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THE BEHAVIOUR AND FIT OF ALTERNATIVE OPERATING MODEL SPECIFICATION FOR TESTING THE PERFORMANCE OF SOUTHERN BLUEFIN TUNA CANDIDATE MANAGEMENT PROCEDURES

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Abstract
Conditioning results are presented from an exploration of the updated operating model for use in the development of a management procedure for southern bluefin tuna. Given the large dimensionality of the operating model, the results do not constitute an exhaustive exploration of the parameter space. The results indicates that a number of outstanding issues need to be addressed in the conditioning process in order to ensure that the set of scenarios selected for the final trials provide an adequate and balanced representation of the underlying uncertainty. In particular, conditioning results and estimates of steepness are sensitive to assumptions about and the modelling of the length frequency data from the early years of the longline fishery. Further consideration is needed about what are appropriate levels of steepness and natural mortality vectors for inclusion in the final trials - in particular, whether high steepness values without either associated high levels of autocorrelation in recruitment or depensation are consistent with the historical data. In addition, the selection of final trials needs to capture the underlying uncertainty about effective sample sizes, depensation in the stock recruitment function, the functional relationship between CPUE and variability in selectivity. The potential number of scenarios needed to capture the uncertainty in all of these factors could be quite large, which makes it unlikely that a full assessment of the performance of a management procedure across the full uncertainty (including interactions) would be feasible. Instead, a selection process will be required to ensure that the evaluation process of candidate management procedures is reliable and robust.

Introduction
At the 2002 CCSBT Stock Assessment Group (SAG) meeting specifications were decided upon for 9 operating models for the initial stage of development of a management procedure (MP) for southern bluefin tuna (SBT) (See Anon. 2002a for details). The nine models represented an initial basis for exploring how uncertainty in SBT dynamics and fishery affected the performance of different decisions rules for setting the total allowable catches (TAC). These initial operating models differed in two basic components of SBT dynamics – the steepness in the stock-recruitment curve and in the natural mortality rate for adult SBT. Except for variation in these two parameters, the remaining input parameters of the operating model were held constant. At the 2002 SAG meeting, it was agreed that these nine models "did not represent the full range of parameter space that might be needed to encompass the uncertainty in the dynamics of the SBT stock and fishery" (Anon. 2002a). Further consideration of other operating model specifications and implementations were to be considered at the second Management Procedure Workshop scheduled for April 2003.

To assist in the process of selecting a full set of operating models for use in development of a management procedure for SBT, the 2002 SAG and Scientific Committee developed specifications for a number of alternative parameterisations for various aspects of the stock and fishery dynamics that might be considered to represent the underlying uncertainty in these (See Anon. 2002b). Vivian Haist distributed to members of the Scientific Committee up-dated computer code which implemented these alternative parameterisations. This provided a common basis for exploration of possible alternative operating models to facilitate the process of determining a set of operating models that were consistent with the historic data and also adequately represented the underlying uncertainty in the SBT stock and fishery dynamics.

The purpose of the present paper is to present results from an exploration of the updated operating model as implemented in the software developed by Vivian Haist. Given the large dimensionality of the operating model, the results do not constitute an exhaustive exploration of the parameter space. In most instances, results are presented which explore only one or a few components of the operating model while the other components are held constant. The issue of interactions is not addressed. It should be noted that, unless specifically documented, all of the results in this paper use the initial parameter values as specified in the control file for running the operating model software provided by Vivian Haist in January.

Steepness Within the Initial Stage Operating Specifications

Steepness (the degree of compensation in the stock recruitment relationship) was the principle uncertainty dimension considered in initial stage operating model. Since the amount of compensation is a critical component determining the overall productivity of the stock, ensuring that uncertainty with respect to it is appropriately represented is critical in the evaluation of candidate decision rules. The initial stage operating specifications considered scenarios in which steepness was fixed at one of three values (0.3, 0.6 or 0.9). Examination of the results of the conditioning to different fixed values for steepness shows substantial differences in the value of the objective function for the different fixed values of steepness when all other parameter values are kept constant (e.g. Table 1). These differences would be highly statistically significant, if the objective function is considered to be a valid likelihood function for the data and model. The negative log-likelihood value for a steepness of 0.3 is 20 less than that for 0.9, which would mean that a value of 0.9 would be highly improbable under the assumption that objective function is an appropriate likelihood function. Even steepness values of 0.6 would not be very probable as the difference in the log likelihood value is 10 between a steepness of 0.3 and 0.6. This conclusion is also reinforced when steepness is estimated in the conditioning process. In this case, the estimated steepness is 0.28 and this is despite the fact that there was a prior placed on steepness centred at 0.6. As such it is important to consider more closely what factors differ in the fit as steepness increases, if in fact higher values (particularly as high as 0.9) are to be maintained as a significant source of uncertainty within the final selection of operating models.

Figure 1 compares temporal trend in SSB and recruitment for the three different steepness values. Figure 2 shows the corresponding estimated stock recruitment curves and the estimated annual estimates of recruitment and spawning stock. Note that years represented by solid filled triangles are the year from 1965 to1995, which corresponds to the years for which CPUE and corresponding length frequency data provide a strong influence on the estimation of recruitment (there is no reliable CPUE for years prior to 1969, and the most recent recruits have not yet appeared in the longline fishery). This convention is used in all the stock recruitment figures presented in this paper. What is evident in these figures is that the estimates of recruitment for the years ~1960 to the mid 1990s are quite similar both in pattern and absolute magnitude. Also the temporal trends in SSB are similar for different steepness values, but their magnitudes differ substantially. The models achieve differences in steepness by adjusting the level of R_0 (or equivalently B_0), and the degree to which the period at the beginning of the fishery on the spawning ground was a period of unusually high recruitment (high steepness requires high positive recruitment deviations in this period). High steepness results in large temporal trends in the residuals from the stock and recruitment relationship. Thus, even when high steepness is imposed on the model, the resulting fit to the data within the context of the baseline operating provides little support for any substantial compensation in recruitment as the spawning stock declined during the main course of the fishery. For the period in which the data should be most informative for estimating stock sizes from the model (i.e. from 1969 to the mid-1990s), the stock and recruitment estimates indicate no evidence of a high degree of compensation even when steepness is forced to 0.90. During these years, the estimates of both SSB and recruitment show a nearly linear decline (Figure 2). As such, the high steepness scenarios in the initial operating model trials would seem relatively implausible. In order for them to be considered plausible would seem to require either introducing a large degree of auto-correlation with high variance in recruitment or an equivalent recruitment regime shift. Either of these would have implications for designing and evaluating results of trials, and thus retaining high steepness trials would appear to require modification both to these trials and the evaluation of results from them.

Table 1 provides a breakdown of the various component of the objective function when steepness is fixed at different values. This table provides an indication as to where the problems are in attempting to force high steepness values when conditioning the operating model. Forcing high steepness values results in a substantial improvement to the fit to the length frequency data from longline fishery 3 and a worse fit to the CPUE series (see also Figure 3) and stock/recruitment relationship. Examination of the length frequency data indicates that the lack of large fish in the early catches is a large source of the conflict between the different elements of the objective function for different values of the objective function and the estimated period of high recruitment around the initiation of the fishery. A major issues is whether this lack of large fish is in fact a reflection of a near total absence of old fish in the population, an artefact of sampling, or a reflection of change in growth (see Polacheck et al, 2002 for detail discussion of this question).

Table 1: Minimum value for the best fit to the objective function and its various components when steepness is fixed at a specific value or when it is estimated.

Steepness	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0.30	259.14	41.90	606.35	210.56	42.22	108.65	-45.46	13.93	42.43	57.47	-75.67	0.18	0.00	1261.70
0.60	258.34	42.24	599.69	211.90	41.33	106.78	-41.77	13.52	42.62	57.23	-59.86	0.33	0.00	1272.37
0.90	255.19	42.64	595.39	207.36	41.12	105.58	-38.92	13.33	43.32	56.52	-40.27	0.57	0.00	1281.84
Fitted (0.28)	259.02	41.87	606.86	210.15	42.33	108.76	-45.69	14.00	42.52	57.46	-76.25	0.18	3.09	1264.29

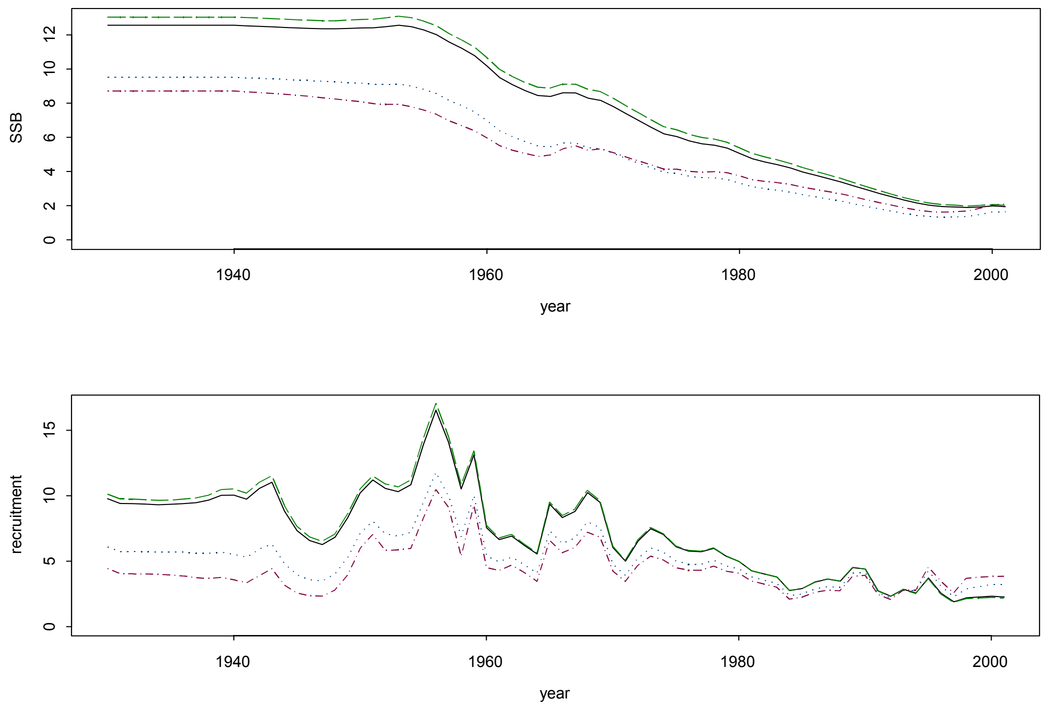


Figure 1: Comparison of the best fit estimates of temporal trends in SSB and recruitment when steepness is fixed at 0.3 (solid line), 0.6 (dotted line) and 0. 9 (dot-dash line) and when steepness is estimated dash line).

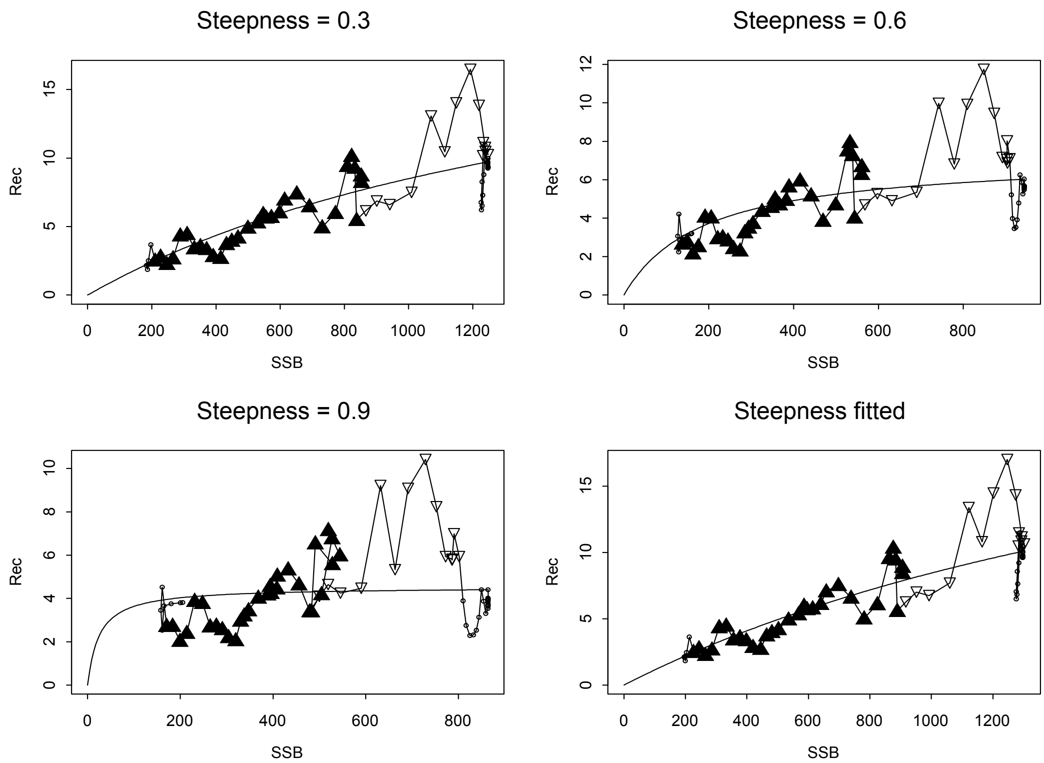


Figure 2: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function when steepness is fixed at different values or when it is estimated.

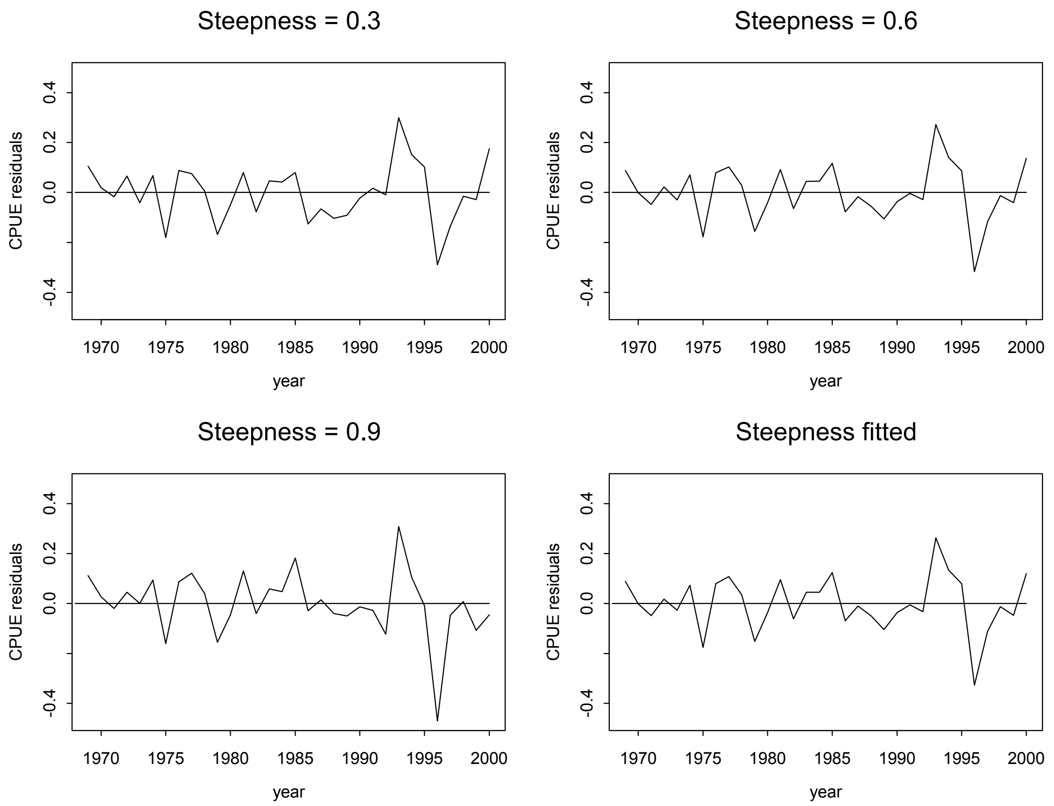


Figure 3: Residual time trends in the fit to the longline CPUE index when steepness is fixed at different values or when it is estimated.

Down Weighting Early and Recent Length Frequency Data From Areas 1 and 2
In the conditioning of the initially defined operating models scenarios, the length frequency data from the early years (pre 1965) of the longline fishery on the feeding grounds (e.g. statistical areas 3-9) were down weighted by a factor of eight to reflect the greater level of uncertainty about these data and how they were aggregated. The early length frequency data from area 1 (fishery 4 in the operating model) was down weighted by less than a factor of 2 (i.e. the effective sample size was reduced from 75 to 40), while no down weighting was made for the Japanese longline fishery in Areas 2 (corresponding to fisheries 3 and 4 in the operating model). However, it seems reasonable that similar uncertainties may exist about these data. Given the magnitude of these early catches from these two areas, combined with possible conflicts in the length frequency data with stock-recruitment assumptions and to a lesser degree the CPUE trend data, the effect of equivalent down-weighting of the pre1965 data from these two areas was explored.

In addition, in the years since 1970, the magnitude of the catches from these two areas was reduced to relatively low levels, but the same weight is given to fitting the length frequency distribution of the catches in these later years. In fact, in a number of years, the actual number of fish sampled for the length or weights was smaller than the multinomial effective sample size assumed in the likelihood function and in some years, the total catch was also smaller. Down weighting the effective sample sizes for the area 1 and 2 catches was also explored to see if the overall fits were unduly affected by “over fitting” of these length frequency data.

Figures 4-6 show the equivalent results as those in Figures 1-3 but with the early data and most recent length frequency data from areas 1 and 2 down weighted. The following are the effective sample sizes used in generating these figures for longline fisheries 3 and 4 in generating these figures:

1. 1951- 1964 Longline fishery 3: 5 (compared to 40 in the base case)
   Longline fishery 4: 5 (compared to 25 in the base case)
2. 1965- 1970 Longline fishery 3: 40 (compared to 40 in the base case)
   Longline fishery 3: 70 (compared to 40 in the base case)
3. 1971-2000 Longline fishery 3: 2 (compared to 40 in the base case)
   1971-2000 Longline fishery 4: 2 (compared to 70 in the base case)

While the results for down weighting as illustrated in Figures 4-6 are similar to those in Figures 1-3, there are some important differences. The predicted peak in recruitment levels in the 1950’s is lower in the down weighted cases. This is what would be expected, as down weighting reduces the conflict between the stock and recruitment relationship and the lack of large fish in the early catches. Probably more important in terms of the projections and testing of candidate management procedures is that the absolute level of the current spawning stock biomass are estimated to be lower. While for the case where steepness is fixed at 0.30, the difference is only 2%, for a steepness of 0.60 the differences is 11% and for a steepness of 0.9, 14%. In addition, if the differences in the value of the likelihood function were to be used as a guide to relative plausibility, then there is a larger difference across the values of steepness with down weighting (Tables 1 and 2). Also, with the down weighting of the early and more recent data from Areas 1 and 2, the fit to the CPUE series with steepness fixed at 0.9 exhibits a strong temporal trend in the residuals with the declines in the early years being underestimated by the model and recent trends being over estimated.

Table 2: Minimum value for the best fit to the objective function and its various components when steepness is fixed at a specific value or when it is estimated and when the early and more recent data from longline fisheries 3 and 4 have been down weighted.

Steep	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0.30	271.48	42.11	58.49	46.81	38.45	113.39	-48.32	14.35	40.79	52.81	-105.7	0.10	0.00	524.75
0.60	268.73	42.17	57.39	48.68	39.23	111.42	-41.81	13.75	40.84	52.92	-97.4	0.26	0.00	536.14
0.90	260.08	42.04	56.61	47.81	38.38	108.16	-27.67	13.32	41.68	51.09	-79.6	0.89	0.00	552.80
Fitted (0.31)	271.50	42.12	58.47	46.85	38.45	113.38	-48.23	14.33	40.76	52.82	-105.7	0.10	2.56	527.41

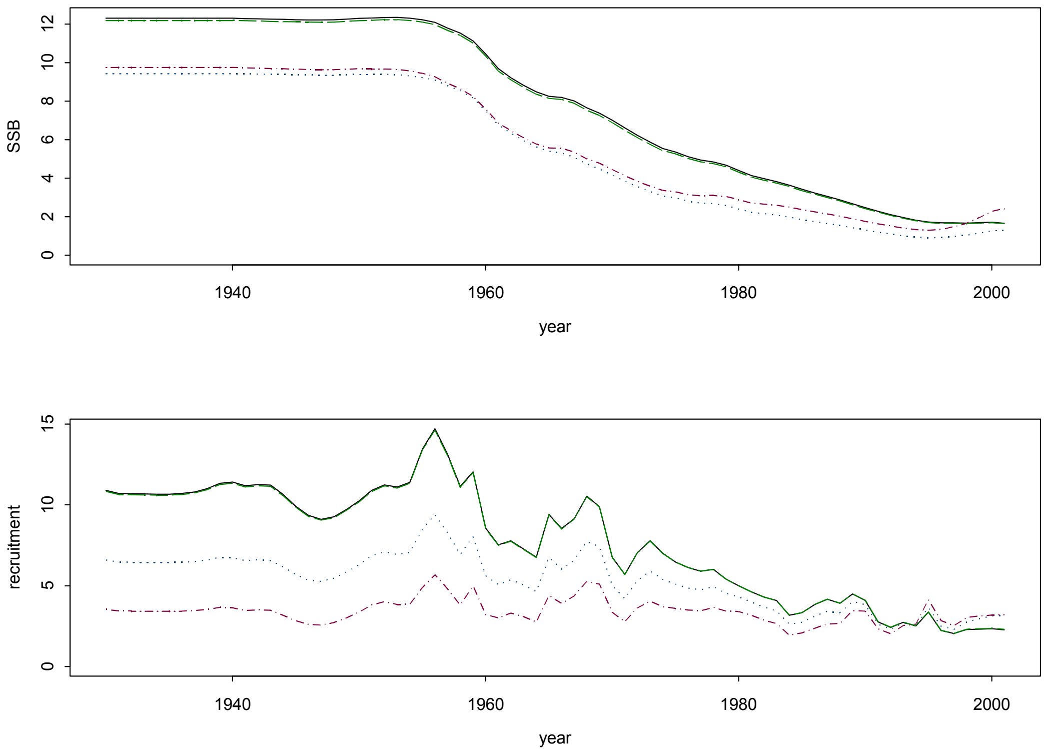


Figure 4: Comparison of the best fit estimates of temporal trends in SSB and recruitment when the early and more recent data from longline fisheries 3 and 4 have been downweighted for different fixed values of steepness (solid line =0.3, dotted line =0.6 and dot-dashed line 0.9) and when steepness is estimated (dashed line).

