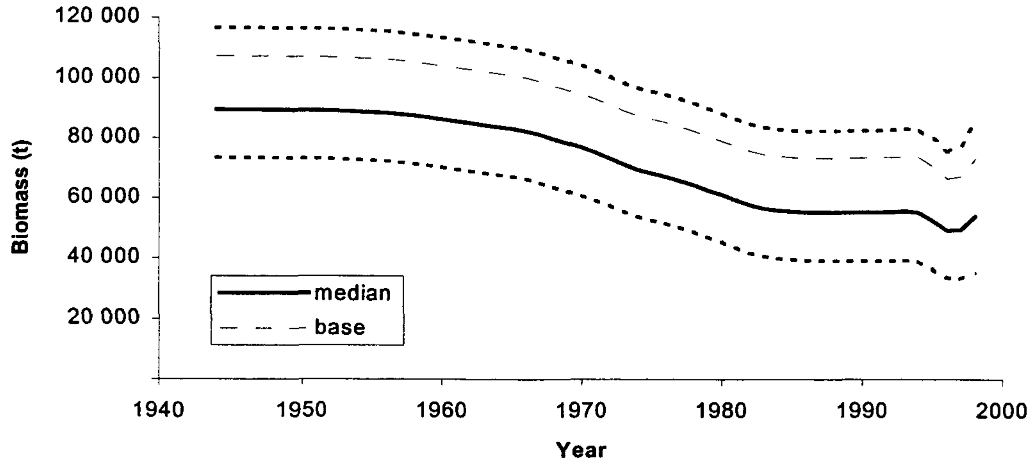


Figure 3: Median biomass trajectory and 90% confidence intervals for TRE 7.

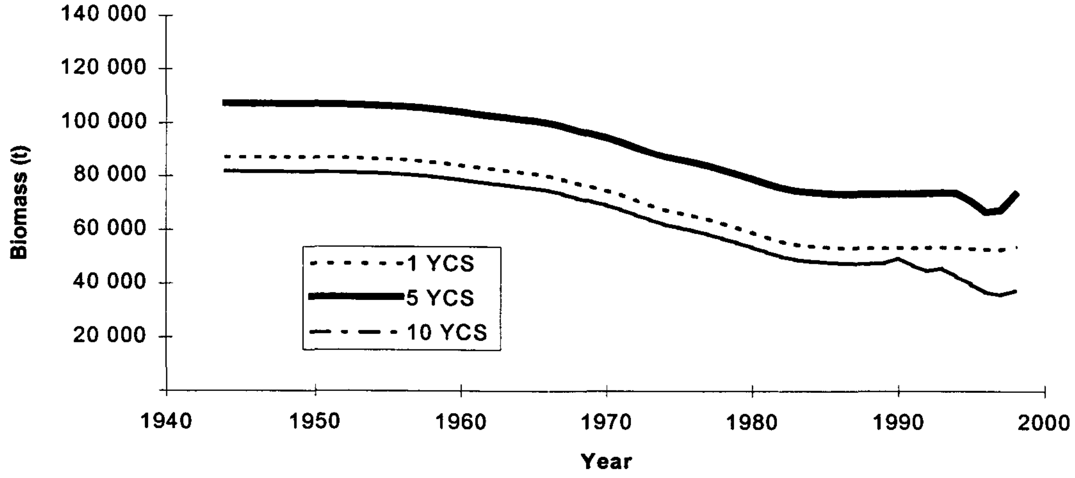


Figure 4: Sensitivity of mid-season recruited biomass to the number of year classes being estimated in the model.

