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Reliable information on recruitment to rock lobster stocks would be useful for interpreting trends in the fishery, for stock assessments and in management procedures. In 1979, a sampling program was established to measure the rates of settlement of postlarval rock lobster (*Jasus edwardsii*). One of the aims of the program is to provide predictions of recruitment to the rock lobster fisheries.

This report describes work done as part of a study to examine the utility of settlement indices for stock assessments of New Zealand rock lobster fisheries. The first part of this study involved calculating standardised indices of settlement (Bentley et al. 2004) from the data generated by the collector program. This report examines whether the standardised settlement indices are consistent with other data collected from rock lobster fisheries and, for each fishery, which settlement index provides the best information on recruitment. A previous study suggested a relation between collector indices and some climatic indices: we also examined the utility of these climatic indices of settlement for stock assessment.

We used two approaches for examining the utility of indices of settlement for stock assessments. The first was to examine the correlation between settlement indices and estimates of recruitment from previous stock assessments. The second was to use a model of a rock lobster population to link changes in settlement to subsequent changes in the CPUE and size frequencies of the fishery by explicitly modelling the growth rates and growth variability of lobsters between settlement and recruitment.

Only a few of the correlations between assessment estimates of recruitment and settlement indices were significant at the 0.05 level. For recruitment estimates from the CRA 3 assessment done in 2001, there was a significant positive correlation with the smoothed M1 climatic index lagged by one year. For the CRA 4 & 5 assessment done in 1999, there were significant negative correlations with the smoothed M1 climatic index lagged by 3 years and with the HSE climatic index lagged by 3 years, both with and without smoothing. For the NSS assessment done in 2000, there were significant negative correlations with the PC1 climatic index and the M1 index at various lags with and without smoothing. The smoothed M1 index lagged by one year showed the strongest correlation with assessment estimates of recruitment deviations.

Stock assessments provide the best estimates currently available of recruitment to rock lobster fisheries. We did not find any significant correlations between indices of settlement derived from collectors and estimates of recruitment from assessments. There were some significant correlations between some climatic indices and model estimates of recruitment. A greater number of significant correlations may have occurred for climatic indices because of the longer time series available and because two-tailed tests, rather than one-tailed tests, were used.

Assessments are not available for all fisheries for which settlement indices are available. In the second part of this study we performed a second test of the utility of settlement indices for stock assessments. We used a simplified version of the stock assessment model to examine the consistency between various settlement indices and CPUE data, size frequency data, estimates of growth rates and their variability, estimates of the size selectivity of fishing and estimates of natural and handling mortalities. Likelihood techniques were used to calculate the goodness of fit between the model's predicted CPUE and proportions-at-size with observed data. We then compared the likelihood obtained when the model was 'driven' with various settlement indices, that is, when each settlement index was assumed to be true. We also estimated a 'best fit' settlement index by maximising the likelihood with respect to annual settlement. Finally, we generated 500 settlement indices by randomly selecting from a lognormal distribution with a coefficient of variation of 0.6 and calculated the

likelihood of the fit for each. If the settlement indices were a good index of recruitment then we would expect them to have a likelihood in the high end of the distribution of likelihoods generated by the random indices.

The settlement indices produced likelihoods that varied widely in their position relative to the distribution of likelihoods obtained by using many random indices. For example, the CRA 8S settlement index had a likelihood in the lowest 1% of likelihoods (0.2 % percentile) for the CRA 8S (Stewart Island) stock. In contrast, the HSE climatic index was in the top 9% of likelihoods (91.8% percentile) for the same stock. There was also variation among areas in the quality of the best fit obtained by estimating a settlement index. Poorest fits occurred in CRA 3 and CRA 8F, and the best fit was for the CRA 4&5 stock.

For the CRA 3 stock the CRA3 collector settlement index produced the best fit, but this was only slightly higher than the median likelihood for the random indices (55.9% percentile). For the CRA 4&5 stock, the M1 climatic index produced the best fit which was in the 82nd percentile of the distribution likelihoods from random indices. The best performing collector settlement index for this stock was the CRA345 index, which had a fit near the average for the random indices (51.3%). For the CRA 7 stock, the PC1 index performed best (59.3%) and the CRA7 settlement index worst (1.8%). The HSE climatic index (91.8%) produced the best fit for the Stewart Island stock while the CRA 8S index produced the worst (0.2%). The CRA8F settlement index had the best performance of all the collector indices with a ranking of 75.6% for the Fiordland area.

In general the collector-based settlement indices did not produce good fits. There may be several reasons for this including (a) imprecision in the collector indices as an index of settlement because of sampling error and spatial variability in settlement rates, (b) annual variation in growth and survival rates between settlement and recruitment and (c) density-dependent growth and survival between settlement and recruitment.

CONTENTS

1. INTRODUCTION

Recent stock assessments for New Zealand rock lobster fisheries have suggested that recruitment to the stock can vary considerably and can have a significant effect on the magnitude of vulnerable biomass and hence catch per unit effort (CPUE) (Bentley et al. 2001, Breen et al. 2002). Information on recruitment to the stock would be useful for interpreting trends in the fishery.

A reliable means of predicting recruitment to the fishery would also be useful for management. Management procedures, such as that being used to increase vulnerable biomass in CRA 7 and CRA 8 (Bentley et al. 2003) or those which could be used for maintaining rock lobster stocks at a desired level (Breen et al. 2003), are likely to perform better if a reliable predictor of recruitment is available.

In Western Australia, settlement rates of puerulus larvae of *Panulirus cygnus* on artificial collectors are used to predict future recruitment to the fishery and hence catches of lobsters (e.g., Caputi et al. 1996). The apparent success of this program has led to puerulus collection programs in other spiny lobster fisheries, including New Zealand (e.g. Booth et al. 2000b).

In 1979, a sampling program was established to measure the rates of settlement of postlarval rock lobster (*Jasus edwardsii*). The program uses sampling devices (collectors) that are placed at various sites around New Zealand. One of the aims of the program is to provide predictions of recruitment to the rock lobster fisheries.

This report describes work done as part of a study to examine the utility of settlement indices for stock assessments of New Zealand rock lobster fisheries. Since 1997, some stock assessments have fitted to settlement indices derived from collector data in sensitivity analyses, but not in base case assessments. Reasons for this include uncertainty in the reliability of the indices and a lack of long-term indices for some stocks.

The first part of this study involved calculating standardised indices of settlement from the data generated by the collector program. That work was described by (Bentley et al. (2003). This report examines whether the standardised settlement indices are consistent with other data collected from rock lobster fisheries and, for each fishery, which settlement index provides the best information on recruitment. A previous study suggested a relation between collector indices and some climatic indices (Booth et al. 2000a): we also examined the utility of these climatic indices of settlement for stock assessment.

Two steps need to be considered in evaluating the reliability of settlement indices for providing information on recruitment to a fishery. First, an index of recruitment must be derived from the settlement index. A directly proportional relation between settlement in one year and recruitment in a subsequent year is not necessarily appropriate. This is because variation in growth among individuals between settlement and recruitment means that a settling cohort will recruit to the fishery in different years, and density-dependent survival and growth may make the relation between settlement and recruitment non-linear.

Second, because recruitment to the fishery is not known, an estimate must be made which can be compared to the prediction derived from settlement indices. For New Zealand rock lobster fisheries, catch per unit effort (CPUE) cannot be used as an index of recruitment. This is because none of the fisheries are wholly dependent on a single year's recruitment: instead the vulnerable biomass results from accumulation of several years of recruitment, growth and mortality, because management changes, such as changes in catch and minimum legal size limits, affect vulnerable biomass and thus catch rates, and because changes in fishing patterns, particularly changes in the seasonality of fishing, affect catch rates.

Given the data currently available, the best estimates of recruitment for the New Zealand rock lobster fishery come from stock assessments. In stock assessments, a model of the fishery is used to infer changes in recruitment from changes in CPUE and size frequency distributions, given other information such as growth rates and their variability, natural and handling mortalities, commercial and non-commercial catches, changes in management regulations and the seasonal distribution of fishing effort. In the first part of this study, we examined the correlation between estimates of recruitment deviations from three stock assessments and several settlement indices for each stock. For collector settlement indices, we used one-tailed tests because the correlation is expected to be positive.

In the second part of this study, we used a simple model rock lobster population to link changes in settlement to subsequent changes in the CPUE and size frequencies of the fishery by explicitly modelling the growth rates and growth variability of lobsters between settlement and recruitment.

We also used estimates of the rate and variability of growth of lobsters before recruitment to illustrate how variability in growth rates affects the variation in the time taken for newly settled lobsters to recruit, and what sizes of lobsters should be targeted for providing predictions of recruitment of different lengths.

Throughout, we use the term "stock" to mean the lobsters in the various areas and groups of areas defined. "Fishing year" is the rock lobster fishing year from 1 April to 31 March. We name years by their first part, viz. "1998-99" is called "1998".

2. SETTLEMENT INDICES

We use the generic term "settlement indices" to refer to indices of rock lobster settlement derived from collectors ("collector indices") and from climatic variables ("climatic indices").

2.1.1. Collector indices

Standardised indices of puerulus settlement for each quota management area were obtained from Bentley et al. (2004). These indices were obtained by using Generalised Linear Models to standardise for the effects of changes in collector locations and missing monthly samples. Standardised indices of puerulus settlement are available for each quota management area where there were sufficient settlement data: CRA 3, CRA 4, CRA 5, CRA 7 and CRA 8. However, because recent stock assessments for CRA 8 have separated data from Fiordland and Foveaux Strait-Stewart Island, separate indices were calculated for each of these areas (CRA 8F and CRA 8S respectively).

Standardisation variables considered were month, site, group and collector. For each quota management area, a forward selection process was used for selecting the final standardisation model. For most areas, month and site or collector were included in the final model.

2.1.2. Climatic indices

We used a subset of the climatic variables generated by Booth et al. (2000a), who calculated the correlation between 24 climatic variables and 41 sets of collectors or collector groupings. Their analysis was repeated four times for climatic variables calculated (i) during the main settlement period, (ii) two months before the settlement period, (iii) four months before the main settlement period and (iv) over the whole calendar year. We used the three climatic variable-lag combinations that had the highest number of significant correlations across all collector groupings. However, because the mean surface geostrophic southerly wind component, VSf, is calculated to the nearest grid point, we used a proxy for southerly flow that could be applied to all collector sites. The climatic variables were lagged to the main settlement period, April to October.

The three climatic indices used here were:

- HSE - frequency of occurrence of the "High to the Southeast" synoptic class for December (of the previous year) to June.
- PC1 - amplitude time series (principal component) of the first Empirical Orthogonal Function of the mean sea-level pressure field over New Zealand for December (of the previous year) to June.
- M1 - meridional index 1 for February to August; an index of southerly flow over the whole of New Zealand. Positive flow is southerly and negative flow is northerly.

The three climatic variables were normalised so that they had a mean of 0 and a standard deviation of 1 using the formula:

$$x_i' = \frac{x_i - \bar{x}}{\sigma_x}$$

where x_i is ith value of the climatic index, x_i' is the normalised climatic index and $\bar{x}$ and σ_x are the mean and standard deviation of the climatic index. We also reverse the sign of the PC1 and HSE variables because Booth et al. (2000a) found a generally negative correlation between these variables and collector indices.

For each stock we considered several potential indices of settlement (Table 1 and Table 2). For example, for CRA 3, three different collector indices derived from CRA 3 data were used: one derived from CRA 3 only, one derived from both CRA 3 and CRA 4, and one derived from all of CRA 3, CRA 4 and CRA 5. These indices are named CRA3, CRA34 and CRA345 respectively. To minimise confusion, stocks are named with a space and indices without a space; thus CRA 3 is a stock and CRA3 is a settlement index from the CRA 3 stock.

3. COMPARISON WITH ASSESSMENT ESTIMATES OF RECRUITMENT

3.1. Methods

Posterior distributions of recruitment deviations were obtained from three previously reported stock assessments (Table 3). The assessment model estimates the number of lobsters that recruit into the smaller size classes of the model. The size distribution of these recruits is determined by a normal distribution with a mean of 32 mm and a standard deviation of 2 mm, and which is truncated at the smallest size, 30 mm tail width (Breen et al 2002).

Stock assessments do not estimate recruitment deviations for every year modelled. During periods where there is limited information, a single recruitment deviation may be applied to several years. We used only those estimated recruitment deviations that applied to a single fishing year.

For each stock, we examined the Spearman's rank correlation coefficient between a particular settlement or climatic index and the estimated recruitment deviations. Spearman's rank correlation coefficient, rather than the more commonly used Pearson product-moment correlation coefficient, was used to measure correlation. The Spearman procedure is nonparametric in that it does not assume that the data come from a bivariate normal distribution. In this application, it has the additional advantage that, being based on ranks, it does not imply a linear relation between the index and the recruitment residual, just that the relation is monotonic.

Because collector indices are expected to be positively correlated with recruitment deviations estimated by the assessment, a one-tailed significance test was done to test whether the correlation was significantly greater than zero. For the climatic indices, where there is no expectation of positive or negative correlation, a two-tailed test was used to test whether the correlation was significantly different from zero.

Correlations were examined in two steps. First, the median of each annual recruitment deviation was calculated from the posterior distribution and the correlation between each index and the median recruitment deviations was calculated. We investigated alternative lags between the settlement index and model recruitment deviations: 0, 1, 2 or 3 years. For each of these lags, the correlation was calculated for the raw index and for the index smoothed with a 3-year running mean. The smoothed indices were examined because the assessment model has little information to distinguish between recruitment deviations in consecutive years and thus model estimates of recruitment may be averaged over a number of years.

Therefore, for each settlement index, eight correlations were calculated (four lags, ordinary or smoothed). When conducting multiple significance tests for a null hypothesis, the overall probability of a type I error (incorrectly declaring a significant correlation) increases, so it is appropriate to apply the Bonferroni correction (Day & Quinn 1989, Bland & Altman 1995) (Table 4) to reduce the significance level used for individual statistical tests:

$$\dot{\alpha} = 1-(1-\alpha)^{\frac{1}{N}}$$

where α is the hypothesis-wide significance level, $\dot{\alpha}$ is the adjusted significance level for each test and N is the number of tests being done.

In the current situation the value of N depends upon the hypothesis being tested. For instance, if the null hypothesis is that "there is no relationship between settlement index CRA3 and recruitment deviations estimated from the assessment for CRA 3" then $N = 8$ because 8 tests are being used to test the hypothesis. However, for the null hypothesis that "there is no relationship between collector indices that use CRA 3 settlement data and recruitment deviations estimated from the assessment for CRA 3" then $N = 8 \times 3 = 24$ because three different collector indices from CRA 3 are being tested. If the null hypothesis is extended further to include all CRA 3 indices (collector indices and climatic indices), then N becomes $N = 8 \times 6 = 48$.

In the second step, we chose the collector index and the climatic index which had the highest individual correlation with median annual recruitment deviations from the assessment model. For these two indices, the Spearman rank correlation was calculated for each lag and smoothing combination for every sample from the posterior distribution of recruitment deviations from the assessment. That is, we calculated the correlation from each sample from the posterior, for each lag and smoothing option, and calculated the cumulative probability, under the null hypothesis, of obtaining a correlation this high. We present this analysis using histograms of the posterior distribution of the probabilities from each sample. Good agreement between recruitment deviations and the index examined would produce a posterior distribution massed near the left-hand edge of the plot at the lower probability levels.

3.2. Results

3.2.1. 2001 CRA 3 stock assessment

The only individual correlation significant at the 0.05 level was the unsmoothed M1 climatic index lagged by one year (Table 5, Figure 1). However, the probability associated with this correlation was greater than the adjusted alpha level for the null hypothesis that there is no relation between this index and recruitment deviations estimated from the assessment.

Only two of the correlations for collector indices were significant at the 0.05 level, but both were for tests involving a very low number of observations and are unreliable (Table 5). Because of the low numbers of observations available for the CRA3 index, the CRA34 settlement index (Figure 1) was used for calculating correlations with samples from the posterior distribution of recruitment deviations.

The posterior distributions of probabilities of the correlations between the CRA34 settlement index and CRA 3 assessment recruitment deviations do not suggest a relationship. For most lags, both the raw and smoothed indices had a low proportion of correlations that were significant at the 0.05 level (Figure 2). For the M1 index, the posterior distributions of probabilities differed substantially depending upon the lag and smoothing (Figure 3). The ordinary M1 climatic index with a 1-year lag had the highest proportion of significant correlations at the 0.05 level.

3.2.2. 1999 CRA 4 & 5 assessment

These comparisons were all made using the 1999 assessment of the combined data from CRA 4 and CRA 5 (Breen et al. 2001), called "CRA 4 & 5". The HSE climatic index lagged by three years, both smoothed and unsmoothed, and the smoothed M1 climatic index lagged by three years (Figure 4) had significant correlations at the 0.05 level (Table 6). None of the collector indices had significant correlations; the one with the most significant correlation was the CRA45 index (Figure 4).

The posterior distributions of probabilities of the correlations between the CRA45 settlement index and CRA 4 & 5 assessment recruitment deviations do not suggest a relationship. For most lags, both the ordinary and smoothed indices had a low proportion of significant correlations at the 0.05 level (Figure 5).

For the M1 index, the posterior distribution of probabilities was generally broad; only for the smoothed index and lag 3 was there a substantial proportion with probability less than 0.05 (Figure 6). The unsmoothed M1 climatic index with a 1-year lag had the highest proportion of significant correlations at the 0.05 level.

3.2.3. 2000 NSS stock assessment

The highest correlation with the median of recruitment deviations was for the smoothed M1 climatic index lagged by one year (Table 7, Figure 7). The probability associated with this correlation was less than the adjusted alpha level for a hypothesis with eight tests (Table 7). None of the correlations for the CRA8F index was significant even at the $\alpha = 0.05$ level.

The posterior distributions of correlation probabilities between the CRA8F index and samples of recruitment deviations from the posterior distribution are broad, with most probabilities being greater than 0.20 (Figure 8). For the M1 index, the distribution of probabilities differed depending upon the lag and smoothing: smoothing tended to decrease the probabilities and greater lag tended to give higher probabilities (lower correlation) (Figure 9).

Figure 10 shows the best combination, i.e. that for the smoothed M1 index lagged by one year. This combination had a correlation which was 0.0059, just less than the adjusted alpha level for an hypothesis involving eight significance tests. Thus we can reject the null hypothesis that the M1 climatic index is not correlated with the estimates of recruitment from the NSS assessment model. However, given that three climatic indices were tested, there is not sufficient evidence to reject the null hypothesis that there is no correlation between climatic indices and assessment estimates of recruitment deviations.

3.3. Summary

We examined the correlation between estimated recruitment deviations from assessments and collector or climatic indices of settlement. The assessment model estimates the series of recruitment deviations that produces the best fit to the observed data. If the settlement indices were consistent with the assessment model and the data to which it is fitted, then a high correlation between the recruitment deviations and settlement indices would be expected.

Our analysis shows little similarity between the observed indices and the assessment model results. Correlations are generally low when the indices are compared with the median of recruitment deviations, and they show little tendency to aggregate near the low-probability end of the distribution of results when we take the Bayesian assessment results into account by using the posterior distributions of recruitment deviations.

4. CONSISTENCY WITH A SIMPLIFIED POPULATION MODEL

In Section 3, we examined the relation between settlement indices and estimates of recruitment deviations from assessments. There are some limitations to this approach. First, only assessments for the CRA 3, CRA 4 & 5 and NSS stocks (based on data for CRA 8) were available. This did not allow for testing of settlement indices for CRA 7 and Stewart Island (CRA 8S). Second, the assessments estimated recruitment deviations only up to 1997–98 and thus it was not possible to correlate settlement indices collected since then.

We used a length-based model of the rock lobster fishery to examine the consistency between puerulus settlement indices and a model of the rock lobster fishery that incorporates data on the fishery from other programs. The model serves as a link between the settlement indices and data observed in the fishery some time later. This model does not estimate parameters but rather uses estimates of growth rates and pot selectivity derived from other studies. We attempted to make the analyses using the simplified model as independent as possible from the analyses using the assessment model estimates of recruitment deviations (Section 3).

4.1. Methods

The model is a simplified version of the stock assessment used for rock lobster in New Zealand (Breen et al. 2002) and is similar to that used in Tasmania (Punt et al. 1997). It is a male-only model with an annual time step. A time series of male-only catches was calculated from observed catches using estimates of the proportions of males within the catches that were derived from the catch sampling data. The model is otherwise structured as described for the 2001 stock assessment, using fewer parameters because of the simplified sexual and seasonal structure (Breen et al. 2002).

The model is driven by a chosen collector or climatic index, normalised as the sequence of deviations from the mean for that index. The strength of the index determines recruitment to the model. We assumed that all indices were directly proportional to recruitment. That is, we ignore the fact that some of the climatic indices were found to have a negative correlation with estimates of recruitment from assessments (Section 3).

The model estimates only one parameter: initial exploitation rate. It does this by minimising the total negative log-likelihood components from the CPUE and length frequencies using the same likelihood functions as for the 2001 assessment (Breen et al. 2002). All other parameters are fixed at values derived from other studies as described below.

For the CRA 7 and Stewart Island (CRA 8S) stocks, we assumed that emigration occurred based on a logistic curve with 50% of migration at length 55 mm tail width and 95% at 65 mm and a maximum migration of 90% of individuals.

The approach taken was to compare the likelihood obtained using each index with the likelihood obtained a) by estimating settlement deviations, b) by assuming constant recruitment and c) by generating a distribution of likelihoods by fitting to a large set of random settlement indices. The random settlement indices were generated from a lognormal distribution with a coefficient of variation of 0.6. If an index is good at explaining the observed behaviour of CPUE and length frequencies, then the likelihood from the index should be near the upper edge of the likelihood distribution from random indices.

This approach is analagous with a classical hypothesis test. The null hypothesis is that there is no information in the settlement and climatic indices. Under the null hypothesis, the likelihood obtained from a chosen index would be near the centre of the distribution of likelihoods obtained from using sets of random numbers. If the null hypothesis were incorrect and the index were informative, the likelihood from that index would be higher than most of the random number likelihoods.

4.2. Parameter values

4.2.1. Growth rate and variation

The growth rate of lobsters between settlement and recruitment is important in assessing the correlation between an index of settlement and recruitment to the fishery. We used two types of published estimates of growth rates for New Zealand rock lobsters.

1. Juvenile modal progression analysis estimates. Annala & Bycroft (1985) and Breen & Booth (1989) in CRA 8, and McKoy & Esterman (1981) in CRA 3, estimated the mean length of modes of juvenile lobsters from dive survey data.

2. Tag-recapture data estimates. Bentley et al. (2002) estimated growth rates for CRA 1 & 2, CRA 3, CRA 4 & 5 and CRA 8 based only on tag-recapture data.

We did not use the estimates of growth rates from the assessments because we wanted this analysis to be as independent as possible from those presented in Section 3.