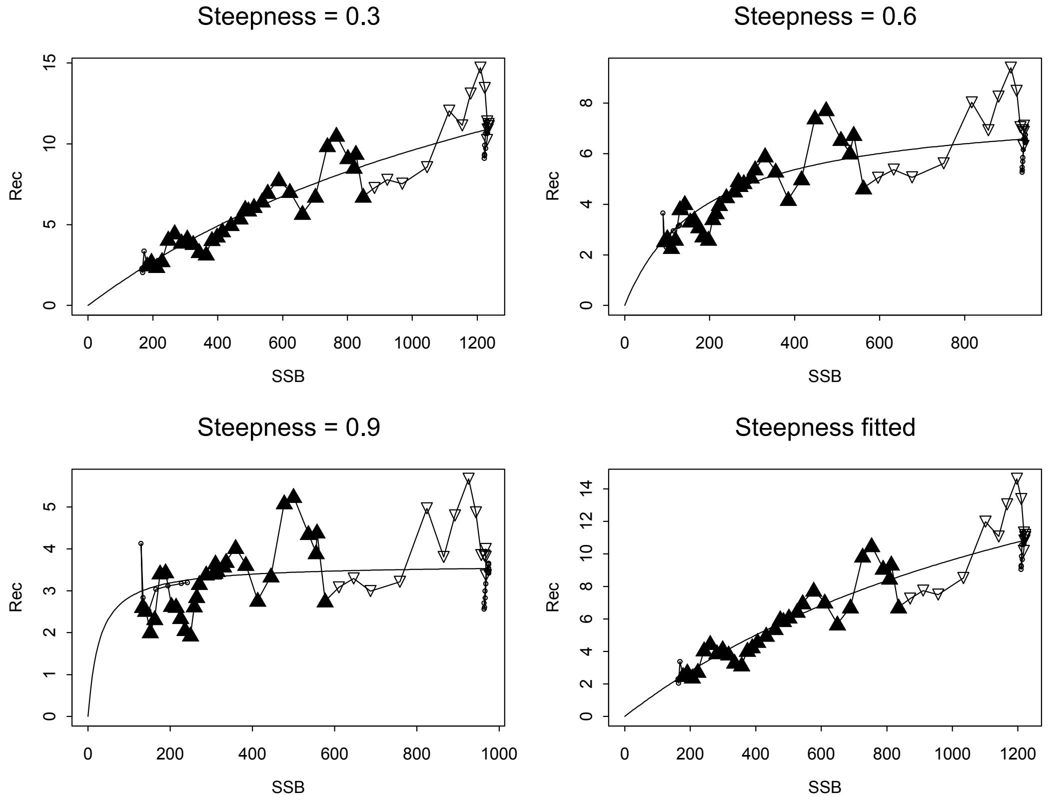


Figure 5: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function when the early and more recent data from longline fisheries 3 and 4 have been down weighted for different fixed value of steepness and when steepness is estimated**.**

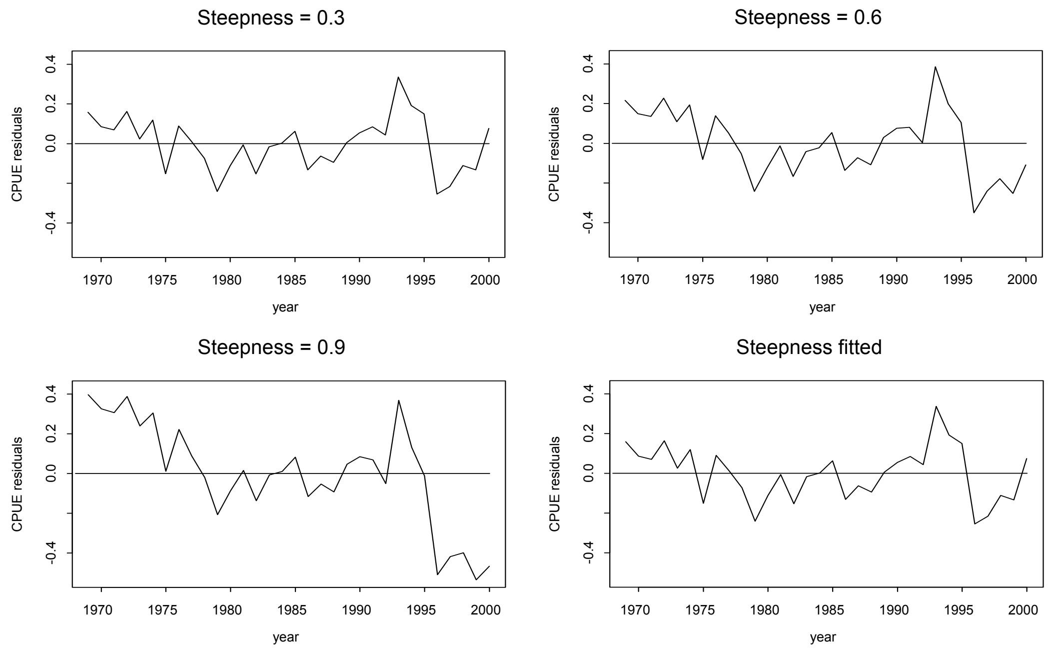


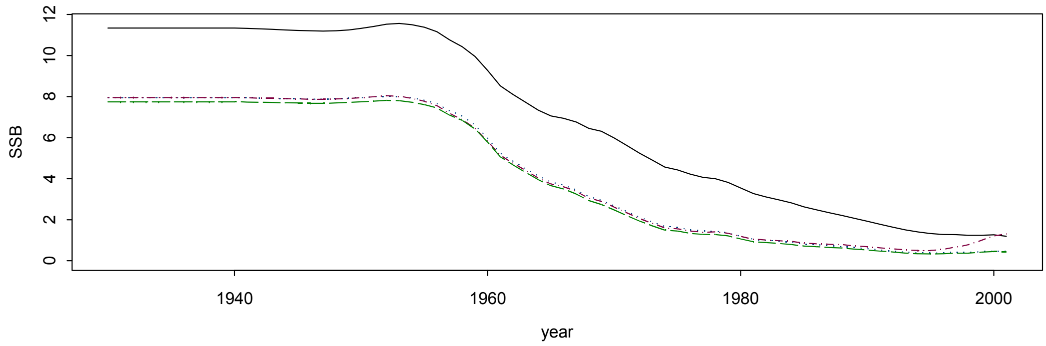
Figure 6: Residual time trends in the fit to the longling CPUE index when the early and more recent data from longline fisheries 3 and 4 have been down weighted for different fixed value of steepness and for when steepness is estimated**.**

Minimum Length For Plus Group Length Class
As noted above and discussed in more detail in Polacheck et al (2002), one hypothesis for the lack of large fish in the early catch data is that there was a change in the asymptotic length of SBT in response to the large reduction in the spawning stock that occurred in the early 1960s. Under this hypothesis, the size of large fish in the early years of the fishery would not provide reliable information for estimating their age if more recent estimates of growth were used. The current structure of the operating conditioning code does not allow for introducing such a growth change. To get an indication of how this might affect the conditioning result, the minimum length for the plus group was reduced (i.e. assuming that information on length provides no relevant information on age for fish above this minimum size). This provides a rough approximation to the types of effects that might be expected if an alternative growth model for the pre-fishery were used. It is an approximation because it ignores all the information on age of larger animals (even in the more recent years where there is reliable information) and it also does not take into account changes in growth (and thus the effect on the estimated age structure of the catch) in the early years.

Figures 7-9 are equivalent to figures 1-3 except that the minimum size of the plus group has been reduced from 186 to 150cm. Reducing the minimum size to this extent results in improved fit to the CPUE time series in all cases. It also results in steepness being estimated to be ~0.60 when steepness is allowed to be an estimable parameter (Table 3 and Figure 8). The difference in the best estimate of steepness in this case compared to the base case results from a value of 0.60 providing a substantial improvement in the sigma R term relative to a steepness of 0.30. Thus, the overall difference in this component of the likelihood function between a steepness of 0.3 and 0.6 is 0.88 when the minimum size is reduced compared to 15.81 in the base case (Table 1 and 3). The other large difference in the fit between a steepness of 0.3 and 0.6 is in the fit to the CPUE index. Thus, between steepness 0.3 and 0.6, the difference in the CPUE log likelihood is 3.69 in the base case compared to 1.52 when the minimum size has been reduced (i.e. an overall improvement of 5.21 in this component of the objective function). Somewhat surprisingly, the differences in the fit to the longline data for different values of steepness are similar in this case compared to the base case in Table 1.

Table 3: Minimum value for the best fit to the objective function and its various components when the minimum length for the plus group in fitting the longline length frequency data has been reduced to xx for different fixed values of steepness and when steepness is estimated.

Steepness	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0.30	204.97	41.30	390.89	55.86	43.67	109.07	-53.39	13.62	37.86	54.44	-88.43	0.00	0.00	809.86
0.60	206.72	41.68	382.68	57.21	39.16	108.76	-54.91	13.18	38.87	54.93	-87.55	0.02	0.00	800.74
0.90	204.16	41.73	379.93	57.48	42.95	105.63	-49.83	12.27	39.62	52.97	-73.45	0.48	0.00	813.94
Fitted (0.65)	207.59	41.76	381.50	57.48	38.52	108.68	-55.21	13.09	39.42	54.79	-87.41	0.01	0.06	800.30



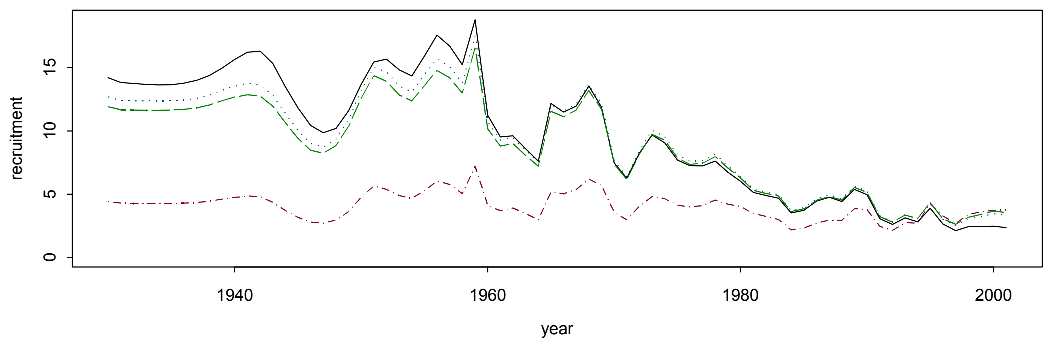


Figure 7: Comparison of the best fit estimates of temporal trends in SSB and recruitment when the minimum length for the plus group in fitting the longline length frequency data has been reduced to xx for different fixed values of steepness (solid line =0.3, dotted line =0.6 and dot-dashed line 0.9) and when steepness is estimated (dashed line).

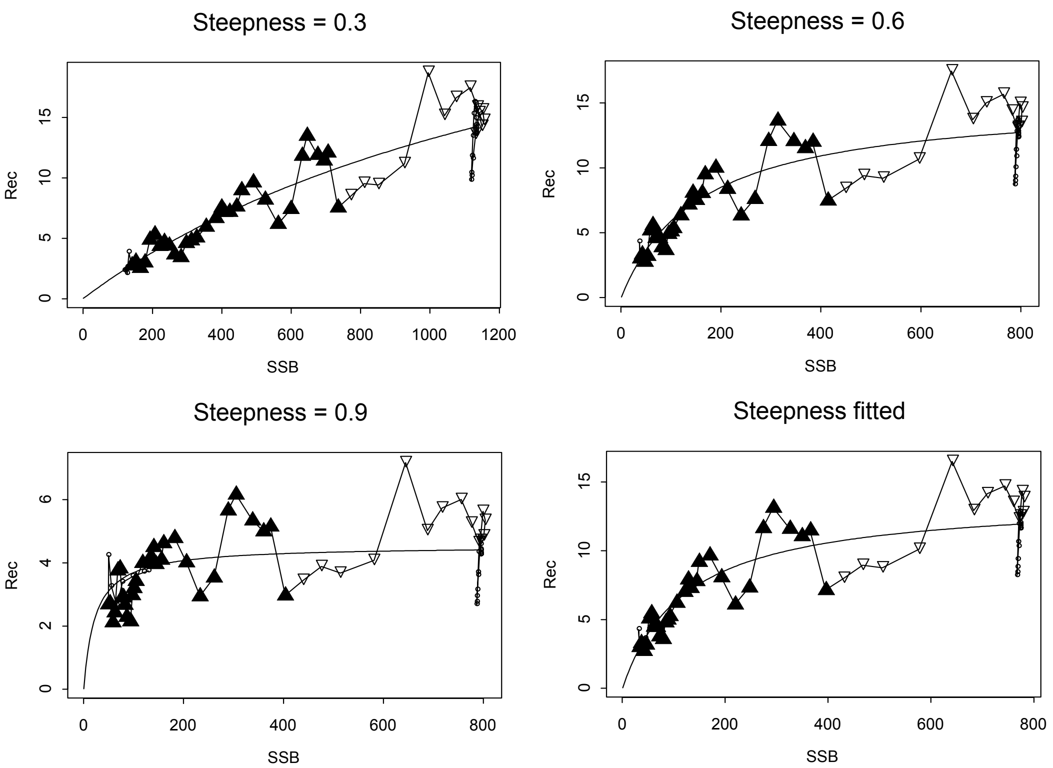


Figure 8: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function when the minimum length for the plus group in fitting the longline length frequency data has been reduced to xx for different fixed values of steepness and when steepness is estimated.

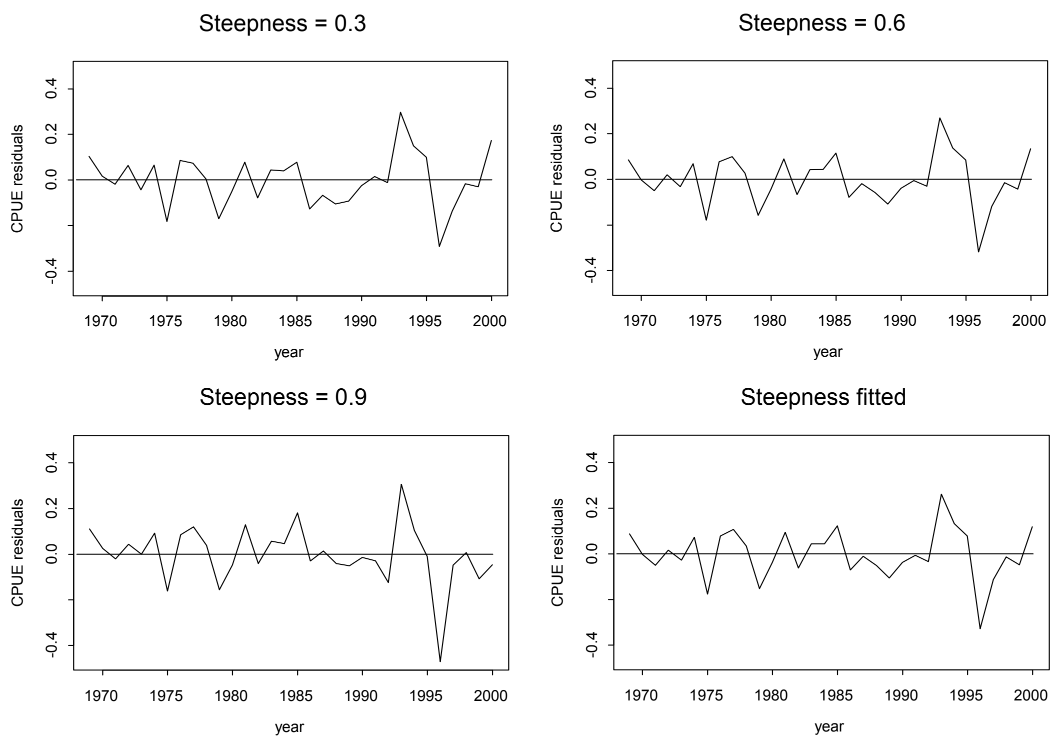


Figure 9: Residual time trends in the fit to the longling CPUE index when the minimum length for the plus group in fitting the longline length frequency data has been reduced to xx for different fixed values of steepness and when steepness is estimated.

Weighting of Length Frequency Data Based on Sampling Intensity
The effective sample sizes for the historical catch-at-length or catch-at-age data are parameter values that must be specified in conditioning the operating model. Sampling effort and its spatial/temporal coverage has varied greatly over time (Eveson and Polacheck, 2002). However, in conditioning results to date, the effective sample sizes are assumed to be constant except for their pre-1965 level in two of the longline fisheries. Eveson and Polacheck (2002) developed a method to assign relative weights or effective sample sizes among years within a specific fishery based on information on the sampling fraction, coverage and whether weight samples were used to estimate length distributions. They applied their approach to longline fishery 1 and the surface fishery. The approach can also be extended to longline fisheries 3 and 4. However, application of this approach cannot fully solve the question of what effective sample sizes should be used in conditioning as it only provides an estimate of the relative effective sample size between years and an absolute value needs to be specified in one year to scale the time series of relative estimates. In addition, the approach cannot be applied to longline fishery 2 or to pre-1965 longline data. Nevertheless, using the approach in Eveson and Polacheck to assign relative weights can provide a better basis to ensure the actual information content of the historic data are reflected in the conditioning results.

The effect of applying the method of assigning relative weights or effective sample sizes in Eveson and Polacheck (2002) was explored. Table 4 provides the relative weights for the effective sample sizes used with each fishery and in each year. For the years 1965 to 1995 for longline fishery 1 and the years 1952 to 1991 for the surface fishery, the values in Table 4 were taken directly form Eveson and Polacheck (2002), For the years 1965 to 1996 for longline fishery 3 and for 1965 to 1990 for longline fishery 4, the values in Table 4 were derived using the approach in Eveson and Polacheck and available data on sampling intensities by area and quarter. For the other time periods and/or fishery, information on sampling intensity was not available for applying this approach. The following assumptions were made in these cases:

1. The relative sampling intensity for the years 1959 to 1964 was half of the average for the years 1965 and 1966 for longline fisheries 1, 2, 3 and 4.
2. The relative sampling intensity for the years 1951 to 1958 was 20% of the values used for the years 1959 to 1964 for longline fisheries 1, 2, 3 and 4
3. In the most recent years (i.e. for years beyond which information is available) for longline fisheries 1,3, 4 and the surface fisheries, sampling intensity has remained constant.
4. For longline fishery 2 and 5, sampling intensity since 1965 has been constant.

Given the relative effective sample sizes in Table 4, the actual annual effective sample sizes used in conditioning the operating model was determined by specifying the maximum effective sample size that ever occurred in any given fishery.

A large range of values for the maximum effective sample sizes was explored. Table 5 provides the objective function components for the maximum likelihood fit for 24 combinations of possible maximum effective sample sizes. The overall fit in terms of SSB and recruitment, the stock recruitment relationship and fit to the CPUE index were all quite similar (Figure 10-12). The resulting estimates of steepness were around 0.40 (compared to 0.28 for the base case) and spanned the range from 0.31 to

0.45. However, there was only one case in which steepness was below 0.39 and this was the when the maximum effective sample size on longline fishery 1 was set relatively small (i.e. 200) and the maximum effective sample size on longline fisheries 3 and 4 was set relatively high (i.e. 300).

Table 4: Relative weightings (effective sample sizes) assigned to size and age frequency data based on relative sampling intensity.

Year	LL1	LL2	LL3	LL4	IND	SURF
1952	0.022	0.100	0.094	0.059	0.100	0.000
1953	0.022	0.100	0.094	0.059	0.100	0.000
1954	0.022	0.100	0.094	0.059	0.100	0.000
1955	0.022	0.100	0.094	0.059	0.100	0.000
1956	0.022	0.100	0.094	0.059	0.100	0.000
1957	0.022	0.100	0.094	0.059	0.100	0.000
1958	0.022	0.100	0.094	0.059	0.100	0.000
1959	0.109	0.500	0.468	0.294	0.500	0.000
1960	0.109	0.500	0.468	0.294	0.500	0.000
1961	0.109	0.500	0.468	0.294	0.500	0.000
1962	0.109	0.500	0.468	0.294	0.500	0.000
1963	0.109	0.500	0.468	0.294	0.500	0.000
1964	0.109	0.500	0.468	0.294	0.500	0.272
1965	0.282	1.000	1.000	1.000	1.000	1.000
1966	0.153	1.000	0.871	0.177	1.000	0.947
1967	0.349	1.000	0.256	0.316	1.000	0.564
1968	0.087	1.000	0.010	0.510	1.000	0.545
1969	0.071	1.000	0.003	0.145	1.000	0.536
1970	0.072	1.000	0.015	0.126	1.000	0.526
1971	0.054	1.000	0.014	0.126	1.000	0.565
1972	0.011	1.000	0.002	0.422	1.000	0.423
1973	0.030	1.000	0.002	0.019	1.000	0.516
1974	0.121	1.000	0.001	0.042	1.000	0.001
1975	0.208	1.000	0.002	0.050	1.000	0.112
1976	0.138	1.000	0.002	0.461	1.000	0.496
1977	0.162	1.000	0.003	0.375	1.000	0.173
1978	0.142	1.000	0.001	0.150	1.000	0.401
1979	0.135	1.000	0.015	0.262	1.000	0.001
1980	0.261	1.000	0.001	0.140	1.000	0.015
1981	0.021	1.000	0.004	0.090	1.000	0.004
1982	0.040	1.000	0.019	0.092	1.000	0.030
1983	0.092	1.000	0.001	0.126	1.000	0.013
1984	0.096	1.000	0.001	0.975	1.000	0.033
1985	0.256	1.000	0.001	0.092	1.000	0.249
1986	0.162	1.000	0.002	0.015	1.000	0.375
1987	0.107	1.000	0.031	0.204	1.000	0.346
1988	0.005	1.000	0.005	0.027	1.000	0.089
1989	0.325	1.000	0.001	0.016	1.000	0.183
1990	0.149	1.000	0.001	0.007	1.000	0.124
1991	0.875	1.000	0.004	0.007	1.000	0.066
1992	0.989	1.000	0.001	0.007	1.000	0.066
1993	0.391	1.000	0.001	0.007	1.000	0.066
1994	0.290	1.000	0.001	0.007	1.000	0.066
1995	0.420	1.000	0.076	0.007	1.000	0.066
1996	1.000	1.000	0.002	0.007	1.000	0.066
1997	1.000	1.000	0.002	0.007	1.000	0.066
1998	1.000	1.000	0.002	0.007	1.000	0.066
1999	1.000	1.000	0.002	0.007	1.000	0.066
2000	1.000	1.000	0.002	0.007	1.000	0.066

Table 5: Minimum value for the best fit to the objective function and its various components when the relative weightings in Table 4 are used for the effective sample size scaled by the maximum value indicated in the first six columns. In all cases, steepness was also fitted and the estimated value is given in the seventh column. Note that the likelihoods are not directly comparable across runs, because of the change in sample sizes, but comparisons in the direction of change in components can be informative.