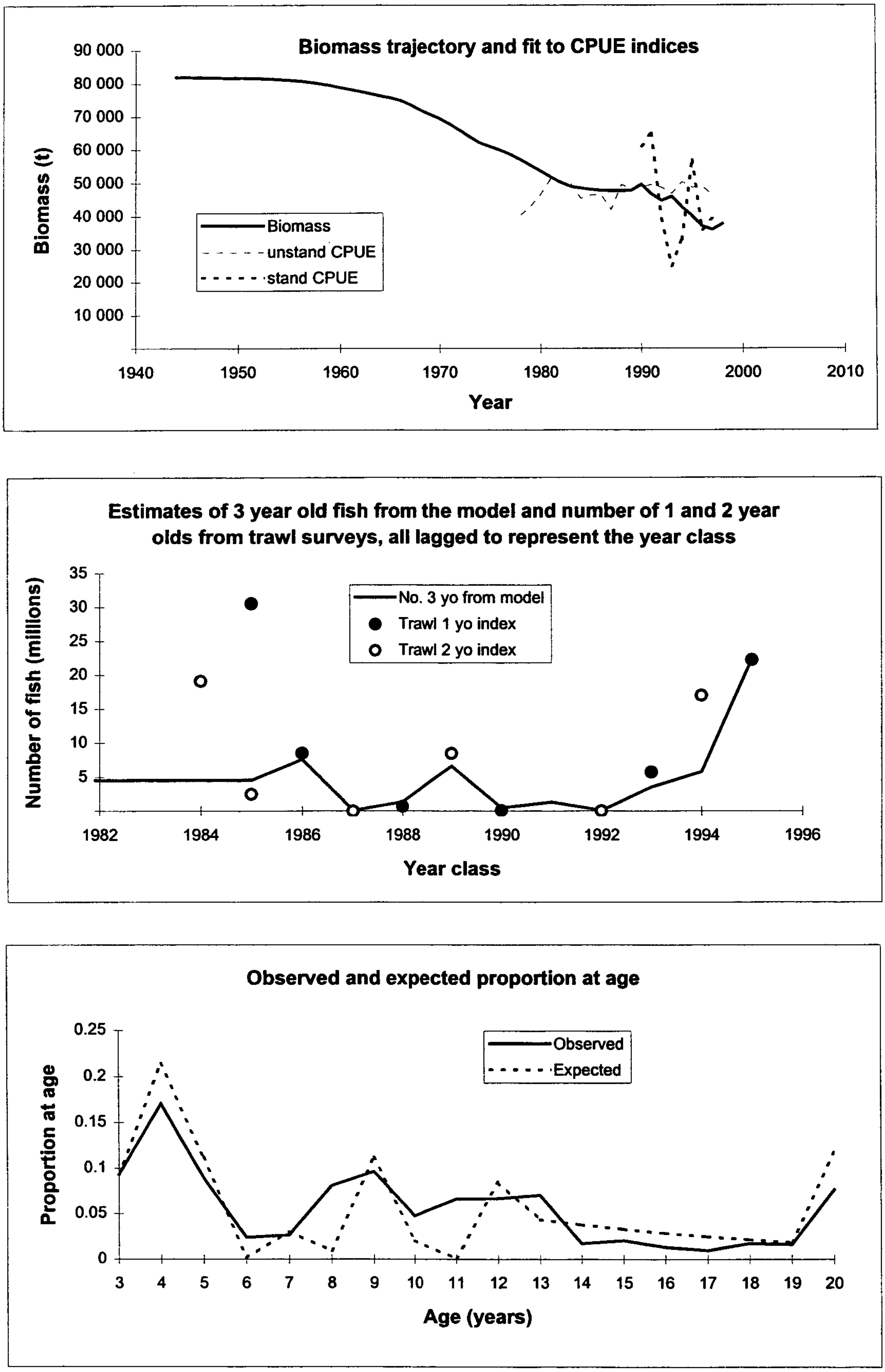


Figure 5: Diagnostic fits for the sensitivity test where 10 year classes were estimated in the model.

