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Stock Assessment for South East and Southern Shark Fishery Species

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Cover photographs

Front cover, top from left: jackass morwong, blue warehou, pink ling, tiger flathead, blue grenadier (on table)
Back cover: tiger flathead (top and bottom) and jackass morwong (centre)

Stock Assessment for South East and Southern Shark Fishery Species

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2001/005 Stock Assessment for South East and Southern Shark Fishery Species

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OBJECTIVES:

- Provide new or updated quantitative assessments for SEF species based on SEFAG priorities
- Provide new or updated quantitative assessments for southern shark species based on SharkFAG priorities

1.1 Outcomes Achieved

The 2003/2004 assessment of stock status of the key South East and Southern Shark fishery species is based on the methodologies presented in this report. Documented are the latest quantitative assessments for five of the key non-shark quota species and three of the major shark species. Typical assessment results provide indications of current stock status, in addition to risk assessments that allow an evaluation of future impacts under different catch strategies and biological scenarios. These assessment outputs are a critical component of the management and TAC setting process for these fisheries. The results from these studies are being used by SEFAG, industry and management to help manage the fishery in accordance with agreed sustainability objectives.

Blue grenadier

Blue grenadier (*Macruronus novaezelandiae*) are found from New South Wales around southern Australia to Western Australia, including the coast of Tasmania. Blue grenadier are caught by demersal trawling. The global agreed TAC in 2004 was 7000 tonnes, down from 9000 t in 2003 and 10000 t the previous year, the level at which it had been since 1994. There are two defined sub-fisheries: the winter spawning fishery off Tasmania and the non-spawning fishery (all other areas and times). The non-spawning fishery catches have been relatively poor over the last few years, whereas the spawning fishery catches have shown a marked increase since the mid-1990s.

The 2004 assessment of blue grenadier uses the age-structured Integrated Analysis model developed during 1998 and 1999. In addition, results from an acoustic survey of spawning biomass, preliminary models of future cyclic recruitment and step-down TACs were considered. The model uses catch (including discards), standardised catch rates and catch-at-age data as well as estimates of absolute abundance based on the egg production method and, as a sensitivity, acoustic biomass estimates. A risk analysis evaluates the consequences of different future levels of harvest by the spawning/non-spawning fisheries.

Overall, results of the 2004 assessment are less optimistic than that conducted in 2003, continuing the trend seen in recent years, primarily due to continuing poor recent recruitment. The cohorts spawned in 1994 and 1995 are estimated to be roughly 6 and 4 times the size predicted by the deterministic stock-recruit relationship respectively. Recruitment appears cyclic, with no indication of good or even average recruitment since 1996. Results from a risk analysis indicate that for all scenarios, there is a very high probability that the spawning biomass will reduce below 40% of the reference spawning biomass over the next 5 years due to the effects of poor recent recruitment. In addition, preliminary models of future cyclic recruitment indicate that the spawner biomass may continue to decline beyond that predicted by the base-case model.

Blue warehou
In contrast to previous stock assessments, the present stock assessment of blue warehou (*Seriolella brama*) is based on there being two stocks off southern Australia (east and west of Bass Strait). This change in assessment assumption was made based on evidence from a variety of methods of identifying stock structure. The stock assessment is based on an age-structured population dynamics model fitted to data on catches, catch-rates, discard rates, age-length keys and length-frequency. The assessment of the stock to the west of Bass Strait is based on a single trawl fishery while that of the stock to the east of Bass Strait is based on three fleets (trawl, non-trawl and Tasmanian meshnet). Uncertainty is quantified by conducting analyses for two definitions for the year (calendar and biological), by changing the assumptions of the assessment (including omitting some of data sources), and by constructing Bayesian posterior distributions for some of the key model outputs.

The spawning biomass for both stocks (west and east) is presently a small fraction of the highest spawning biomass over the period since 1985/86. Although unsustainable fishing is a cause of the decline in spawning biomass, the primary cause may have been a lack of strong year-classes after 1986. The results of the assessment provide a basis for evaluating the consequences of future levels of catch. The projections suggest that increased catches to the east of Bass Strait are sustainable while the implications of different levels of future catch for the stock to the west of Bass Strait are highly uncertain. The results for the eastern stock, however, depend critically on whether estimates of recent strong recruitment are reliable. Unfortunately, a) there is no catch-rate index for 2003 so all inferences regarding the strength of recent recruitments are based on fits to the age-composition data, the sample sizes for which are relatively small for recent years, and b) previous assessments have estimated recruitment for the most recent years of the assessment period to be high but this has subsequently been found not to be the case.

Gummy shark

The assessment of gummy shark (*Mustelus antarcticus* Günther) is based on an age- and sex-structured population dynamics model tailored to the specifics of a shark species. The model accounts for the nature of the pupping process and explicitly includes five gear-types (four mesh sizes of gillnets and longlines). The model is applied assuming that there are separate populations of gummy shark in Bass Strait and off South Australia. Evidence in support this assumption include operational and biological factors. Although gummy shark are harvested off Tasmania, no attempt is made to assess the status of the populations of gummy shark in this area owing to lack of data. The free parameters of the assessment model are the sizes of each population at the start of 1927, the annual deviations in pup survival, natural mortality, and parameters related to density-dependence and availability.

The major difference between the present assessment and that of Pribac *et al.* (in press) is that the latter assessment based the estimates of some key population dynamics parameters on the data for Bass Strait only and then assumed that the "best" estimates of these quantities also apply to gummy shark off South Australia, when conducting assessments of gummy shark off South Australia. In contrast, the present assessment is based on analyzing the data for Bass Strait and South Australia simultaneously.

The populations of gummy shark in Bass Strait and off South Australia are both estimated to be currently slightly above the proxy for the level at which *MSY* would be achieved, and recruitment to the fisheries in Bass Strait is estimated to better than expected given the number of maternal females, while that off South Australia has generally been poorer than expected. However, although this qualitative appraisal of the status of the populations is robust to the specifications of the assessment, this is not the case for the actual quantitative results. In particular, the results are very sensitive to assumptions about density-dependent processes, and the extent to which gummy sharks are unavailable to the fishing gear. Furthermore, two of the key data sources included in the assessment (the tagging and length-frequency data) appear to be in conflict to some extent.

Jackass morwong

The 2004 assessment of jackass morwong (*Nemadactylus macropterus*) uses a generalised age-structured modelling approach to assess the status and trends of the jackass morwong trawl fishery in the eastern zones, using data from the period 1915-2002. Although data are provided for the western areas of the SEF, these data were not included in the assessment, as it is not clear these landings are from the same stock as that from which the landings in the east are taken. However, as landings from western Victoria in particular have become a substantial component of the annual total, determining the relatedness of fish in western areas to those caught in eastern zones should be a priority

Catches of jackass morwong rose to a peak of 1,600 t in 1989. They have since dropped, but have remained relatively stable at between 700 and 1,000 t. Since 1989, the mean unstandardised catch rate of jackass morwong has continued to decline and it has triggered AFMA's catch rate performance criterion since 1996. Catch rates dropped further in 2002 to a record low. The negative trends in the CPUE data occur during a period where catches are much lower than previously in the history of the fishery and there are no obvious trends in the age- or length-composition data. The population model attempts to reconcile these pieces of information by estimating that annual recruitments have largely been below average since the mid-1980s, thus enabling the stock to continue to decline even though removals are low.

Results indicate that jackass morwong in the eastern areas appear to be somewhere around 25-45% of 1915 spawning biomass. The projection results presented would indicate that, given the assumptions in the base-case scenario, current removals from the eastern areas are perhaps sustainable. The sensitivity analyses which provided a more pessimistic prediction of 2003 stock status unsurprisingly suggest that a lower TAC than that suggested by the base-case analysis may be appropriate.

Pink ling
A formal stock assessment of pink ling (*Genypterus blacodes*) was conducted in 2003, in addition to a CPUE standardisation. Trawl CPUE was standardised using a generalised linear model that attempted to take account of the influence of area, season, depth and fishing vessel on catch rates. The data used to calculate the standardised index was also filtered to select catch records from vessels that have fished for ling for more than 2 years, and consistently targeted ling each year. The standardised index was mostly influenced by the filtering, and did not show a declining trend in recent years. The decline shown by the raw CPUE was therefore mostly caused by vessels that did not consistently fish for ling. It was not clear whether the catch rates from those opportunistic vessels might provide an important indicator of ling abundance.

Two different stock assessments were produced using integrated analysis – one using raw CPUE and the other using standardised CPUE. The current proportion of spawning stock biomass relative to virgin levels was estimated to be 34% for the assessment using raw CPUE, and 56% for standardised CPUE. Simple deterministic projections to 2020 using the current selectivity pattern for raw CPUE showed that a catch of 1600 t (current catch levels) is not sustainable, while the results for standardised CPUE showed that this catch is sustainable. Both assessments showed that a catch of 1,200 t was sustainable, while 2,000 t was not.

Sawshark and elephantfish
Sawshark (*Pristiophorus cirratus* and *P. nudipinnis*) and elephantfish (*Callorhinchus milii*) are the major byproduct species of the directed shark fishery and substantial quantities of these species are also taken by trawl. Formal quantitative stock assessments of these species have not been undertaken before. Initial assessments of these species in Bass Strait are undertaken by fitting an age- and sex-structured population dynamics model to catch, catch-rate and length-frequency data. The basic approach is therefore similar to that applied for the assessment of gummy shark. However, owing to the lack of data, the results are much more uncertain than those for gummy shark, and it was not possible to explore as wide a range of scenarios as was the case for gummy shark.

The results of the assessments suggest that both sawshark and elephantfish are depleted to below 40% of the 1950 pup production (perhaps substantially so in the case of elephantfish). These results are, however, imprecise, particularly those for sawshark. The analyses suggest that it is possible to conduct assessments of sawshark and elephantfish. However, these analyses also highlight several research topics which, if addressed, could lead to more reliable assessments.

Tiger flathead

The stock assessment of tiger flathead (*Neoplatycephalus richardsoni*) stocks uses a two-sector (otter trawl and Danish seine) age- and length-structured quantitative assessment, and examines the implications of future catch levels on the stock. The assessment uses 89 years (1915-2003) of historical fishing data to estimate the virgin spawning biomass and current relative biomass and provides, for the first time, a complete picture of the dynamics of the tiger flathead fishery.

Historical catch records show that this stock has been exploited mainly off NSW and in eastern Bass Strait for almost 90 years. On several occasions, over that period, catches have exceeded 3,000 t for extended periods, but this has always resulted in subsequent reduced catch rates and reduced catch levels. The 2004 assessment suggests that the current stock size in the historical area of the fishery (NSW, eastern Victoria, and Bass Strait) is well above the limit reference level of 20% of unfished spawning stock size. The assessment also confirms that recent catch levels in excess of 3,000 t, if maintained, would drive the stock down towards this limit level over time. This is consistent with the observation that catch levels in this part of the fishery have averaged 2,400 t over the past 20 years, during which time the stock has remained fairly stable. The longer term sustainable yield for the three zones assessed appears to lie between 2,000 t and 2,500 t.

KEYWORDS: fishery management, south east scalefish and shark fishery, stock assessment, trawl fishery, non-trawl fishery

2. Background

The South East Scalefish and Shark Fishery (SESSF) is a Commonwealth-managed, multi-species and multi-gear fishery that catches over 80 species of commercial value and is the main provider of fresh fish to the Sydney and Melbourne markets. Precursors of this fishery have been operating for more than 85 years. Catches are taken from both inshore and offshore waters, as well as offshore seamounts, and the fishery extends from Fraser Island in Queensland to south west Western Australia.

Management of the SESSF is based on a mixture of input and output controls, with over 20 commercial species or species groups currently under quota management. For the previous South East Fishery (SEF), there were 17 species or species groups managed using TACs. Five of these species had their own species assessment groups (SAGs) – orange roughy (ORAG), eastern gemfish (EGAG), blue grenadier (BGAG), blue warehou (BWAG), and redfish (RAG). The assessment groups comprise scientists, fishers, managers and (sometimes) conservation members, meeting several times in a year, and producing an annual stock assessment report based on quantitative species assessments. In addition to these five key species, quantitative assessments for several additional species each year were also conducted. Species for which such assessments have been conducted recently include school whiting, pink ling and spotted warehou. The previous Southern Shark Fishery (SSF), with its own assessment group (SharkFAG), harvested two main species (gummy and school shark), but with significant catches of saw shark and elephantfish.

In 2003, these assessment groups were restructured and their terms of reference redefined. Part of the rationale for the amalgamation of the previous separately managed fisheries was to move towards a more ecosystem-based system of fishery management (EBFM) for this suite of fisheries, which overlap in area and exploit a common set of species. The restructure of the assessment groups was undertaken to better reflect the ecological system on which the fishery rests. To that end, the assessment group structure now comprises:

- SESSFAG (an umbrella assessment group for the whole SESSF)
- Shelf Assessment Group (SHAG)
- Slope Assessment Group (SLAG)
- Deepwater Assessment Group (DAG)
- Shark Assessment Group (SAG)

Each of the three depth-related assessment groups (SHAG, SLAG and DAG) is responsible for undertaking stock assessments for a suite of key species, and for reporting on the status of those species to SESSFAG. The SAG is responsible for assessments of all chondrychthian species.

The plan for the four assessment groups (SHAG, SLAG, SAG and DAG) is to focus on suites of species, rather than on each species in isolation, which has tended to be the practice to date. The new approach has helped to identify common factors affecting these species (such as environmental conditions), as well as consideration of marketing and management factors on key indicators such as catch rates. Assessments are also identifying where catches of two species are inversely related due to targeting.

The quantitative assessments produced annually by the Assessment Groups are a key component of the TAC setting process for the South East Scalefish and Shark Fishery. Prior to this report, the assessments were at a variety of stages of maturity and new species were regularly being added depending on Assessment Group priorities. To support the assessment work of the four Assessment Groups, the aims of the work conducted in this report were to develop new assessments, and update and improve existing ones for priority species in the SESSF.

3. Need

A stock assessment that includes the most up-to-date information and considers a range of hypotheses about the resource dynamics and the associated fisheries is a key need for the management of a resource. In particular, the information contained in a stock assessment is critical for selecting harvest strategies and setting Total Allowable Catches.

There is often a need for calculations to be conducted outside of the formal assessment process to meet management's requirements. A recent example in the South East Fishery was the need to estimate extinction risk for eastern gemfish so that AFMA could address issues raised under endangered species legislation. Having modelers available that are familiar with the key assessments will rapidly facilitate the resolution of such problems. Lack of modeling support was identified as a key threat in the SharkFag budget proposal for 2001/02.

4. Objectives

1. Provide new or updated quantitative assessments for SEF species based on SEFAG priorities.

2. Provide new or updated quantitative assessments for southern shark species based on SharkFAG priorities.

5. Stock assessment for blue grenadier *(Macruronus novaezelandiae)* based on data up to 2003

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5.1 Background

5.1.1 The Fishery

Blue grenadier are found from New South Wales around southern Australia to Western Australia, including the coast of Tasmania. Data support the hypothesis of a single breeding population in Australian waters. Blue grenadier is a moderately long-lived species with a maximum age of about 25 years and an age at maturity of 4-5 years. Spawning occurs off western Tasmania between late May and early September. Adults are thought to migrate to the spawning area from throughout southeastern Australia, with large fish arriving earlier in the spawning season (Smith and Wayte, 2004).

Blue grenadier are caught by demersal trawling. The global agreed TAC in 2004 was 7000 tonnes, down from 9000 t in 2003 and 10000 t the previous year, the level at which it had been since 1994. There are two defined sub-fisheries: the spawning and non-spawning fisheries. The non-spawning fishery catches have been relatively poor over the last few years, whereas the spawning fishery catches have shown a marked increase since the mid-1990s (Figure 5.1). On-board observations during the 2003 non-spawning fishery showed little evidence of recent recruitment, and discarding was low throughout the fishery.

5.1.2 Previous Assessments

The 2003 assessment of blue grenadier used the age-structured “integrated assessment” model developed during 1998 and 1999 (Punt *et al.,* 2001; Tuck and Thomson, 2003a,b). Prior to 1998, TACs were based on a biomass estimate derived from a swept area trawl survey and commercial logbook data from the early 1980s. There were no reliable estimates of virgin or current biomass. However preliminary results from an acoustic survey and application of stock reduction analysis methods suggested that virgin biomass was at least 30000t. The Blue Grenadier Assessment Group was formed in 1997. Results from a workshop in 1997 indicated that there were a large number of small fish across the fishery, suggesting improved recruitment. This led to increased discarding from the non-spawning fishery. In 1998, an age-structured model was used to assess the status of the stock and to provide the basis for population projections and risk assessment. This assessment used SEF1 logbook data up to 1997 and verified SEF2 data, size and age-composition data, and on-board (SMP) observations of discard rates.

The 2003 assessment showed a continued declining trend in spawning biomass. This was primarily due to several recent years of poor recruitment (since the large 1994 and

1995 recruitments). However, the assessment is very sensitive to the estimated egg survey measures of female spawning abundance. Regardless of their actual values, the model predicted a decline in biomass over the next five years.

5.2 Data

The data used were annual landings by the spawning and non-spawning sub-fisheries (Table 5.1, Figure 5.1) from the SEF1 log-book data; estimated discards by the non-spawning sub-fishery; catch-per-unit effort information (CPUE) standardised by GLM analysis (Table 5.2; Haddon, 2004); proportion-at-age for the catches and discards; mean length- and weight-at-age; and estimates of the female spawning biomass in 1994 and 1995 from egg surveys (Bulman *et al.,* 1999). An acoustic estimate of spawning biomass in August 2003 was also used in sensitivity tests. Data were formulated by calendar year (i.e. 1 January to 31 December).

5.2.1 Catches

The landings from the SEF1 logbook data have been adjusted upwards to take account of fish reported as headed and gutted (multiple of 1.4 for the non-spawning fishery; 1.2 for the spawning fishery up to and including 1996). These figures were then scaled up to the SEF2 data. As SEF2 data were only available from 1993, for years prior to this the average scaling factor from 1993 to 1998 was used to scale the data. As a sensitivity test, a factor to account for loss of blue grenadier catches due to “burst bags” in the spawning fishery was also considered. The burst bag scaling factors, up to 1997, were estimated during a previous BGAG meeting by industry members. The burst bag factor was 5% for all years prior to 1993, 20% for 1993, 15% for 1994, 10% for 1995 and 5% for 1996. No adjustment was made after 1996.

5.2.2 Length-frequency

Although length frequency information is collected at ports around Australia, only those collected in Portland (and Beachport for 2002 and 2003) were used here. This was done because BGAG had traditionally used only Portland data - earlier and continuing investigations by BGAG indicated that Portland was representative of all areas. However, future work will examine the sensitivity of the model results to using all available data, in particular those from the east coast.

5.3 Analytical approach

5.3.1 The population dynamics model

The population and likelihood models applied in 2004 are exactly the same as that used in the 2003 assessment and are based upon the integrated analysis model developed for blue grenadier in the South East Fishery by Punt *et al.* (2001; Appendix 5.A; see also Tuck and Thomson, 2003a,b). The 2004 model is updated and extended by including the following data:

- the total mass landed and discarded during 2003; the catch-at-age during 2003 and the estimated mean length and weight of each age-class present during 2003,
- recalculating the standardised CPUE series,
- including, as a sensitivity test, an acoustic estimate of August 2003 spawning biomass.

Two sub-fisheries are included in the model – the spawning sub-fishery that operates during winter (June – August inclusive) off west Tasmania, and the non-spawning sub-fishery that operates during other times of the year and in other areas throughout the year. The model is sex disaggregated, however male and female fish are assumed to grow at the same rate.

Parameter uncertainty is examined through the use of sensitivity tests and by applying the Markov Chain Monte Carlo (MCMC) algorithm (Hastings, 1970; Gelman *et al.,* 1995). The sensitivity of the assessment model to various assumptions is tested by running the base-case model with a single alternative assumption. The full range of models tested is:

1) the base-case model
2) burst bags sensitivity
3) the estimated spawner biomass from the egg survey is halved
4) the estimated spawner biomass from the egg survey is doubled
5) the estimated spawner biomass from the acoustic survey is included
6) the estimated spawner biomass from the acoustic survey is doubled (no egg estimates included)
7) the estimated spawner biomass from the acoustic survey is tripled (no egg estimates included)

5.3.2 The objective function

The negative of the logarithm of the likelihood function includes five components. These relate to minimizing the sizes of the recruitment residuals, fitting the observed catches and discards by fleet, fitting the observed age-compositions by fleet, fitting the catch rate information, and fitting the estimates of spawner biomass from the egg and acoustic surveys. Appendix 5.A has details of the likelihood formulations (see also Punt *et al.,* (2001)).

5.3.3 Parameter estimation

The values assumed for some of the (non-estimated) parameters of the base case model are shown in Table 5.3. The model has 106 estimated parameters: 2 catchability coefficients; 1 female natural mortality, 1 B_0, 25 annual fishing mortality rates for each of the two sub-fisheries; recruitment residuals for 24 years and 19 age classes in the first year; 2 selectivity parameters for the spawning sub-fishery and 3 for the non-spawning; and 4 parameters for the probability of discarding-at-length function.

The values for the parameters that maximize the objective function are determined using the AD Model Builder package[1]. This assessment quantifies the uncertainty of the estimates of the model parameters and of the other quantities of interest using Bayesian methods. The Markov Chain Monte Carlo (MCMC) algorithm (Hastings, 1970; Gelman *et al.,* 1995) was used to sample 1000 equally likely parameter vectors from the joint posterior density function. The samples on which inference is based were generated by running 2,000,000 cycles of the MCMC algorithm, discarding the first 1,000,000 as a

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burn-in period and selecting every 500th parameter vector thereafter until 1000 parameter vectors have been chosen.

5.3.4 Projections

5.3.4.1 Fixed annual catches

To assess the risk associated with different future levels of catch, forward projections (1000 simulations) were carried out over a 20-year period with the catch held at a range of levels.

The projections are based on 1000 random samples from the Bayesian posterior distribution. For each sampled parameter set, the population dynamics model is projected forward with a particular pre-determined catch level. The catch is split 75:25 between the spawning and non-spawning components of the fishery. The projections will tend to over-estimate risk because such 'fixed catch' projections implicitly assume that future data will be ignored. The outcomes of the projections are quantified by the probability that the spawning biomass exceeds 40% and 20% of the reference spawning biomass (i.e. $0.4B_{ref}$ and $0.2B_{ref}$), where the reference biomass (B_{ref}) is the average spawning biomass over the 1979 to 1988 period.

The assessment sensitivities considered were:

1) the base-case assessment
2) the half egg estimate assessment
3) the double egg estimate assessment.

5.3.4.2 Varied annual catches

In addition, for the base-case model, future annual catches were varied according to the catch series described in Table 5.6a. These series were considered because the future biomass trajectory shows a substantial decline at least over the next several years and a gradual reduction, followed by gradual increase in annual catch may provide better outcomes for the stock and fishery.

5.3.4.3 Future cyclic recruitment

As the estimated historic recruitment multipliers appear periodic in nature (Tuck and Thomson, 2003a; Section 5.4), two preliminary, simple models of cyclic recruitment were considered. Under the base-case scenario, future annual recruitment multipliers (the amount by which the recruitment deviated from that predicted by the stock recruitment relationship) are chosen from a log-normal distribution (see Punt *et al.,* (2001)). The two alternative cyclic recruitment scenarios are:

1) that multipliers are chosen in a block from 3 historic cycles of approximately 9 years. The blocks were chosen at random.
2) as with (2) above, but with 2003 and 2004 showing poor recruitment (recruitment multiplier equivalent to the year 2000 value).

5.4 Results

5.4.1 Base-case analysis

Figure 5.1 shows the observed and predicted fits to the landings and discards from each sub-fishery. The model is forced to fit the recorded landings because of the very low c.v. that is used ($\sigma_c = 0.05$, Table 5.3). It is able to fit the recent drop in the mass of discards however the large discard measured in 1997 is not well estimated despite the ability of the model to allow for density dependant discarding.

The estimated natural mortality figure for females is 0.20 and consequently that for males is 0.24 (= 1.2*female natural mortality).

The model is not able to fit the early fluctuations in the CPUE for the winter spawning sub-fishery but it is able to achieve a reasonably good fit to the CPUE for recent years (Figure 5.2). The fit to the CPUE for the non-spawning sub-fishery is reasonably good although the increase in the CPUE after 1998 is not as well estimated as might be expected. The drop in CPUE for 2000 is not predicted by the model which actually predicts an increase, consistent with the growth of a large cohort of grenadier spawned in 1994. However, the last two years' estimates of CPUE follow the downward trend indicated by the standardized catch rates.

The estimated vulnerability of fish of a given length class to being caught (but not necessarily landed) by either sub-fishery is shown in Figure 5.3 (top plot). The probability that a fish will be discarded once it has been caught is shown in the bottom plot.

The fits to the catch-at-age and the discard-at-age data for both sub-fisheries are reasonably good (Figure 5.4). Figures 5.4 and 5.5 (which shows the estimated annual recruitments) illustrate that there does not appear to be recruitment to follow the strong year-class of 1995. While a small increase in recruitment is estimated by the model for 2002, this will not have been well estimated (as these fish have mostly not moved into the fishery) and the real strength of this cohort will need to be determined over the next few years.

Figure 5.6 shows the estimated annual fishing mortalities for both sub-fisheries. The fishing mortality for the non-spawning sub-fishery has remained relatively stable, however the spawning fishery mortality has increased rapidly since the mid-1990s and is now above natural mortality.

Figure 5.7 shows the estimated abundance (in millions of fish) by age and year for the base-case model. This figure illustrates the broad number of ages in the population in the early years of the fishery and that the recent age-structure has reduced so that it is now dominated by 8 and 9 year olds. These fish were spawned in 1994 and 1995 and clearly there has not been a strong recruitment since.

The female spawning biomass and available biomass estimates for the base-case and egg survey sensitivities are shown in Figure 5.8. The increase in estimated spawning biomass due to the entry of the large 1994 and 1995 cohorts into the spawning stock has now abated as the cohort moves through and is not replaced with further strong cohorts.

The projections from the last two year's assessments have indicated a likely drop in spawning biomass for 2003, which has now eventuated (Figure 5.9).

Figure 5.10 shows the female spawning biomass trajectory for the base-case model fit to the data. Also shown are percentiles of the spawning biomass and the median trajectory relative to the egg survey estimates (intervals are 2 standard deviations).

5.4.1 Sensitivity tests

Table 5.4 shows the results of various sensitivity tests. The quantities of interest shown are the estimated pristine spawning biomass (B_0); the reference biomass (B_{ref}); the spawning biomass in 1979 ($\widetilde{B}_{79}$) and in 2003 ($\widetilde{B}_{2003}$) and its size in 1986, 1993, and 2003 relative to the reference level (depletion, $\widetilde{B}_y \big/ B_{ref}$); the estimated fishing mortality rate for the spawning (F^1_{curr}) and non-spawning (F^2_{curr}) sub-fisheries; the estimated recruitment residual for the strong 1994 cohort, and the negative log likelihood (-ln L) value from the model. Also shown are the base-case results for the previous two year's assessments. Note that the final year of biomass estimation (*curr*) is one year less than the year the assessment is produced.

The base-case model concludes that the reference biomass is around 42000 t and that current female spawner biomass (as at 2003) is approximately 43% of the reference biomass. The "burst bags" sensitivity varies little from the base-case model. The sensitivity tests that examine possible bias in the results of the egg surveys ("Half" and "Double egg estimates" in Table 5.4) produce the lowest and highest estimated spawning biomass values (Figure 5.8).

An acoustic survey estimate of spawning biomass in the Pieman Canyon (conducted on 9 August 2003) was included as a sensitivity (Ryan *et al.* 2003). The acoustic estimate was 64000 t with a cv of 0.19 (Figure 5.11). Note that this cv is only a measure of the survey sampling variability and does not incorporate any of the large uncertainties, such as target strength (the estimate could be half or double its value), turnover, or the proportion of fish in the wider region (Tim Ryan, pers. comm.) As the biomass estimate includes both males and females, it was halved in order to fit to female spawning biomass alone. The model fit is illustrated in Figure 5.12. In order to account for turnover and other uncertainties, other sensitivities were conducted where the acoustic estimate was doubled and tripled (accounting for different assumptions about turnover rates). The egg survey estimates were not included in this sensitivity (Table 5.4, Figure 5.13). Not surprisingly the biomass estimates increase, although the level of depletion remains around 50% relative to the reference biomass.

5.4.2 Projections

Figure 5.14 shows future projections of median female spawning biomass relative to the reference level for the base-case model, egg survey sensitivities and assuming no fishing had occurred in the fishery (*F*=0). Projections with two fixed annual TACs are shown, TAC=5000 t and TAC=10000 t. These figures indicate that the relative spawning biomass is likely to continue the downward trend for at least the next 3 to 4 years (even with no fishing).

Figure 5.15 shows the median projected female spawner biomass for fixed future TACs varying between 2000 t and 8000 t (base-case recruitment model). Figure 5.16 shows, for various model assumptions, the probability of the spawner biomass being above 20% of the reference level in 5 years given different TAC levels. Table 5.5 shows these probabilities for the base-case model and the egg survey sensitivities, for 20% and 40% of the reference biomass and over 5, 10 and 20 years. Similarly, the probabilities for the step-down catch series of Table 5.6a are shown in Table 5.6b.

As the estimates of recruitment (Figures 5.5 and 5.17) appear cyclic in nature, an alternative model of recruitment was constructed that assigns future recruitment multipliers as a block taken from a random choice of 3 pre-determined periods from historical estimates. These periods are shown in Figure 5.17 (left) as A (1974 to 1981), B (1982 to 1990) and C (1991 to 1999). The first apparent cycle (prior to 1974) was not chosen as the recruitment estimates from the parameter sets chosen by the MCMC algorithm indicated that the recruitment multipliers did not consistently show a cycle prior to 1974 (Figure 5.17, right). However, cycles since 1974 were consistently shown. Figure 5.17 (right) shows, for a single set of simulation parameters, the future recruitments chosen for the cyclic recruitment model and the base-case model (multipliers chosen from a log-Normal distribution). This illustrates the more random (non-cyclic) nature of the base-case recruitment model. The base-case model also allows more immediate and potentially strong recruitments to occur, as opposed to the gradual increase of recruitment observed in the cyclic model. A second cyclic model, with two further years of poor recruitment (equivalent to that of year 2000) before selection of the historical cyclic recruitment blocks, was also considered.

Figure 5.18 shows the median spawner biomass relative to the reference biomass for the three future recruitment models and a fixed TAC of 5000 t. The figure indicates that if recruitment is truly cyclic the future spawner biomass may fall further over the next few years than would have been estimated by the base-case model.

5.5 Discussion

Results from the 2004 assessment of blue grenadier from the South East Fishery, are generally less optimistic than those of 2003, continuing the trend of recent years. The apparent poor state of the stock is, to a large extent, due to continued poor recruitment to the fishery. There has been no indication of a good, or even average, recruitment to the fishery since the strong cohorts that were spawned in 1994 and 1995 (approximately 6 and 4 times average recruitment respectively). While typically the fishery was capturing fish from several cohorts (eg across 10 age-classes for the spawning fishery), the fishery currently is predominantly harvesting fish from the strong cohorts spawned in the mid-1990s. As such, future population projections show substantial declines in spawning biomass over at least the short-term for all potential catch scenarios considered.

For the first time, acoustic studies provided estimates of spawning biomass for the Pieman Canyon that could be included in the stock assessment (Ryan *et al.,* 2003). A peak acoustic biomass estimate of approximately 64000t was used with no turnover, or double or triple turnover. The ‘no-turnover’ sensitivity provided estimates that were similar to the base-case result and the ‘two-times turnover’ results were between those of the base-case and double-egg sensitivities.

As recruitment patterns appear cyclic in nature, preliminary models of cyclic recruitment were developed and tested for the projections. Results indicated that the spawner biomass may continue to decline beyond that predicted by the base-case model. This is because the non-cyclic models assume that recruitment can be average (or better than average) immediately into the projection period, whereas the cyclic models continue periods of poor recruitment prior to strong recruitment periods returning.

For the risk assessment, a range of constant TACs from 1,000 to 15,000 t were examined together with a range of step-down TAC scenarios. Results indicate that for all scenarios, there is a very high probability that the spawning biomass will reduce below 40% B_{ref} for all future catches in 5 years due to the effects of poor recruitment to date. The current TAC of 7000 tonnes leads to a probability of almost 80% of being below 20% B_{ref} in 5 years (for the base-case). Projections to 10 years and longer are more optimistic due to the stock assessment model accommodating improved recruitment in the future. The step-down scenarios reduce the probability of being below 20% B_{ref} to about 50%.

As observed in previous assessments of blue grenadier, the assessment is very sensitive to the absolute biomass estimates used. For example, with the double egg estimate, the probability of being below 20% B_{ref} in 5 years is 7% compared to 95% for the half egg estimate.

5.6 Further development

- Assessment modeling should continue the development of the cyclic recruitment models (presented here in preliminary form) for the risk assessment.
- In addition, fixed probabilities for reference points may not be appropriate for a species showing cyclic recruitment. For example, a moderate probability of being below 20% B_{ref} in some future year might be acceptable if strong year classes are known to be about to enter the spawning fishery. Conversely it would not if poor recruitment was evident.
- Models should also further develop the step-down TAC setting scenarios that allow a more appropriate exploration of harvesting regimes for a fishery which is predicted to show a substantial decline in biomass over the next several seasons.
- In collaboration with acoustic scientists, the spawning biomass estimates of Western Tasmania fish from acoustic studies should be further refined and included as appropriate in the model estimation procedure.
- For a fishery strongly driven by (possibly cyclic) recruitment, there is a clear need to monitor the non-spawning fishery for evidence of recent improved recruitment.
- Likewise, hypotheses should be developed (and tested) that lead to causal links between the patterns observed and environmental drivers (oceanography, nutrient availability, etc.). Identification of the causes of the recruitment patterns has clear management benefits.
- In the meantime, an assessment of spatial and temporal closures, as well as regional closures should be considered.

5.7 Acknowledgements

The authors would like to thank the staff of Primary Industries Research Victoria (Queenscliff, Victoria) for providing the fisheries data that were used in this model and to Malcolm Haddon (TAFI) for providing standardised CPUE values. Corey Green of the Central Aging Facility is thanked for providing the age length keys, as is Bob Stanley of AFMA for providing the spawning length frequencies. The members of the Slope Fishery Assessment Group, Sally Wayte, Tim Ryan and Rudy Kloser (CMR), are thanked for useful discussions, explanations, and hypothesis generation.

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Table 5.1. Landed and discarded catches for the winter spawning and non-spawning sub-fisheries by calendar year. These estimates have been adjusted to account for reporting of headed and gutted catches, and scaled up to the sef2 data (see text).

Year	**Landings**		**Discards**	
	Spawning	**Non-spawning**	**Spawning**	**Non-spawning**
1979	321	375		
1980	537	627		
1981	295	344		
1982	511	596		
1983	590	688		
1984	885	1032		
1985	787	918		
1986	323	1850		
1987	1025	2226		
1988	418	2291		
1989	47	2831		
1990	747	2618		
1991	1165	4215		
1992	936	2683		
1993	990	2359		
1994	1212	1944		
1995	1199	1562		79.5
1996	1499	1539		974.8
1997	2952	1581		3715.6
1998	3265	2468		1329
1999	6103	3223		123.47
2000	6061	2594		69.25
2001	7626	1498		9.75
2002	7430	1730		1.62
2003	7555	919		3.52

Table 5.2. Standardised CPUE (Haddon, 2004) for the spawning and non-spawning sub-fisheries by calendar year.

Year	**Spawning**		**Non-spawning**	
	CPUE	**Records**	**CPUE**	**Records**
1986	1.000	86	1.000	2425
1987	1.431	199	1.407	2540
1988	2.516	92	1.433	2848
1989	0.802	31	1.418	3302
1990	0.893	154	1.483	3147
1991	3.299	170	1.100	4357
1992	1.463	207	0.949	3961
1993	2.683	175	0.663	4644
1994	1.747	378	0.591	4899
1995	0.777	524	0.426	5353
1996	1.183	506	0.356	5599
1997	0.982	422	0.352	5702
1998	1.088	606	0.661	6148
1999	0.775	867	0.699	6391
2000	0.890	957	0.487	7995
2001	0.934	1111	0.412	6235
2002	1.049	1047	0.301	5779
2003	0.831	901	0.223	5208

Table 5.3. Parameter values assumed for some of the non-estimated parameters of the base-case model.

Parameter	**Description**	**Value**
N	Weight for the catch- and discard-at-age data	50
σ_r	c.v. for the recruitment residuals	1.0
σ_c	c.v. for the landings data	0.05
σ_d	c.v. for the discard data	0.3
σ_q	c.v. for the CPUE data	0.3
h	"steepness" for the Beverton-Holt stock-recruit curve	0.9
x	age of plus group	15 years
μ	fraction of mature population that spawn each year	0.77
l_∞	von Bertalanffy parameter (maximum length)	102.76 cm
κ	von Bertalanffy parameter (growth rate)	0.16 y-1
t_0	von Bertalanffy parameter	-2.209 y
aa	allometric length-weight equations	0.00375 g-1.cm
bb	allometric length-weight equations	3.013
l_m	length at maturity (knife-edged)	70 cm

Table 5.4. Estimated values for several parameters of interest. The base case model is shown as well as sensitivity tests. Results are shown for base-case runs in the previous 2 years for comparison with the 2004 assessment. 'Curr' refers to the current or final year of the estimation. 'Half' and 'Double egg estimate' sensitivities either halve or double the estimated egg survey spawning biomass. 'Burst bags' accounts for some catch in the spawning sub-fishery being lost due to bags bursting. 'Acoustic estimate' includes an estimate from an acoustic survey on the spawning grounds of Pieman Canyon in August 2003.

Specification	B_0	B_{ref}	$\widetilde{B}_{79}$	$\widetilde{B}_{curr}$	$\widetilde{B}_{86} / B_{ref}$	$\widetilde{B}_{93} / B_{ref}$	$\widetilde{B}_{curr} / B_{ref}$	F^{1}_{curr}	F^{2}_{curr}	R_{94}	-ln L
Previous assessment results											
Base-case, *curr*=2001	39333	61090	63930	40817	94.48%	70.47%	66.81%	0.168	0.020	4.44	305.60
Base-case, *curr*=2002	33026	52605	51685	31241	98.04%	81.94%	59.39%	0.175	0.027	6.00	352.42
2004 assessment results, curr=2003											
Base-case	26877	42082	41441	18066	97.85%	81.86%	42.93%	0.278	0.026	6.19	362.06
Burst bags	26910	42274	41449	18078	98.03%	81.96%	42.76%	0.277	0.026	6.19	362.06
Half egg est	18399	23941	22430	9390	100.68%	90.95%	39.22%	0.557	0.047	7.66	356.98
Double egg est	68808	130994	137580	63987	94.39%	72.82%	48.85%	0.074	0.008	5.21	369.84
Acoustic estimate	34071	55829	55991	26770	96.88%	79.37%	47.95%	0.185	0.018	5.96	363.08
Acoustic est x2; no egg	50977	89131	91494	46460	95.64%	76.35%	52.13%	0.104	0.011	5.64	366.15
Acoustic est x3; no egg	80604	150394	157602	79685	94.54%	73.66%	52.98%	0.059	0.006	5.34	368.05

Table 5.5a. Probabilities of being above 40% and 20% of the reference biomass in 5, 10 and 20 years for the base-case model.

Base-case	Probability (in %) above 40% B_{ref} in Y years			Probability (in %) above 20% B_{ref} in Y years		
TAC	Y=5	Y=10	Y=20	Y=5	Y=10	Y=20
1000	21.4	79.1	97.4	94.2	99.6	100
2000	15.3	67.1	92.4	83.4	97.1	99.7
3000	10.3	54.1	81.9	67.6	90.6	97.9
4000	7.9	43.1	67.5	54.2	80.4	92.7
5000	6.7	32.6	53.1	39.9	68.5	78.7
6000	5.0	25.4	39.1	29.4	55.2	62.0
7000	3.5	18.7	28.2	21.9	43.8	46.6
8000	2.8	13.5	19.7	16.7	32.2	33.9
9000	2.5	9.1	13.1	12.3	22.9	23.9
10000	2.2	7.2	9.0	8.7	16.8	15.8
11000	2.0	5.0	6.1	6.2	11.9	9.9
12000	1.6	3.3	4.0	5.2	9.3	6.7
13000	1.0	2.2	2.2	4.1	5.8	4.5
14000	0.9	1.5	1.5	3.2	4.2	3.5
15000	0.7	1.4	0.7	2.5	2.7	2.1

Table 5.5b. Probabilities of being above 40% and 20% of the reference biomass in 5, 10 and 20 years for the half egg estimate model.

Half egg	Probability (in %) above 40% B_{ref} in Y years			Probability (in %) above 20% B_{ref} in Y years		
TAC	Y=5	Y=10	Y=20	Y=5	Y=10	Y=20
1000	15.3	75.5	97.9	84.4	99.0	100.0
2000	9.3	56.5	87.5	58.2	91.0	99.1
3000	6.5	37.7	65.5	35.7	74.2	89.0
4000	4.8	22.2	40.9	20.9	52.0	61.3
5000	2.7	13.8	20.9	13.2	30.4	35.3
6000	1.8	8.6	9.9	8.3	17.3	16.6
7000	1.2	4.2	4.5	5.0	9.9	7.9
8000	0.7	1.5	1.6	3.4	5.0	3.5
9000	0.4	0.5	0.6	2.5	2.1	1.0
10000	0.2	0.3	0.4	1.9	0.7	0.5
11000	0.1	0.2	0.2	0.8	0.3	0.4
12000	0.0	0.1	0.1	0.5	0.2	0.1
13000	0.0	0.1	0.0	0.1	0.1	0.0
14000	0.0	0.0	0.0	0.0	0.1	0.0
15000	0.0	0.1	0.0	0.2	0.1	0.1

Table 5.5c. Probabilities of being above 40% and 20% of the reference biomass in 5, 10 and 20 years for the double egg estimate model.

Double egg	Probability (in %) above 40% B_{ref} in Y years			Probability (in %) above 20% B_{ref} in Y years		
TAC	Y=5	Y=10	Y=20	Y=5	Y=10	Y=20
1000	34.7	82.9	95.7	99.9	99.9	100.0
2000	31.0	78.8	94.4	99.7	99.7	99.9
3000	27.7	74.3	92.0	99.4	99.5	99.9
4000	23.9	70.2	89.6	98.8	98.6	99.9
5000	20.6	65.7	86.8	97.9	97.6	99.7
6000	18.5	61.9	82.6	96.3	96.6	99.5
7000	16.6	57.6	80.0	93.4	95.5	98.9
8000	15.0	53.0	76.0	89.8	93.3	98.0
9000	12.3	48.9	71.7	84.7	90.6	96.6
10000	11.0	44.9	67.5	78.5	88.0	94.7
11000	9.9	41.1	63.2	73.1	84.6	92.1
12000	8.7	37.0	58.6	65.9	79.9	89.5
13000	8.2	34.4	53.1	60.6	75.8	85.2
14000	7.9	31.0	48.3	53.5	71.4	80.7
15000	7.0	28.1	43.4	48.5	66.1	75.2

Table 5.6a. The step-wise TAC catch series used in projections under the base-case scenario.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013+
Series A	7000	5000	4000	3000	3000	3000	4000	5000	7000	7000
Series B	7000	4000	3000	3000	3000	3000	4000	5000	7000	7000
Series C	7000	5000	4000	3000	2000	2000	3000	4000	5000	5000
Series D	7000	4000	3000	3000	2000	2000	3000	4000	5000	5000

Table 5.6b. Probabilities of being above 40% and 20% of the reference biomass in 5, 10 and 20 years for the base-case model and annual TACs adjusted according to the catch series in Table 5.6a.

Base-case	Probability (in %) above 40% B_{ref} in Y years			Probability (in %) above 20% B_{ref} in Y years		
TAC	Y=5	Y=10	Y=20	Y=5	Y=10	Y=20
7000 fixed	3.5	18.7	28.2	21.9	43.8	46.6
Series A	7.8	35.6	39.2	48.4	71.9	63.4
Series B	8.1	37.3	39.8	54.5	73.9	64.2
Series C	7.8	45.3	59.8	50.5	82.3	87.1
Series D	8.4	47.5	60.6	56.3	84.6	87.6

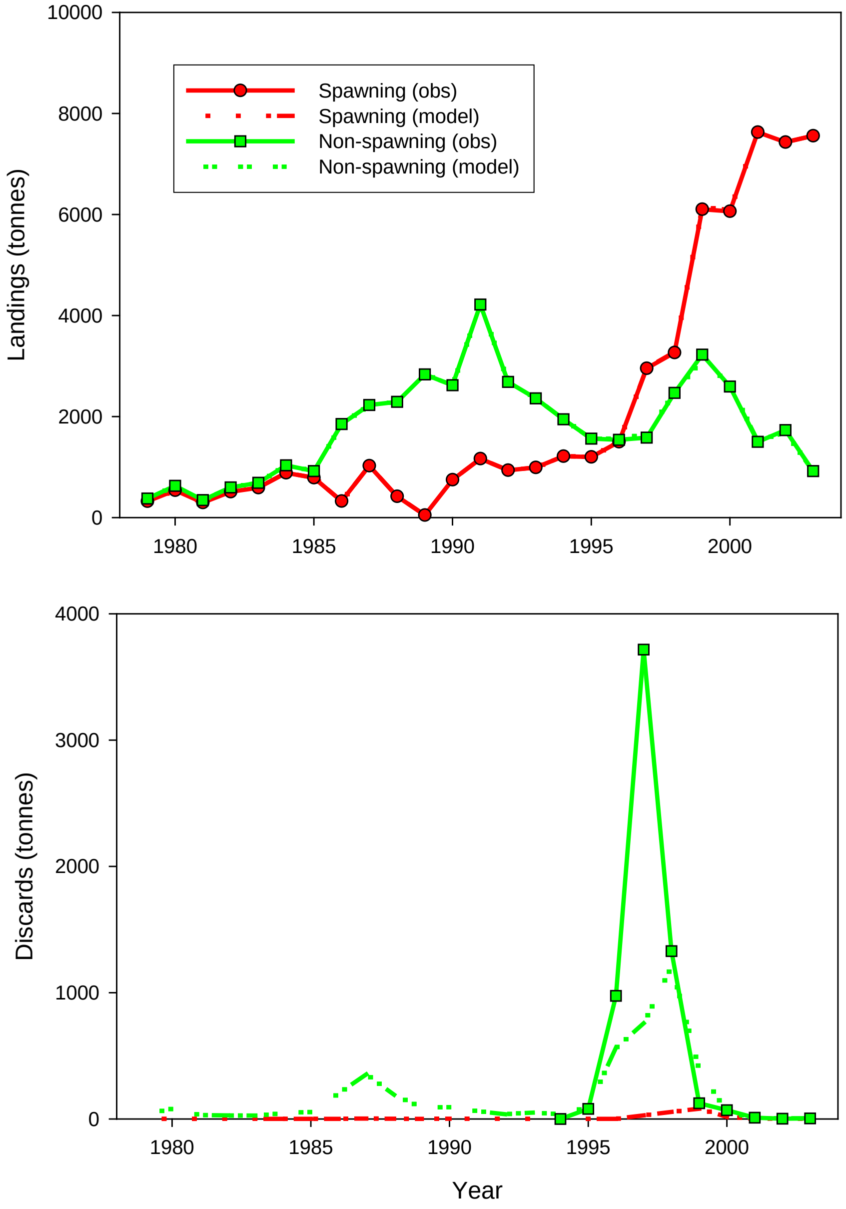


Figure 5.1. Top plot: Annual estimated landings of blue grenadier (obs; scaled to account for headed and gutted fish and to sef2) and estimated by the base case model (model). Bottom plot: Discards estimated from the ISMP (obs) and model estimated (model). The spawning and non-spawning sub-fisheries are shown.