Max. Effective Sample Size						Fit														
LL1	LL2	LL3	LL4	IND	SF	Stp	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
1000	50	300	300	300	500	0.44	462.57	51.57	104.71	196.48	45.69	150.53	-41.90	17.78	54.46	87.08	-29.48	0.11	0.79	1100.39
1000	50	300	300	300	240	0.41	459.78	51.00	105.44	196.30	40.11	102.18	-42.43	13.87	50.89	64.10	-33.64	0.13	1.10	1008.84
1000	50	300	50	300	500	0.42	461.11	51.60	98.64	38.00	46.22	149.26	-40.97	17.49	55.20	86.85	-39.14	0.05	0.95	925.28
1000	50	300	50	300	240	0.41	457.38	51.04	99.40	38.30	40.61	101.62	-41.39	13.59	51.53	62.98	-41.81	0.07	1.05	834.35
1000	50	50	300	300	500	0.41	457.38	51.04	99.40	38.30	40.61	101.62	-41.39	13.59	51.53	62.98	-41.81	0.07	1.05	834.35
1000	50	50	300	300	240	0.41	457.38	51.04	99.40	38.30	40.61	101.62	-41.39	13.59	51.53	62.98	-41.81	0.07	1.05	834.35
1000	50	50	50	300	500	0.41	457.38	51.04	99.40	38.30	40.61	101.62	-41.39	13.59	51.53	62.98	-41.81	0.07	1.05	834.35
1000	50	50	50	300	240	0.41	457.38	51.04	99.40	38.30	40.61	101.62	-41.39	13.59	51.53	62.98	-41.81	0.07	1.05	834.35
500	50	300	300	300	500	0.45	259.09	50.79	103.52	193.93	45.81	146.40	-44.44	14.77	41.71	78.66	-32.62	0.13	0.69	858.44
500	50	300	300	300	240	0.40	257.27	50.01	104.93	193.79	39.58	100.67	-45.07	11.23	38.16	55.53	-38.57	0.15	1.15	768.85
500	50	300	50	300	500	0.43	258.08	50.82	96.90	38.56	46.16	145.00	-44.11	14.64	42.29	79.00	-44.85	0.05	0.84	683.38
500	50	300	50	300	240	0.40	256.27	50.11	99.56	37.57	39.98	100.52	-44.80	11.08	38.94	56.51	-52.84	0.06	1.22	594.17
500	50	50	300	300	500	0.40	256.27	50.11	99.56	37.57	39.98	100.52	-44.80	11.08	38.94	56.51	-52.84	0.06	1.22	594.17
500	50	50	300	300	240	0.40	256.27	50.11	99.56	37.57	39.98	100.52	-44.80	11.08	38.94	56.51	-52.84	0.06	1.22	594.17
500	50	50	50	300	500	0.40	256.27	50.11	99.56	37.57	39.98	100.52	-44.80	11.08	38.94	56.51	-52.84	0.06	1.22	594.17
500	50	50	50	300	240	0.40	256.27	50.11	99.56	37.57	39.98	100.52	-44.80	11.08	38.94	56.51	-52.84	0.06	1.22	594.17
200	50	300	300	300	500	0.43	124.59	49.58	103.49	192.32	46.37	143.35	-50.23	12.86	31.68	73.97	-38.55	0.09	0.84	690.35
200	50	300	300	300	240	0.31	124.82	48.55	108.23	192.40	39.79	102.39	-51.75	9.70	27.72	51.95	-57.35	0.11	2.52	599.09
200	50	300	50	300	500	0.44	123.90	49.61	96.30	38.71	46.49	141.43	-50.28	12.83	32.12	74.27	-50.07	0.03	0.72	516.06
200	50	300	50	300	240	0.39	123.34	48.76	101.74	37.35	39.98	100.75	-51.04	9.54	28.24	51.72	-63.88	0.04	1.34	427.88
200	50	50	300	300	500	0.39	123.34	48.76	101.74	37.35	39.98	100.75	-51.04	9.54	28.24	51.72	-63.88	0.04	1.34	427.88
200	50	50	300	300	240	0.39	123.34	48.76	101.74	37.35	39.98	100.75	-51.04	9.54	28.24	51.72	-63.88	0.04	1.34	427.88
200	50	50	50	300	500	0.39	123.34	48.76	101.74	37.35	39.98	100.75	-51.04	9.54	28.24	51.72	-63.88	0.04	1.34	427.88

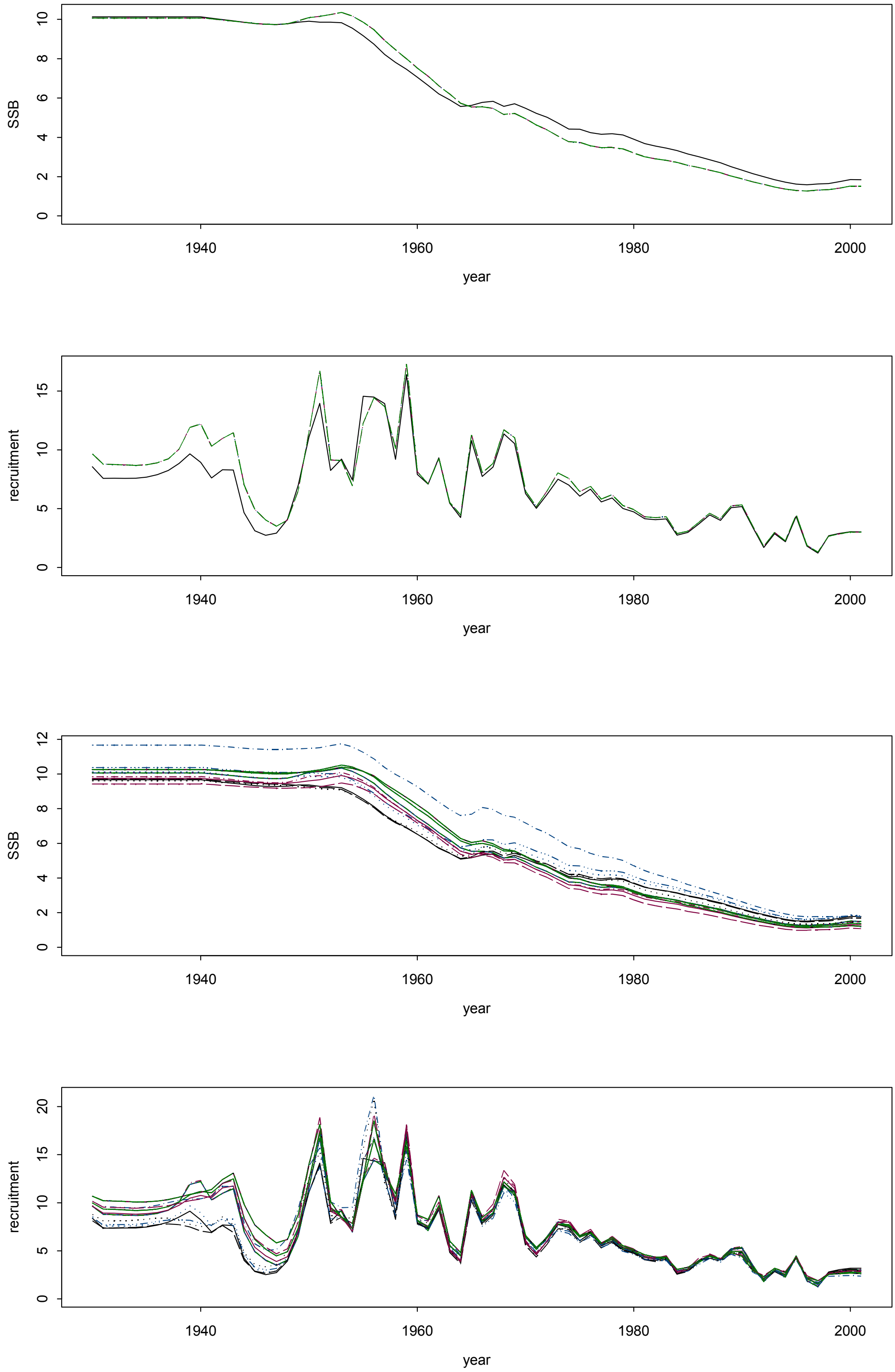


Figure 10: Comparison of the best fit estimates of temporal trends in SSB and recruitment for versions 2, 4, 6 and 8 (upper two panels) and all versions (lower two panels) in Table 5.

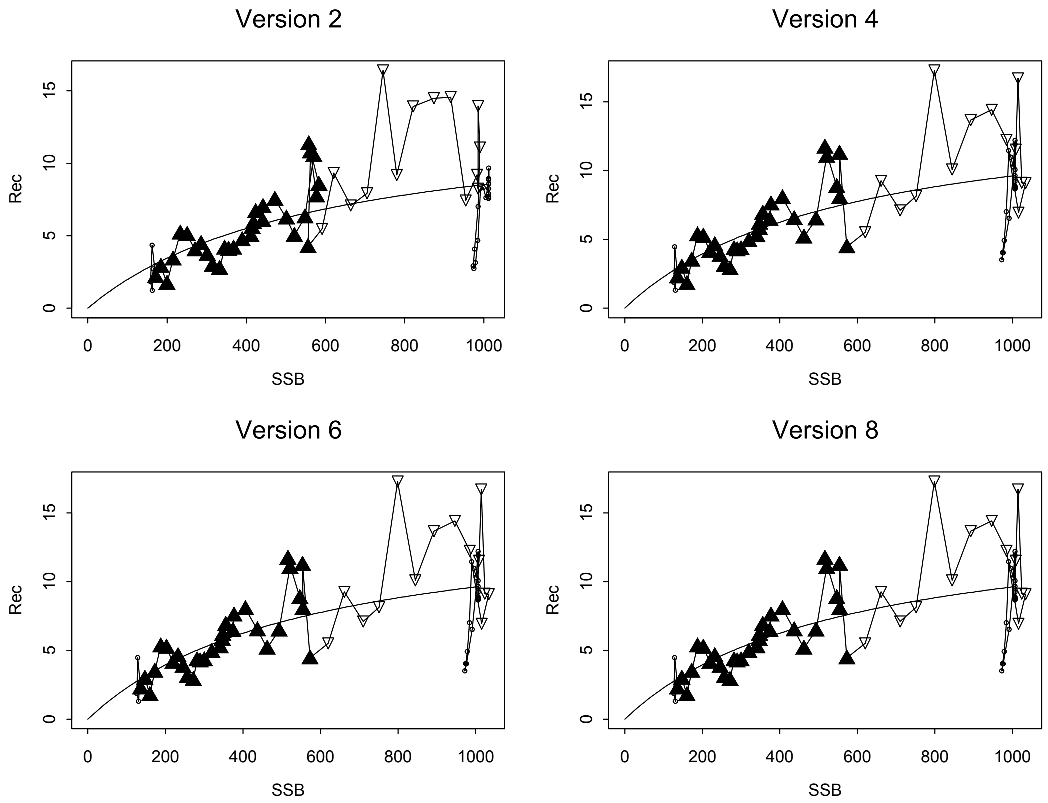


Figure 11: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function for versions 2, 4, 6 and 8 in Table 5.

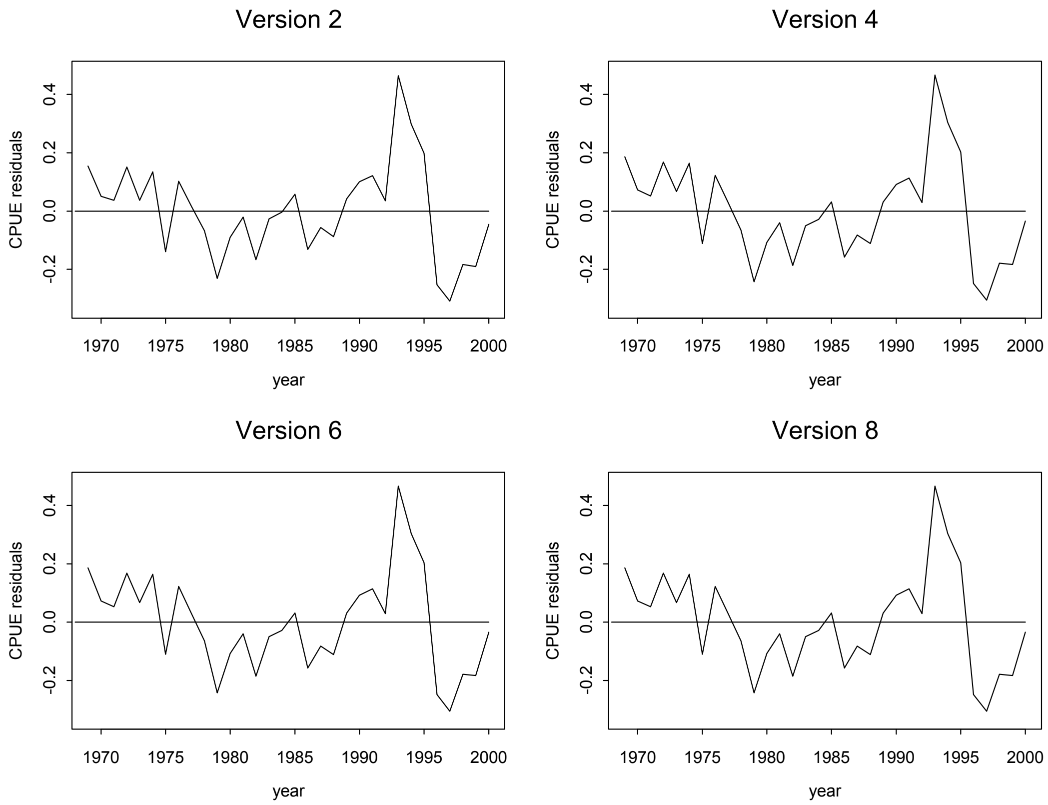


Figure 12: Residual time trends in the fit to the longline CPUE index for versions 2, 4, 6 and 8 in Table 5.

Alternative Relationship Between CPUE and Abundance
Anon (2002b) defined the following general function for the relationship between CPUE and abundance to be used in conditioning the operating model:

$$CPUE_y = q_y \tilde{N}_y^{\varpi} \left(1 + \beta \left(\frac{E_y - E_{2000}}{E_{2000}} \right) + \gamma \left(\frac{E_y - E_{2000}}{E_{2000}} \right)^2 \right)$$

$$\text{where} \quad \tilde{N}_y = \sum_a \left(\frac{s_{LL1,y,a}}{\frac{1}{(a_2 - a_1 + 1)} \sum_{j=a_1}^{j=a_2} s_{LL1,y,j}} \right)^{\psi} N_{y,a}$$

$$\text{and} \quad E_y = \frac{C_{LL1,y}}{CPUE_y}$$

In any given conditioning runs, parameters $\beta, \gamma, \varpi, \psi, q_y$ and a_1 and a_2 are fixed and are not considered estimable. Given the complexity of this functional relationship and the large number of parameters, it is not *a priori* clear what the most appropriate values might be. A limited exploration of the effect of different combination of values for the parameters $\beta, \gamma, \varpi, \psi$ and a_1 and a_2 was explored. We had hoped that some parameterization of this functional relation might smooth out the dramatic CPUE residuals observed in the mid-1990s (that may have been related to a transient age structure), but there was no evidence that this can be achieved. Results from this exploration are presented in the following four sub-sections. The nature of the presentation of the results is similar to those above and only limited discussion of the results is provided.

Beta and gamma
Table 6 and 7 provides the minimum value for the best fit to the objective function and its various components for various combinations of β and γ in the situation where steepness is estimated and when it is fixed to 0.60. Figures 13-15 show the estimates of the SSB, recruitment, the stock/recruitment relationship and the fit to the CPUE series for the results in which steepness was estimated. In both the cases where steepness was fixed at 0.60 or estimated, the best fit in terms of the objective function was achieved with β and γ set to zero. In general, β and γ had only a small effect on the estimate of steepness (Table 8). The greatest effect on steepness was when β was set to zero and γ was set to 2.0. In this case, the estimated steepness increased from 0.28 to 0.37. Different values of β and γ appear to primarily effect the early (particularly pre-fishery) estimates of recruitment. The more recent estimates of recruitment and SSB in Figure 13 were similar across all values of β and γ.

Omega
Table 9 and 10 provides the minimum value for the best fit to the objective function and its various components for various values for ω in the situation where steepness is estimated and when it is fixed to 0.60. Figures 16-18 show the estimates of the SSB, recruitment, the stock/recruitment relationship and the fit to the CPUE series for the results in which steepness was estimated. In both the cases were steepness was fixed at 0.60 or estimated, the best fit in terms of the objective function was achieved with

ω set to zero. ω had relatively a small effect on the estimate of steepness (Table 11). The greatest effect on steepness was when ω was set to 2.0. In this case, the estimated steepness increased from 0.28 to 0.38. Different values of ω appear to affect the absolute estimate level of SSB and the earlier (particularly pre-fishery) estimates of recruitment. The more recent estimates of recruitment in Figure 16 were similar across the values of ω.

Age range

Table 13 and 14 provides the minimum value for the best fit to the objective function and its various components for various values for the age range included in the fitting the CPUE index to abundance (parameters a_1 and a_2) in the situation where steepness is estimated and when it is fixed to 0.60. Figures 19-21 show the estimates of the SSB, recruitment, the stock/recruitment relationship and the fit to the CPUE series for the results in which steepness was estimated. In the case where steepness was estimated, the best fit in terms of the objective function was achieved with the age range set 4-12, but the greatest difference in the objective function was 2.3 for the combinations of age ranges explored. For this age range the estimate of steepness went to the bound of 0.20 and in all cases explored the estimated value of steepness was low (0.31 or less) (Table 14). In the case where steepness was fixed at 0.60, the best fit in terms of the objective function was achieved with the age range set 8-30 and the greatest difference in the objective function was 8.2. Different age ranges appear to have little effect on the estimates of SSB and primarily affect the earlier (particularly pre-fishery) estimates of recruitment. The more recent estimates of recruitment in Figure 16 were similar across all combinations of age ranges.

Psi

Table 15 and 16 provides the minimum value for the best fit to the objective function and its various components for various values for ψ in the situation where steepness is estimated and when it is fixed to 0.60. Figures 22-24 show the estimates of the SSB, recruitment, the stock/recruitment relationship and the fit to the CPUE series for the results in which steepness was estimated. In the cases where steepness is estimated, the best fit in terms of the objective function was achieved with ψ set to 1 and there was quite a reasonable difference in the value of the objective function for ψ equal to 2.0 (a difference of 8.5). When steepness was fixed at 0.60, there was virtually no difference in the value of objective function for different values of ψ. This means that if steepness is fixed in scenarios for testing candidate management procedures there is little basis for selecting a value of ψ, while allowing for different values of ψ in the projection component of the operating model could affect candidate MP performance. Estimates of steepness tended to increase with increasing values of ψ (Table 17). When ψ was set to 2.0, estimated steepness was 0.35. Different values of ψ appear to affect the absolute estimate level of SSB and the earlier (particularly pre-fishery) estimates of recruitment. The more recent estimates of recruitment in Figure 16 were similar across the values of ψ.

Table 6: Minimum value for the best fit to the objective function and its various components for various combinations of β and γ when steepness is fitted.

β	γ	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0.0	0.0	259.02	41.87	606.9	210.15	42.33	108.76	-45.69	14.00	42.52	57.46	-76.25	0.18	3.09	1264.3
0.0	0.5	258.13	41.96	605.8	210.14	41.76	108.6	-35.24	14.01	42.54	57.49	-74.81	0.19	2.91	1273.5
0.5	0.0	257.91	41.95	605.7	210.28	41.58	108.46	-33.61	13.94	42.58	57.34	-74.07	0.25	2.52	1274.9
0.5	0.5	257.53	41.95	605.2	210.40	41.32	108.37	-26.31	13.92	42.66	57.32	-73.56	0.26	2.40	1281.5
2.0	0.0	257.28	41.94	604.7	210.53	41.09	108.34	-17.14	13.93	42.76	57.34	-73.29	0.24	2.43	1290.2
0.0	2.0	256.92	41.94	604.9	210.85	41.06	108.04	-13.68	13.80	42.91	56.98	-72.43	0.46	1.60	1293.3
2.0	2.0	257.28	41.94	604.7	210.53	41.09	108.34	-17.14	13.93	42.76	57.34	-73.29	0.24	2.43	1290.2

Table 7: Minimum value for the best fit to the objective function and its various components for various combinations of β and γ when steepness is fixed at 0.60.

β	γ	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0.0	0.0	258.34	42.24	599.7	211.90	41.33	106.78	-41.77	13.52	42.62	57.23	-59.86	0.33	0.00	1272.4
0.0	0.5	257.41	42.28	600.2	211.61	41.00	106.78	-32.07	13.53	42.65	57.08	-60.62	0.42	0.00	1280.3
0.5	0.0	257.21	42.25	600.9	211.52	41.02	106.81	-31.18	13.51	42.65	56.93	-61.69	0.50	0.00	1280.5
0.5	0.5	256.73	42.24	601.4	211.53	40.88	106.80	-24.16	13.51	42.71	56.79	-62.63	0.59	0.00	1286.4
2.0	0.0	256.35	42.21	601.8	211.63	40.78	106.80	-15.05	13.52	42.81	56.66	-63.64	0.68	0.00	1294.5
0.0	2.0	256.09	42.15	603.1	211.80	40.90	106.88	-5.90	13.51	42.98	56.44	-66.13	0.89	0.00	1302.7
2.0	2.0	256.35	42.21	601.8	211.63	40.78	106.80	-15.05	13.52	42.81	56.66	-63.64	0.68	0.00	1294.5

Table 8: Estimates of steepness for various combinations of β and γ.

β	γ	Fitted Steepness Value
0.0	0.0	0.28
0.0	0.5	0.29
0.5	0.0	0.31
0.5	0.5	0.32
2.0	0.0	0.31
0.0	2.0	0.37
2.0	2.0	0.31

Table 9: Minimum value for the best fit to the objective function and its various components for various values of ω when steepness is an estimable parameter.

ω	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0.5	259.02	41.87	606.86	210.15	42.33	108.76	-45.69	14.00	42.52	57.46	-76.25	0.18	3.09	1264.29
1.0	259.32	41.72	603.39	209.88	39.62	108.74	-30.83	14.62	43.12	58.90	-73.26	0.05	4.73	1280.00
2.0	260.29	42.36	606.94	212.44	46.58	108.90	-31.92	14.17	44.26	57.00	-77.33	0.89	1.42	1285.98

Table 10: Minimum value for the best fit to the objective function and its various components for various values of ω when steepness is fixed at 0.60.

ω	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0.5	258.34	42.24	599.69	211.90	41.33	106.78	-41.77	13.52	42.62	57.23	-59.86	0.33	0.00	1272.37
1.0	256.68	42.08	599.75	211.78	39.95	106.60	-20.74	13.65	42.99	56.93	-59.44	0.41	0.00	1290.64
2.0	258.88	42.55	602.80	213.43	45.29	107.68	-27.33	13.67	43.36	56.61	-69.01	0.89	0.00	1288.81

Table 11: Estimates of steepness for various values ω.

ω	Fitted Steepness Value
0.5	0.28
1.0	0.20
2.0	0.38

Table 12: Minimum value for the best fit to the objective function and its various components for various values of a_1 and a_2 when steepness is an estimable parameter.

Age range	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
4-30	259.02	41.87	606.86	210.15	42.33	108.76	-45.69	14.00	42.52	57.46	-76.25	0.18	3.09	1264.29
8-12	262.10	41.51	605.79	209.19	40.56	108.76	-51.41	14.36	42.36	58.65	-74.32	0.00	4.73	1262.28
8-30	261.24	41.76	606.54	210.00	42.91	108.76	-47.85	13.98	42.05	57.78	-76.47	0.18	3.23	1264.12
4-8	259.21	41.86	609.34	210.50	40.13	108.90	-47.97	14.16	42.34	57.80	-76.68	0.05	3.62	1263.27
4-12	259.37	41.67	606.29	209.48	40.94	108.83	-49.61	14.30	43.26	58.17	-75.09	0.00	4.35	1261.98

Table 13: Minimum value for the best fit to the objective function and its various components for various values of a_1 and a_2 when steepness is fixed at 0.60.

Age range	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
4-30	258.34	42.24	599.69	211.90	41.33	106.78	-41.77	13.52	42.62	57.23	-59.86	0.33	0.00	1272.37
8-12	263.11	42.17	592.57	208.73	39.63	106.24	-47.45	13.99	42.40	58.36	-40.04	0.01	0.00	1279.71
8-30	259.98	42.14	600.42	211.41	41.74	106.74	-43.31	13.54	42.41	57.27	-61.30	0.43	0.00	1271.48
4-8	256.13	42.55	597.52	211.87	39.84	106.50	-43.02	13.94	41.53	57.53	-46.54	0.04	0.00	1277.90
4-12	260.02	42.30	592.07	209.85	39.89	106.40	-45.49	13.93	42.97	58.21	-41.49	0.01	0.00	1278.67

Table 14: Estimates of steepness for various values of a_1 and a_2.

Age range	Fitted Value of Steepness
4-30	0.31
8-12	0.20
8-30	0.27
4-8	0.25
4-12	0.20

Table 15: Minimum value for the best fit to the objective function and its various components for various values of ψ when steepness is estimated.

ψ	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0.5	259.02	41.87	606.86	210.15	42.33	108.76	-45.69	14.00	42.52	57.46	-76.25	0.18	3.09	1264.29
1.0	257.58	41.77	606.13	209.98	41.07	108.76	-48.17	14.07	42.61	57.77	-74.00	0.05	3.34	1260.97
2.0	262.41	41.89	608.09	210.35	43.00	108.43	-43.60	13.88	43.03	56.55	-77.08	0.79	1.83	1269.57

Table 16: Minimum value for the best fit to the objective function and its various components for various values of ψ when steepness is fixed at 0.60.

ψ	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0.5	258.34	42.24	599.69	211.90	41.33	106.78	-41.77	13.52	42.62	57.23	-59.86	0.33	0.00	1272.37
1.0	257.26	42.34	596.21	211.53	40.37	106.72	-44.35	13.68	42.43	57.72	-51.21	0.09	0.00	1272.78
2.0	261.04	42.14	605.45	211.71	42.56	107.34	-41.35	13.47	43.05	56.50	-70.48	0.89	0.00	1272.33

Table 17: Estimates of steepness for various values of ψ.