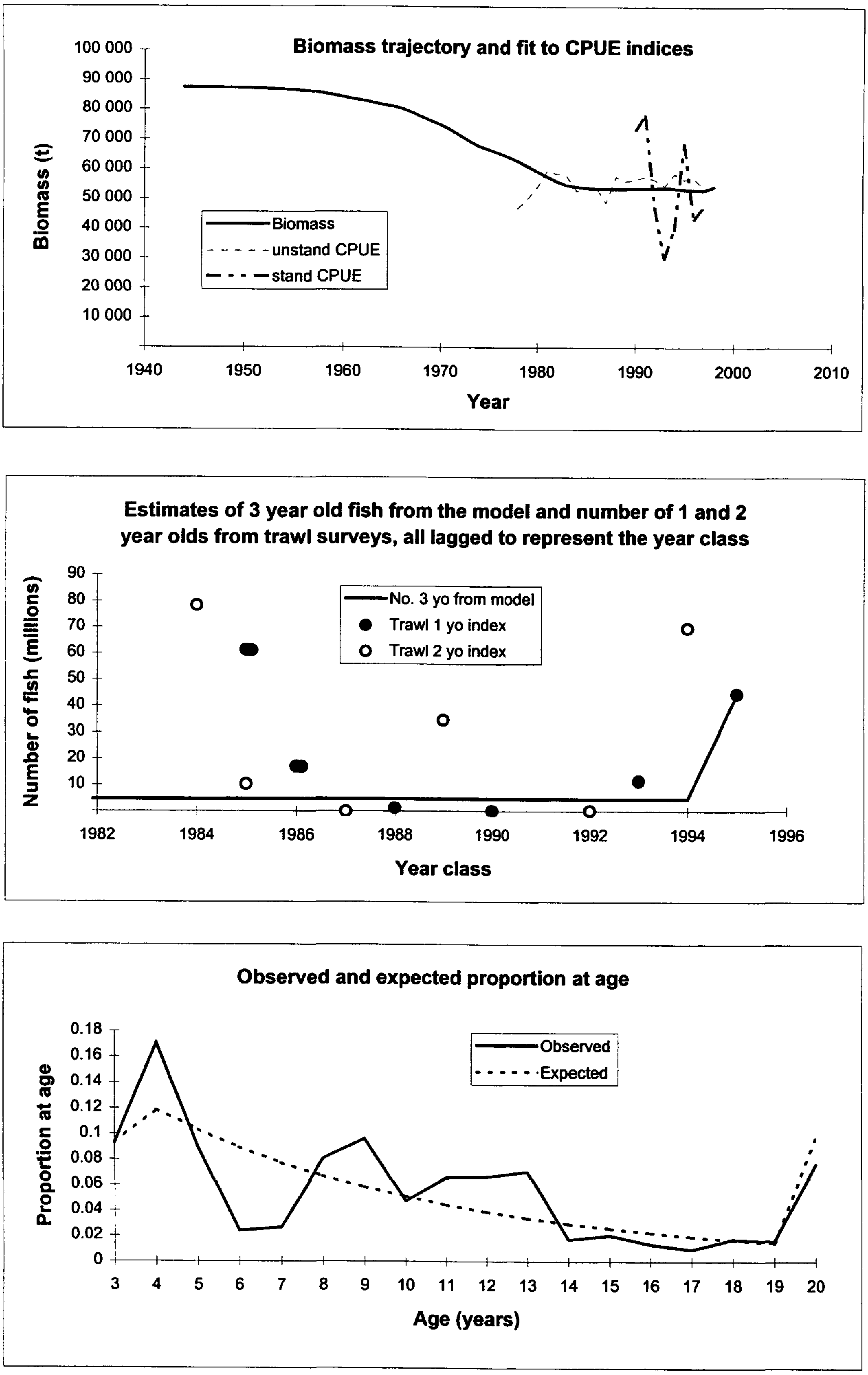


Figure 6: Diagnostic fits for the sensitivity test where 1 year class was estimated in the model.