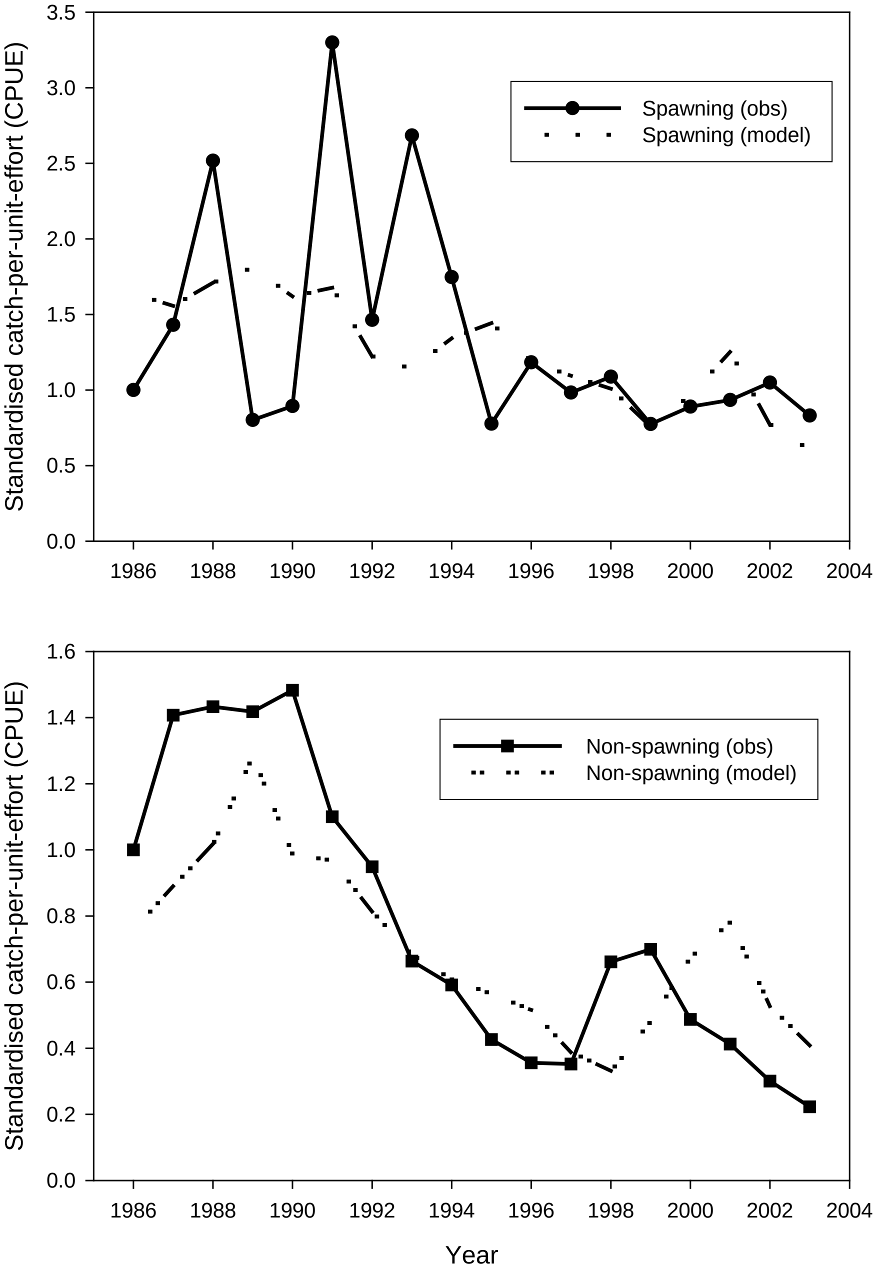


Figure 5.2. Catch-per-unit-effort (CPUE) calculated using a GLM to standardise CPUE from log-books (obs) and the base case model estimated CPUE (model) for the spawning fishery (top) and the non-spawning fishery (bottom).

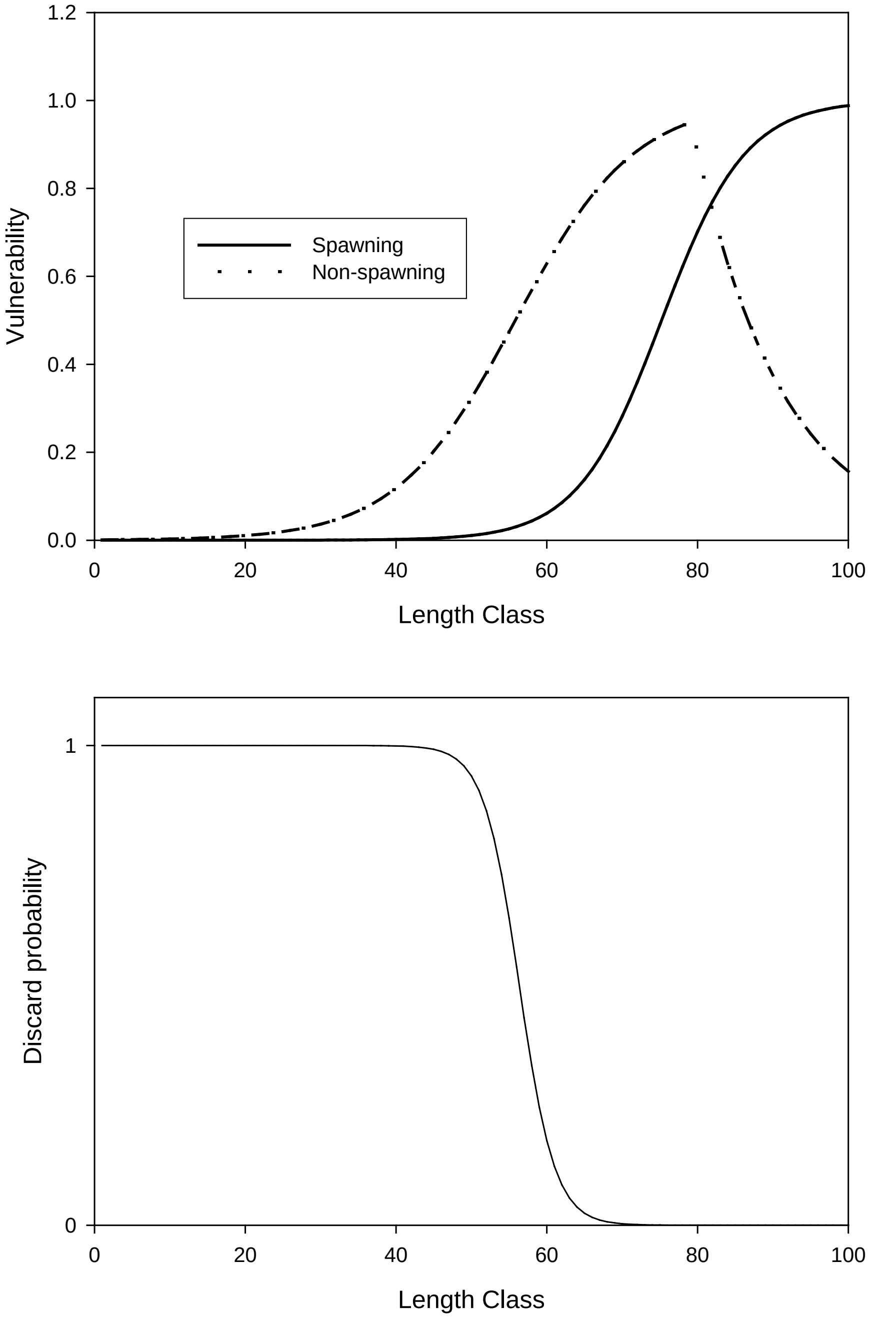


Figure 5.3. Vulnerability of blue grenadier to being caught (but not necessarily landed) by the two sub-fisheries (top) and the probability of being discarded if caught (bottom) as a function of length class.

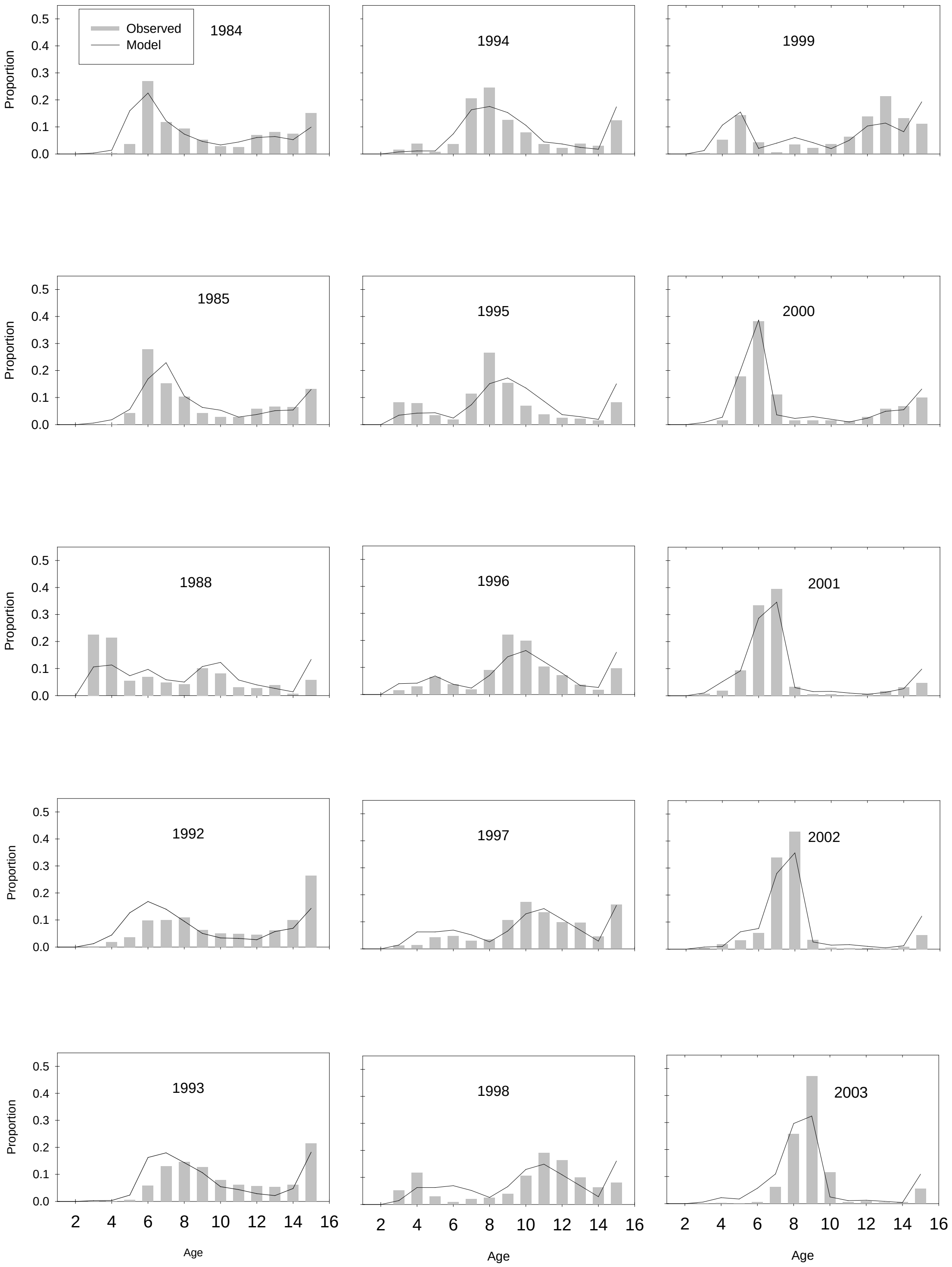


Figure 5.4a. Observed (bars) and model estimated (lines) proportion caught-at-age for the spawning sub-fishery and base-case model.

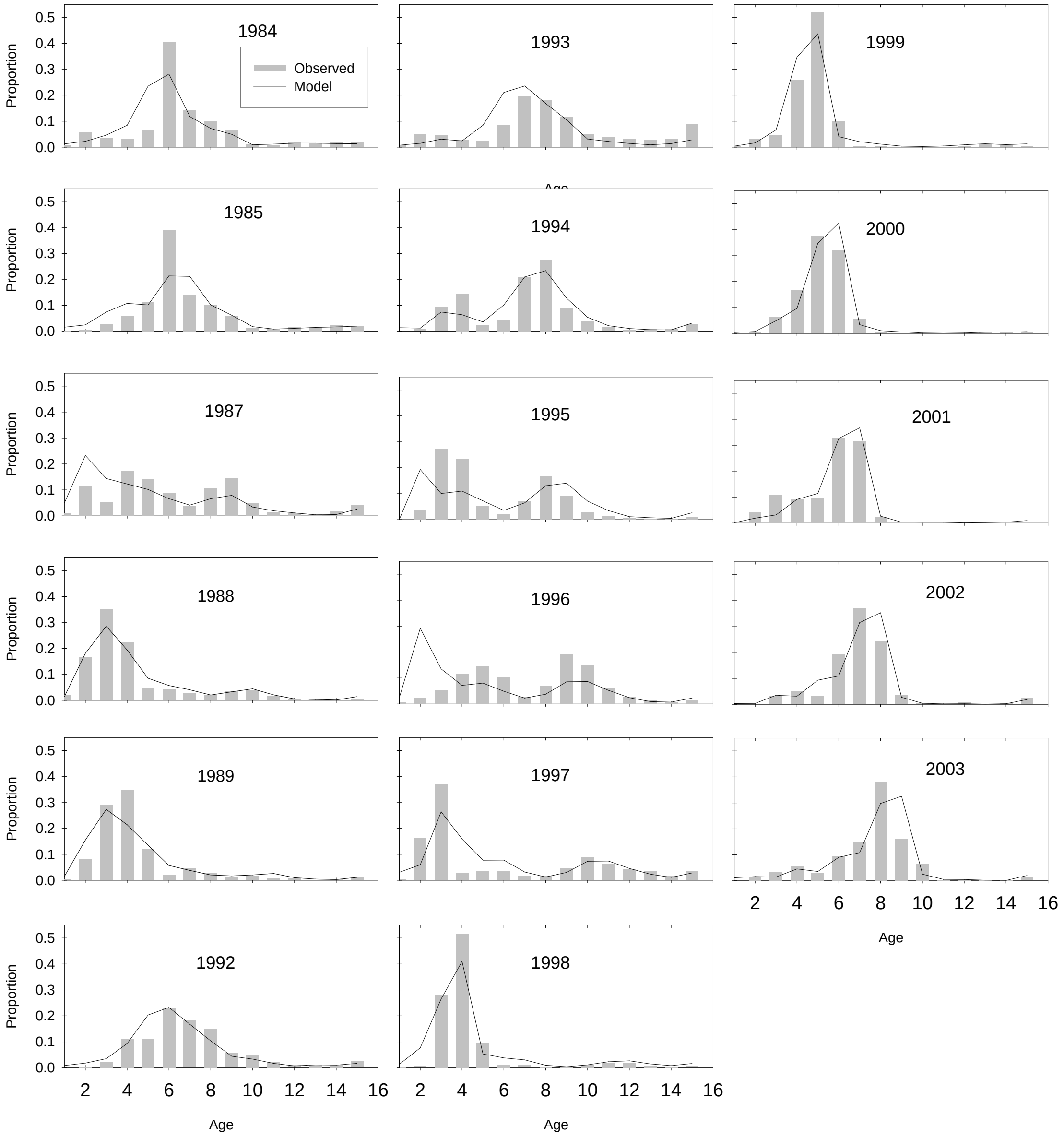


Figure 5.4b. Observed (bars) and model estimated (lines) proportion caught-at-age for the non-spawning sub-fishery and base-case model.

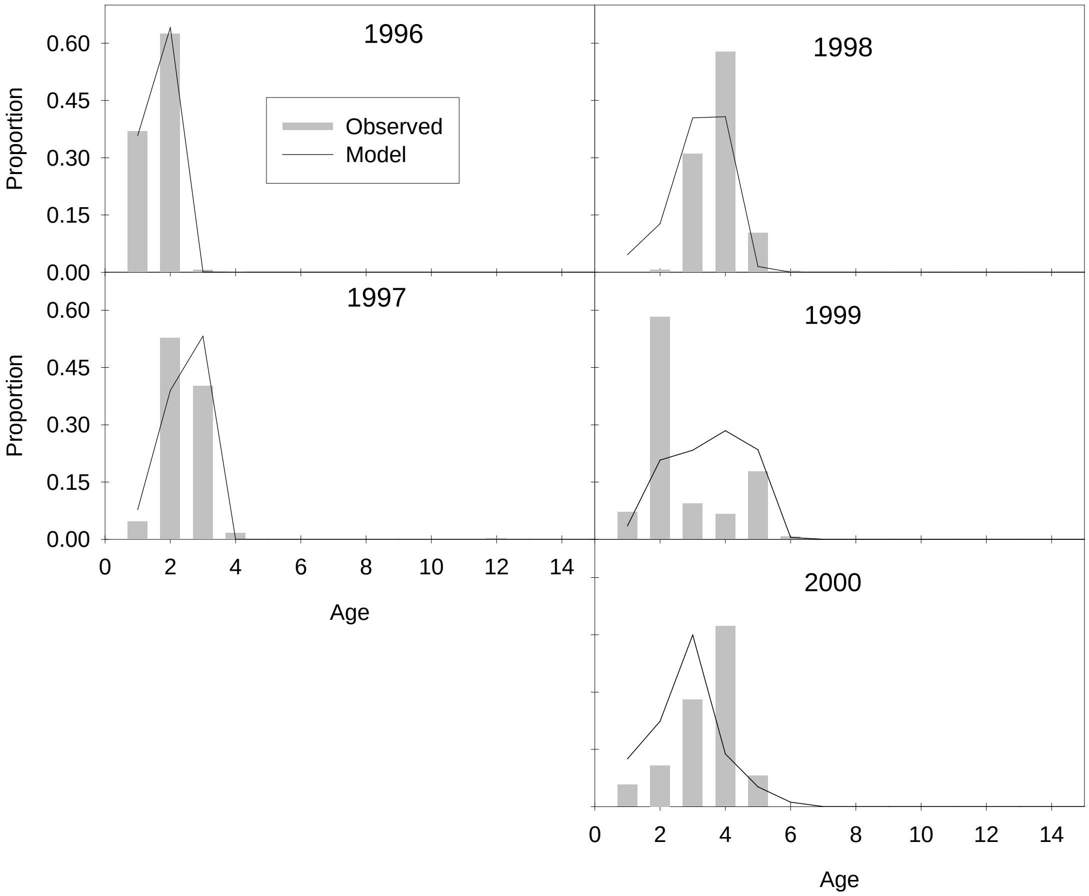


Figure 5.4c. Observed (bars) and model estimated (lines) proportion discarded-at-age for the non-spawning sub-fishery.

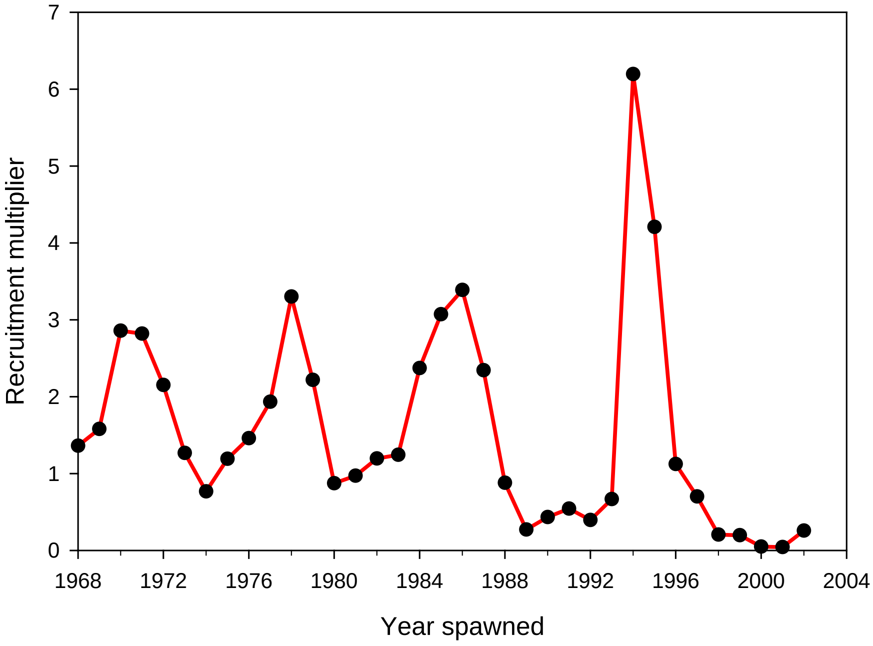


Figure 5.5. Estimated recruitment multipliers (the amount by which the recruitment deviated from that predicted by the stock-recruit relationship) versus year of spawning from the base-case model.

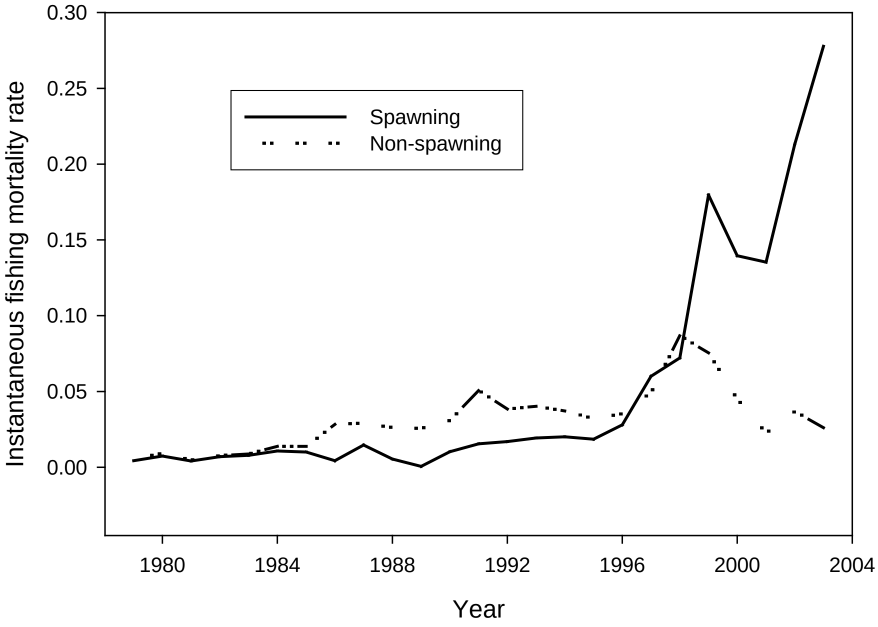


Figure 5.6. The estimated instantaneous fishing mortality rate by sub-fishery from an application of the base-case model.

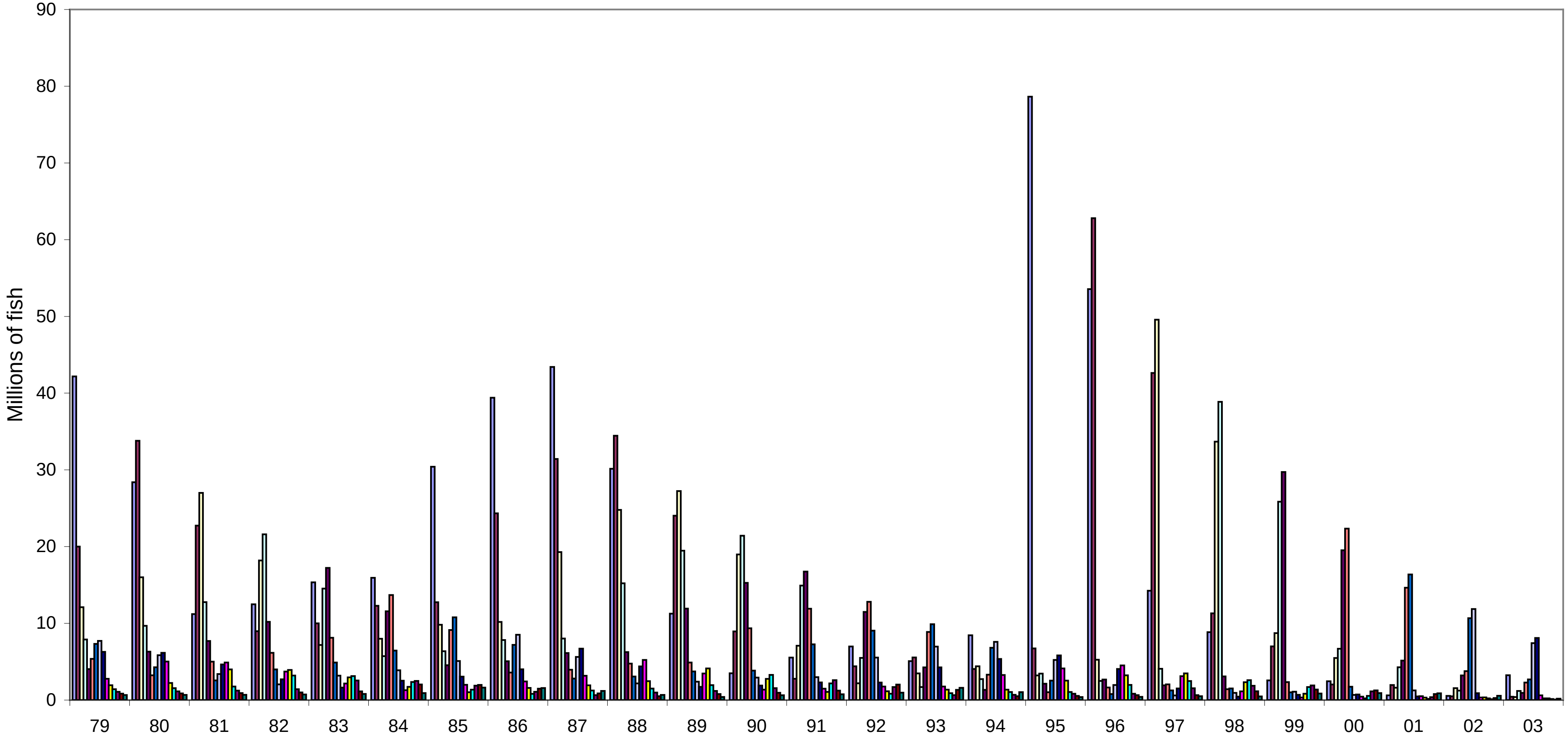


Figure 5.7. The estimated numbers-at-age of blue grenadier by year for the base case model.

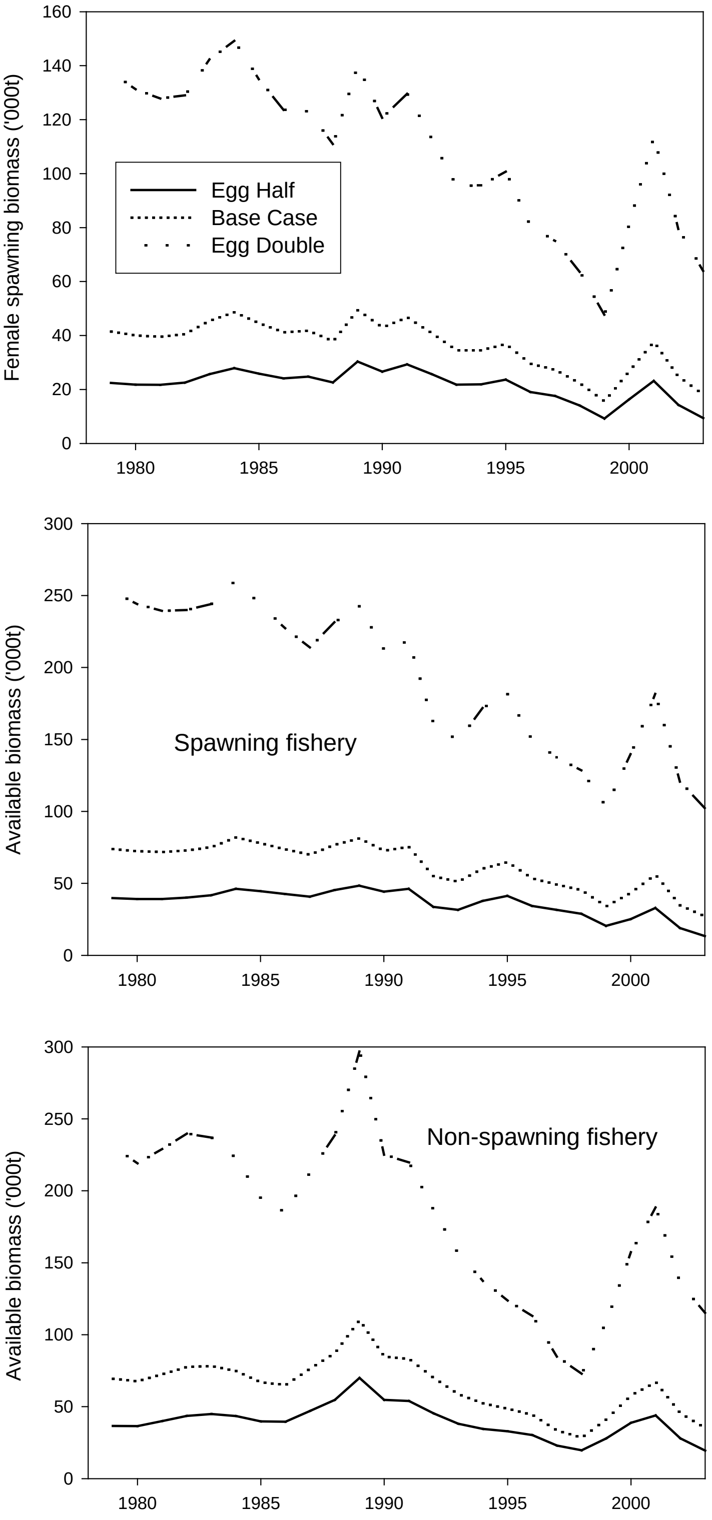


Figure 5.8. Estimated female spawning biomass (top), estimated available biomass for the spawning sub-fishery (middle) and the non-spawning sub-fishery (bottom) for the base-case model and models where the estimated biomass from the egg surveys is halved or doubled.

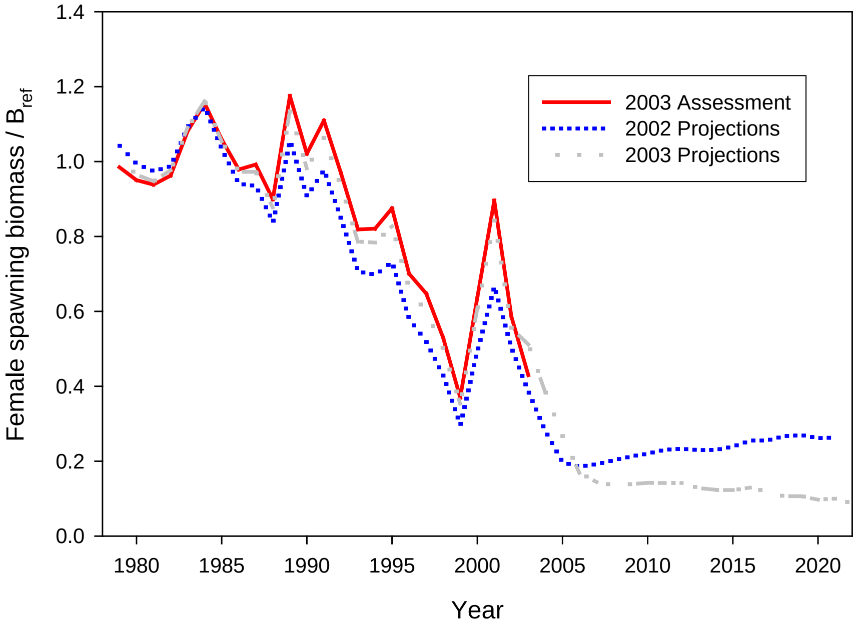


Figure 5.9. Estimated female spawning biomass relative to B_{ref} for the base-case model assessment of 2004 against that of 2002 and 2003 with future projections having a TAC of 10000 t.

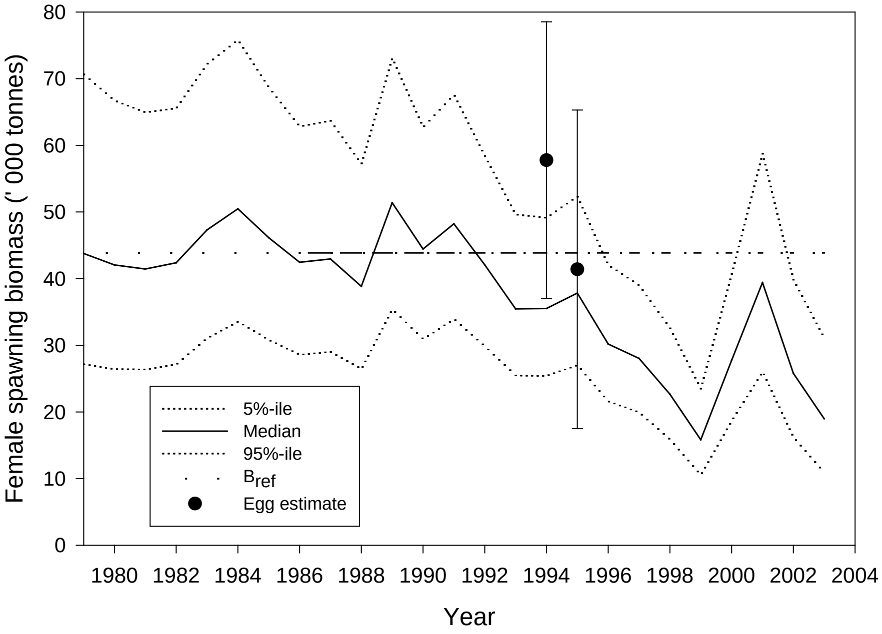


Figure 5.10. Trajectory of female spawning biomass for the base case model. The vertical lines show the estimates of spawning biomass derived from surveys of egg abundance. The horizontal line shows B_{ref}, which is defined as the average female spawning biomass over the period 1978 to 1988.

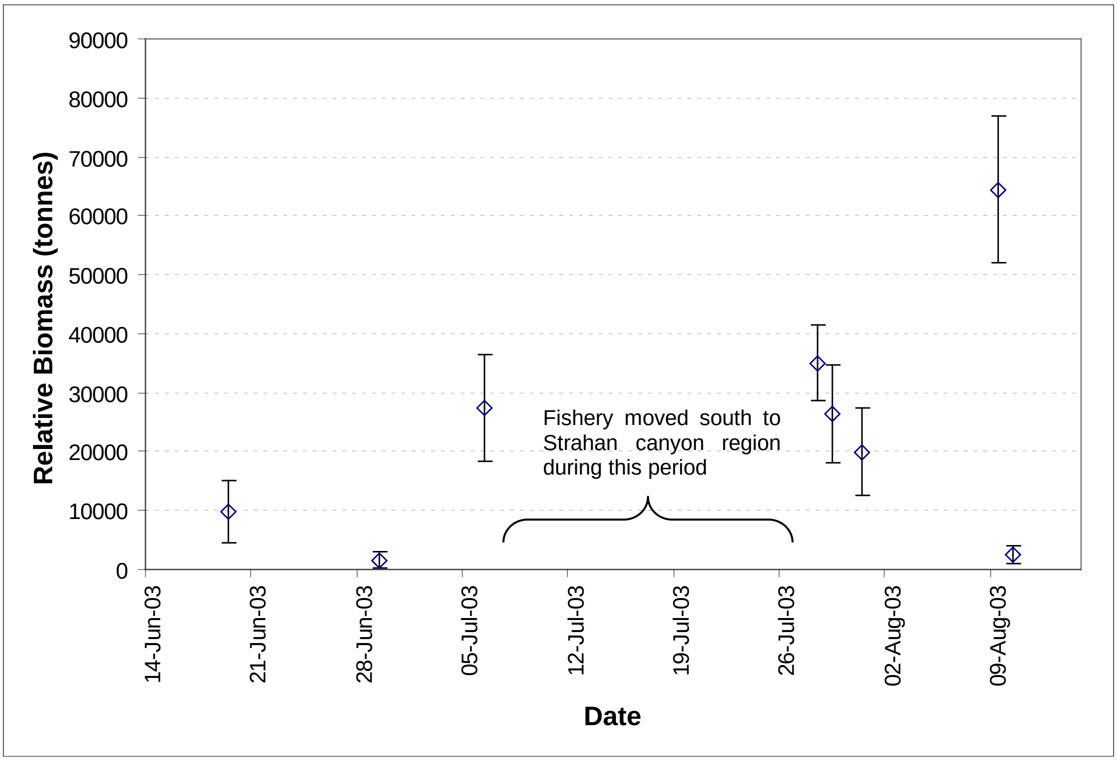
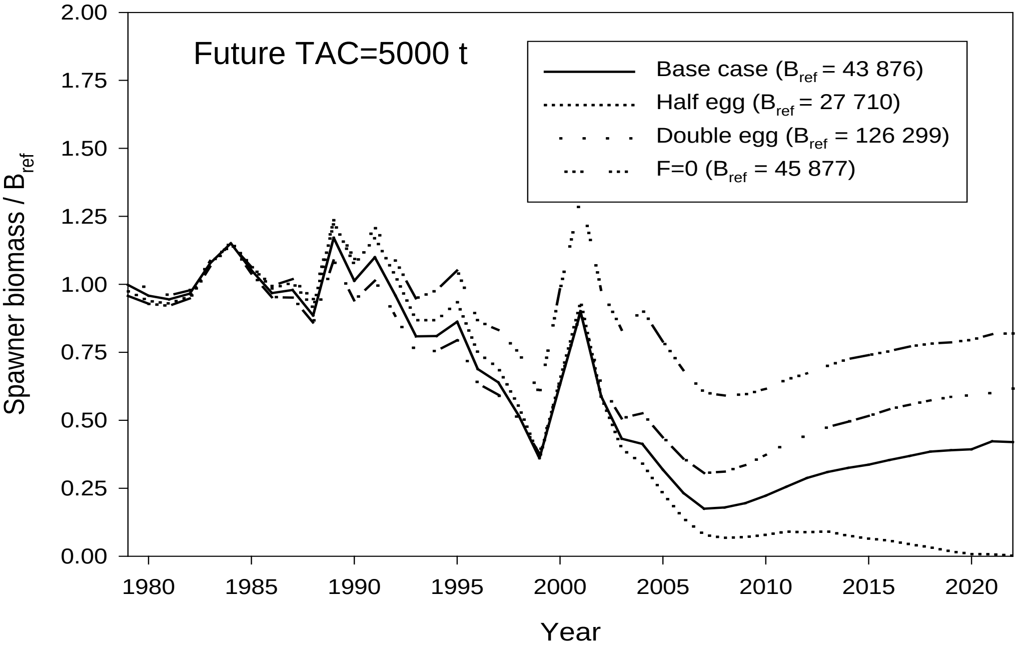


Figure 5.11. Time series of blue grenadier biomass estimates from snapshot acoustic surveys at Pieman Canyon throughout the spawning period. Error bars are +/- 1 SD based on acoustic survey sampling variance only (Ryan *et al.,* 2003).

Figure 5.12. Estimated female spawning biomass for a sensitivity model where the 9 August 2003 acoustic estimate is included. It has been assumed that females represented half the spawning biomass estimated by the acoustic survey.

Figure 5.13. Estimated female spawning biomass relative to B_{ref} for the base-case model (no acoustic estimate) and for a model with the acoustic estimate of female spawner biomass doubled (64000 t) and no egg survey estimates included.



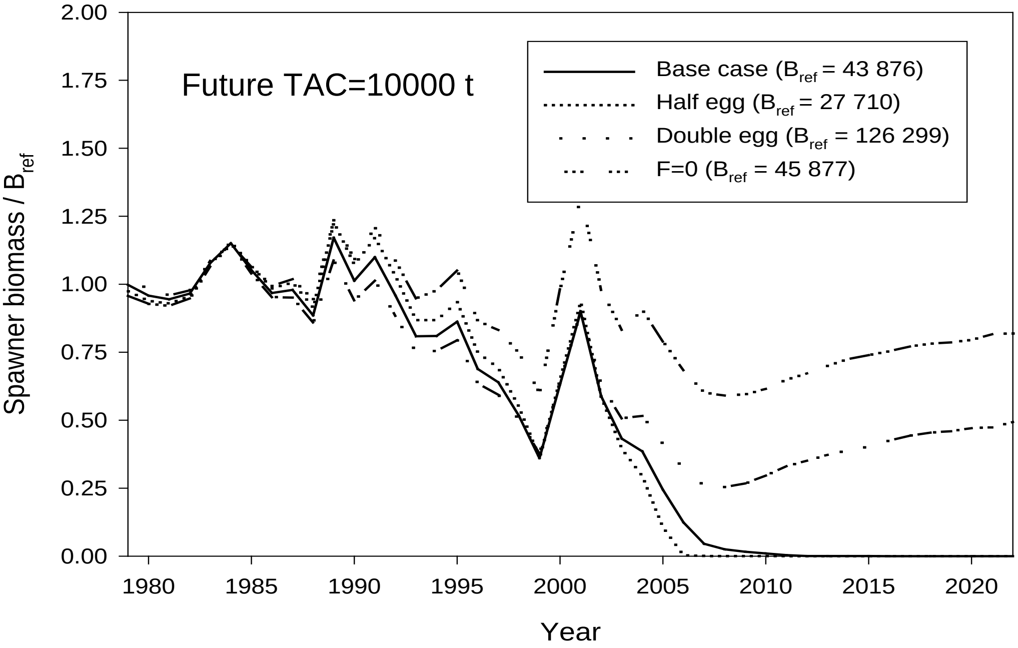


Figure 5.14. Estimated historic and future median spawner biomass for blue grenadier, shown as a function of B_{ref}. Results are shown for the base case, which uses absolute estimates of biomass derived from egg surveys, and for cases in which F=0 or the true spawner biomass is assumed to be half or double that estimated by the egg surveys. Future projections assume a constant TAC of (top) 5000 t and (bottom) 10000 t (except in the F=0 case, as no fishing mortality occurs). Future annual recruitments anomalies are derived from a log-normal distribution (the base-case recruitment model).

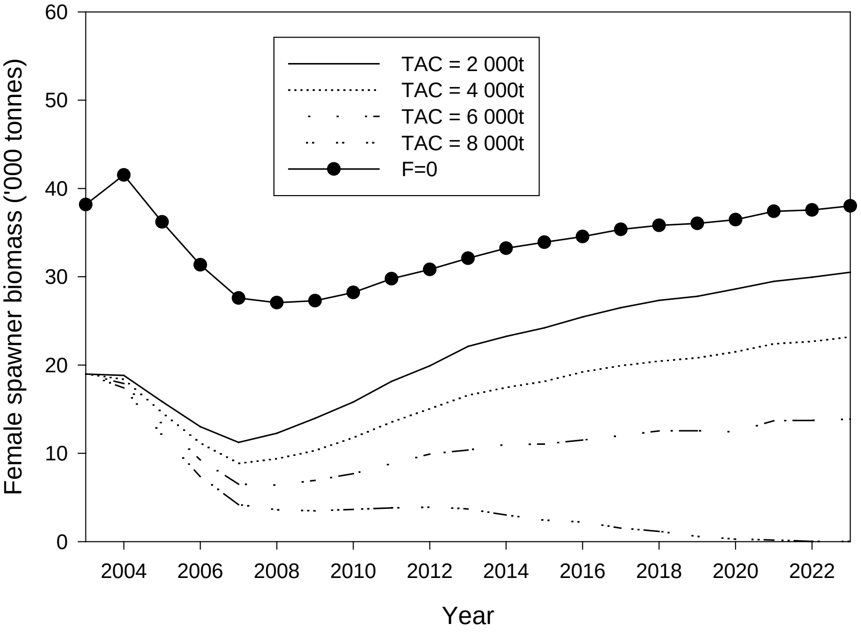


Figure 5.15. Estimated median female spawner biomass for the base-case model under four future constant TACs and F=0.

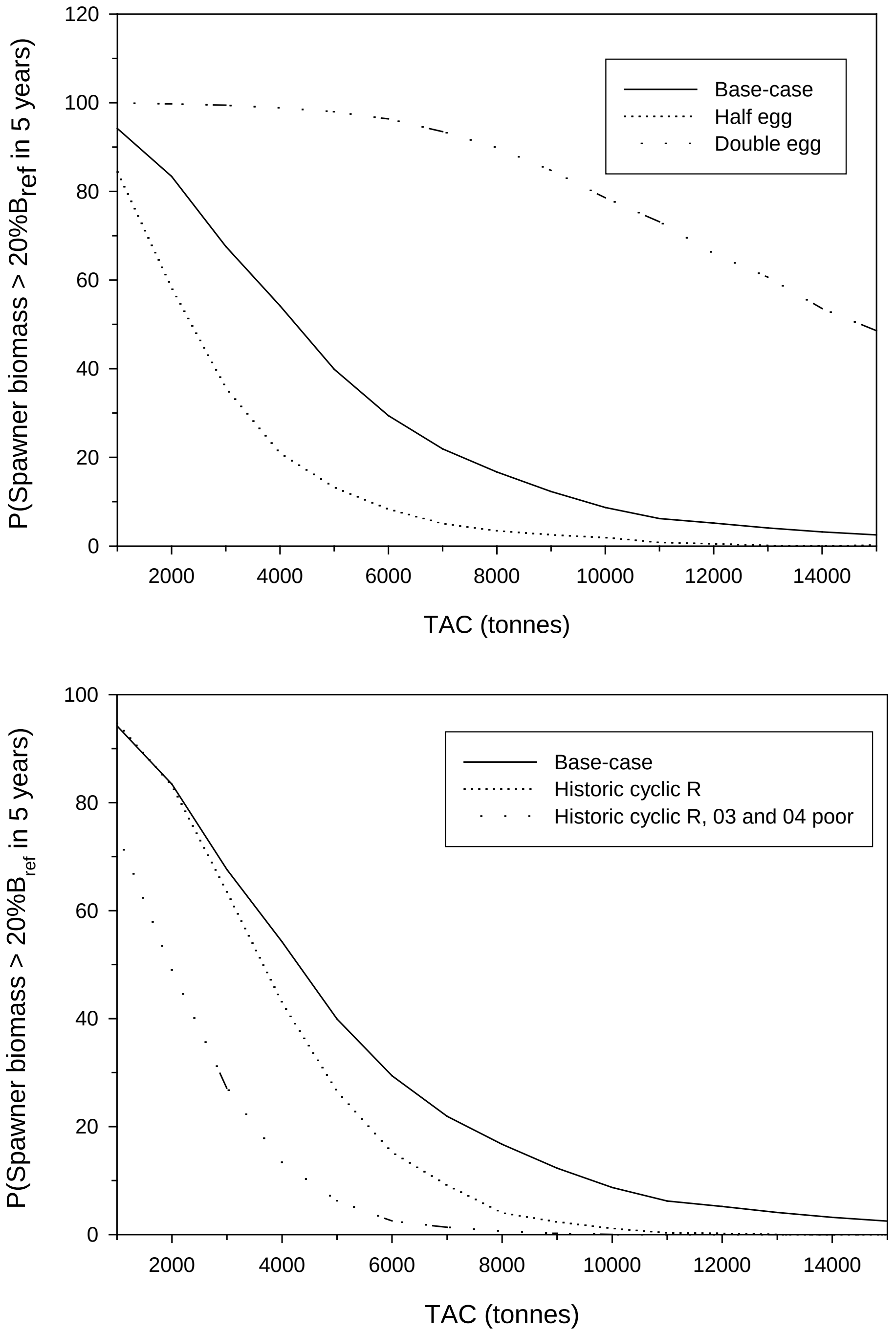


Figure 5.16. The probability that the female spawner biomass is greater than 20% of the reference biomass in 5 years time for (top) base-case and half and double egg survey estimates; (bottom) base-case and two scenarios with recruitment having cyclic periods.

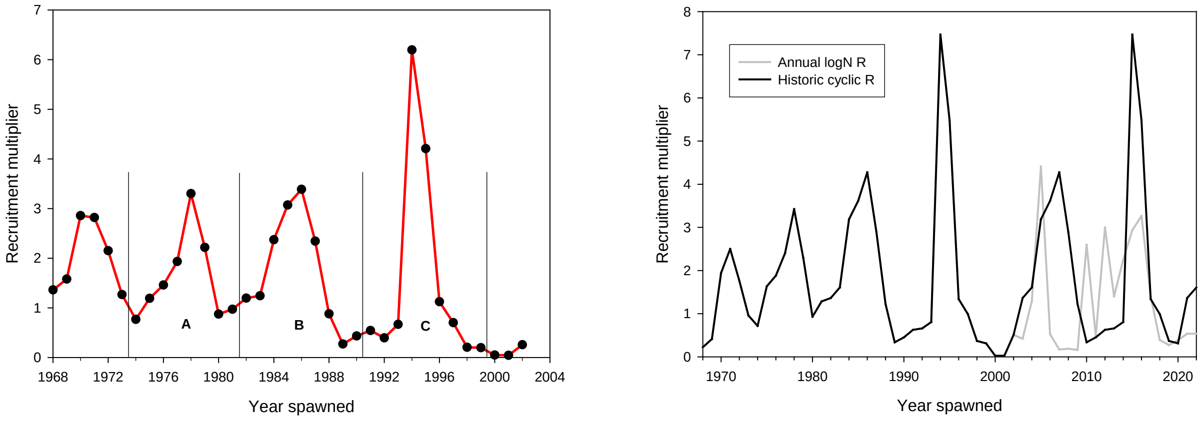


Figure 5.17. Left: The estimated recruitment multipliers for the base-case model with the designated historical cycles (named A, B and C) used in the model of future recruitments where future recruitment multipliers are given from a random selection of these 3 periods. Right: An example from one projection simulation showing the different recruitment multipliers chosen for the 2 recruitment models (i) having multipliers derived from a log normal distribution (grey), and (ii) assigned according to a random choice of the 3 historic periods A, B and C (black).