ψ	Fitted Steepness Value
0.5	0.26
1.0	0.28
2.0	0.35

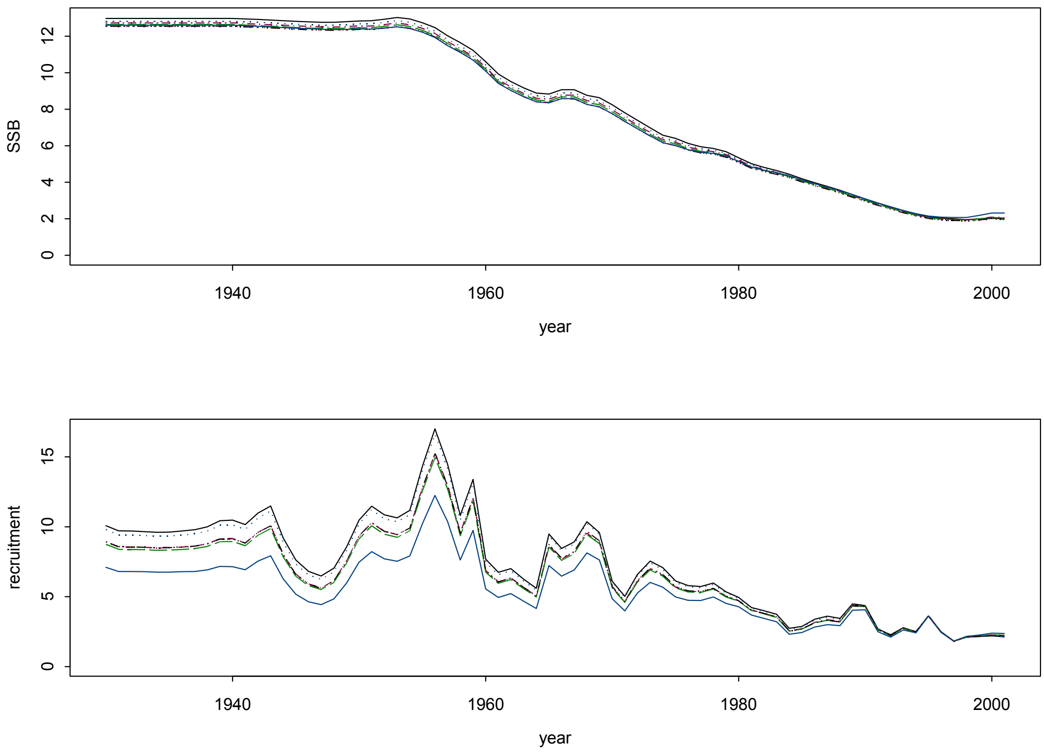


Figure 13: Comparison of the best fit estimates of temporal trends in SSB and recruitment for the different combinations of β and γ in Table 6.

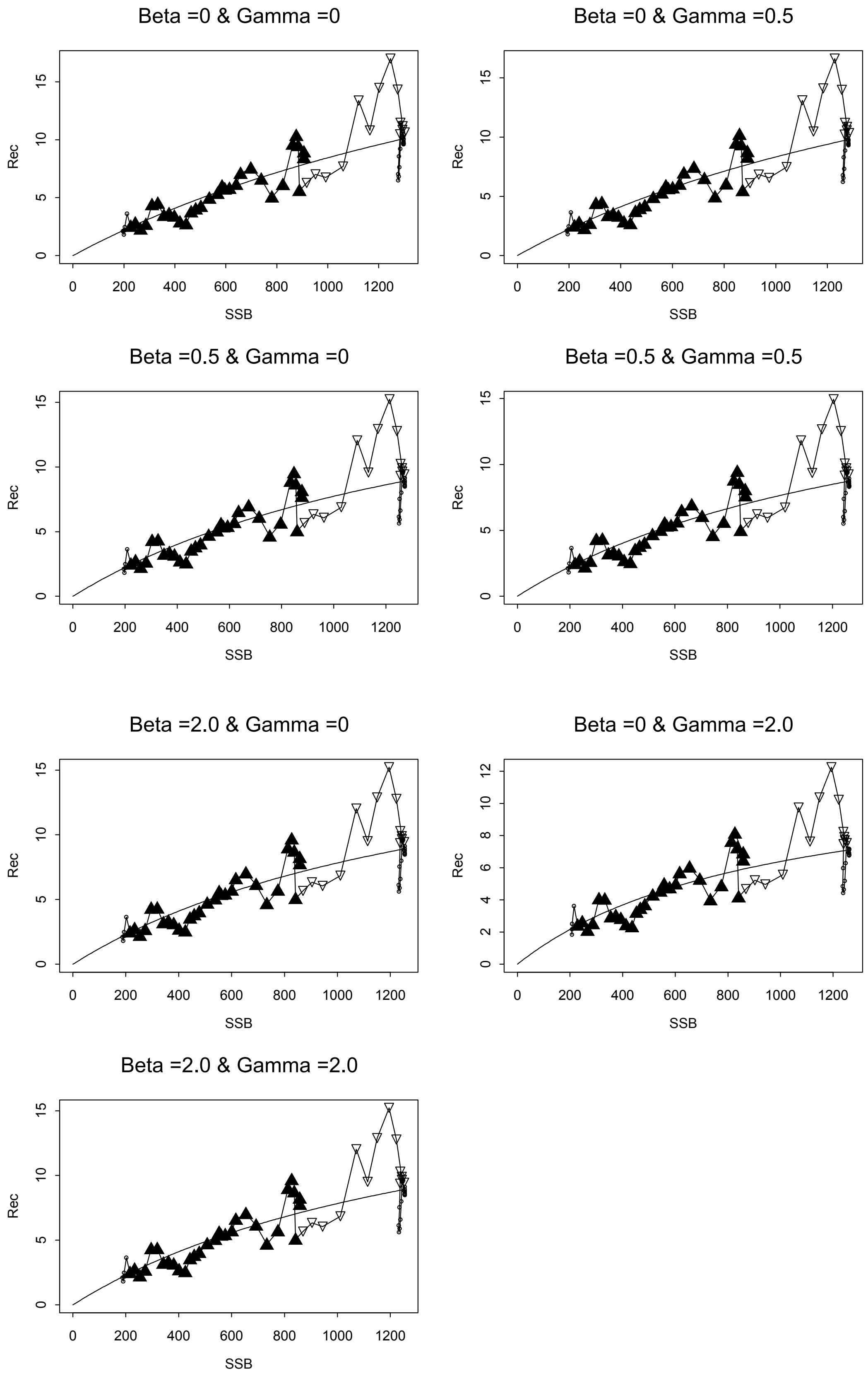


Figure 14: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function for the different combinations of β and γ in Table 6.

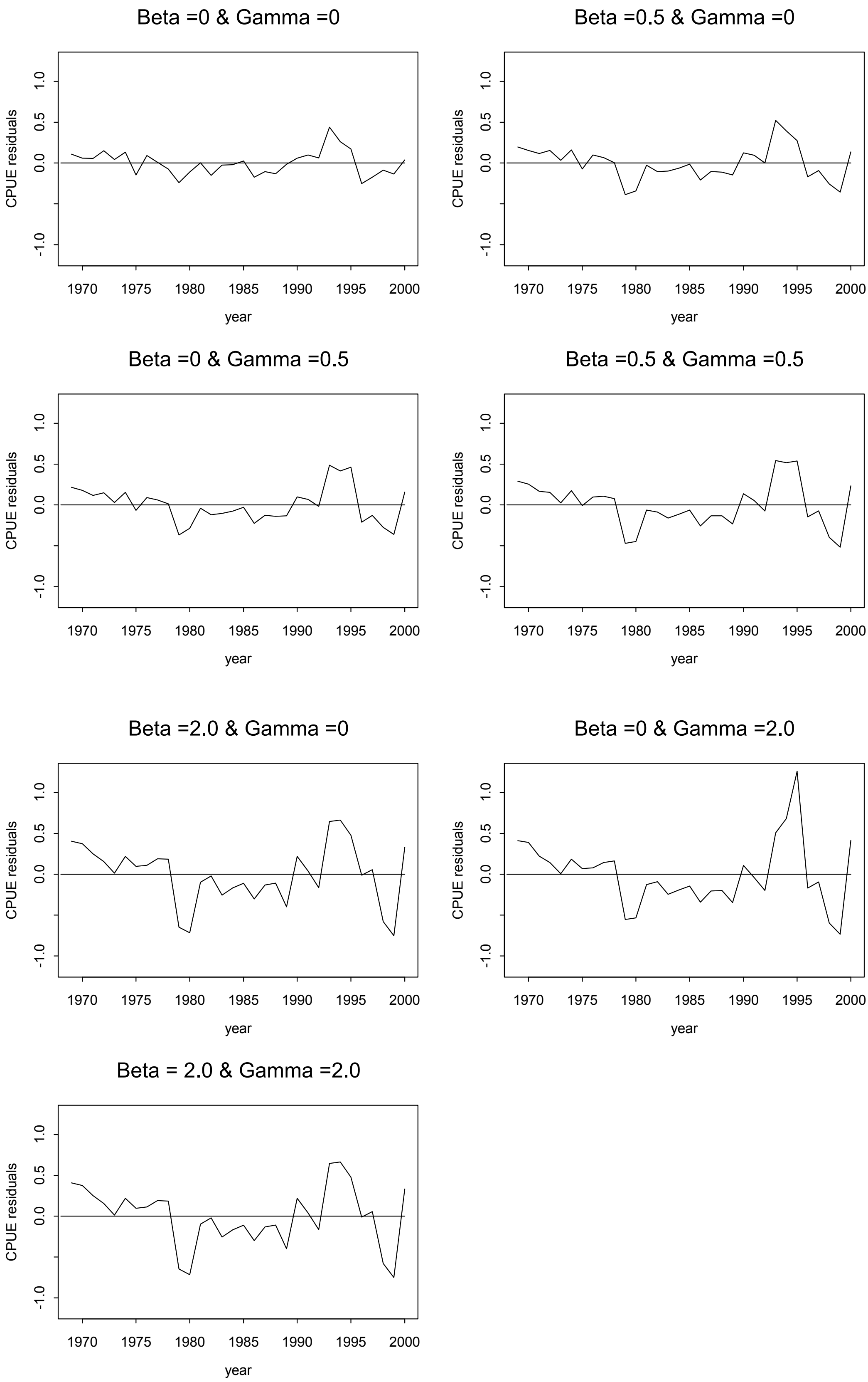


Figure 15: Residual time trends in the fit to the longline CPUE index for the different combinations of β and γ in Table 6.

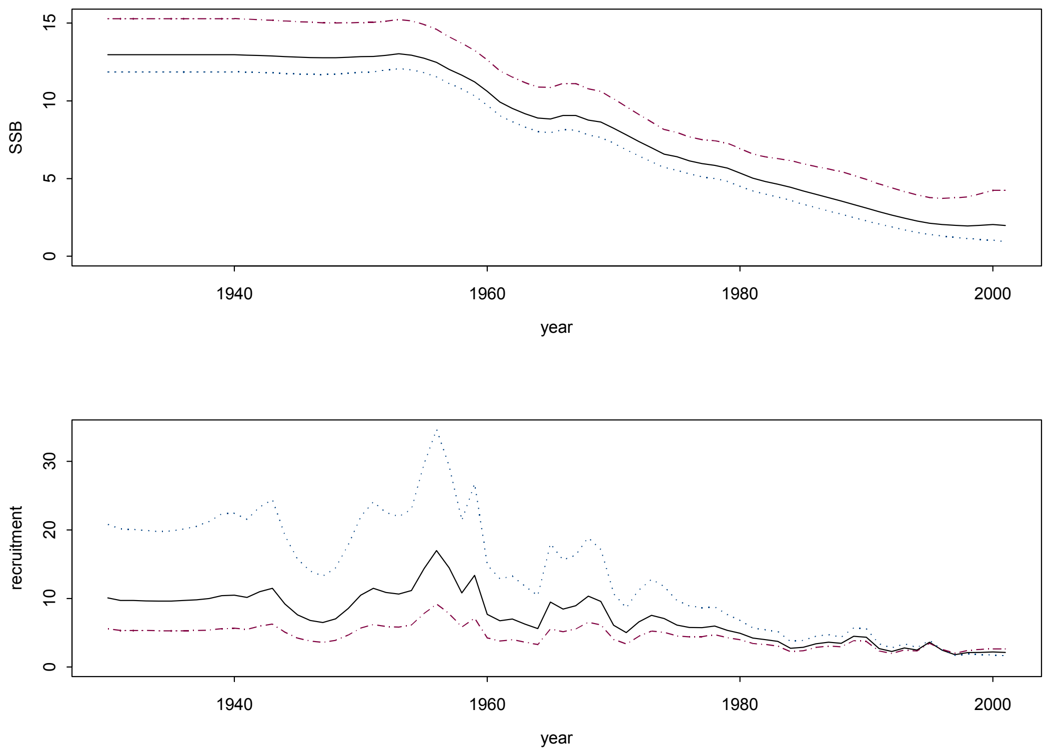


Figure 16: Comparison of the best fit estimates of temporal trends in SSB and recruitment for the different values of ω in Table 9 and with steepness fitted.

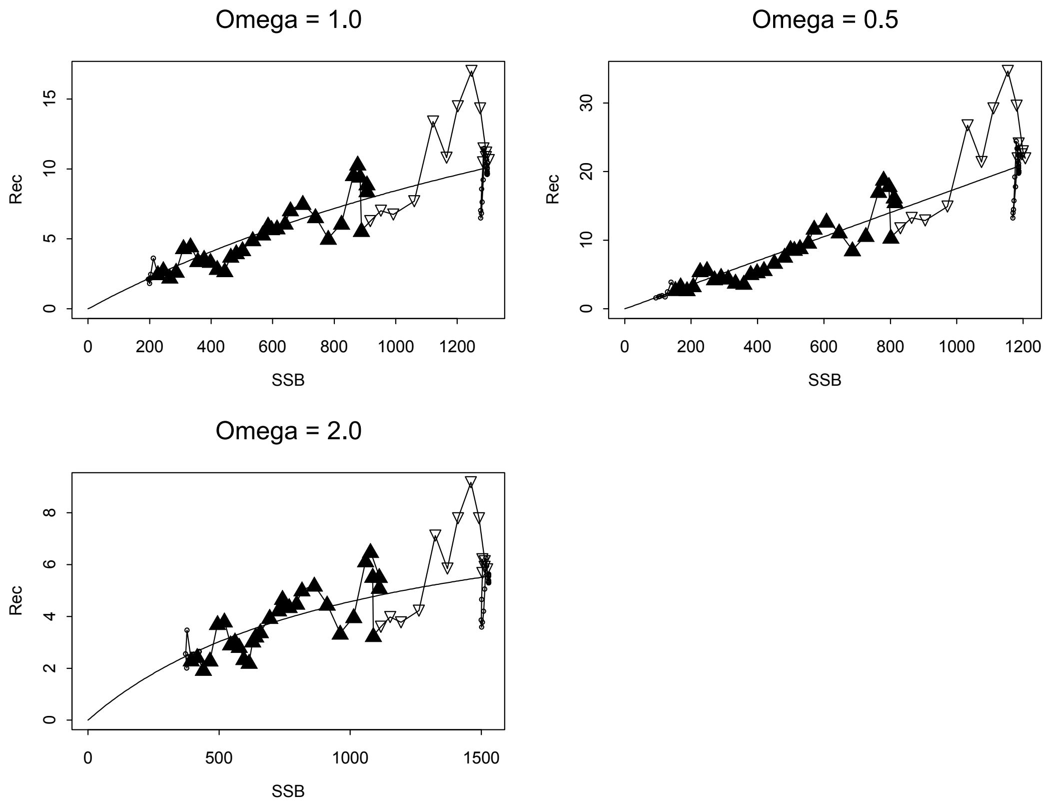


Figure 17: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function for the different values of ω in Table 9 and with steepness fitted.

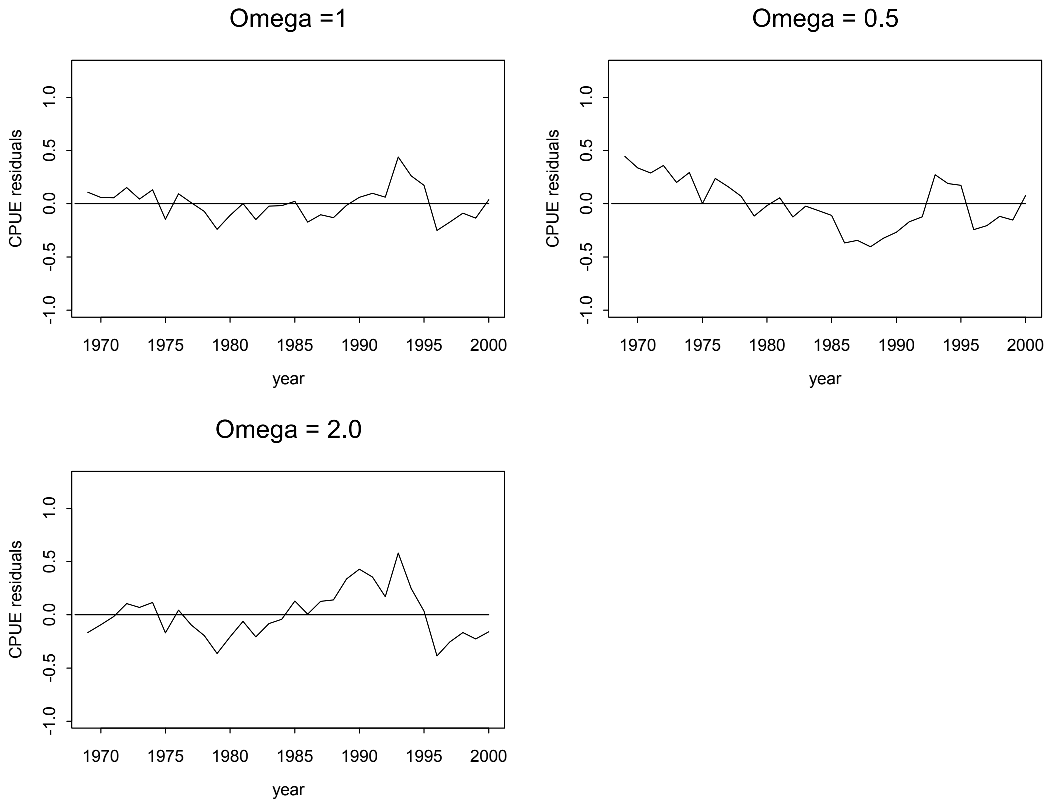


Figure 18: Time trends in the residuals in the fit to the longline CPUE index for the different values of ω in Table 9 and with steepness fitted.

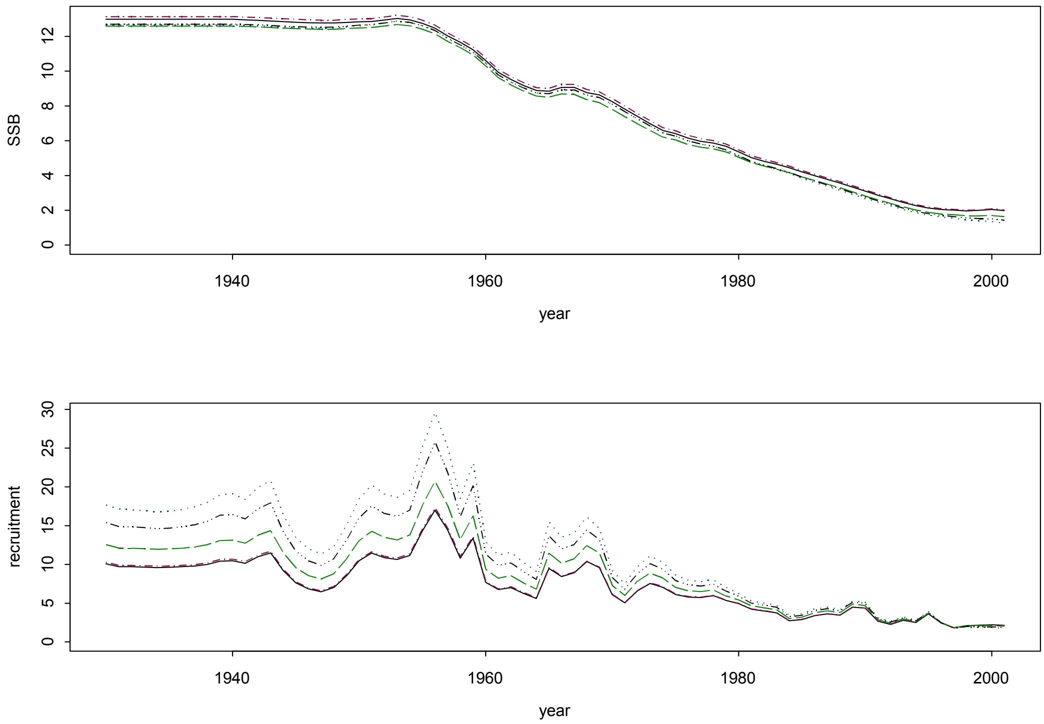


Figure 19: Comparison of the best fit estimates of temporal trends in SSB and recruitment for the different combinations of age ranges in Table 12 and with steepness fitted.

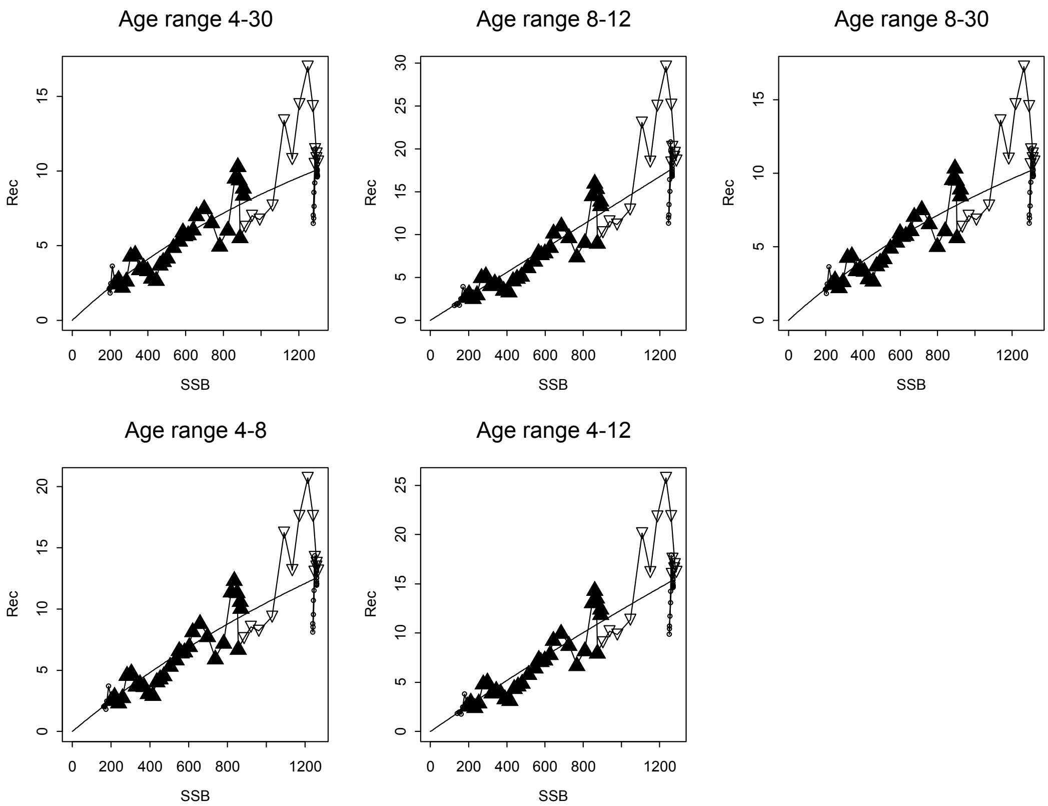


Figure 20: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function for the different combinations of age ranges in Table 12 and steepness fitted.