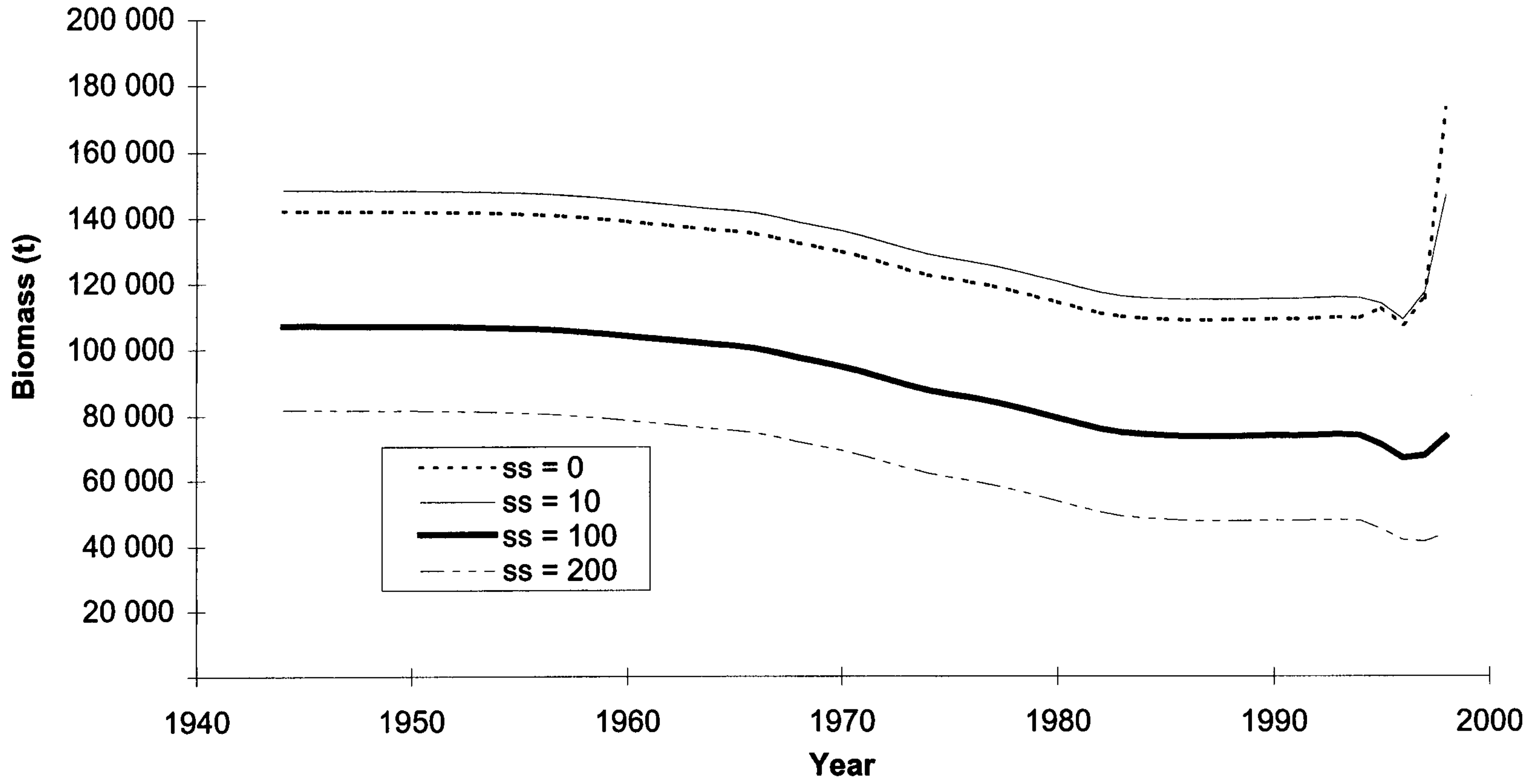


Figure 7: Sensitivity of mid-season recruited biomass to the weight (sample size) used for the proportion-at-age data.