These two sets of data come from different parts of the lobster population. The mean length of the largest mode estimated from dive surveys in CRA 8 was 77.8 mm carapace length (equivalent to about 43 mm tail width). The same value in CRA 3 was 58.0 mm (equivalent to about 31 mm tail width). In contrast, tagged lobsters are generally larger than 45 mm tail width.

In an attempt to obtain the most accurate estimate of growth rates of lobsters over all sizes, we produced a growth curve which was a combination of the estimates from juvenile dive surveys and tagging.

We used the mean size and age of modes estimated by Annala & Bycroft (1985), Breen & Booth (1989) and McKoy & Esterman (1981) to estimate a von Bertalanffy growth curve for juvenile lobsters. Juvenile growth from CRA 3 was used for CRA 3, CRA 4 and CRA 5 growth curves (Figure 11). Juvenile growth from CRA 8 was used for CRA 7, Stewart Island and Fiordland growth curves (Figure 12). These growth curves were then used to estimate mean annual growth of juvenile lobsters at different sizes up to 45 mm tail width.

Beyond 45 mm tail width, the mean annual growth at size from tag-recapture data was used (Table 8). For all sizes, the coefficient of variation in growth and minimum standard deviation estimated from tagging data was used (Table 8).

4.2.2. Other

As in recent lobster assessments, we assumed that the instantaneous rate of natural mortality was 0.10 for all stocks and that handling mortality was 0.10 (Breen et al. 2002). Parameters for the selectivity curve were set at the values from the most recent assessments for each area (Table 9). For CRA 7, we assumed that growth rates and selectivity parameters were the same as for CRA 8 but that maximum selectivity occurred at the size limit for CRA 7, which is approximately 46 mm tail width.

4.3. Data

In 2001, the rock lobster stock assessment team constructed a database of summarised catch sampling data from the scientific observer and industry logbook programs. The database has totals of the number of lobsters in each 2-mm tail width size class from 30 mm to 90+ mm by month and statistical area. We used those data to produce annual size frequencies of male lobsters in each statistical area.

Standardised CPUE (kg of legal lobsters per potlift) was obtained from Bentley et al. (2001) for CRA 3 and CRA 7. For CRA 4 & 5, data from CRA 4 and CRA 5 were amalgamated and the methods used by Bentley et al. (2001) were used to standardise CPUE for changes in the distribution of effort across months and statistical areas.. For CRA 8S (Stewart Island), raw CPUE for statistical area 924 were used. For CRA 8F (Fiordland), raw CPUE from statistical area 926 was used.

4.4. Results

4.4.1. Summary of results

Table 10 shows, for each stock and each index used for that stock, the model's estimated initial exploitation rate, *Ustart*, the log-likelihoods from the fits and the relative position of the total log-likelihood on the frequency distribution of likelihoods obtained from 500 random number strings used in place of the index. If an index has good information, the log-likelihood should be high when the index is used to drive the simple model, and that log-likelihood should be positioned near the right-hand side of the distribution, with a high percentile.

Table 10 shows that few indices were found near the right-hand side of the distribution obtained from random strings. Exceptions are the PC1 and HSE indices for CRA 8S, both above the 80th percentile. The highest settlement index is CRA 8F for stock CRA 8F, at the 76th percentile.

4.4.2. CRA 3

For the CRA 3 stock, the fits to CPUE from the best-fitting random string and the actual settlement index (Figure 13) are shown in Figure 14. Neither fits very well, but the best fit fits better than the CRA 34 settlement index.

Figure 15 and Figure 16 show the fits to proportions-at-length from the best-fitting random string and the actual settlement index respectively, and they show (as reflected in the higher log-likelihood, Table 10) a better fit from the best random string.

Figure 17 shows the positions of the log-likelihoods from each index relative to the distribution observed from the random strings. All are near the centre of the distribution or to left of centre, indicating that information in these indices is not influential in the model fits.

4.4.3. CRA 4 & 5

For the CRA 4 & 5 stock, the fits to CPUE from the best-fitting random string and the actual settlement index (Figure 18) are shown in Figure 19. The former fits very well and the actual settlement index fits poorly. Fits to the length frequency data are shown in Figure 20 and Figure 21.

Figure 22 shows the positions of the log-likelihoods from each index relative to the distribution observed from the random strings. All are near the centre of the distribution except the M1 climatic index. The low percentiles (Table 10) indicate that information in these indices is not influential in the model fits.

4.4.4. CRA 7

For the CRA 7 stock, the fits to CPUE from the best-fitting random string and the actual settlement index (Figure 23) are shown in Figure 24. Neither fits very well and the actual settlement index fits more poorly than the best fit estimates. Fits to the length frequency data are shown in Figure 25 and Figure 26.

Figure 27 shows the positions of the log-likelihoods from each index relative to the distribution observed from the random strings. All are near the centre of the distribution or left of centre. The low percentiles (Table 10) indicate that information in these indices is not influential in the model fits.

4.4.5. CRA 8S – Stewart Island

For the CRA 8S stock, the fits to CPUE from the best-fitting random string and the actual settlement index (Figure 28) are shown in Figure 29. The former fits reasonably well and the actual settlement index fits very poorly. Fits to the length frequencies are shown in Figure 30 and Figure 31.

Figure 32 shows the positions of the log-likelihoods from each index relative to the distribution observed from the random strings. All are near the centre of the distribution or left of centre except the HSE and PC1 climatic indices, which are toward the right-hand end and suggest that these are informative. The low percentiles (Table 10) for other indices indicate that information in these indices is not influential in the model fits.

4.4.6. CRA 8F – Fiordland

For the CRA 8F stock, the fits to CPUE from the best-fitting random string and the actual settlement index (Figure 33) are shown in Figure 34. The actual settlement index fits poorly, whereas the best random fit is much better. Fits to the length frequencies are shown in Figure 35 and Figure 36.

Figure 37 shows the positions of the log-likelihoods from each index relative to the distribution observed from the random strings. All are near the centre of the distribution or left of centre except the settlement index CRA8F, to the right of centre. The low percentiles (Table 10) for other indices indicate that information in these indices is not influential in the model fits.

4.5. Sensitivity to growth rates

In the tests presented above, the settlement indices were tested for their consistency with assumptions on the growth rates of lobsters, the dynamics of the stock and the accuracy of CPUE and size frequency data. The results are likely to be sensitive to these assumptions. In particular, if growth rates of lobsters between settlement and recruitment are mis-specified, then a 'true' index of settlement would not perform as well in the tests.

To examine the sensitivity of these results to growth rate assumptions, a biased test was performed. In this test, a growth curve was estimated based on the assumption that the CRA34 settlement index is a true index of settlement in CRA34. Only two parameters, the growth at 50 mm tail width and the coefficient of variation of growth, could be estimated using the simple model (the model implementation is not designed for estimating many parameters). The estimated growth curve predicts slower growth of lobsters than growth based on the estimates derived in Section 4.2.1 (Figure 38).

The estimated growth curve was then used to repeat the procedure described in Section 4.1. As expected, under this biased test the CRA34 index performed best and was in the 90th percentile of the distribution of likelihoods obtained from random settlement strings (Table 11, Figure 39).

4.6. Summary

In this section we have performed a classical statistical hypothesis test. The null hypothesis is that the settlement and climatic indices contain little information relevant to fitting of stock assessment models. We used a simplified version of the assessment model, allowing us to eliminate many parameters and to ignore many of the assessment estimates, so as to be independent in these trials from the actual assessments and to allow the improvement in fit deriving from the settlement indices to be transparent.

If the settlement and climatic indices contain information that is relevant and influential to the model, then driving the model with these indices should give better fits than constant recruitment or sets of random numbers. However, the log-likelihoods stemming from most of the fits based on real settlement and climatic indices were not in the upper 5% of the log-likelihoods obtained from the sets of random numbers. Exceptions are the CRA8F index for the CRA 8F stock and two climatic indices in CRA 7. Thus we are forced to accept the null hypothesis that the settlement and climatic indices do not significantly improve the explanatory power of the stock assessment models beyond an hypothesis of constant or randomly varying recruitment.

The simple model did show some problems when fitted to CRA 7 and CRA 8S – the estimates of *Ustart* were very low (Table 10). This may result from some model mis-specification, especially with respect to migration from one area to the other.

We performed a single sensitivity test to illustrate that our results will be sensitive to the assumptions made in the model. In particular, the ability to predict recruitment from settlement indices will be dependent on good estimates of growth rates of juvenile lobsters.

5. TIME TO RECRUITMENT

The growth transition matrices estimated for CRA 3, CRA 4 & 5 and CRA 8 in Section 4.2.1 can be used to calculate the probability of a lobster of a given size recruiting within a given time. This can in turn be used to calculate what sizes of lobsters should be targeted for providing predictions of a given length. We present these estimates here because they are useful for considering how variability in growth rates affects the variation in the time taken for newly settled lobsters to recruit to the fishery, and which sizes of lobsters should be targeted for providing predictions of recruitment of differing time spans.

Based on the available estimates of growth rates and variability, there is large variation in the time taken for a lobster of settlement size to reach the size limit (Figure 40). For example, in CRA 8 it is estimated that 25% of male settlers reach the size limit in 6 years, 32% in 7 years and 21% in 8 years.

In all areas a large proportion of lobsters that will recruit to the fishery in the following year are close to the size limit (Table 12, Table 13, Table 14). For example, in CRA 4 & 5, 97% of next year's recruits are in the size range 46–53 mm (Table 13). In CRA 8, 85% of lobsters that will recruit in two year's time are in the size range 40–53 mm (Table 14). There is a large amount of tagging data associated with these sizes of lobsters and these estimates are likely to be accurate. These proportions suggest that one- to two-year prediction of recruitment to the fishery might be derived from the relative abundance of pre-recruits caught in pots.

6. DISCUSSION

Analyses presented in this report indicate that the observed settlement indices show little similarity with the estimated assessment model recruitments. Correlations are generally low when the indices are compared with the median of recruitment deviations estimated from assessments, and they show little tendency to aggregate near the low-probability end of the distribution of results when we take the Bayesian assessment results into account by using the posterior distributions of recruitment deviations.

The tests using the simplified model indicate that collector and climatic indices for most stocks (with some exceptions) do not correspond well with other data collected from the same fishery. For all trials, the indices of settlement derived from collectors and climatic variables did not perform significantly better than a series of randomly generated settlement indices.

6.1. Possible causes for lack of consistency

The lack of consistency between collector indices and independent estimates of recruitment used in this study may be due to several causes.

First, the estimates of recruitment from stock assessments, although the best that are currently available, may be imprecise. They are based on a large amount of data from the fishery including CPUE, size frequency and tagging data. However, the stock assessment model is designed to model the part of the population that is vulnerable to the fishery. It is not concerned with the growth and survival of small lobsters. Its estimates of recruitment in each year are primarily dependent upon the growth rates and variability that it also estimates based on information on larger lobsters. Despite this, given the large number of lags tested, with and without smoothing, higher correlations would have been expected if settlement indices provided good information on subsequent recruitment to the fishery.

Second, the assumptions used in the simplified length-based model on the growth rates and variability of lobsters, the dynamics of the stock and the accuracy of CPUE and size frequency data may be incorrect. Mis-specifications in the model would mean that a 'true' index of settlement would not perform as well in terms of fit. In particular, the growth rates and growth variability between settlement and recruitment are important in determining the fit between settlement indices and other data. We used the best available information. This highlights the fact that settlement indices alone are not sufficient for predicting recruitment to fisheries. They need to be at least accompanied by estimates of the rates and variability of growth of juvenile lobsters made over several years. Currently this information is available only for Stewart Island.

Third, for several reasons the collector indices may not provide good information on recruitment to the fishery; these include:

- natural variability and uncertainty in the settlement indices, plus the sampling variability caused by collectors being located in a small sample of possible locations,
- variation in survival among cohorts, weakening the settlement signal before it reaches recruitment to the fishery,
- attenuation of the signal through density-dependent survival,
- variation in juvenile lobster growth rates from year to year, altering the time between settlement and recruitment between one cohort and the next (mean size at (assumed) age for juvenile lobsters measured in dive surveys at Stewart Island shows such variation (Section 4.2.1, Figure 12)) and
- attenuation of the signal through density-dependent growth.

The second two possible causes would operate even if settlement indices were accurate and precise.

Our results are contrary to the apparent success of using puerulus collectors to predict catches in the Western Australian rock lobster (*Panulirus cygnus*) fishery. This difference may be due to a combination of factors. In particular, the time between settlement and recruitment appears to be less in Western Australia than in New Zealand. In Western Australia, an index of recruitment has been derived from an average of settlement indices estimated 3 and 4 years previously (Caputi et al. 1995). Based on our analyses, it takes on average 6–7 years between settlement and recruitment in New Zealand, with much individual variability around these values. This doubles the time during which growth and survival variability may dampen the relationship between settlement and recruitment.

There also appears to be a significant difference between the Western Australian and New Zealand fisheries in the way that they exploit the lobster populations. A large part of the Western Australian fishery is based on migrating individuals of about 4 to 6 years old (Caputi et al. 1995). Scientists in Western Australia have been able to relate settlement indices to subsequent catches. This is because numbers of pots, rather than total catches, are limited in that fishery. This means that the fishery is similar to a constant exploitation rate fishery in which catches fluctuate with vulnerable biomass. In effect, the Western Australian *prediction method relates settlement with subsequent vulnerable* biomass. As discussed in the Introduction, in the New Zealand fishery this is not possible due to vulnerable biomass being a result of the accumulated effects of recruitment, growth and mortality over a number of years. Instead, as we have done in this study, it is necessary to attempt to relate settlement indices with potentially inaccurate estimates of recruitment.

6.2. Alternatives for predicting recruitment to the fishery

A reliable means of predicting recruitment to the fishery would be useful for management. In particular, management procedures are likely to perform better, i.e., result in better performance values for management objectives such as yield and stability, if recruitment can be predicted with sufficient accuracy.

There are several ways of predicting recruitment to the fishery. Rather than focussing on whether current settlement indices are reliable predictors of recruitment to the fishery, two more fundamental questions need to be answered. First, what length of forecast is required for management? Second, what precision of prediction is required for management?

There is likely to be a strong trade-off between the length of prediction and its precision. Long-term predictions, such as those derived from settlement indices, are likely to be less precise than predictions based on observations of lobsters closer to the size of recruitment. This arises because of the length of time upon which variations in growth and survival can act to weaken the link between what is measured and what eventually recruits to the fishery. An imprecise predictor of recruitment would produce more risk of making incorrect management decisions.

The marginal improvement in management benefits with increasing length of predictions is likely to decrease. For example, a prediction with a length of 6 years is unlikely to provide much greater benefits over a prediction with a length of 5 years (even if it did have the same level of precision).

We recommend that a study (a) examine ways to incorporate predictions of recruitment into management procedures for rock lobsters and (b) simulates management procedures using recruitment predictions with differing lengths and precisions to determine the management benefits associated with each. The results from such a study could then be used to evaluate formally the relative benefits of different prediction methods with their relative costs.

We also recommend that data on the catch rates of lobster below the size limit, which is currently collected in catch sampling programs, be analysed to examine for relationships with subsequent recruitment to the fishery. A predictor of recruitment based upon lobsters in the size range 40 to 53 mm tail width may be more precise than one based upon settlement but may still provide an adequate length of prediction. In Western Australia, catch rates of lobsters below the size limit (obtained by sampling of commercial catches) have been used to improve the accuracy of catch predictions from those based on puerulus collectors alone (Phillips et al. 1994, Caputi et al. 1995).

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Table 1: Relative settlement and climatic indices used in this study from puerulus collectors and climatic variables. Values represent multipliers of the average for the series. Where an annual value was missing, average settlement was assumed (a value of 1.00). CRA8S is the index from Stewart Island and CRA8F the index from Fiordland.

	Collector									Climatic		
Year	CRA3	CRA34	CRA345	CRA4	CRA45	CRA5	CRA7	CRA8S	CRA8F	PC1	HSE	M1
1979	1.00	0.87	0.90	0.95	0.92	1.00	1.00	1.00	1.00	0.70	0.47	0.50
1980	1.00	1.44	1.50	1.21	1.50	0.01	1.00	1.95	1.00	1.39	2.66	1.52
1981	1.00	1.93	1.74	2.05	1.72	1.77	1.00	14.74	1.00	0.48	0.88	0.27
1982	1.00	0.83	0.65	0.89	0.64	0.08	1.35	0.40	1.00	0.41	0.13	0.98
1983	1.00	1.29	1.29	1.31	1.28	1.58	10.83	3.42	1.00	2.28	1.76	1.99
1984	1.00	0.91	0.82	0.88	0.82	0.33	0.77	0.73	1.00	0.54	0.54	0.30
1985	1.00	0.59	0.54	0.60	0.53	0.38	0.02	0.02	0.84	0.31	0.29	0.30
1986	1.00	0.52	0.43	0.52	0.42	0.18	0.02	0.28	0.20	1.34	1.24	1.02
1987	1.00	1.49	1.42	1.48	1.40	1.56	3.05	3.04	2.59	0.57	1.18	1.85
1988	1.00	0.92	0.85	0.94	0.84	0.82	0.02	0.43	1.48	0.83	0.64	2.44
1989	1.00	1.28	1.08	1.32	1.08	1.33	4.11	1.63	1.97	0.25	0.60	1.07
1990	1.00	0.89	0.73	0.86	0.73	0.44	1.64	1.01	1.87	1.45	1.40	1.06
1991	1.41	1.88	2.31	1.87	2.34	9.23	0.58	1.64	1.13	4.24	5.42	2.62
1992	2.03	1.99	2.37	1.92	2.37	10.02	0.38	0.77	0.51	1.74	2.51	10.81
1993	1.74	1.34	1.51	1.27	1.46	4.70	0.24	0.02	0.14	1.30	3.00	0.81
1994	2.55	1.17	1.24	0.89	0.98	1.38	0.29	1.79	2.85	1.33	1.27	1.95
1995	0.98	0.80	0.86	0.79	0.84	1.66	0.11	0.53	0.45	0.58	0.59	1.09
1996	0.93	1.20	1.27	1.25	1.37	1.27	1.47	0.52	2.28	1.18	0.70	2.23
1997	0.94	1.13	1.23	1.15	1.30	2.32	0.58	0.85	2.32	0.46	0.36	2.62
1998	1.28	1.09	1.20	1.13	1.20	3.13	1.20	0.48	0.39	0.23	1.01	0.39
1999	0.09	0.22	0.27	0.30	0.34	2.25	0.28	0.37	1.31	0.14	0.23	0.81
2000	0.83	0.58	0.65	0.55	0.62	1.88	7.15	1.76	1.52	0.27	1.01	0.37

Table 2: Settlement indices considered for each stock. The stock "CRA 4&5" is the combined CRA 4 and CRA 5 stock.

Stock	Collector indices	Climatic indices
CRA 3	CRA3, CRA34, CRA345	PC1,HSE, M1
CRA 4&5	CRA45, CRA345	PC1,HSE, M1
CRA 7	CRA7	PC1,HSE, M1
CRA 8S	CRA8S	PC1,HSE, M1
CRA 8F	CRA8F	PC1,HSE, M1

Table 3: Stock assessments from which estimates of recruitment residuals were obtained for correlation analyses. The "CRA 4 & 5" assessment was done on the combined CRA 4 and CRA 5 data. The NSS stock comprises CRA 7 and CRA 8.

Stock	Year of assessment	Fishing years for which annual deviations were estimated	Number of deviations	Number of samples in posterior	Reference
CRA 3	2001	1983–84 – 1997–98	15	4950	Breen et al. 2002
CRA 4 & 5	1999	1977–78 – 1997–98	21	5000	Breen et al. 2001
NSS	2000	1976–77 – 1997–98	22	2945	Bentley et al. 2001

Table 4: Bonferroni adjustments for testing hypotheses with multiple statistical tests.

Number of tests	Adjusted alpha to be used for each test
8	0.0064
16	0.0032
24	0.0021
48	0.0011

Table 5: Spearman's rank correlation coefficient (r), number of observations (n) and associated probability (p) for the relation between various settlement indices and recruitment deviations from the 2001 assessment model for CRA 3, with various lags and with or without smoothing. Tests for settlement indices are one-tailed; tests for climatic indices are two-tailed.

Index	Lag	Smoothing	r	n	p	Index	Lag	Smoothing	r	n	p
CRA3	0	No	-0.286	7	0.726	PC1	0	No	-0.225	15	0.419
		Yes	-0.107	7	0.609			Yes	-0.157	15	0.576
	1	No	-0.657	6	0.932		1	No	0.254	15	0.361
		Yes	-0.771	6	0.971			Yes	0.236	15	0.397
	2	No	-0.400	5	0.775		2	No	0.114	15	0.686
		Yes	-0.800	5	0.933			Yes	0.239	15	0.389
	3	No	0.800	4	0.042		3	No	-0.229	15	0.411
		Yes	1.000	4	0.042			Yes	-0.218	15	0.434
CRA34	0	No	0.014	15	0.482	HSE	0	No	-0.143	15	0.611
		Yes	0.050	15	0.431			Yes	-0.118	15	0.676
	1	No	0.339	15	0.108		1	No	0.189	15	0.498
		Yes	0.432	15	0.055			Yes	0.079	15	0.783
	2	No	-0.168	15	0.730		2	No	-0.082	15	0.773
		Yes	-0.029	15	0.538			Yes	0.043	15	0.883
	3	No	-0.032	15	0.543		3	No	-0.089	15	0.753
		Yes	-0.171	15	0.734			Yes	-0.086	15	0.763
CRA345	0	No	-0.061	15	0.589	M1	0	No	-0.064	15	0.822
		Yes	0.136	15	0.315			Yes	0.018	15	0.954
	1	No	0.368	15	0.089		1	No	0.614	15	0.017
		Yes	0.386	15	0.078			Yes	0.386	15	0.157
	2	No	-0.154	15	0.708		2	No	0.343	15	0.211
		Yes	-0.057	15	0.584			Yes	0.314	15	0.254
	3	No	-0.082	15	0.614		3	No	-0.132	15	0.639
		Yes	-0.175	15	0.738			Yes	-0.007	15	0.985

Table 6: Spearman's rank correlation coefficient (r), number of observations (n) and associated probability (p) for the relation between various settlement indices and recruitment deviations from the 1999 assessment model for CRA 4 & 5, with various lags and with or without smoothing. Tests for settlement indices are one-tailed; tests for climatic indices are two-tailed. Bold indicates significance.