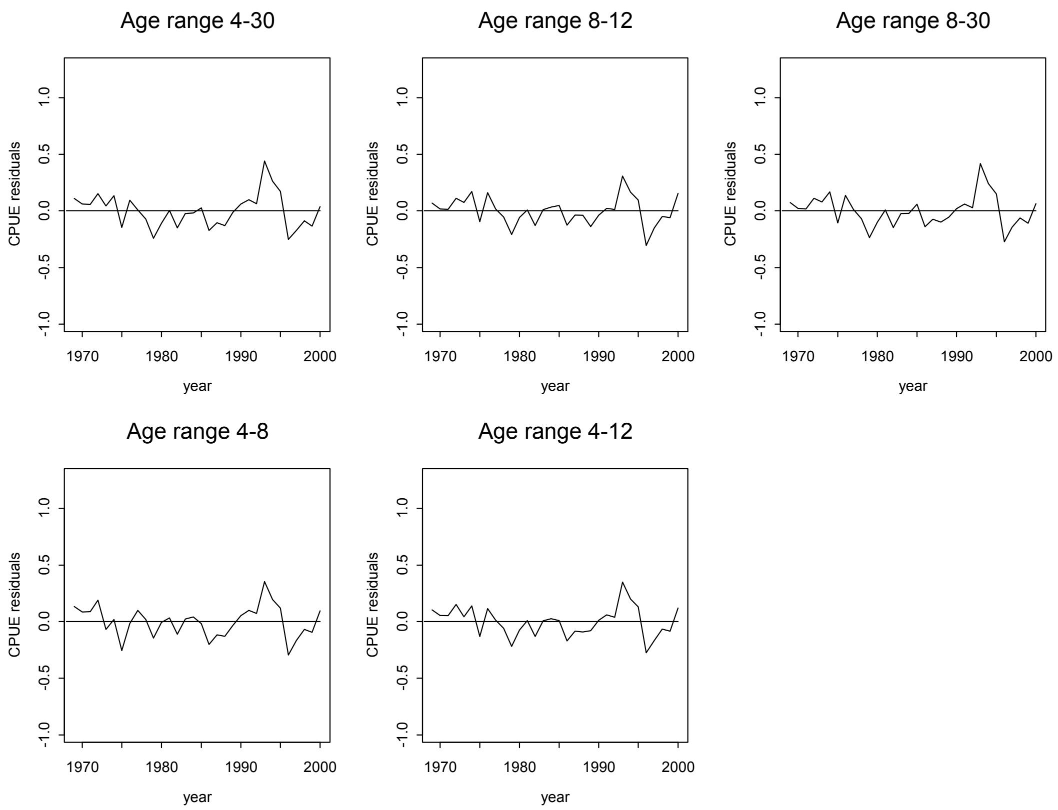


Figure 21:Time trends in the residuals in the fit to the longline CPUE index for the different combinations of age ranges in Table 12 and when steepness is fitted.

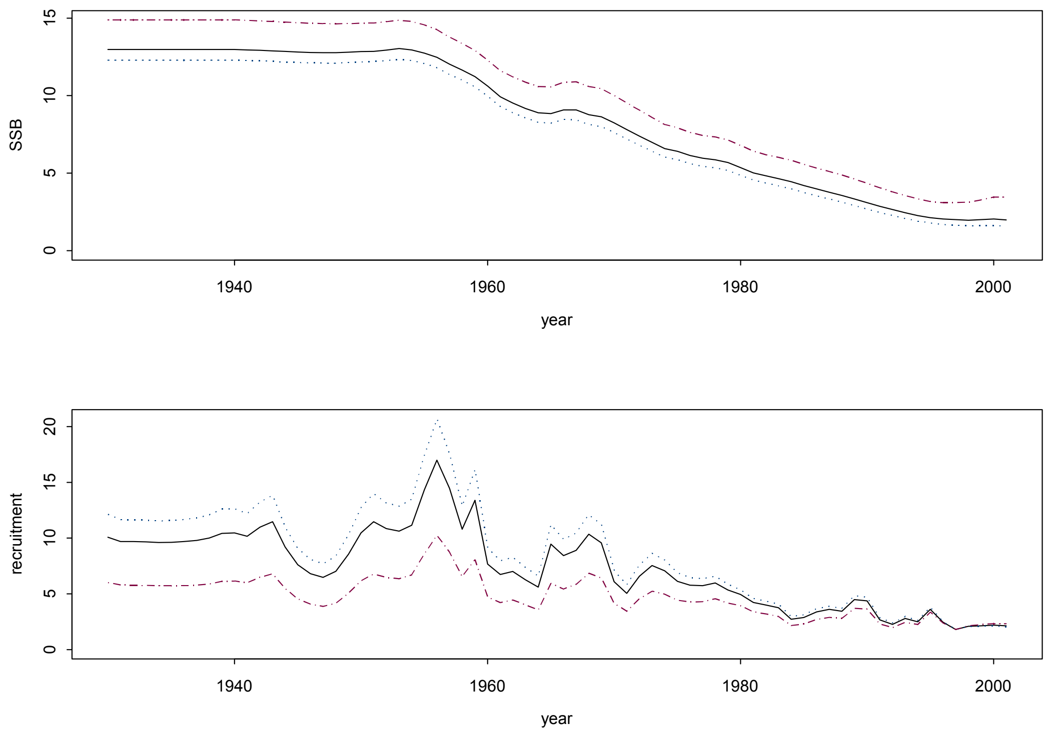


Figure 22: Comparison of the best fit estimates of temporal trends in SSB and recruitment for the different values of ψ in Table 15 and with steepness fitted.

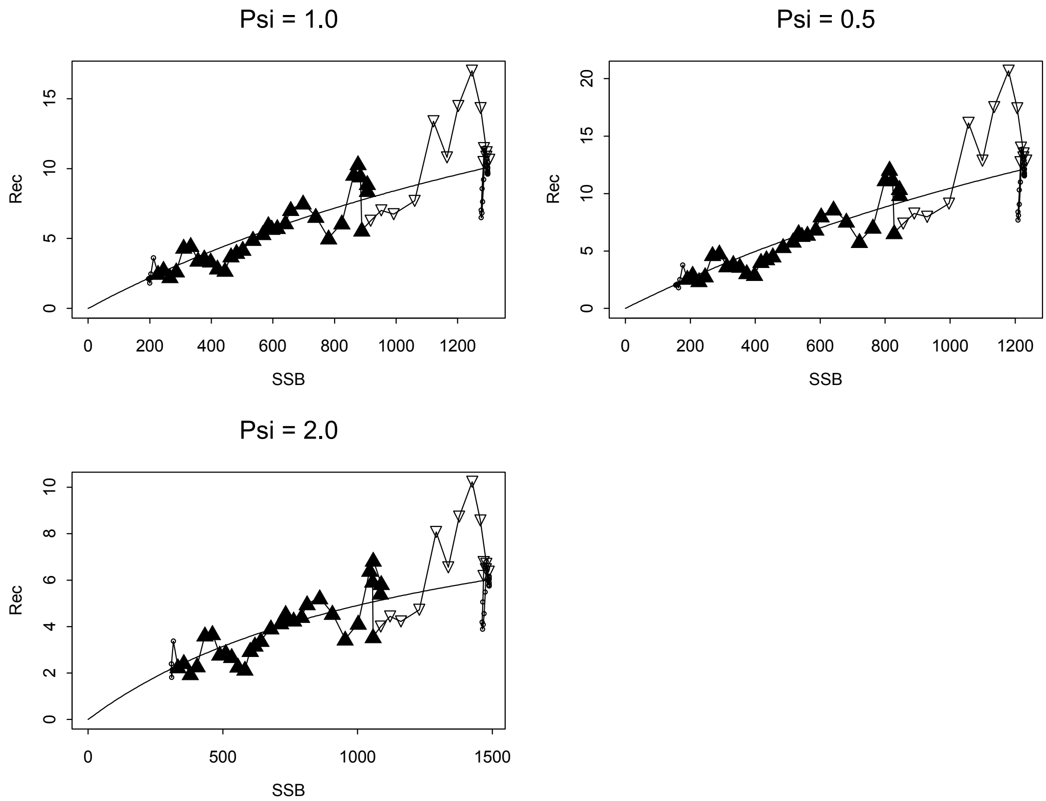


Figure 23: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function for the different values of ψ in Table 15 and with steepness fitted.

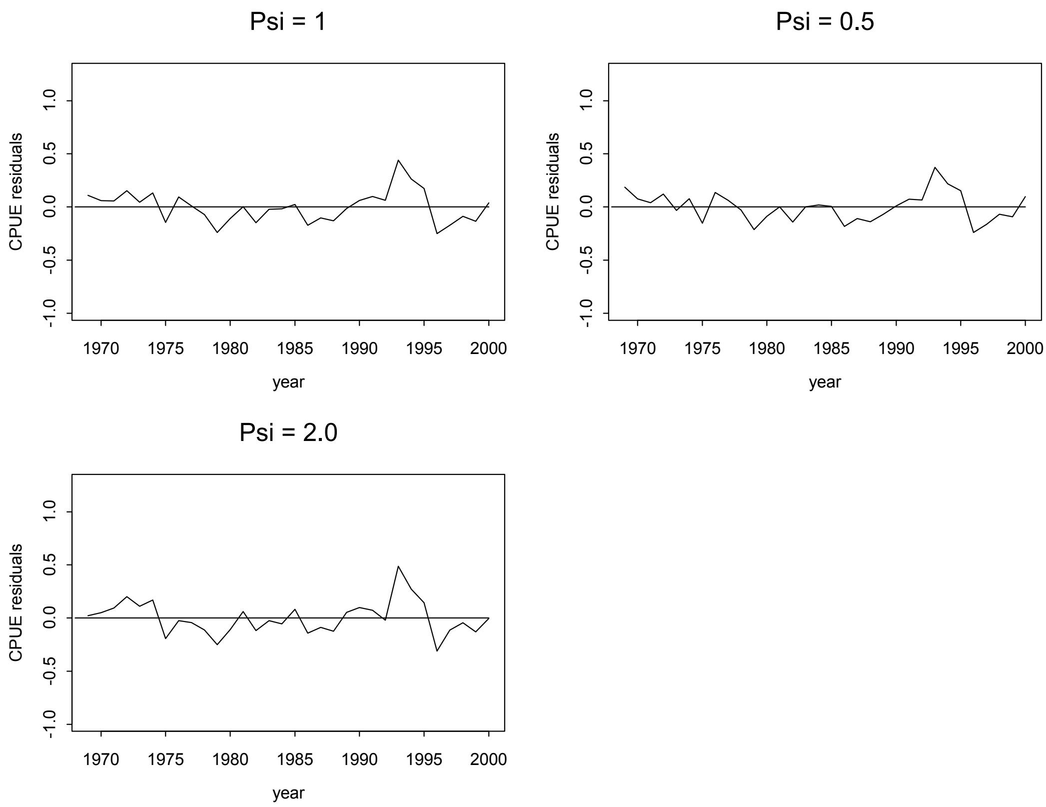


Figure 24: Time trends in the residuals in the fit to the longline CPUE index for the different values of ψ in Table 15 and with steepness fitted.

Linear Trends in Catchability

Temporal changes in catchability will affect the relationship between CPUE and abundance and could have a large effect on the performance of management decision rules that use CPUE as part of the basis for setting future TACs. However, in the case of the Japanese SBT longline fishery, there is little available data that allows for the quantitative estimation of possible changes. In order to explore the possible effects of changes in catchability over time, linear changes in catchability were considered.

Tables 18-20 provide the minimum value for the best fit to the objective function and its various components for various values for various different overall increases in the changes in catchability over the 32 year CPUE time series. The change is assumed to occur linearly over this period. Results are presented for the situation where steepness is estimated and when it is fixed at either 0.30 or 0.90. In all cases the best fit is obtain when no change is assumed to occur. This is perhaps not surprising given the time trend in the CPUE residuals. Thus, the observed CPUE is estimated to be too large at the beginning of the time period and too low at the end relative to the predicted (Figure 3). Allowing for an increasing trend in catchability, exasperates this trend in the CPUE residuals (Figure 27), but the differences appear not to be very substantial. When steepness is estimated, the difference in the value of the objective function is 4.9 between no change and a 75% change in catchability. The estimated trends in SSB over this range of changes in catchability are almost identical and as are the estimates of the more recent recruitment (post 1980) (Figure 25). The main difference in the estimates are in the estimates of the early recruitments (particularly those prior to the fishery). This in turns results in decreasing estimates of steepness with increasing magnitude of change in catchability (Table 21, Figure 26)

Table 18: Minimum value for the best fit to the objective function and its various components for various linear trends in catchability when steepness is estimated (ΔQ refers to the total change in catchability between 1969 and 2000).

ΔQ	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0%	259.02	41.87	606.86	210.15	42.33	108.76	-45.69	14.00	42.52	57.46	-76.25	0.18	3.09	1264.29
25%	259.16	41.79	606.51	209.68	42.06	108.91	-44.67	14.16	42.39	57.78	-75.93	0.06	3.81	1265.72
50%	259.28	41.74	606.24	209.28	41.83	108.99	-43.59	14.31	42.36	58.04	-75.52	0.01	4.35	1267.33
75%	259.35	41.70	606.00	209.00	41.58	109.02	-42.24	14.42	42.38	58.27	-75.04	0.00	4.73	1269.17

Table 19: Minimum value for the best fit to the objective function and its various components for various linear trends in catchability when steepness is fixed at 0.30. (ΔQ refers to the total change in catchability between 1969 and 2000).

ΔQ	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0%	259.14	41.90	606.35	210.56	42.22	108.65	-45.46	13.93	42.43	57.47	-75.67	0.18	0.00	1261.70
25%	259.55	41.86	605.06	210.82	41.69	108.61	-44.05	14.02	42.21	57.87	-74.20	0.06	0.00	1263.51
50%	259.95	41.83	603.98	211.03	41.21	108.57	-42.70	14.13	42.16	58.22	-72.84	0.01	0.00	1265.56
75%	260.27	41.80	603.07	211.21	40.76	108.52	-41.18	14.23	42.21	58.55	-71.61	0.00	0.00	1267.81

Table 20: Minimum value for the best fit to the objective function and its various components for various linear trends in catchability when steepness is fixed at 0.90. (ΔQ refers to the total change in catchability between 1969 and 2000).

ΔQ	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0%	255.19	42.64	595.39	207.36	41.12	105.58	-38.92	13.33	43.32	56.52	-40.27	0.57	0.00	1281.84
25%	255.41	42.65	593.86	206.38	40.72	105.57	-37.13	13.41	43.69	56.89	-35.25	0.38	0.00	1286.59
50%	255.73	42.66	592.76	205.64	40.43	105.59	-35.59	13.49	44.04	57.21	-31.54	0.27	0.00	1290.67
75%	255.98	42.65	592.00	205.11	40.21	105.61	-33.86	13.56	44.34	57.47	-28.89	0.19	0.00	1294.37

Table 21: Estimates of steepness for various values of ΔQ .

ΔQ	Fitted Steepness Value
0%	0.28
25%	0.24
50%	0.22
75%	0.20

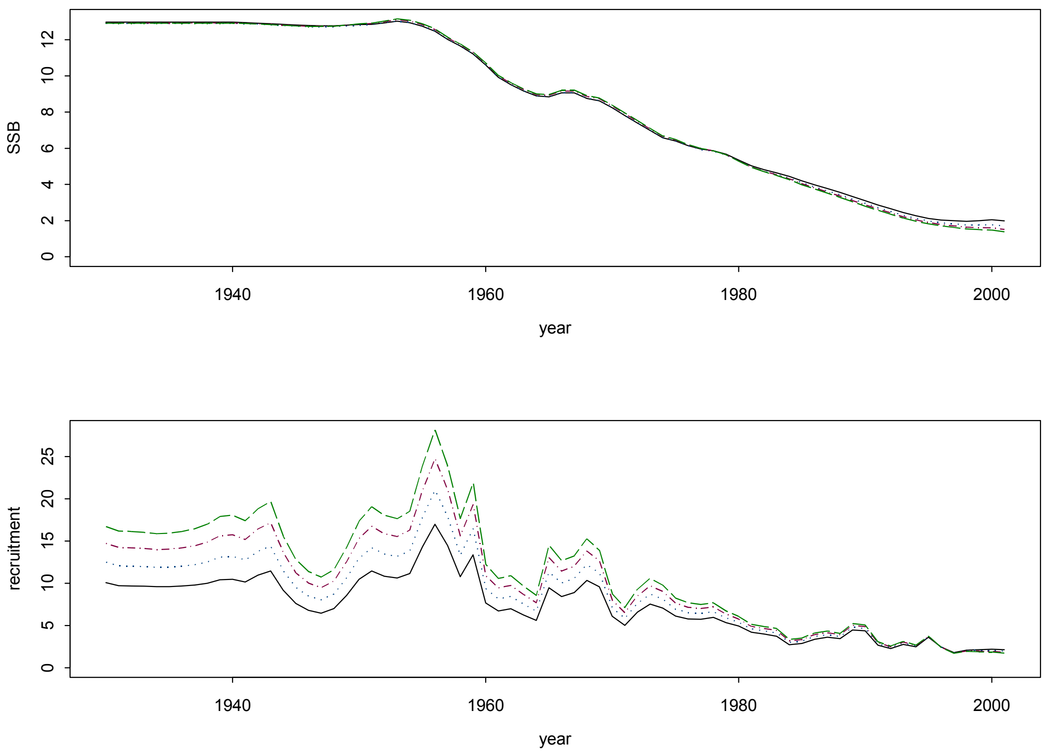


Figure 25: Comparison of the best fit estimates of temporal trends in SSB and recruitment for various linear trends in catchability when steepness is estimated.

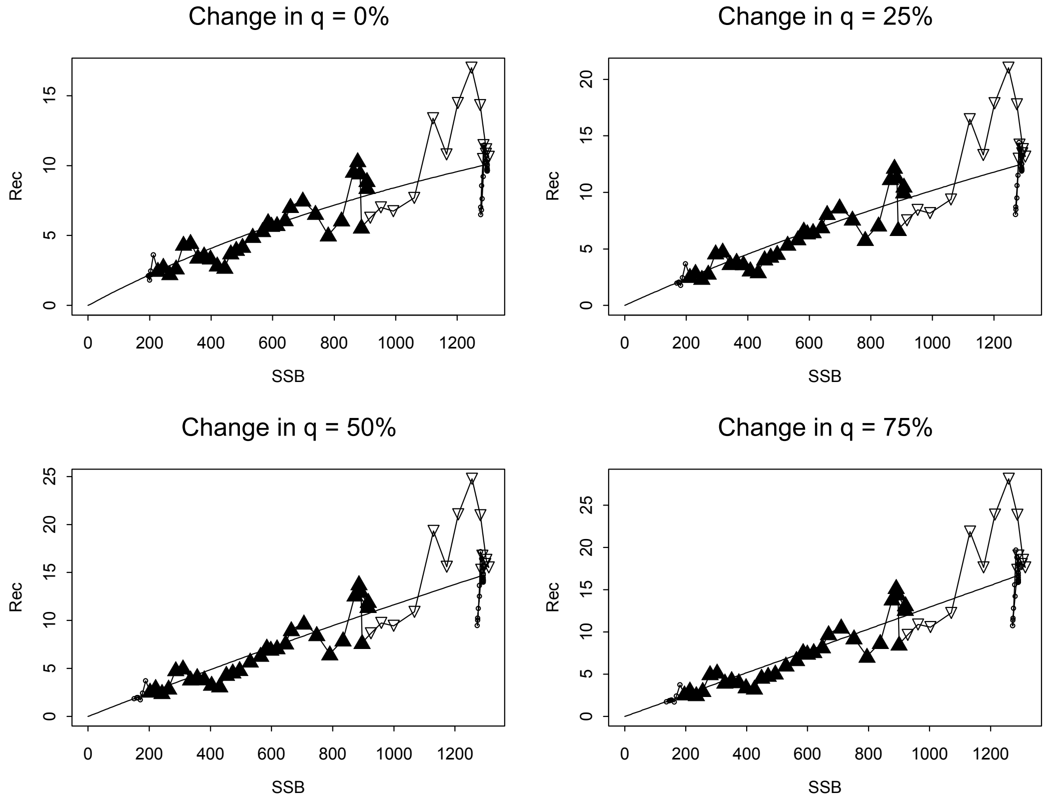


Figure 26: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function for various linear trends in catchability when steepness is estimated. (ΔQ refers to the total change in catchability between 1969 and 2000)

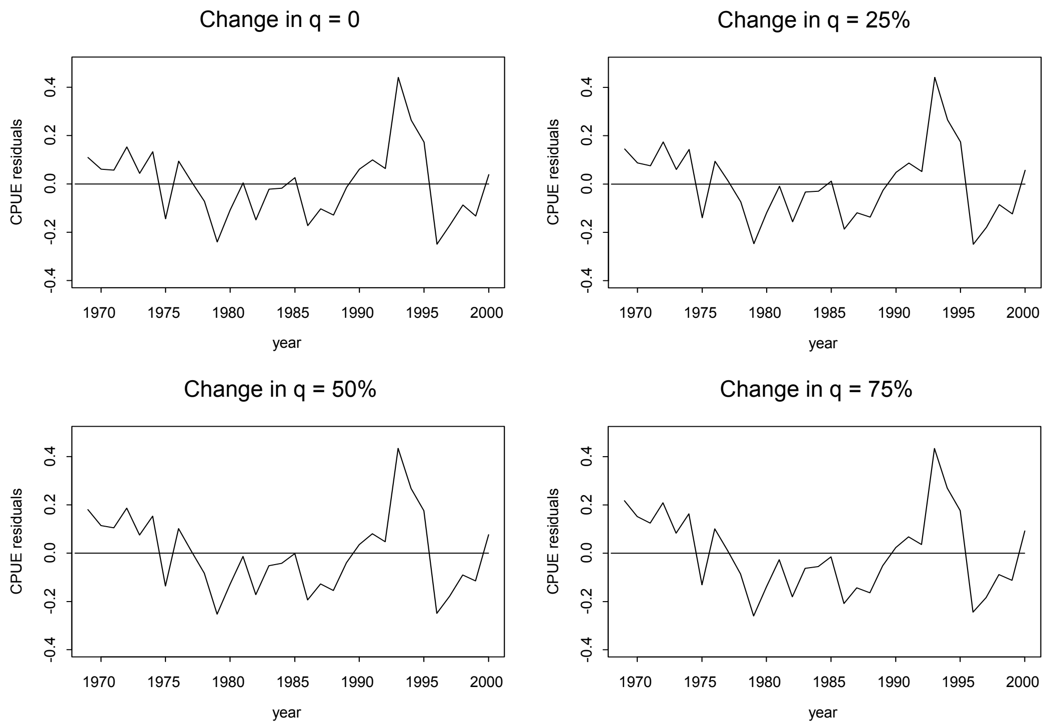


Figure 27: Time trends in the residuals in the fit to the longline CPUE index for various linear trends in catchability when steepness is estimated. (ΔQ refers to the total change in catchability between 1969 and 2000).

Tag Reporting Rates and Weighting of Tagging Data

The weight given to the tagging data and the particular reporting rates model are user-specified input parameters when conditioning the operating model. The sensitivity of the results to different reporting rate models and weights given to the tagging data was explored. Tables 22 and 23 provide the minimum value for the best fit to the objective function and its various components for the different reporting rate models and for different weightings of the objective function for the situation when steepness is fixed at 0.60. There is little difference in the overall value of the objective function for the different reporting rate models or for the non-tagging components when the tagging data are given additional weight. The resulting estimates of SSB and recruitment are very similar (Figure 28 and 29). Similar behaviour was seen when steepness was estimated.

Table 22: Minimum value for the best fit to the objective function and its various components for different tag reporting rate models when steepness is fixed at 0.60.

Model	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
1	258.03	42.34	599.66	211.85	41.36	106.85	-41.91	13.64	42.59	57.20	-59.21	0.31	0.00	1272.71
2	258.76	42.48	599.62	212.13	41.37	107.45	-42.10	13.03	42.34	57.04	-60.46	0.35	0.00	1272.02
3	258.80	42.57	599.60	212.17	41.37	107.59	-42.09	13.83	42.32	57.05	-60.63	0.36	0.00	1272.95
4	259.34	42.66	599.58	212.34	41.38	108.09	-42.18	14.48	42.17	56.96	-61.46	0.38	0.00	1273.75
5	258.34	42.24	599.69	211.90	41.33	106.78	-41.77	13.52	42.62	57.23	-59.86	0.33	0.00	1272.37
6	259.08	42.38	599.65	212.17	41.34	107.38	-41.95	12.81	42.39	57.07	-61.10	0.38	0.00	1271.60
7	259.12	42.48	599.63	212.20	41.34	107.53	-41.94	13.66	42.37	57.08	-61.26	0.39	0.00	1272.58
8	259.67	42.56	599.60	212.37	41.35	108.03	-42.02	14.23	42.22	56.99	-62.09	0.41	0.00	1273.32

Table 23: Minimum value for the best fit to the objective function and its various components for different values of sigma tag when steepness is fixed at 0.60.