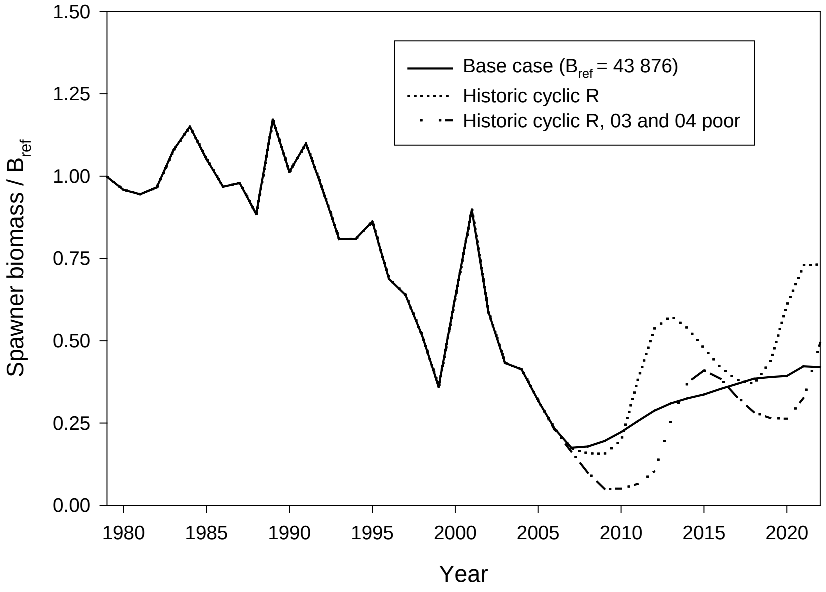


Figure 5.18. Estimated historic and future median spawner biomass for blue grenadier, shown as a function of B_{ref}. with future annual TAC=5000 t. Shown are the base-case model projections, with annual recruitment anomalies derived from a log-normal distribution and 2 alternative recruitment models to account for the apparent cyclic nature of recruitment. ‘Historic cyclic R’ draws randomly from 3 periods of approximately 9 year cycles since 1974. ‘Historic cyclic R, 03 and 04 poor’, assumes that the recruitment of 2003 and 2004 is equivalent to that of 2000, and then draws randomly from the 3 recruitment cycles.

APPENDIX 5.A : The population dynamics model and likelihood model

The equations presented in this appendix have been adapted from those in Punt *et al.* (2001).

5.A.1 Basic dynamics

The dynamics of animals of sex *s* aged 1 and above are governed by the equation:

$$N^s_{y+1,a} = \begin{cases} N^s_{y+1,1} & \text{if } a = 1 \\ N^s_{y,a-1} e^{-Z^s_{y,a-1}} & \text{if } 1 < a < x \\ N^s_{y,x}\, e^{-Z^s_{y,x}} + N^s_{y,x-1}\, e^{-Z^s_{y,x-1}} & \text{if } a = x \end{cases} \qquad (5.A.1)$$

where $N^s_{y,a}$ is the number of fish of sex *s* and age *a* at the start of year *y* (where *y* runs from 1 to *t*),

$Z^s_{y,a}$ is the total mortality on fish of sex *s* and age *a* during year *y*:

$$Z^s_{y,a} = M^s + S^1_a\, F^1_y + S^2_a\, F^2_y \qquad (5.A.2)$$

M^s is the (age-independent) rate of natural mortality for animals of sex *s*,

$S^f_{y,a}$ is the vulnerability by sub-fishery *f* (*f*=1 for the ‘spawning’ sub-fishery, and *f*=2 for the ‘non-spawning’ sub-fishery) on fish of age *a* during year *y*,

F^f_y is the fully-selected fishing mortality by sub-fishery *f* during year *y*, and

x is the maximum age-class (taken to be a plus-group).

The number of 1-year-olds of sex *s* at the start of year *y*+1 is related to the spawner biomass of females in the middle of the preceding year according to the equation:

$$N^s_{y+1,1} = \left[0.5\,\tilde{B}_y\,/(\alpha + \beta\,\tilde{B}_y)\right] e^{\varepsilon_y} \qquad (5.A.3)$$

where $\tilde{B}_y$ is the spawner biomass of females in the middle of year y:

$$\tilde{B}_y = \mu \sum_{a=1}^{x} f_{y,a}\, w_{y,a}\, N^{\mathrm{f}}_{y,a}\, e^{-Z^{\mathrm{f}}_{y,a}/2} \qquad (5.A.4)$$

μ is the proportion of mature females that spawn each year,

$f_{y,a}$ is the proportion of females of age *a* that are mature during year *y*:

$$f_{y,a} = \begin{cases} 1 & \text{if } L_{y,a} \geq 70\,\text{cm} \\ 0 & \text{otherwise} \end{cases}$$

$w_{y,a}$ is the mass of a fish of age *a* in the middle of the year *y*,

$L_{y,a}$ is the mean length of a fish of age *a* during year *y* (given either by the empirical mean length-at-age each year, or from the fit of a von Bertalanffy growth curve),

α, β are the parameters of the stock-recruitment relationship, and

ε_y is the recruitment residual for year *y* (for ease of presentation, $\exp(\varepsilon_y)$ will be referred to as the recruitment anomaly for year *y*).

The values for α and β are determined from the steepness of the stock-recruitment relationship (*h*) and the virgin biomass (B_0) using the equations of Francis (1992). The assumption that maturity is knife-edged at 70 cm is very crude and a research project has been proposed to provide a more realistic picture of maturity as a function of length. In principle, the probability of being mature-at-length could have been assumed to be the same as vulnerability to the 'spawning' sub-fishery. This assumption has been made for assessments of blue grenadier in New Zealand (e.g. McAllister *et al.* 1994). However, it may be substantially in error for blue grenadier in Australia because it is known that fish of different sizes arrive on the spawning grounds at different times, and that some immature fish are caught during the 'spawning' sub-fishery.

The specifications for the numbers-at-age at the start of 1979 are based on the assumption that the stock would have been close to its unexploited equilibrium size at that time:

$$N^s_{1979,a} = 0.5\begin{cases} R_0\, e^{-(a-1)M^s}\, e^{\varepsilon_a} & \text{if } a < x \\ R_0\, e^{-(x-1)M^s} / (1 - e^{-M^s}) & \text{if } a = x \end{cases} \qquad (5.A.5)$$

where R_0 is the expected number of 1-year-olds at unexploited equilibrium (the sex ratio at age 1 is taken to be 1:1), and

ε_a is the recruitment residual for age *a*.

The equation for the plus-group does not include a contribution by a recruitment residual because this group comprises several age-classes, which will largely damp out the impact of inter-annual variation in year-class strength.

5.A.2 Vulnerability

The vulnerability of the gear is governed by a logistic curve that permits the probability of capture to drop off with length:

$$S^f_{y,a} = \begin{cases} (1 + e^{-\ell n 19 (L_{y,a} - L^f_{50})/(L^f_{95} - L^f_{50})})^{-1} & \text{if } L_{y,a} \le L^f_{95} \\ (1 + e^{-\ell n 19 (L_{y,a} - L^f_{50})/(L^f_{95} - L^f_{50})})^{-1} e^{-\lambda^f (L_{y,a} - L^f_{95})} & \text{otherwise} \end{cases} \qquad (5.A.6)$$

where L^f_{50} is the length-at-50%-vulnerability for sub-fishery *f*,

L^f_{95} is the length-at-95%-vulnerability for sub-fishery *f*, and

λ^f is the "vulnerability slope" for sub-fishery *f*.

The vulnerability pattern for the ‘spawning’ sub-fishery is assumed to be asymptotic (i.e. $\lambda = 0$ for the ‘spawning’ sub-fishery).

5.A.3 Catches

The catch (in number) of fish of age *a* by sub-fishery *f* during year *y*, $\hat{C}^f_{y,a}$, and the number of fish of age *a* discarded by sub-fishery *f*, during year *y*, $\hat{D}^f_{y,a}$, are given by the equations:

$$\hat{C}^f_{y,a} = \sum_s \frac{(1-P_{y,a}) S^f_{y,a} F^f_y}{Z^s_{y,a}} N^s_{y,a} (1-e^{-Z^s_{y,a}}) \qquad (5.A.7a)$$

$$\tilde{D}^f_{y,a} = \sum_s \frac{P_{y,a} S^f_{y,a} F^f_y}{Z^s_{y,a}} N^s_{y,a} (1-e^{-Z^s_{y,a}}) \qquad (5.A.7b)$$

where $P_{y,a}$ is the probability of discarding a fish of age *a* during year *y*:

$$P_{y,a} = \frac{\gamma(\sum_s N^s_{y,1})^\phi / \max_{y'}(\sum_{s'} N^{s'}_{y',1})^\phi}{1+e^{-(L_a - L^D_{50})/\delta}} \qquad (5.A.8)$$

γ is the maximum possible discard rate for the largest year-class,

L^D_{50} is the length at which discarding is half the maximum possible rate,

δ is the parameter that determines the width of the relationship between length and the discard probability, and

ϕ is the parameter that controls the extent of density-dependent discarding.

The rate of discarding is therefore assumed to be related only to the size of the year-class at birth; the impact of density-dependence on the rate of discarding is assumed to be constant during the whole of an animal’s life. The first assumption will be violated to some extent because *inter alia* the rate of discarding will depend on the abundance of other year-classes in the population (through high-grading). Violation of the second assumption is probably inconsequential because for older ages the form of the denominator of Equation (5.A.8) will mean that $P_{y,a} \approx 0$.

The model estimates of the catch (in mass) by sub-fishery *f* during year *y*, $\hat{C}^f_y$, and of the mass of fish discarded by sub-fishery *f* during year *y*, $\hat{D}^f_y$, are given by the equations:

$$\hat{C}^f_y = \sum_{a=1}^{x} w_{y,a} \hat{C}^f_{y,a} \qquad (5.A.9a)$$

$$\hat{D}^f_y = \sum_{a=1}^{x} w_{y,a} \hat{D}^f_{y,a} \qquad (5.A.9b)$$

Equations (5.A.9a) and (5.A.9b) imply that the (expected) mass of a fish of age *a* that is discarded is the same as the (expected) mass of a fish of age *a* that is retained.

5.A.4 The likelihood function

The negative of the logarithm of the likelihood function includes five contributions. These relate to minimising the sizes of recruitment residuals, fitting the observed catches / discards by fleet, fitting the observed catch / discard age-compositions, fitting the catch rate information, and fitting the estimates of spawner biomass from the egg-production method.

$$L = \sum_{i=1}^{5} L_i \tag{5.A.10}$$

The contribution of the recruitment residuals to the negative of the logarithm of the likelihood function is based on the assumption that the inter-annual fluctuations in year-class strength are independent and log-normally distributed with a CV of σ_r [2]:

$$L_1 = \tfrac{1}{2\sigma_r^2}\left(\sum_{a=1}^{x-1}\varepsilon_a^2 + \sum_{y=1}^{t-1}\varepsilon_y^2\right) \tag{5.A.11}$$

The contribution of the observed catch (in mass) information to the negative of the logarithm of the likelihood function is based on the assumption that the errors in measuring the catch in mass are log-normally distributed with a CV of σ_c:

$$L_2 = \tfrac{1}{2\sigma_c^2}\sum_{f}\sum_{y=1}^{t}(\ell\mathrm{n}C_y^{f,\mathrm{obs}} - \ell\mathrm{n}\hat{C}_y^{f})^2 \tag{5.A.12}$$

where $C_y^{f,\mathrm{obs}}$ is the observed catch (in mass) by sub-fishery *f* during year *y*.

The contribution of the observed mass of discards to the negative of the logarithm of the likelihood function follows Equation (5.A.12) except that $\hat{C}_y^f$ is replaced by $\hat{D}_y^f$, $C_y^{f,obs}$ is replaced by the observed mass of discards by sub-fishery *f* during year *y*, and the summations over year are restricted to those years for which estimates of discards are available.

The contribution of the age composition information to the negative of the logarithm of the likelihood function is based on the assumption that the age-structure information is determined from a random sample of *N* animals from the catch:

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[2] The summation in Equation (5.A.11) runs to *x*-1 and *t*-1 because the plus-group (age *x*) is not impacted by variability in year-class strength, and because the model is not used to predict the number of 1-year-olds for year *t*+1.

$$L_3 = -\sum_f \sum_y \sum_{a=1}^{15+} N\, \rho_{y,a}^{f,\mathrm{obs}}\, \ell n(\hat{\rho}_{y,a}^{f}) \tag{5.A.13}$$

where $\rho_{y,a}^{f,\mathrm{obs}}$ is the observed proportion which fish of age a made up of the catch during year y by sub-fishery f,

$\hat{\rho}_{y,a}^{f}$ is the model-estimate of the proportion which fish of age a made up of the catch during year y by sub-fishery f:

$$\hat{\rho}_{y,a}^{f} = \sum_{a''} \chi_{a,a''}\, \hat{C}_{y,a''}^{f} \Big/ \sum_{a'=1}^{x} \hat{C}_{y,a'}^{f} \tag{5.A.14}$$

$\chi_{a,a'}$ is the probability that an animal of age a' will be found to be age a (the age-reading error matrix. For the models presented in this chapter the age-reading error is ignored and thus the matrix is diagonal).

Note that all animals aged 15 and older are treated as a single “age-class” when fitting to the catch proportion-at-age information. This prevents data for older fish (for which there is relatively little data) having a disproportionate influence on the results. The summations over year include only those years for which age-composition data are available. The contribution of the age-composition of the discards follows Equations (5.A.13) and (5.A.14), except that $\hat{\rho}_{y,a}^{f}$ is replaced by the model-estimate of the proportion which fish of age a made up of the discards during year y by sub-fishery f, and $\rho_{y,a}^{f,obs}$ is replaced by the observed proportion which fish of age a made up of the discards during year y by sub-fishery f.

The contribution of the catch rate data to the negative of the logarithm of the likelihood function is based on the assumption that fluctuations in catchability are log-normally distributed with a CV of σ_q:

$$L_4 = \tfrac{1}{2\sigma_q^2} \sum_f \sum_y (\ell \mathrm{n} I_y^f - \ell \mathrm{n}(q^f\, B_y^f))^2 \tag{5.A.15}$$

where q^f is the catchability coefficient for sub-fishery f, and

I_y^f is the catch-rate index for sub-fishery f and year y, and

B_y^f is the mid-season (available) biomass for sub-fishery f and year y:

$$B_y^f = \sum_s \sum_a w_{y,a}\, (1 - P_{y,a})\, S_a^f\, N_{y,a}^s\, e^{-Z_{y,a}^s/2} \tag{5.A.16}$$

The summation over year includes only those years for which catch rate data are available.

The contribution of the egg-production or acoustic estimates to the negative of the logarithm of the likelihood function is given by:

$$L_5 = \sum_{y=1994/5} (\widetilde{B}_y - B_y^{obs})^2 /(2\sigma_y^2) \qquad (5.A.17)$$

where B_y^{obs} is the estimate of female spawner biomass for year y based on egg-production or acoustic methods, and

σ_y is the standard error of B_y^{obs}.

6. Stock Assessment for Blue Warehou (*Seriolella brama*) Based on Data up to 2003

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6.1 Background

Blue warehou (*Seriolella brama*) are found in continental shelf and upper slope waters throughout south-eastern Australia (NSW, Victoria, Tasmania and South Australia). The species is also found in New Zealand waters. Adults are caught in depths to 500 m, although most commercial catches occur from 50 to 300 m. Spawning occurs during winter-spring in various locations throughout the adult distribution of the species (Knuckey and Sivakumaran, 2001). Small juveniles are pelagic, commonly occurring in association with jellyfish in open coastal waters, and sub-adults often occur in the sheltered waters of large marine embayments. Growth is rapid, with a mean length of about 20 cm LCF being attained after one year (Figure 6.1). The species has a maximum age of about 15 years. Recent studies suggest that maturity occurs at 3-4 years of age (Knuckey and Sivakumaran, 2001).

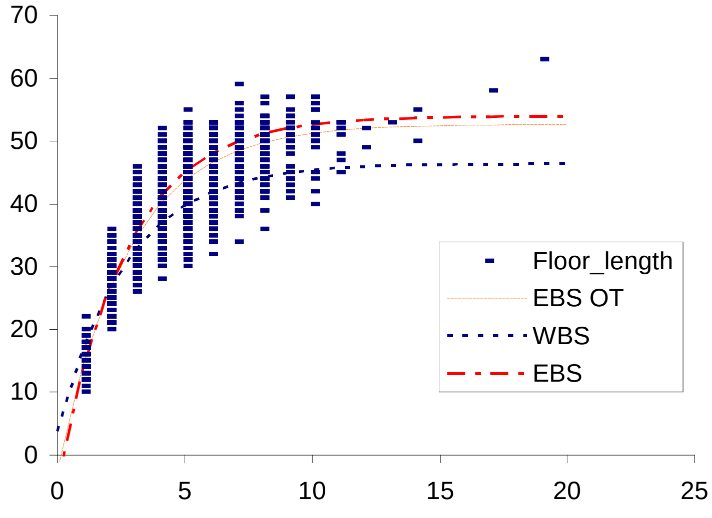

Figure 6.1 : Von Bertalanffy growth curves for blue warehou taken west of Bass Strait (WBS) and east of Bass Strait (EBS). “EBS” includes trawl and non-trawl catches, “EBS OT” includes trawl-caught fish only. (Source: Smith and Wayte (2004)).

Assessments prior to 2000 were based on the assumption that blue warehou form a single stock off southeast Australia, given an absence of evidence to support a more complicated stock structure. However, there was increasing, though indirect, evidence for separate stocks to the east and west of Bass Strait: (a) two main spawning areas, (b) differences in the size- and age-compositions of the catch east and west of Bass Strait, and (c) differences in growth between areas (e.g. Figure 6.1). Recently Talman *et al.*

(2003) found that several techniques, including MtDNA, morphometrics, otolith microchemistry and otolith shape analysis indicated significant differences east and west of Bass Strait. Given this strong evidence for separate stocks east and west of Bass Strait, results are not reported in this Chapter for the scenario in which there is a single stock of blue warehou.

This chapter outlines and then applies a stock assessment method to estimate past trends in abundance of blue warehou. This assessment then forms the basis for population projections to assess the risk associated with different levels of future catch.

6.1.1 Previous assessments

Quantitative analyses based on fitting population dynamics models to catch, catch-rate and catch-at-age data have formed the basis for stock assessments since the establishment of the Blue Warehou Assessment Group (BWAG) in 1997. Prior to 1997, management advice was based on the results of a yield-per-recruit analysis (Smith *et al.* 1994) and from visual examination of trends in catch and in nominal and GLM-standardized catch-rates (Smith and Wayte, 2004).

The 1997 and 1998 assessments of blue warehou were based on the application of a fleet-disaggregated Virtual Population Analysis to catch-at-age and standardized fishing effort data (Punt, 1998). These assessments involved three fleets (“western trawl”, “eastern trawl” and “non-trawl”). From 1999 onwards, assessments of blue warehou (Punt, 1999, 2000) have been based on the ‘integrated analysis’ approach (e.g. Methot 1989, 1990, 2000; Haist *et al.,* 1993; Smith and Punt, 1998). This approach forms the basis for the bulk of the assessments of species in Australia’s South East Fishery (Smith *et al.* 2001). Information on catches, discard rates, catch rates, and the length/age of discards and landed catch were included in the 1999 and 2000 assessments. The 1999 and 2000 assessments of blue warehou were based on four (rather than three) fleets (“western trawl”, “eastern trawl”, “non-trawl” and the Tasmanian meshnet fishery).

6.2 Data

There are many sources of data for blue warehou. These include values for biological parameters, landed catches, discard rates (defined here as the ratio of the discard catch (in mass) to the landed catch), catch-rates, length-frequencies for the landed and discarded catches, and age-length keys.

As was the case for the 1999 and 2000 assessments, the following four “fleets” are considered in the assessment:

(i) the otter trawl fishery in regions 10, 20 and 30 of the SEF (denoted “east trawl”),
(ii) the otter trawl fishery in regions 40, 50 and 60 of the SEF (denoted “west trawl”),
(iii) the meshnet fishery off Tasmania (denoted “Tas meshnet”), and
(iv) the Commonwealth gill-net fishery (denoted “non-trawl”).

These four “fleets” were selected by BWAG after consideration of their catch length-frequency distributions, and the likely impact of management measures (e.g. the Tasmanian meshnet fishery is not covered by the *TAC*s set by AFMA). The following sections outline the data available for assessment purposes. The analyses are conducted assuming that the 'west trawl' fleet is fishing a different stock from the other three fleets.

In addition to conducting analyses based on the assumption of a calendar year lifecycle, analyses are also conducted assuming a 'biological year' lifecycle, where the biological year is defined as 'May – April', based on spawning starting in winter. This requires that each of the data sources need to be computed for calendar as well as biological years.

6.2.1 Catches

Information on catches is available from the SEF1 and GNO1 logbooks, the SEF2 and SAN2 catch validation databases, from Tasmania, and from historical records (for the years prior to 1986 (SEF1) and 1997 (GNO1) – data are available for 1985 in the SEF1 database but these data are known to be subject to considerable uncertainty). Blue warehou are closely related to spotted warehou and mixed catches do occur. Early catch statistics were recorded for all warehou species combined, commonly referred to as 'Tassie trevally'. Comparisons between logbook and 'verified' catch data in the late 1980s also indicated problems with correct recording of each species. However, consideration by SEFAG of the two data sets indicated that records in the SEF1 logbook gave the best data on individual species.

For the trawl fishery, the annual catches by fleet were extracted from the SEF1 database. These catches were then rescaled so that the total (over fleet) catch by species equals the total validated catch based on the SEF2 records, i.e.:

$$\tilde{C}_y^f = \tilde{C}_y^{f,\mathrm{SEF1}} \frac{\tilde{C}_y^{\mathrm{SEF2}}}{\sum_{f'} \tilde{C}_y^{f',\mathrm{SEF1}}} \tag{6.1}$$

where $\tilde{C}_y^f$ is the catch (in mass) by fleet f ('east trawl' and 'west trawl') during year y used in the analyses,

$\tilde{C}_y^{f,\mathrm{SEF1}}$ is the catch (in mass) by fleet f during year y recorded in the SEF1 database, and

$\tilde{C}_y^{\mathrm{SEF2}}$ is the catch (in mass) during year y recorded in the SEF2 database.

Ideally Equation 6.1 should have been applied by fleet. Unfortunately, it is currently infeasible to link the SEF2 records with the SEF1 records to enable an appropriate comparison to be made (the SEF2 records are by port and vessel callsign whereas the SEF1 records are shot-by-shot).

SEF2 catches are only available from 1992. It is therefore not possible to apply Equation 6.1 directly for the years prior to 1992. For the purposes of the analyses of this report therefore, the catches prior to 1992 have been adjusted using the formula:

$$\tilde{C}_y^f = \tilde{C}_y^{f,\mathrm{SEF1}} \frac{\sum\limits_{1992 \le y \le 1998} \tilde{C}_{y'}^{\mathrm{SEF2}}}{\sum\limits_{1992 \le y \le 1998} \sum\limits_{f'} \tilde{C}_{y'}^{f,\mathrm{SEF1}}} \tag{6.2}$$

The adjustment factor for the pre-1992 catches is 1.17. The catches by biological year are obtained by adding the SEF1 catches (after the adjustments based on Equations 6.1 and 6.2 are made) for May-December for year *y* to those for January-April for year *y*+1, i.e. the biological-year catches are computed by first adjusting the annual catches so that they sum to the SEF2 catches on an annual basis and then splitting the catches to month and hence biological year.

The catches by the non-trawl fleet for the years 1997–2002 were extracted from the GN01 logbook records. No attempt was made to adjust these catches so that they equal the total catches recorded in SAN2 database. The non-trawl catches for 1986–96 were provided by Dr David Smith. Catches of blue warehou are made off the northwest and southeast of Tasmania, but the bulk of the catch is taken off the southeast (82% - 1996–2002). Given the lack of data on length-frequency for many years and the fact that most of the catch is taken from the southeast of Tasmania, all of the catches off Tasmania are assumed to be taken from the eastern stock.

Table 6.1 lists the catches by fleet included in the analyses of this report.

6.2.2 Catch-rates

Catch-rate data constitute the primary source of information to determine trends in population size for the species in the South East Fishery. However, the catch and effort data need to be standardized to (attempt to) eliminate the impact of factors other than changes in abundance on trends in catch-rates (Gavaris, 1980; Kimura, 1981; Vignaux, 1994). Catch-rate indices were developed for the ‘east trawl’, ‘west trawl’ and ‘non-trawl’ fleets by fitting a linear model (with normal error structure) to log-transformed catch rate data (Haddon, 2003). This approach has been used widely to standardize catch and effort data for SEF species (e.g. Klaer, 1994; Punt *et al.* 2001a).

The model fitted to the trawl data (separately for ‘east trawl’ and ‘west trawl’) was:

$$\text{Log}(C/E) = \text{Constant} + \text{Year} + \text{Month} + \text{Zone} + \text{Boat\_name} + \text{Depth} + \text{Month}*\text{Zone}$$

where year, month, zone, and boat_name are categorical variables. The depth of the catch was transformed from a continuous variable to a discrete variable by dividing the range of depths into 50 m intervals (Haddon, 2003). Only those vessels active in the fishery for more than two years and with median annual catches greater than 4 tonnes were included in the analysis. Records in which the catch or the effort was zero were ignored when standardizing the catch and effort data.

The non-trawl catch-rate indices were based on the application of a GLM model to catch and effort data for a subset of the non-trawl fleet. The number of records drops over time. The base-case analyses consequently ignore the data point for the last year of this index (1999 for the calendar-year analyses and 1999/2000 for the biological-year analyses).

The standardized catch-rate indices used in the analyses are listed in Table 6.1

6.2.3 Discard rates

Information on the fraction of the catch (in mass) which is discarded annually is available from onboard observers. Two observer programmes, the SMP (Liggins *et al.* 1997) and the ISMP (Knuckey *et al*., 1999) have collected onboard data which can be used to estimate discard rates. The data collected by observers are estimates by shot of the mass retained and the mass discarded. The discard rate used here is simply the ratio of the mass discarded (summed over all shots by a given fleet in a given year) to the retained mass. The data were validated by excluding any records for which the gear code was not bottom trawl and in which the catch did not occur in one of SEF zones 10, 20, 30, 40, 50 or 60. The resultant discard rates are listed (by year and fleet) in Table 6.1. The data prior to 1996 are not included in the analyses of this report due to small sample sizes.

6.2.4 Age- and length-frequency data

Length frequency data are available from port measurers and from onboard sampling. The former generally involve much larger sample sizes than the latter (Table 6.2). In contrast, the onboard sampling programmes provide information on the length-frequencies of the discarded as well as the landed catch.

6.2.4.1 Port length-frequencies

The port length-frequencies for a given fleet are constructed from the raw data collected by the measurers using the equation:

$$N^f_{y,L} = \sum_v \tilde{N}^{f,v}_{y,L} / R^{f,v}_y \tag{6.3}$$

where $N^f_{y,L}$ is the number of animals in the component of the landed catch by fleet f during year y that was measured that are in length-class L,

$\tilde{N}^{f,v}_{y,L}$ is the number of animals in the v^{th} sample collected from the landed catch by fleet f during year y that are in length-class L, and

$R^{f,v}_y$ is the fraction of the catch of the v^{th} sample collected from the landed catch by fleet f during year y that was measured.

This approach to constructing catch length-frequencies is based on the assumption that the samples for a given fleet are a simple random sample of the catch of that fleet. In principle, this approach to constructing length-frequencies could be generalized so that, for example, port-specific length-frequencies are constructed and these then weighted by the port-specific contribution to the overall catch. Any reported catches of fish smaller than 24cm are assumed to be errors and are discarded.

Figure 6.2 plots the port-based length-frequencies from the ISMP database for 1991–2003. Results are shown in Figure 6.2 for the three key ports (Eden, Lakes Entrance, and Portland) and for three SEF zones (East A, East B, and West). Eden, Lakes Entrance and Portland constitute 98% of the length-frequency records. The other ports for which data are available are Hobart, Beachport, and Bermagui. As expected, the length-frequencies for the West zone are based almost exclusively on the data for vessels from Portland. The picture in the east is less clear because: a) the length-frequencies for vessels based in Eden and those based in Lakes Entrance often differ substantially, and b) there is not a clear match between the port-based length-frequencies by port and the port-based length-frequencies by SEF zone. The port-based length-frequencies on which the analyses of this report are based were constructed as follows: ‘west trawl’ – the port-based length-length-frequencies for vessels from Portland; ‘east trawl’ – the port-based length-frequencies for vessels from Eden (1998–2002) and data collected at sea and in port from Eden-based vessels (1994–97) by the SMP. The latter data are included in the assessment because the sample sizes prior to 1997 in Figure 6.2 are very small. In contrast, the SMP sample sizes for 1994–97 are 2889, 2260, 2833 and 3730 respectively (Table 6.2). The data set ‘west trawl’ starts in 1991 (Figure 6.2). However, data on length-frequency are available for the west for 1987 and 1988 (Smith *et al*., 1995).

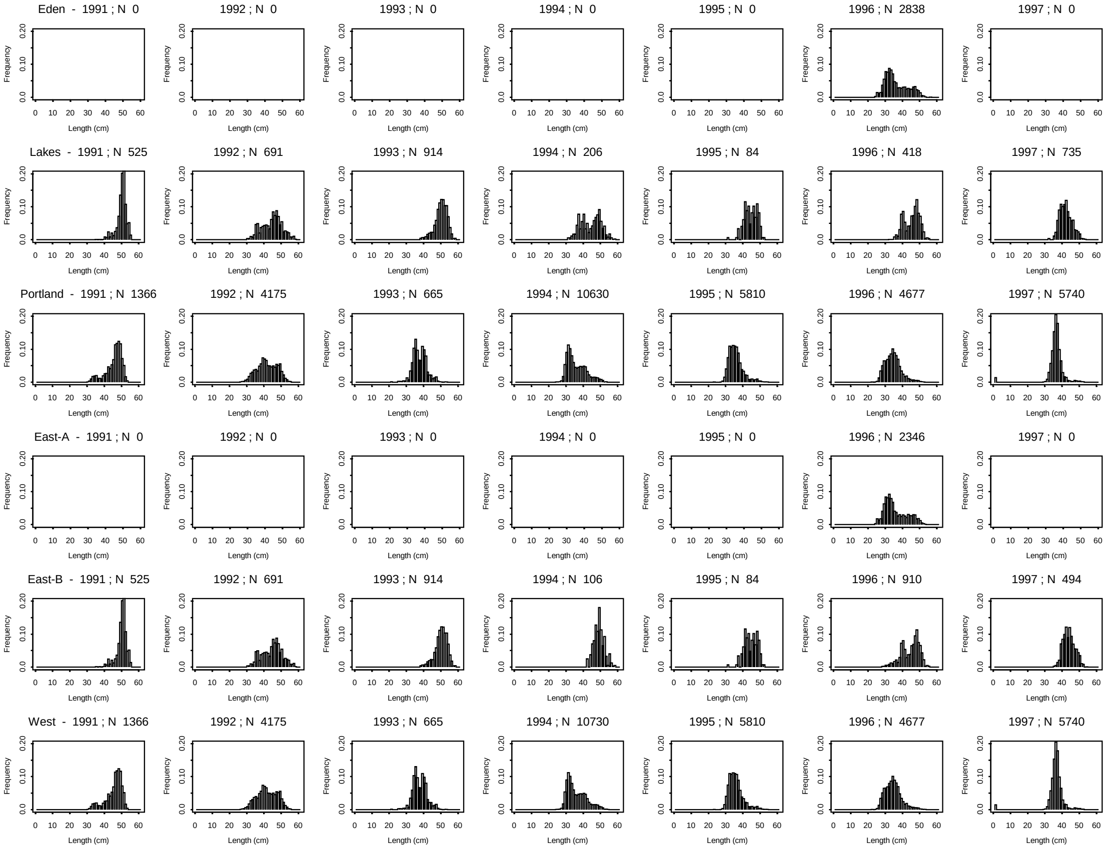

Figure 6.2a : Port-based length-frequency data from the SMP and ISMP for blue warehou. Results are shown by port of landing (Eden, Lake Entrance, Portland) and by SEF zone (East A, East B, and West).

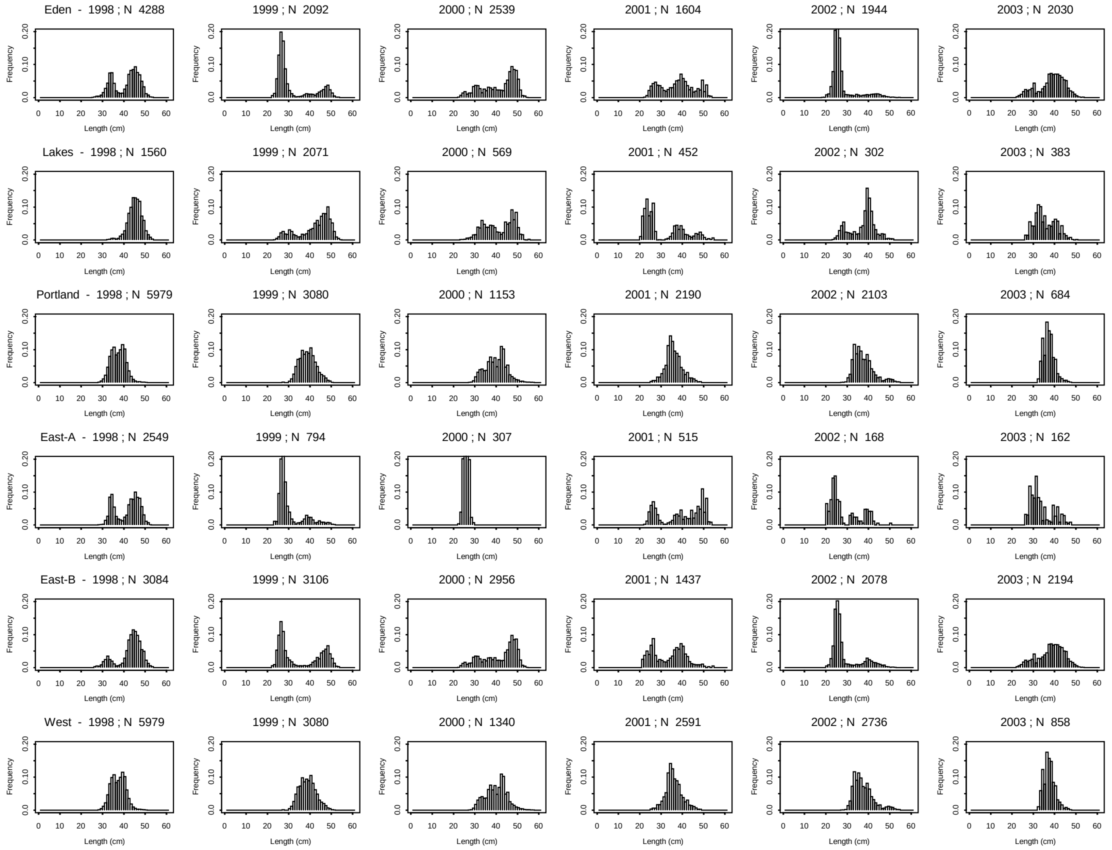

Figure 6.2b : Port-based length-frequency data from the SMP and ISMP for blue warehou. Results are shown by port of landing (Eden, Lake Entrance, Portland) and by SEF zone (East A, East B, and West).

The length-frequency data for Tasmania for 1997–99 were supplied by Jeremy Lyle (TAFI, pers. comm.). Table 6.2 lists the sample sizes on which the analyses are based and which are used when weighting the data during model fitting.

6.2.4.2 *Discard length-frequencies*

The proportion of the trawl catch which is discarded by length-class can be determined from the onboard length-frequency data using Equation 6.3. Information on discards is available for the years 1993–2002. However, the discard data (discard rates and length-frequencies) for the years 1993–95 are ignored (Table 6.1) because they are based on small sample sizes (Table 6.2), were collected from a pilot programme, and appear anomalous in several respects.

6.2.4.3 *Age-composition data*

Over 4000 fish have now been aged using sectioned (rather than whole) otoliths by the Central Ageing Facility in Queenscliff. Unlike results from ages estimated using whole otoliths, it now appears possible to track age classes between years. The ageing data have been used to construct age-length keys for the ‘east’ and ‘west’ stocks. Table 6.2 lists the sample sizes for each year.

Age-composition data (port / on board - by fleet and year) have been constructed by multiplying the length-frequencies by the stock- and year-specific age-length keys (length-at-age is assumed to be independent of fleet). The assumption that length-at-age is independent of fleet[3] will be invalid to some extent if selectivity is strongly size-dependent (Walker *et al*., 1998).

There are cases in which length-frequency data exist for some (2 cm) length-classes for which age data are not available. When this happened, the length-classes adjacent to that for which age data were required were investigated and the age data for these length-classes averaged to obtain age data for the length-class for which this was needed. This process of searching adjacent length-classes was repeated if the length-classes adjacent to that for which age data were needed also had no age data and this process of an expanding search repeated until ageing data were obtained. Ages greater than 7 were pooled into a plus-group at age 7.

6.3 Analytical approach

6.3.1 Overview of the model and the likelihood function

Appendix 6.A details the population dynamics model underlying the assessment. It is age-structured but allows selectivity and the probability of discarding to depend on length rather than on age. Variability in length-at-age is accounted for when converting from selectivity in terms of length into selectivity in terms of age. The probability of discarding is assumed to depend on fleet and fish size but to be independent of time. This last assumption will be violated to some extent if markets change their preferences for different sizes of fish over time. Discarding is assumed to be substantial for only the “east” and “west” fleets. The assessment is based on the assumption that the catch is taken instantaneously in the middle of the year (Pope’s approximation – Pope, 1972). This assumption substantially reduces the time required to conduct the calculations with negligible impact to the overall assessment.

Appendix 6.B details the contribution of each data source to the negative of the logarithm of the likelihood function. Two approaches for including the length-frequency / age-length data are considered: treating these as separate data sources or multiplying the age-length keys by the length-frequencies to obtain age-compositions. The analyses of this paper are based primarily on the former because it better represents the underlying structure of the data although sensitivity is explored to fitting to the age-composition data in the tests of sensitivity.

6.3.2 Parameter estimation

In principle, it is possible to estimate the values for all of the parameters of the model (Table 6.3) but paucity of data precludes this in practice. Thus, for example, the rate of natural mortality, M, is pre-specified rather than estimated. The base-case value for M is 0.45yr^{-1} and sensitivity is explored to choices of 0.3yr^{-1}, 0.4yr^{-1}, 0.5yr^{-1} and 0.6yr^{-1}. The base-case assumptions that selectivity is time-invariant and that its dependence on

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[3] Growth is estimated separately for the eastern and western stocks.

length can be described by one of two simple functional forms (see Equation 6.A.7) reduces the number of "free" parameters markedly. Table 6.3 lists the 39 (38 for a "calendar year" analysis) "free" parameters of the population dynamics model for the base-case east assessment and the 35 (34 for a "calendar year" analysis) "free" parameters of the population dynamics model for the base-case west assessment. The base-case analysis does not estimate the values for the parameter related to density-dependence in growth rate. Rather than assuming that maturity is a knife-edged function of age, the assessment is based on the assumption that maturity is related to length by a logistic curve with 50 and 95%iles of 33.4 and 42.9 cm, subject to the constraint that all animals smaller than 32 cm or younger than 3 years are immature (Figure 6.3) (Knuckey and Sivakumuran, 2001).

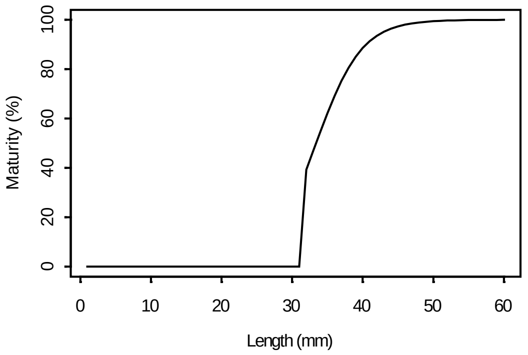

Figure 6.3 : Maturity as a function of length.

It is possible, in principle, to estimate the values for all of the residual standard deviations. However, this can be unreliable, so, instead, the relative magnitudes of the residual standard deviations are pre-specified and an overall residual standard deviation estimated (i.e. for the discard data, $\sigma_d = \tilde{\sigma}_d \, \tilde{\sigma}$ where $\tilde{\sigma}_d$ is relative magnitude of the residual standard deviation for these data and $\tilde{\sigma}$ is the overall residual standard deviation). Table 6.4 lists the base-case choices for the relative residual standard deviations and the weights assigned when a multinomial error model is assumed for the length / age data. The weight, ω, assigned to the age-length key information (see Equation 6.B.6) is 0.05. The extent of variation in recruitment, σ_r, is taken to be 0.6. This assumption essentially places no constraints on the estimates of recruitment.

The values for the parameters that maximise the likelihood function are determined using the AD Model Builder package[4]. Previous assessments (e.g. Punt, 1998, 2000) quantified uncertainty using a bootstrap procedure. In contrast, this assessment quantifies the uncertainty of the estimates of the model parameters and of the other quantities of interest using Bayesian methods. The Metropolis-Hastings variant of the Markov-Chain Monte Carlo (MCMC) algorithm (Hastings, 1970; Gelman *et al.*, 1995; Gilks *et al.*, 1996; Punt and Hilborn, 1997) with a multivariate normal jump function was used to sample 1,000 equally likely parameter vectors from the joint posterior density function. This sample implicitly accounts for correlation among the model parameters and considers uncertainty in all parameter dimensions simultaneously. The samples on which inference is based were generated by running 5,000,000 cycles of the MCMC algorithm, discarding the first 1,000,000 as a burn-in period and selecting every

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[4] Copyright 1991, 1992 Otter Software Ltd.

4,000th parameter vector thereafter. The initial parameter vector was taken to be the vector of maximum posterior density (MPD) estimates. A potential problem with the MCMC algorithm is how to determine whether convergence to the actual posterior distribution has occurred, and the selection of 5,000,000, 1,000,000 and 4,000 was based on generating a sample which showed no noteworthy signs of lack of convergence to the posterior distribution. Whether convergence had occurred was examined by applying the diagnostic statistics developed by Geweke (1992), Heidelberger and Welch (1983), and Raftery and Lewis (1992) and by examining the extent of auto-correlation among the samples in the chain.

6.3.3 Projections and risk analysis

Projections are conducted to assess the risk associated with different future levels of catch. All of the projections are based on fixed levels of catch and hence should over-estimate risk because such projections implicitly assume that future data will be ignored. A more realistic, but computationally more intensive, approach would be to consider feedback-control harvest strategies (e.g. Punt and Smith, 1999; Punt *et al.*, 2001b). However, consideration of such strategies is beyond the scope of this report.

The risk analysis involves projecting the population ahead 5 years (i.e. from 2004 to 2008 - calendar year, and from 2004/05 to 2008/09 – biological year) under different alternative future levels of catch by fleet. Table 6.5 lists the catches considered in the projections. The risk associated with different levels of catch is determined using five performance indicators (reported for t=2008):

(i) $P(\tilde{B}_t > \min(\tilde{B}_y : y = 1991,92..,97)\}$ - the probability that the spawning biomass during year t is greater than the lowest spawning biomass over the period 1991–97.

(ii) $P(\tilde{B}_t > 0.2\tilde{B}_0)$ - the probability that the spawning biomass during year t is greater than 20% of the virgin biomass.

(iii) $P(\tilde{B}_t > 0.3\tilde{B}_0)$ - the probability that the spawning biomass during year t is greater than 30% of the virgin biomass.

(iv) $P(\tilde{B}_t > 0.4\tilde{B}_0)$ - the probability that the spawning biomass during year t is greater than 40% of the virgin biomass.

(v) $P(\overline{F}_t < M)$ - the probability that the arithmetic average fishing mortality on mature animals during year t is less than natural mortality:

$$\overline{F}_y = \tfrac{1}{x-2}\sum_{a=3}^{x} F_{y,a} \tag{6.4}$$

As will be shown later, there is evidence that the average level of recruitment changed in about 1986. This poses some problems for the definition of quantities of management interest such as $\tilde{B}_0$ and for how future recruitment should be generated. Two ways of calculating $\tilde{B}_0$ are explored to overcome this problem, both of which calculate $\tilde{B}_0$ by multiplying the spawning biomass-per-recruit in the absence of exploitation by the average recruitment in the absence of fishing, $\overline{R}$. The two approaches differ in terms of how $\overline{R}$ is calculated.

The first approach ("recent B_0") sets $\bar{R}$ to the average recruitment from 1986 (1985/86 for the analyses based on a biological year) for the years in which the spawning biomass was larger than the median spawning biomass from 1986 (1985/86). This approach effectively assumes that a change in carrying capacity (or a "regime shift") occurred in 1986 and that the recruitment estimates for the years prior to 1986 are not relevant to evaluating the status of the resource relative to reference points.

The second approach ("old B_0") calculates $\bar{R}$ by taking an arithmetic average of all recruitments including those that can be inferred from the age-structure in the first year of the analysis. These latter recruitments are calculated using the formula:

$$N_{y_1-a+1,1} = N_{y_1,a} / \prod_{a'=1}^{a-1} [1 - e^{-M}(1 - \sum_f F^f_{y_1,a'})] \qquad (6.5)$$

where y_1 is the first year considered in the analyses (either 1986 or 1985/86).

This second approach implicitly assumes that any patterns in recruitment are random. Another (and, perhaps in the longer term, better) way to estimate $\tilde{B}_0$ is to fit a stock-recruitment relationship. However, the time-series of stock and recruitment data for blue warehou is currently very short. Nevertheless, the idea of attempting to fit a stock-recruitment relationship should be considered during the next assessment because the results for some of the analyses (e.g. biological year for the western stock) are suggestive of a relationship between spawning biomass and subsequent recruitment.

It is necessary to generate future recruitments to conduct the projections. In the absence of sufficient data to attempt to fit a stock-recruitment relationship, future recruitments are either selected at random from those for the years 1986-2003 (1985/86–2003/04) ("recent B_0") or from all recruitments, including those inferred from the age-structure in the first year of the analysis ("old B_0"). Both of these approaches will produce over-optimistic results for scenarios in which the spawning biomass is predicted to drop over time if, in reality, there is a stock recruitment relationship.

6.4 Results and discussion

6.4.1 The base-case analyses

6.4.1.1 Diagnostic statistics

Figures 6.4 and 6.5 show the fits of the four base-case analyses (two definitions of "year" ["calendar" and "biological"] and two stocks ["east" and "west"]) to the discard and catch-rate data. The model mimics the discard rates for trawl fishery in the east reasonably well prior to about 2000, but fails to mimic the large (and variable) discard rates thereafter. The model predicts a low level of discarding for the trawl fishery in the west and consequently cannot mimic the outlying discard rate for 1997.

The fits to the catch-rate series are good, with the model mimicking the data very well in recent years. The ability to fit the data for the first few years is somewhat poorer, however. One consequence of this is that there are "runs" of residuals for some of the fits (e.g. to that for the trawl fishery in the east for a biological year; Figure 6.5, lower left panel).

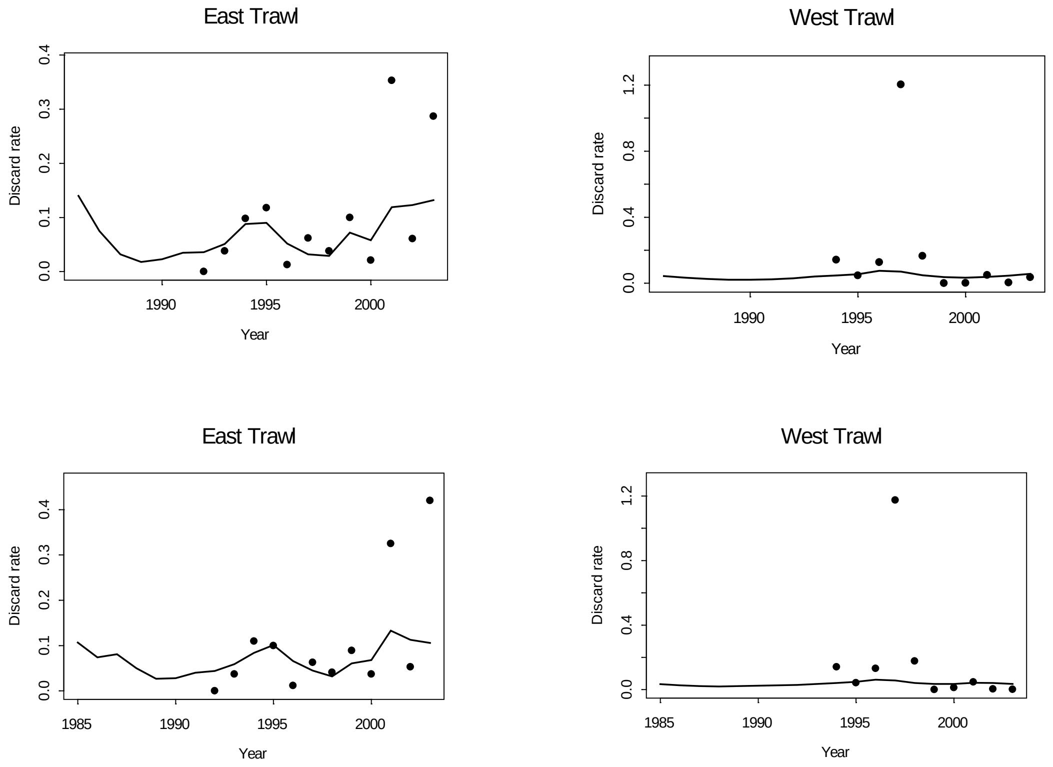


Figure 6.4 : Observed (solid dots) versus model-predicted (dotted lines) discard rates. Results are shown for the trawl fisheries in the eastern and western stocks. Results are shown for analyses based on a calendar year in the upper panels and for analyses based on a biological year in the lower panels.