Index	Lag	Smoothing	r	n	p	Index	Lag	Smoothing	r	n	p
CRA345	0	No	0.019	19	0.470	HSE	0	No	-0.03	21	0.886
	0	Yes	0.142	19	0.280		0	Yes	0.08	21	0.724
	1	No	0.307	18	0.108		1	No	-0.04	21	0.854
	1	Yes	-0.011	18	0.520		1	Yes	-0.04	21	0.872
	2	No	-0.245	17	0.832		2	No	-0.02	21	0.921
	2	Yes	-0.228	17	0.814		2	Yes	-0.02	21	0.921
	3	No	-0.653	16	0.996		3	No	-0.46	21	**0.037**
	3	Yes	-0.659	16	0.997		3	Yes	-0.48	21	**0.030**
CRA45	0	No	0.046	19	0.427	M1	0	No	-0.14	21	0.535
	0	Yes	0.200	19	0.205		0	Yes	-0.18	21	0.422
	1	No	0.352	18	0.076		1	No	-0.02	21	0.921
	1	Yes	0.069	18	0.393		1	Yes	-0.14	21	0.539
	2	No	-0.206	17	0.790		2	No	-0.12	21	0.593
	2	Yes	-0.189	17	0.770		2	Yes	-0.28	21	0.222
	3	No	-0.609	16	0.993		3	No	-0.31	21	0.169
	3	Yes	-0.653	16	0.996		3	Yes	-0.48	21	**0.027**
PC1	0	S	-0.100	21	0.665						
	0	R	-0.169	21	0.463						
	1	S	-0.105	21	0.649						
	1	R	-0.151	21	0.513						
	2	S	0.168	21	0.466						
	2	R	0.034	21	0.886						
	3	S	-0.269	21	0.238						
	3	R	-0.351	21	0.120						

Table 7: Spearman's rank correlation coefficient (r), number of observations (n) and associated probability (p) for the relation between various settlement indices and recruitment deviations from the 2000 assessment model for NSS, with various lags and with or without smoothing. Tests for settlement indices are one-tailed; tests for climatic indices are two-tailed. Bold indicates significance.

Index	Lag	Smoothing	r	n	p	Index	Lag	Smoothing	r	n	p
CRA8F	0	No	0.033	13	0.460	HSE	0	No	-0.398	22	0.068
		Yes	0.176	13	0.283			Yes	-0.373	22	0.088
	1	No	-0.168	12	0.706		1	No	-0.283	22	0.201
		Yes	0.000	12	0.504			Yes	-0.370	22	0.091
	2	No	-0.127	11	0.653		2	No	-0.272	22	0.221
		Yes	-0.445	11	0.918			Yes	-0.365	22	0.095
	3	No	-0.139	10	0.659		3	No	-0.127	22	0.572
		Yes	-0.188	10	0.708			Yes	-0.331	22	0.132
PC1	0	No	-0.438	22	**0.043**	M1	0	No	-0.437	22	**0.044**
		Yes	-0.493	22	0.021			Yes	-0.442	22	**0.041**
	1	No	-0.144	22	0.521		1	No	-0.362	22	0.099
		Yes	-0.172	22	0.442			Yes	-0.575	22	**0.006**
	2	No	0.014	22	0.952		2	No	-0.200	22	0.369
		Yes	0.093	22	0.679			Yes	-0.445	22	**0.040**
	3	No	0.145	22	0.518		3	No	-0.188	22	0.400
		Yes	0.362	22	0.097			Yes	-0.160	22	0.473

Table 8: Growth rate parameters used for each area. All growth parameter estimates are from Bentley et al. (2002). *d50:* moult increment of a 50mm tail width lobster, *d80:* moult increment of a 80mm tail width lobster, *c.v.:* coefficient of variation of moult increment, min. std. dev: minimum standard deviation of moult increment.

		CRA 3	CRA 4 & 5	CRA 7	CRA 8S	CRA 8F
Growth < 45mm	*K*	0.353	0.353	0.132	0.132	0.132
tail width	L_∞ *(mm CL)*	99.65	99.65	182.72	182.72	182.72
Growth >=	*d50*	2.15	2.09	1.95	1.95	1.95
45mm tail width	*d80*	0.11	0.25	-0.09	-0.09	-0.09
	c.v.	0.50	0.69	0.52	0.52	0.52
	min. std. dev	0.43	0.59	1.49	1.49	1.49

Table 9: Selectivity and emigration parameters used for each area. Selectivity parameter estimates are from: CRA 3, Breen et al. (2002); CRA 4 & 5, Breen et al. (2001); CRA 7, CRA 8S, CRA 8F, Bentley et al. (2001). See Breen et al. (2002) for an explanation of the parameters.

		CRA 3	CRA 4 & 5	CRA 7	CRA 8S	CRA 8F
Selectivity	*MLS1*	52	54	46	54	54
	VL1	30	49.1	55.52	55.52	55.52
	MLS2	52	54	46	54	54
	VL2	30	19.8	35.06	35.06	35.06
Emigration	*S50*	-	-	55	55	-
	S95	-	-	65	65	-
	Max	-	-	0.9	0.9	-

Table 10: Summary statistics for the fit of the model to the CPUE and length frequency data when driven by the indices shown. The following are provided for each stock and index: the model estimates of the starting exploitation rate (*Ustart*), the log-likelihoods from the size frequency data, log-likelihoods from the CPUE indices and the total log-likelihoods. The location of the likelihood from each index relative to the distribution of total log-likelihoods obtained from the random strings is provided as a percentile. The "Best fit" index is the maximum likelihood estimated index. The "Constant" fit was obtained by assuming a constant recruitment index.

			Log-likelihood			
Stock	Index	*Ustart*	Size frequencies	CPUE	Total	Percentile
CRA 3	CRA34	0.252	126.69	-45.65	81.04	26.9
	CRA345	0.259	126.82	-47.70	79.12	21.2
	CRA3	0.269	128.06	-39.12	88.94	55.9
	PC1	0.269	127.76	-42.26	85.50	41.3
	HSE	0.252	126.33	-52.69	73.64	6.8
	MI	0.266	128.02	-41.90	86.12	43.5
	Constant	0.269	128.05	-39.22	88.83	55.5
	Best fit	0.271	125.19	-5.34	119.85	-
CRA 4 & 5	CRA345	0.189	149.03	-11.08	137.95	51.3
	CRA45	0.188	149.02	-11.66	137.36	50.3
	PC1	0.175	148.47	-17.51	130.96	38.9
	HSE	0.190	148.65	-11.85	136.80	49.3
	M1	0.206	149.81	0.22	150.03	82.0
	Constant	0.200	149.84	-9.43	140.41	57.1
	Best fit	0.222	150.96	10.32	161.27	-
CRA 7	CRA7	0.01	133.66	-68.67	64.99	1.8
	PC1	0.01	134.19	-29.97	104.22	59.3
	HSE	0.01	133.61	-33.46	100.15	43.5
	MI	0.01	133.84	-61.44	72.40	3.0
	Const	0.01	133.87	-31.52	102.35	52.5
	Best fit	0.669	134.03	0.85	134.88	-
CRA 8S	CRA8S	0.01	140.32	-42.94	97.38	0.2
	PC1	0.01	140.79	1.19	141.98	80.4
	HSE	0.01	140.7	2.44	143.14	91.8
	M1	0.01	140.35	0.23	140.58	62.7
	Constant	0.01	141.12	-0.29	140.83	65.1
	Best fit	0.094	140.47	7.01	147.48	-
CRA 8F	CRA8F	0.094	115.4	6.89	122.29	75.6
	PC1	0.116	115.2	6.47	121.67	39.5
	HSE	0.081	114.43	6.46	120.89	13.0
	M1	0.091	115.09	6.92	122.01	60.7
	Constant	0.104	115.27	6.58	121.85	51.5
	Best fit	0.303	117.47	6.85	124.32	-

Table 11: Summary statistics for the CRA 3 sensitivity run using growth rates estimated assuming the CRA34 index is correct. See Table 10 for explanations.

		Log-likelihood			
Index	*Ustart*	Size frequencies	CPUE	Total	Percentile
CRA34	0.260	127.81	-29.89	97.93	90.0
CRA345	0.264	127.81	-31.25	96.56	84.4
CRA3	0.265	128.70	-37.43	91.26	60.1
PC1	0.265	128.29	-38.07	90.21	54.7
HSE	0.260	127.20	-31.30	95.90	82.8
MI	0.265	128.11	-36.74	91.37	60.5
Constant	0.265	128.70	-37.43	91.26	60.1

Table 12: The estimated proportion of recruits in each size class by time to recruitment for CRA 3. For example, 21% of the recruits to the fishery in 3 years time are in size class 42–43 mm tail width. Size classes are 2 mm wide and are represented by the lower bound.

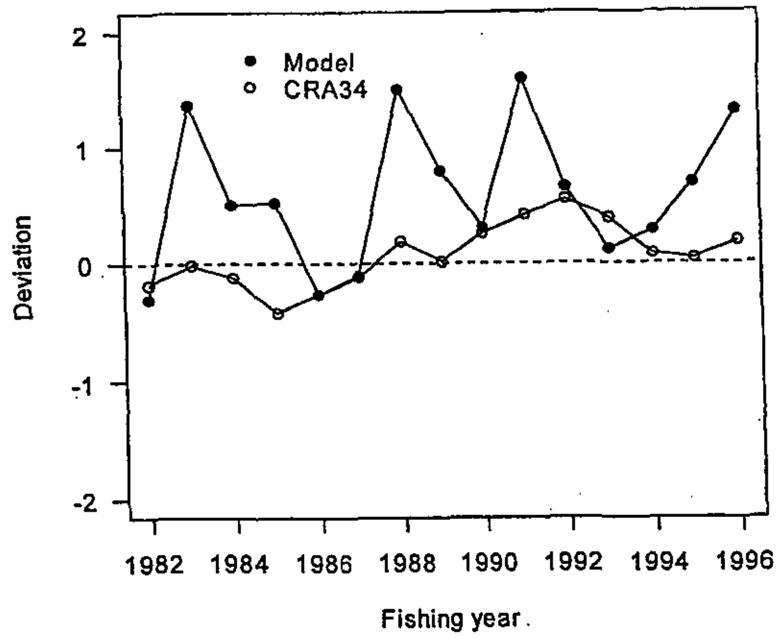
	Years to recruitment			
Size class	1	2	3	4
30	0.00	0.00	0.01	0.09
32	0.00	0.00	0.03	0.12
34	0.00	0.00	0.05	0.14
36	0.00	0.00	0.09	0.14
38	0.00	0.01	0.15	0.12
40	0.00	0.04	0.20	0.08
42	0.00	0.11	0.21	0.05
44	0.00	0.20	0.15	0.02
46	0.03	0.29	0.08	0.01
48	0.15	0.25	0.02	0.00
50	0.36	0.09	0.00	0.00
52	0.45	0.01	0.00	0.00

Table 13: The estimated proportion of recruits in each size class by time to recruitment for CRA 4 & 5. See Table 12 for details.

	Years to recruitment			
Size class	1	2	3	4
30	0.00	0.01	0.07	0.11
32	0.00	0.01	0.09	0.11
34	0.00	0.02	0.11	0.10
36	0.00	0.04	0.14	0.10
38	0.00	0.07	0.15	0.08
40	0.00	0.06	0.16	0.08
42	0.00	0.11	0.17	0.06
44	0.01	0.18	0.14	0.03
46	0.05	0.24	0.09	0.01
48	0.16	0.21	0.04	0.01
50	0.32	0.11	0.01	0.00
52	0.43	0.03	0.00	0.00

Table 14: The estimated proportion of recruits in each size class by time to recruitment for CRA 8. See Table 12 for details.

	Years to recruitment			
Size class	1	2	3	4
30	0.00	0.00	0.04	0.10
32	0.00	0.00	0.06	0.11
34	0.00	0.00	0.08	0.11
36	0.00	0.01	0.11	0.11
38	0.00	0.03	0.14	0.10
40	0.00	0.04	0.15	0.09
42	0.00	0.09	0.16	0.07
44	0.00	0.16	0.14	0.04
46	0.04	0.21	0.10	0.02
48	0.14	0.20	0.05	0.01
50	0.29	0.12	0.03	0.01
52	0.41	0.04	0.01	0.00



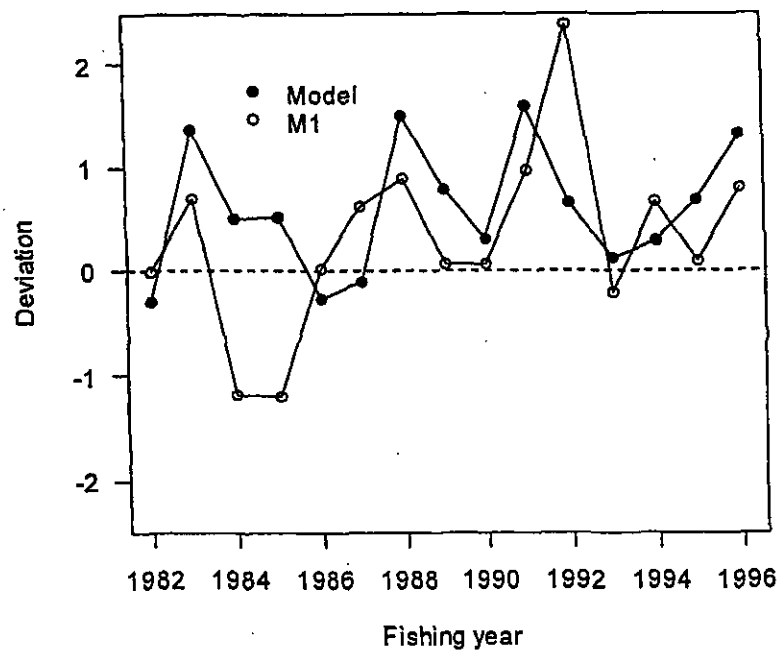


Figure 1: Relation between the median of recruitment deviations from the 2001 CRA 3 assessment model and the smoothed CRA34 collector index lagged by one year (top) and the unsmoothed M1 climatic index lagged by one year (bottom). The year is correct for the settlement or climatic index; the model indices have been set back one year.

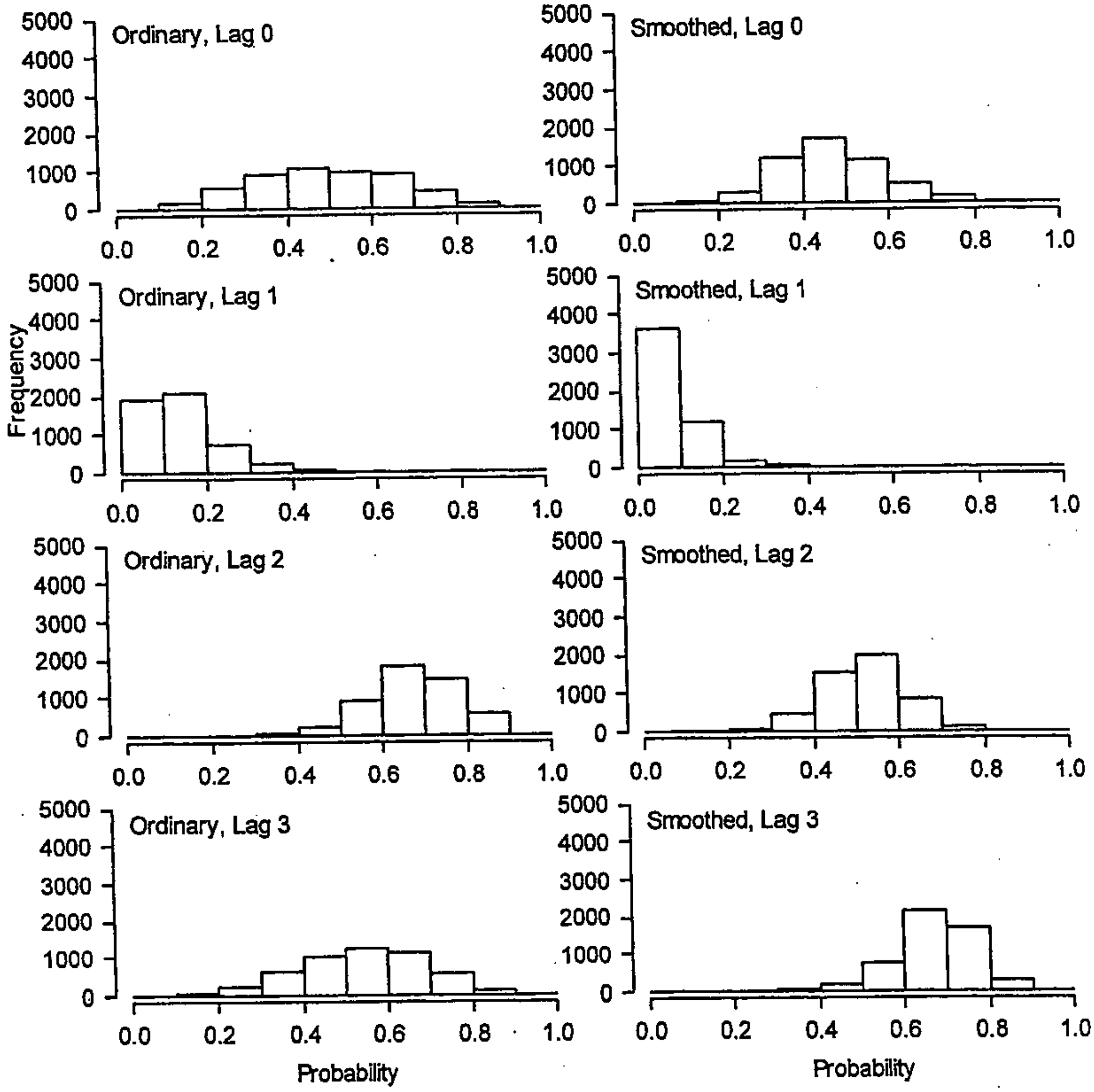


Figure 2: Posterior distributions of correlation probabilities between the CRA34 settlement index and recruitment deviations from the posterior distribution of the 2001 CRA 3 assessment model.

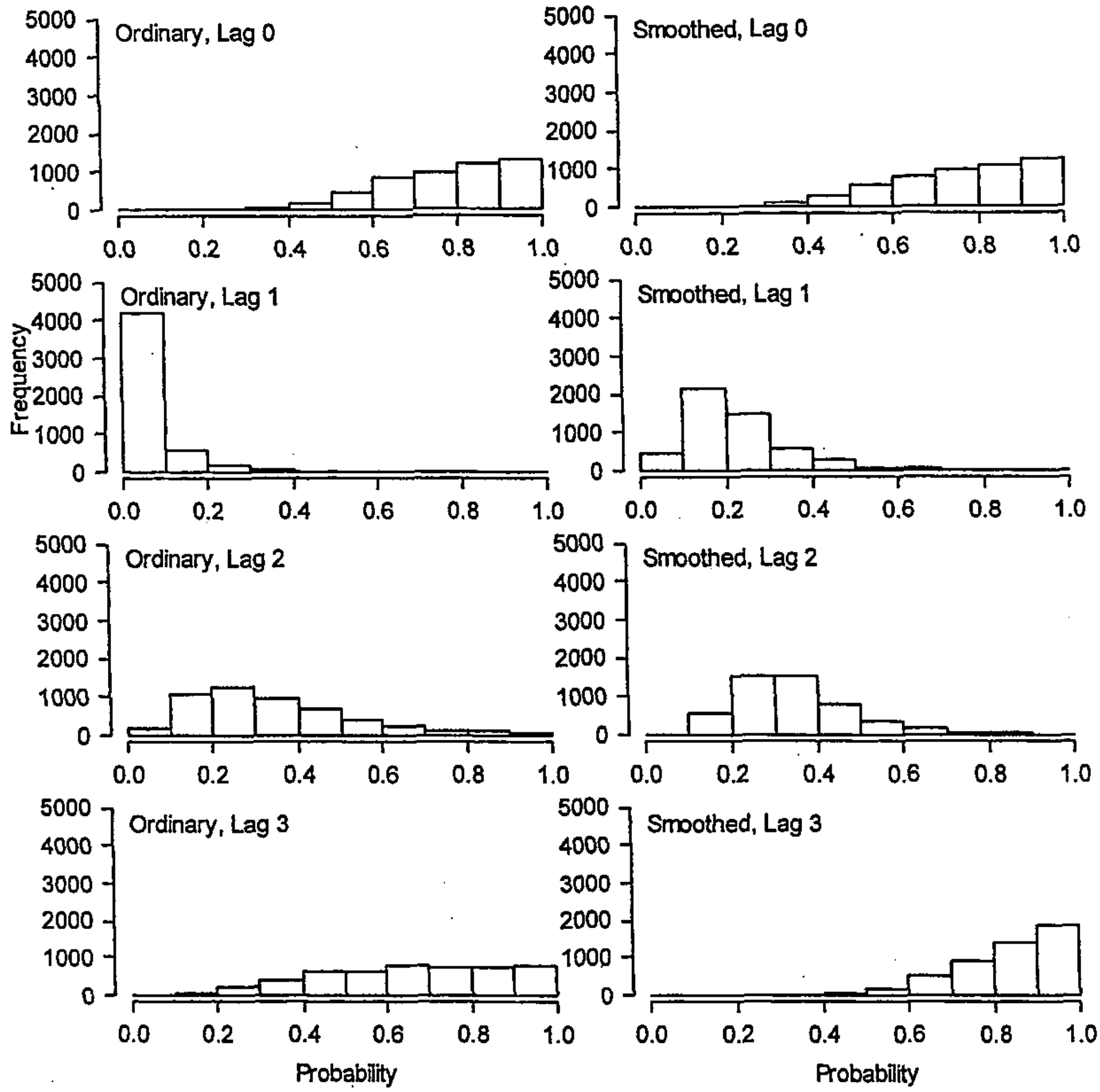
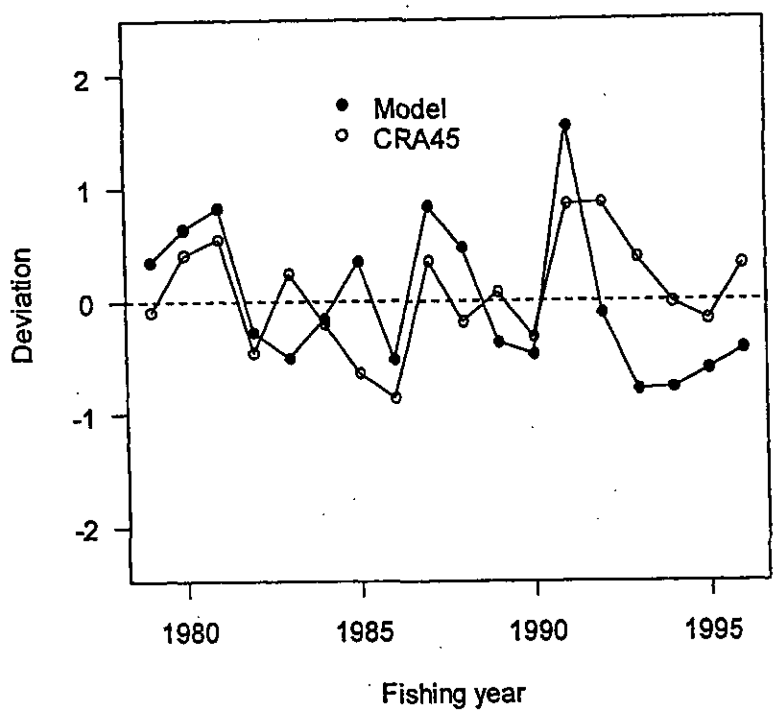


Figure 3: Posterior distributions of correlation probabilities between the M1 climatic index and recruitment deviations from the posterior distribution of the 2001 CRA3 assessment model.