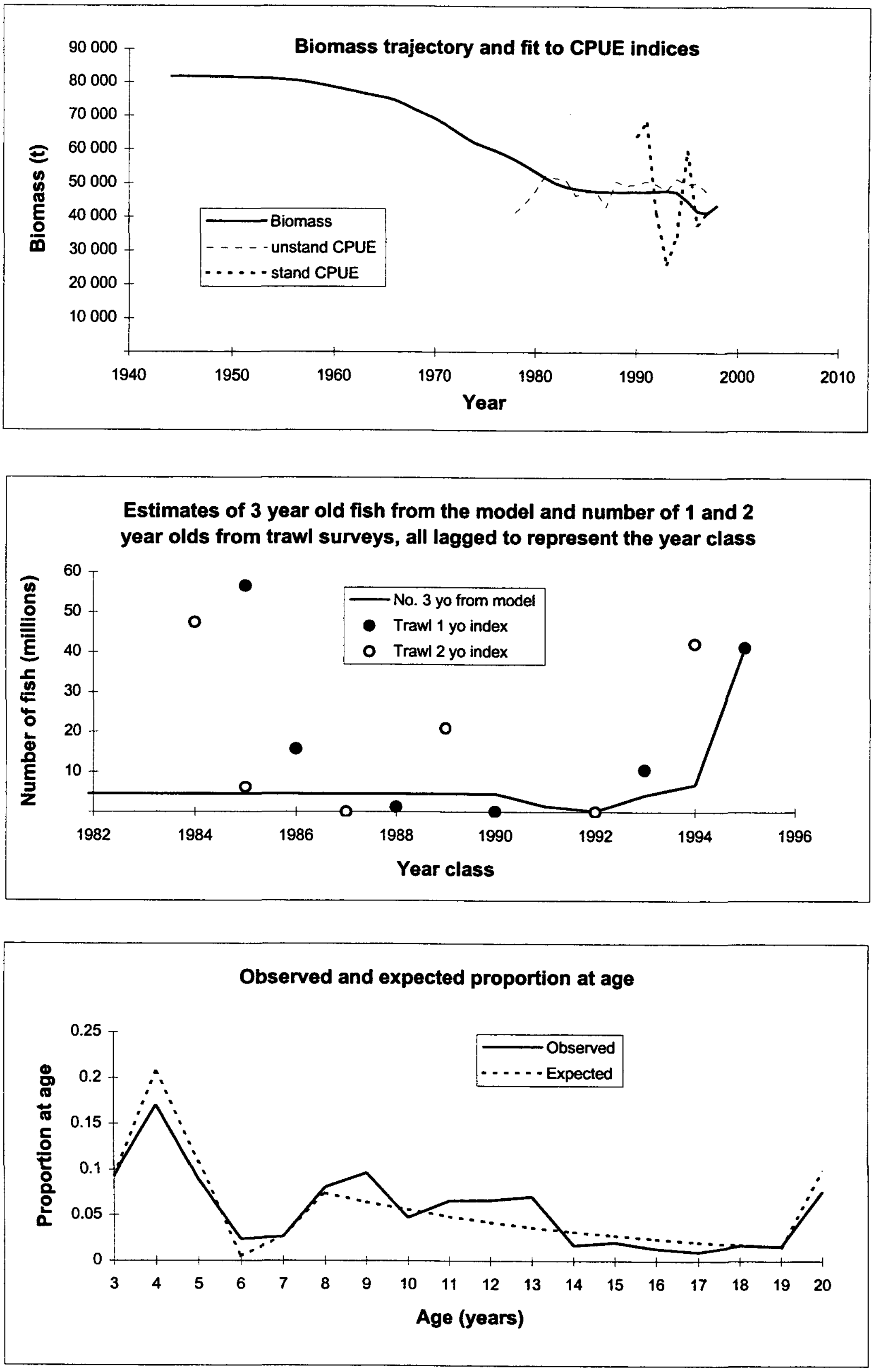


Figure 8: Diagnostic fits for the sensitivity test where sample size equals 200