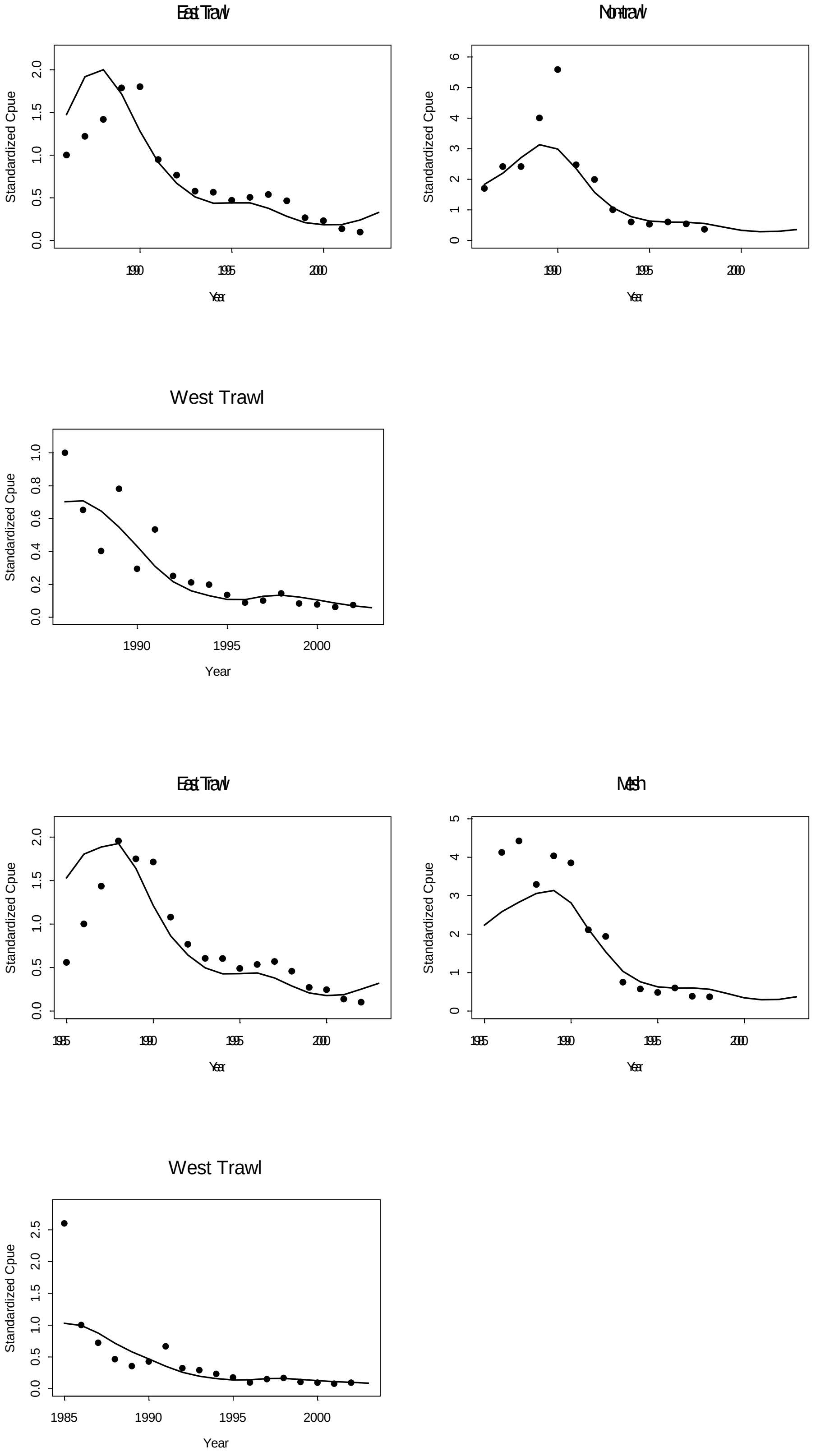


Figure 6.5 : Observed (solid dots) versus model-predicted (dotted lines) catch-rates. Results are shown for the trawl fisheries in the east and west and for the non-trawl fishery in the east. Results are shown for analyses based on a calendar year in the upper panels and for analyses based on a biological year in the lower panels.

The plots of the fits to length-frequency data are particularly voluminous. These fits are therefore provided for each of the four base-case analyses in Appendices 6.C.1 and 6.C.2 (landed and discarded length-frequencies respectively) rather than in main text. Note that, as before, discard data are only available for one of the fleets in the east. The fits to the landed length-frequency data are adequate for the Tasmania meshnet fishery, and for the non-trawl fishery for the years during which the catch by this fleet was substantial. The fits to the data from the two trawl fisheries are poorer, particularly for the trawl fishery in the west.

The fits to the discard length-frequencies are poorer than to the landed length-frequencies, although it is pleasing that the model captures the modal lengths in the length-frequency data for the discarded catch adequately for most years. The inability to mimic the discard length-frequencies is perhaps not a particularly large concern owing to the small sample sizes involved (Table 6.2).

The base-case analyses do not use the age-compositions of the catches directly when estimating the values for the parameters of the model because the model is fit to the age-length keys and the length-frequencies. However, the base-case analyses can be used to produce estimates of the age-composition of the catches. Appendices 6.C.3 and 6.C.4 contrast the age-composition data (landed and discarded) with the model predictions. Perhaps not surprisingly, the model does not fit the age-composition data as well as it fits the length-frequency data. This is perhaps most noticeable for the fits to the age- and length-composition data for the non-trawl fleet.

6.4.1.2 Assessment outcomes

Figure 6.6 plots the overall selectivity patterns (S_L^f) and the probability of a fish being discarded as a function of length (P_L^f). Results are shown for each fleet and for each of the four base-case analyses. The probability of discarding for the Tasmanian meshnet and non-trawl fleets is zero because these fleets are assumed not to discard. The selectivity patterns for the two trawl fleets (east and west) are similar although that for trawl fleet in the east tends to be shallower (particularly when the analysis is based on a calendar year). The Tasmanian meshnet selectivity pattern is dome-shaped whereas that for the non-trawl fleet is focused exclusively on large animals. The difference in selectivity pattern between the Tasmanian and non-trawl fleets is not unexpected given the length-frequencies in Appendix 6.C.1 which show that the Tasmanian fleet catches smaller animals than the non-trawl fleet.

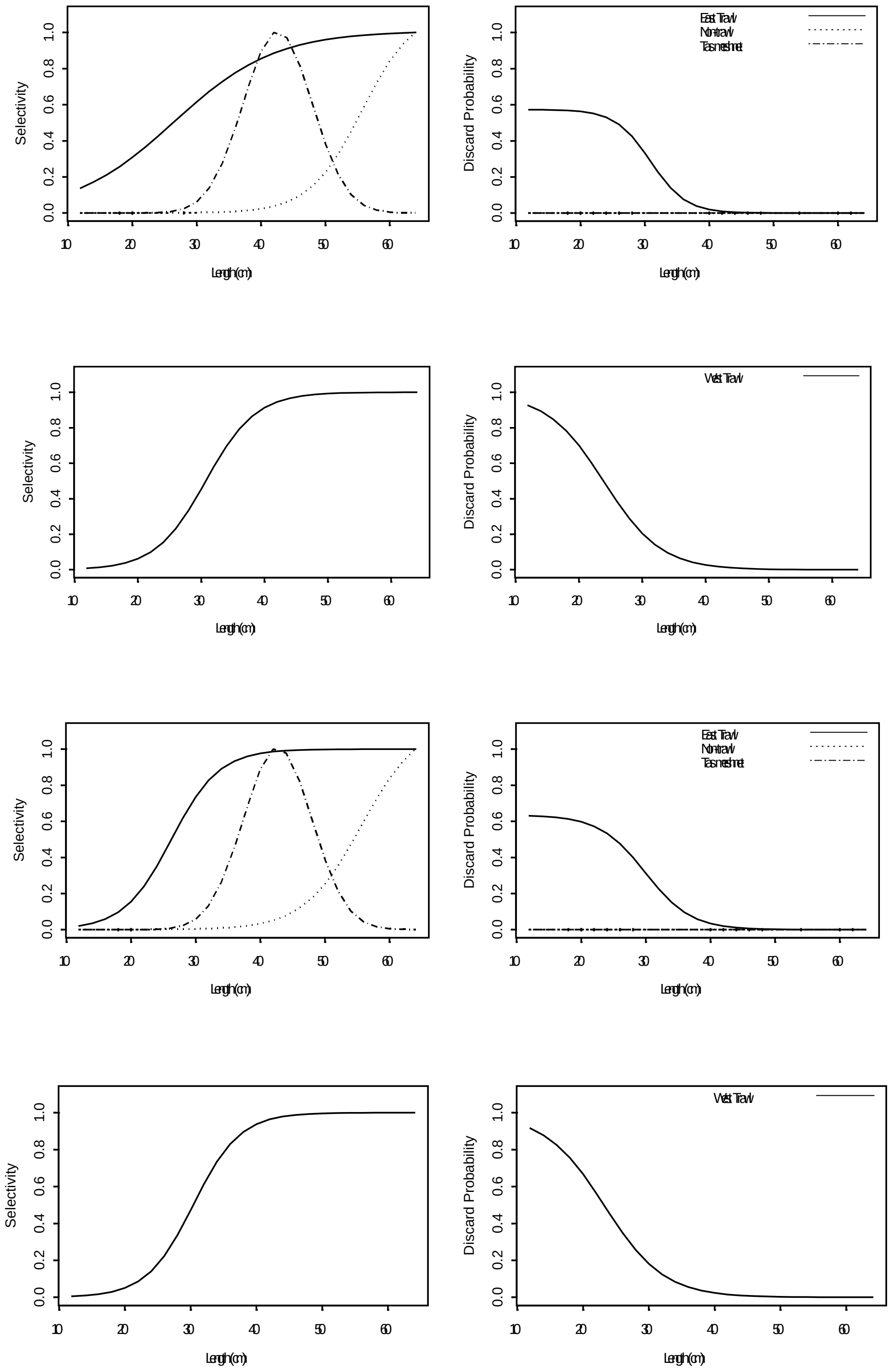


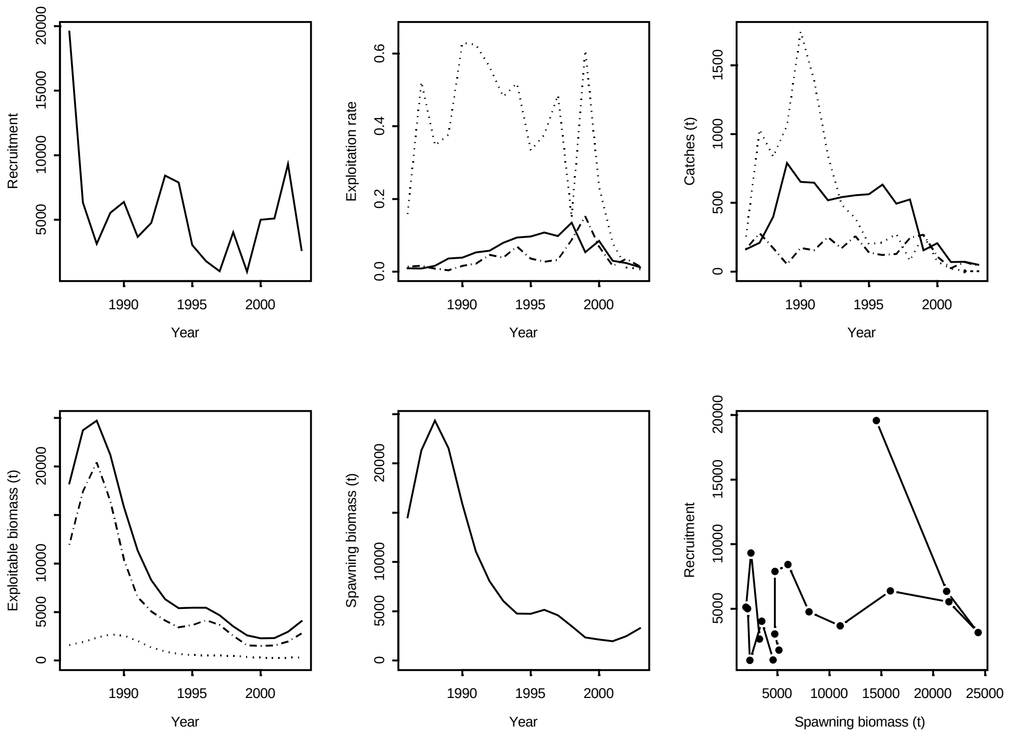
Figure 6.6 : Length-specific selectivity patterns. The left panels show the overall selectivity pattern while the right panels show the probability of being discarded as a function of length. Results are shown for analyses based on a calendar year in the upper panels and for analyses based on a biological year in the lower panels.

Figure 6.7 plots summaries of each of the four base-case analyses. The plot for each analysis shows the time-trajectory of recruitment (upper left panel), exploitation rate by fleet (upper centre panel), catch by fleet (upper right panel), exploitable biomass by fleet (lower left panel), and spawning biomass (lower centre panel). The lower right panel for each plot shows the stock-recruitment data. The spawning biomass for both stocks (west and east) is presently a small fraction of the highest spawning biomass over the period since 1985/86. This is not, however, unexpected given the trends in catch-rates (Fig. 6.5). Recruitment for the eastern stock declined substantially between 1985/86 and 1989 and has since largely stabilized (Fig. 6.7; Table 6.6). In contrast, recruitment to the western stock is estimated to be close to its lowest level since 1985/86. One of the reasons for the decline in recruitment is that the catches alone are not sufficient to have caused the large reductions in biomass implied by the changes in catch-rate. The trends in catch-rates (particularly those for the non-trawl fleet) are, however, real (rather than an artifact of the method used to standardize the catch and effort data) although the relationship between catch rates and abundance remains uncertain. Exploitation rate increased over the period considered in the assessment. However, exploitation rates in the eastern stock are now well below peak levels (owing primarily to the large reduction in fishing pressure by the non-trawl fleet). In contrast, the exploitation rate for the western stock is presently close to the maximum over the period considered in the assessment (Fig 6.7; Table 6.7).

The biomass available to the non-trawl fleet is estimated to substantially smaller than that available to the trawl and, to a lesser extent, the Tasmanian meshnet fleets. This is primarily because the selectivity ogive for the non-trawl fleet (Fig. 6.6) is such that only the largest individuals are vulnerable to capture by this fleet.

The numbers-at-age and exploitation rate-at-age matrices for both stocks (Tables 6.6 and 6.7) suggest very low levels of exploitation in 1985/86 and the presence in the population at the start of the first year considered in the analyses of several strong year-classes (Fig. 6.8). This implies that one of the main reasons for the decline in biomass is the lack of additional strong year-classes. In fact, it could be argued that the fishery has had a smaller impact on spawning biomass than the trend in recruitment.

(a) Calendar year – eastern stock



(b) Calendar year – western stock

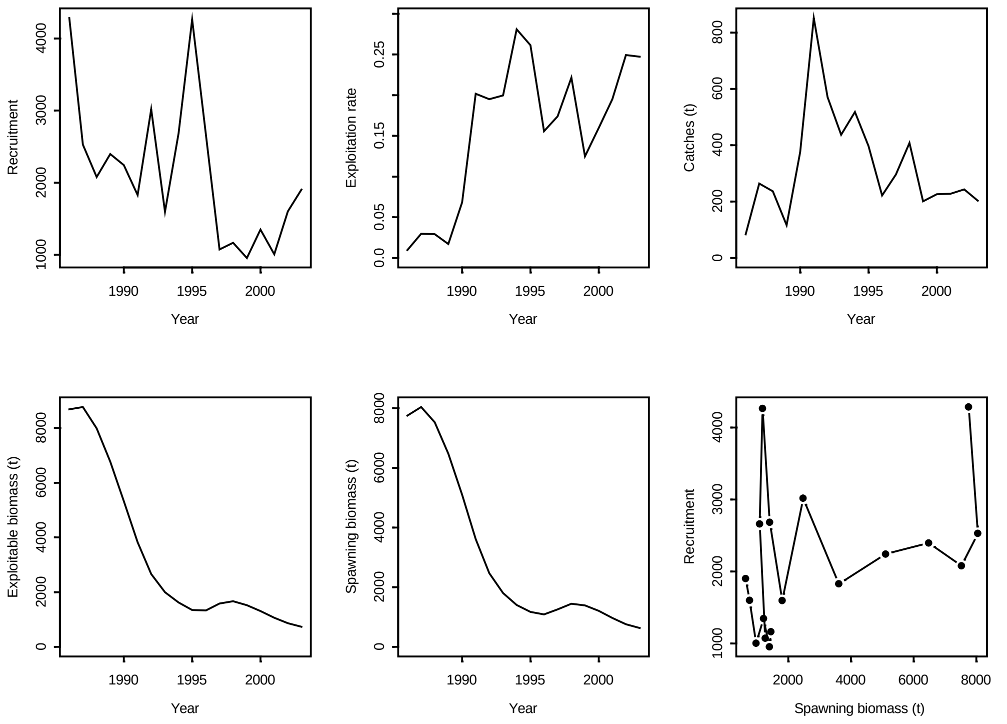
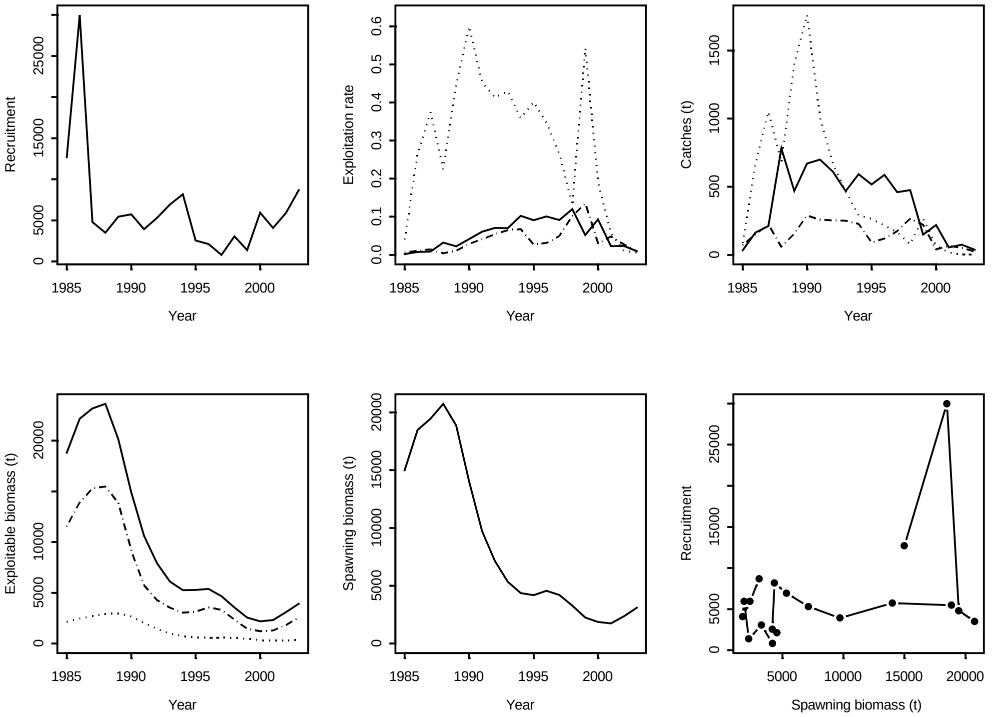


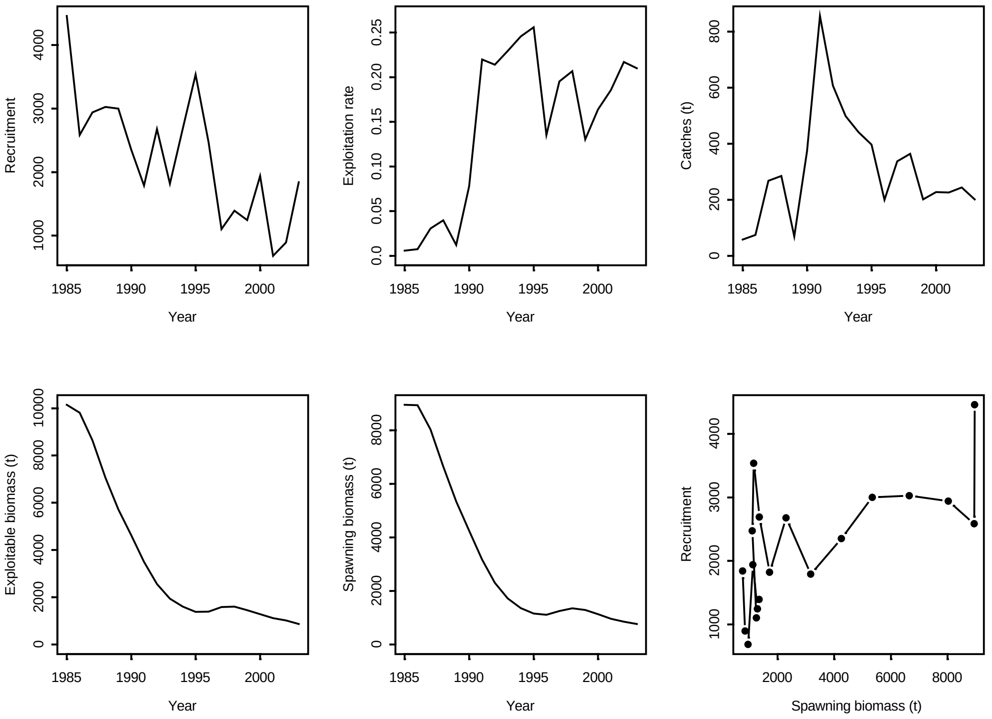
Figure 6.7 : Diagnostic statistics for the four base-case analyses.

(Figure 6.7 Continued)

(c) Biological year – eastern stock



(d) Biological year – western stock



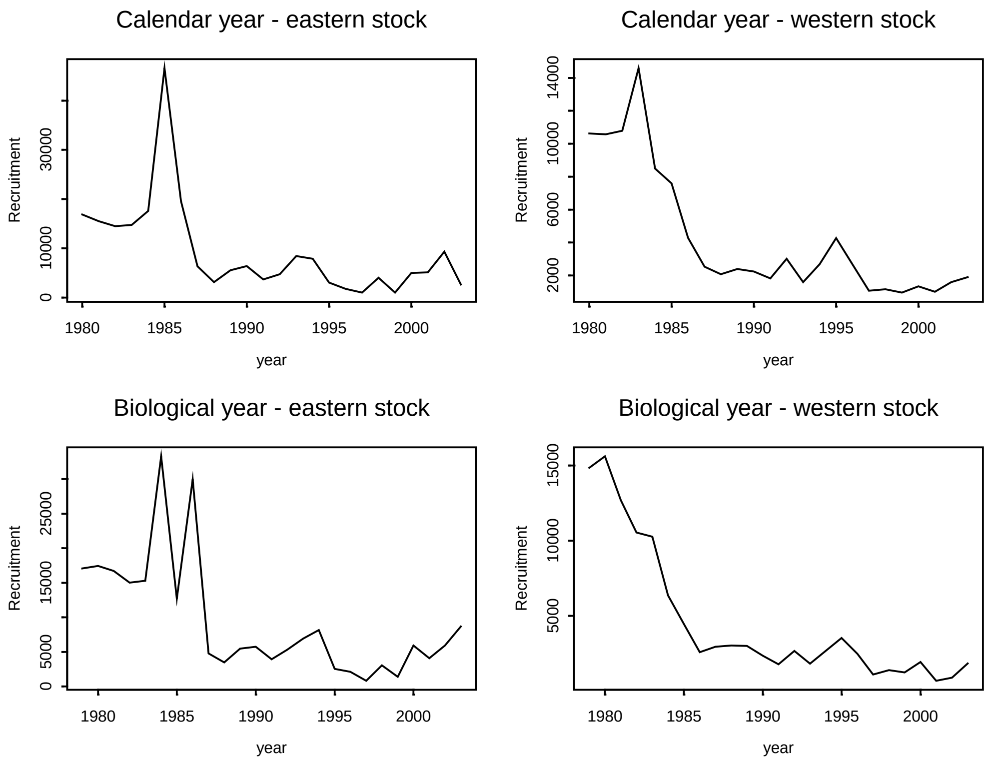


Figure 6.8 : Time-trajectories of recruitment for all of the year-classes included in the assessment. The sizes of the year-class spawned prior to the first year included in the assessment are calculated using Equation 6.5.

6.4.2 Sensitivity tests

The sensitivity of the results for the base-case analyses to a variety of modifications to assumptions of the assessment is examined in Table 6.8. Table 6.8 lists the values for ten quantities of potential interest to management:

1. $\tilde{B}_{03}$ - the spawning biomass during 2003 (2003/04 for the analyses based on a biological year).
2. $\tilde{B}_{97} / \tilde{B}_{91}$ - the ratio (expressed as a percentage) of the spawning biomass in 1997 (1997/98) to that in 1991 (1991/92).
3. $\tilde{B}_{03} / \tilde{B}_{97}$ - the ratio (expressed as a percentage) of the spawning biomass in 2003 (2003/04) to that in 1997 (1997/98).
4. $\tilde{B}_{03} / \tilde{B}_{91}$ - the ratio (expressed as a percentage) of the spawning biomass in 2003 (2003/04) to that in 1991 (1991/92).
5. $\tilde{B}_{03} / \tilde{B}_{0}(1)$ - the ratio (expressed as a percentage) of the spawning biomass in 2003 (2003/04) to the average unexploited level, when $\tilde{B}_0$ is calculated based on recent (post 1985) recruitments.
6. $\tilde{B}_{03} / \tilde{B}_{0}(2)$ - the ratio (expressed as a percentage) of the spawning biomass in 2003 (2003/04) to the average unexploited level, when $\tilde{B}_0$ is calculated based on all recruitments.
7. *MSY* (1) – Maximum Sustainable Yield if the recruitment at the *MSY* level of 0.4 $\tilde{B}_0$ is computed based on recent (post 1985) recruitments.

8. *MSY* (2) – Maximum Sustainable Yield if the recruitment at the *MSY* level of 0.4 $\tilde{B}_0$ is computed based on all recruitments.
9. Likelihood – the objective function (the negative of the logarithm of the likelihood function plus any penalty terms) corresponding to the estimates provided.
10. Overall Sigma – the value of $\tilde{\sigma}$ corresponding to the estimates provided.

The present inability to estimate a stock-recruitment relationship for blue warehou makes estimation of quantities related to *MSY* problematical. To provide an impression of the likely values for *MSY*, the exploitation rate corresponding to *MSY* has been defined to be that which reduces the spawning biomass-per-recruit to 40% of its unfished level and it is also assumed that recruitment is independent of spawning biomass at (and above) 0.4 B_0. Sensitivity is explored to the two different ways of computing $\bar{R}$, and the hence the recruitment corresponding to *MSY*. The fleet-specific exploitation rates needed to compute the exploitation rate corresponding to *MSY* for the eastern stock is based on the arithmetic average exploitation rate over 1993-97, a period of relative stability in biomass.

The sensitivity tests for which the ratio $\tilde{B}_{03} / \tilde{B}_{91}$ differs from that for the base-case analysis by more than 20% are indicated by underlines in Table 6.8 to assist with the interpretation of the results of the sensitivity analyses. It should be noted that it was not possible to check in detail that each of the sensitivity tests had converged completely to the global minimum of the objective function owing to the very large number of sensitivity tests conducted.

There are several factors to which all of the analyses are sensitive, and generally in a similar way.

1. Omitting the trawl catch-rate indices. Ignoring these data leads to a more optimistic impression of stock status. This is most evident for the western stock (for which there is only one index of abundance). Somewhat surprisingly, ignoring the non-trawl catch-rate data when conducting the assessment of the eastern stock has a much smaller impact than ignoring the trawl catch-rate data.
2. Omitting the data for the last few years. The impact of this is again greatest for the western stock. Note that the sensitivity of the results for very recent years to ignoring data for recent years is not surprising. It is perhaps more noteworthy that the time-trajectories of spawning biomass for the period to about 2000, and quantities such as $\tilde{B}_{97} / \tilde{B}_{91}$, are remarkably robust to ignoring the data for most recent few years (Fig. 6.9).
3. Assuming a multinomial or robust normal likelihood. The results for multinomial likelihood are much optimistic than those for the base-case analysis. This occurs because the weight assigned to length composition data dominates that assigned to the catch-rate data when the sample sizes in Table 6.4 are assumed. This is evident from the generally higher values for $\tilde{\sigma}$ for these sensitivity tests.

The estimates of *MSY* in Table 6.8 should be interpreted with considerable caution because, *inter alia*, they assume no relationship between spawning biomass and recruitment. The estimates of *MSY* are, not surprisingly, sensitive to how average recruitment is defined (particularly for the western stock). *MSY* is also fairly sensitive to the value assumed for the rate of natural mortality, *M* (generally, but not always, larger for higher values for *M*). Another impact of changing *M* is that the impact of historical fishing on past population size gets larger as *M* is reduced – this result is intuitive, the catch-at-length data provide an estimate of total mortality, and the contribution to total mortality owing to fishing depends on the value assumed for *M*.

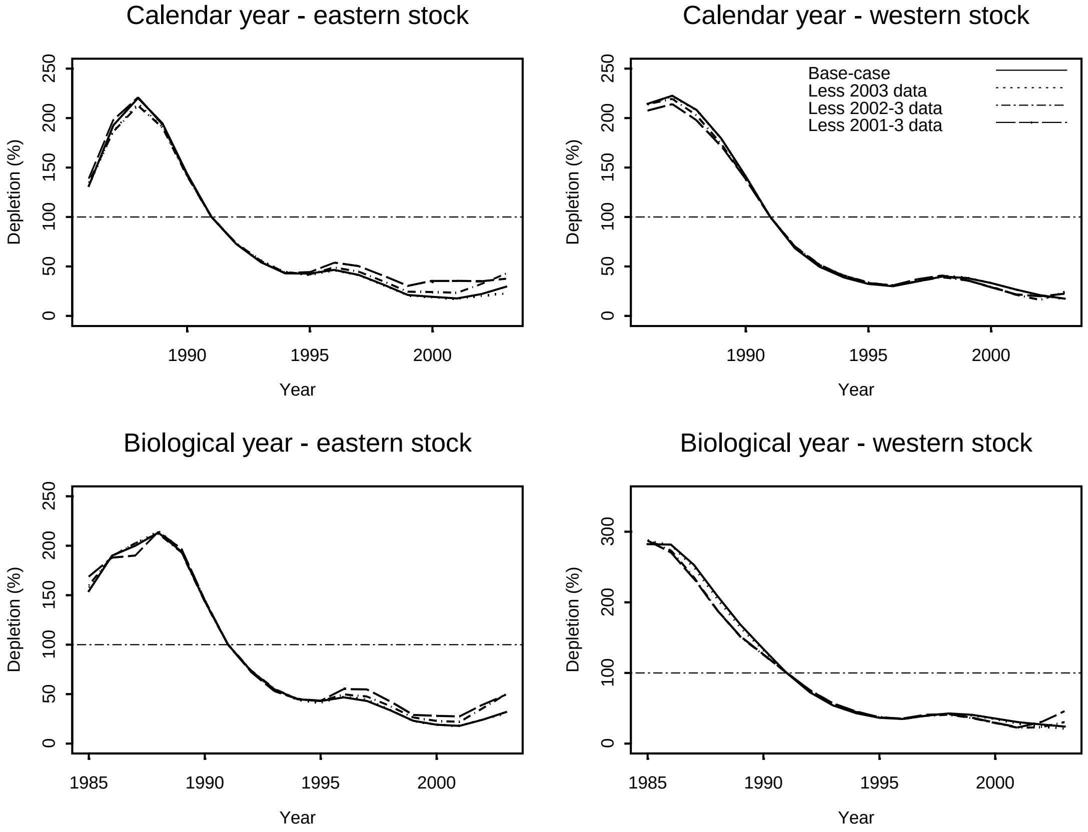


Figure 6.9 : Sensitivity of the time-trajectories of spawning biomass (scaled to 1991) to omitting recent data from the analysis.

6.4.3 Bayesian analyses

6.4.3.1 Evaluation of convergence

A very large number of potential diagnostic statistics and plots were examined for the base-case analyses. However, none of these indicates major problems with convergence of the MCMC chains to the posterior distributions for the base-case analyses. Appendix 6.D provides diagnostics plots for five of the model outputs for the base-case “biological year - eastern stock” analysis. The panels for each quantity in Appendix 6.D show the trace, the posterior density function (estimated using a normal kernel density estimator), the correlation at different lags, the 50-point moving average against cycle number (dotted line in the rightmost panels), and the running mean and running 95% probability intervals (solid lines in the rightmost panels). The base-case “biological year - eastern stock” analysis was chosen for presentation because it has the greatest number of parameters (see Table 6.4). None of the model outputs in Appendix 6.D exhibit features that might suggest a lack of convergence. Detailed examination of the results indicates that some of the selectivity parameters (particularly those for the non-trawl and Tasmanian fleets) did not converge adequately (see, for example, Fig. 6.10). It should be noted that although there is evidence for lack of convergence in Fig. 6.10, the ranges for the parameters displayed are very narrow.

6.4.3.2 Results of the Bayesian analyses

The Bayesian analyses are summarized by the posterior distributions (medians and 90% probability intervals) for the time-trajectories of spawning biomass expressed as a percentage of the "recent" B_0 (Fig. 6.11) and the marginal posterior distributions for:

1. the ratio (expressed as a percentage) of the 2003 spawning biomass to "recent" B_0 ("Depletion (new B0)")),
2. the ratio (expressed as a percentage) of the 2003 spawning biomass to "old" B_0 ("Depletion (old B0)"),
3. the ratio (expressed as a percentage) of the 2003 to the 1991 spawning biomass, ("Depletion (1991)")
4. the ratio (expressed as a percentage) of the 2003 to the 1986 spawning biomass, and ("Depletion (1986)")
5. the Maximum Sustainable Yield based on the "recent" B_0.

The posterior distributions (medians and 90% probability intervals) for the time-trajectories of recruitment for each of the four base-case analyses are shown in Figure 6.12.

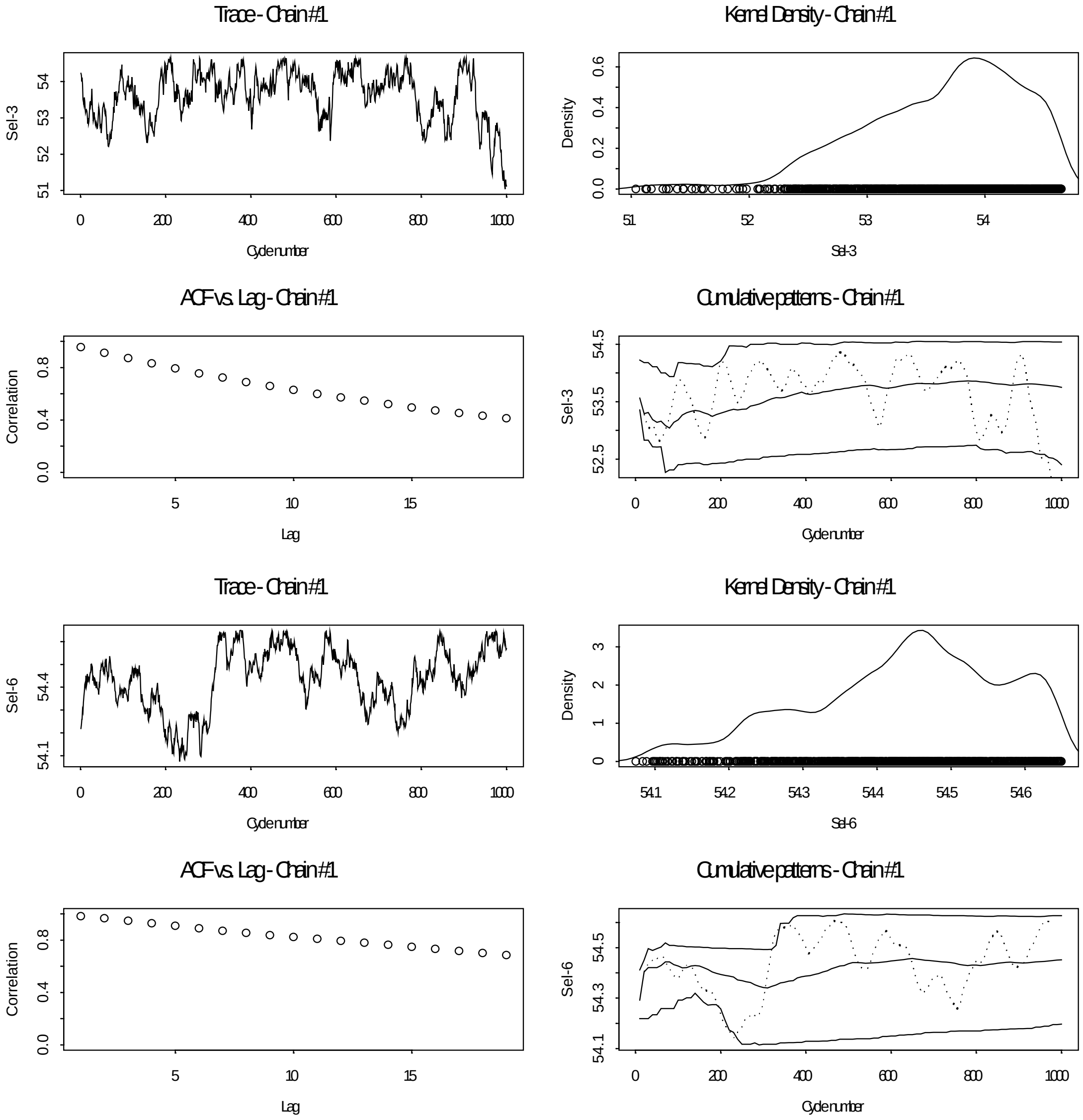
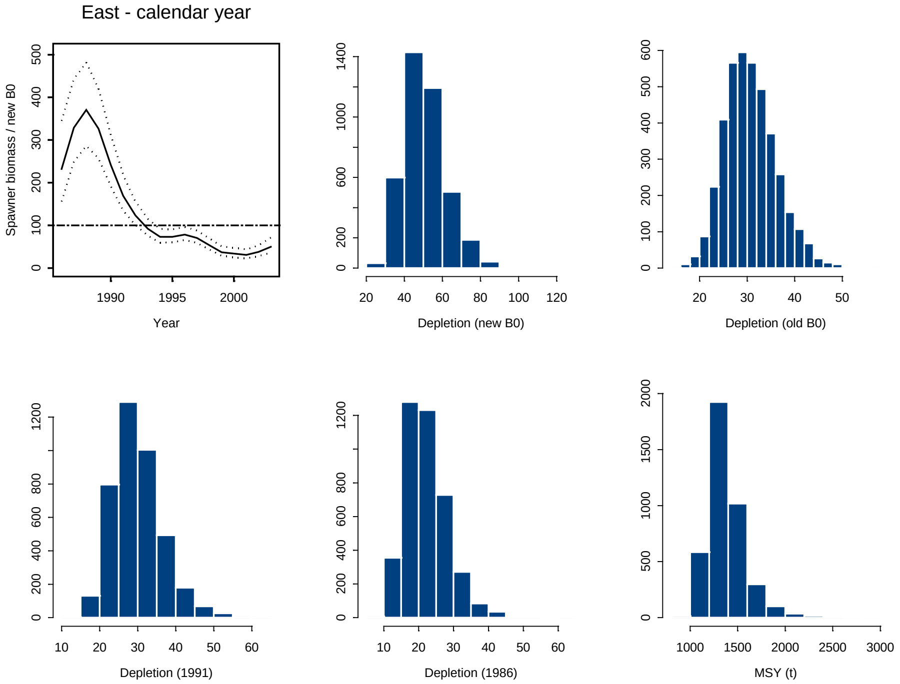


Figure 6.10 : Diagnostic plots to evaluate convergence of the MCMC chain for the two of the selectivity parameters for the “Biological year - eastern stock” analysis.

(a) Calendar year – eastern stock



(b) Calendar year – western stock

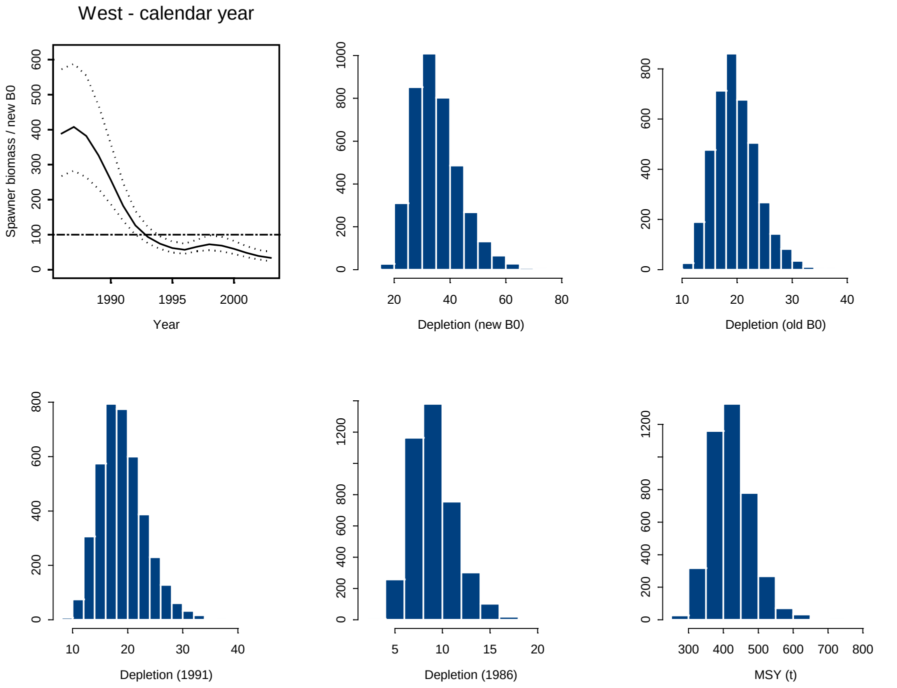
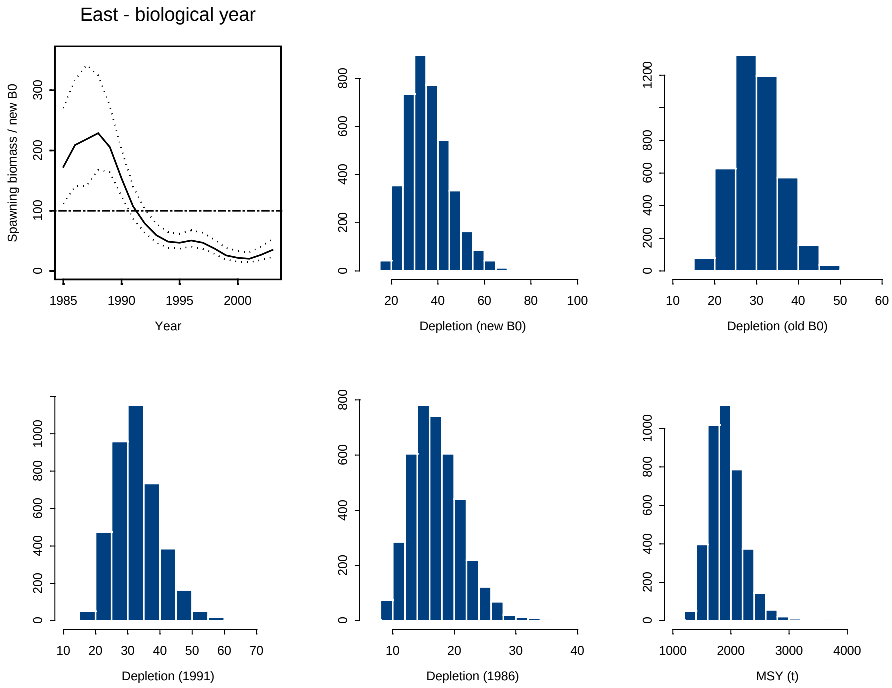


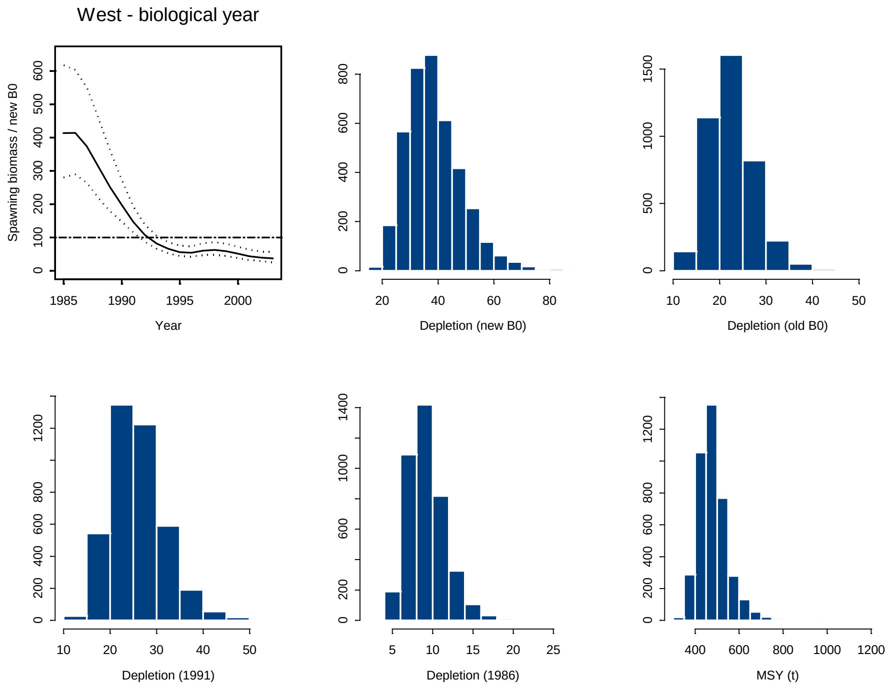
Figure 6.11 : Bayesian posterior distributions (solid line – median; dotted lines – 90% probability intervals) for the time-trajectory of spawning biomass (relative to "recent" B_0 – dashed line) and marginal posterior distributions for various quantities of management interest. Results are shown for each of the four base-case analyses.

(Figure 6.11 Continued)

(c) Biological year – eastern stock



(d) Biological year – western stock



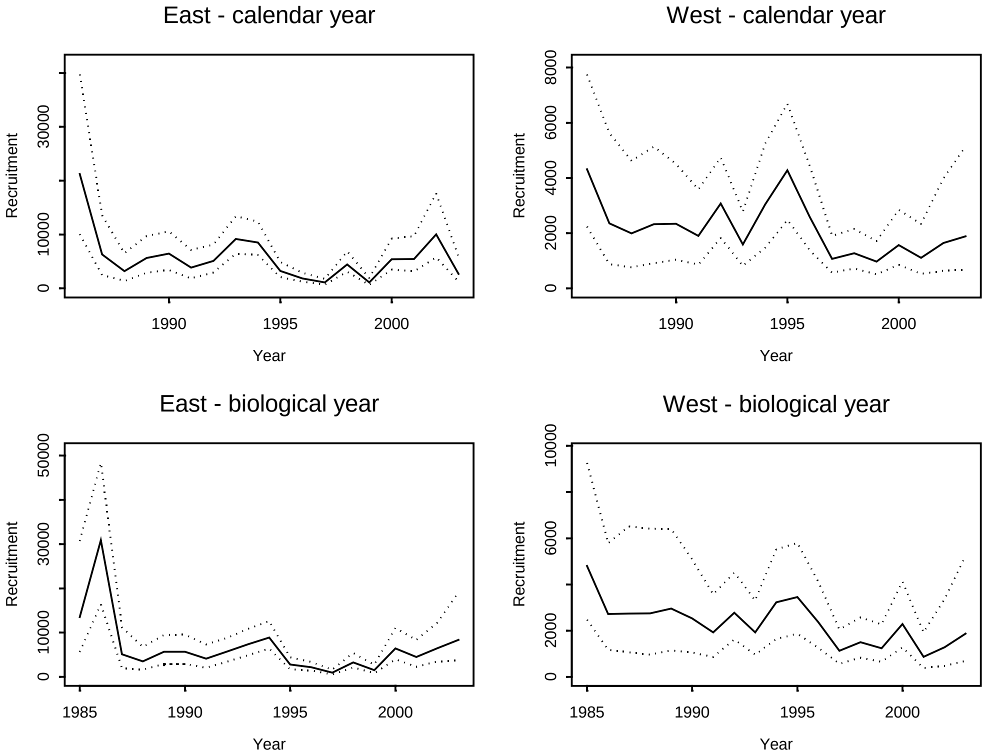


Figure 6.12 : Bayesian posterior distributions (solid line – median; dotted lines – 90% probability intervals) for the time-trajectories of recruitment. Results are shown for each of the four base-case analyses.