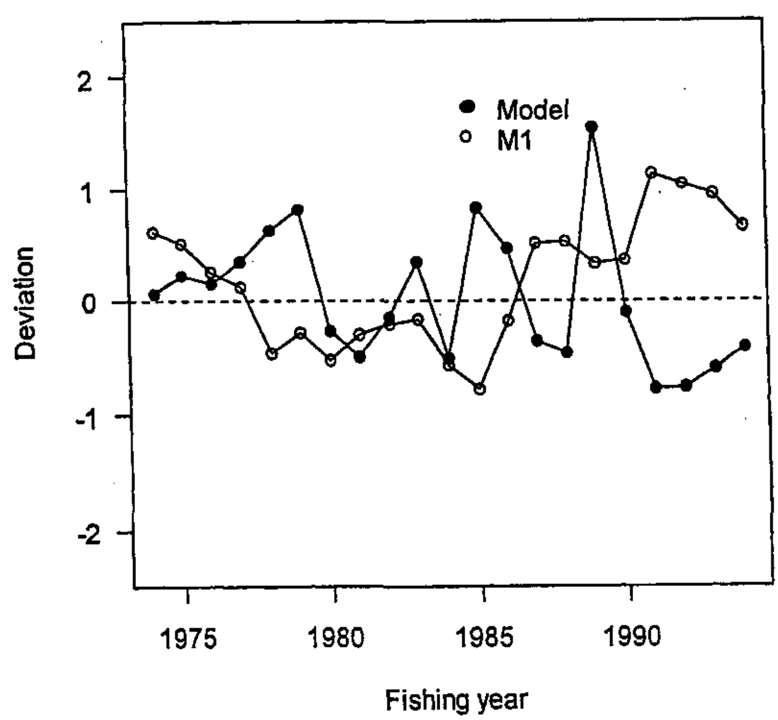


Figure 4: Relation between the median of recruitment deviations from the 1999 CRA 4 & 5 assessment model and the unsmoothed CRA45 settlement index lagged by 1 year (top) and the smoothed M1 climatic index lagged by 3 years (bottom). Fishing year is correct for the settlement index.

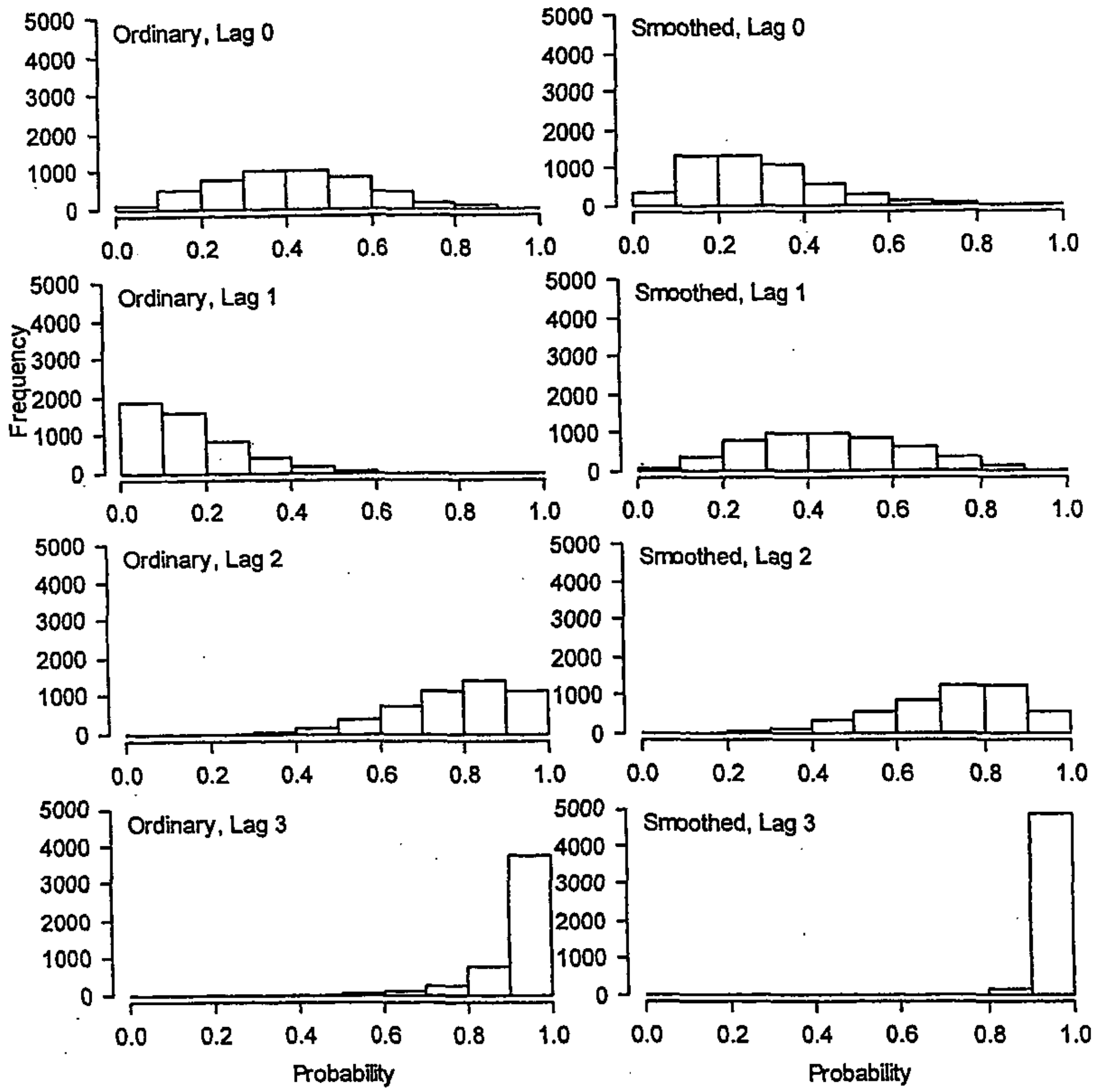


Figure 5: Posterior distributions of correlation probabilities between the CRA45 settlement index and recruitment deviations from the posterior distribution of the 1999 CRA 4 & 5 assessment model.

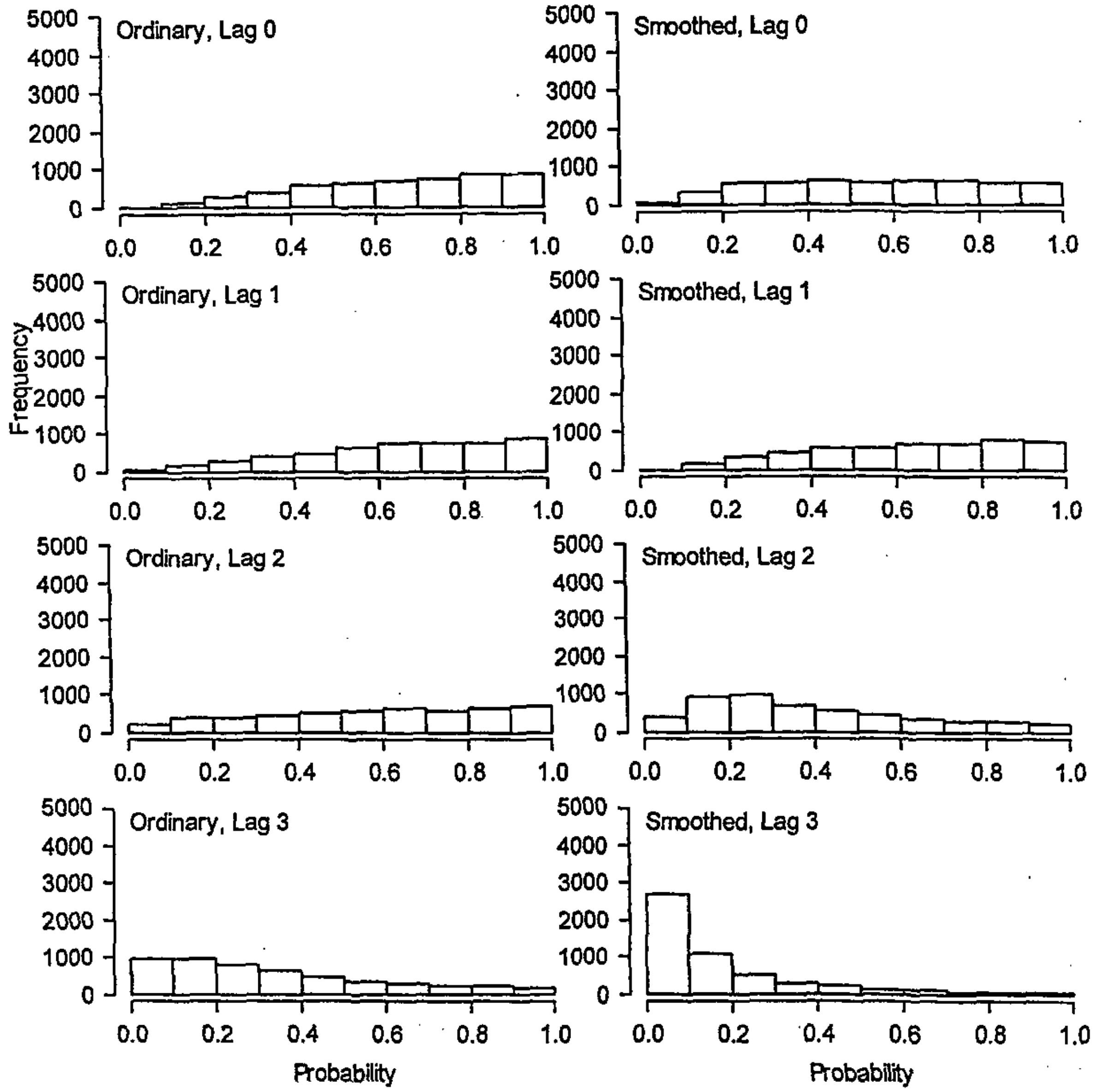


Figure 6: Posterior distributions of correlation probabilities between the M1 climatic index and recruitment deviations from the posterior distribution of the 1999 CRA 4 & 5 assessment model.

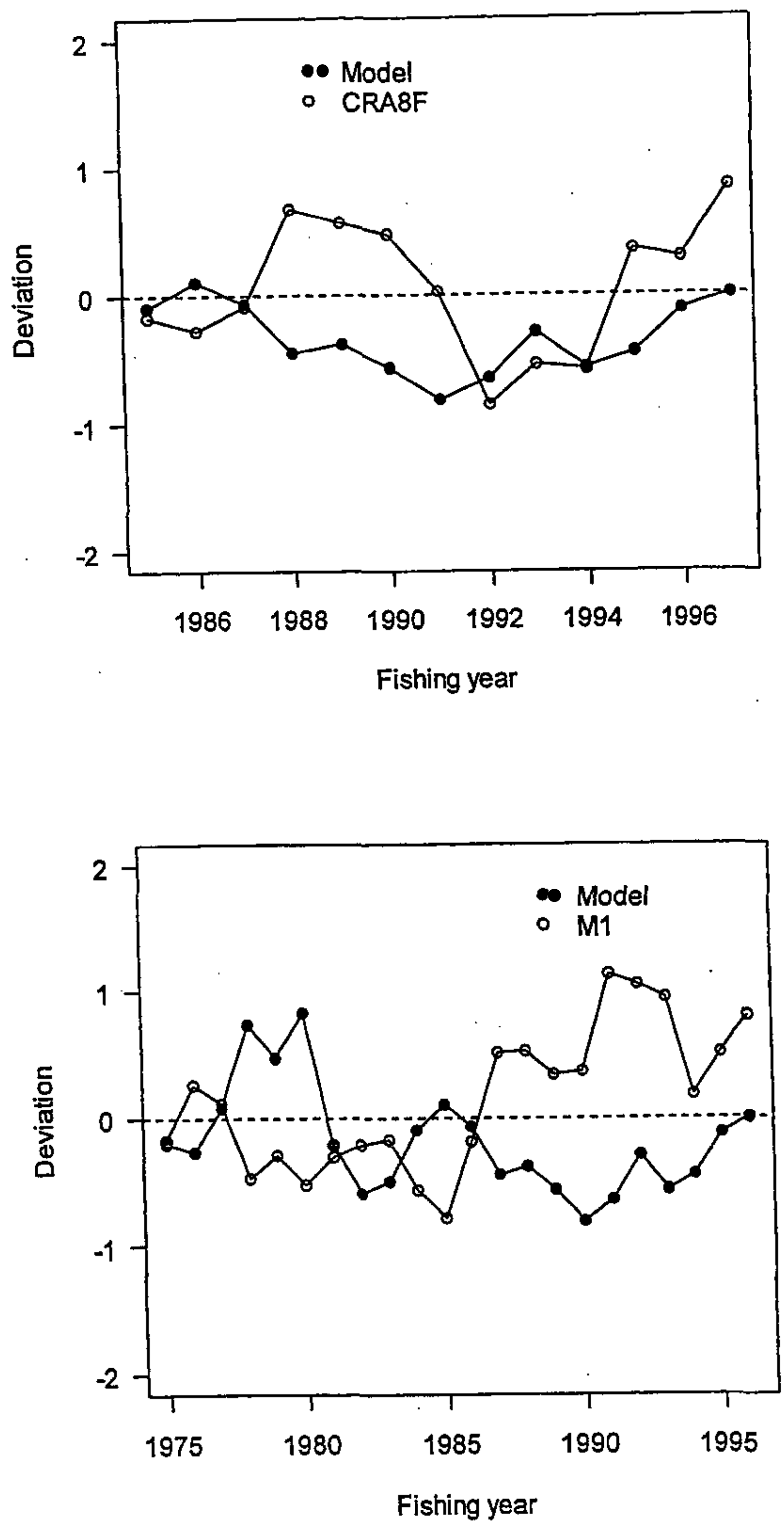


Figure 7: Relation between the median of recruitment deviations from the 2000 NSS assessment model and the CRA8F settlement index smoothed (top) and the smoothed M1 climatic index lagged by one year (bottom). Fishing year is correct for the settlement index.

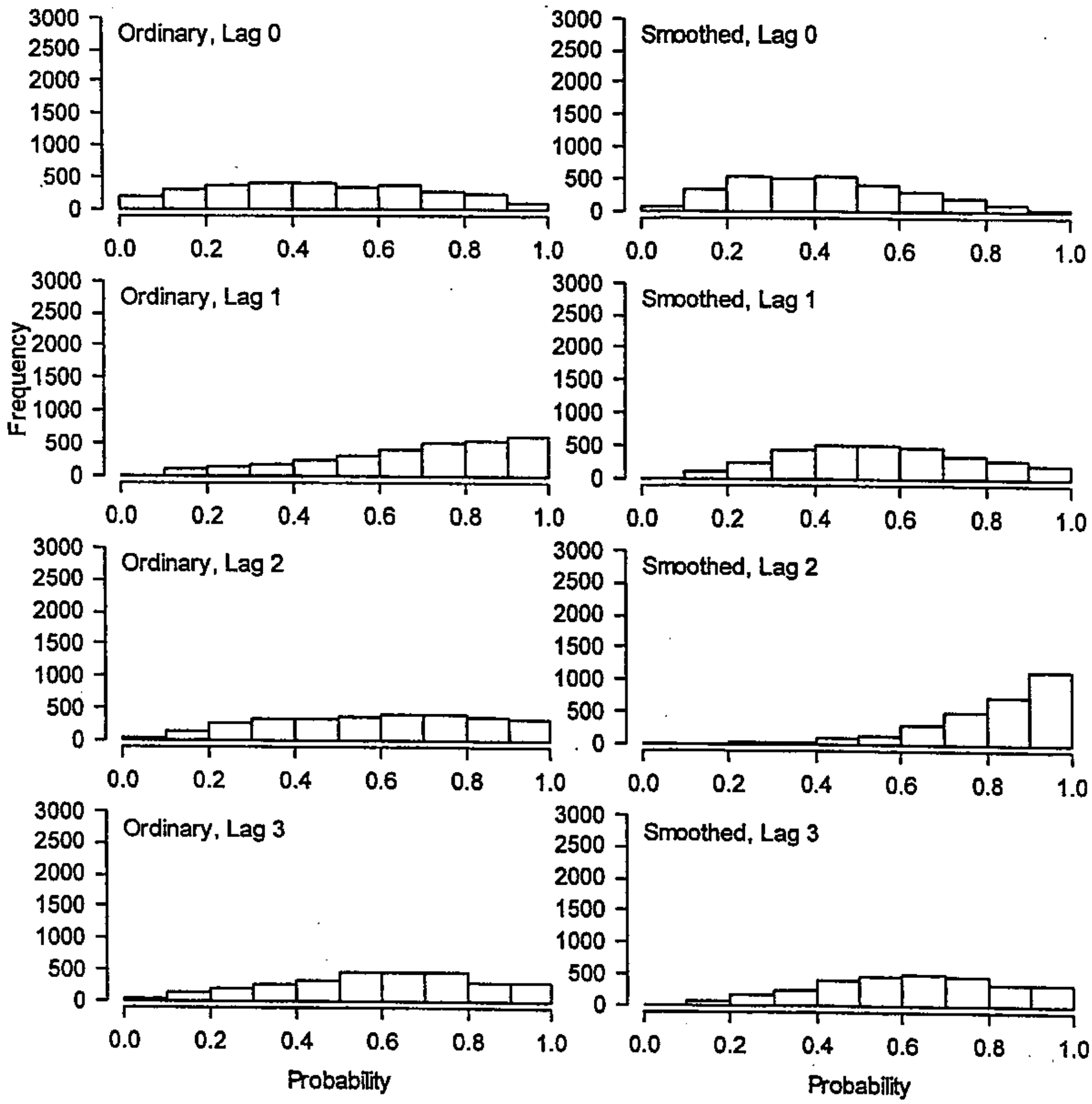


Figure 8: Posterior distributions of correlation probabilities between the CRA8F settlement index and recruitment deviations from the posterior distribution of the 2000 NSS assessment model.

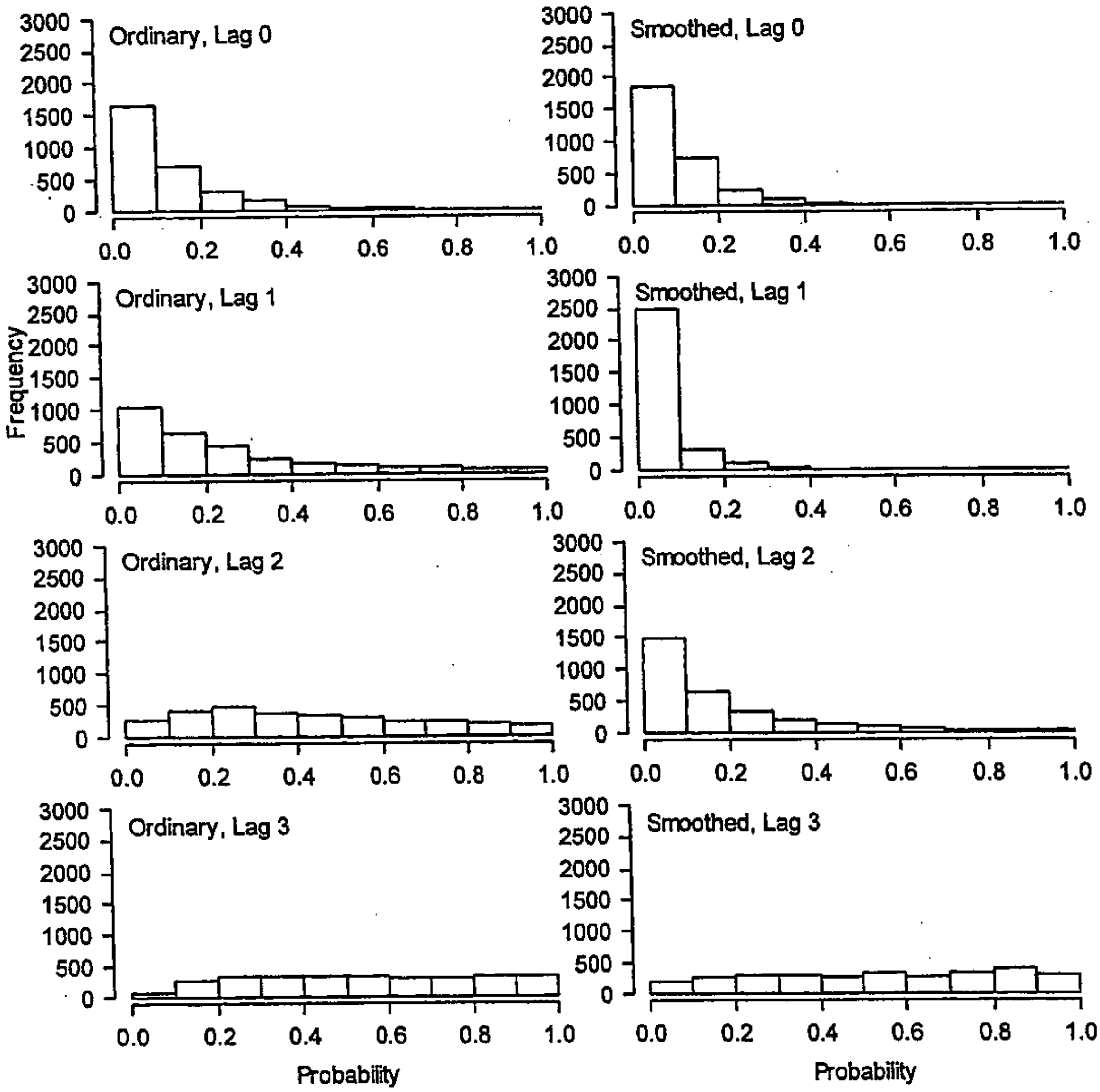


Figure 9: Posterior distribution of correlation probabilities between the M1 climatic index and recruitment deviations from the posterior distribution of the 2000 NSS assessment model.