Sig. Tag	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0.8	260.83	43.00	599.93	211.82	41.32	117.41	-42.00	28.16	41.52	57.42	-59.82	0.31	0.0	1299.90
1.6	258.34	42.24	599.69	211.90	41.33	106.78	-41.77	13.52	42.62	57.23	-59.86	0.33	0.00	1272.37
3.2	257.81	41.73	600.08	212.07	41.36	102.02	-41.87	5.72	43.94	57.71	-61.37	0.43	0.00	1259.63

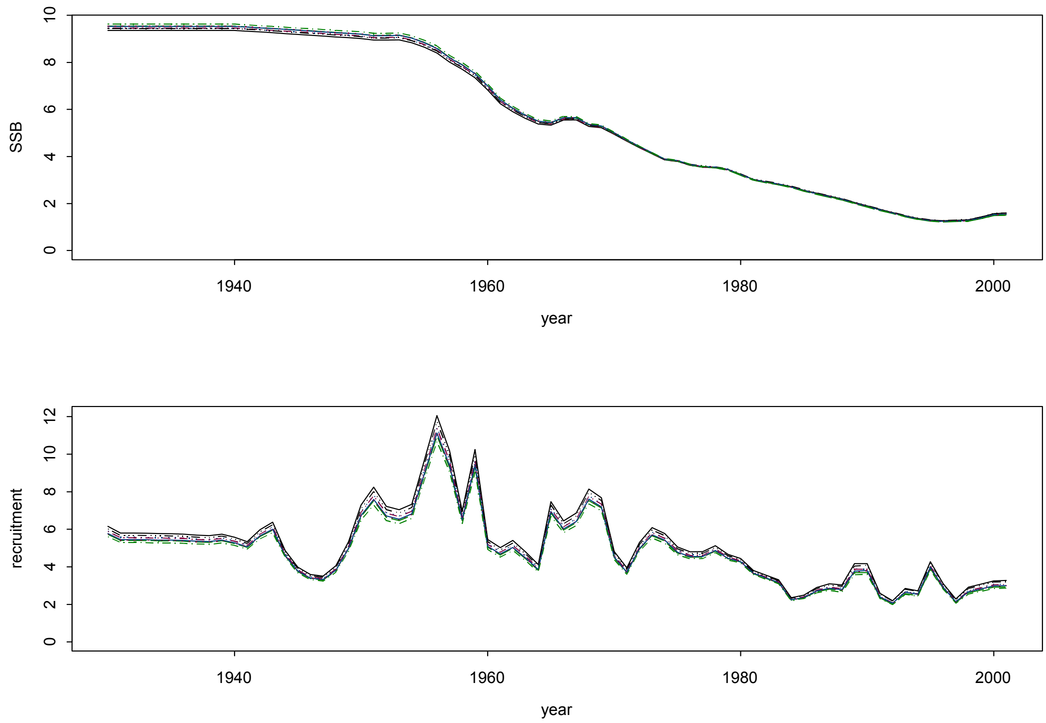


Figure 28: Comparison of estimate time trends in recruitment and spawning stock biomass for the eight different models for tag reporting with steepness fixed at 0.60 the remaining parameters as per the specifications for the initial operating models.

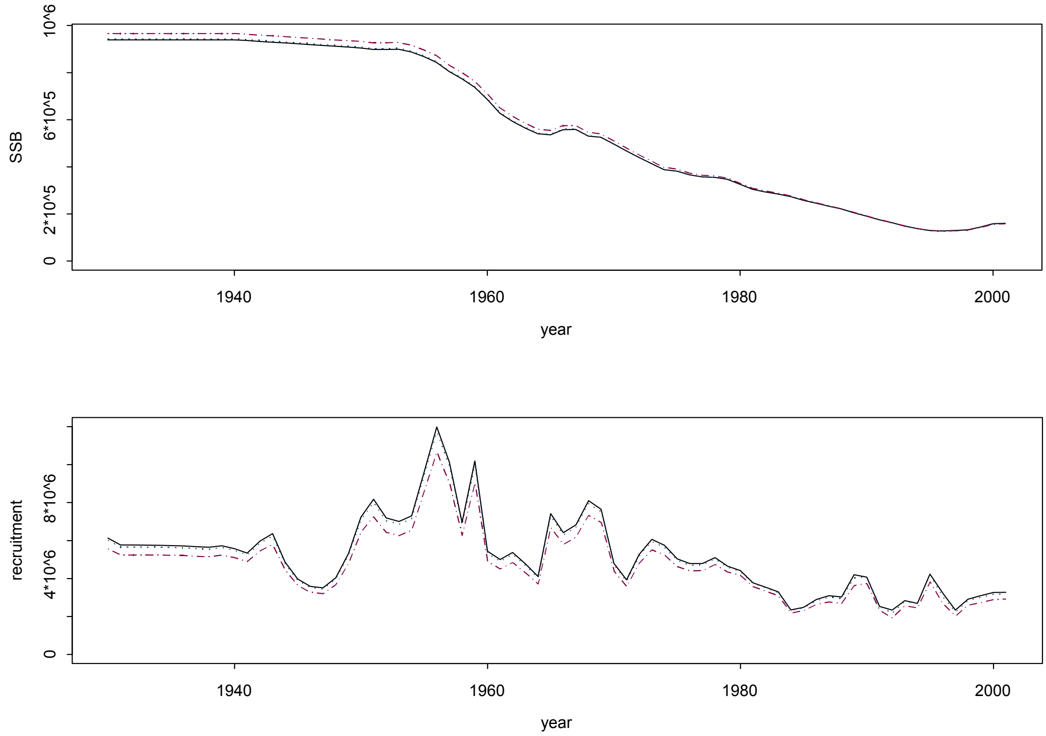


Figure 29: Comparison of estimate time trends in recruitment and spawning stock biomass for three different values for sigma tag (0.8 – solid line, 1.6- dotted line and 2.4 – dash line) with steepness fixed at 0.60.

Depensation

Anon (2002b) defined the following stock-recruitment relationship in order to allow for the possibility of depensation:

$$R_y = \frac{\alpha S_y}{\beta + S_y}\left(1 - \exp\left(\frac{\ln(0.5) S_y}{\Phi S_0}\right)\right)$$

where the parameter Φ is the fraction of unexploited spawning biomass (S_0) at which fertilization rate is 50% the maximum rate possible at large spawning biomass.

Note that setting Φ to a very small number corresponds in the limit to no depensation. In the code for conditioning the operating model, Φ is a fixed input parameter specified by the user. Figures 30-38 present results of conditioning the operating model to four different values for the parameter Φ and Tables 24-27 provides the resulting fit to the objective function and its various components. Results are presented for fixed values of steepness corresponding to 0.3, 0.6 and 0.9 as well as the case where steepness is estimated. This was done because there is an interaction between the value of Φ and steepness.

When steepness is estimated, the values of the objective function are quite similar for values of Φ ranging from ~0 to 0.20 (i.e. a maximum difference of 1.7) and the best fits are for either high or low values of Φ. However, as Φ is increased so is the estimated value of the steepness parameter (Table 28). Thus, steepness increases from 0.28 to 0.57 as Φ increases from 0 to 0.20. If steepness is fixed at 0.3, then a value of zero for Φ results in the best fit (Table 25). The estimates of SSB tend to shift to higher values, while the recruitment estimates are basically unchanged (Figure 33). However, for fixed steepness values of 0.60 and 0.90, increasing the value of Φ results in a better overall fit. The estimates of SSB tend to be shifted to higher values in the early years and to somewhat lower values in the more recent years (Figure 36). A similar shift is also seen in the recruitment estimates (Figure 36).

Table 24: Minimum value for the best fit to the objective function and its various components for different levels of depensation (Φ) when steepness is estimated.

Φ	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
1e-10	259.02	41.87	606.86	210.15	42.33	108.76	-45.69	14.00	42.52	57.46	-76.25	0.18	3.09	1264.29
0.10	257.04	41.62	604.47	210.13	42.45	108.28	-44.93	14.19	42.04	57.21	-67.97	0.18	1.26	1265.98
0.15	256.77	41.60	604.02	210.11	42.46	108.23	-44.79	14.21	41.95	57.17	-66.80	0.17	0.32	1265.42
0.20	256.77	41.59	604.40	209.98	42.53	108.30	-44.93	14.24	42.01	57.17	-67.41	0.17	0.03	1264.86

Table 25: Minimum value for the best fit to the objective function and its various components for different levels of depensation (Φ) when steepness is fixed at 0.30.

Φ	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
1e-10	259.14	41.90	606.35	210.56	42.22	108.65	-45.46	13.93	42.43	57.47	-75.67	0.18	0.00	1261.70
0.10	256.69	41.52	606.01	209.10	42.78	108.57	-45.44	14.44	42.37	57.18	-69.52	0.21	0.00	1263.91
0.15	255.79	41.39	606.29	208.37	43.06	108.62	-45.38	14.72	42.52	57.08	-67.59	0.25	0.00	1265.11
0.20	255.14	41.28	606.66	207.90	43.27	108.67	-45.28	14.98	42.72	57.03	-66.06	0.30	0.00	1266.62

Table 26: Minimum value for the best fit to the objective function and its various components for different levels of depensation (Φ) when steepness is fixed at 0.60.

Φ	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
1e-10	258.34	42.24	599.69	211.90	41.33	106.78	-41.77	13.52	42.62	57.23	-59.86	0.33	0.00	1272.37
0.10	257.53	41.81	601.51	211.63	41.83	107.62	-43.64	13.88	41.88	57.24	-63.38	0.20	0.00	1268.14
0.15	257.18	41.70	602.96	210.87	42.17	108.01	-44.35	14.05	41.84	57.21	-65.84	0.17	0.00	1265.95
0.20	256.52	41.38	604.66	210.44	42.62	108.70	-45.83	14.35	41.33	57.21	-69.01	0.07	0.00	1262.40

Table 27: Minimum value for the best fit to the objective function and its various components for different levels of depensation (Φ) when steepness is fixed at 0.90.

Φ	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
1e-10	255.19	42.64	595.39	207.36	41.12	105.58	-38.91	13.33	43.32	56.52	-40.27	0.57	0.00	1281.84
0.10	257.55	42.17	597.76	211.61	41.30	106.53	-41.39	13.60	42.54	57.11	-54.14	0.34	0.00	1274.97
0.15	258.08	42.00	600.14	212.18	41.50	107.22	-42.74	13.72	42.13	57.26	-61.53	0.24	0.00	1270.20
0.20	258.28	41.92	602.02	212.02	41.73	107.70	-43.67	13.80	41.99	57.33	-66.14	0.20	0.00	1267.18

Table 28: Estimates of steepness for various values of Φ.

Φ	Fitted Steepness Value
1e-10	0.28
0.10	0.39
0.15	0.50
0.20	0.57

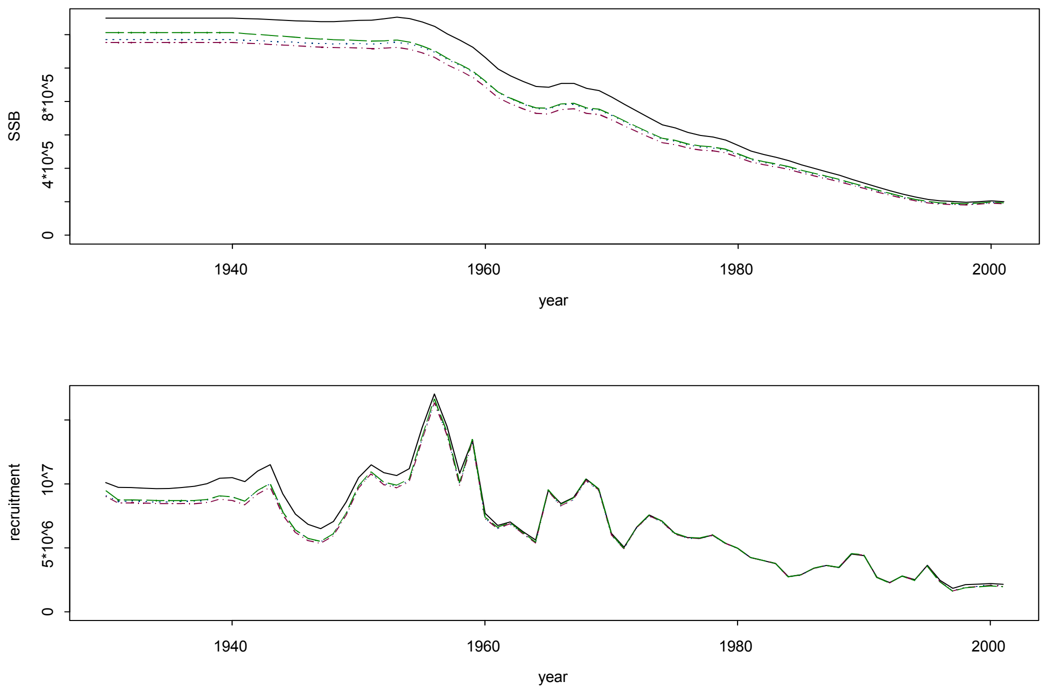


Figure 30: Comparison of estimate time trends in recruitment and spawning stock biomass for four different values for the depensation parameter in the stock recruitment curve (1e-10 – solid line, 0.10 - dotted line, 0.15 – dash line and 0.20 dash-dot line) with steepness being fitted, M_{10}=0.10 and the remaining parameters as per the specifications for the initial operating models.

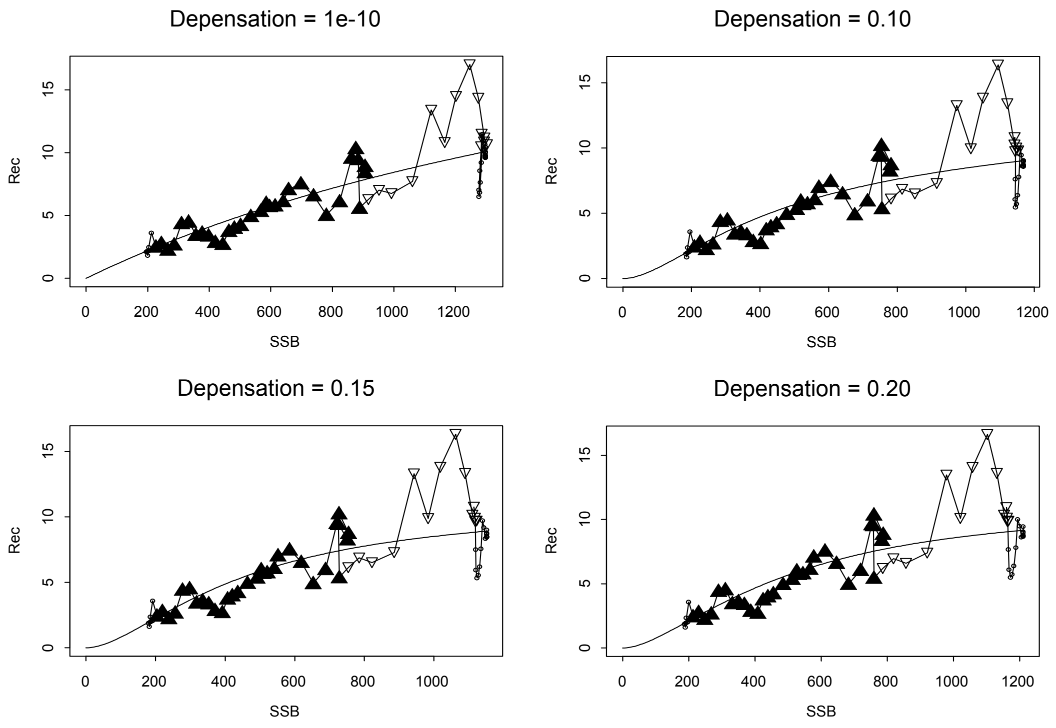


Figure 31: Comparison of the estimated stock and recruitment relationship for four different values for the depensation parameter in the stock recruitment curve with steepness being fitted and the remaining parameters as per the specifications for the initial operating models.

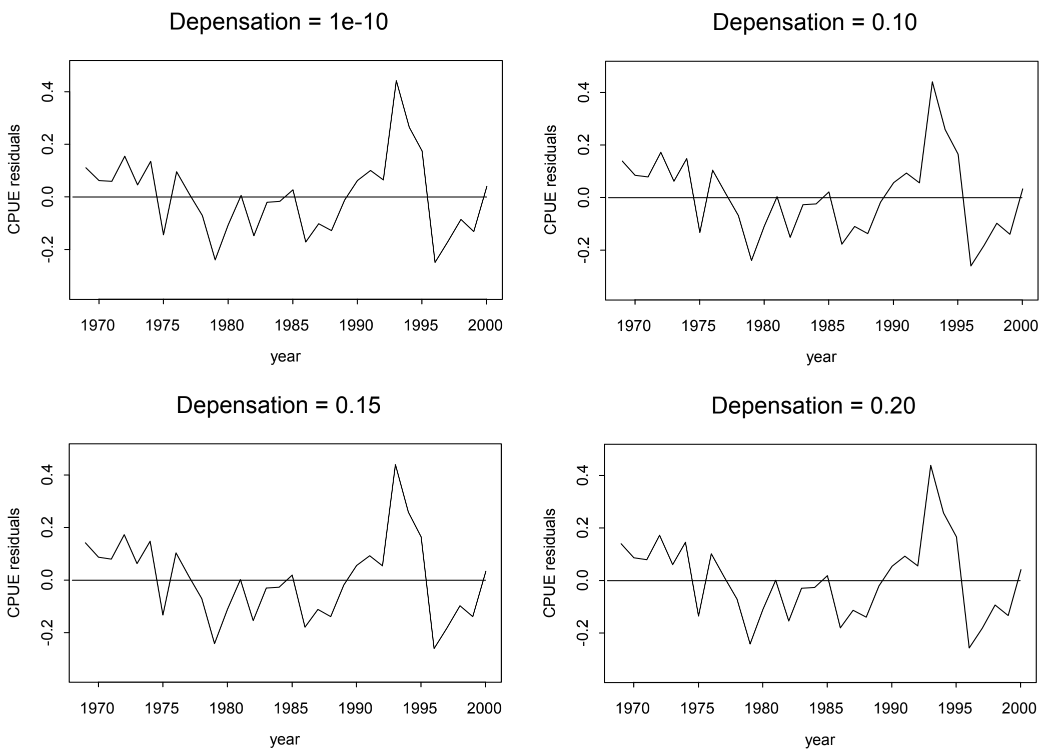


Figure 32: Time trends in the residuals in the fit to the longline CPUE index for four different values for the depensation parameter in the stock recruitment curve with steepness being fitted and the remaining parameters as per the specifications for the initial operating models.

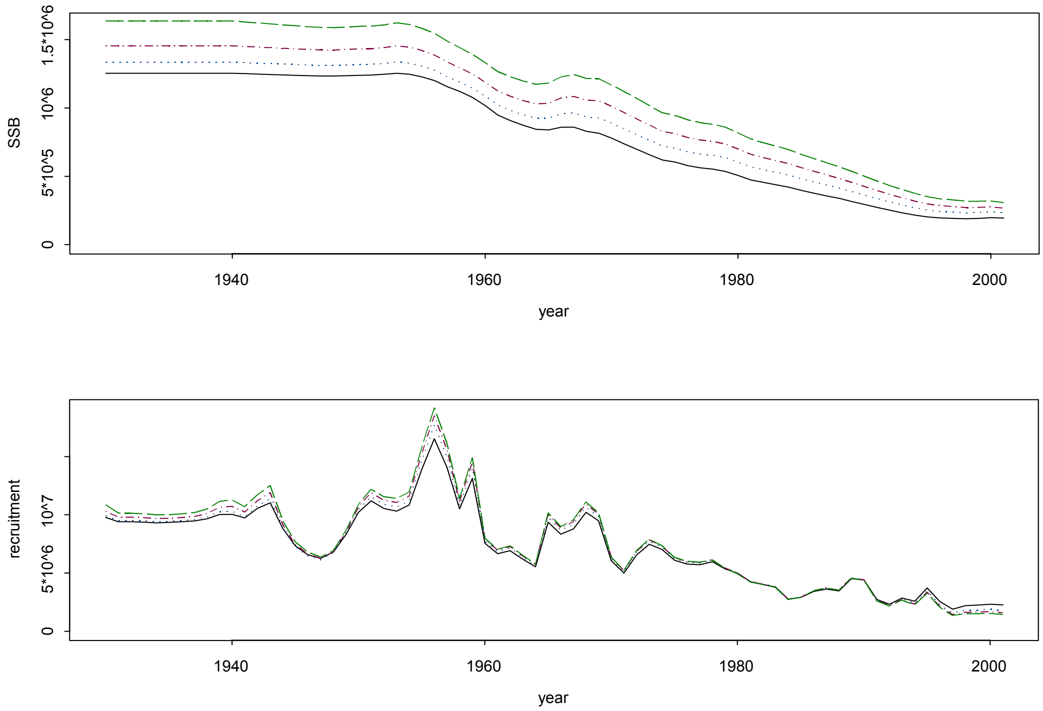


Figure 33: Comparison of estimate time trends in recruitment and spawning stock biomass for four different values for the depensation parameter in the stock recruitment curve (1e-10 – solid line, 0.10 - dotted line, 0.15 – dash line and 0.20 dash-dot line) with steepness fixed at 0.30 and the remaining parameters as per the specifications for the initial operating models.

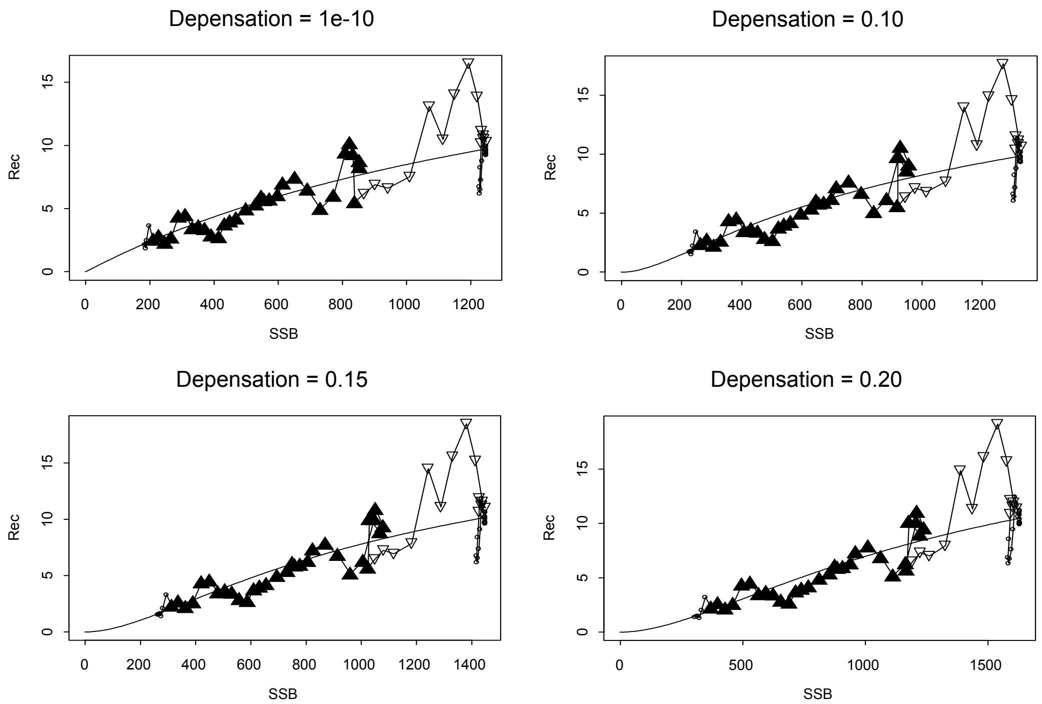


Figure 34: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function for four different natural mortality with steepness fixed at 0.30 and the remaining parameters as per the specifications for the initial operating models.