The posterior distributions in Fig. 6.11 are consistent with the point estimates (actually the modes of the posterior distributions – the MPD estimates) in Table 6.8 because the MPD estimates lie well within the marginal posterior distributions. The estimates of the key model outputs are, however, fairly imprecise. For example, the 90% probability intervals for $\tilde{B}_{03} / \tilde{B}_{91}$ are [0.21, 0.41], [0.13, 0.27], [0.22, 0.46], and [0.18, 0.36] for the four base-case analyses. These probability intervals are, however, overly tight because no account is taken of uncertainty about, for example, M and the reliability of the various data sources (e.g. is catch-rate really related linearly to abundance).

6.4.4 Projections

The results of the projections are summarized in Figs 6.13 and 6.14 and Tables 6.9 and 6.10. Figs 6.13 and 6.14 show the median time-trajectories of spawning biomass from 1986 (1985/86) to 2008 (2008/2009) and Tables 6.9 and 6.10 list the values for the five performance measures (see Section 6.3.3 for details) at the end of the 5-year projection period. Results are shown in Figs 6.13 and 6.14 and Tables 6.9 and 6.10 for each scenario regarding future catch (Table 6.5), for each stock, for the two definitions for B_0, and for two scenarios concerning future recruitment. The two recruitment scenarios are:

a) future recruitments are selected at random (and with replacement) from those for the range of years used when determining B_0 (1979-2003 for "old" B_0 and 1986-2003 for "recent" B_0); and
b) future recruitments are selected at random (and with replacement) from those for 1999-2003.

The first of the recruitment scenarios reflects the assumption that the patterns in recruitment (e.g. Fig. 6.12) are random whereas the second scenario reflects the assumption that there may be a "stock-recruitment effect" and the best indicator of recruitment in the short-term are the most-recent recruitments. Results are shown in Fig 6.13 and Table 6.9 for the base-case value for M (0.45yr^{-1}) while results are shown in Fig 6.14 and Table 6.10 for M=0.3yr^{-1}.

The results of the projections for the western stock are much more sensitive to how future recruitment is projected than to whether a calendar or biological year is adopted. The sensitivity of the results for western stock to how future recruitment is generated is not surprising because recruitment appears to be lower for the most-recent few years (Fig. 6.12). None of the catch scenarios perform well in terms of achieving high values for the performance indicators if the future recruitments are similar to those for 1999-2003.

The results for both stocks are sensitive to whether the reference points (and the recruitments) are based on the "old" or the "recent" B_0. The results for "recent" B_0 are much more optimistic than for "old" B_0.

There is a high probability that the eastern stock will be above the reference points for all of the scenarios regarding future catches. In contrast, the results of the projections for the western stock are much less clear. For some scenarios (e.g. projections based on all recruitments and performance indicators based on the "old B_0"; Table 6.9a left columns), a catch of 300t from the western stock leads to values for the performance indicators of 47% of above. However, for other scenarios (projections based on recent recruitments and performance indicators based on the "old B_0"; Table 6.9b left columns) even the lowest catch (150t) does not achieve this standard.

One of the reasons for the relatively optimistic projections for the eastern stock is that recruitment is estimated to be relatively strong for a recent year (2002 for the calendar year assessment and 2003/04 for the biological year assessment; Table 6.6). Although the size of this recruitment is estimated relatively imprecisely (Fig. 6.12), the actual extent of uncertainty is greater than indicated in Fig. 6.12. This is because: a) there is no catch-rate index for 2003 so all inferences regarding the strength of recent recruitments are based on fits to the age-composition data, the sample sizes for which are relatively small for recent years (Table 6.2), and b) previous assessments have estimated recruitment for the most recent years to be high but this has subsequently been found not to be the case.

The reliance of the projections on estimates of recruitment for recent years means that the projections themselves are somewhat unreliable. Although the results of the projections could be used to support a *TAC* in excess of the current 300 t, this support depends critically on the reliability of the strength of some poorly-determined recruitments. It may be prudent to wait until additional data (age-composition and catch-rates) are available that pertain to these recruitments before basing management advice on them.

(a) Projections based on recruitments for all years

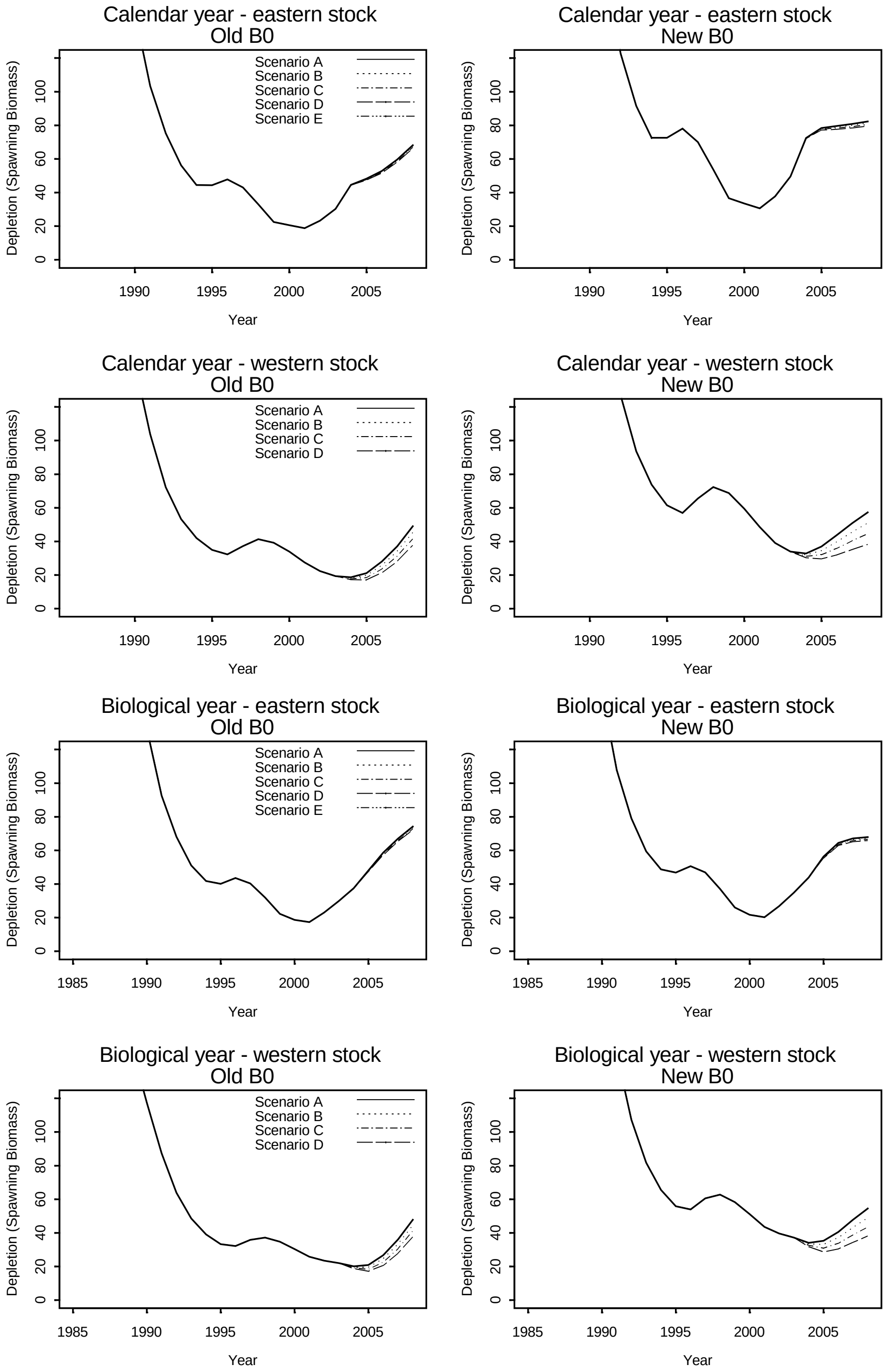
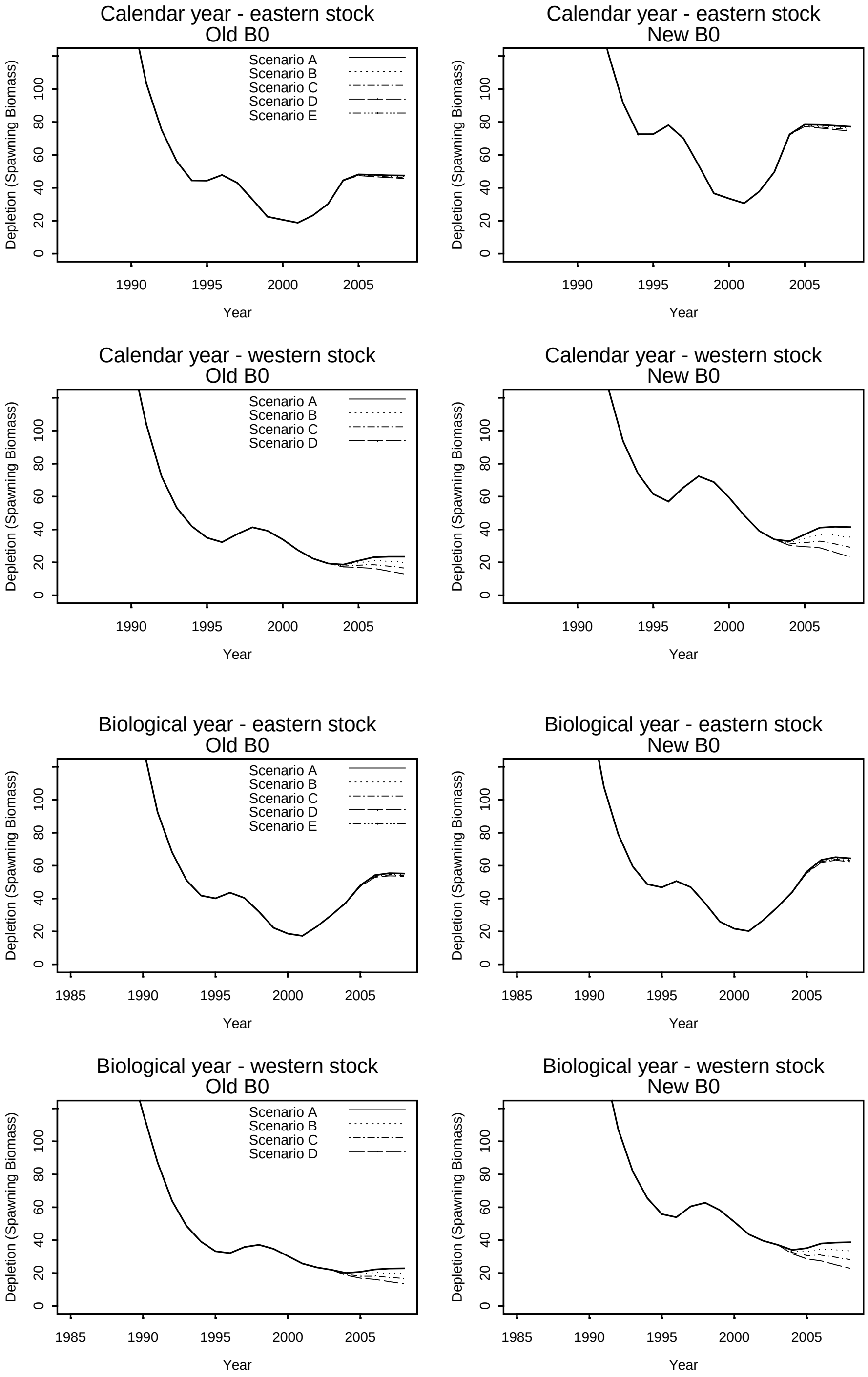


Figure 6.13 : Posterior median time-trajectories of spawning biomass (relative to B_0) for each of the projection scenarios for the base-case analyses. Results are shown for the western and eastern stocks, for assessments based on calendar and biological years, and for the two different definitions for B_0.

(Figure 6.13 Continued)

(b) Projections based on recruitments for 1999-2003.



(a) Projections based on recruitments for all years

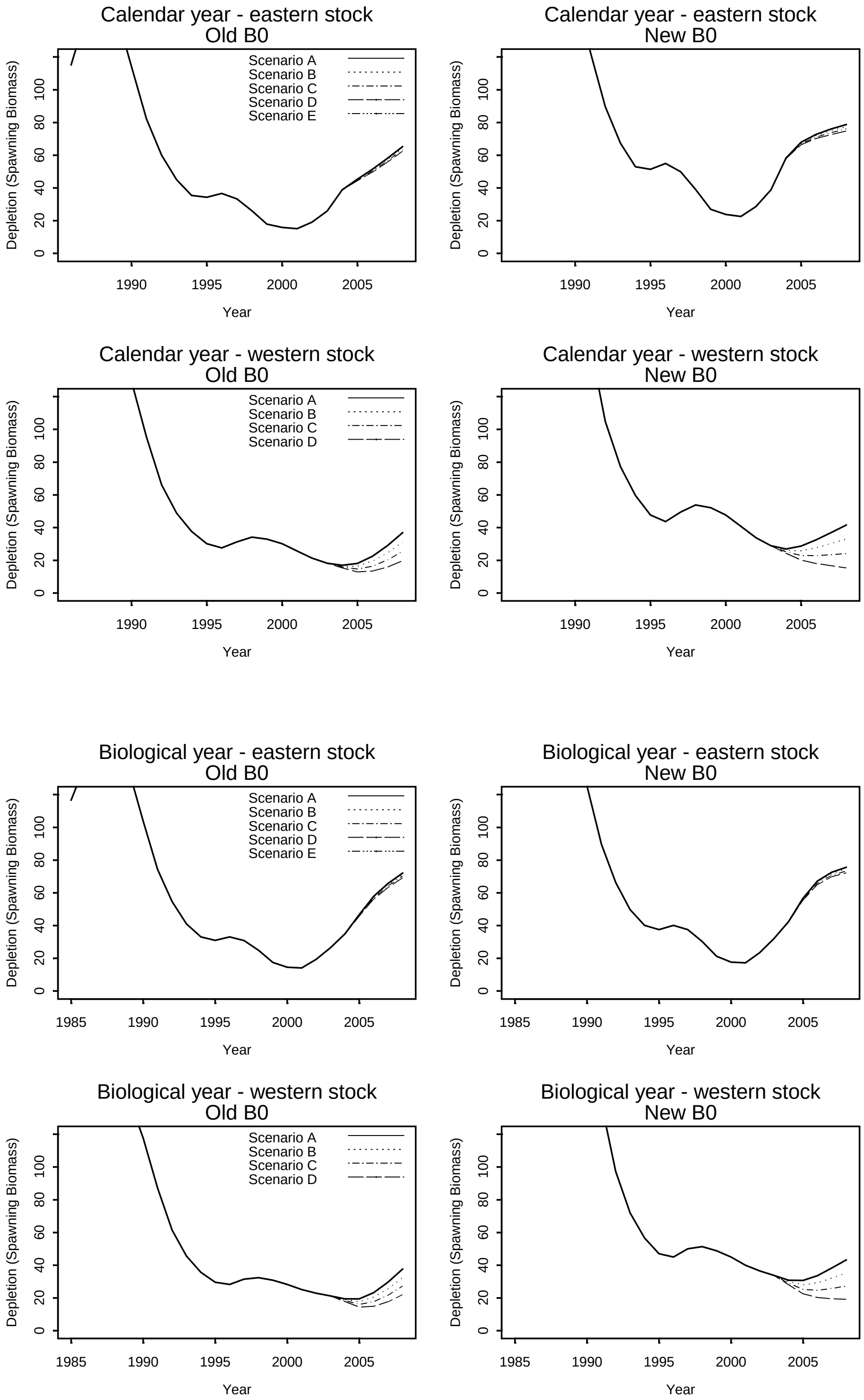
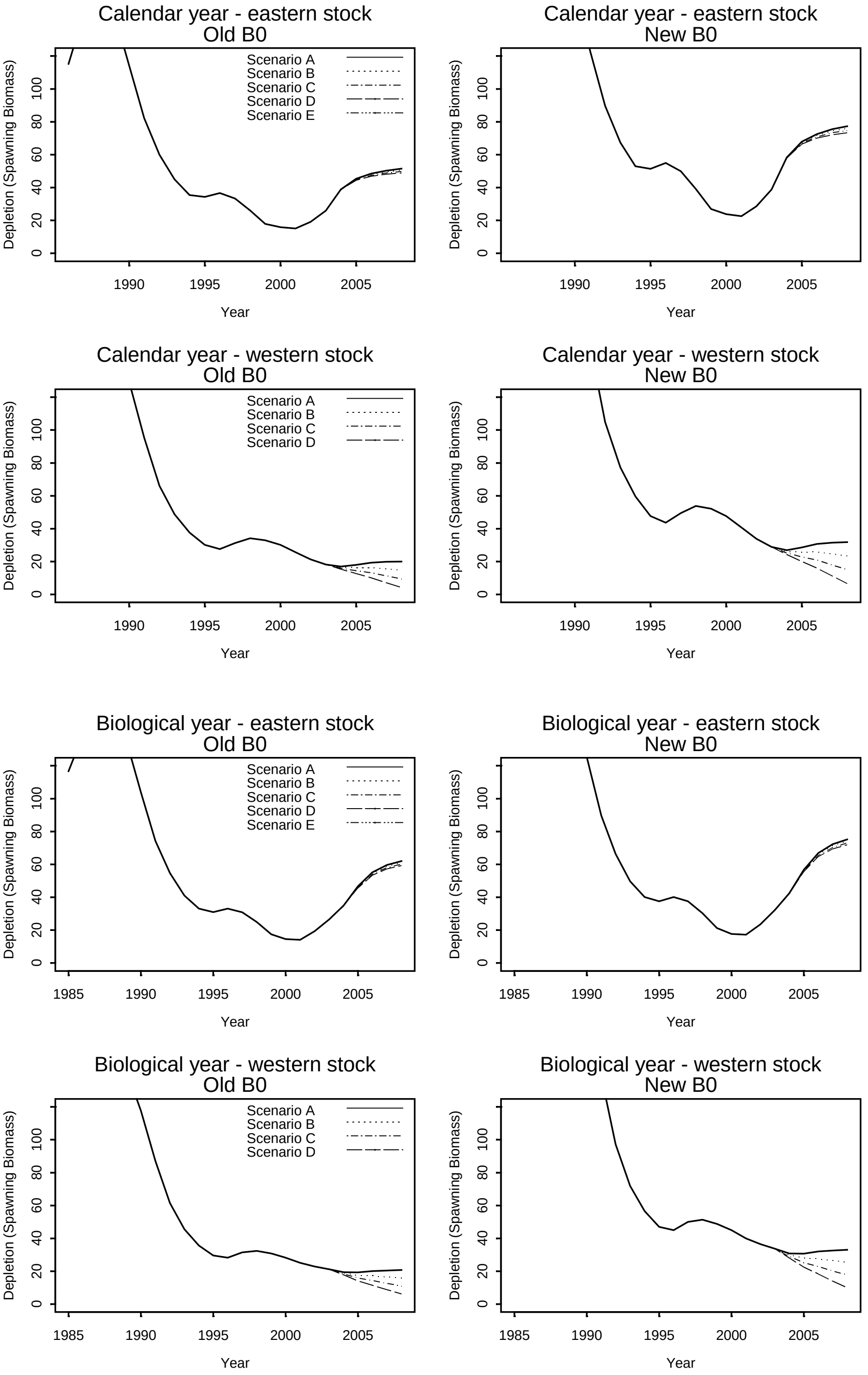


Figure 6.14 : Posterior median time-trajectories of spawning biomass (relative to B_0) for each of the projection scenarios for the sensitivity tests in which M=0.3yr^{-1}. Results are shown for the western and eastern stocks, for assessments based on calendar and biological years, and for the two different definitions for B_0.

(Figure 6.14 Continued)

(b) Projections based on recruitments for 1999-2003.



6.5 Further development

1. The age-reading error matrix (Table 6.B.1) should be updated using the most recent information.
2. Consideration should be given the including sex-structure into the population dynamics model. Although the length-frequency data are not sex-specific, much of the recent ageing data include the sex of the animal.
3. Although substantial improvements have been made regarding the storage of the data for the SEF, extraction of the length-frequency data for blue warehou remains problematical. As a first priority, the data from the SMP should be validated and included in the ISMP database.
4. The fishery catches are very low at present. This leads to lower sample sizes for length-frequency and further concern regarding the validity of catch-rates as indices of abundance.
5. Consideration should be given to evaluating objective methods for detecting resource recovery. Such methods may also be of value for several of the other species in the SEF (e.g. eastern gemfish).
6. There is a need to collect additional length-frequency for the Tasmanian component of the fishery (owing to the present size of this sector relative to the rest of the fishery).
7. Future assessments should consider quantifying the relationship between spawning biomass and recruitment, and perhaps basing management reference points on this relationship.
8. The impact of the catches from northwestern Tasmania coming from the western rather than the eastern stock should be examined.

6.6 Acknowledgements

Kyne KrusicGolub (PIRVic), Sonia Talman (PIRVic), Jeremy Lyle (TAFI), Sally Wayte (CSIRO), and Malcolm Haddon (University of Tasmania) are thanked for providing the data on which the analyses of the assessment are based. Geoff Tuck and Jemery Day (CSIRO) are thanked for their comments on an initial draft of this document.

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Table 6.1. Reported catches (tonnes), discard rates and catch-rates by fleet. The discard rates indicated by asterisks are included in these tables but not in the calculations owing to low sample sizes. The 1999 and 1999/2000 catch-rates for the non-trawl fishery (indicated by ampersands) are excluded from the base-case analyses as noted in the main text.

(a) Calendar year

Year	Catches				Discard rates		Catch-rates		
	East	West	Non-trawl	Tas	East	West	East	West	Non-trawl
1986	163	84	254	165	-	-	1.000	1.000	1.700
1987	210	264	1033	278	-	-	1.218	0.652	2.410
1988	398	237	835	170	-	-	1.416	0.403	2.410
1989	790	116	1061	52	-	-	1.784	0.781	4.000
1990	652	376	1746	172	-	-	1.799	0.294	5.580
1991	647	852	1386	154	-	-	0.946	0.534	2.470
1992	519	571	842	249	0.000*	-	0.763	0.251	1.990
1993	542	437	487	168	0.038*	-	0.576	0.211	1.000
1994	555	518	389	257	0.098*	0.142*	0.564	0.198	0.600
1995	563	397	199	138	0.118*	0.047*	0.469	0.136	0.530
1996	632	222	213	119	0.013	0.127	0.504	0.088	0.600
1997	494	296	274	127	0.062	1.203	0.537	0.101	0.540
1998	524	408	79	244	0.038	0.166	0.464	0.145	0.360
1999	154	201	264	268	0.100	0.000	0.264	0.083	1.000$^{\&}$
2000	207	226	72	109	0.021	0.002	0.231	0.077	-
2001	70	228	20	24	0.353	0.050	0.136	0.062	-
2002	71	243	3	70	0.061	0.004	0.097	0.074	-
2003	49	203	2	40	0.287	0.036	-	-	-

(Table 6.1 Continued)

(b) Biological year

Year	Catches				Discard rates		Catch-rates		
	East	West	Non-trawl	Tas	East	West	East	West	Non-trawl
1985/86	33	58	85	70	-	-	0.558	2.598	-
1986/87	163	74	667	150	-	-	1.000	1.000	4.120
1987/88	211	268	1051	222	-	-	1.434	0.721	4.420
1988/89	782	285	678	58	-	-	1.953	0.463	3.290
1989/90	470	69	1405	156	-	-	1.747	0.356	4.030
1990/91	671	373	1761	288	-	-	1.712	0.426	3.850
1991/92	699	856	1008	257	-	-	1.078	0.667	2.110
1992/93	610	607	668	252	0.000*	-	0.767	0.322	1.940
1993/94	468	498	468	250	0.037*	-	0.605	0.291	0.750
1994/95	592	441	290	226	0.110*	0.141*	0.602	0.233	0.570
1995/96	517	397	264	90	0.100*	0.043*	0.488	0.176	0.480
1996/97	587	200	216	119	0.012	0.132	0.534	0.096	0.600
1997/98	460	337	165	175	0.063	1.174	0.569	0.15	0.380
1998/99	475	364	78	265	0.041	0.177	0.457	0.169	0.370
1999/00	148	201	267	220	0.089	0.000	0.270	0.104	1.000$^{\&}$
2000/01	219	227	68	39	0.037	0.013	0.244	0.095	-
2001/02	54	226	16	64	0.325	0.047	0.136	0.078	-
2002/03	74	244	3	50	0.053	0.004	0.101	0.094	-
2003/04	37	201	2	24	0.420	0.002	-	-	-

Table 6.2. Sample sizes for age-length keys and length-frequencies for the landed / discarded catches.

(a) Calendar year

Year	Age-length keys		Landed length-frequencies				Discard length-frequencies	
	East	West	East	West	Non-trawl	Tas	East	West
1986	-	-	-	-	-	-	-	-
1987	-	139	-	4031	-	-	-	-
1988	-	238	-	1882	-	-	-	-
1989	-	-	-	-	-	-	-	-
1990	-	-	-	-	-	-	-	-
1991	409	-	-	1366	6920	-	-	-
1992	192	-	-	4175	3475	-	-	-
1993	0	187	-	665	5442	-	26	-
1994	162	191	2889	10630	630	-	102	-
1995	85	172	2260	5810	110	-	73	-
1996	274	169	2833	4677	312	-	17	-
1997	281	189	3730	5740	1478	1325	93	124
1998	393	195	4288	5979	561	2758	191	184
1999	208	194	2092	3080	4038	1456	117	-
2000	591	366	2539	1153	410	-	59	-
2001	540	484	1604	2190	284	-	342	336
2002	318	432	1944	2103	244	-	26	10
2003	110	187	2030	684	18	-	631	-

(b) Biological year

Year	Age-length keys		Landed length-frequencies				Discard length-frequencies	
	East	West	East	West	Non-trawl	Tas	East	West
1985/86	-	-	-	-	-	-	-	-
1986/87	-	-	-	-	-	-	-	-
1987/88	-	139	-	4031	-	-	-	-
1988/89	-	238	-	1882	-	-	-	-
1989/90	-	-	-	-	-	-	-	-
1990/91	94	-	-	123	1397	-	-	-
1991/92	315	-	-	1243	6056	-	-	-
1992/93	192	-	-	4175	4785	-	-	-
1993/94	-	187	-	3094	3733	-	55	-
1994/95	162	191	2889	8586	496	-	216	-
1995/96	166	172	2260	5841	219	-	141	-
1996/97	240	205	2833	4443	869	-	24	-
1997/98	234	153	3730	6825	812	1325	186	248
1998/99	419	195	4157	4712	743	2758	414	368
1999/00	249	195	2518	3080	3856	1456	202	-
2000/01	612	365	2105	1153	410	-	118	87
2001/02	452	484	1642	2190	284	-	684	585
2002/03	333	432	2422	2103	262	-	52	20
2003/04	138	310	1453	684	-	-	1252	-

Table 6.3. The "free" parameters of the population dynamics model (the number of parameters listed pertains to an assessment based on a biological year; one less parameter is estimated when the assessment is based on a calendar year)[1].

Quantity	Symbols	No parameters	
		East	West
Initial age-structure	$\{\ell n\, N_{1986,a} : a = 2,3,..,7\}$	6	6
Recruitments	$\{\ell nN_{y,1} : y = 1985/86, 86/87.., 2002/03\}$	18	18
Average recruitment	$\ell n\overline{N}$	1	1
Overall selectivity	$L_{50}^f,\ L_{95}^f,\ L_{\max}^f, L_5^f$ [2]	6	2
Discard selectivity	$L_{50}^{D,f}, L_{50}^{D,f}, \gamma^f$	3	3
Growth curve	ℓ_∞, κ, t_0	3	3
Variability in growth	σ_1, σ_2	2	2
Density-dependent growth	ϕ	1[3]	1[3]
Total		39[3]	35[3]

1. the values for the overall standard deviation, the catchability coefficients and the parameters $\overline{\varepsilon}$ and α are computed analytically given the values for the remaining parameters.
2. selectivity for each fleet is defined using only two of these four parameters (normal: Tasmanian meshnet; logistic: east and west trawl, and non-trawl).
3. density-dependent growth is not included in the base-case specifications

Table 6.4. Relative magnitudes for the residual standard deviations and the effective sample sizes.

Data source	Relative standard deviations	Effective sample sizes
Discard rate	0.2	
Catch rate	0.25 (east) 0.10 (west)	
Landed length-frequency	0.2	25
Discard length-frequency	0.25	10
Landed age-composition	0.25	25
Discard age-composition	0.30	10

Table 6.5. The levels of catch (tonnes) by fleet from 2004 (calendar year projections) and 2004/2005 (biological year projections).

(a) Eastern stock

	Option				
	A	B	C	D	E
East Trawl	25	50	75	100	150
Non-trawl	5	5	5	5	5
Tasmania	50	50	50	50	50

(b) Western stock

	Option			
	A	B	C	D
West Trawl	150	200	250	300

Table 6.6. Base-case numbers-at-age matrices. Results are shown for the western and eastern stocks, for assessments based on calendar and biological years.

(a) Calendar year

Year	Eastern stock							Western stock						
	1	2	3	4	5	6	7+	1	2	3	4	5	6	7+
1986	19575	29653	7104	3736	2278	1501	996	4286	4842	3446	3753	1756	1087	690
1987	6334	12461	18803	4459	2318	1402	1519	2528	2733	3082	2185	2373	1110	1122
1988	3143	4032	7897	11738	2715	1369	1642	2078	1612	1733	1931	1358	1471	1382
1989	5528	1998	2547	4932	7209	1633	1752	2396	1324	1022	1086	1201	842	1767
1990	6378	3501	1248	1569	2983	4256	1923	2243	1528	842	645	683	753	1636
1991	3669	4038	2183	760	924	1689	3309	1828	1429	962	515	388	407	1422
1992	4749	2317	2496	1309	439	513	2588	3019	1162	878	541	273	200	936
1993	8416	2996	1427	1473	738	239	1588	1596	1920	715	495	288	142	586
1994	7883	5287	1824	831	822	399	935	2684	1015	1179	402	263	149	373
1995	3032	4938	3187	1031	442	423	655	4266	1704	614	628	196	123	242
1996	1783	1898	2978	1835	571	239	565	2661	2710	1035	331	312	94	173
1997	1018	1114	1138	1705	1012	306	414	1073	1693	1679	599	183	170	145
1998	4020	637	671	654	939	539	365	1164	682	1045	961	326	98	166
1999	987	2499	375	364	333	474	459	954	740	417	579	498	165	132
2000	4996	623	1536	209	184	163	447	1347	607	461	247	331	280	166
2001	5105	3136	378	879	114	99	326	1005	857	376	266	136	179	240
2002	9312	3237	1966	233	536	69	257	1599	639	527	212	142	71	217
2003	2644	5912	2035	1208	141	325	199	1903	1016	389	287	107	69	138
2004	-	1682	3743	1276	753	88	327	-	1209	619	212	145	52	100

(Table 6.6 Continued)

(b) Biological year

Year	Eastern stock							Western stock						
	1	2	3	4	5	6	7+	1	2	3	4	5	6	7+
1985	12687	21225	6209	3873	2721	1789	1103	4460	4059	4170	2721	2077	1620	977
1986	29983	8089	13518	3940	2447	1715	1818	2584	2844	2586	2649	1726	1317	1646
1987	4781	19113	5134	8490	2437	1487	2087	2941	1648	1811	1641	1678	1093	1876
1988	3487	3047	12116	3209	5193	1453	2041	3027	1875	1045	1132	1018	1039	1836
1989	5462	2221	1909	7464	1951	3107	2034	3001	1929	1187	649	697	625	1761
1990	5733	3480	1398	1179	4497	1139	2861	2352	1913	1227	751	410	439	1503
1991	3922	3650	2166	839	678	2477	2034	1788	1498	1202	744	446	242	1143
1992	5307	2495	2249	1272	471	369	2345	2677	1138	916	660	383	225	691
1993	6927	3375	1528	1301	700	252	1383	1819	1703	697	505	341	194	461
1994	8174	4405	2067	880	708	369	824	2691	1157	1040	380	257	170	323
1995	2550	5192	2651	1151	462	362	592	3536	1711	704	560	190	125	238
1996	2112	1620	3147	1522	636	247	486	2472	2249	1039	376	277	91	173
1997	810	1342	977	1787	831	338	375	1101	1574	1398	606	211	154	146
1998	3055	515	813	556	974	444	374	1392	700	967	781	320	110	154
1999	1387	1939	306	439	280	487	416	1243	886	429	536	407	164	134
2000	5931	882	1197	174	226	138	434	1939	791	551	251	303	227	166
2001	4074	3769	534	687	97	124	309	682	1234	489	315	137	163	210
2002	5922	2596	2371	327	409	57	259	893	434	760	275	168	72	194
2003	8687	3772	1633	1462	199	249	194	1839	568	266	418	142	85	133
2004	-	5537	2393	1029	916	124	278	-	1170	348	147	217	72	110

Table 6.7. Base-case exploitation rate-at-age matrices. Results are shown for the western and eastern stocks, for assessments based on calendar and biological years.

(a) Calendar year

Year	Eastern stock							Western stock						
	1	2	3	4	5	6	7+	1	2	3	4	5	6	7+
1986	0.002	0.006	0.016	0.027	0.035	0.043	0.050	0.000	0.002	0.006	0.008	0.009	0.009	0.009
1987	0.002	0.006	0.021	0.045	0.074	0.104	0.131	0.000	0.005	0.017	0.025	0.028	0.029	0.029
1988	0.003	0.009	0.021	0.037	0.056	0.077	0.096	0.000	0.005	0.017	0.025	0.027	0.028	0.029
1989	0.007	0.020	0.034	0.051	0.074	0.098	0.119	0.000	0.003	0.010	0.014	0.016	0.016	0.017
1990	0.007	0.022	0.045	0.076	0.112	0.150	0.184	0.001	0.012	0.040	0.058	0.064	0.066	0.067
1991	0.010	0.030	0.059	0.094	0.130	0.166	0.199	0.003	0.037	0.119	0.170	0.189	0.196	0.198
1992	0.011	0.034	0.075	0.116	0.147	0.175	0.201	0.003	0.036	0.115	0.165	0.183	0.189	0.192
1993	0.015	0.045	0.086	0.124	0.152	0.177	0.200	0.003	0.036	0.117	0.168	0.187	0.194	0.196
1994	0.018	0.054	0.114	0.166	0.194	0.216	0.236	0.004	0.051	0.165	0.237	0.263	0.272	0.276
1995	0.018	0.054	0.097	0.131	0.151	0.168	0.183	0.004	0.048	0.154	0.220	0.245	0.254	0.257
1996	0.020	0.060	0.102	0.135	0.159	0.180	0.199	0.002	0.028	0.091	0.131	0.146	0.151	0.153
1997	0.018	0.055	0.098	0.136	0.165	0.192	0.216	0.003	0.032	0.102	0.147	0.163	0.169	0.171
1998	0.025	0.077	0.150	0.201	0.208	0.204	0.202	0.003	0.040	0.130	0.187	0.208	0.215	0.218
1999	0.010	0.036	0.126	0.207	0.232	0.243	0.256	0.002	0.023	0.073	0.105	0.117	0.121	0.123
2000	0.016	0.049	0.103	0.145	0.156	0.160	0.164	0.002	0.029	0.094	0.135	0.150	0.155	0.157
2001	0.005	0.017	0.032	0.043	0.047	0.050	0.053	0.003	0.036	0.115	0.164	0.183	0.189	0.192
2002	0.004	0.014	0.036	0.052	0.051	0.045	0.041	0.004	0.046	0.147	0.210	0.234	0.242	0.245
2003	0.002	0.007	0.017	0.023	0.023	0.021	0.019	0.004	0.045	0.145	0.209	0.232	0.240	0.243

(Table 6.7 Continued)

(b) Biological year

Year	Eastern stock							Western stock						
	1	2	3	4	5	6	7+	1	2	3	4	5	6	7+
1985	0.000	0.001	0.005	0.009	0.011	0.013	0.015	0.000	0.001	0.004	0.005	0.005	0.006	0.006
1986	0.000	0.005	0.015	0.030	0.047	0.065	0.082	0.000	0.001	0.005	0.007	0.007	0.007	0.007
1987	0.000	0.006	0.020	0.041	0.065	0.090	0.114	0.000	0.006	0.019	0.027	0.029	0.030	0.030
1988	0.001	0.017	0.034	0.047	0.062	0.078	0.093	0.000	0.007	0.025	0.035	0.038	0.039	0.039
1989	0.001	0.013	0.031	0.055	0.084	0.116	0.145	0.000	0.002	0.008	0.011	0.011	0.012	0.012
1990	0.002	0.024	0.059	0.098	0.136	0.176	0.213	0.001	0.014	0.049	0.068	0.074	0.076	0.077
1991	0.002	0.034	0.079	0.118	0.147	0.174	0.198	0.002	0.041	0.139	0.193	0.210	0.216	0.218
1992	0.003	0.039	0.093	0.137	0.163	0.184	0.203	0.002	0.040	0.136	0.188	0.204	0.210	0.212
1993	0.003	0.039	0.097	0.147	0.173	0.193	0.212	0.002	0.043	0.145	0.202	0.219	0.225	0.227
1994	0.004	0.056	0.126	0.177	0.199	0.213	0.227	0.003	0.046	0.156	0.216	0.235	0.241	0.243
1995	0.003	0.049	0.100	0.133	0.160	0.185	0.209	0.003	0.048	0.162	0.225	0.244	0.251	0.253
1996	0.004	0.055	0.109	0.143	0.166	0.187	0.206	0.001	0.025	0.086	0.119	0.129	0.133	0.134
1997	0.003	0.050	0.107	0.145	0.162	0.172	0.182	0.002	0.036	0.124	0.172	0.187	0.191	0.193
1998	0.004	0.066	0.154	0.211	0.217	0.207	0.199	0.002	0.038	0.131	0.182	0.197	0.202	0.204
1999	0.002	0.032	0.112	0.194	0.225	0.239	0.254	0.001	0.024	0.083	0.115	0.125	0.128	0.129
2000	0.003	0.050	0.100	0.127	0.140	0.148	0.157	0.002	0.031	0.104	0.144	0.157	0.161	0.162
2001	0.001	0.013	0.042	0.066	0.068	0.062	0.058	0.002	0.035	0.118	0.163	0.177	0.182	0.184
2002	0.001	0.013	0.033	0.046	0.046	0.042	0.038	0.002	0.040	0.138	0.191	0.207	0.213	0.215
2003	0.000	0.005	0.012	0.017	0.017	0.016	0.015	0.002	0.039	0.133	0.185	0.201	0.206	0.208

Table 6.8. Quantities of management interest for the base-case analyses and the sensitivity tests. Sensitivity tests in which the ratio of the spawning biomass in 2003 (2003/04 for the analyses based on a biological year) to that for 1991 (1991/1992) differs by more than 20% from that for the base-case analysis is indicated by an underline.

(a) Calendar year – eastern stock

Specification		$\tilde{B}_{03}$ Tonnes	$\tilde{B}_{97}/\tilde{B}_{91}$ (%)	$\tilde{B}_{03}/\tilde{B}_{97}$ (%)	$\tilde{B}_{03}/\tilde{B}_{91}$ (%)	$\tilde{B}_{03}/\tilde{B}_{0}(1)$ (%)	$\tilde{B}_{03}/\tilde{B}_{0}(2)$ (%)	$MSY\,(1)$	$MSY\,(1)$	Likelihood	Overall Sigma
East											
Base-case	0	3283	41.6	71.4	29.7	30.1	47.1	1998	1276	513.18	1.165
Pre-specify growth curve	1	4079	48.5	60.6	29.4	30.2	42.7	2682	1900	669.62	1.788
With density-dep growth	2	1993	45.3	34.6	15.7	35.8	39.3	1253	1140	415.03	1.065
No trawl CPUE	3	5194	43.1	105	45.2	41.2	73.3	2330	1309	463.51	1.139
No 86-91 trawl CPUE	4	2862	38.1	63.2	24.1	24.4	42.3	2120	1223	507.17	1.151
No 92-02 trawl CPUE	5	5166	42.4	110	46.6	43.6	75.0	2209	1284	493.34	1.14
No non-trawl CPUE	6	3662	46.9	71.1	33.4	32.8	47.4	2030	1406	466.15	1.173
Full non-trawl CPUE series	7	3598	44.5	73.5	32.7	32.6	50.0	2026	1321	495.63	1.177
Less 2003 data	8	2858	40.9	55.6	22.8	24.7	37.5	1945	1278	409.84	1.102
Less 2002-3 data	9	4454	44.8	96.0	43.0	42.1	62.7	1930	1297	407.56	1.078
Less 2001-3 data	10	3595	50.3	74.8	37.6	35.5	51.0	1909	1331	396.54	1.015
Double wght on CPUE data	11	2260	40.3	55.4	22.3	23.7	35.3	1773	1189	645.48	1.271
Half wght on CPUE data	12	4076	43.9	82.3	36.1	34.7	55.9	2149	1333	472.58	1.135
Multinomial likelihood	13	4584	58.7	93.4	54.9	44.5	60.8	1926	1408	471.28	2.526
Robust lognormal	14	17892	24.1	50.3	12.1	21.2	59.5	6849	2438	189.51	1.407
Fit to age not length data	15	2323	49.4	74.5	36.8	30.5	35.3	1363	1177	1132.4	1.111
M=0.3yr^{-1}	17	2508	40.2	77.0	31.0	25.4	37.2	1180	806	803.81	1.168
M=0.4yr^{-1}	18	2928	40.9	72.1	29.5	28.5	43.8	1645	1071	575.68	1.166
M=0.5yr^{-1}	19	3764	42.6	71.4	30.4	31.6	50.3	2469	1551	471.30	1.164
M=0.6yr^{-1}	22	5355	45.2	72.2	32.6	34.5	56.6	3856	2349	424.94	1.161
Dome-shaped trawl select	23	3300	41.6	72.8	30.3	30.5	47.7	1992	1271	522.6	1.163
$\sigma_r = 0.4$	20	3913	43.7	79.3	34.7	33.4	53.2	2152	1352	483.49	1.194
$\sigma_r = 1$	21	2849	40.2	64.5	25.9	27.4	42.8	1892	1211	540.54	1.151

(Table 6.8 Continued)

(b) Calendar year – western stock

Specification		$\tilde{B}_{03}$ Tonnes	$\tilde{B}_{97} / \tilde{B}_{91}$ (%)	$\tilde{B}_{03} / \tilde{B}_{97}$ (%)	$\tilde{B}_{03} / \tilde{B}_{91}$ (%)	$\tilde{B}_{03} / \tilde{B}_{0}(1)$ (%)	$\tilde{B}_{03} / \tilde{B}_{0}(2)$ (%)	MSY (1)	MSY (1)	Likelihood	Overall Sigma
East											
Base-case	0	633	34.9	50.2	17.5	17.9	30.7	670	390	525.69	2.381
Pre-specify growth curve	1	24958	41.2	46.6	19.2	20.9	50.9	3337	1371	466.44	2.611
With density-dep growth	2	632	33.3	52.4	17.5	19.6	33.2	626	369	531.14	2.355
No trawl CPUE	3	3339	152.4	89.7	136.8	76.6	100.5	831	633	411.37	2.158
No 86-91 trawl CPUE	4	703	43.5	48.4	21.0	20.8	30.8	642	434	484.96	2.364
No 92-02 trawl CPUE	5	3349	156.7	88.3	138.4	76.0	100.5	840	635	407.68	2.227
Less 2003 data	8	619	35.2	48.0	16.9	17.2	29.5	672	391	495.97	2.424
Less 2002-3 data	9	835	34.9	69.4	24.2	23.1	39.3	665	392	510.93	2.225
Less 2001-3 data	10	775	37.1	60.6	22.5	22.3	35.3	636	402	445.08	2.183
Double wght on CPUE data	11	632	32.7	51.3	16.8	17.7	29.2	684	416	531.28	2.542
Half wght on CPUE data	12	793	47.1	50.8	24.0	22.5	45.6	667	330	508.82	2.257
Multinomial likelihood	13	1452	60.1	104.4	62.7	44.8	82.5	749	407	764.69	6.855
Robust lognormal	14	14364	33.6	25.9	8.7	19.6	32.4	2022	1223	171.43	1.737
Fit to age not length data	15	513	35.9	45.9	16.5	15.7	25.1	636	400	674.22	1.966
M=0.3yr^{-1}	17	571	34.8	53.3	18.6	17.4	26.1	396	264	797.02	2.461
M=0.4yr^{-1}	18	601	33.6	52.2	17.5	17.7	30.0	557	330	600.60	2.390
M=0.5yr^{-1}	19	672	36.3	48.7	17.7	18.1	31.1	804	467	469.73	2.374
M=0.6yr^{-1}	22	861	42.4	46.5	19.7	19.9	33.5	1211	720	390.15	2.400
Dome-shaped trawl select	23	718	32.1	49.3	15.8	17.2	29.7	724	418	444.88	2.358
$\sigma_r = 0.4$	20	743	34.7	61.8	21.5	21.8	36.7	658	390	543.84	2.425
$\sigma_r = 1$	21	553	34.5	41.7	14.4	14.9	25.2	673	398	511.87	2.320

(Table 6.8 Continued)

(c) Biological year – eastern stock

Specification		$\tilde{B}_{03}$ Tonnes	$\tilde{B}_{97} / \tilde{B}_{91}$ (%)	$\tilde{B}_{03} / \tilde{B}_{97}$ (%)	$\tilde{B}_{03} / \tilde{B}_{91}$ (%)	$\tilde{B}_{03} / \tilde{B}_{0}(1)$ (%)	$\tilde{B}_{03} / \tilde{B}_{0}(2)$ (%)	$MSY(1)$	$MSY(1)$	Likelihood	Overall Sigma
East											
Base-case	0	3101	43.1	73.9	31.9	29.1	32.3	2002	1801	535.60	1.338
Pre-specify growth curve	1	4077	47.0	67.0	31.5	32.9	28.4	2392	2769	660.15	1.76
With density-dep growth	2	2684	42.0	66.7	28.0	28.5	28.2	1830	1849	554.49	1.339
No trawl CPUE	3	4248	42.5	94.4	40.1	30.8	50.0	2599	1601	471.92	1.288
No 86-91 trawl CPUE	4	2586	38.8	63.0	24.5	19.9	31.0	2420	1550	521.18	1.286
No 92-02 trawl CPUE	5	4076	40.8	98.3	40.1	35.1	44.8	2206	1728	520.16	1.318
No non-trawl CPUE	6	3360	46.1	71.6	33.0	33.8	29.8	1850	2104	483.61	1.324
Full non-trawl CPUE series	7	3367	46.0	75.7	34.8	31.3	34.8	2023	1818	520.04	1.347
Less 2003 data	8	2832	44.4	68.1	30.2	28.2	31.1	1858	1682	488.2	1.161
Less 2002-3 data	9	4653	47.5	105.3	50.1	44.3	51.8	1976	1690	417.54	1.135
Less 2001-3 data	10	4591	54.6	90.7	49.6	42.8	46.8	1980	1814	356.07	1.097
Double wght on CPUE data	11	2180	41.3	59.4	24.6	23.6	22.9	1749	1797	684.23	1.480
Half wght on CPUE data	12	3785	45.3	82.7	37.5	32.6	39.6	2178	1796	488.33	1.298
Multinomial likelihood	13	5230	66.4	104.1	69.1	48.1	65.6	2029	1488	463.69	2.778
Robust lognormal	14	1966	54.9	46.3	25.4	18.6	23.3	1963	1570	783.74	2.358
Fit to age not length data	15	1995	52.3	67.1	35.1	21.8	26.0	1406	1179	1225.19	1.039
M=0.3yr^{-1}	17	2525	41.4	85.2	35.3	25.9	30.3	1207	1033	860.62	1.331
M=0.4yr^{-1}	18	2822	42.4	76.5	32.4	28.1	31.7	1658	1469	608.19	1.334
M=0.5yr^{-1}	19	3507	44.1	72.7	32.0	30.3	33.3	2466	2246	489.48	1.341
M=0.6yr^{-1}	22	4780	46.4	74.3	34.5	33.4	36.3	3792	3493	449.23	1.347
Dome-shaped trawl select	23	3245	42.6	79.9	34.0	30.9	34.1	2020	1827	559.96	1.342
$\sigma_r = 0.4$	20	4035	48.0	88.3	42.4	35.4	45.5	2159	1680	510.02	1.372
$\sigma_r = 1$	21	2627	40.8	63.5	25.9	24.5	26.5	1994	1843	544.08	1.309

(Table 6.8 Continued)

(d) Biological year – western stock

Specification		$\tilde{B}_{03}$ Tonnes	$\tilde{B}_{97}/\tilde{B}_{91}$ (%)	$\tilde{B}_{03}/\tilde{B}_{97}$ (%)	$\tilde{B}_{03}/\tilde{B}_{91}$ (%)	$\tilde{B}_{03}/\tilde{B}_{0}(1)$ (%)	$\tilde{B}_{03}/\tilde{B}_{0}(2)$ (%)	*MSY* (1)	*MSY* (1)	Likelihood	Overall Sigma
East											
Base-case	0	766	39.6	60.9	24.1	20.7	33.4	716	443	512.83	2.547
Pre-specify growth curve	1	26215	49.6	49.7	24.6	21.2	53.4	3625	1438	473.86	2.676
With density-dep growth	2	1188	29.4	101.2	29.8	34.2	54.5	746	469	467.52	2.554
No trawl CPUE	3	6998	101.5	299.3	303.9	139.9	217.0	910	587	491.24	1.656
No 86-91 trawl CPUE	4	776	41.0	63.0	25.8	23.8	33.9	613	431	497.13	2.369
No 92-02 trawl CPUE	5	5605	121.7	217.0	264.0	122.1	187.2	841	549	463.21	1.922
Less 2003 data	8	652	39.7	52.4	20.8	17.5	28.0	704	440	504.37	2.355
Less 2002-3 data	9	879	39.2	77.8	30.5	25.0	37.6	681	453	563.28	2.093
Less 2001-3 data	10	1278	40.7	112.7	45.9	36.3	55.7	663	432	546.28	2.104
Double wght on CPUE data	11	697	37.2	58.3	21.7	19.0	28.5	724	482	546.82	2.727
Half wght on CPUE data	12	1127	39.7	92.8	36.9	29.8	53.8	686	380	505.51	2.126
Multinomial likelihood	13	1851	64.8	124	80.3	53.5	100.4	798	425	749.14	7.166
Robust lognormal	14	2039	33.0	27.4	9.1	24.7	17.7	926	1292	204.52	1.752
Fit to age not length data	15	516	31.7	65.7	20.8	16.9	24.0	611	431	864.27	1.824
M=0.3yr^{-1}	17	682	34.4	69.3	23.8	20.5	31.6	404	263	773.36	2.611
M=0.4yr^{-1}	18	736	37.8	63.4	23.9	20.7	33.4	595	369	574.86	2.568
M=0.5yr^{-1}	19	796	41.0	58.9	24.1	20.6	33.1	857	532	466.79	2.524
M=0.6yr^{-1}	22	869	42.0	55.6	23.4	20.3	32.5	1217	763	404.18	2.473
Dome-shaped trawl select	23	1583	34.4	53.3	18.3	19.2	32.9	1247	728	346.06	2.384
$\sigma_r = 0.4$	20	923	40.4	73.4	29.7	25.2	41.3	719	439	517.14	2.630
$\sigma_r = 1$	21	571	34.0	52.5	17.8	18.8	23.4	524	421	559.51	2.157

Table 6.9. Performance indicators for the risk analyses based on the base-case analyses. Results are shown for the western and eastern stocks, for assessments based on calendar and biological years.