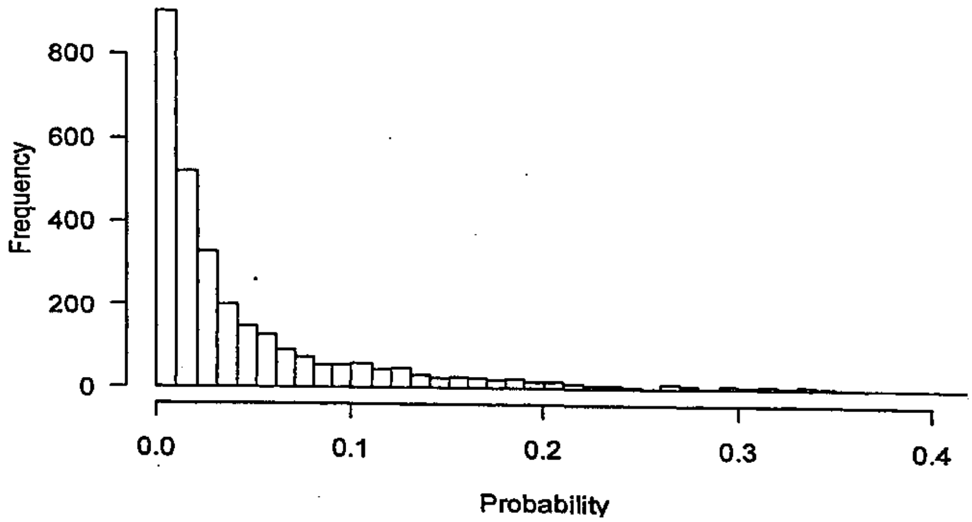


Figure 10: Posterior distribution of correlation probabilities between the smoothed M1 climatic index lagged by one year and recruitment deviations from the posterior distribution of the 2000 NSS assessment model.

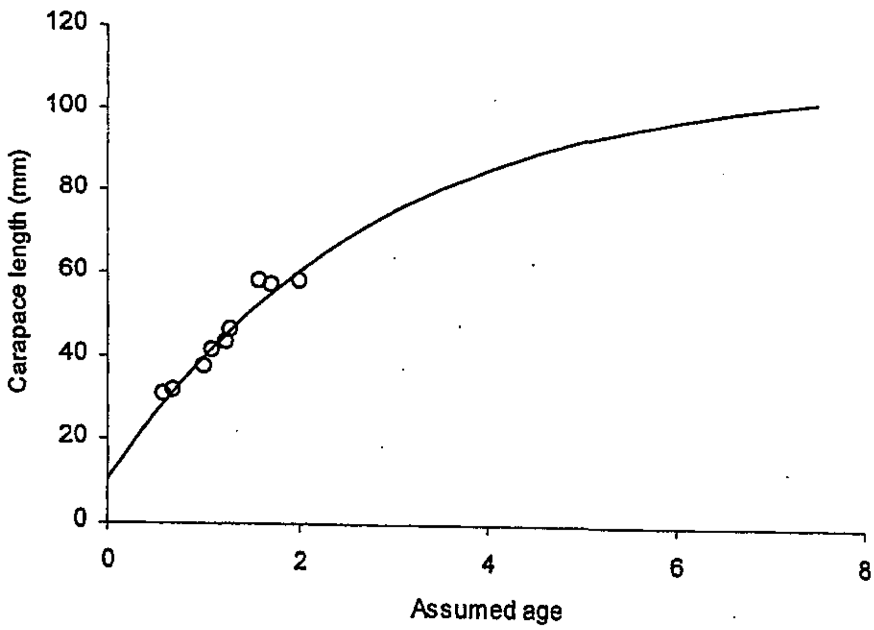


Figure 11: Modal length-at-age and the fitted von Bertalanffy curve for CRA 3 from McKoy & Esterman (1981).

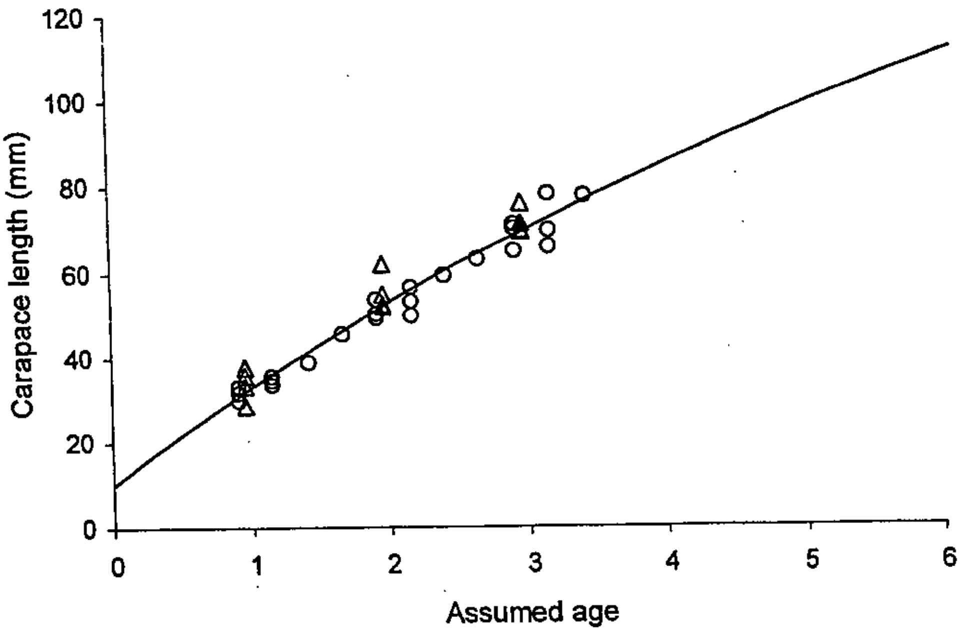


Figure 12: Model length-at-age and the fitted von Bertalanffy curve for CRA 8 from Annala & Bycroft (1985) (circles) and Breen & Booth (1989) (triangles).

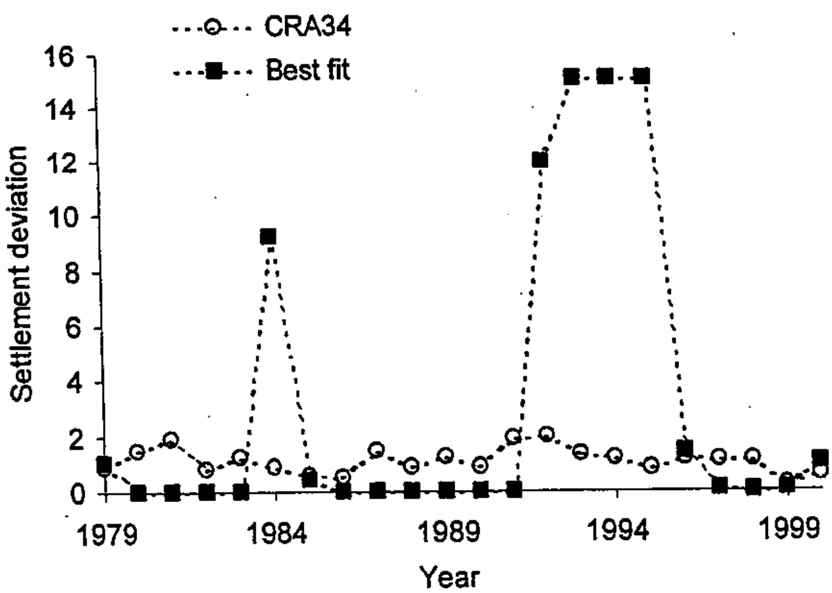


Figure 13: Comparison of the best fit settlement estimate for CRA 3 and the CRA34 settlement index.

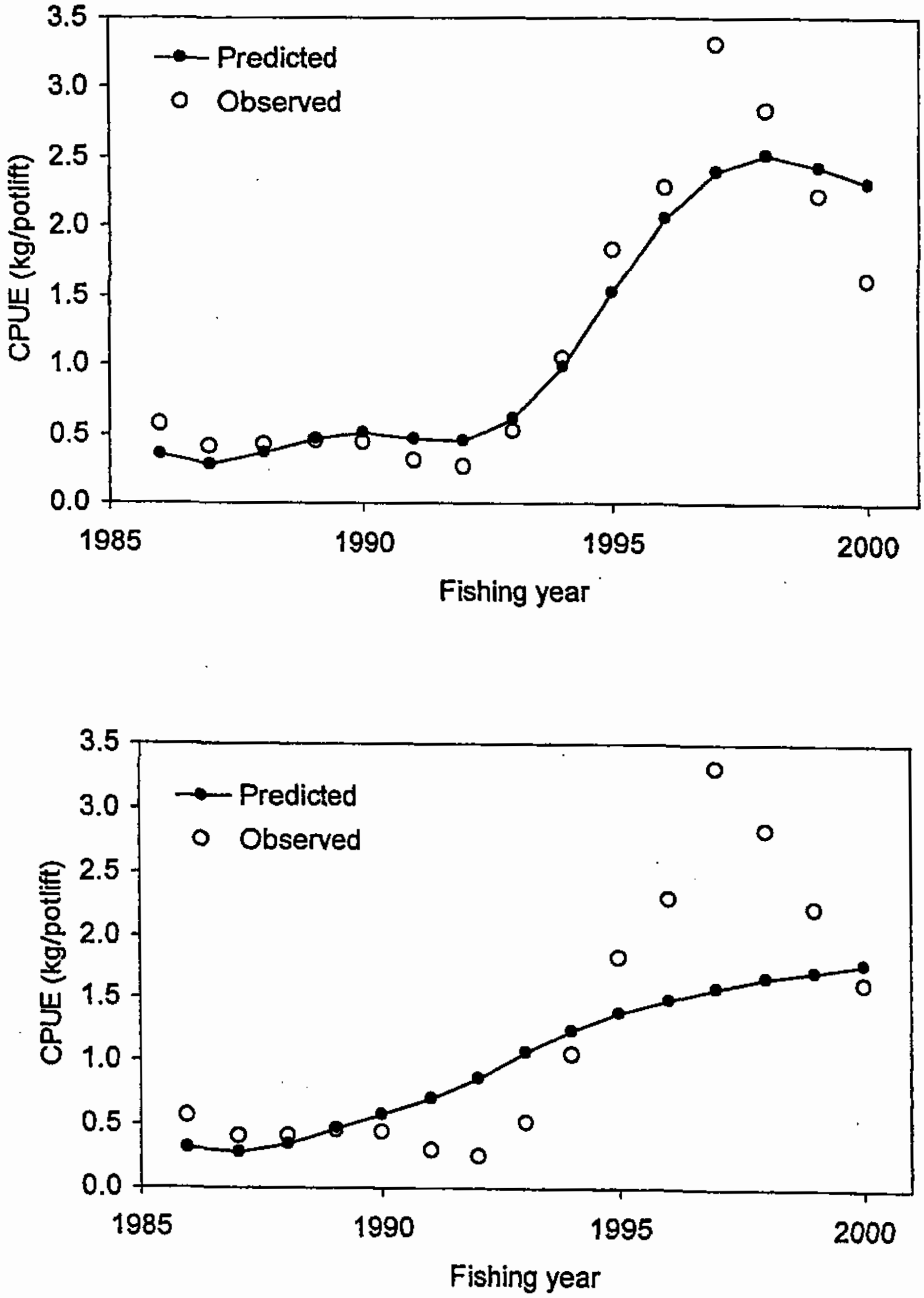


Figure 14: Fit to the CPUE data from CRA 3 based on the best fit settlement (top) and the CRA34 settlement index (bottom).

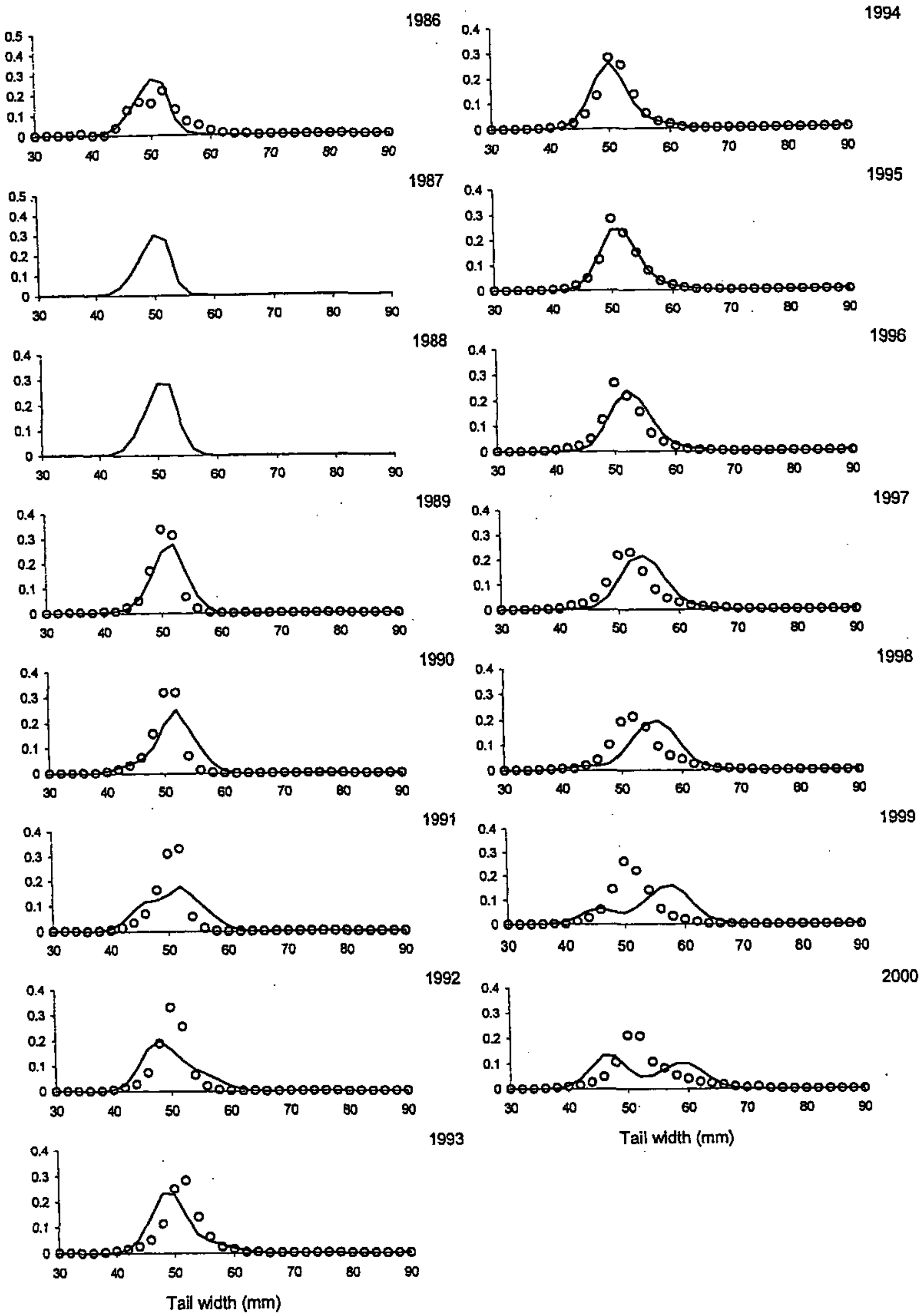


Figure 15: Fit to the length frequency data from CRA 3 based on the best-fit settlement index.

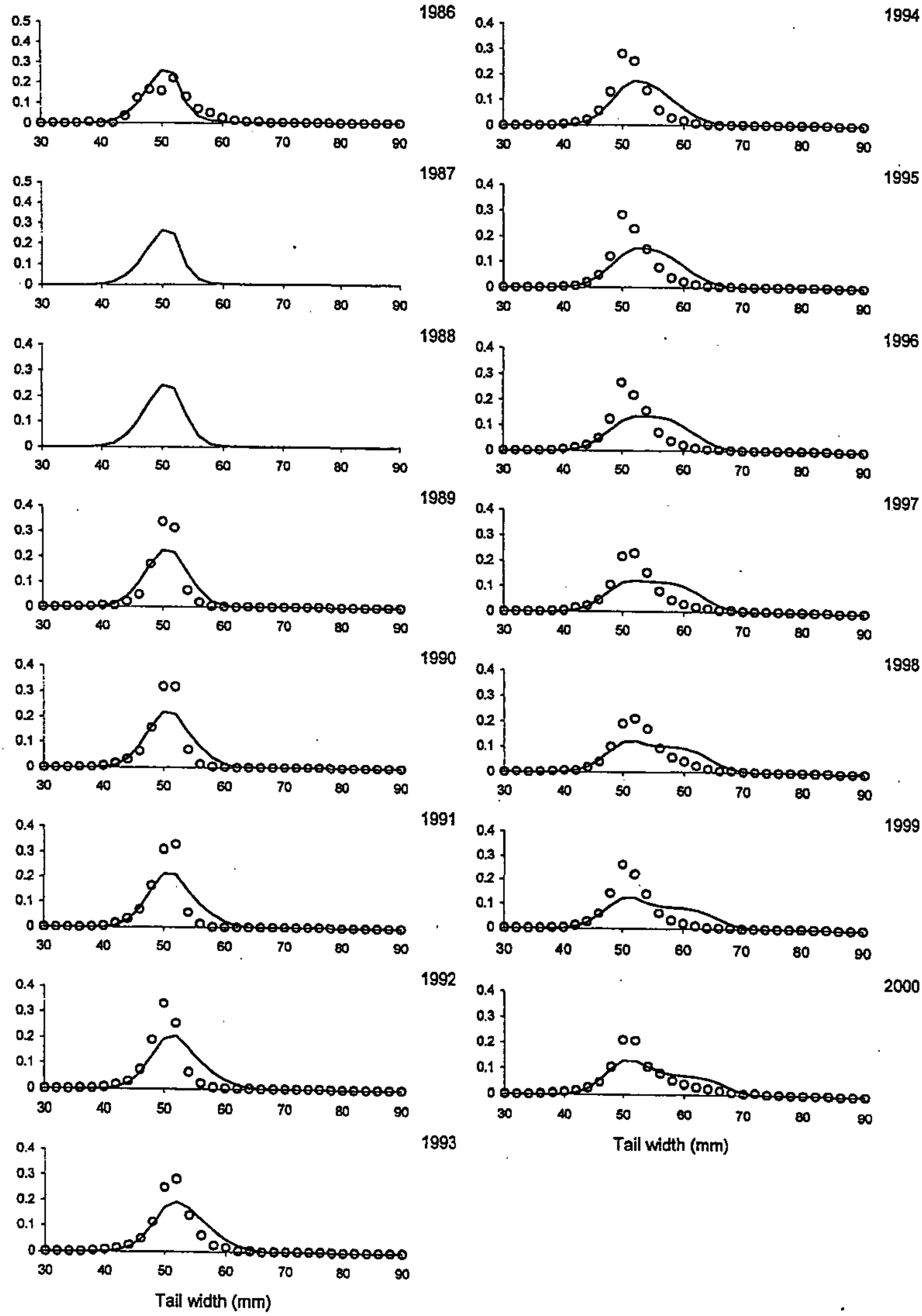


Figure 16: Fit to the length frequency data from CRA 3 based on the CRA34 settlement index.

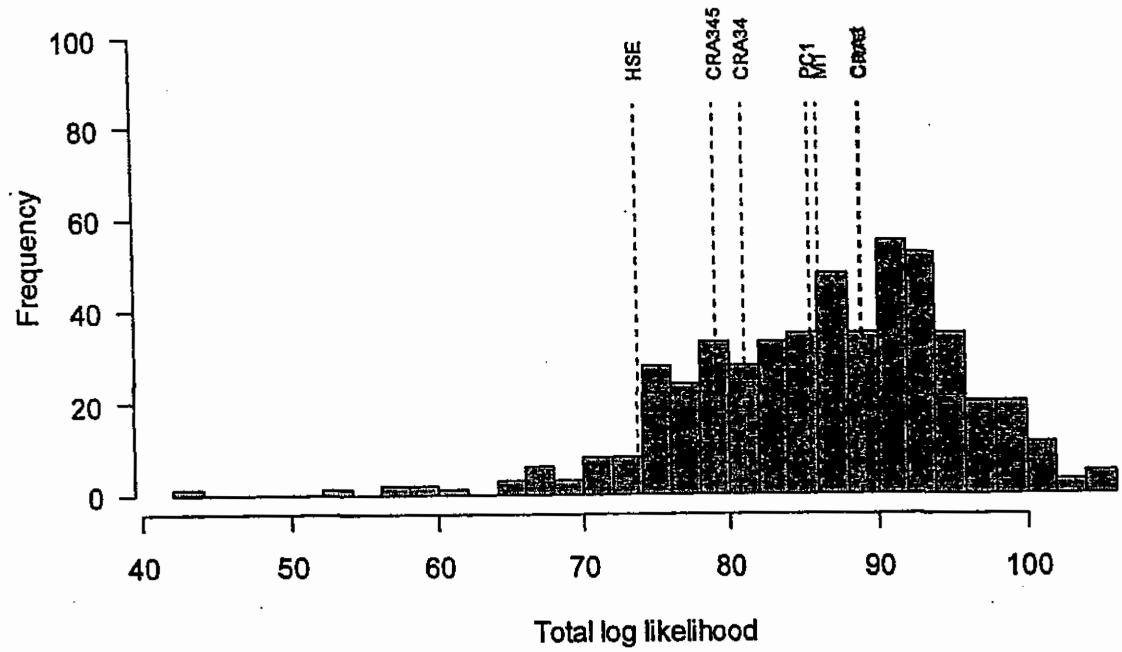


Figure 17: Distribution of total log-likelihoods from the fits of the 500 randomly drawn recruitment series to the CRA 3 CPUE indices and the CRA 3 length frequency data. The location of each of the examined settlement indices is also provided in terms of its total log-likelihood.

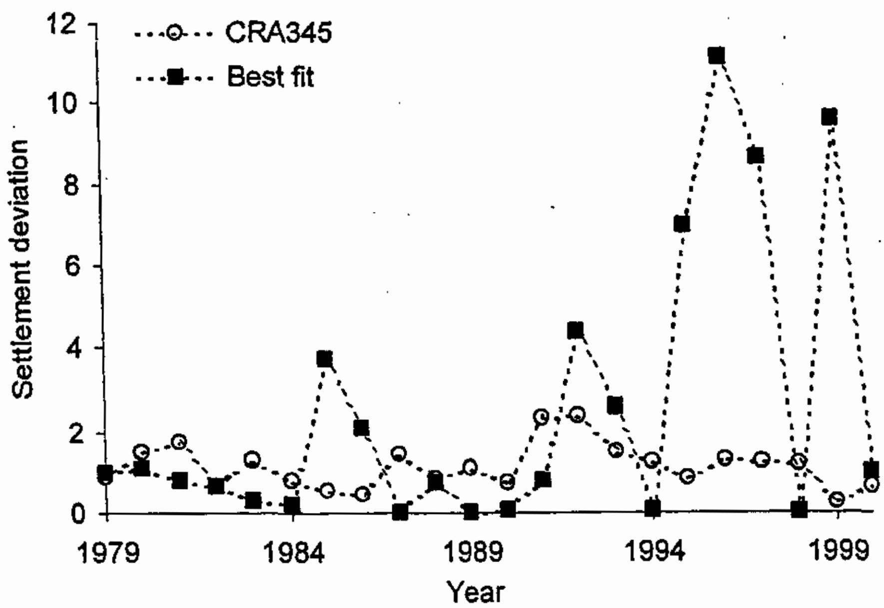


Figure 18: Comparison of the best fit settlement estimate for CRA 4 & 5 and the CRA345 settlement index.