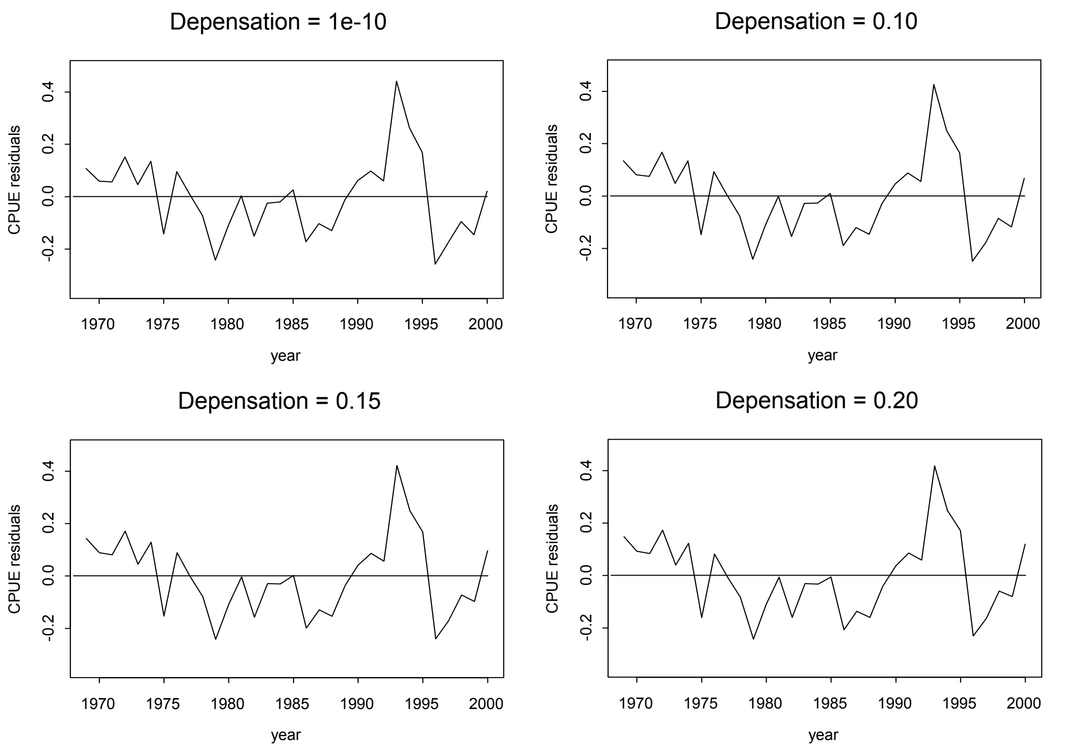


Figure 35: Time trends in the residuals in the fit to the longline CPUE index for four different values for the depensation parameter in the stock recruitment curve with steepness fixed at 0.30 and the remaining parameters as per the specifications for the initial operating models

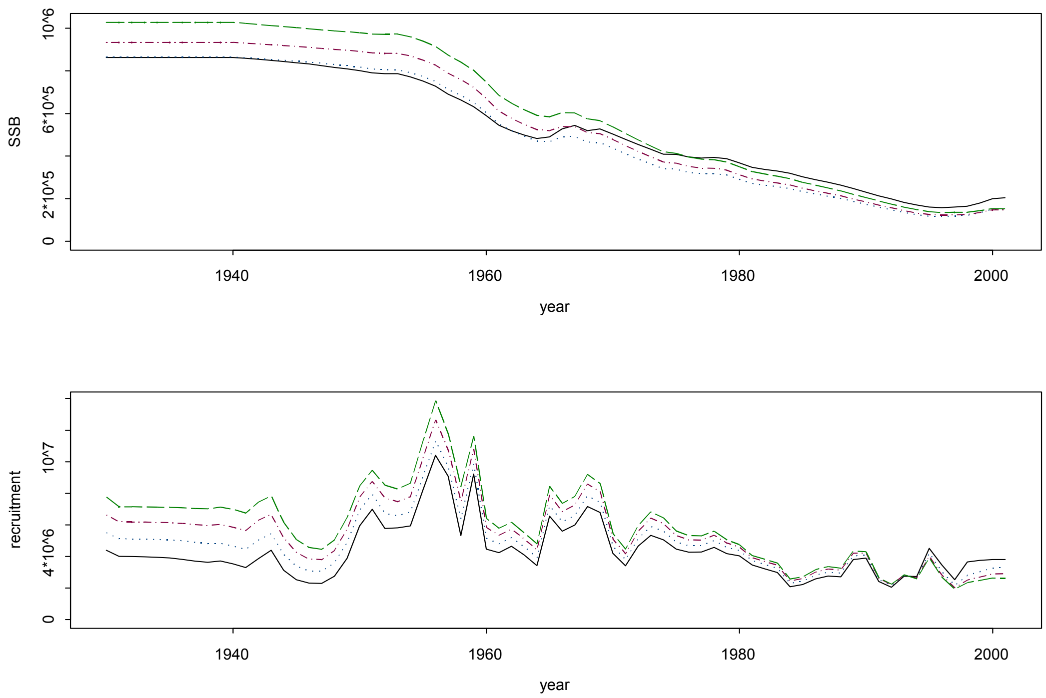


Figure 36: Comparison of estimate time trends in recruitment and spawning stock biomass for four different values for the depensation parameter in the stock recruitment curve (1e-10 – solid line, 0.10 - dotted line, 0.15 – dash line and 0.20 dash-dot line) with steepness fixed at 0.90 and the remaining parameters as per the specifications for the initial operating models.

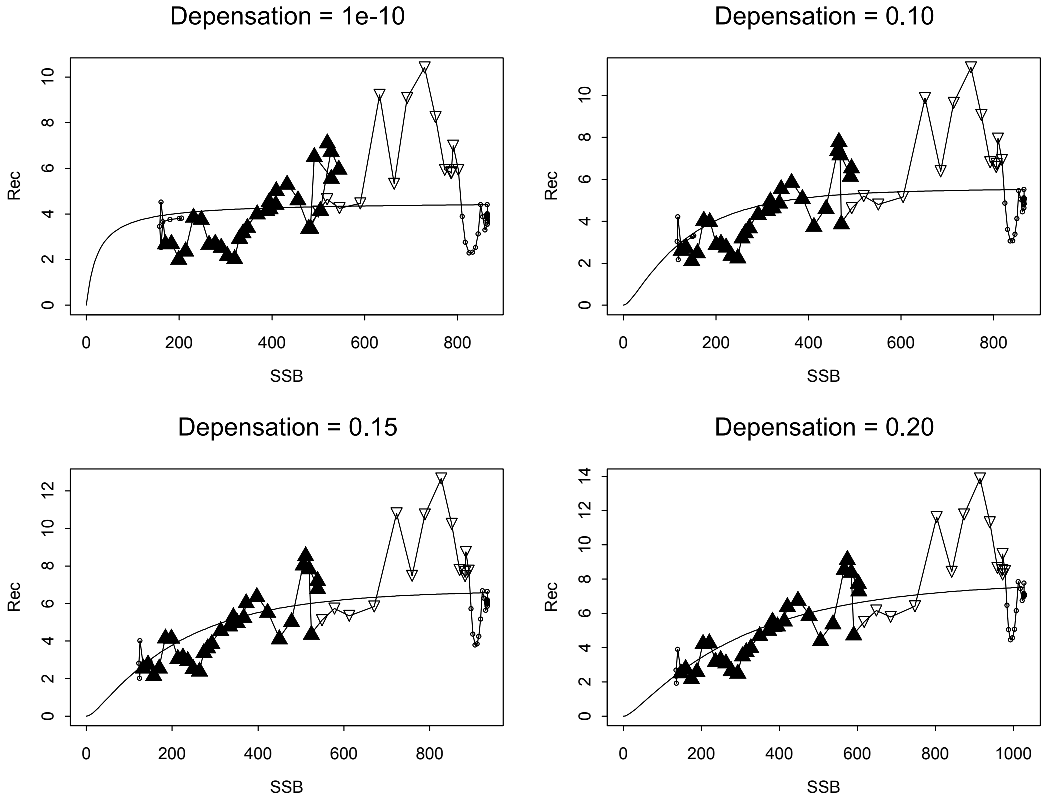


Figure 37: Comparison of estimate time trends in recruitment and spawning stock biomass for four different values for the depensation parameter in the stock recruitment curve with steepness fixed at 0.90 and the remaining parameters as per the specifications for the initial operating models.

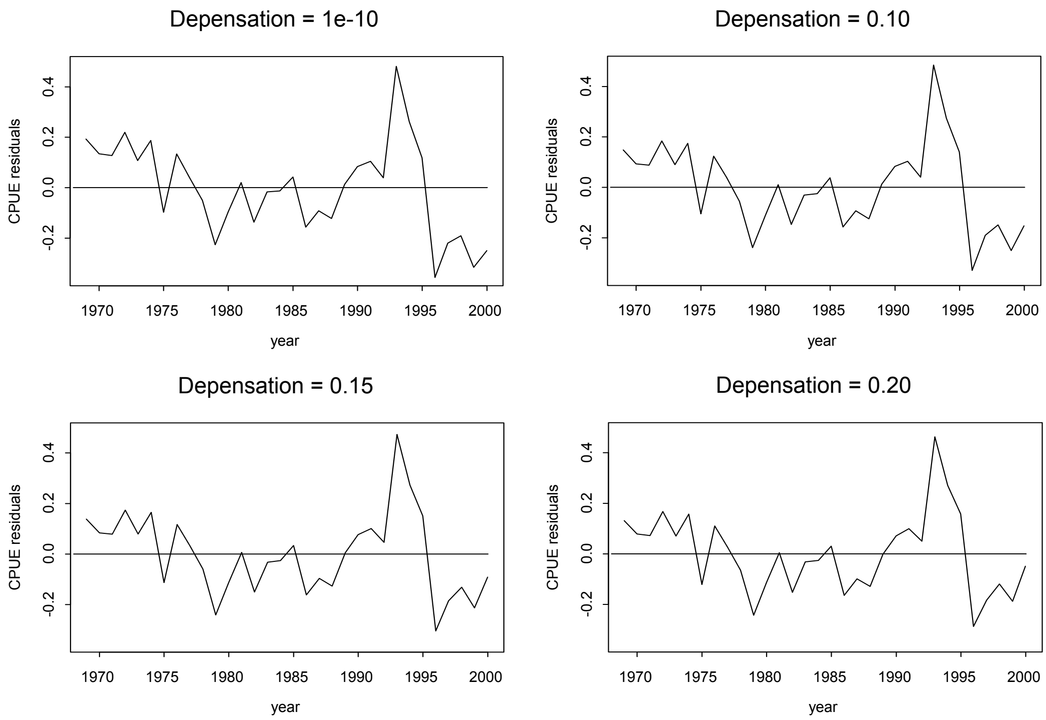


Figure 38:Time trends in the residuals in the fit to the longline CPUE index for four different values for the depensation parameter in the stock recruitment curve with steepness fixed at 0.90 and the remaining parameters as per the specifications for the initial operating models.

Natural Mortality

The default operating model specifications have M_0 as an estimable parameter and with of M_{10} being specified at 0.10. The estimate of M_0 is inversely related to the value of steepness (Table 29). When steepness is fixed at 0.90, the resulting estimate of M_0 appears low relative to estimates that have been generated from multi-year tagging experiments (which are independent of any assumed stock and recruitment relation). In order to explore the sensitivity of the operating model to different age-specific natural mortality rate vectors, the three age-specific natural mortality vectors used in recent SBT assessment were used in fitting the operating model. Results are presented in Figures 38-43 and Tables 30-31. When steepness is fixed at 0.30, the differences in value of the objective function for the different M vectors and in the case where M is fitted are small as are the estimates of SSB and recruitment. When steepness is fixed at 0.90, however, substantial differences occur and the fit in terms of the value of the objective function is substantially poorer for the M vector cases, particularly for M vectors 1 and 2.

Table 29: Fitted values of M_0 when steepness is fixed at different values.

Steepness	Fitted value of M_0
0.30	0.31
0.60	0.28
0.90	0.24
Fitted (0.28)	0.31

Table 30: Minimum value for the best fit to the objective function and its various components for different natural mortality vectors compared to when M is fitted when steepness is fixed at 0.30.

M	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
Fitted	259.14	41.90	606.35	210.56	42.22	108.65	-45.46	13.93	42.43	57.47	-75.67	0.18	0.00	1261.70
vec. 1	259.67	42.21	606.06	212.70	42.91	109.12	-44.98	14.15	41.90	59.18	-76.16	0.00	0.00	1266.75
vec. 2	259.29	42.06	606.66	210.71	42.26	109.30	-45.58	13.80	42.50	58.39	-76.26	0.00	0.00	1263.14
vec. 3	258.97	41.91	606.82	209.70	41.85	109.07	-44.52	14.29	42.95	57.56	-74.86	0.00	0.00	1263.75

Table 31: Minimum value for the best fit to the objective function and its various components for different natural mortality vectors compared to when M is fitted when steepness is fixed at 0.90.

M	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
Fitted	255.19	42.64	595.39	207.36	41.12	105.58	-38.92	13.33	43.32	56.52	-40.27	0.57	0	1281.84
vec. 1	254.17	43.07	590.77	205.30	42.33	106.48	-43.45	15.40	42.35	58.79	-19.92	0.00	0	1295.27
vec. 2	254.66	42.97	592.63	206.44	41.73	106.49	-42.46	13.50	42.71	58.05	-30.36	0.00	0	1286.36
vec. 3	255.16	42.80	594.38	207.09	41.34	106.25	-40.49	13.24	43.12	57.20	-36.73	0.00	0	1283.36

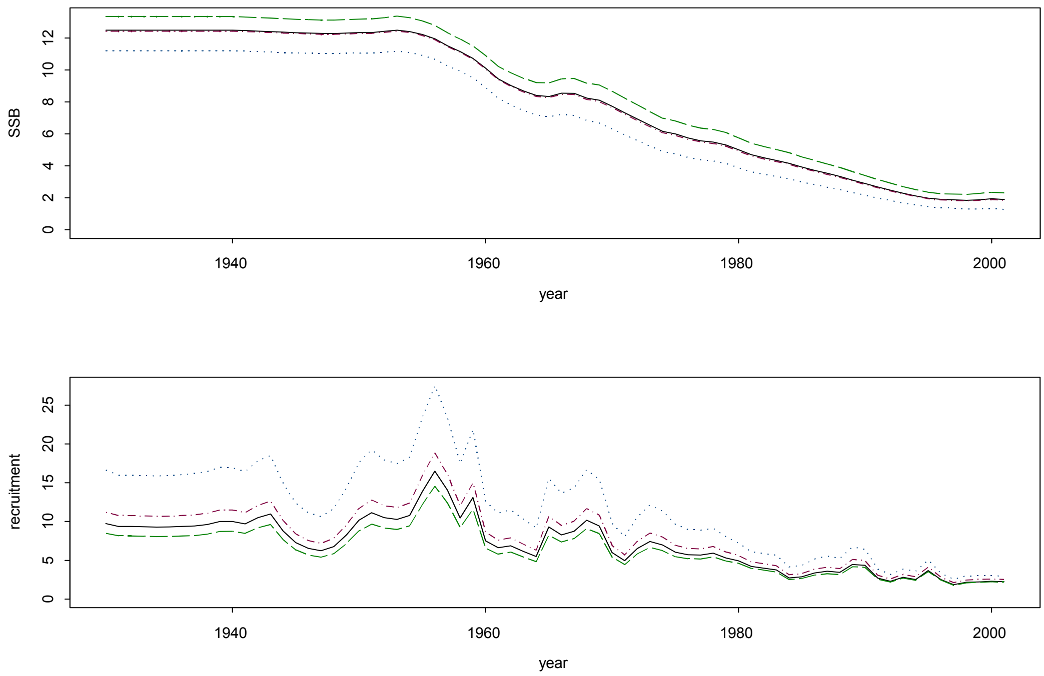


Figure 38: Comparison of estimate time trends in recruitment and spawning stock biomass for four different natural mortality vectors (M$_0$ fitted (base specification) – solid line, 0.10, M vector 1 - dotted line, M vector 2 – dash line and M vector 3 - dash-dot line) with steepness fixed at 0.30 and the remaining parameters as per the specifications for the initial operating models.

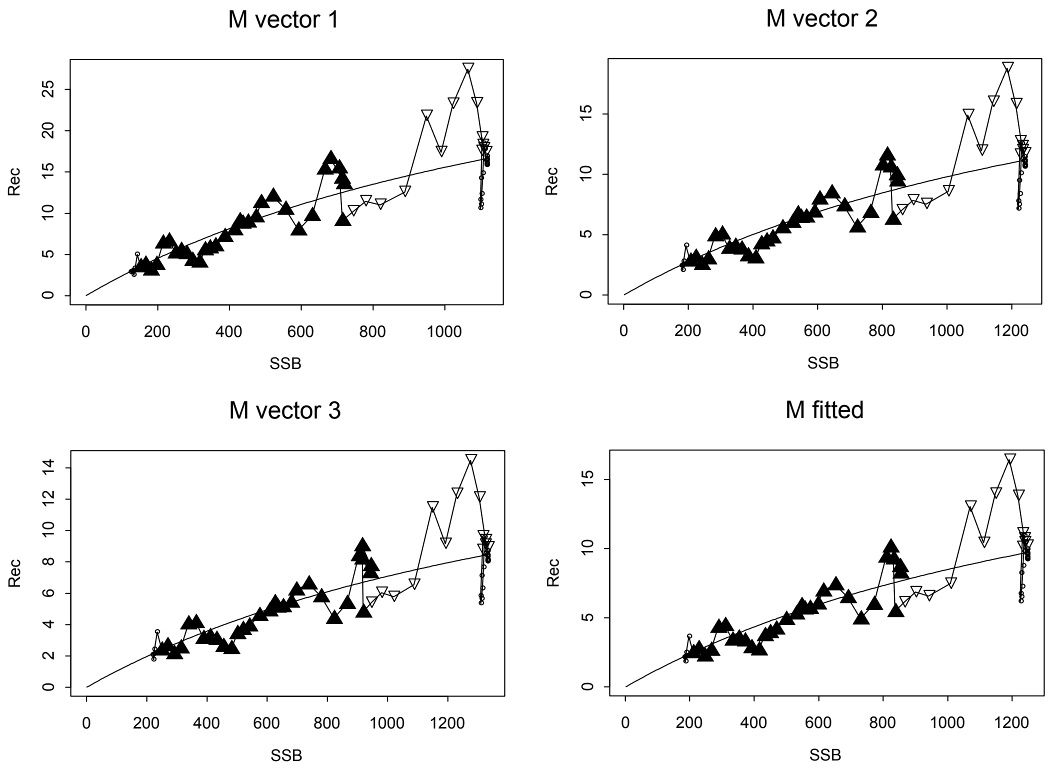


Figure 39: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function for four different natural mortality with steepness fixed at 0.30 and the remaining parameters as per the specifications for the initial operating models.

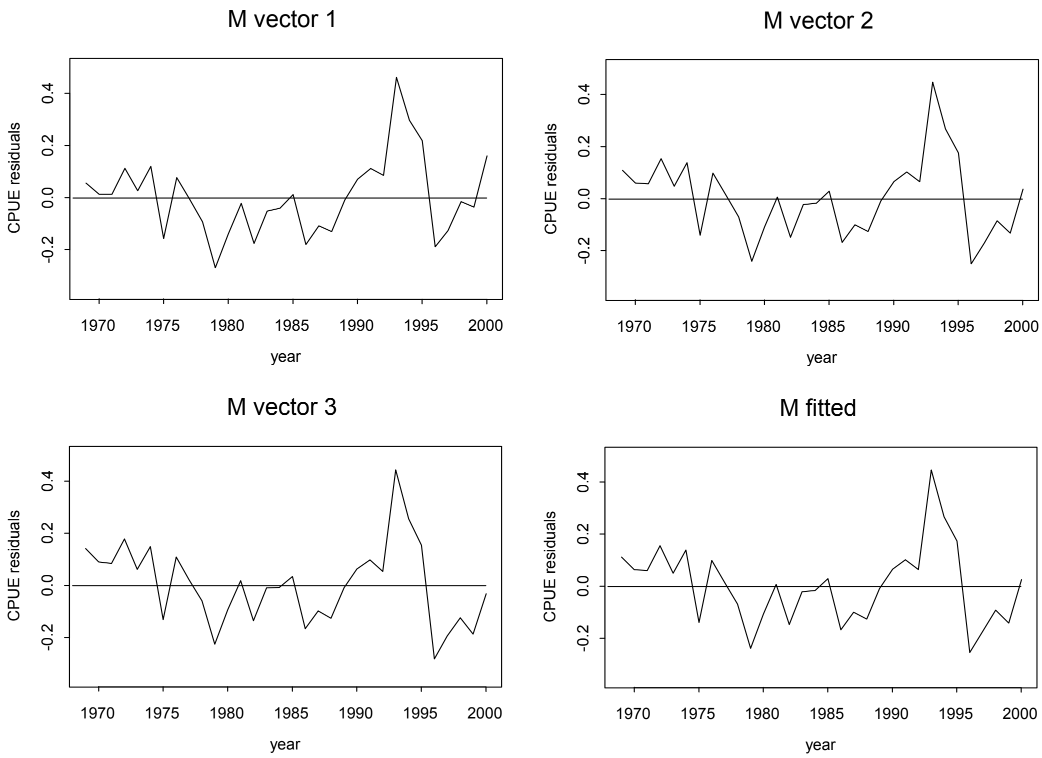


Figure 40:Time trends in the residuals in the fit to the longline CPUE index for four different natural mortality with steepness fixed at 0.30 and the remaining parameters as per the specifications for the initial operating models.

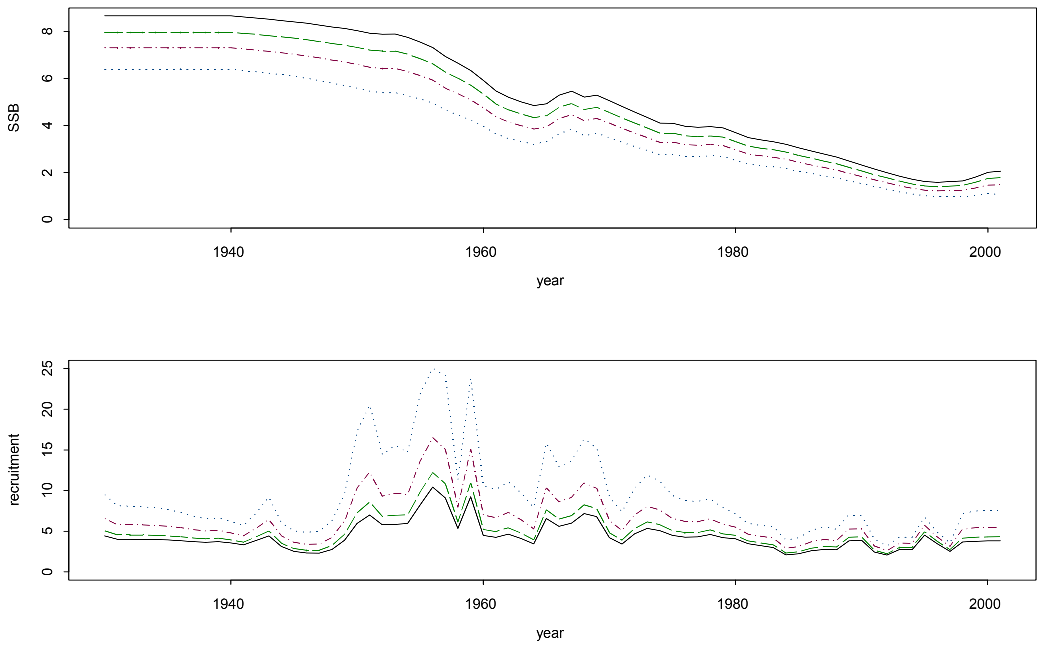


Figure 41: Comparison of estimate time trends in recruitment and spawning stock biomass for four different natural mortality vectors   (M_0 fitted (base specification) – solid line, 0.10, M vector 1 - dotted line, M vector 2 – dash line and M vector 3 - dash-dot line) with steepness fixed at 0.90 and the remaining parameters as per the specifications for the initial operating models.