(a) Projections based on recruitments for all years

	Old B_0					New B_0				
Scenario	(i)	(ii)	(iii)	(iv)	(v)	(i)	(ii)	(iii)	(iv)	(v)
(1) Calendar year – eastern stock										
A	87.30	100.00	99.96	98.40	90.20	72.12	100.00	100.00	99.96	99.02
B	86.72	100.00	99.94	98.24	89.54	70.92	100.00	100.00	99.96	98.88
C	85.96	100.00	99.94	97.98	89.06	69.74	100.00	100.00	99.90	98.64
D	85.08	100.00	99.94	97.70	88.42	68.10	100.00	100.00	99.86	98.44
E	83.52	100.00	99.92	97.06	87.18	65.32	100.00	100.00	99.82	97.72
(2) Calendar year – western stock										
A	76.28	100.00	94.94	81.16	62.94	49.98	100.00	99.04	93.26	81.02
B	69.86	99.92	91.02	74.70	57.58	38.70	99.64	96.28	86.62	70.56
C	63.68	98.94	85.78	67.64	52.22	28.12	96.86	91.22	77.00	58.54
D	57.42	96.08	79.82	61.36	47.02	19.90	88.96	82.90	65.52	46.62
(3) Biological year – eastern stock										
A	95.88	100.00	100.00	99.50	95.36	90.00	100.00	100.00	99.12	94.06
B	95.40	100.00	100.00	99.42	95.04	89.06	100.00	99.98	99.02	93.56
C	94.90	100.00	99.98	99.34	94.64	88.06	100.00	99.96	98.88	92.90
D	94.56	100.00	99.98	99.20	94.14	87.00	100.00	99.94	98.60	92.18
E	93.34	100.00	99.98	98.92	93.04	85.02	100.00	99.94	98.20	90.60
(4) Biological year – western stock										
A	76.58	100.00	95.26	79.88	61.62	50.14	99.96	98.86	92.42	78.68
B	70.18	99.88	91.46	73.84	56.58	39.72	99.70	96.28	86.24	68.36
C	64.06	99.24	86.40	67.52	51.54	30.30	97.92	91.74	77.32	57.32
D	58.52	97.58	80.60	61.80	47.00	22.52	92.72	84.70	66.86	46.04

(Table 6.9 Continued)

(b) Projections based on recruitments for 1999-2003.

	Old B_0					New B_0				
Scenario	(i)	(ii)	(iii)	(iv)	(v)	(i)	(ii)	(iii)	(iv)	(v)
(1) Calendar year – eastern stock										
A	63.12	100.00	99.48	91.82	69.44	63.12	100.00	100.00	99.60	97.04
B	61.80	100.00	99.36	91.04	68.34	61.80	100.00	99.98	99.50	96.78
C	60.26	100.00	99.28	90.26	66.66	60.26	100.00	99.98	99.40	96.22
D	58.72	100.00	99.04	89.36	64.94	58.72	100.00	99.96	99.28	95.62
E	55.86	100.00	98.66	87.36	61.68	55.86	100.00	99.92	99.00	94.42
(2) Calendar year – western stock										
A	25.26	99.58	63.26	30.12	12.42	25.26	99.58	91.98	74.30	53.00
B	18.66	95.12	49.98	22.02	8.82	18.66	95.12	82.38	61.42	41.30
C	13.84	82.70	38.34	16.22	6.42	13.84	82.70	69.76	48.38	31.52
D	10.06	64.78	29.12	11.60	4.82	10.06	64.78	56.08	37.58	23.58
(3) Biological year – eastern stock										
A	87.00	100.00	99.94	97.76	86.60	87.00	100.00	99.96	98.82	91.80
B	86.20	100.00	99.94	97.34	85.20	86.20	100.00	99.90	98.62	91.12
C	85.12	100.00	99.94	97.00	84.22	85.12	100.00	99.90	98.42	90.34
D	84.20	100.00	99.88	96.58	82.92	84.20	100.00	99.88	98.20	89.46
E	81.84	100.00	99.82	95.82	80.32	81.84	100.00	99.82	97.38	87.46
(4) Biological year – western stock										
A	24.38	99.46	62.06	27.24	11.12	24.38	99.46	89.40	70.20	47.32
B	18.30	95.60	49.40	20.22	8.06	18.30	95.60	80.06	57.62	36.80
C	13.28	84.94	38.18	15.30	5.84	13.28	84.94	68.58	46.22	28.94
D	9.90	69.08	28.90	11.14	4.18	9.90	69.08	56.26	35.96	21.66

Table 6.10. Performance indicators for the risk analyses based on the M=0.3yr^{-1} sensitivity test. Results are shown for the western and eastern stocks, for assessments based on calendar and biological years.

(a) Projections based on recruitments for all years

	Old B_0					New B_0				
Scenario	(i)	(ii)	(iii)	(iv)	(v)	(i)	(ii)	(iii)	(iv)	(v)
(1) Calendar year – eastern stock										
A	98.16	100.00	99.98	99.44	94.10	96.40	100.00	100.00	99.98	99.44
B	97.88	100.00	99.98	99.22	93.38	95.64	100.00	100.00	99.94	99.32
C	97.46	100.00	99.98	99.00	92.30	94.74	100.00	100.00	99.92	98.90
D	97.02	100.00	99.98	98.66	91.26	93.62	100.00	100.00	99.86	98.68
E	96.10	100.00	99.94	98.06	88.72	91.26	100.00	100.00	99.76	97.62
(2) Calendar year – western stock										
A	70.02	99.30	87.00	64.86	44.22	44.56	97.92	92.88	76.80	53.64
B	57.56	92.50	75.18	52.42	34.86	27.20	82.46	79.86	56.80	34.16
C	46.02	76.12	62.04	41.46	27.14	15.14	51.10	59.84	36.70	20.00
D	35.60	56.12	49.12	32.24	20.56	8.22	23.22	38.76	21.24	10.42
(3) Biological year – eastern stock										
A	99.78	100.00	100.00	99.86	97.96	99.64	100.00	100.00	99.84	98.28
B	99.70	100.00	100.00	99.84	97.36	99.52	100.00	100.00	99.76	97.78
C	99.60	100.00	100.00	99.76	97.04	99.36	100.00	100.00	99.76	97.26
D	99.52	100.00	100.00	99.68	96.44	99.00	100.00	100.00	99.70	96.72
E	99.22	100.00	100.00	99.44	95.08	98.28	100.00	99.98	99.50	95.48
(4) Biological year – western stock										
A	71.62	99.66	89.24	67.30	45.88	46.26	98.82	94.82	80.68	58.32
B	59.12	95.66	79.26	55.22	37.30	30.14	88.96	85.06	62.78	39.28
C	48.08	82.40	66.44	44.88	30.04	17.36	61.46	67.28	43.48	23.68
D	39.24	64.00	54.10	36.12	24.22	9.10	31.50	47.74	26.22	13.36

(Table 6.10 Continued)

(b) Projections based on recruitments for 1999-2003.

	Old B_0					New B_0				
Scenario	(i)	(ii)	(iii)	(iv)	(v)	(i)	(ii)	(iii)	(iv)	(v)
(1) Calendar year – eastern stock										
A	93.86	100.00	99.94	97.42	81.30	93.86	100.00	100.00	99.92	98.46
B	92.58	100.00	99.94	96.90	78.82	92.58	100.00	100.00	99.82	98.10
C	91.26	100.00	99.92	96.20	76.72	91.26	100.00	99.98	99.70	97.52
D	89.82	100.00	99.82	95.08	74.52	89.82	100.00	99.98	99.66	96.98
E	86.44	100.00	99.62	92.74	69.78	86.44	100.00	99.98	99.36	95.62
(2) Calendar year – western stock										
A	27.36	88.74	50.16	21.58	8.24	27.36	88.74	78.42	54.32	32.86
B	17.12	58.78	32.10	13.38	4.82	17.12	58.78	58.20	35.66	20.64
C	10.46	30.10	20.28	7.54	2.94	10.46	30.10	38.78	22.32	13.18
D	6.20	14.68	12.34	4.54	1.84	6.20	14.68	24.20	14.00	7.92
(3) Biological year – eastern stock										
A	99.40	100.00	100.00	99.64	94.62	99.40	100.00	100.00	99.84	97.66
B	99.24	100.00	100.00	99.58	93.48	99.24	100.00	100.00	99.78	97.14
C	98.94	100.00	100.00	99.40	92.44	98.94	100.00	100.00	99.70	96.46
D	98.52	100.00	100.00	99.08	91.10	98.52	100.00	100.00	99.56	95.98
E	97.76	100.00	100.00	98.42	88.46	97.76	100.00	100.00	99.08	94.54
(4) Biological year – western stock										
A	28.12	91.20	52.80	23.52	9.12	28.12	91.20	80.02	57.06	35.90
B	18.20	65.40	36.40	14.60	5.32	18.20	65.40	62.34	39.92	23.58
C	11.26	37.26	23.84	9.20	2.84	11.26	37.26	44.58	26.60	14.86
D	6.82	18.64	14.44	5.28	1.76	6.82	18.64	29.70	16.70	9.30

APPENDIX 6.A : The population dynamics model

6.A.1 Basic dynamics

The dynamics of animals aged 1 and above are governed by the equation:

$$N_{y+1,a} = \begin{cases} N_{y+1,1} & \text{if } a = 1 \\ (N_{y,a-1}e^{-M/2} - C_{y,a-1})e^{-M/2} & \text{if } 1 < a < x \\ ((N_{y,x} + N_{y,x-1})e^{-M/2} - C_{y,x} - C_{y,x-1})e^{-M/2} & \text{if } a = x \end{cases} \tag{6.A.1}$$

where $N_{y,a}$ is the number of fish of age *a* at the start of year *y* (where *y* runs from 1986 to 2003 or 1985/86 to 2003/2004),

$C_{y,a}$ is the catch (landed and discarded) during year *y* of fish of age *a*:

$$C_{y,a} = \sum_{f=1}^{n_f} (C^f_{y,a} + D^f_{y,a}) \tag{6.A.2}$$

$C^f_{y,a}$ is the number of fish of age *a* landed during year *y* by fleet *f*,

$D^f_{y,a}$ is the number of fish of age *a* discarded during year *y* by fleet *f*,

M is the (age-independent) rate of natural mortality,

n_f is the number of fleets, and

x is the maximum age-class (taken to be a plus-group and equal to 7).

6.A.2 Catches

The model estimates of the catch (in numbers) of fish of age *a* by fleet *f* during year *y*, $C^f_{y,a}$, and of the number of fish of age *a* discarded by fleet *f* during year *y*, $D^f_{y,a}$, are given by the equations:

$$\begin{aligned} C^f_{y,a} &= F^f_y \, N_{y,a} \, e^{-M/2} \sum_L (1 - P^f_L) \, S^f_L \, A^L_{y,a} \\ D^f_{y,a} &= F^f_y \, N_{y,a} \, e^{-M/2} \sum_L P^f_L \, S^f_L \, A^L_{y,a} \end{aligned} \tag{6.A.3}$$

where F^f_y is the fully-selected exploitation rate by fleet *f* during year *y*,

$A^L_{y,a}$ is the proportion of fish of age *a* that are in length-class *L* during year *y*,

P^f_L is the probability of fleet *f* discarding a fish in length-class *L*, and

S^f_L is the vulnerability by fleet *f* on fish in (2cm) length-class *L*.

The model estimates of the catch (in numbers) of fish in length-class L by fleet f during year y, $C^f_{y,L}$, and of the number of fish in length-class L discarded by fleet f during year y, $D^f_{y,L}$, are given by the equations:

$$\begin{aligned} C^f_{y,L} &= (1-P^f_L)\, S^f_L\, F^f_y \sum_{a=1}^{x} A^L_{y,a}\, N_{y,a}\, e^{-M/2} \\ D^f_{y,L} &= P^f_L\, S^f_L\, F^f_y \sum_{a=1}^{x} A^L_{y,a}\, N_{y,a}\, e^{-M/2} \end{aligned} \tag{6.A.4}$$

The model estimates of the landed catch (in mass) by fleet f during year y, C^f_y, and of the mass of fish discarded by fleet f during year y, D^f_y, are given by the equations:

$$C^f_y = \sum_L w_L\, C^f_{y,L} \tag{6.A.5a}$$

$$D^f_y = \sum_L w_L\, D^f_{y,L} \tag{6.A.5b}$$

where w_L is the mean mass of a fish in length-class L.

The fully-selected exploitation rate by fleet f during year y, F^f_y, is found by solving Equation (6.A.5a), i.e. the landed catches are assumed to be reported without substantial error. The exploitation rate for fish of age a during year y by fleet f is given by:

$$F^f_{y,a} = F^f_y \sum_L S^f_L\, A^L_{y,a} \tag{6.A.6}$$

6.A.3 Vulnerability

The vulnerability of the gear is governed either by a logistic curve (Equation 6.A.7a) or by a normal curve (Equation 6.A.7b):

$$S^f_L = (1 + e^{-\ell n 19(\overline{L}_L - L^f_{50})/(L^f_{95} - L^f_{50})})^{-1} \tag{6.A.7a}$$

$$S^f_L = \exp\{\ell n(0.05)(\overline{L}_L - L^f_{\max})^2 / (L^f_5 - L^f_{\max})^2\} \tag{6.A.7b}$$

where L^f_{50} is the length-at-50%-vulnerability for fleet f,

L^f_{95} is the length-at-95%-vulnerability for fleet f,

$L^f_{\max}$ is the length corresponding to maximum vulnerability for fleet f,

L_5 is the length at which vulnerability is 5% of the maximum for fleet f, and

$\overline{L}_L$ is the mean length of a fish in length-class L (the mid-point of the range).

The probability of fleet f discarding a fish in length-class L, P_L^f, is modelled using the equation:

$$P_L^f = \gamma^f [1 + e^{-\ell n 19(\bar{L} - L_{50}^{D,f})/(L_{95}^{D,f} - L_{50}^{D,f})}]^{-1} \tag{6.A.8}$$

where $L_{50}^{D,f}$ is the length at which discarding is half the maximum possible rate for fleet *f*,

$L_{95}^{D,f}$ is the length at which discarding is 95% of the maximum possible rate for fleet *f*, and

γ^f is the maximum rate of discarding.

6.A.4 Growth

The proportion of animals of age *a* that are in length-class *L* during year *y* is given by:

$$A_{y,a}^L = \int_{\bar{L}-\Delta L}^{\bar{L}+\Delta L} \frac{1}{\sqrt{2\pi}\,\sigma_a\, l} e^{-\frac{(\ell n l - \ell n \ell_{y,a})^2}{2\sigma_a^2}} dl \tag{6.A.9}$$

where ΔL is half the width of a length-class (1 cm),

$\ell_{y,a}$ is the mean length of a fish of age *a* during year *y*:

$$\ell_{y,a} = \ell_\infty (1 - e^{-\kappa_{y-a}\,(a+0.5-t_0)})$$

σ_a is (approximately) the coefficient of variation of ℓ_a (σ_a^2 is assumed to change linearly with ℓ_a),

κ_{y-a} is the growth rate for the cohort spawned in year *y-a*:

$$\kappa_{y,a} = \begin{cases} \kappa \ \left(N_{y-a+1,1} / \bar{N}_1\right)^\phi & \text{if } y-a+1 \geq 1986 \\ \kappa & \text{otherwise} \end{cases} \tag{6.A.10}$$

ϕ is a parameter that determines the extent of density-dependence in growth rate,

$\bar{N}_1$ is the mean number of 1-year-olds over the period 1986 – 2003, and

ℓ_∞, κ, t_0 are the parameters of the von Bertalanffy growth curve.

The mean mass of a fish in length-class *L*, w_L, is given by:

$$w_L = e_1 \bar{L}_L^{\,e_2}$$

where e_1, e_2 are the parameters of the length-mass relationship (0.03 and 2.90 respectively).

6.A.5 Spawning biomass

The spawner biomass in the middle of year y, $\widetilde{B}_y$, is calculated using the equation:

$$\tilde{B}_y = \sum_{a=3}^{x} (N_{y,a}\, e^{-M/2} - C_{y,a}/2) \sum_{L} f_L\, w_L\, A_{y,a}^{L} \tag{6.A.11}$$

where f_L is the proportion of animals in length-class L that are mature (Fig. 6.3).

APPENDIX 6.B :The likelihood function

The data available for assessment purposes are:

(a) the proportion of the landed catch (in mass) discarded by fleet,
(b) catch-rates by fleet,
(c) age-length keys,
(d) the proportion of the (landed / discarded) catch by fleet and age, and
(e) the proportion of the (landed / discarded) catch by fleet and length-class.

The following sections describe how each of these data sources is included in the likelihood function. The summations over year and fleet are modified as necessary to handle missing data.

6.B.1 Discard rates

The contribution of the observed discard rates (defined as the ratio of the mass of fish discarded to the mass of fish landed) to the negative of the logarithm of the likelihood function (ignoring constants independent of the model parameters) is based on the assumption that the errors in measuring the discard rates for fleet *f* are log-normally distributed with a CV of σ_d^f :

$$L=\sum_f\sum_y\left\{\ell n\sigma_d^f+\tfrac{1}{2(\sigma_d^f)^2}(\ell\mathrm{n}\tilde{D}_y^{f,obs}-\ell\mathrm{n}\tilde{D}_y^f)^2\right\} \tag{6.B.1}$$

where $\tilde{D}_y^{f,obs}$ is the observed discard rate for fleet *f* and year *y*,

$\tilde{D}_y^f$ is the model-estimate of the discard rate for fleet *f* and year *y*:

$$\tilde{D}_y^f=D_y^f/C_y^f$$

σ_d^f is the residual standard error for fleet *f*.

6.B.2 Catch rates

The contribution of the catch-rate data for fleet *f* to the negative of the logarithm of the likelihood function (ignoring constants independent of the model parameters) is based on the assumption that fluctuations in catchability for fleet *f* are log-normally distributed with a CV of σ_q^f :

$$L=\sum_f\sum_y\left\{\ell\mathrm{n}\sigma_q^f+\tfrac{1}{2(\sigma_q^f)^2}(\ell\mathrm{n}I_y^f-\ell\mathrm{n}(q^f\,(B_y^f)^{\gamma^f}))^2\right\} \tag{6.B.2}$$

where q^f is the catchability coefficient for fleet *f*,

I_y^f is the catch-rate index for fleet *f* and year *y*,

γ^f is a non-linearity factor for fleet *f* (assumed to be 1 for all of the analyses in this report),

B_y^f is the mid-season biomass available to fleet *f* during year *y*:

$$B_y^f=\sum_{a=1}^{x}(N_{y,a}e^{-M/2}-C_{y,a}/2)\sum_L w_L\,A_{y,a}^L\,(1-P_L^f)\,S_L^f \tag{6.B.3}$$

σ_q^f is the residual standard error for fleet *f*.

6.B.3 Catch / discard proportion data

The contribution of the catch age-composition information to the negative of the logarithm of the likelihood function depends on the assumption regarding the relationship between the observed fraction of the catch falling in an age-class and the corresponding model-estimate. Three assumptions are considered: (a) lognormal with a CV that depends on the model estimate and the number of animals aged, (b) multinomial, and (c) the robust likelihood function of Fournier *et al.* (1990). The negative of the logarithm of the likelihood function (ignoring constants independent of the model parameters) for each of these alternatives is:

$$L = \sum_f \sum_y \sum_a \left\{ \ell\text{n}\left(\frac{\sigma_z^f}{\sqrt{Q_y^f\, \rho_{y,a}^f / \rho_{y,a}^{f,obs}}} \right) + \frac{\rho_{y,a}^f\, Q_y^f}{2(\sigma_z^f)^2} (\ell\text{n}\rho_{y,a}^{f,obs} - \ell\text{n}\rho_{y,a}^f)^2 \right\} \qquad (6.B.4a)$$

$$L = -\sum_f \tilde{Q}^f \sum_y Q_y^f \sum_a \rho_{y,a}^{f,obs}\, \ell\text{n}(\rho_{y,a}^f / \rho_{y,a}^{f,obs}) \qquad (6.B.4b)$$

$$L = \sum_f \sum_y \sum_a \left\{ \ell\text{n}\left(\frac{\sigma_z^f \sqrt{\rho_{y,a}^{f,obs}(1-\rho_{y,a}^{f,obs}) + 1/Q_y^{I,f}}}{\sqrt{Q_y^f}} \right) + \frac{Q_y^f \left(\rho_{y,a}^{f,obs} - \rho_{y,a}^f \right)^2}{2(\sigma_z^f)^2 \left(\rho_{y,a}^{f,obs}(1-\rho_{y,a}^{f,obs}) + 1/Q_y^{I,f} \right)} \right\} \qquad (6.B.4c)$$

where $\rho_{y,a}^{f,\text{obs}}$	is the observed proportion which fish of age *a* made up of the (landed) catch during year *y* by fleet *f*,
$\rho_{y,a}^f$	is the model-estimate of the proportion which fish of age *a* made up of the (landed) catch during year *y* by fleet *f*:

$$\rho_{y,a}^f = \frac{1}{\sum_{a''} C_{y,a''}^f} \sum_{a'=1}^{x} C_{y,a'}^f\, \Omega_{a',a} \qquad (6.B.5)$$

$\Omega_{a',a}$	is the probability that an animal of actual age *a'* will be aged to be *a* (the age-reading error matrix - see Table 6.B.1),
Q_y^f	is the number of animals aged during year *y* from the landed catch by fleet *f*, expressed as a fraction of the average number of animals aged from the landed catch by fleet *y* over all years,
$\tilde{Q}^f$	is the weight assigned to the age-composition data for the landed catch by fleet *f*,
$Q_y^{I,f}$	is the number of ages for which landed catch data are available for year *y* and fleet *f*, and
σ_z^f	is the residual standard error for fleet *f*.

The contribution to the likelihood function by the age-composition of the discards follows Equations (6.B.4) and (6.B.5), except, for example, that $\rho_{y,a}^f$ is replaced by the model-estimate of the proportion which fish of age *a* made up of the discards during year *y* by fleet *f*, and $\rho_{y,a}^{f,obs}$ is replaced by the observed proportion which fish of age *a* made up of the discards during year *y* by fleet *f*. A similar approach is used to include the length composition data in the likelihood function (except, of course, that account is not taken of age-reading error).

6.B.4 Age-length keys

The age-length keys provide information on the proportion of each age-class in each length-class each year. Under the assumption that animals are sampled randomly within each age-class, the contribution of the age-length keys to the negative of the logarithm of the likelihood function is given by:

$$-\omega \sum_{y} \sum_{L} W_{y,L} \sum_{a=1}^{x} \left(A^{obs}_{y,L,a} \,\ell\text{n}(\rho_{y,L,a}) - A^{obs}_{y,L,a} \,\ell\text{n}(A^{obs}_{y,L,a}) \right) \qquad (6.B.6)$$

where $A^{obs}_{y,L,a}$ is the observed fraction during year y of animals in length-class L that are of age a,

$\rho_{y,L,a}$ is the model-estimate of the fraction during year y of animals in length-class L that are estimated to be of age a:

$$\rho_{y,L,a} = \frac{1}{\sum_{a''} A^{L}_{y,a''} N_{y,a''}} \sum_{a'=1}^{x} A^{L}_{y,a'} \, N_{y,a'} \, \Omega_{a',a} \qquad (6.B.7)$$

$W_{y,L}$ is the sample size for length-class L during year y, and

ω is the weight assigned to the age-length key information.

The term $-A^{obs}_{y,L,a} \,\ell\text{n}(A^{obs}_{y,L,a})$ is a constant, independent of the model parameters, and is included in Equation (6.B.6) for improved numerical stability.

6.B.5 Penalties on the recruitment residuals

The prior placed on recruitment is based on the assumption of no trend in recruitment from 1986 onwards and a smooth exponential decline in year-class strength at the start of 1986, i.e.:

$$P = \frac{1}{2\sigma_r^2} \left(\sum_{y=1985/86}^{2002/03} (\ell\text{n}N_{y,1} - \bar{\varepsilon})^2 + \sum_{a=1}^{7+} (\ell\text{n}N_{1986,a} - \alpha - Ma)^2 \right) \qquad (6.B.8)$$

where σ_r is the (assumed) extent of variability in recruitment,

$\bar{\varepsilon}$ is the logarithm of the geometric mean recruitment over 1986–2003, and

α is estimated by regressing $N_{1986,a}$ on age.

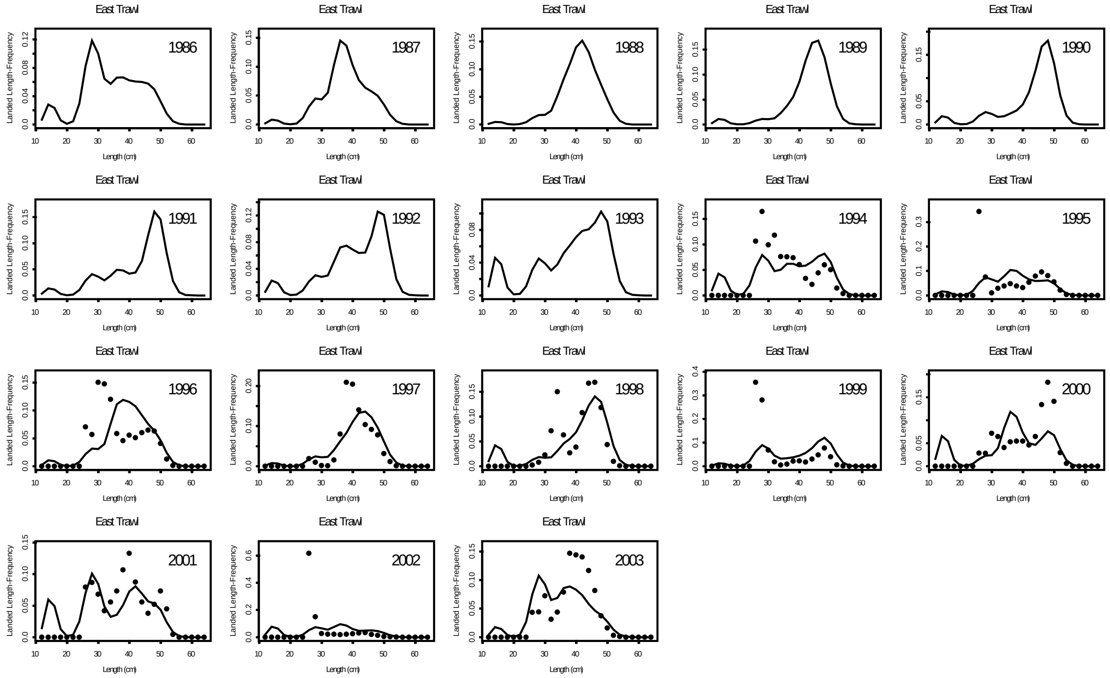
Table 6.B.1 : The age-reading error matrix.

Actual Age	Estimated age						
	1	2	3	4	5	6	7
1	0.817	0.183	0.000	0.000	0.000	0.000	0.000
2	0.019	0.845	0.110	0.026	0.000	0.000	0.000
3	0.000	0.051	0.658	0.256	0.034	0.000	0.000
4	0.000	0.000	0.104	0.558	0.325	0.013	0.000
5	0.000	0.000	0.000	0.250	0.656	0.094	0.000
6	0.000	0.000	0.000	0.000	0.200	0.600	0.200
7	0.000	0.000	0.000	0.000	0.000	0.000	1.000

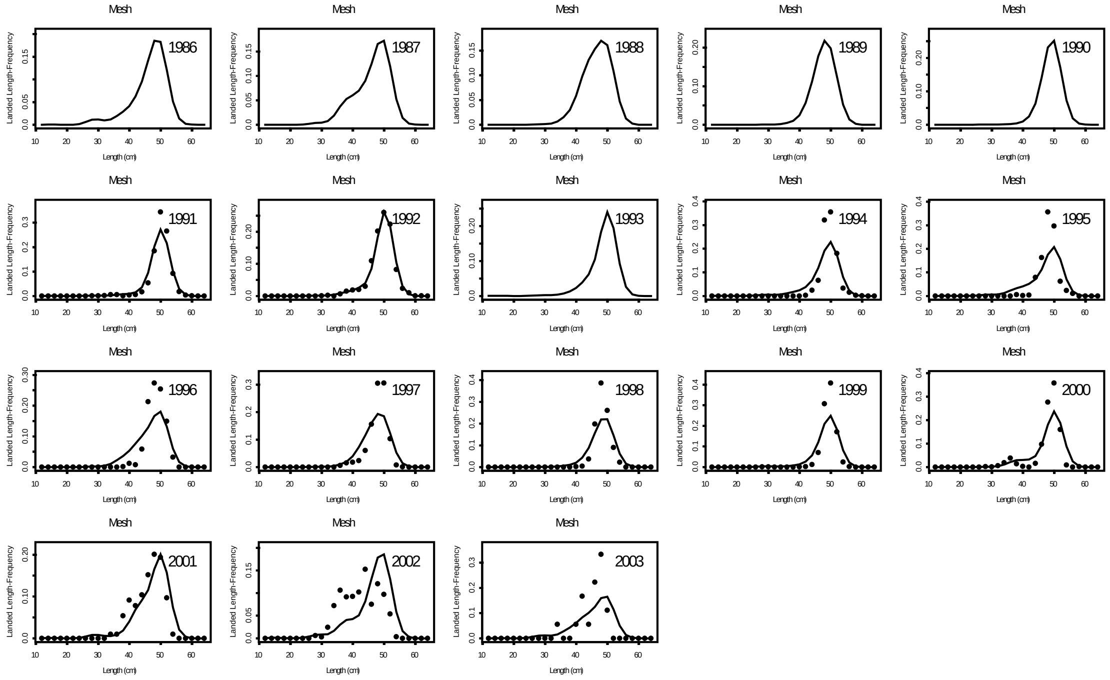
APPENDIX 6.C.1 : Fits to the landed length-frequencies

(a) Calendar year – Eastern stock

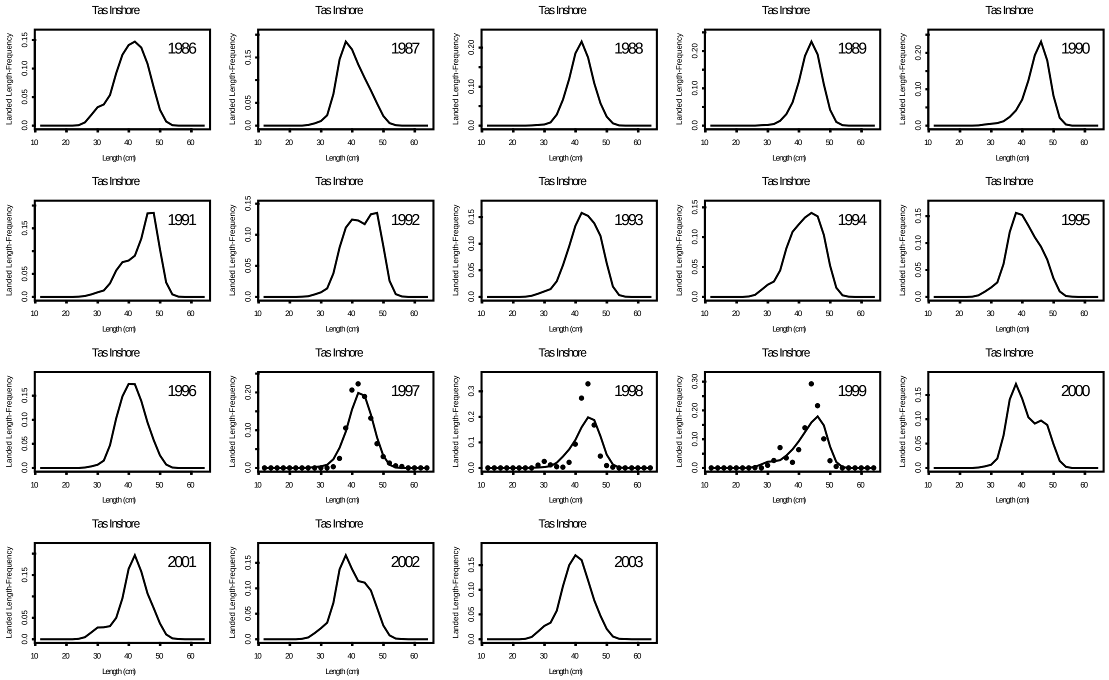
(i) East Trawl



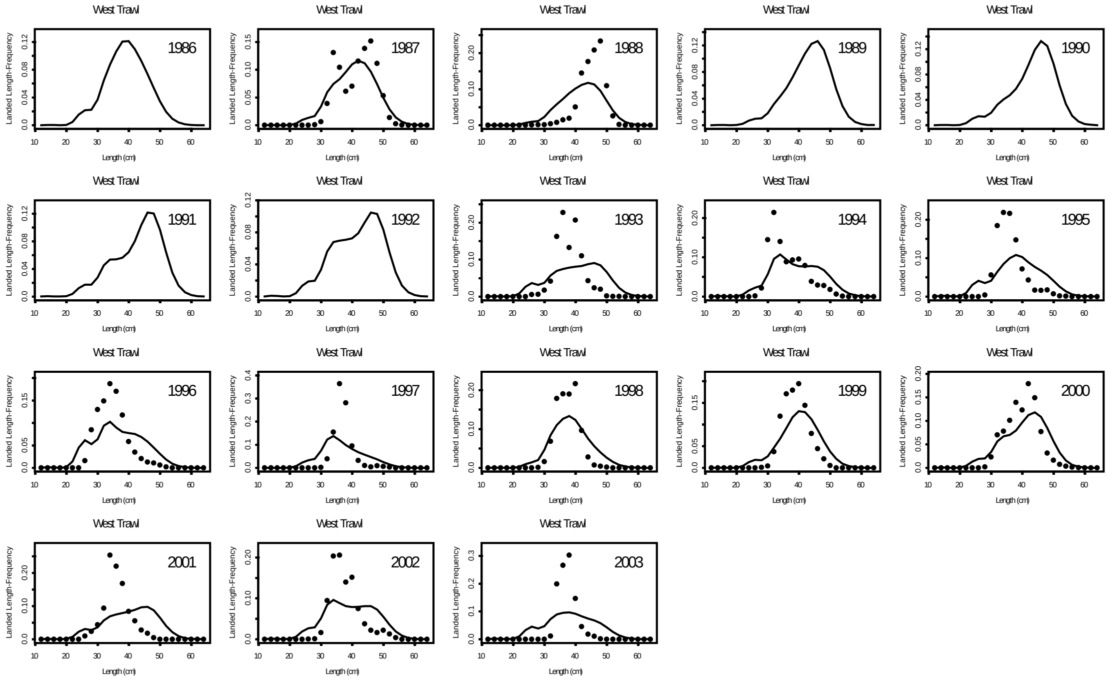
(ii) Non-trawl



(iii) Tasmania meshnet

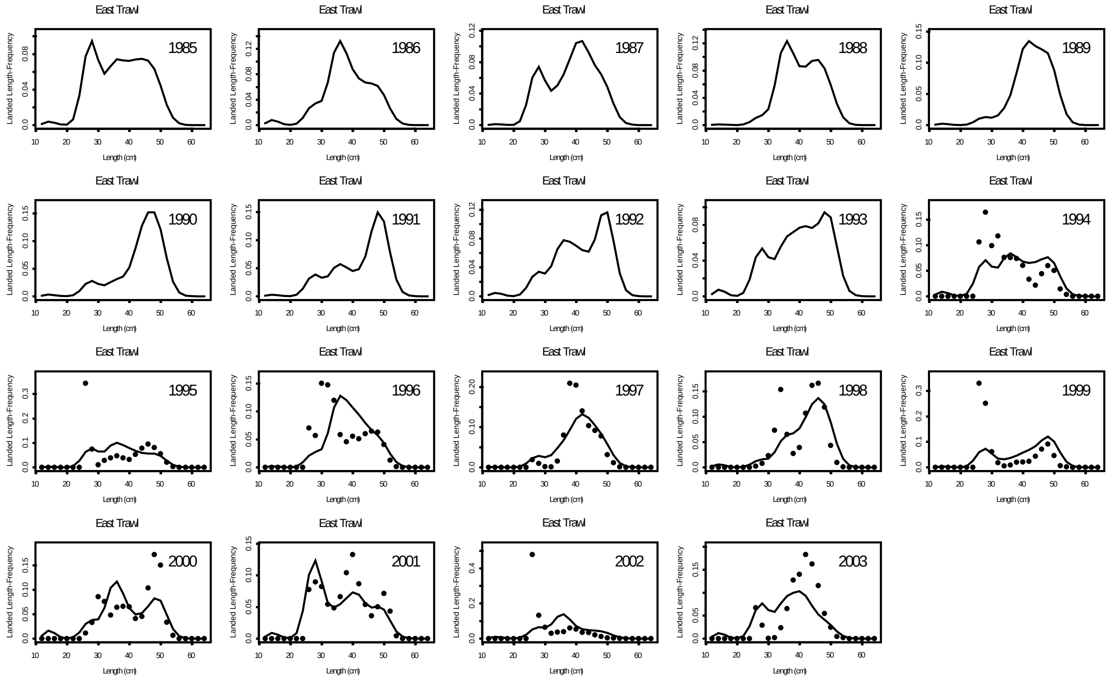


(b) Calendar year – Western stock

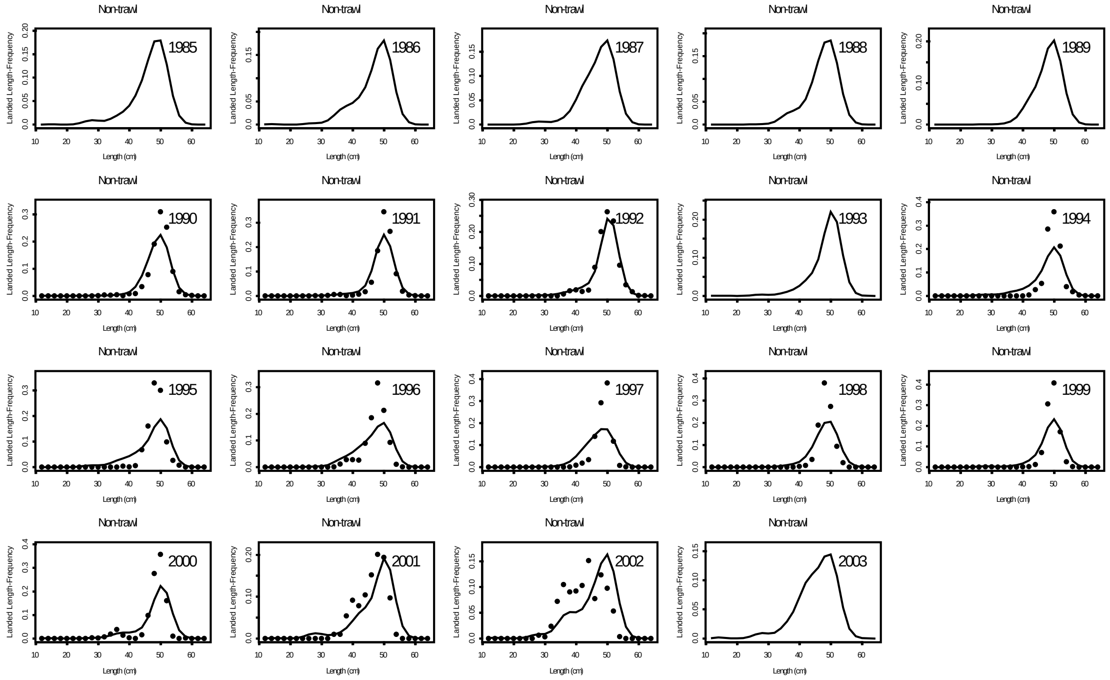


(c) Biological year – Eastern stock

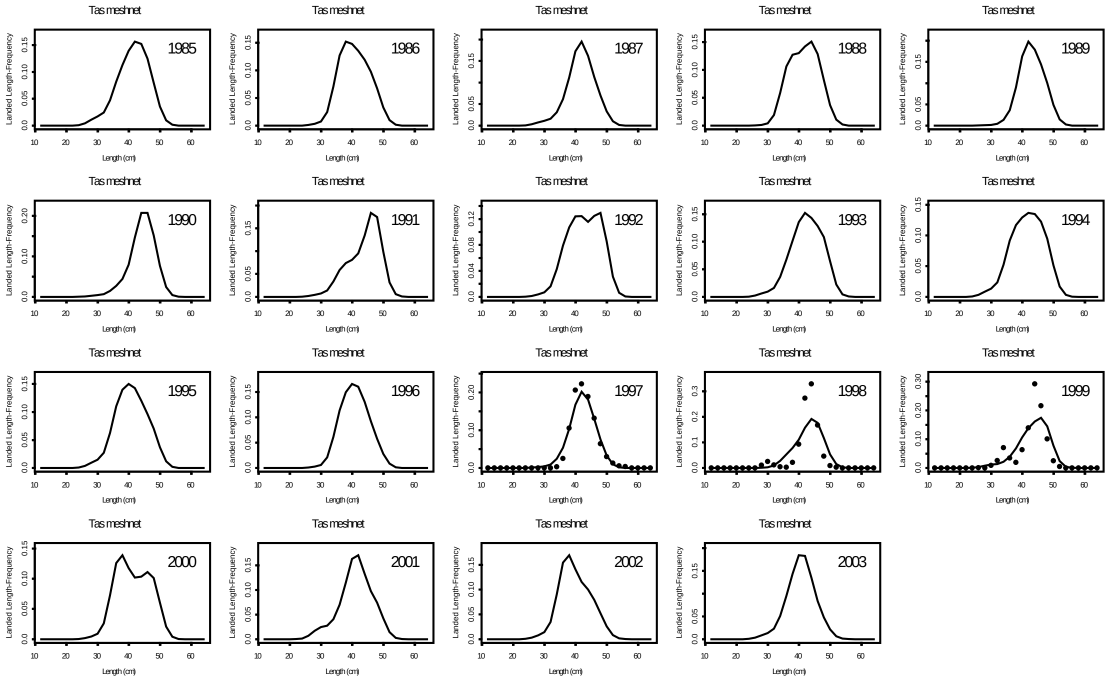
(i) East Trawl



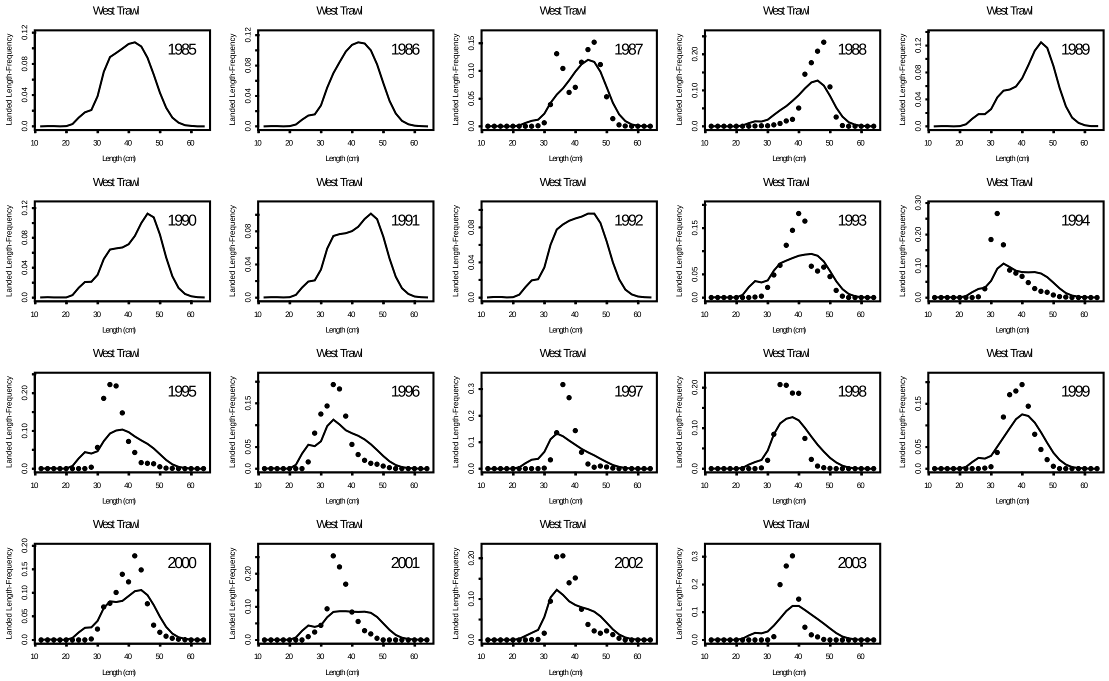
(ii) Non-trawl



(iii) Tasmania meshnet

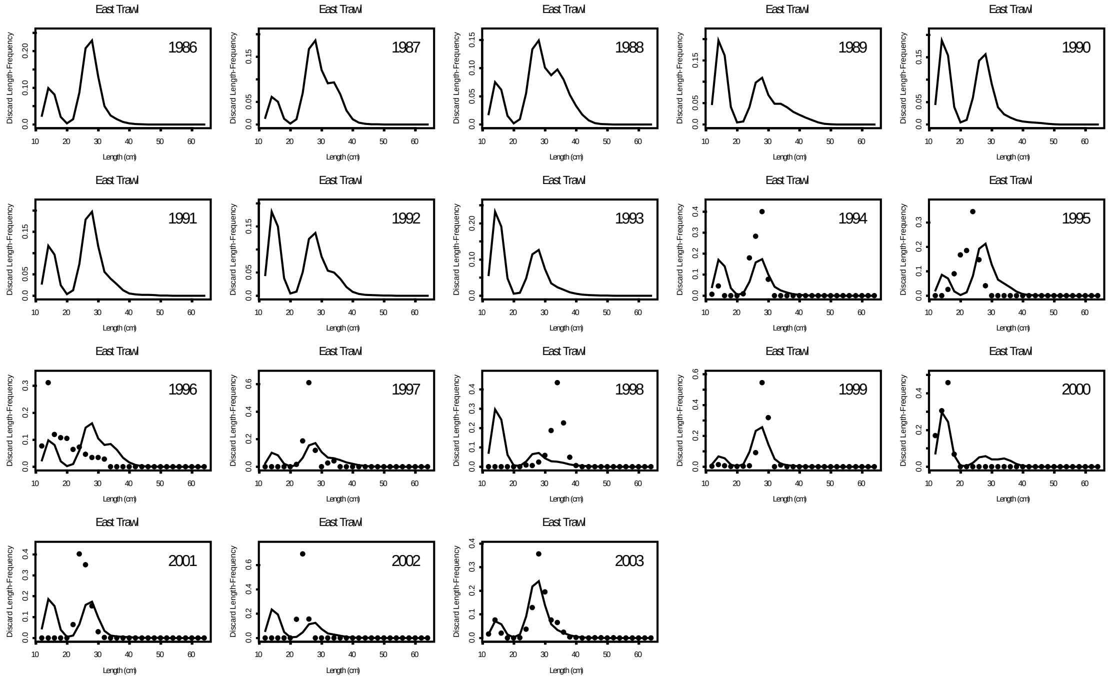


(d) Biological year – Western stock

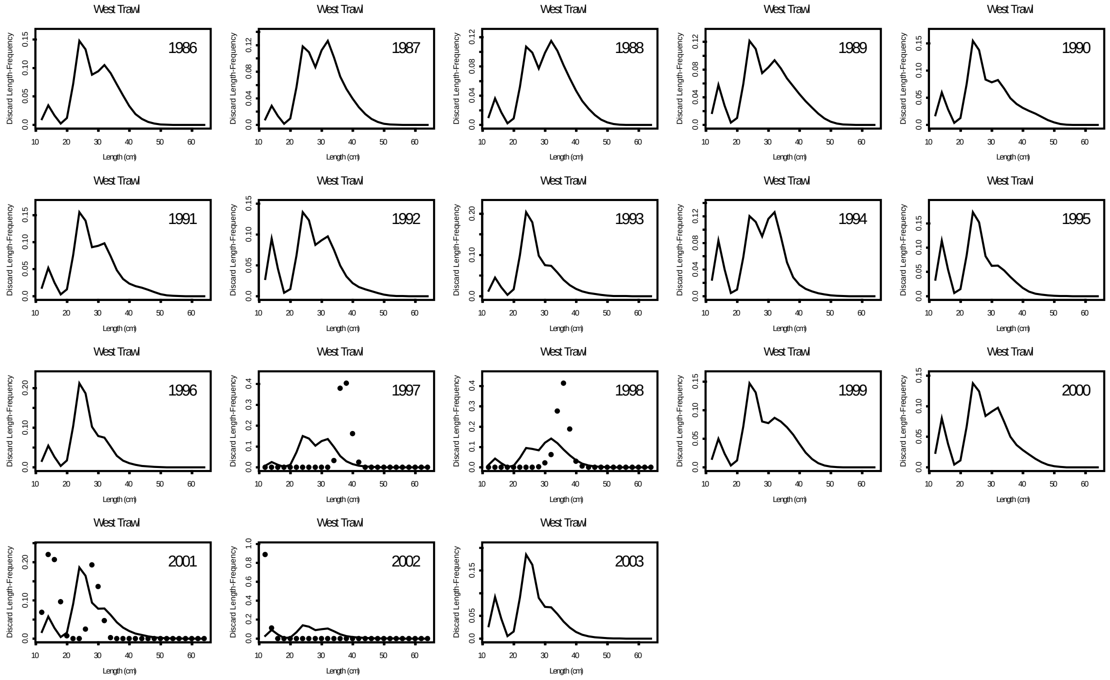


APPENDIX 6.C.2 : Fits to the discard length-frequencies

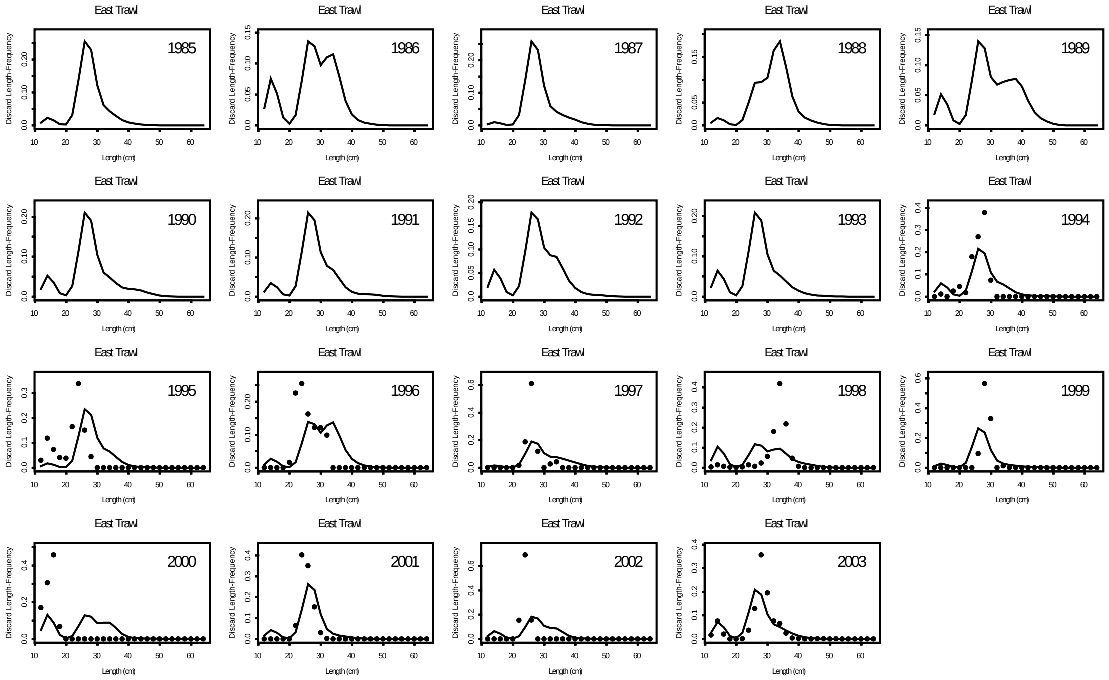
(a) Calendar year – Eastern stock (East trawl)