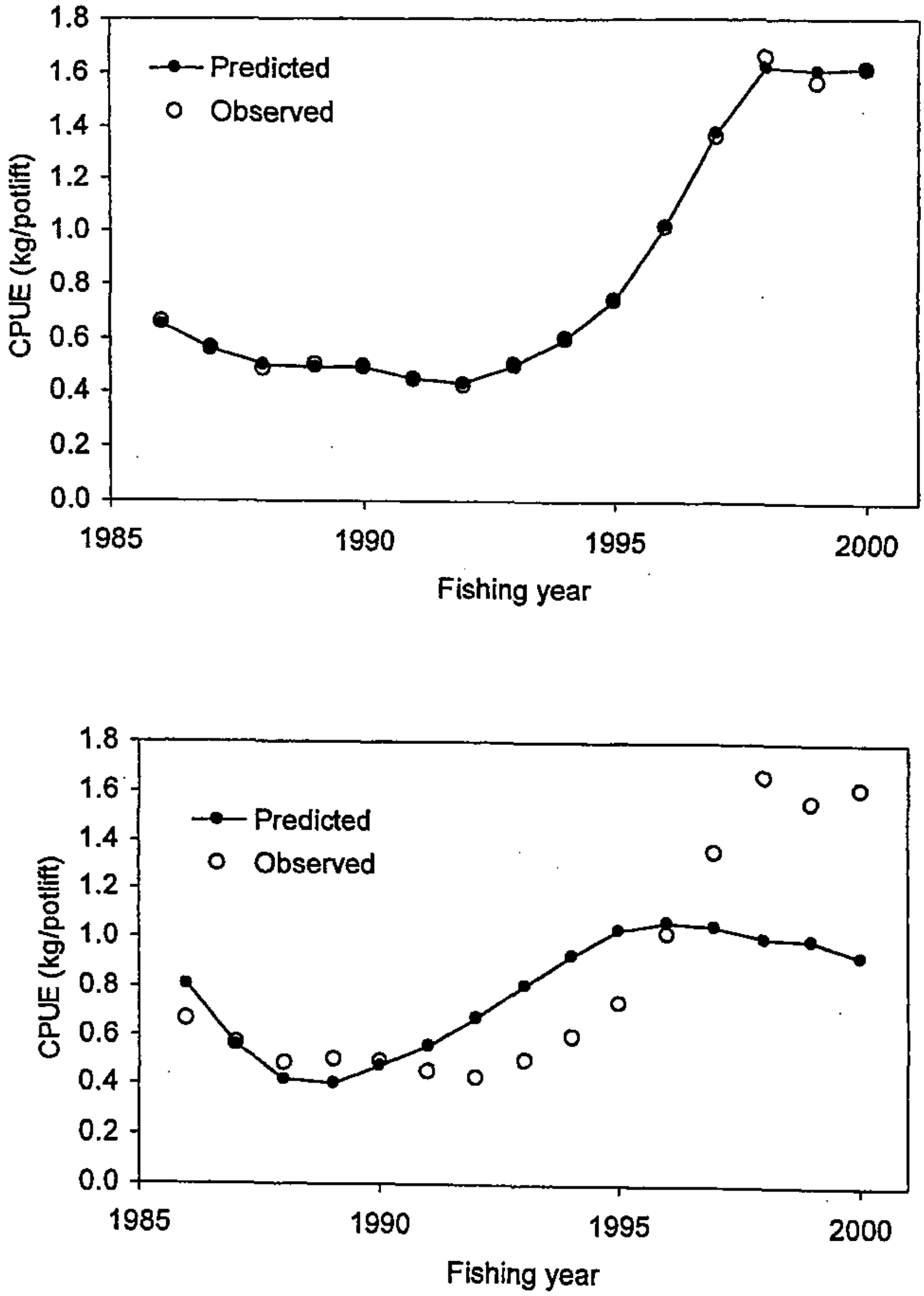


Figure 19: Fit to the CPUE data from CRA 4&5 based on the best fit settlement (top) and the CRA 45 settlement index (bottom).

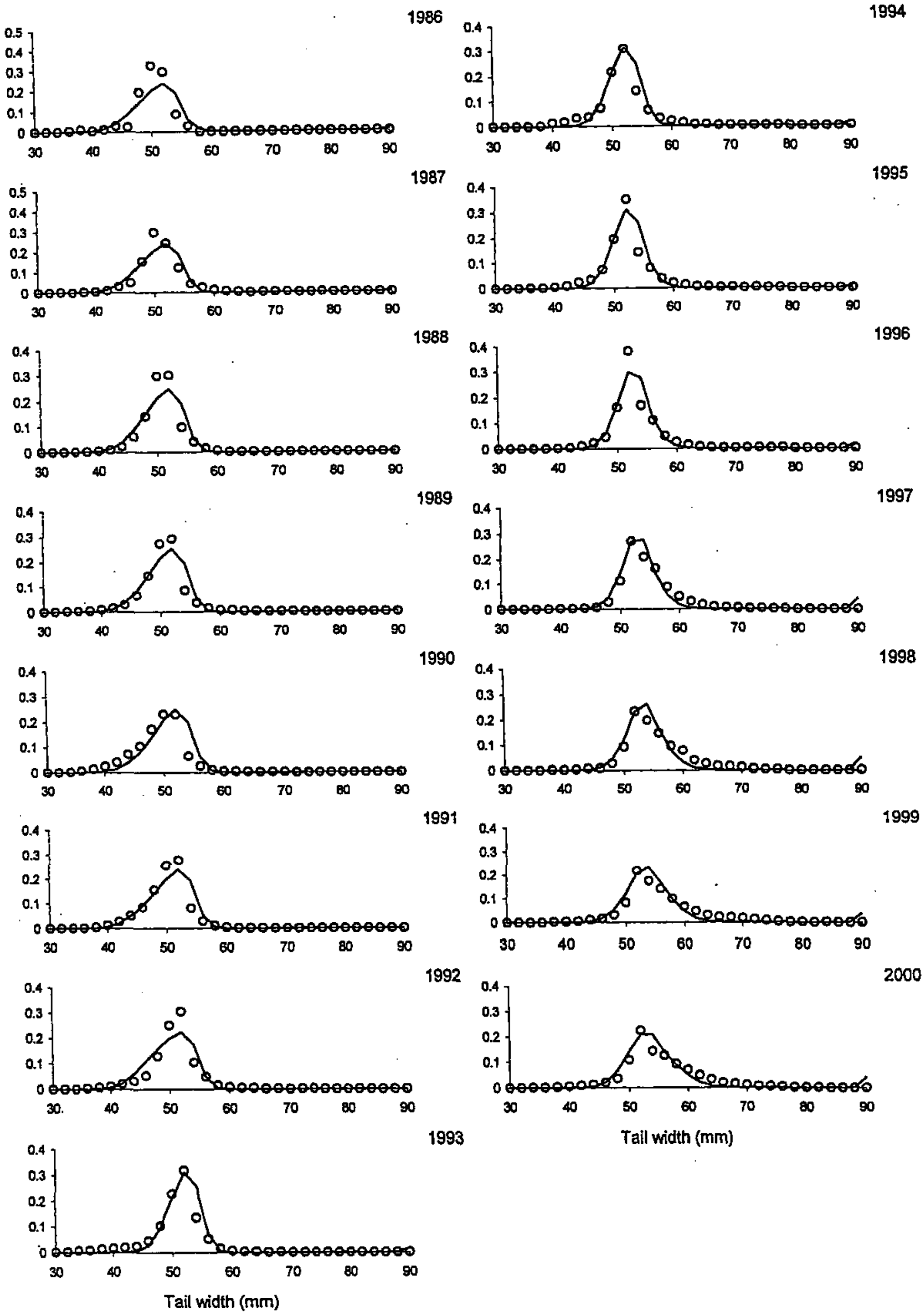


Figure 20: Fit to the length frequency data from CRA 4&5 based on the best fit settlement index.

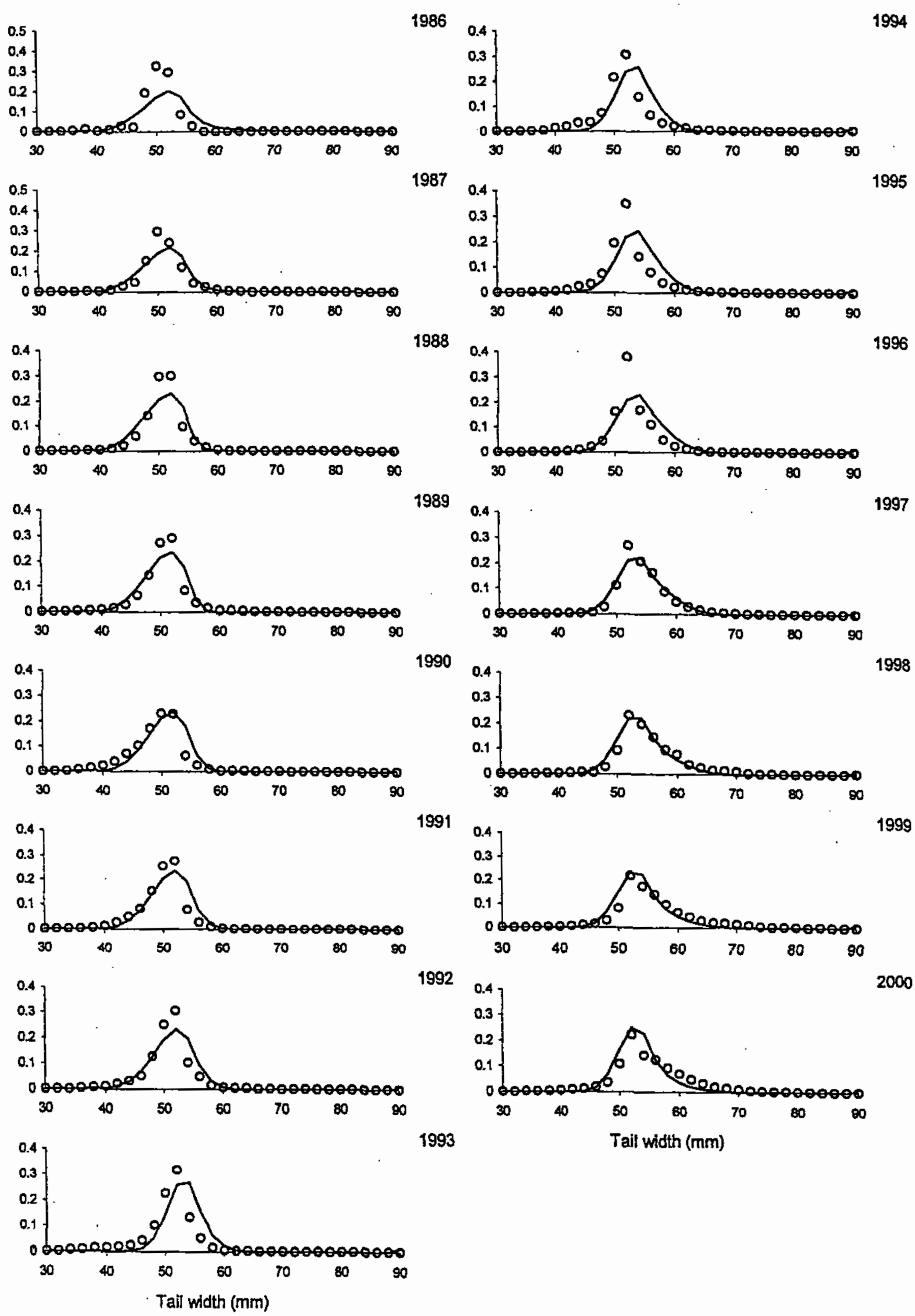


Figure 21: Fit to the length frequency data from CRA 4 & 5 based on the CRA45 settlement index.

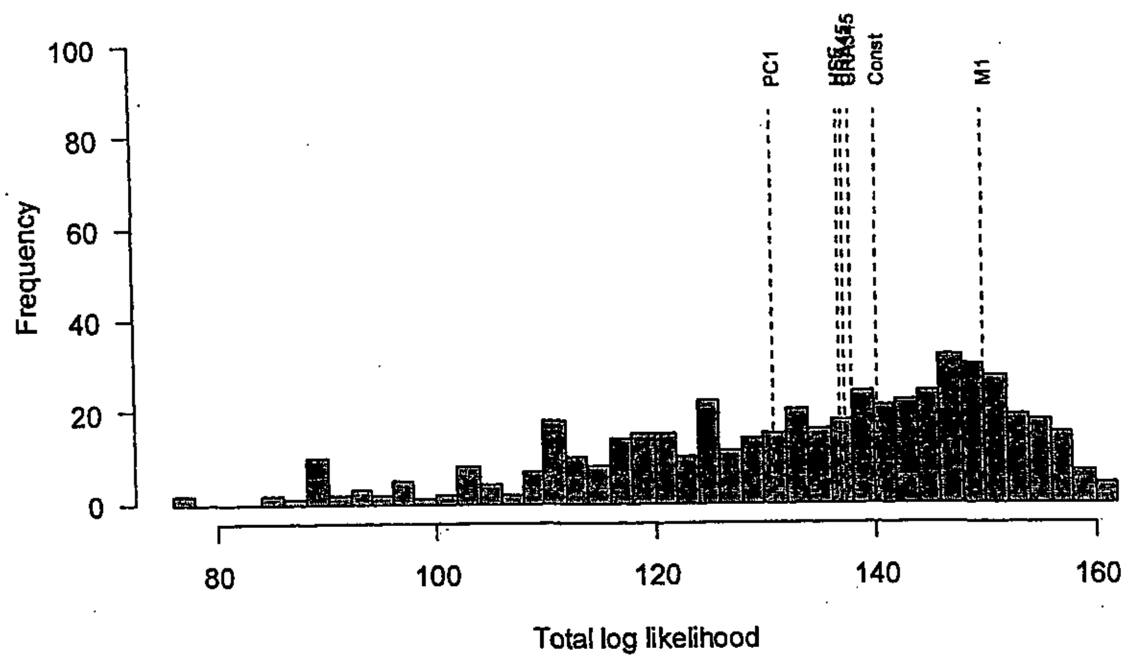


Figure 22: Distribution of total log-likelihoods from the fits of the 500 randomly drawn recruitment series to the CRA 4 & 5 CPUE indices and length frequency data. The location of each of the examined settlement indices is provided in terms of its total log-likelihood fit.

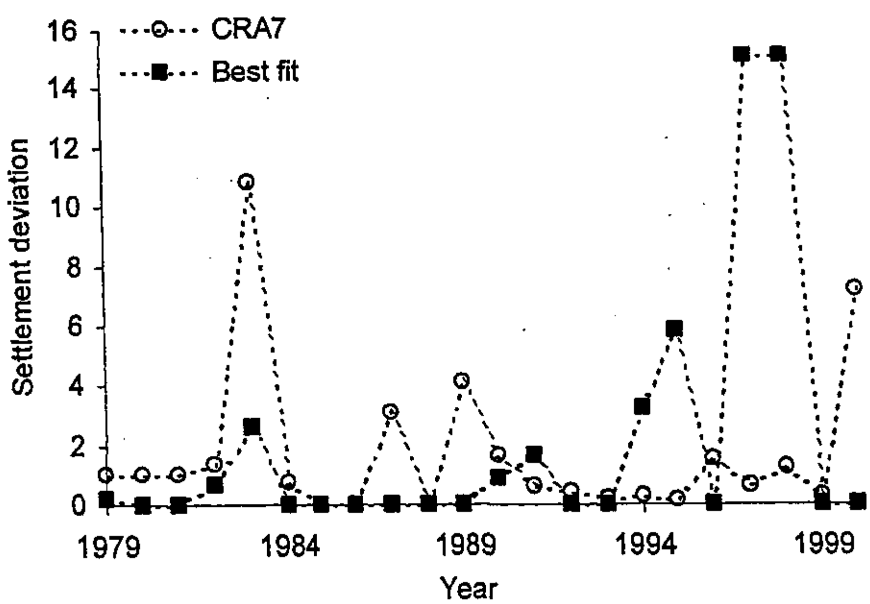


Figure 23: Comparison of the best fit settlement estimate for CRA 7 and the CRA7 settlement index.

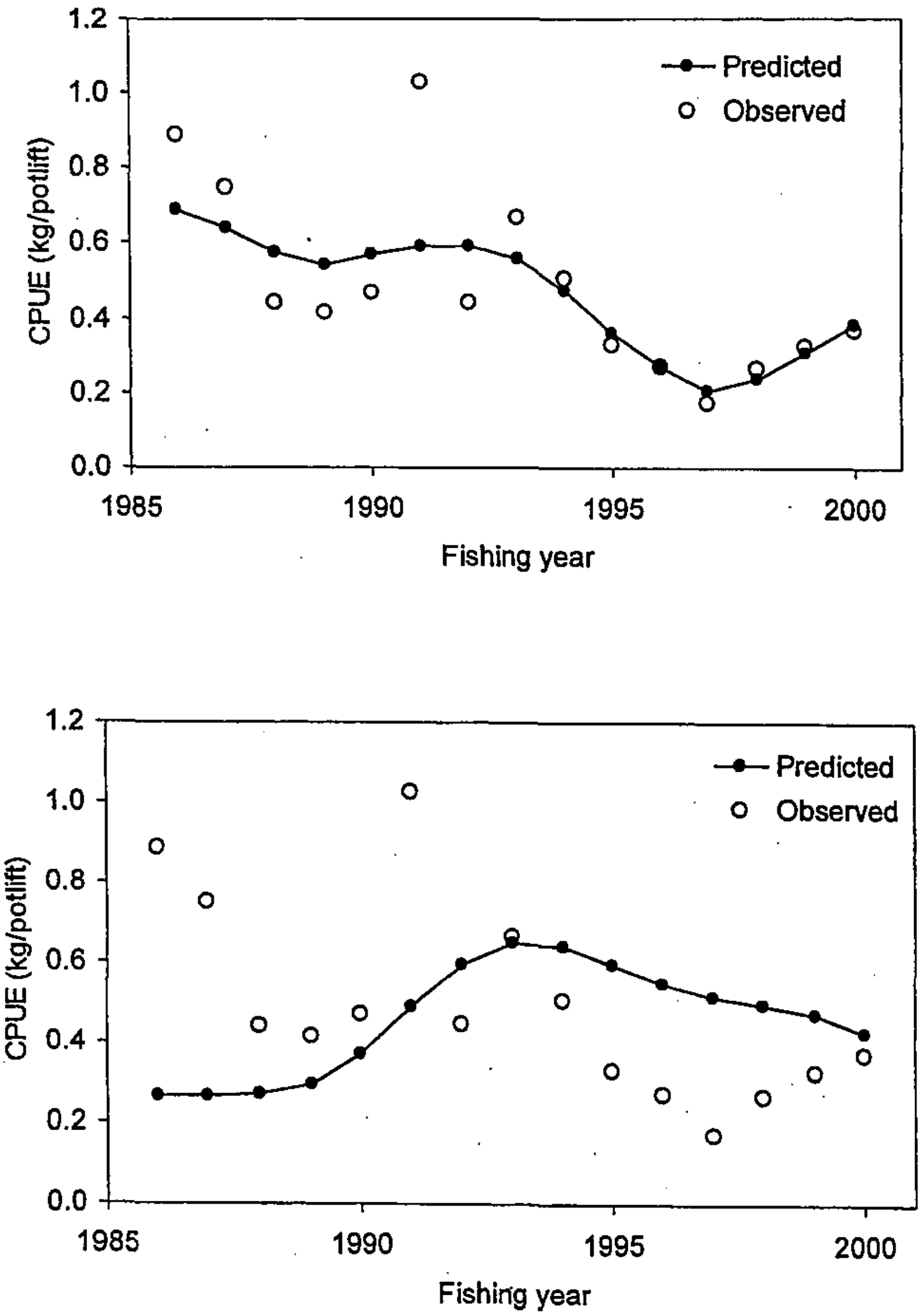


Figure 24: ***Fit to the CPUE data from CRA 7 based on the best fit settlement (top) and the CRA7 settlement index (bottom).***

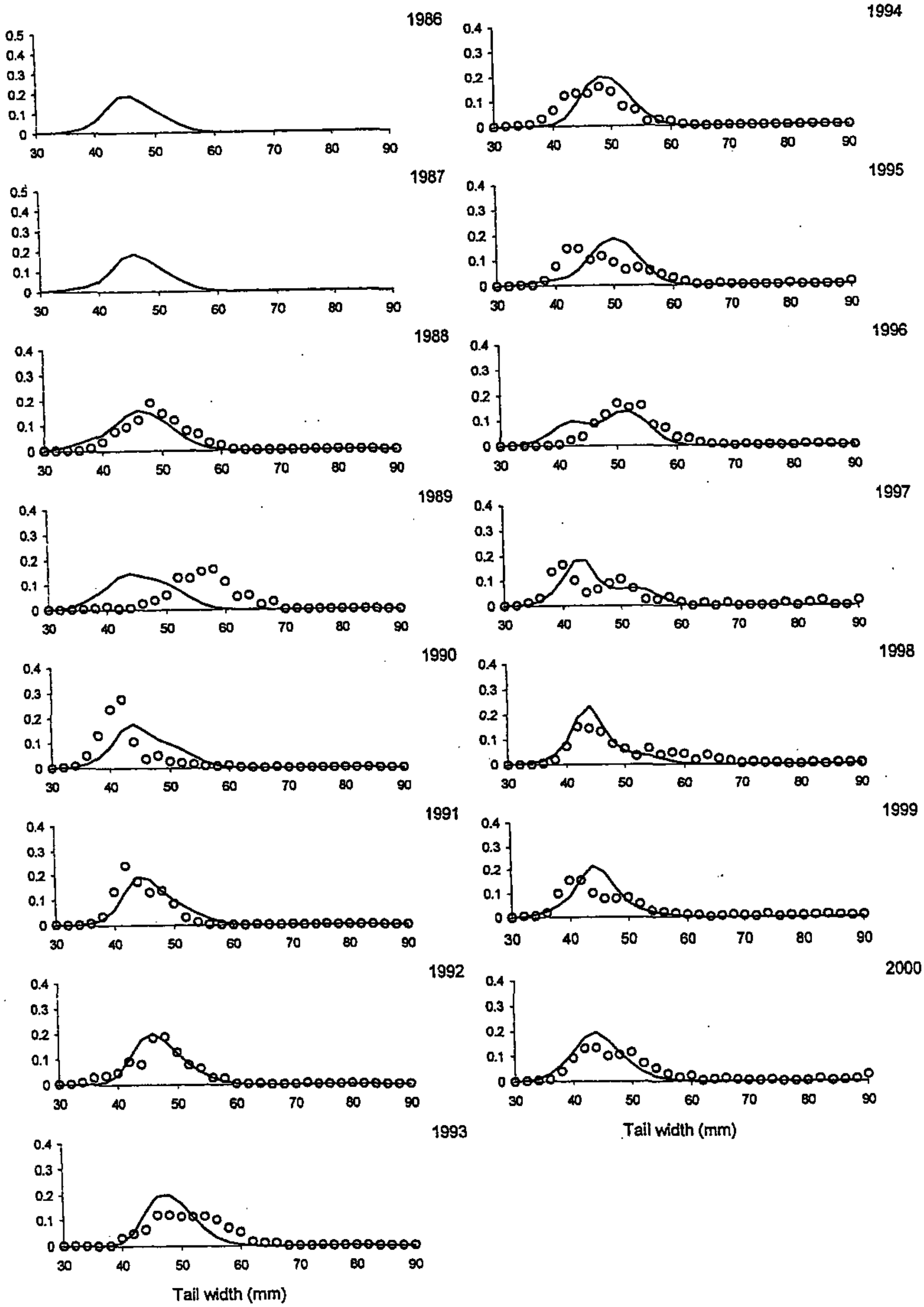


Figure 25: Fit to the length frequency data from CRA 7 based on the best fit settlement index.