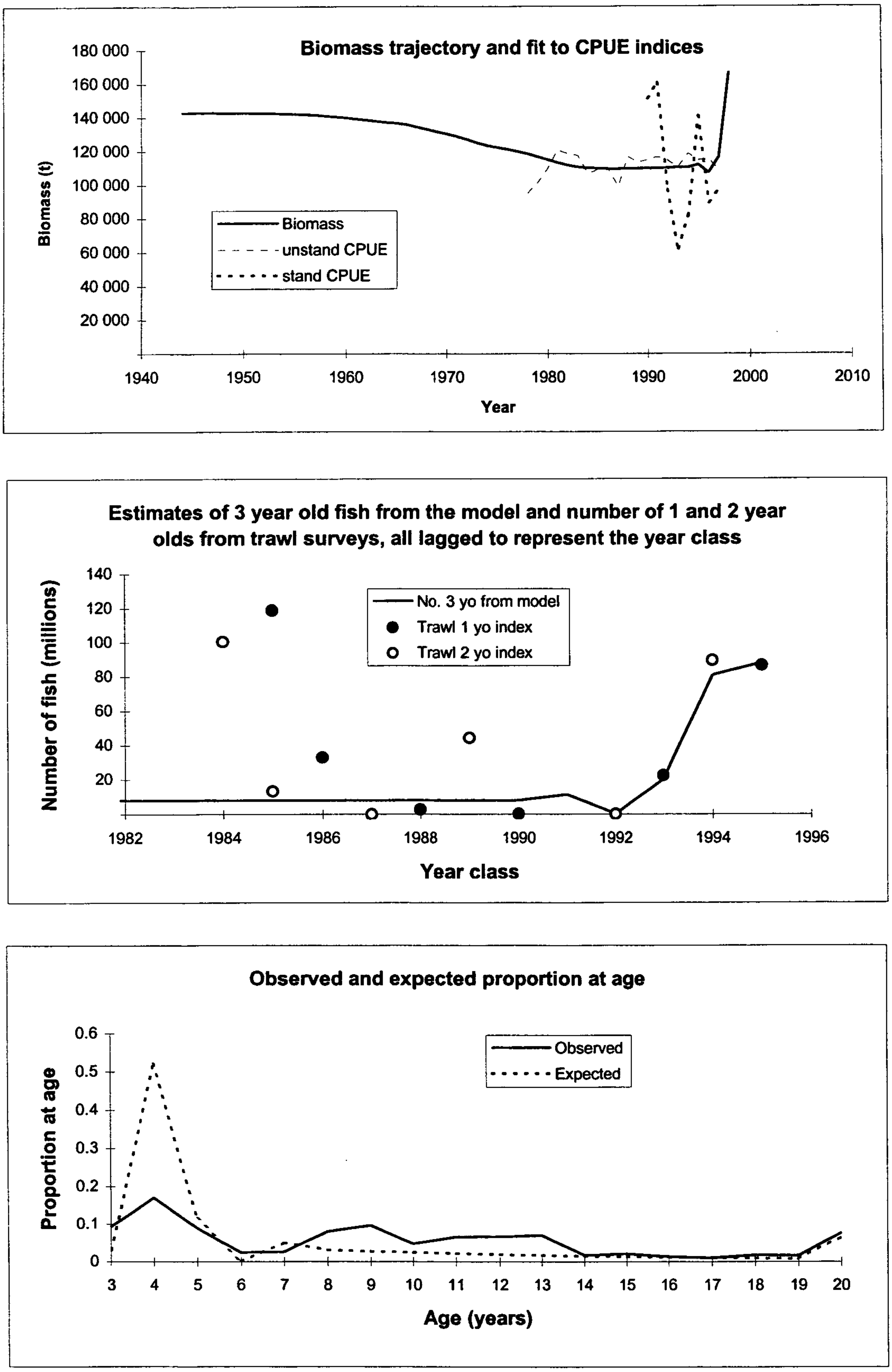


Figure 9: Diagnostic fits for the sensitivity test where sample size equals 10.