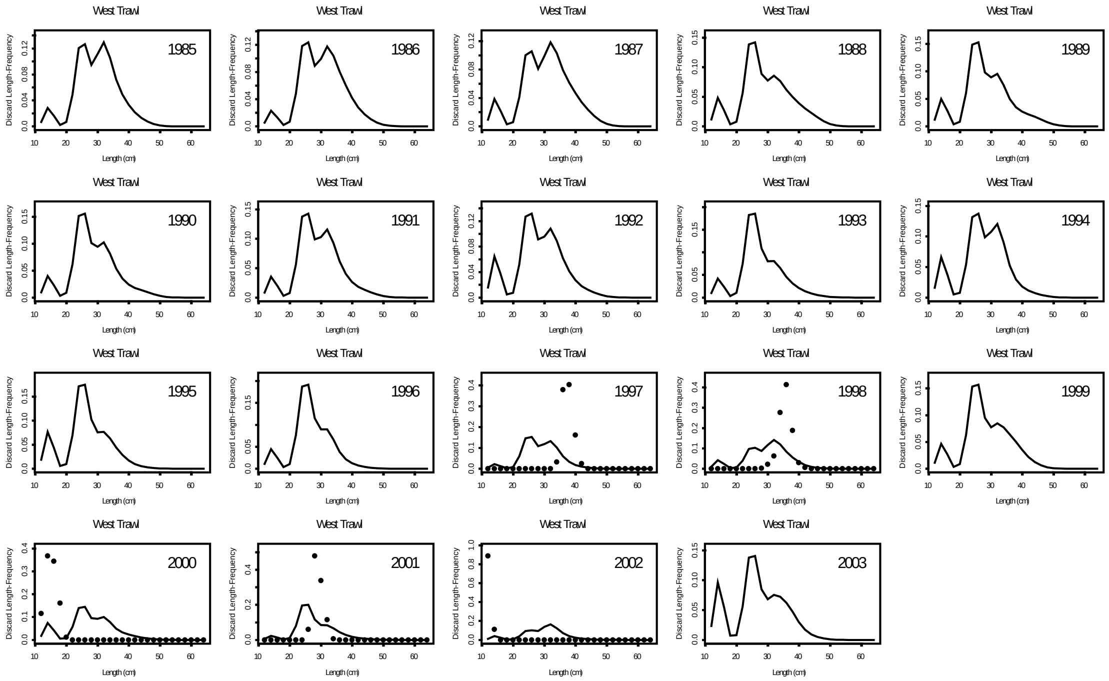
(b) Calendar year – Western stock



(c) Biological year – Eastern stock (East trawl)



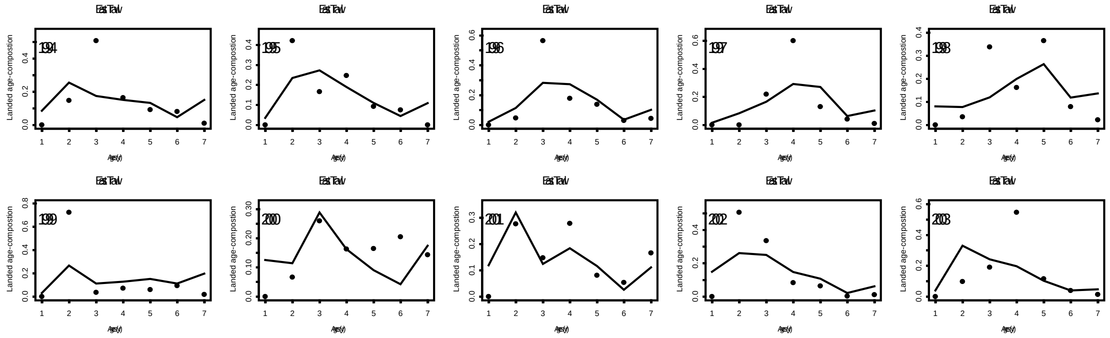
(d) Biological year – Western stock



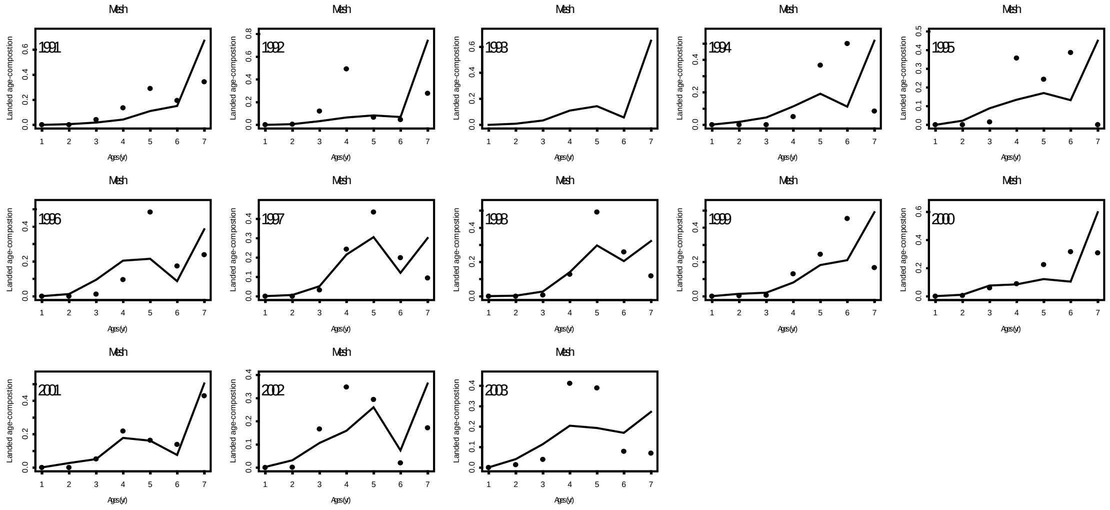
APPENDIX 6.C.3 : Fits to the landed age-compositions

(a) Calendar year – Eastern stock

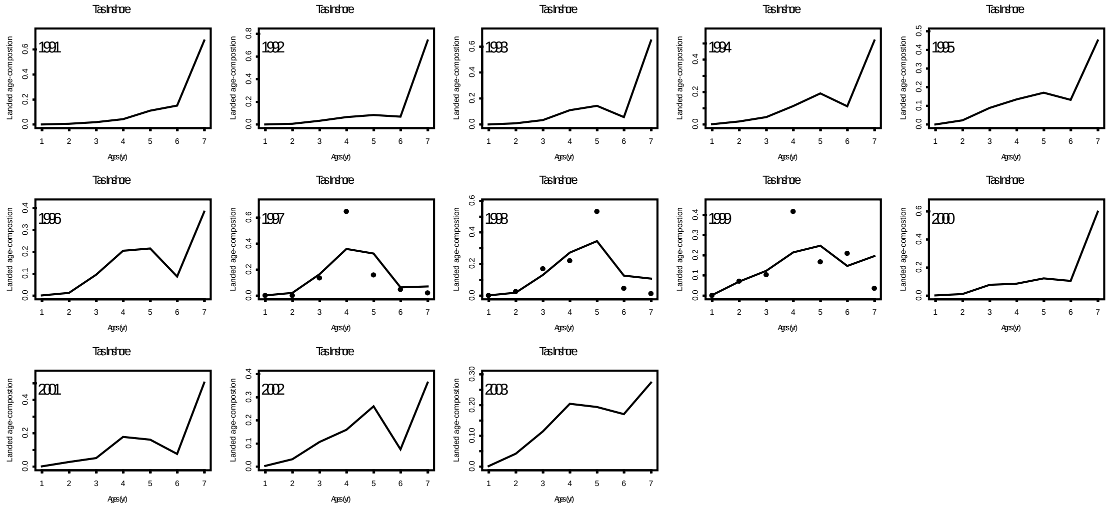
(i) East Trawl



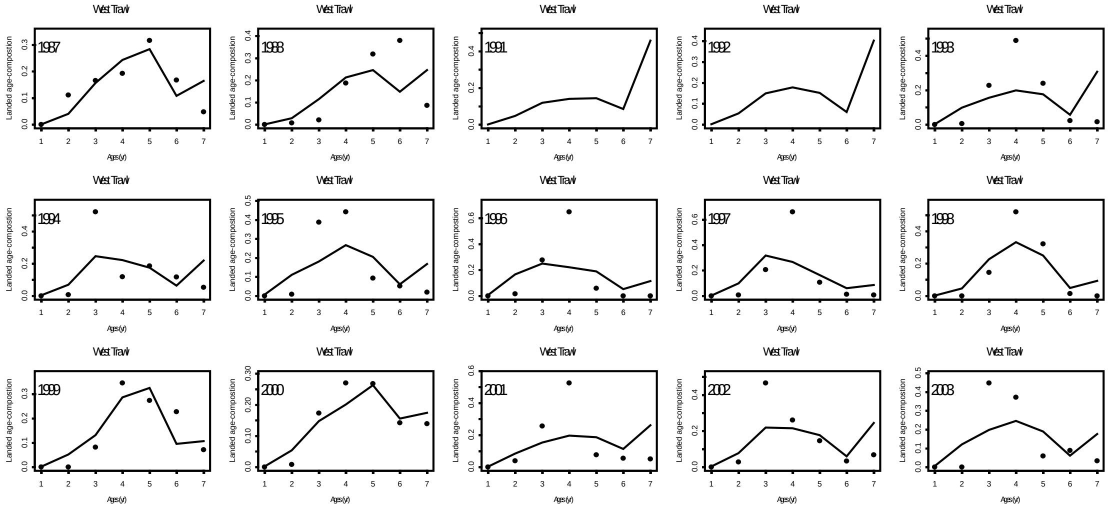
(ii) Non-trawl



(iii) Tasmania meshnet

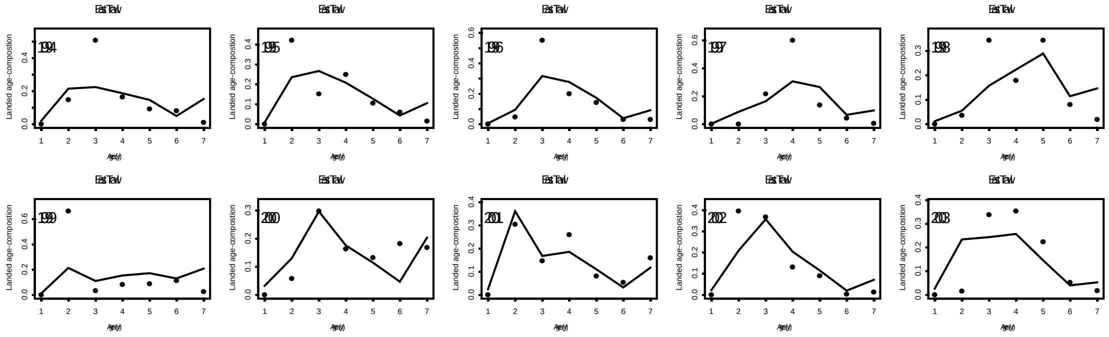


(b) Calendar year – Western stock

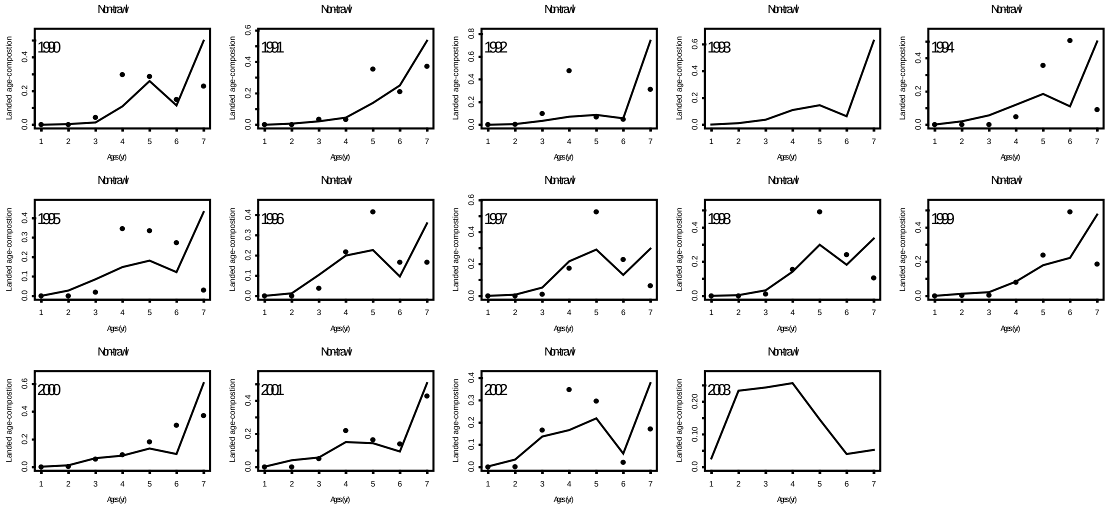


(c) Biological year – Eastern stock

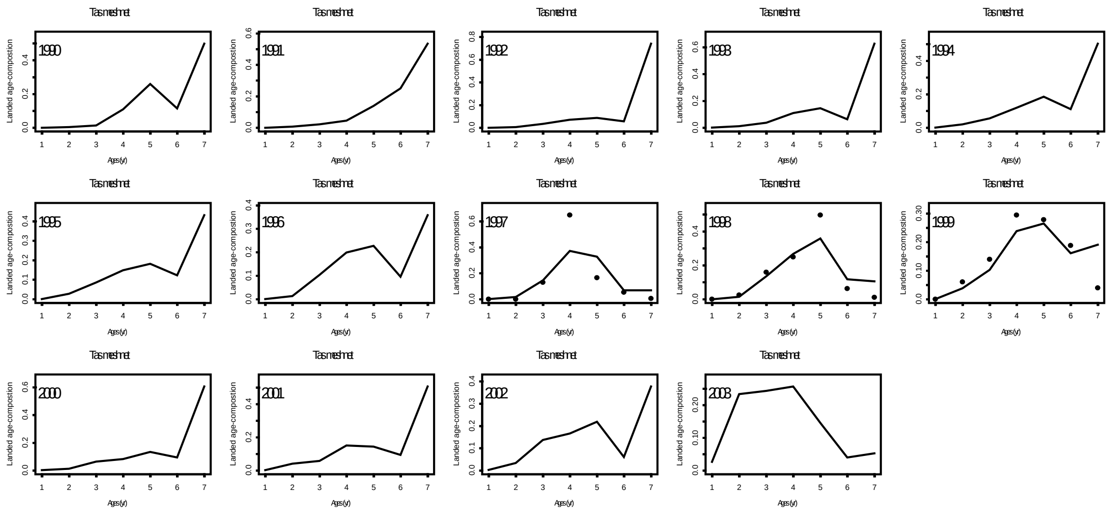
(i) East Trawl



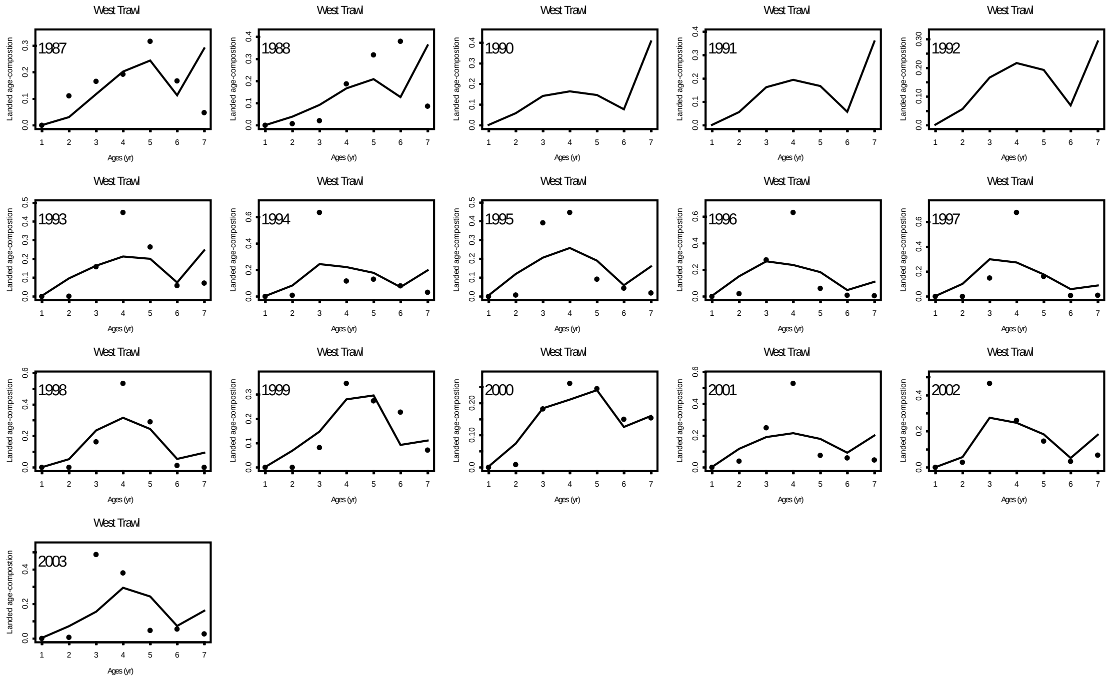
(ii) Non-trawl



(iii) Tasmania meshnet

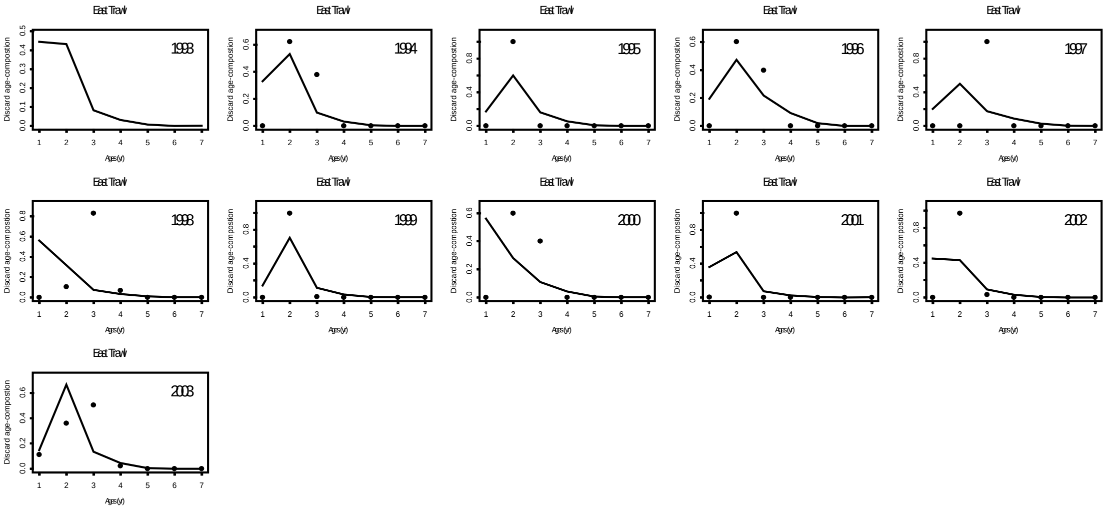


(d) Biological year – Western stock

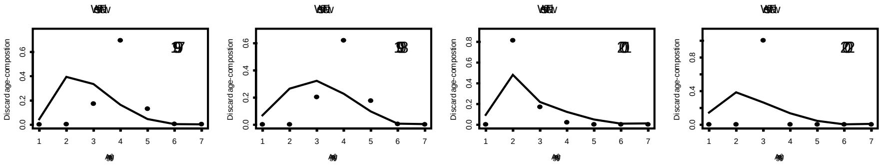


APPENDIX 6.C.4 : Fits to the discarded age-compositions

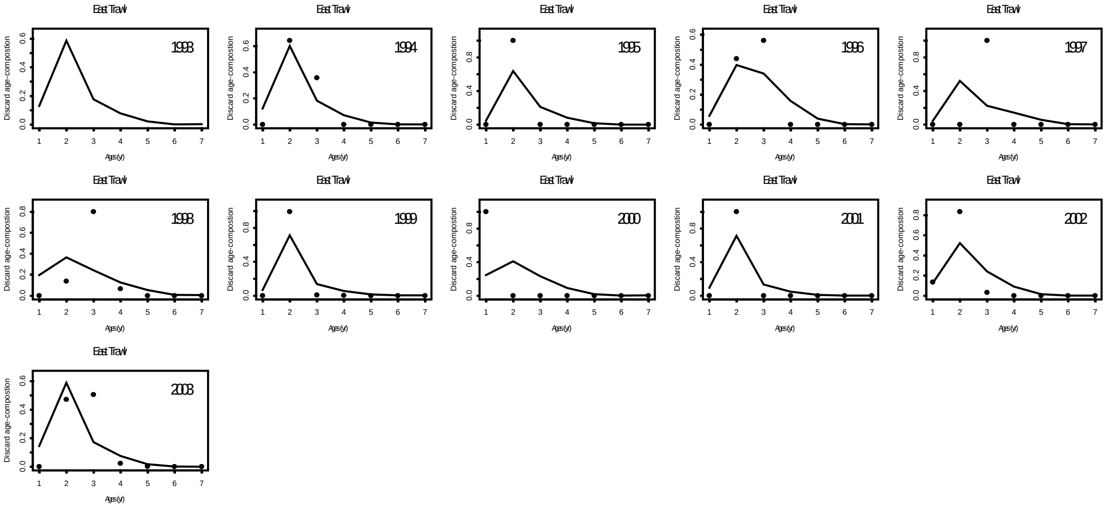
(a) Calendar year – Eastern stock (East trawl)



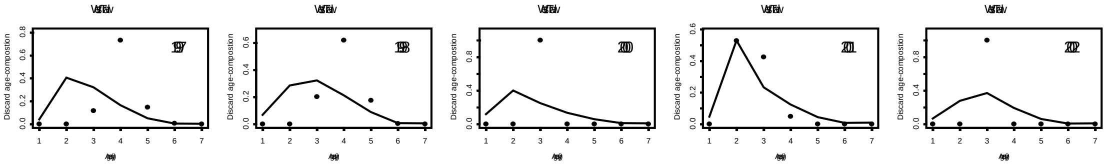
(b) Calendar year – Western stock



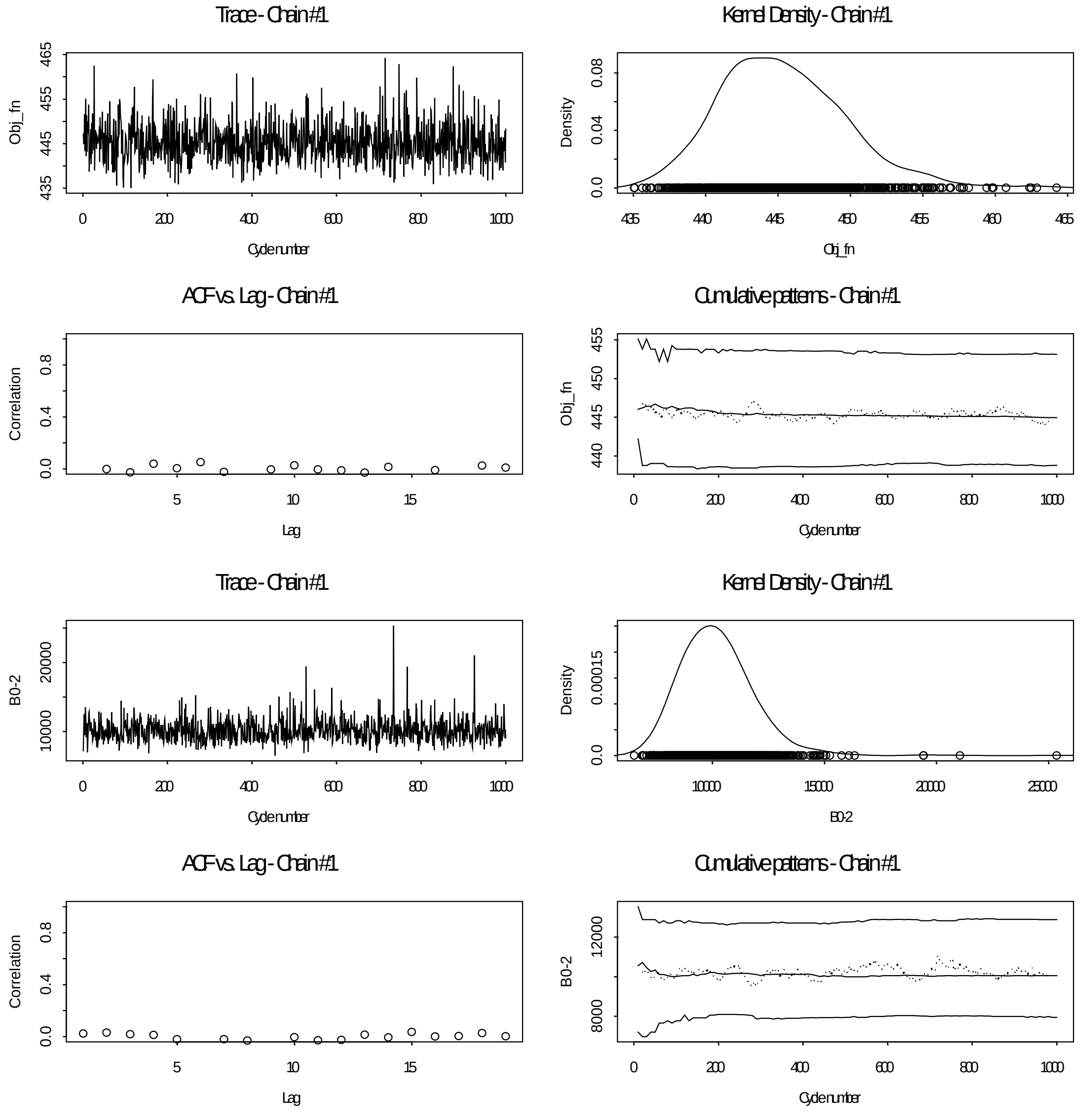
(c) Biological year – Eastern stock (East trawl)

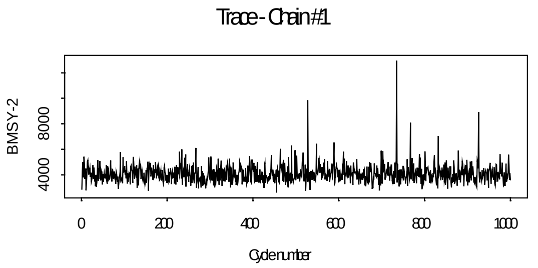


(d) Biological year – Western stock



APPENDIX 6.D : Diagnostic Statistics - Bayesian analyses




Trace - Chain #1
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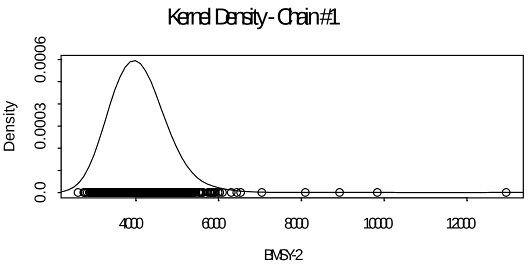
4000
8000
0
200
400
600
800
1000
Cycle number


Kernel Density - Chain #1
Density
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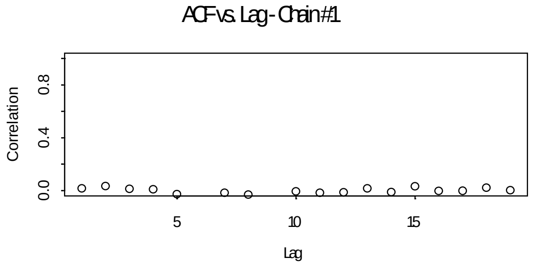
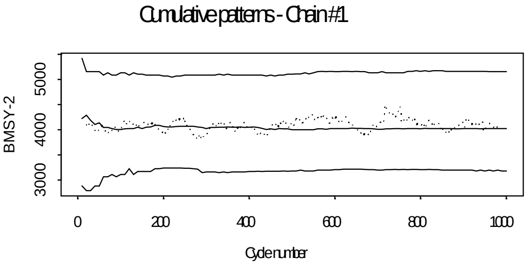
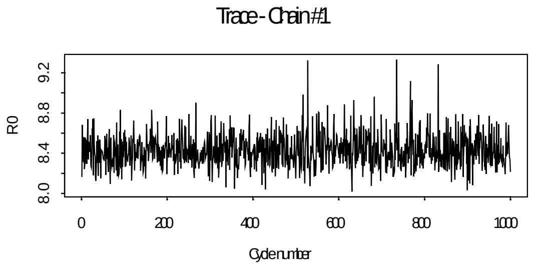
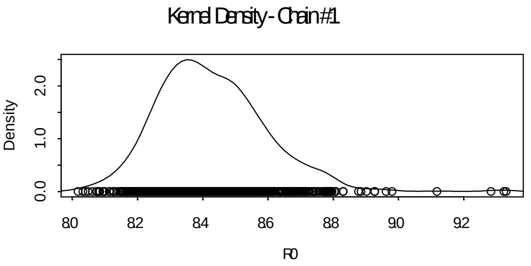
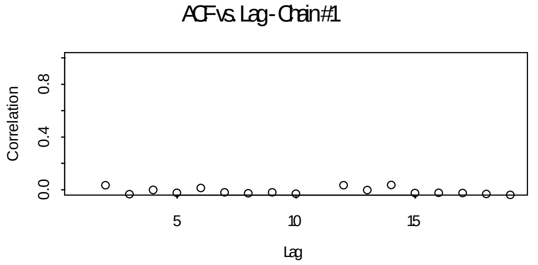
0.0003
0.0006
4000
6000
8000
10000
12000
BMSY-2

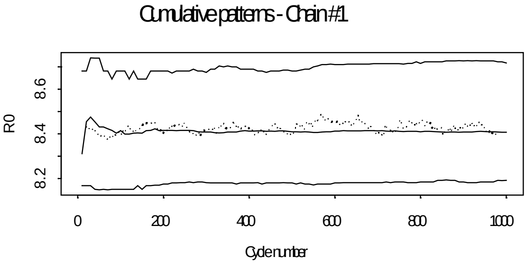

ACF vs. Lag - Chain #1
Correlation
0.0
0.4
0.8
5
10
15
Lag

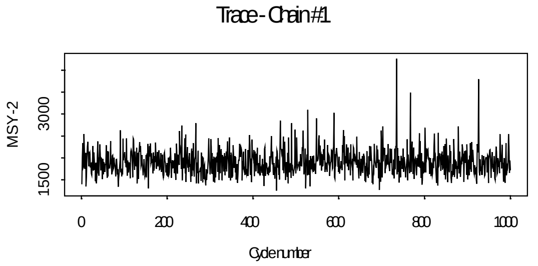

Cumulative patterns - Chain #1
BMSY-2
3000
4000
5000
0
200
400
600
800
1000
Cycle number

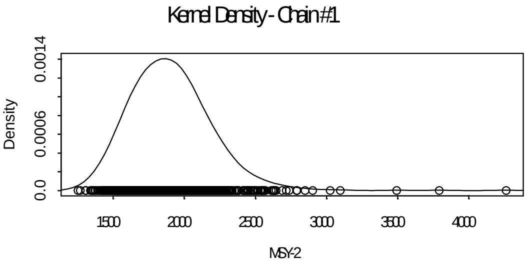

Trace - Chain #1
R0
8.0
8.4
8.8
9.2
0
200
400
600
800
1000
Cycle number


Kernel Density - Chain #1
Density
0.0
1.0
2.0
80
82
84
86
88
90
92
R0


ACF vs. Lag - Chain #1
Correlation
0.0
0.4
0.8
5
10
15
Lag


Cumulative patterns - Chain #1
R0
8.2
8.4
8.6
0
200
400
600
800
1000
Cycle number


Trace - Chain #1
MSY-2
1500
3000
0
200
400
600
800
1000
Cycle number


Kernel Density - Chain #1
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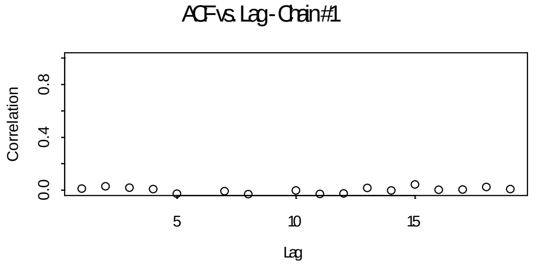
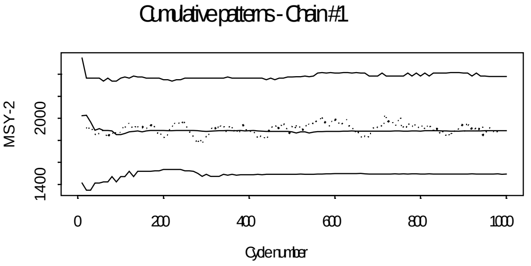
0.0
0.0006
0.0014
1500
2000
2500
3000
3500
4000
MSY-2


ACF vs. Lag - Chain #1
Correlation
0.0
0.4
0.8
5
10
15
Lag


Cumulative patterns - Chain #1
MSY-2
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2000
0
200
400
600
800
1000
Cycle number

7. Stock Assessment for Gummy Shark (*Mustelus antarcticus*) Based on Data up to 2003

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7.1 Background

Assessments of the populations of gummy shark (*Mustelus antarcticus* Günther) in Bass Strait and off South Australia and Tasmania are needed to determine the current status of this resource relative to agreed target and limit reference points and as the basis for the evaluation of alternative harvest strategies. Assessments are conducted separately for each of these three regions for various reasons. For instance, tagging data suggest low rates of movement across the South Australia / Victoria border (Walker *et al*., 2000), there are differences in habitat among regions, and there appear to be differences in the proportion of gummy shark breeding in Bass Strait and South Australia (Walker *et al*., 1989). Other reasons for treating the populations of gummy shark in the two regions differently are not biological. For example, the existence of political boundaries and hence past management jurisdictions, differences in targeting practices over time (gummy shark have been targeted extensively using gill-nets in Bass Strait since the early 1970s whereas gummy shark have only recently become the prime target species in South Australia). Also, the difference in the types, amount and quality of data available for the different regions (negligible data available for Tasmania until very recently, whereas the data set for Bass Strait is extensive) warrants treating the three regions differently.

Quantitative assessments for gummy shark have been based on a wide variety of methods, ranging from yield-per-recruit approaches (Walker, 1986) to applications of age- and sex-structured production model approaches (Prince, 1992; Walker, 1992, 1994a, 1994b, 1998). These age-structured approaches assumed that the natural mortality rate was density-dependent, ignored inter-annual fluctuations in pup survival, and used only a sub-set of the available information (catch rates and information on the mean weight or length of the catch) to estimate the parameters of the model. The most recent assessment of gummy shark (Punt *et al.,* 2001; Pribac *et al.,* in press) was also based on an age- and sex-structured population dynamics model but was fitted to a broader range of data types (catches, catch-rates, catch length-composition data, catch age-composition data, and tagging data).

The final year of the assessment conducted by Punt *et al.* (2001) and Pribac *et al.* (in press) was 1998. An additional four years of data are now available. This document updates the assessment of gummy shark based on the data for the five-year period 1999–2003. Several of the data sources have been revised extensively since the last assessment in 2000. Therefore, some of the differences between the results of the present assessment and those of the 2000 assessment are attributable to the changes to the historical data and not the addition of the post-1998 data.

The following sections outline the data available for assessment purposes, the population dynamics model (and how it differs from that on which the previous assessment was based), the estimation framework, and the results of the assessment. Assessments are presented in this document for the populations of gummy shark in Bass Strait and off South Australia. There are insufficient data to carry out an assessment for Tasmania.

7.2 Data

The data available for assessment purposes include catches by gear-type (1927–2003), catch-rates (1976–2003), length-frequency data (1970–2003), age-composition data (1986–87, 1990–93) and tagging data (1943–2003). Each of these data sources is described in turn below.

The data are presented for ten ‘sub-regions’ off southern Australia: i) western Australia (WA), ii) western South Australia (WSA), iii) central South Australia (CSA), iv) eastern South Australia (SAV-W), v) far western Bass Strait (SAV-E), vi) western Bass Strait (WBas), vii) eastern Bass Strait (EBas), viii) western Tasmania (WTas), ix) eastern Tasmania (ETas), and x) New South Wales (NSW). These regions (Figure 7.1) were selected by the Shark Fishery Assessment Group (SharkFAG) on the basis of their physiography, the history of the fishery, movement patterns of gummy sharks inferred from tag release-recapture data, and the spatial distribution of the various age-classes inferred from available length-at-age and length-frequency data. The region Bass Strait comprises sub-regions SAV-E, EBas and WBas; the region South Australia comprises sub-regions WSA, CSA and SAV-W; and the region Tasmania comprises sub-regions WTas and ETas. Data are presented for sub-regions WA and NSW for information only – the data for these sub-regions are ignored when conducting assessments.

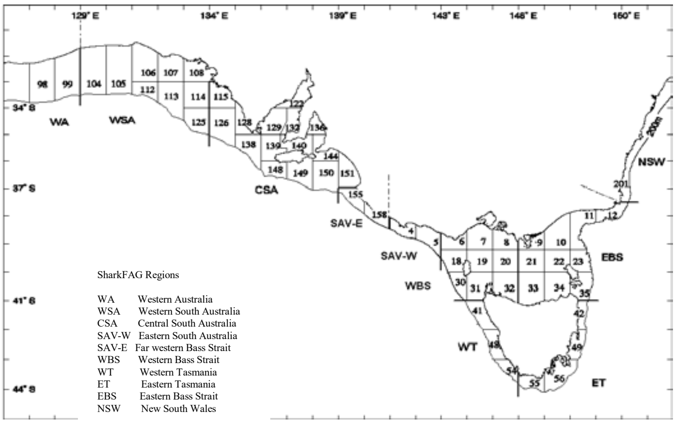

Figure 7.1 : Sub-regions of the Southern Shark Fishery.

7.2.1 Catch data

Catches of gummy shark are taken by several sectors and an assessment of gummy shark needs to be based on time-series of catches for each sector that takes a ‘substantial’ catch of gummy shark. The main commercial fishing sectors are the southern shark fishery (Commonwealth), the State fisheries for shark off Tasmania and South Australia, the South East Non-trawl fishery, the South East Trawl fishery, and the Great Australian Bight Trawl Fishery. Small quantities of gummy shark are also taken within Victorian Territorial waters by fishing methods other than shark monofilament gillnets and shark longlines. Figure 7.2 summarizes the time-series of catches by gear-type and region used in the analyses of this document.

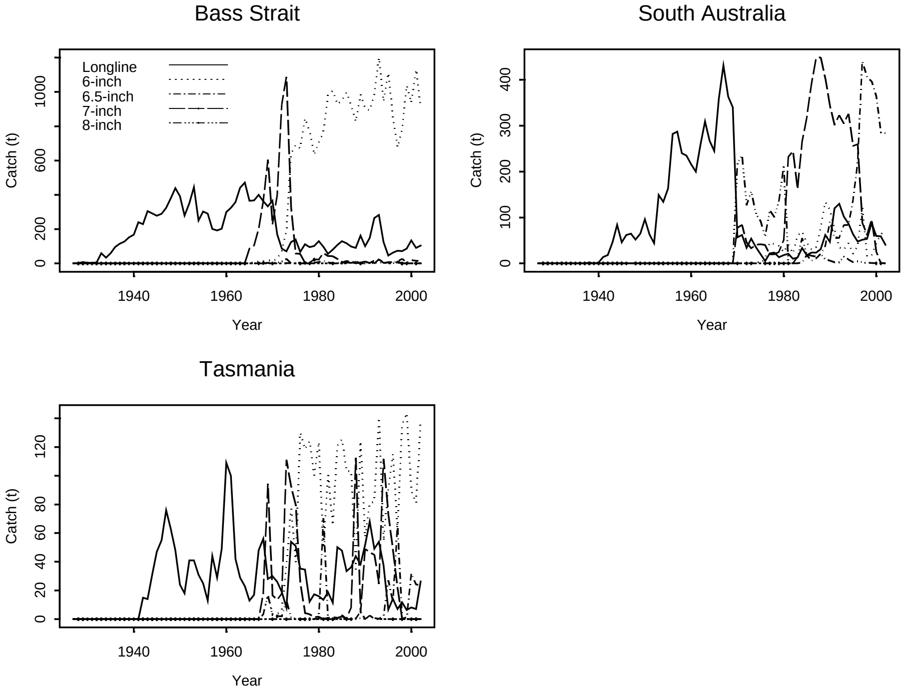

Figure 7.2 : Catch series (carcass weight, tonnes) by gear-type and region.

7.2.1.1 *The directed shark fisheries (State and Commonwealth) and the Commonwealth non-trawl fishery*

The catches of gummy shark by these fisheries by longline and mesh (6-inch, 6.5-inch, 7-inch and 8-inch) gears for 1927–72 and 1973–2003 are listed in Tables 7.1 and 7.2, respectively. Taylor *et al.* (1996) describe the methods used to estimate the catches using longline and mesh gears for the years 1973–2003. The data for the years 1973–2002 are stored in the Southern Shark Fishery Monitoring Database (SSFMBD). The SSFMDB provides for data validation, checking and correcting for multiple reporting from fishers, for standardization of landed catch weights, and for reporting of data summaries for management, licensing, monitoring and research purposes. Landed catch weights of sharks are adjusted to ‘untrimmed carcass weight’ (i.e. beheaded and gutted shark with all fins attached); this is necessary because the fins are removed from the carcasses in some regions of the fishery.

The methods used to estimate catches for the years 1927–72 (Table 7.1) differ from those used to estimate catches for 1973 onwards (Table 7.2) because the early data were not recorded in a particularly systematic manner. The catches for three periods were assembled from different sources: 1927–56 from Olsen (1959), 1957–64 from annual summaries in *Fisheries Newsletter*, and 1965–72 from computer summaries prepared by the Australian Bureau of Statistics. The mean ratio of gummy shark to school shark (i.e. 3:7) from Victorian catch and effort data available for the period 1952–64 was adopted to split the combined school and gummy shark catch presented by Olsen (1959) for the years before 1952.

The catches by State operators for 2003 were not available at the time of writing. These are relatively a small percentage (<5%) of the total catch of gummy shark in Bass Strait and off South Australia and Tasmania, but some account of them needs to be taken. For purposes of the analyses of this report, the catch by State operators for 2003 is assumed equal to that for 2002 (74t) and this catch is pro-rated according to the 2003 information to gear-type and sub-region.

7.2.1.2 South East / Great Australian Bight Trawl fisheries

Table 7.3 lists the reported catches (kg) of gummy shark for the South East and Great Australia Bight trawl fisheries by year and sub-region. The catches by the SEF for 1991 to 1996 include estimated catches determined by splitting catches reported as school and gummy shark combined. If some catches by species are available for years / sub-regions for which species-combined catches are also available, the split to species for the year / sub-region concerned is used to split the combined catch. If this is not the case, the split (by sub-region) of the total gummy to school catch over all years is used. The catch by the Danish seiners and otter trawlers for 2002 and 2003 (Table 7.3c) aggregates data over what used to be the Great Australian Bight and the South East Trawl Fisheries. The catch for 2003 (90t) is substantially larger than the catches for 2002 and earlier.