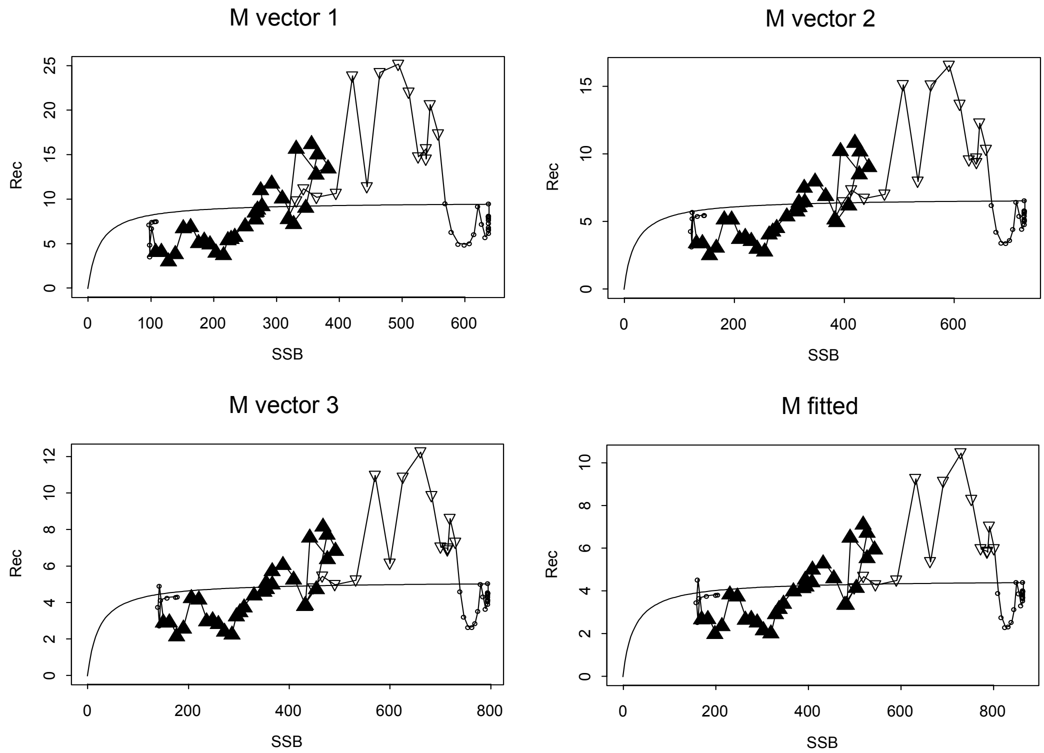


Figure 42: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function for four different natural mortality with steepness fixed at 0.90 and the remaining parameters as per the specifications for the initial operating models.

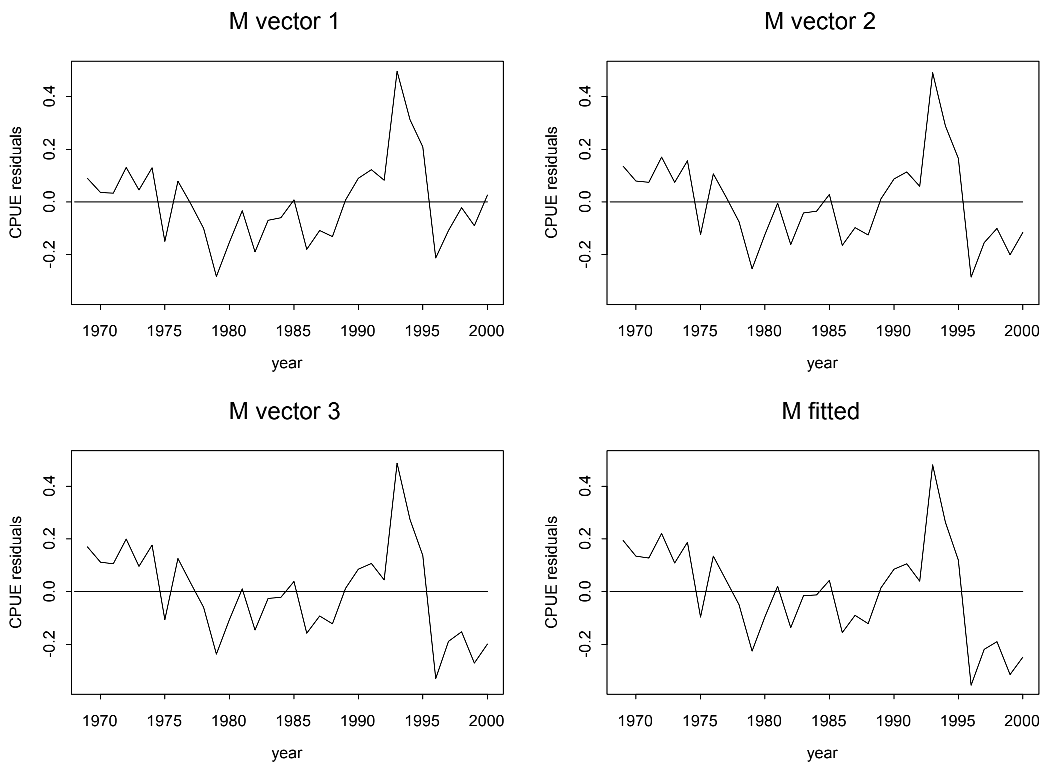


Figure 43: Time trends in the residuals in the fit to the longline CPUE indexfor four different natural mortality with steepness fixed at 0.90 and the remaining parameters as per the specifications for the initial operating models.

Smoothness weights and Second Differencing

The form of smoothing (over ages) for the selectivity function, and the weight given to try to ensure smoothness in the selectivity function were explored. Second differencing was only considered for longline fisheries 1, 3, 4 and 5 since the other two fishery components would appear to require some type of dome shaped selectivity relationship. Results are presented in Tables 32-34 and Figures 44-46. Second or third differencing had minimal effect on the estimated time trends of SSB and recruitment as long as the default smoothness penalty was used, although third differencing yields a substantially lower value for the objective function. Similarly, increasing the weight to the selectivity smoothness term had little effect on the estimated trends. However, the combination of introducing second differencing and increasing the weight on the penalty function had significant effects (Figure 46).

Table 32: Minimum value for the best fit to the objective function and its various components when 2nd or 3rd differencing is use for the selectivity function for longline fisheries 1, 3, 4 and 5.

Differenc.	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
2nd	270.22	41.72	610.23	208.95	42.16	108.38	-44.60	14.02	40.42	102.14	-75.23	0.38	4.04	1322.83
3rd	259.02	41.87	606.86	210.15	42.33	108.76	-45.69	14.00	42.52	57.46	-76.25	0.18	3.09	1264.29

Table 33: Minimum value for the best fit to the objective function and its various components for different weights given to the selectivity smoothness term (i.e. sigma smoothness).

Sigma smoothness.	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
0.30	259.02	41.87	606.86	210.15	42.33	108.76	-45.69	14.00	42.52	57.46	-76.25	0.18	3.09	1264.29
0.15	279.67	48.23	615.65	210.14	45.80	147.90	-45.43	13.80	42.16	59.88	-74.78	0.22	3.25	1346.49
0.05	343.39	51.38	641.89	212.90	51.96	175.65	-43.76	14.29	40.28	60.42	-69.50	0.30	3.80	1483.01

Table 34: Minimum value for the best fit to the objective function and its various components when 2nd or 3rd differencing is use for the selectivity function for longline fisheries 1, 3, 4 and 5 with increased weight given to the selectivity smoothness term (i.e. sigma smoothness decreased from 0.30 to 0.05).

Differenc.	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
2nd	468.80	50.76	696.80	223.42	59.24	175.99	-35.22	17.19	29.15	328.05	-22.60	0.89	0.00	1992.45
3rd	343.39	51.38	641.89	212.90	51.96	175.65	-43.76	14.29	40.28	60.42	-69.50	0.30	3.80	1483.01

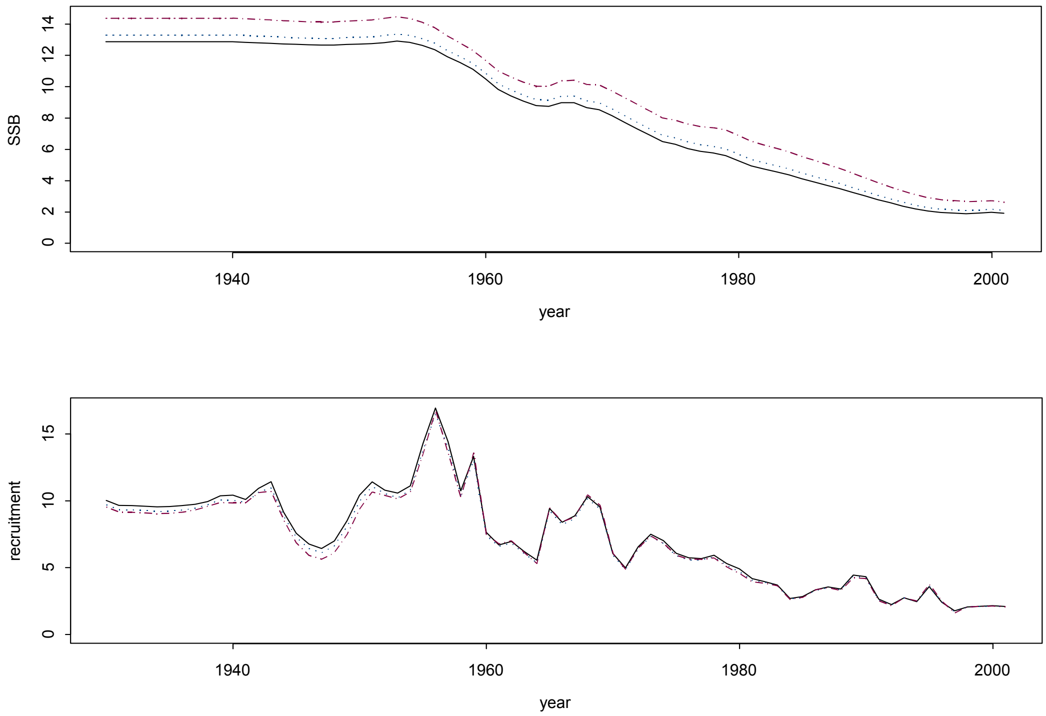


Figure 44: Comparison of estimate time trends in recruitment and spawning stock biomass for three different values for sigma smoothness (0.30 – solid line, 0.15- dotted line and 0.05 – dash line).

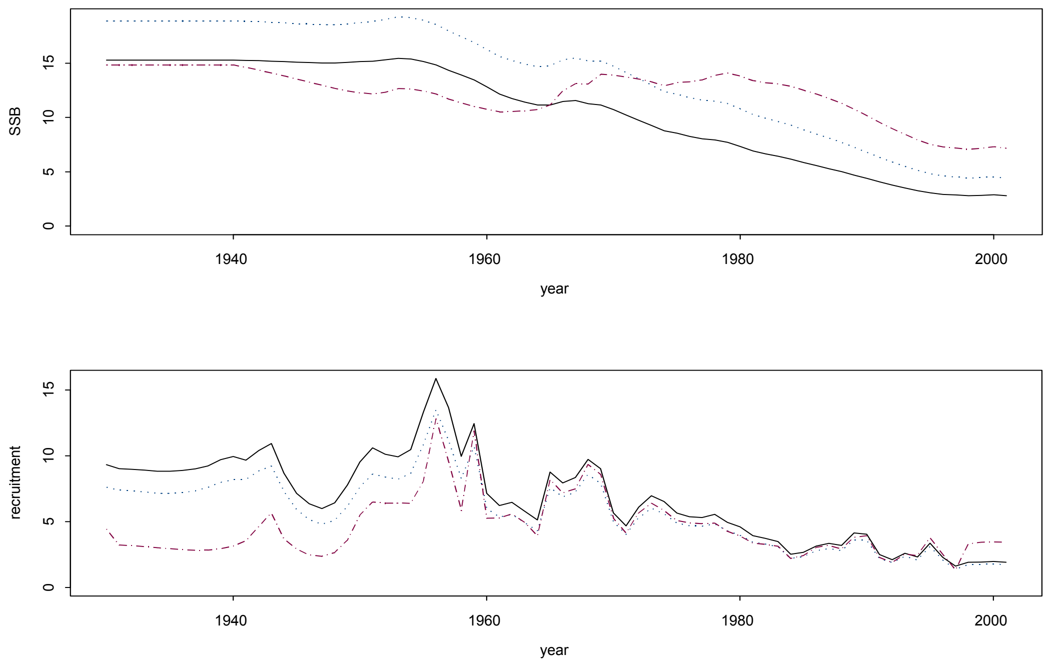


Figure 45: Comparison of estimate time trends in recruitment and spawning stock biomass with second differencing and with three different values for sigma smoothness (0.30 – solid line, 0.15- dotted line and 0.05 – dash line).

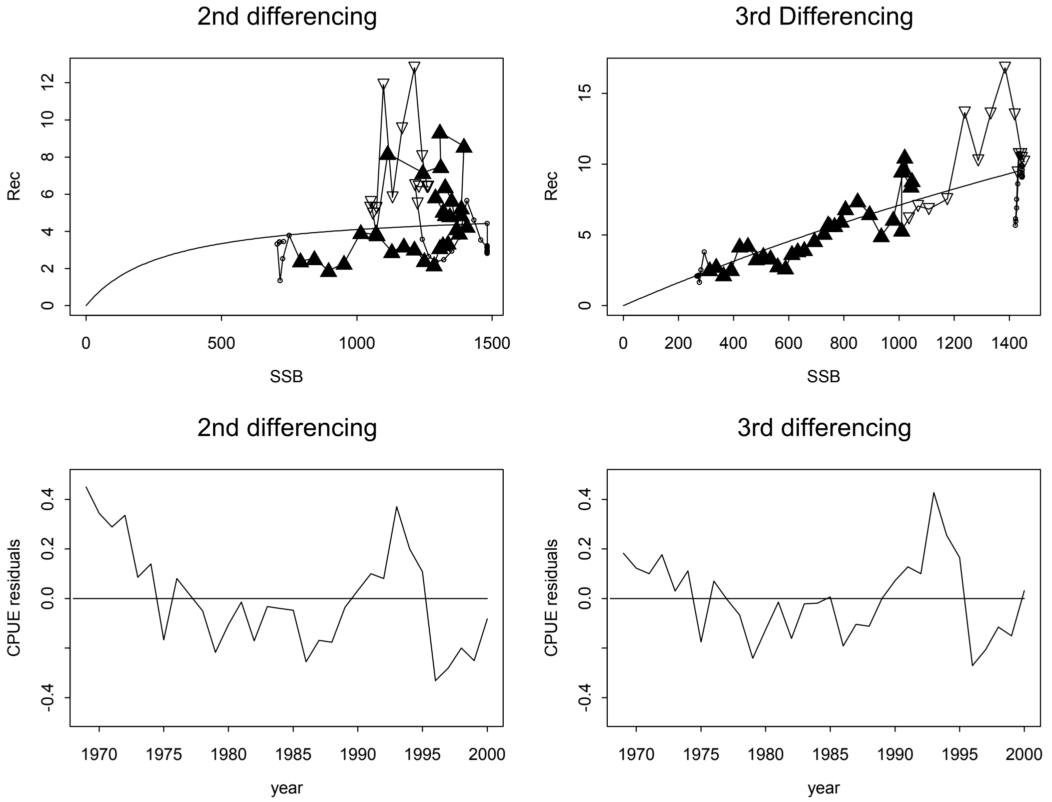


Figure 46: Comparison of fitted stock and recruitment relationship and temporal trends in the residual to the CPUE index with second and third differencing and with sigma smoothness equal to 0.05

Frequency of Selectivity Changes

The frequency with which selectivity changes are allowed to occur was explored minimally. Results are presented which allowed changes in selectivity in longline fisheries 3 and 4 in 1957, 1961 and 1965. Table 36 provides the resulting value for the objective function. (Note that inadvertently the change in selectivity in 1974 for longline fishery 3 in the base case was omitted in this case which is the reason why the value of the objective function for LL3 increases). Figures 47 and 48 show the resulting trends in the estimates of SSB, recruitment and CPUE residuals. Interestingly, allowing for changes in selectivity in the early years of the longline fishery in these two fisheries increased the estimate of steepness from 0.28 to 0.38.

Table 36: Minimum value for the best fit to the objective function and its various components when changes were made to the frequency of selectivity changes for longline fisheris 3 and 4.

Select. Changes	LL1	LL2	LL3	LL4	IND	SURF	CPUE	Tags	Sel.Ch	Sel.sm	Sg.R	M.0.	Steep	Total
Base	259.02	41.87	606.86	210.15	42.33	108.76	-45.69	14.00	42.52	57.46	-76.25	0.18	3.09	1264.29
Increased	261.77	41.55	662.26	171.32	41.82	108.20	-44.22	13.95	76.72	66.10	-69.00	0.21	1.37	1332.07

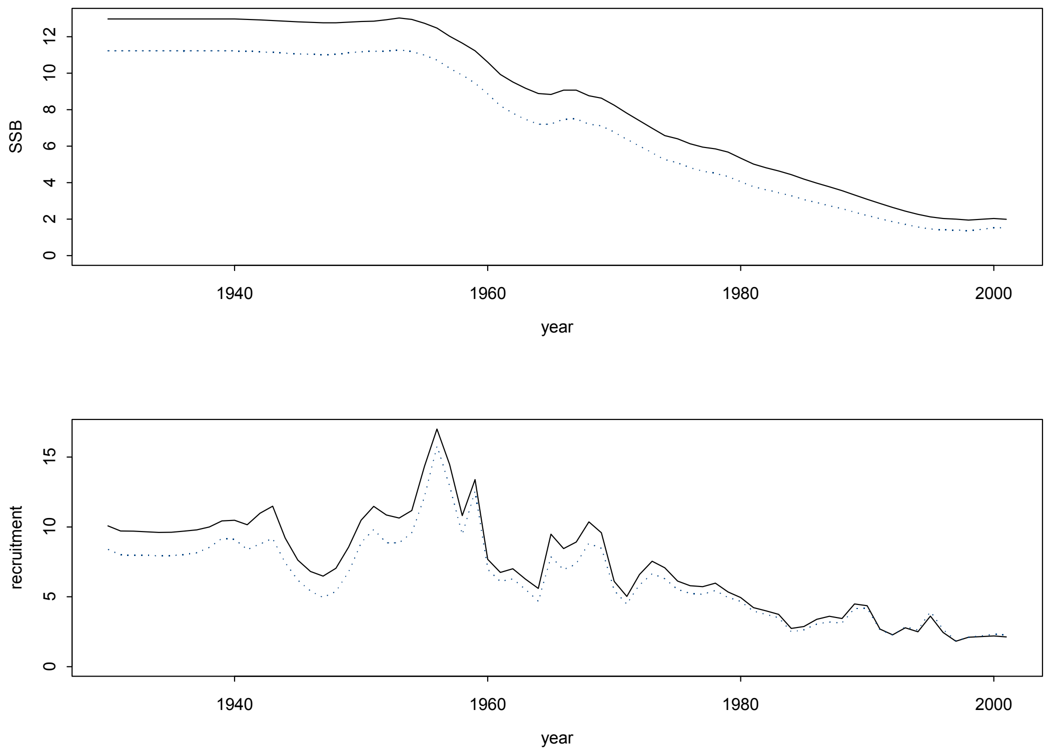


Figure 47: Comparison of estimate time trends in recruitment and spawning stock biomass with increased frequency initially in the selectivity change for longline fisheries 3 and 4 (base specification – solid line, increased frequency - dotted line) and the remaining parameters as per the specifications for the initial operating models.

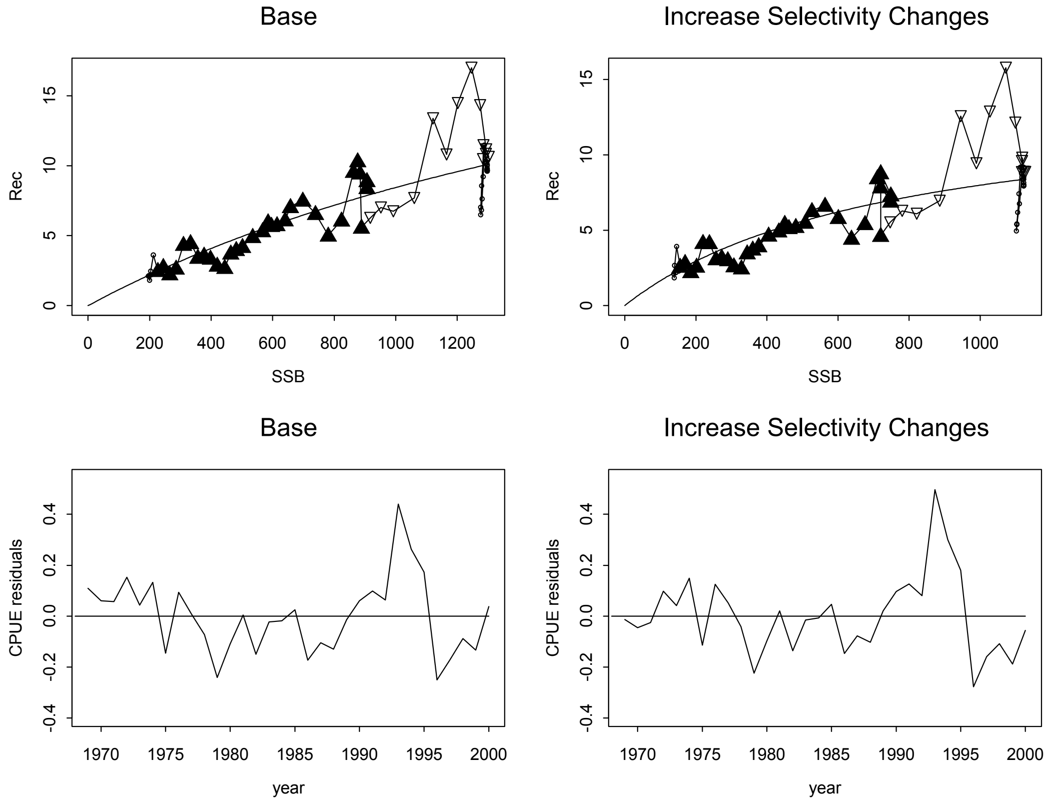


Figure 48: Comparison of the estimates of recruitment and SSB with the estimated stock and recruitment function and temporal trends in the residuals to the CPUE index with increased frequency initially in the selectivity change for longline fisheries 3 and 4 and the remaining parameters as per the specifications for the initial operating models.

Concluding Remarks

The exploration of the updated operating model for use in the development of a management procedure for SBT indicates that a number of outstanding issues need to be addressed in the conditioning process in order to ensure that the set of scenarios selected for the final trials provide an adequate and balanced representation of the underlying uncertainty. In some cases, conditioning results can be sensitive to parameter settings for which there is little basis for selecting an appropriate value (e.g. effective sample sizes). In others cases, a range of alternative hypothesis seem nearly equally consistent with the historic data and yet may have large implications for projections and the performance of a management procedure (e.g. depensation, functional relationship between CPUE and abundance). Conditioning results and estimates of steepness are sensitive to assumptions about and the modelling of the length frequency data from the early years of the longline fishery. Further consideration is needed about what are appropriate levels of steepness and natural mortality vectors for inclusion in the final trials - in particular, whether high steepness values without either associated high levels of autocorrelation in recruitment or depensation are consistent with the historical data. In addition, the selection of final trials needs to capture the underlying uncertainty about effective sample sizes, depensation in the stock recruitment function, the functional relationship between CPUE and variability in selectivity. The potential number of scenarios needed to capture the uncertainty in all of these factors could be quite large, which makes it unlikely that a full assessment of the performance of a management procedure across the full uncertainty (including interactions) would be feasible. Instead, a selection process will be required to ensure that the evaluation process of candidate management procedures is reliable and robust. This in turn will depend in part on the approach adopted for synthesizing simulation results across different operating model scenarios (see Polacheck and Kolody 2003).

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