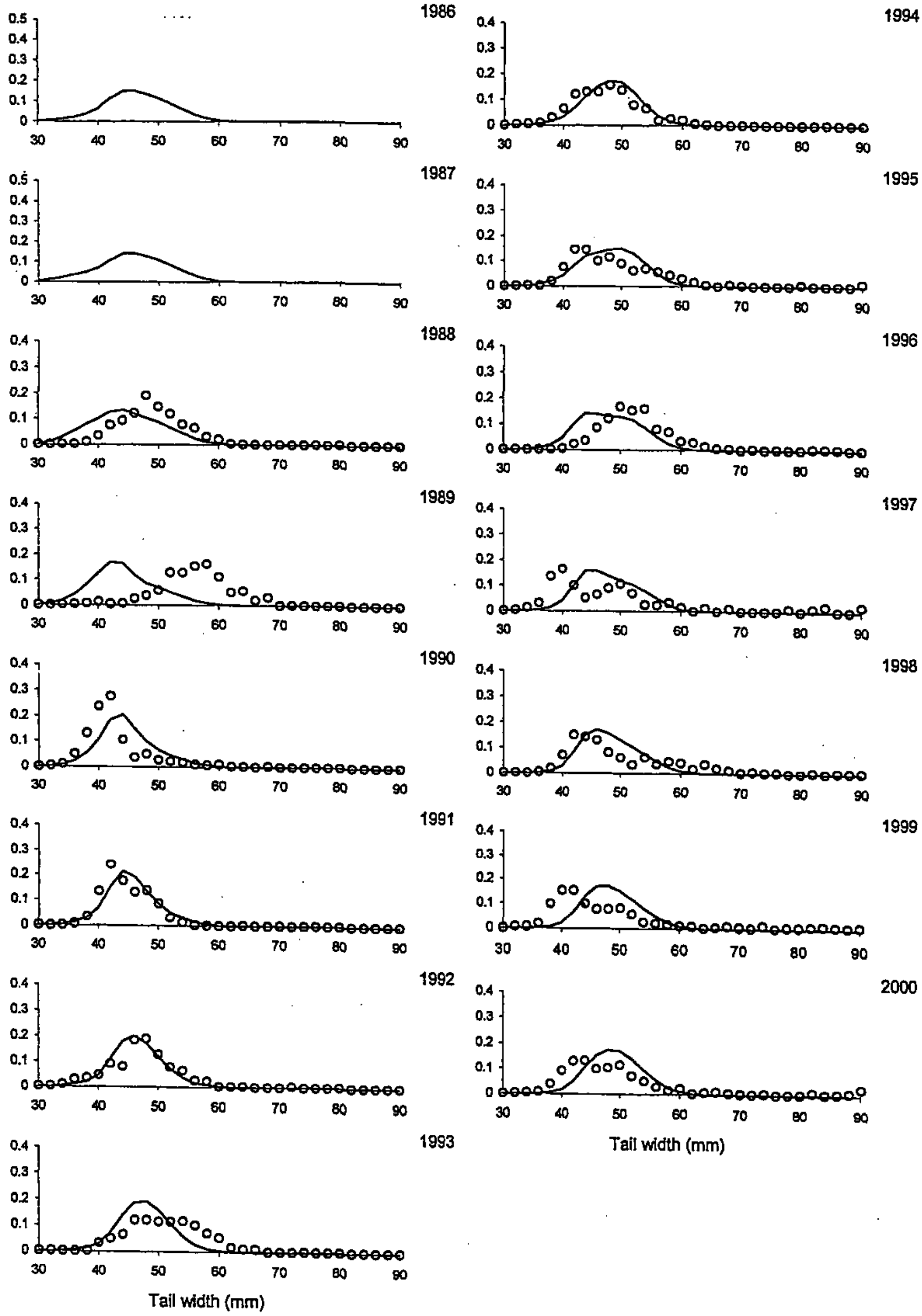


Figure 26: Fit to the length frequency data from CRA 7 based on the CRA7 settlement index.

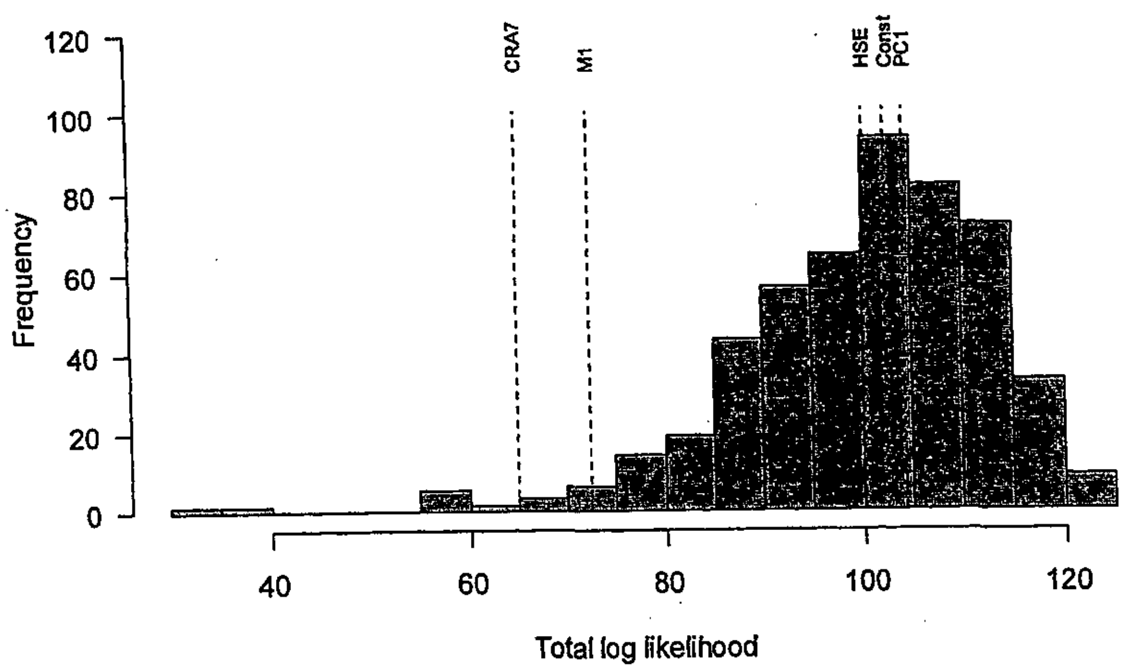


Figure 27: Distribution of total log-likelihoods from the fits of the 500 randomly drawn recruitment series to the CRA 7 CPUE indices and length frequency data. The location of each of the examined settlement indices is provided in terms of its total log-likelihood fit.

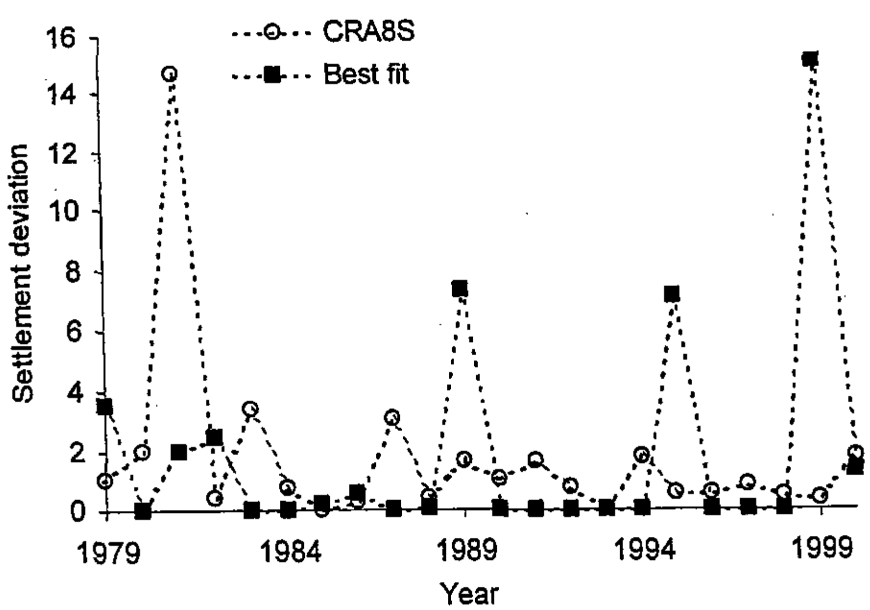


Figure 28: Comparison of the best fit settlement estimate for CRA 8S and the CRA8S settlement index.

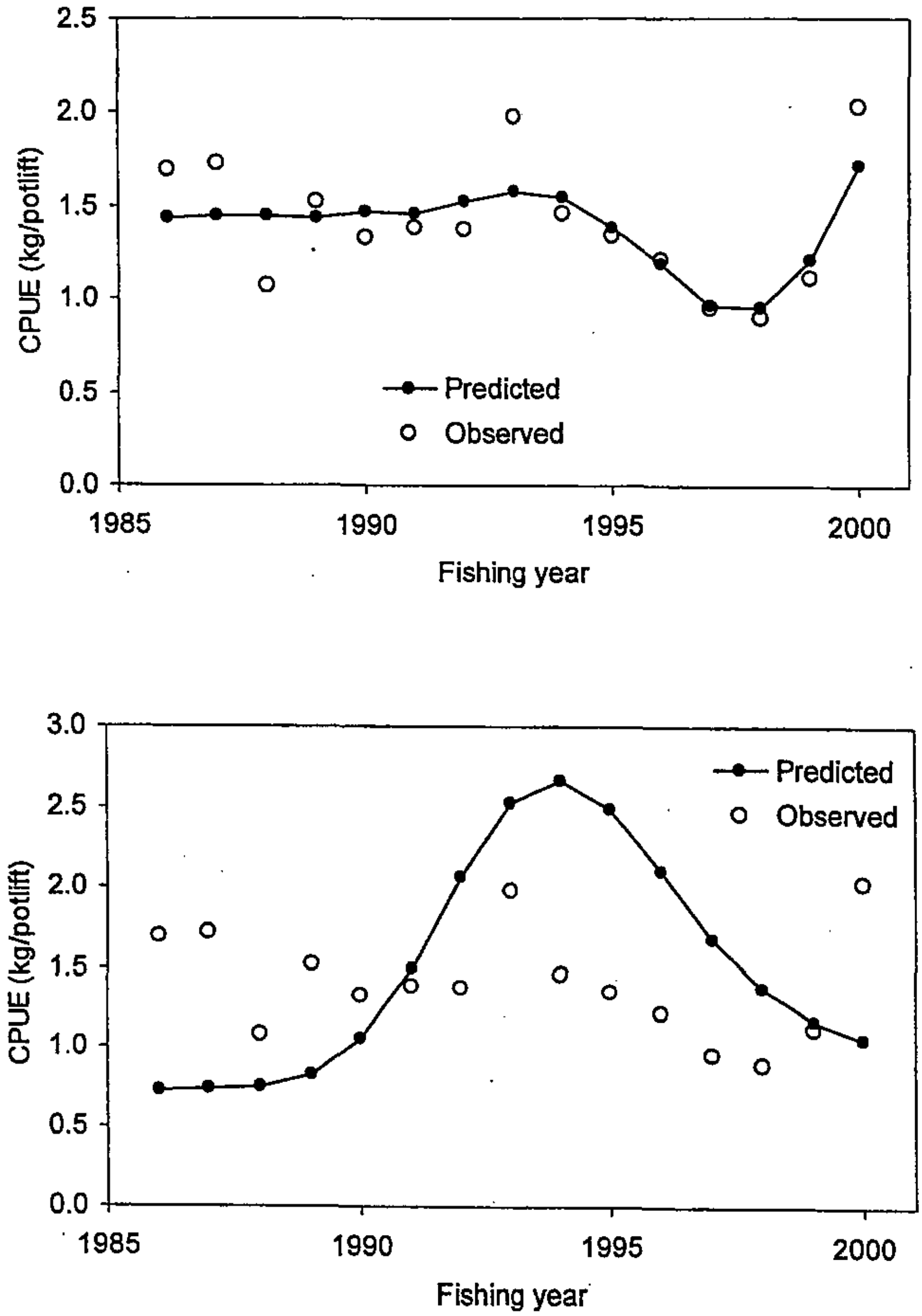


Figure 29: Fit to the CPUE data from CRA 8S based on the best fit settlement (top) and the CRA8S settlement index (bottom).

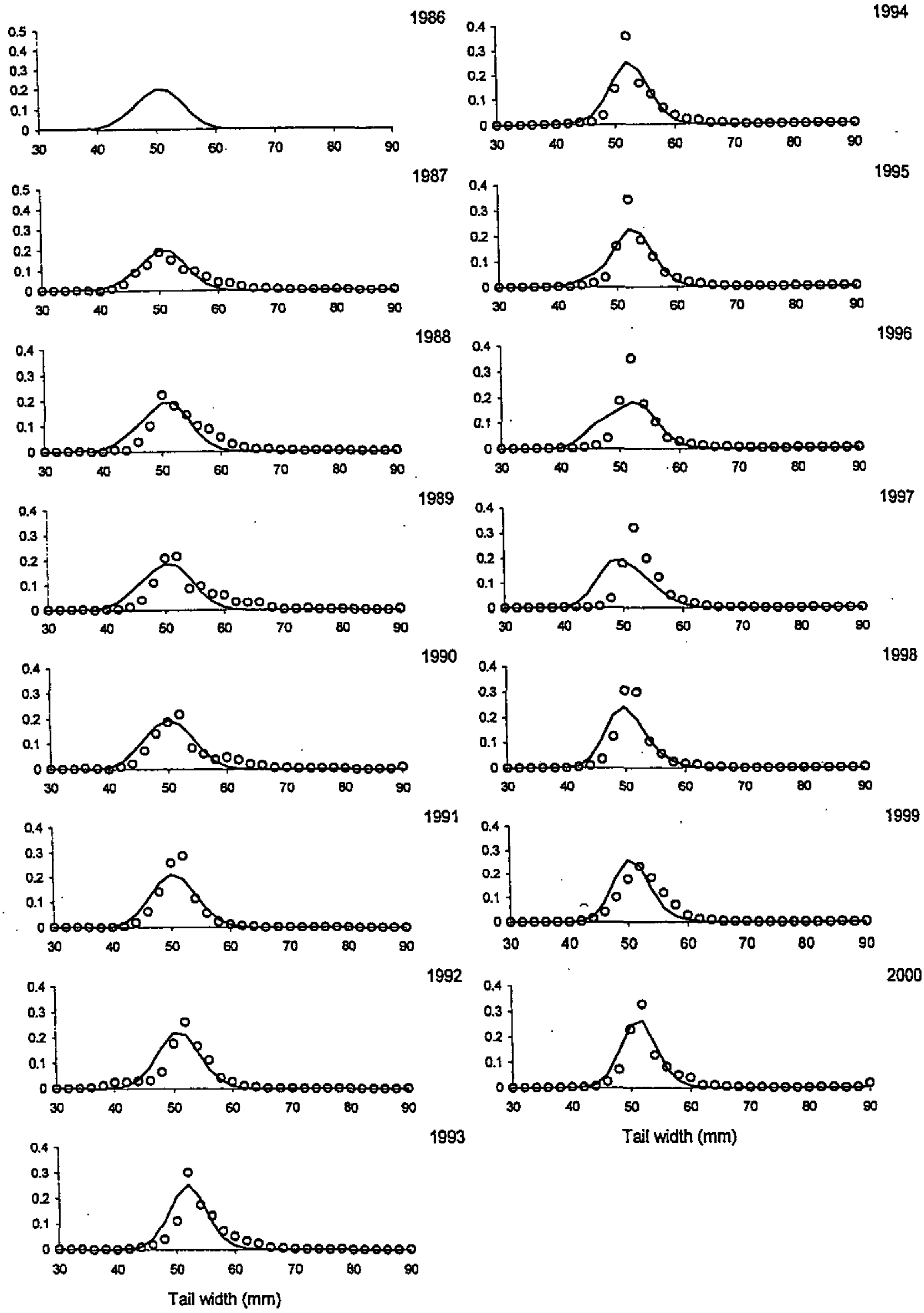


Figure 30: Fit to the length frequency data from CRA 8S (Stewart Island) based on the best fit settlement index.

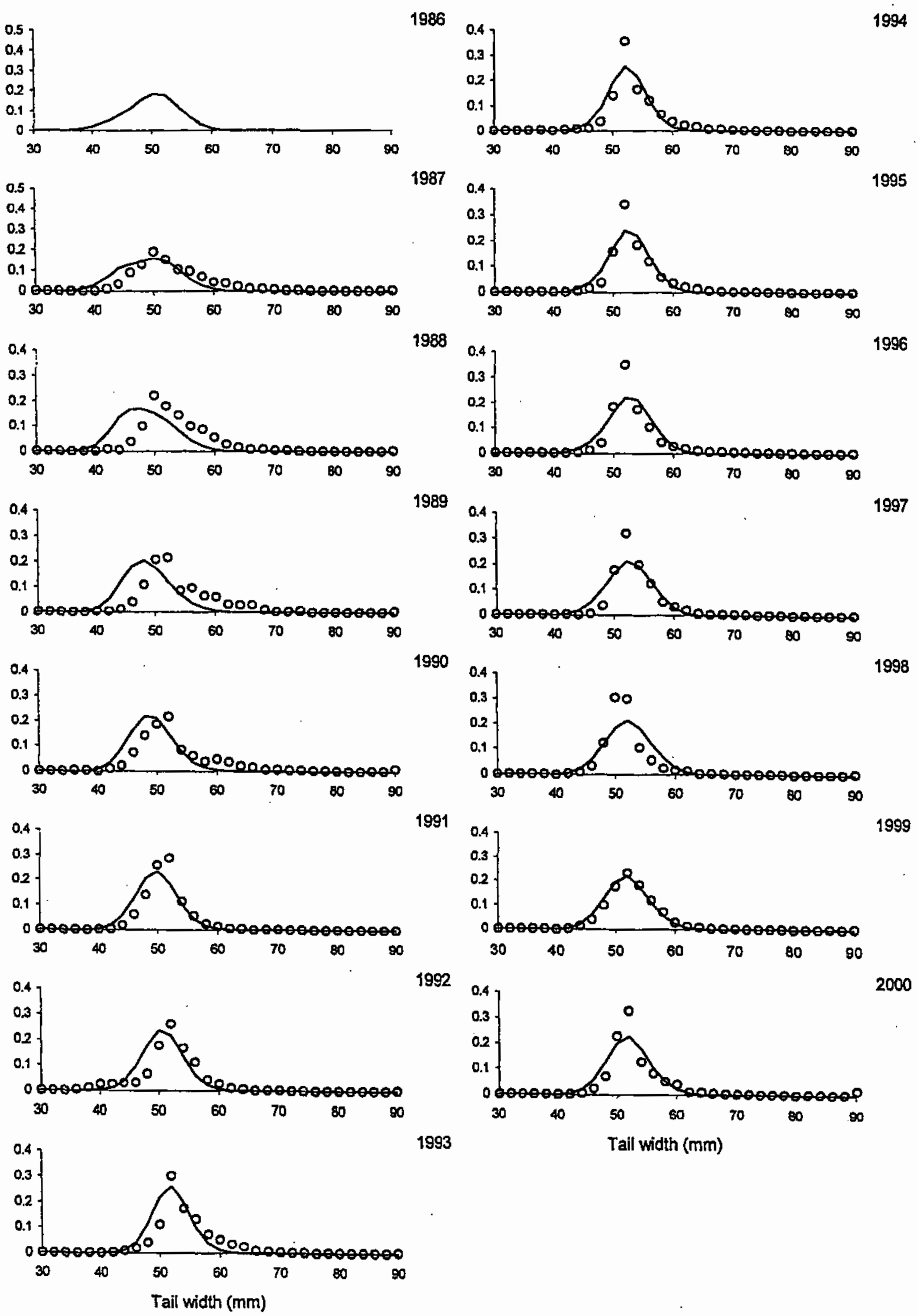


Figure 31: Fit to the length frequency data from CRA 8S (Stewart Island) based on the CRA8S settlement index.

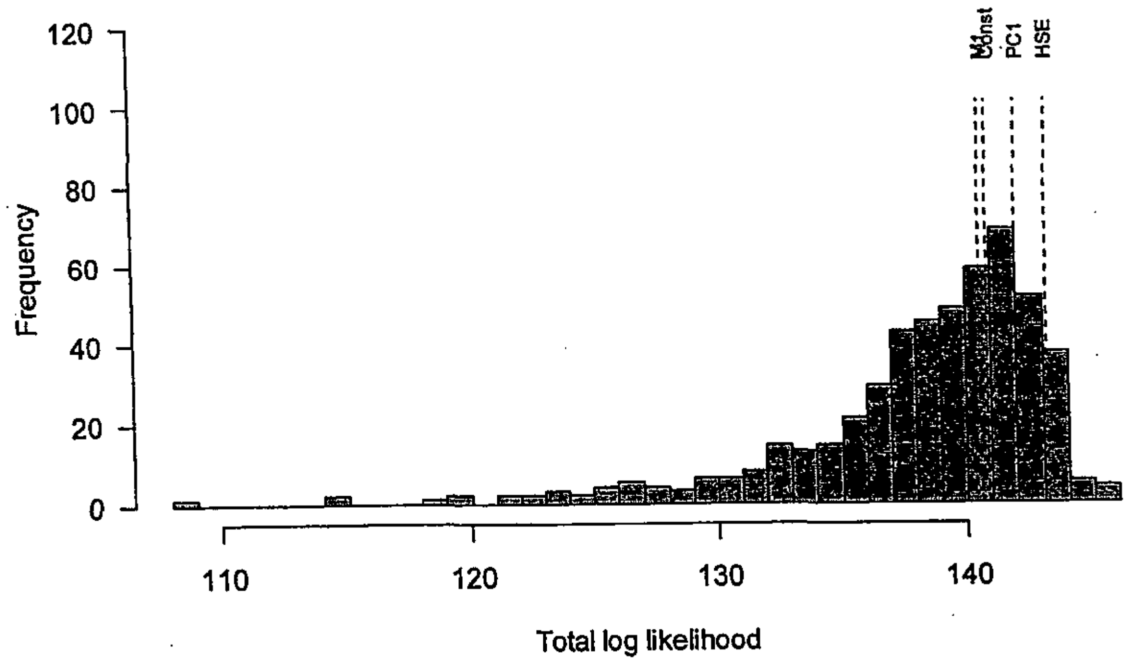


Figure 32: Distribution of total log-likelihoods from the fits of the 500 randomly drawn recruitment series to the CRA 8S CPUE indices and the CRA8S length frequency data. The location of each of the examined settlement indices series is provided in terms of its total log-likelihood fit. The CRA8S index is not visible because it has a total log likelihood of less than 110.