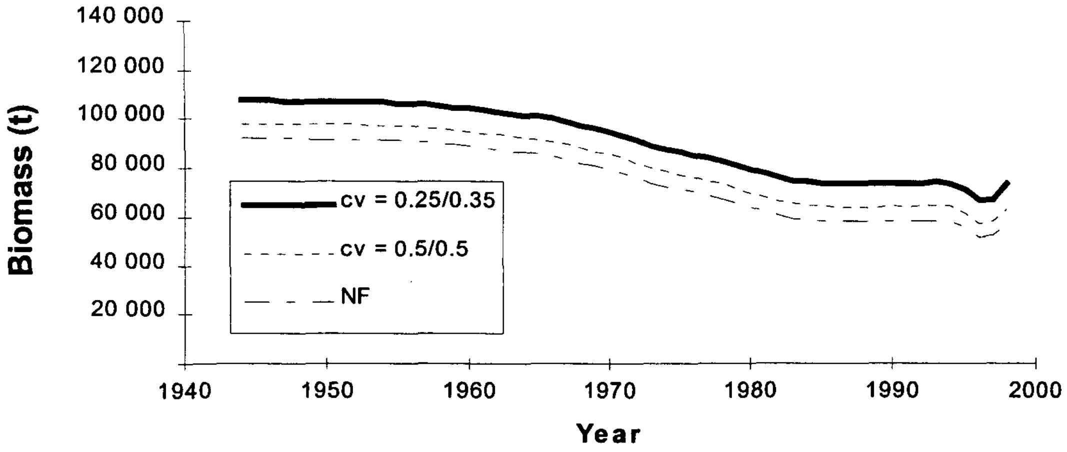


Figure 10: Sensitivity of mid-season recruited biomass to the weighting (*c.v.*) used for the trawl survey indices when fitted in the model.

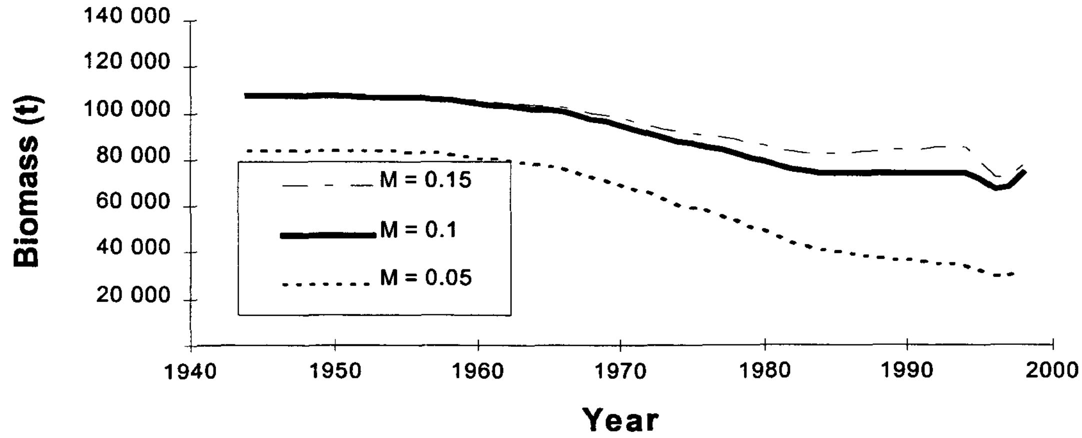


Figure 11: Sensitivity of mid-season recruited biomass to natural mortality (M).

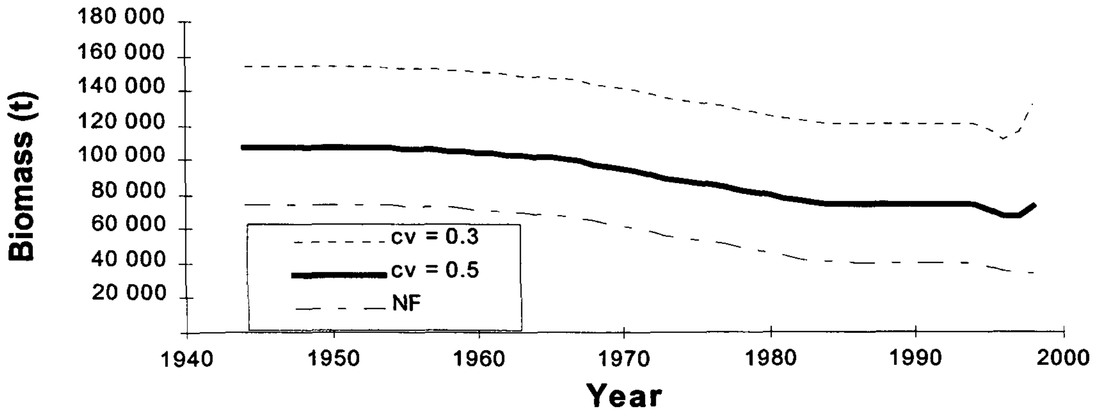


Figure 12: Sensitivity of mid-season recruited biomass to the weighting (c.v.) used for the CPUE indices when fitted in the model.