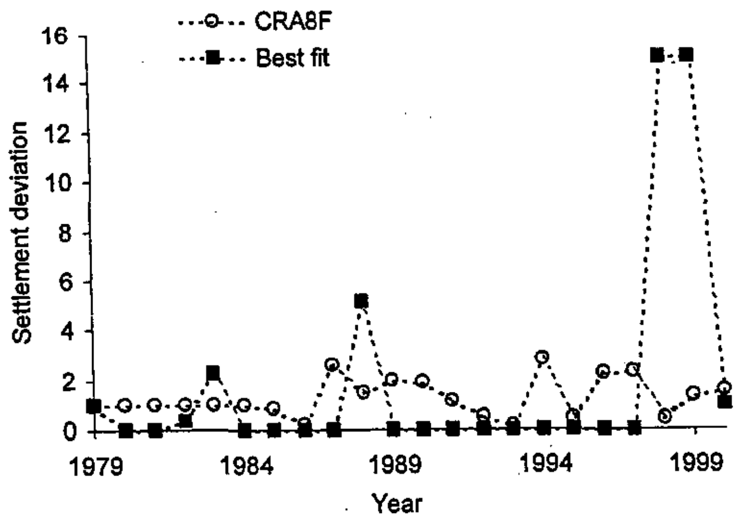
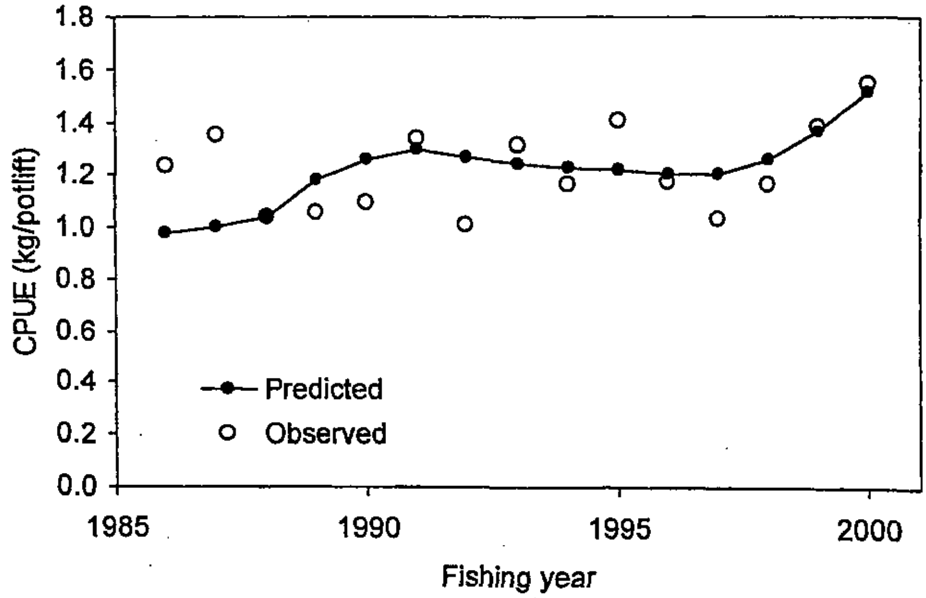


Figure 33: Comparison of the best fit settlement estimate for CRA 8F and the CRA8F settlement index.



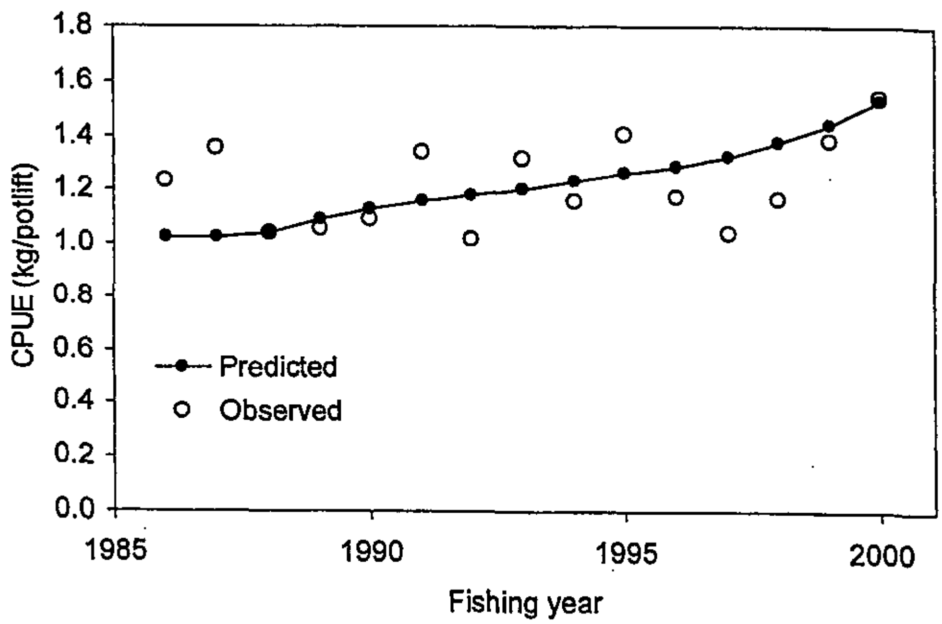


Figure 34: Fit to the CPUE data from CRA 8F based on the best fit settlement (top) and the CRA8F settlement index (bottom).

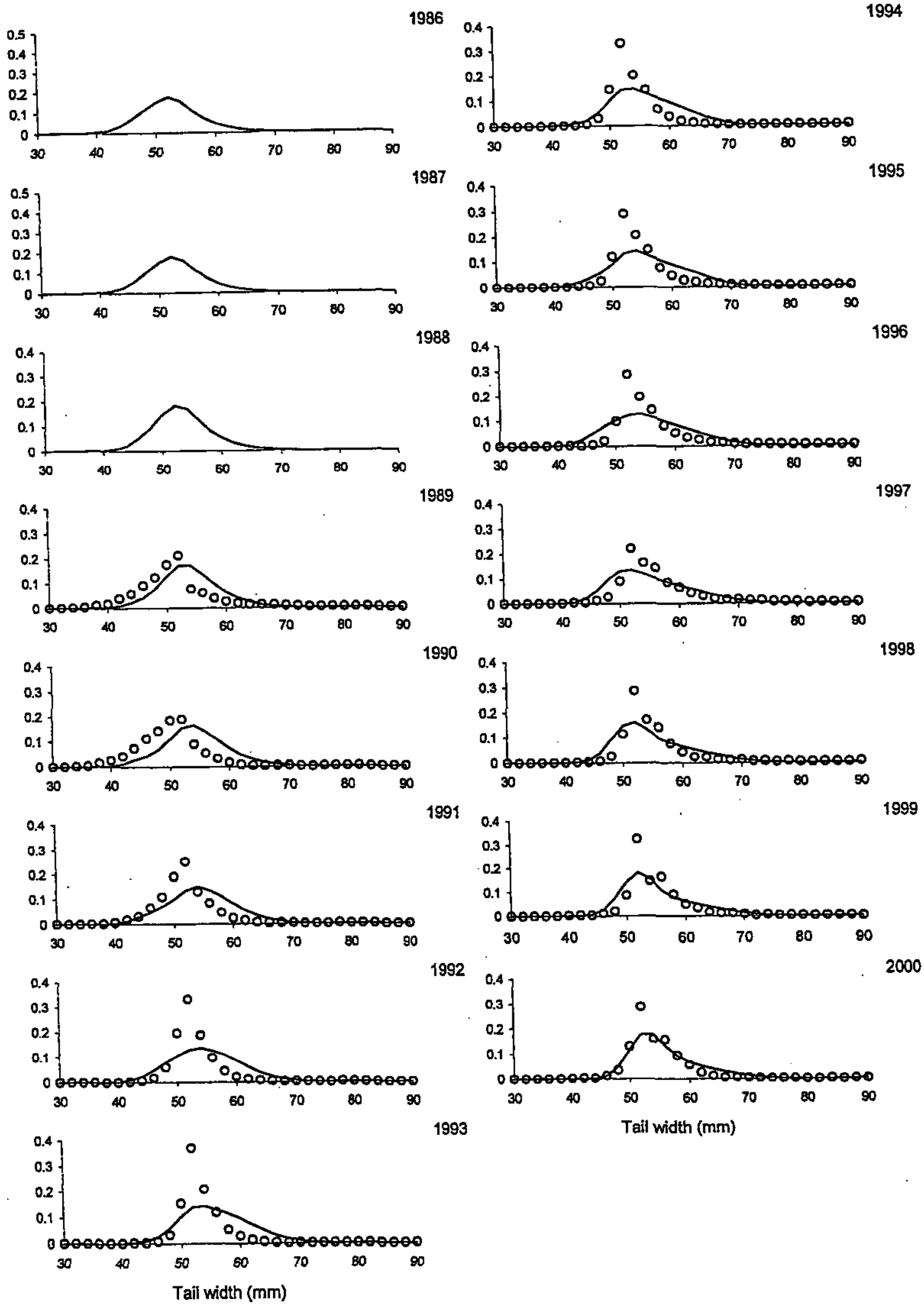


Figure 35: Fit to the length frequency data from CRA 8F (Fiordland) based on the best settlement index.

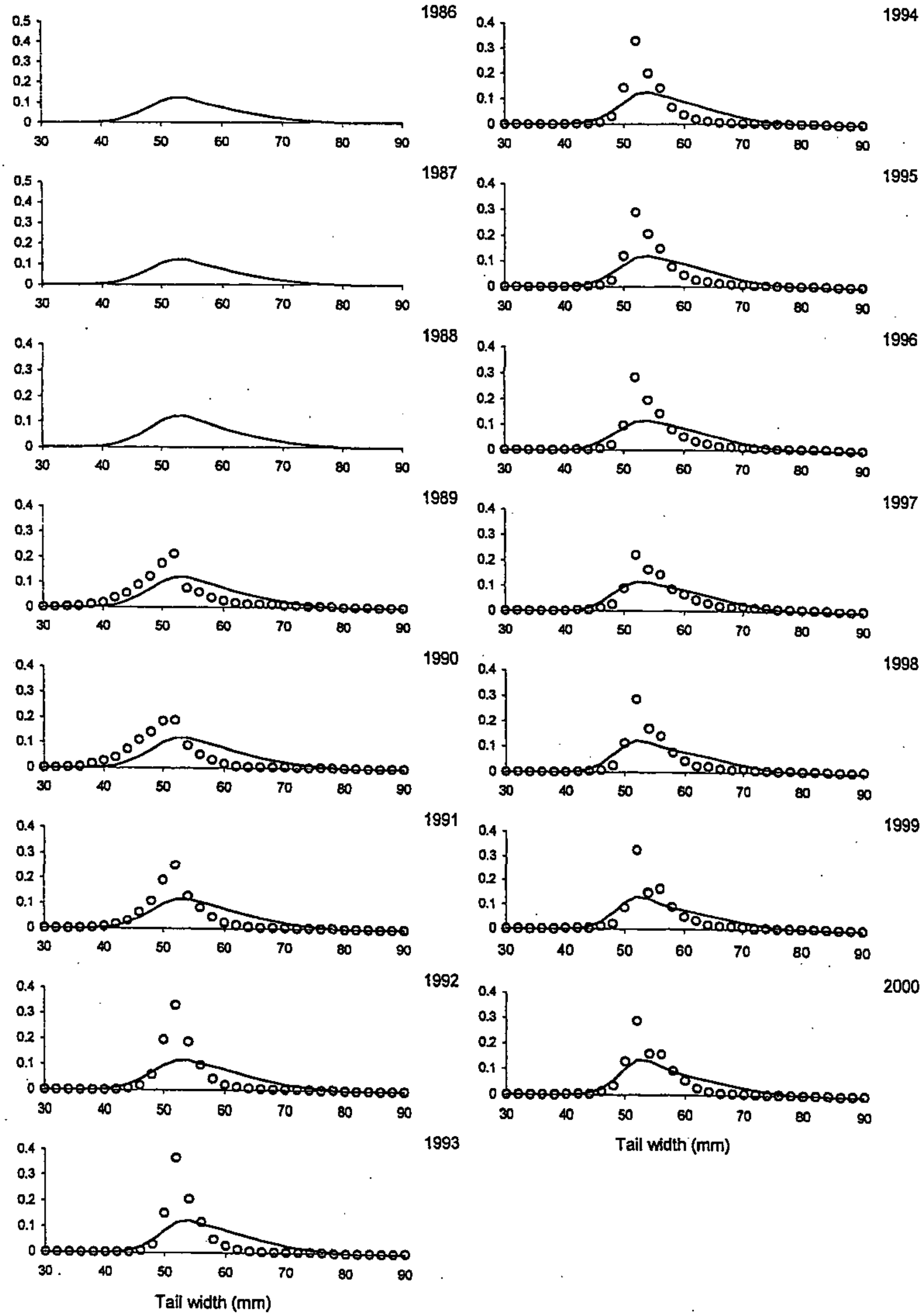


Figure 36: ***Fit to the length frequency data from CRA 8F (Fiordland) based on the CRA8F settlement index.***

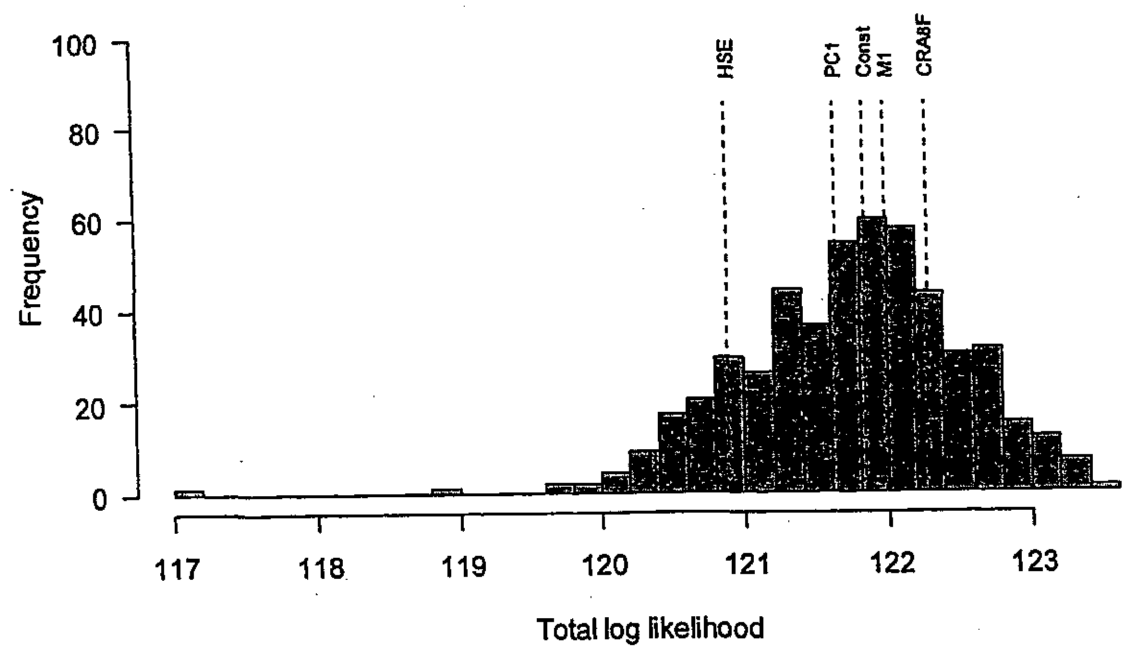


Figure 37: Distribution of total log-likelihoods from the fits of the 500 randomly drawn recruitment series to the CRA 8F CPUE indices and the CRA8F length frequency data. The location of each examined settlement indices is provided in terms of its total log-likelihood fit.

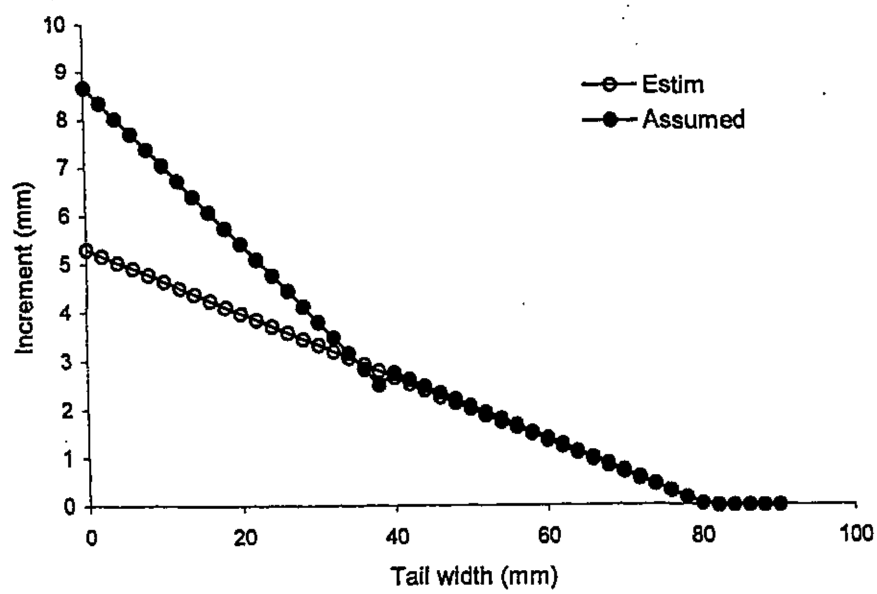


Figure 38: Moult increments estimated in the CRA 3 sensitivity test compared to those assumed in the normal test.

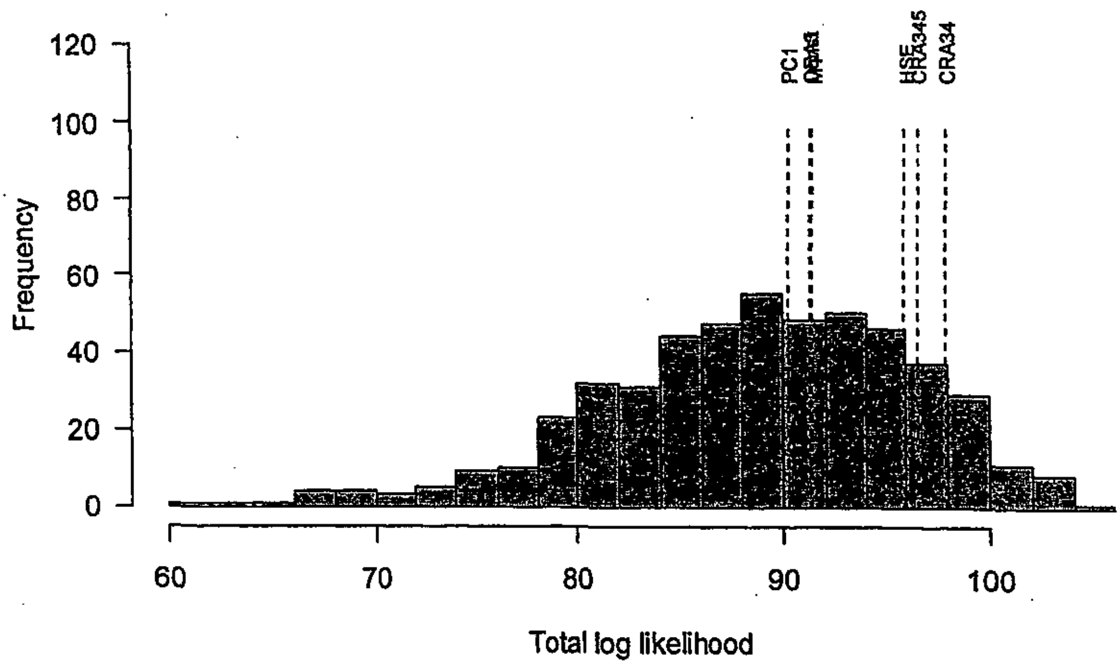


Figure 39: Distribution of total log-likelihoods from the fits of the 500 randomly drawn recruitment series to the CRA 3 CPUE indices and the CRA 3 length frequency data using growth rates estimated by assuming the CRA34 index is a true index of settlement. The location of each of the CRA 3 recruitment series and climatic indices is also provided in terms of its total log-likelihood.

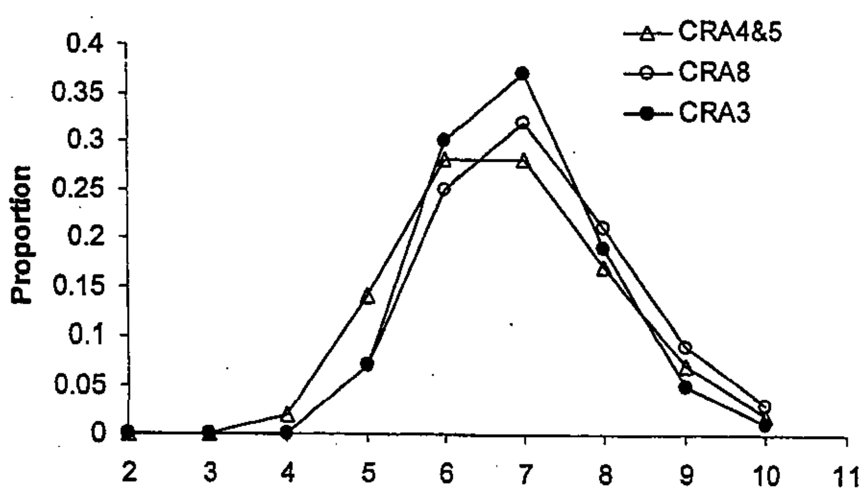


Figure 40: The distribution of years in which a lobster of 4 to 6 mm tail width will recruit to the fishery for each of the areas indicated using the growth rates we used in Section 4.2.