The catches by trawl are treated as catches by longline in the analyses because longlines catch the broadest range of sizes of gummy shark and the trawl catches consist of a wide range of sizes of gummy shark.

7.2.1.3 Catch series used in the assessments

There are at least three reasons why the historical catches of gummy shark may be in error (deliberate mis-reporting during the ‘mercury ban’ in Victoria during 1973–85, general under-reporting, and reporting of ‘paper fish’ in anticipation of possible management actions). Therefore, in addition to a catch series based on the ‘best estimates’ of the historical catches, analyses are also conducted for an alternative series of historical catches. This series involves increasing the catches (all regions) by 15% (1927–79), 10% (1980–89) and 5% (1990–96) to reflect the last two sources of error. Industry advice at the May 2000 meeting of SharkFAG was that attempts to circumvent the ‘mercury ban’ in Victoria would not have led to mis-reporting of school as gummy shark in any substantial numbers.

7.2.2 Catch rate indices

The standardized catch-rate indices are given in Table 7.4. Appendix 7.A outlines the derivation of the catch-rate indices for school and gummy shark.

7.2.3 Tagging data

Sharks were tagged and released in the Southern Shark Fishery during 1947–56, 1973–76 and 1990–2003. Most were school and gummy sharks but small numbers of 26 other species of sharks, rays and a chimaera were also tagged. The available tag release-recapture data have been consolidated in the Southern Shark Tag Database developed in Microsoft ACCESS as part of two FRDC projects (Walker *et al*., 1997; Brown *et al*., 2000; Walker *et al*., 2000). The database is routinely updated with tag recaptures.

Of the gummy sharks tagged and released during 1947–56, 363 were double tagged with an external Petersen disc tag and an internal tag while 223 were tagged only with an internal tag. Of these, 60 (10%) have been recaptured and reported by fishers. The last one was during 1969 after 14.7 years at liberty. During 1973–76, 1,525 gummy sharks were tagged with internal tags of which 380 (25%) had been recaptured by the end of 2002. The last one was in 1987 after 12.6 years at liberty. During 1990–2003, gummy sharks were tagged with roto-, jumbo, dart and other tags.

It is necessary to specify a tag-shedding rate for each tag-type and tag-reporting rates for each combination of year, tag-type and sub-region / region of recapture to include the tagging data in the assessment.

7.2.3.1 Tag-shedding rate

Rototags and jumbo tags attached to the anterior lower portion of the first dorsal fin of sharks during 1990–2003 were highly successful with low shedding rates. Similarly, internal tags inserted into the coelomic cavity of sharks during 1947–56 and 1973–76 were successful in that they were not shed. However, they were not always seen by fishers when the sharks were caught. Peterson disc fin tags attached to the first dorsal fins during 1947–56 and nylon-headed dart tags inserted into dorsal muscle tissue had very high shedding rates. Inserting nylon-headed dart tags into the cartilage at the base of the first dorsal fin during 1990–99 rather than in the dorsal musculature reduced the shedding rate.

Tag shedding rates were addressed through double-tag experiments as part of the tag projects. Table 7.5 lists the various tag-types represented in the tagging database. Xiao *et al.* (1999) describe a general approach for estimating the rate of tag-shedding from the results of a double-tagging experiment. Table 7.6 lists the tag-shedding rates for the tag-types for which the methods outlined by Xiao *et al.* (1999) allow reliable estimation. The results in this table are based on data up to the end of May 2002. Results are shown in Table 7.6 for separate analyses based on the assumption that the tag-shedding rate is sex-specific and on the assumption that it is the same for males and females. The negative log-likelihoods in Table 7.6 suggest that the tag-shedding rates for males and females can be assumed to be the same.

7.2.3.2 Tag-reporting rate

Two methods: (a) the ‘tag reporting rate from catch method’ (TRRC Method) and (b) the ‘tag reporting rate from tags per unit catch method’ (TRRT Method) have been applied to data for gummy and school shark combined (Brown and Walker, 1999). Application to the combined data set is based on the assumption that the tag-reporting rate should be independent of species (but dependent on sub-region and time). Table 2.10 of Punt *et al.* (2001) lists the estimates of tag-reporting rates for the five sub-regions for which sufficient data are available (the results for SAV-E and SAV-W have been pooled). Figure 7.3 lists the tag-recovery reporting rates by year selected by SharkFAG. The tag-reporting rate is higher (0.7 compared to 0.5) during the years in which some tagging occurred.

Figure 7.3 : Annual tag-recovery reporting rates.

The tag-reporting rate for internal tags is assumed to be 0.929 (Punt *et al.*, 2000).

7.2.4 Length- and age-composition data

Length-frequency and sex composition data for commercial gummy shark landings have been collected routinely by a team of part-time fish measurers operating in several fishing ports and regional fish processing plants in Victoria during 1970–2003 and South Australia during 1973–76 and 1986–2003. Total length was measured for each shark sampled at sea and the partial length from the fifth gill-slit to the base of the tail was measured for each shark sampled from commercial landings. A small proportion of the data have been collected at sea. Data from samples of 40–150 sharks (less in the case of very small catches) are stored in the Southern Shark Fishery Monitoring Database. Within this database, the samples can be matched by vessel distinguishing mark and date of landing with fishers' catch and effort data to assign samples to sub-region, fishing gear and, for some samples, fishing depth-range.

The numbers of sharks measured annually by gear-type, sex, and sub-region are listed in Table 7.7. The sample sizes for longlines and 8-inch gill-nets are small (generally less than 100 fish per annum). Therefore, the assessment is based solely on the data for 6- and 7-inch mesh (Bass Strait) and 6.5- and 7-inch mesh (South Australia). Length-frequency data are available for each sub-region separately. Therefore to construct length-frequencies by region, the data by sub-region were combined after weighting by the corresponding catch (Table 7.8). For Bass Strait, the 6-inch mesh length-frequency data for 1984, 1985, and the years prior to 1974 and the 7-inch mesh length-frequency data for the years after 1974 are not included in Table 7.8 and the assessment. This is because the length-frequency data for 1984 and 1985 are known to be unreliable and the sample sizes for the other years are small. Compared to the 2000 stock assessment, the present assessment includes substantial quantities of data for 6.5" mesh in South Australia (the previous assessment was based on data for 1997 and 1998 only).

Length-at-age data are available for gummy sharks sampled from Bass Strait (1973–75, 1986–87, and 1990–93), South Australia (1986–87 and 1990–93), and Tasmania (1990–

93). The numbers of sharks for which age estimates are available by year, gear-type, sex and region are listed in Table 7.9. The sample sizes for 1973–75 are very small and the data for these years are consequently not included in the assessment. Table 7.10 lists the age-composition data actually included in the assessment.

7.3 Analytical approach

7.3.1 Population dynamics model

The basic population biology of gummy shark and the selectivity of the gear used in the Southern Shark Fishery is reasonably well understood. Population dynamics models, based on that used by Punt and Walker (1998) to assess the school shark resource off southern Australia are applied to gummy shark (see Appendix 7.B). These models include the nature of the pupping process, the selectivity patterns of the various gears used in the fishery, and the growth rates of gummy shark (Equations 7.B.11 to 7.B.13). Pup production is assumed to be related closely to the number of pregnant females (Equations 7.B.3 and 7.B.4) although allowance is also made for (limited) variability in pregnancy rates / pup survival rates so that the actual number of pups differs from the value predicted from the deterministic component of Equation (7.B.3). The magnitude of process error is determined by the value assumed for σ_r (see Equation 7.B.3). The choice for σ_r of 0.4 is largely arbitrary and was chosen to be lower than the values for this parameter typically assumed for teleost fish (e.g. Beddington and Cooke, 1983) but greater than that assumed for school shark by Punt and Walker (1998).

Density-dependence is assumed to act through an impact on the natural mortality rate of a range of age-classes (e.g. all ages, ages 0-4 and pups) consistent with previous assessments of gummy shark (e.g. Walker, 1994a, 1994b). The base-case assumption is that density-dependence affects all age-classes (i.e. a_d in Equation (7.B.21) is equal to the maximum age, x) although sensitivity is examined to alternative assumptions including that density-dependence only impacts the survival rate of the pups[5] (see Equation 7.B.3).

The population dynamics model includes both length-specific gear-selectivity (Equations 7.B.14 and 7.B.15 for longlines and gill-nets respectively) and length-specific availability (Equations 7.B.16 and 7.B.17). The values for the parameters of the selectivity functions are based on experimental results (Kirkwood and Walker, 1986). Differentiating availability from selectivity allows animals to be vulnerable to the gear (i.e. the selectivity of the gear allows them to be captured) but not to be available to the fishery (e.g. because they are not where the fishery operates) and hence not to be caught. Empirical evidence for non-uniform availability arises from analyses of length-frequency data collected during fishery-independent surveys (A. E. Punt, unpublished data). Non-uniform availability may be a consequence of behavioral changes associated with ontogenetic changes in prey preference.

The population dynamics model in Appendix 7.B differs from that applied by Punt *et al.* (2001) and Pribac *et al.* (in press) because availability as a function of length is modeled using a normal distribution rather than using a double logistic function.

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[5] This is essentially identical to assuming that density-dependence impacts the pregnancy rate.

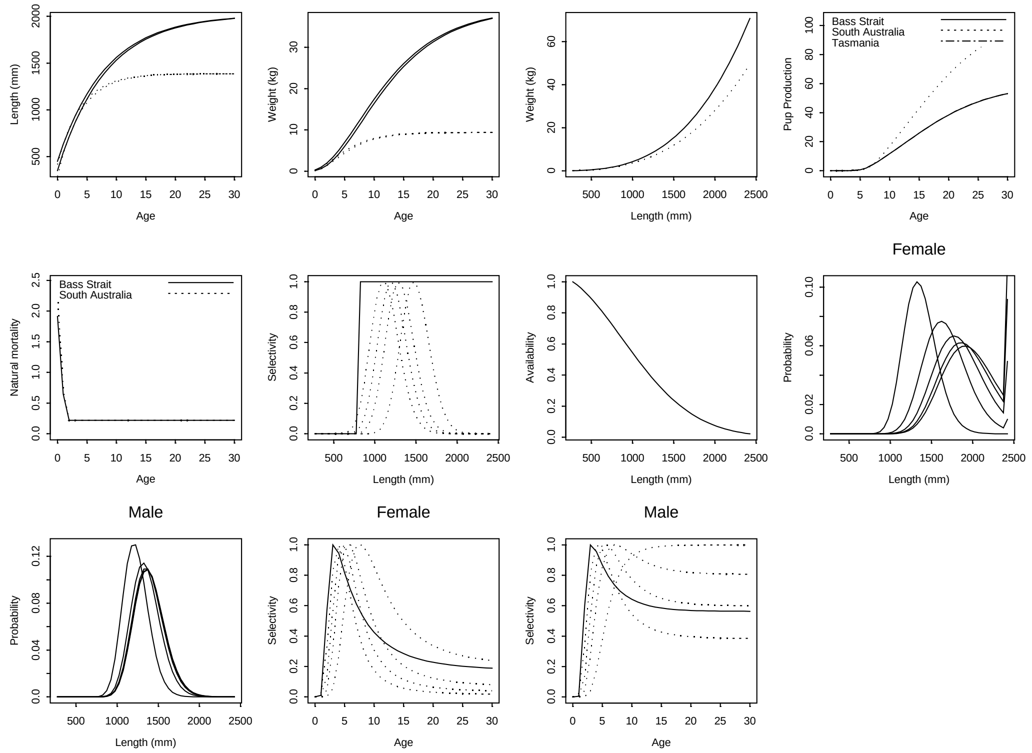

Figure 7.4 : Biological and technological parameters for gummy shark.

Figure 7.4 summarizes the biological parameters for gummy shark in terms of the relationships between length and age, weight and age, pup production (the product of the number of pups per mature female and the proportion of females of each age that are mature) and age. These relationships imply a particular level of natural mortality for pups in order for the population to remain in balance; Figure 7.4 therefore shows natural mortality as a function of age when the natural mortality rate for animals 2 and older is 0.2yr^{-1}. Figure 7.4 also show selectivity as a function of length (solid line – longlines; dotted lines – gillnets) and age. Finally, these figures include the distributions of length-at-age for ages 3, 8, 11, etc.

7.3.2 The base-case assessment

The base-case assessment reflects a 'most likely' set of assumptions, and sensitivity tests examine sensitivity to changing these assumptions. The following are the base-case assumptions (assumptions indicated with asterisks are examined further in sensitivity tests):

a) Density-dependence impacts the instantaneous rate of natural mortality ($a_{\mathrm{d}}=\infty$), and is functionally related to the total (1+) biomass - these assumptions are made to avoid (unrealistic) oscillatory trajectories of population size*.
b) The variance in length-at-age increases linearly with expected length, $\sigma_{g,a} = \sigma_g \sqrt{\ell_{g,a} / \ell_{\infty,g}}$ - this assumption was selected after an initial analysis of the data.

c) The weights assigned to the catch rate, length-frequency and age-composition data are: $\sigma_j = 0.15$, N_j^{len} = 50 (Bass Strait) = 25 (South Australia), and $N_j^{\text{age}} = 25$ *.
d) Any recaptures within 60 days of release are treated as 'early recaptures' (see Equations 7.C.7 and 7.C.9)*.
e) Natural mortality is independent of age above age 2 ($M_x / M_2 = 1$).
f) Effort is related to fishing mortality according to Equation (7.C.2c)*.
g) The value of μ_L is set to 0.

7.3.3 Parameter and variance estimation

The software used to conduct the 2000 gummy shark assessment was developed in FORTRAN. However, most fish and invertebrate assessments in the south-east region of Australia and off New Zealand, South Africa and the west coast of the United States are conducted using software packages developed using the AD Model Builder Package (e.g. Coleriane (Hilborn *et al*., 2003); CASAL (Bull *et al*., 2003)). Use of the ADMB package as the basis for stock assessments is desirable for several reasons:

1) the derivatives of the objective function with respect to the model parameters are calculated analytically (rather than numerically);
2) the package includes much of the code needed to control the process of fitting the model to the data; and
3) the package includes a module to generate parameter vectors from Bayesian posterior distributions using the Markov Chain Monte Carlo (MCMC) algorithm.

One requirement for use of the ADMB package is that the objective function is differentiable at all the points examined by the minimiser. Unfortunately, there are several reasons why the objective function underlying past assessments is not differentiable. Specifically, past assessments have placed a prior on *MSYR* and computed the density-dependence parameters (Q_0 and V – see Equations 7.B.4 and 7.B.21) using numerical methods. The revised approach to assessing shark species in Australia's Southern Shark Fishery is based on a somewhat different approach, namely to place priors on Q_0 and V (and assume that they, rather than *MSYR*, are common across populations). Under this revised approach therefore, *MSYR* is a model output rather than being a model parameter. Actually, it may prove somewhat easier to place a prior on V (which must lie between 0 and 1) and on Q_0 (which must be larger than 1) as these parameters relate to specific biological processes (the extent to which natural mortality decreases with population size and the extent to which pup survival increases with reduced population size). One consequence of this change in approach is that *MSYR* differs between South Australian and Bass Strait gummy shark. This occurs because biological parameters such as those which govern the relationship between maturity and age differ between gummy shark in Bass Strait and off South Australia.

The values for all of the parameters of the population dynamics model, except those related to the virgin biomass (B_0), the magnitude of density-dependence[6], natural mortality (M_2), the parameters that determine the relationship between effort and fishing mortality (q, γ and γ_1 - see Equations 7.C.1 and 7.C.2), the parameter that determines the width of the function that relates availability to length (σ_L), and the recruitment residuals (ε_t - see Equation 7.B.3) are fixed using ancillary information (see, for example, Table 7.B.1). The values for Q_0, V, M_2 and σ_L are assumed to the same for gummy shark in Bass Strait and off South Australia whereas the remaining parameters (B_0, the parameters of the relationship between effort and fishing mortality and the annual recruitment residuals) are assumed to differ between South Australia and Bass Strait.

The values for the parameters not determined using ancillary information are estimated by maximizing a likelihood function that includes contributions from the catch-rate, length-frequency, age-composition and tagging data (see Appendix B). The estimates for the parameters M_2, Q_0 and V are constrained to lie within the intervals [0.1, 0.3yr^{-1}], [1, 50], and [0, 1] respectively. Recruitment residuals are estimated for the years 1927–2001.

The approach used to include the catch-rate data in the likelihood function (Equations 7.C.1–7.C.3) allows for a general relationship between fishing mortality and effort; Equation (7.C.2a) reflects the assumption that effort is linearly proportional to exploitation rate whereas Equations (7.C.2b) and (7.C.2c) allow for ‘gear competition’ effects. ‘Gear competition’ has been postulated for the fishery for gummy shark off southern Australia based on the observation that catches have been relatively insensitive to large changes in fishing effort. The forms chosen for Equations 7.C.2b and 7.C.2c are such that if the data support the concept of ‘gear competition’, this can be tested by means of a likelihood ratio test (Equation 7.C.2a is nested within Equations 7.C.2b and 7.C.2c).

The variances for the estimates of the model parameters and for the other quantities of interest are determined using Bayesian methods. The Metropolis-Hastings variant of the Markov-Chain Monte Carlo (MCMC) algorithm (Hastings, 1970; Gilks *et al.*, 1996; Gelman *et al.*, 1995) with a multivariate normal jump function was used to sample 900 equally likely parameter vectors from the joint posterior density function. This sample implicitly accounts for correlation among the model parameters and considers uncertainty in all parameter dimensions simultaneously. The samples on which inference is based were generated by running 1,000,000 cycles of the MCMC algorithm, discarding the first 100,000 as a burn-in period and selecting every 1,000th parameter vector thereafter. The initial parameter vector was taken to be the vector of maximum posterior density (MPD) estimates. A potential problem with the MCMC algorithm is how to determine whether convergence to the actual posterior distribution has occurred, and the selection of 1,000,000, 10,000 and 1000 was based on generating a sample which showed no noteworthy signs of lack of convergence to the posterior distribution. Whether convergence had occurred was examined by applying the diagnostic statistics

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[6] determined through Q_0 and V – depending on whether density-dependence impacts pup survival or natural mortality

developed by Geweke (1992), Heidelberger and Welch (1983), and Raftery and Lewis (1992) and by examining the extent of auto-correlation among the samples in the chain.

7.4 Results and discussion

7.4.1 Fits to the data

7.4.1.1 Bass Strait

The base-case model estimates that there is severe gear competition in Bass Strait so that essentially the same *expected* exploitation rate results for all levels of standardized fishing effort during 1976–2003 (Figure 7.5). Gear competition is estimated to be substantial primarily because the effort data are negatively correlated with exploitation rate for some years. For example, the higher exploitation rates since 1990 and the lower exploitation rates during 1983–91 (solid lines in Figure 7.5) correspond to periods when effort was low and high respectively. The estimated extent of gear competition is fairly robust to the weight placed on the effort data.

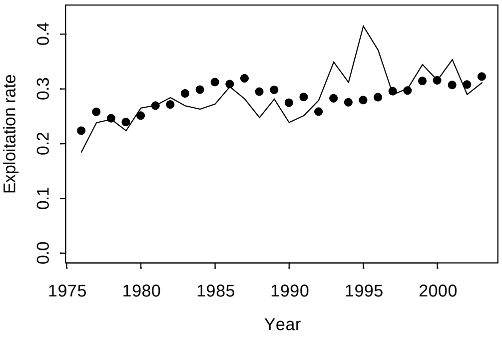

Figure 7.5 : Estimated exploitation rate time-trajectory for 6-inch mesh gear in Bass Strait (dotted line) and the values inferred from the effort information through Equation (7.C.2c) (solid line).

The fits to the length-frequency (Figures 7.6 and 7.7) and age-composition data (Figure 7.8) capture the general patterns. The fits to the data for the years for which sample size is large tend to be better than to the data for those years for which the sample size is low. However, there is a tendency to overestimate the mean length of the catch, particularly for 7-inch mesh (Figure 7.7) and 6-inch mesh in recent years (Figure 7.6).

The fits to the age-composition data, although generally adequate, are remarkably poor for some years (1990 and 1991 for females and 1986 for males). The model is able to mimic the recent pattern in tag recaptures adequately (Figure 7.9). However, the model over-estimates the number of recaptures during the 1970s. Whether this is a consequence of poor choices for the tag-reporting rates or a structural problem with the underlying population dynamics model is, however, unclear.

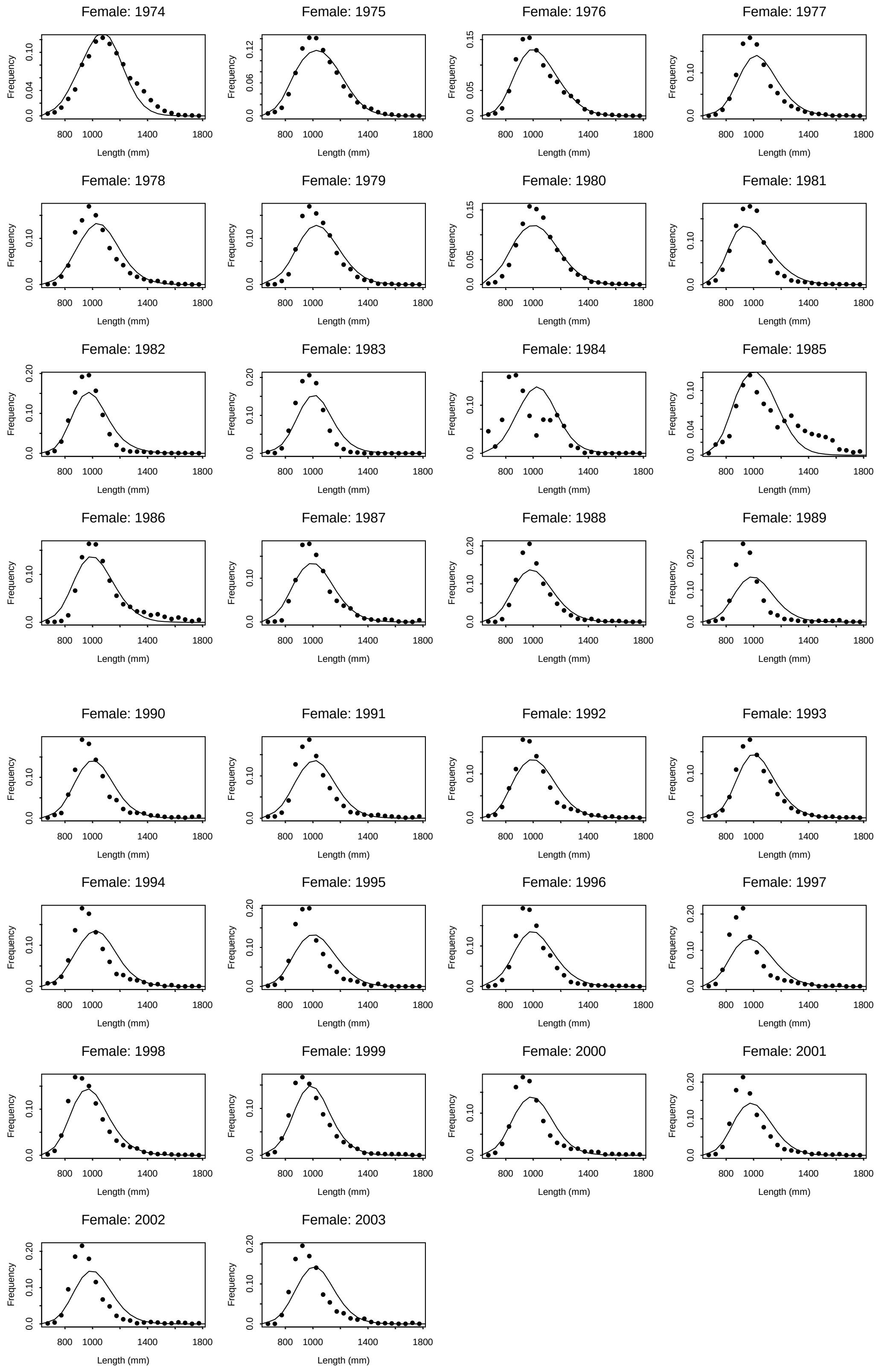

Figure 7.6(a) : Observed (solid dots) and model-predicted (solid lines) female length-frequency data for 6-inch mesh catches in Bass Strait.

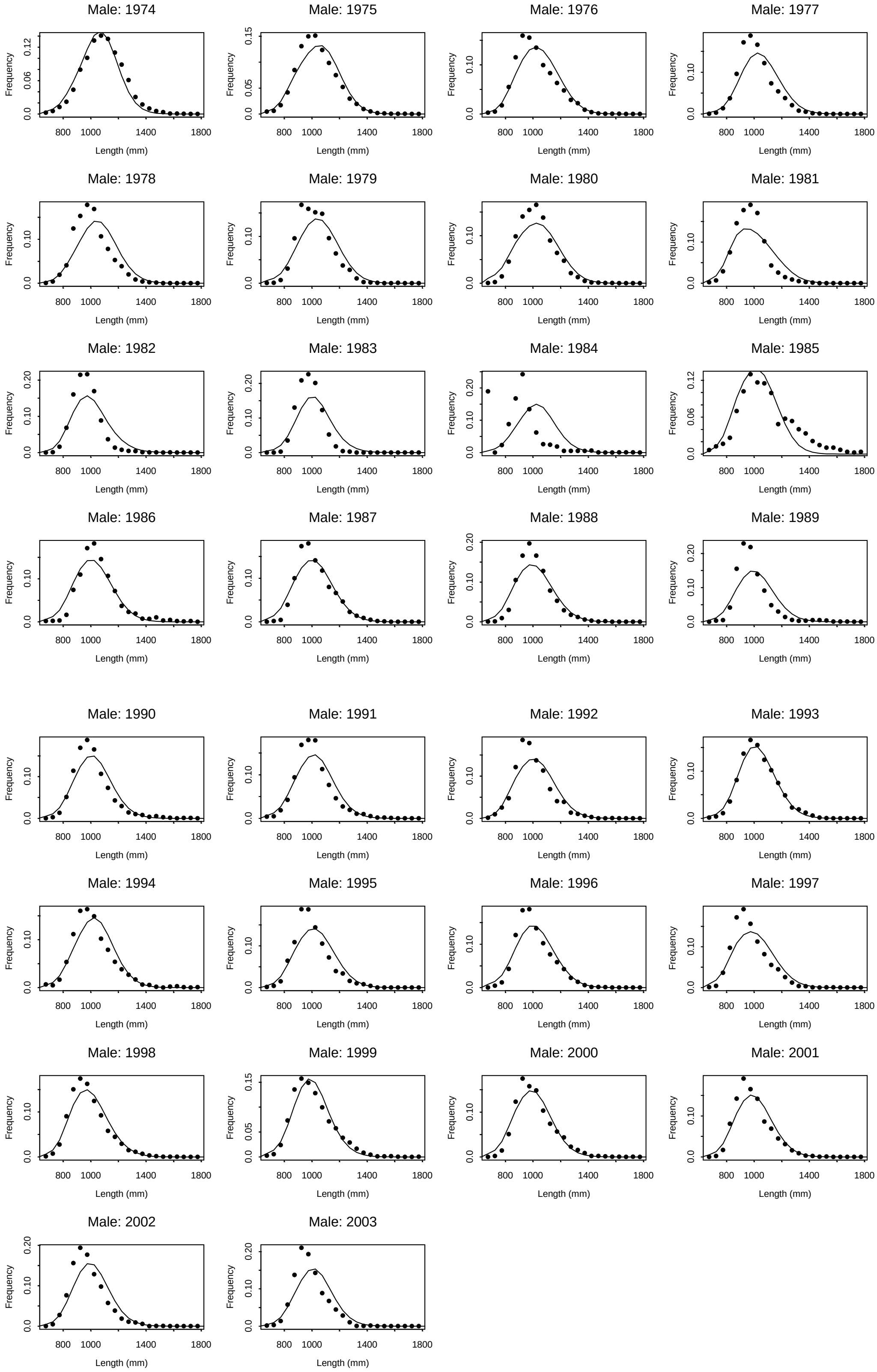

Figure 7.6 (b) : Observed (solid dots) and model-predicted (solid lines) male length-frequency data for 6-inch mesh catches in Bass Strait.

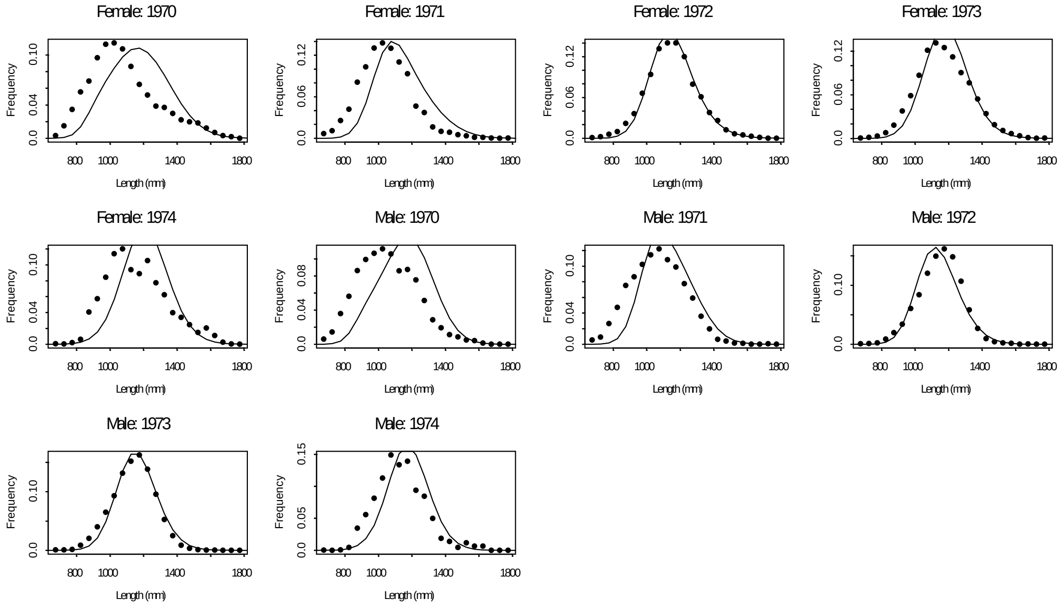

Figure 7.7 : Observed (solid dots) and model-predicted (solid lines) male length-frequency data for 7-inch mesh catches in Bass Strait. Results are shown separately for females and males.

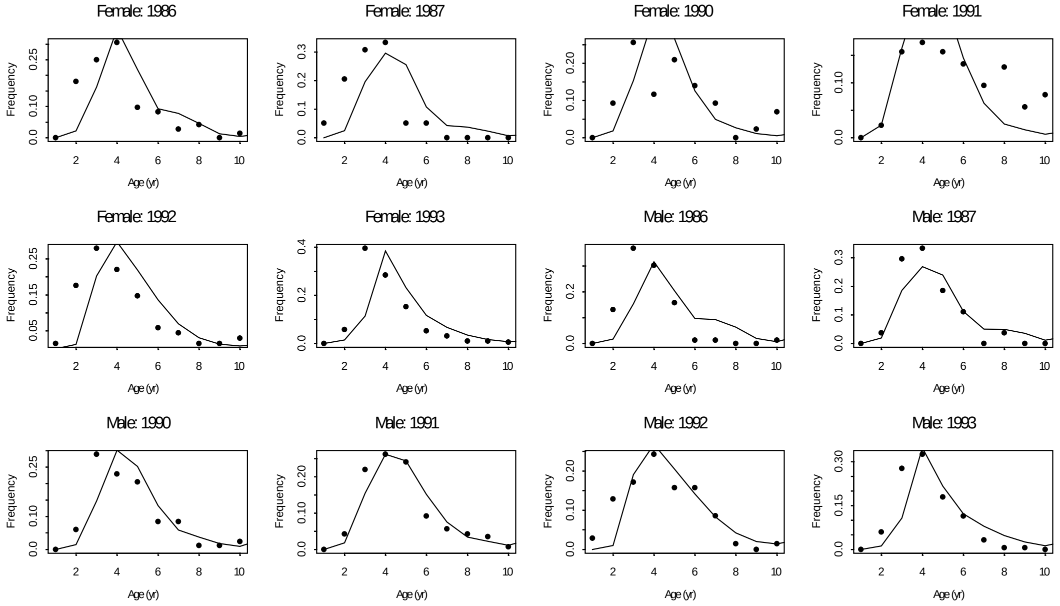

Figure 7.8 : Observed (solid dots) and model-predicted (solid lines) age-composition data (6-inch mesh catches) in Bass Strait. Results are shown separately for females and males.

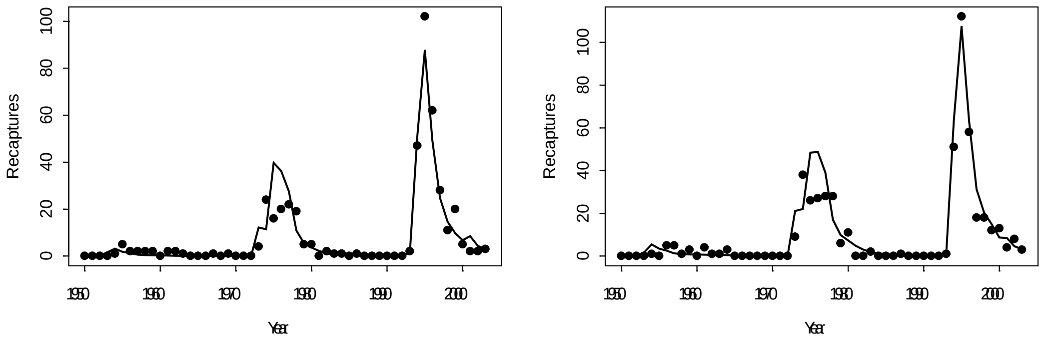

Figure 7.9 : Observed (solid dots) and model-predicted (solid lines) number of tag recaptures in Bass Strait (by sex).

7.4.1.2 South Australia

The model mimics the trend in exploitation rate well (Figure 7.10). The fits to the length-frequency and age-composition data are, however, notably poorer for South Australia than was the case for Bass Strait (Figures 7.11 – 7.13). There are some cases in which the model fails to capture even the predominant lengths in the catch (e.g. 1997 for 6.5-inch mesh; 1990 for 7-inch mesh; Figure 7.12). The reasons for this are unclear but are probably related to the very small sample sizes for some years (see Table 7.7). The fit to the tag recapture information (Figure 7.14) is also not as good as was the case for Bass Strait although the model is able to capture the recent trend in tag recaptures.

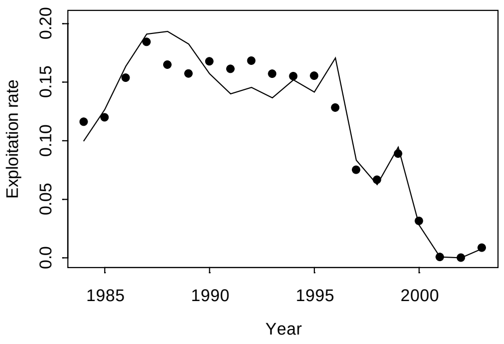

Figure 7.10 : Estimated exploitation rate time-trajectory for 7-inch mesh gear in South Australia (dotted line) and the values inferred from the effort information through Equation (7.C.2c) (solid line).

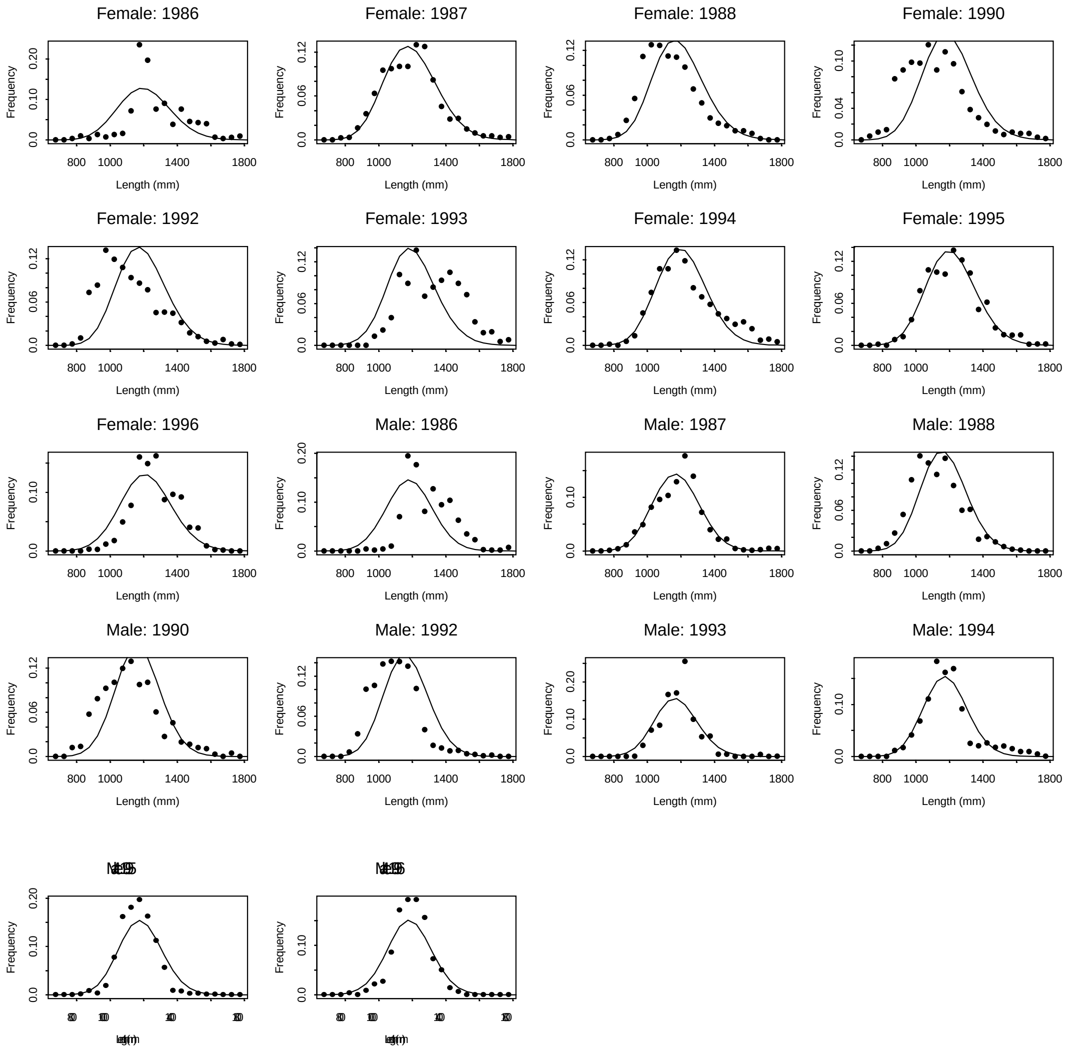

Figure 7.11 : Observed (solid dots) and model-predicted (solid lines) age-composition data (7-inch mesh catches) in South Australia. Results are shown separately for females and males.

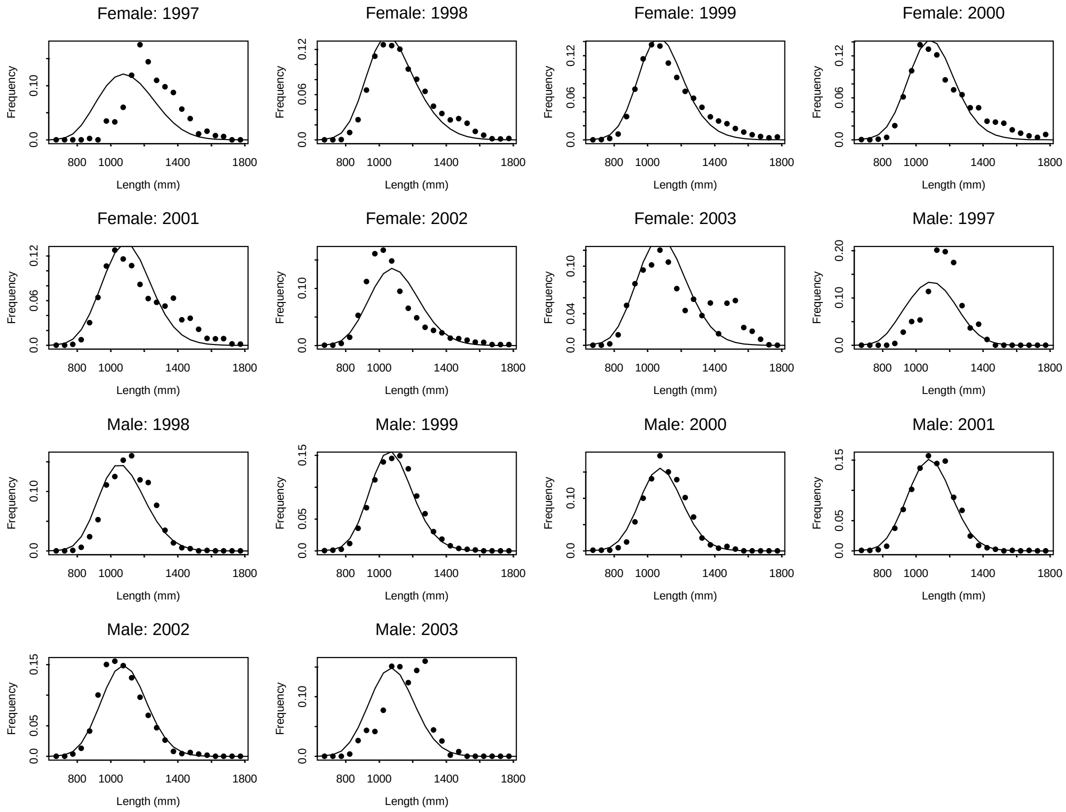

Figure 7.12 : Observed (solid dots) and model-predicted (solid lines) age-composition data (6.5-inch mesh catches) in South Australia. Results are shown separately for females and males.

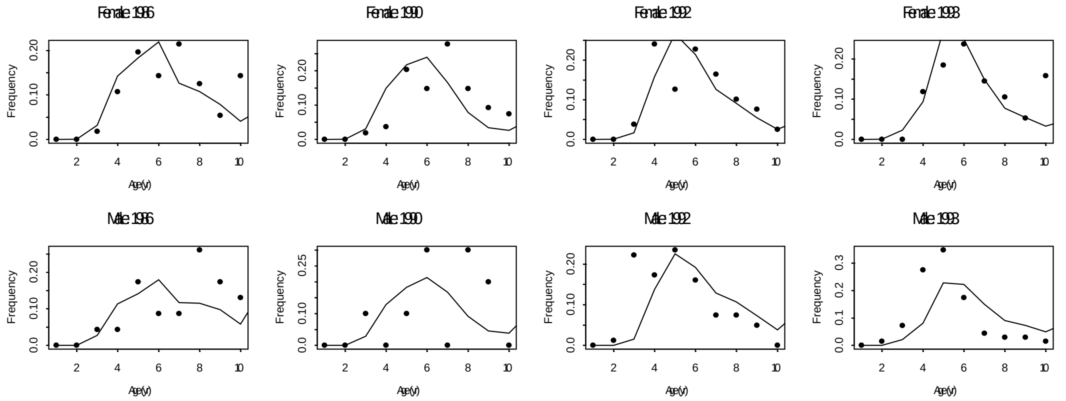

Figure 7.13 : Observed (solid dots) and model-predicted (solid lines) age-composition data (7-inch mesh catches) in South Australia. Results are shown separately for females and males.

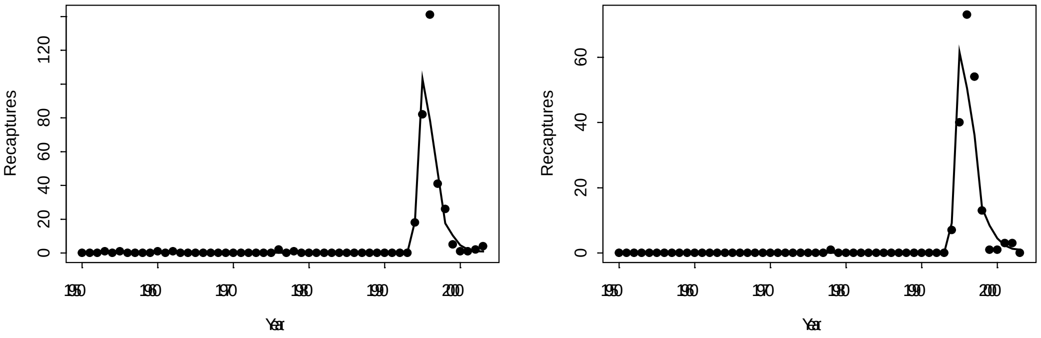

Figure 7.14 : Observed (solid dots) and model-predicted (solid lines) number of tag recaptures South Australia (by sex).

7.4.2 Markov Chain Monte Carlo diagnostics

Figures 7.15(a) – (e) summarize the convergence statistics for five of the key model outputs (the objective function, the logarithm of SB_0 for Bass Strait and South Australia, M_2, and V). The panels for each quantity show the trace, the posterior density function (estimated using a normal kernel density), the correlation at different lags, the 50-point moving average against cycle number (dotted line in the rightmost panels), and the running mean and running 95% probability intervals (solid lines in the rightmost panels).

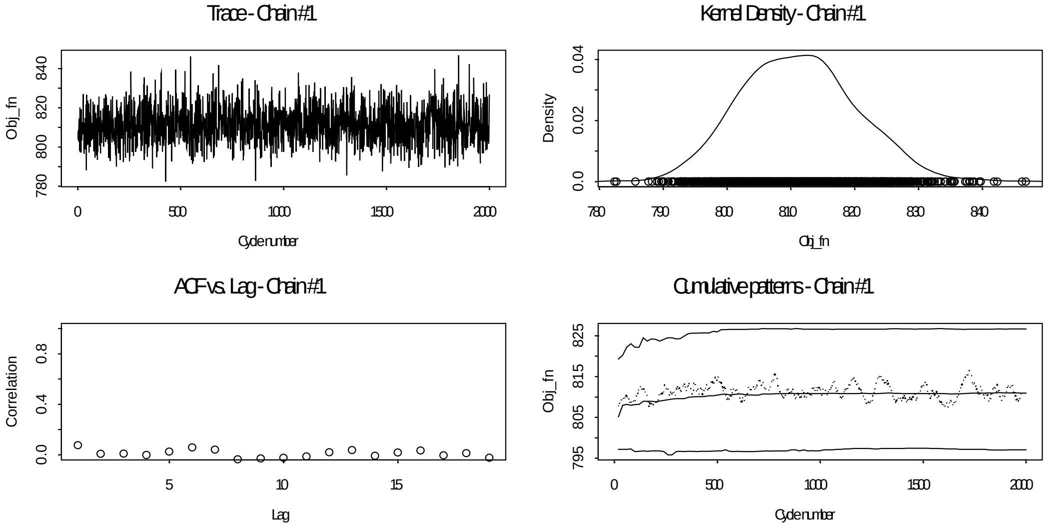

Figure 7.15(a): Convergence statistics for the objective function.

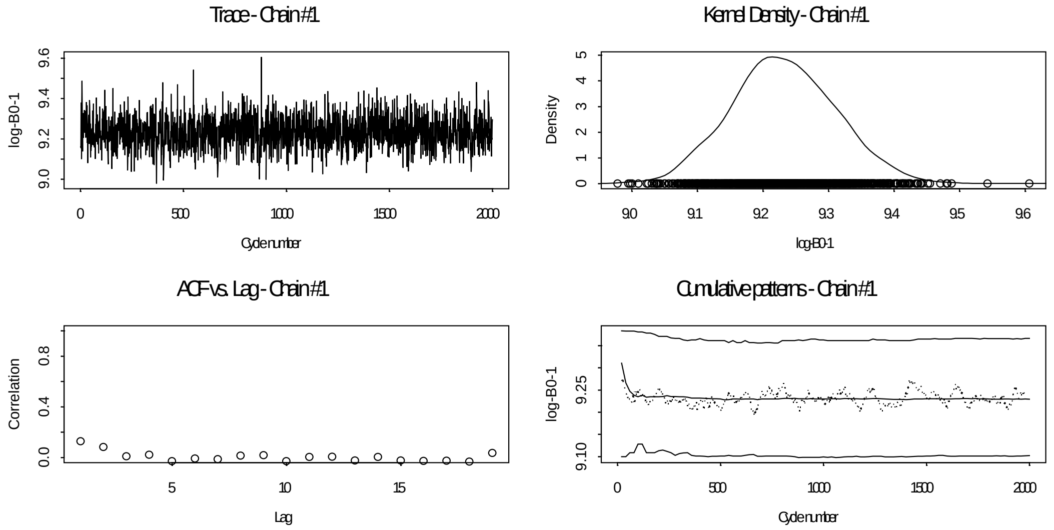

Figure 7.15(b): Convergence statistics for the logarithm of SB_0 for Bass Strait.

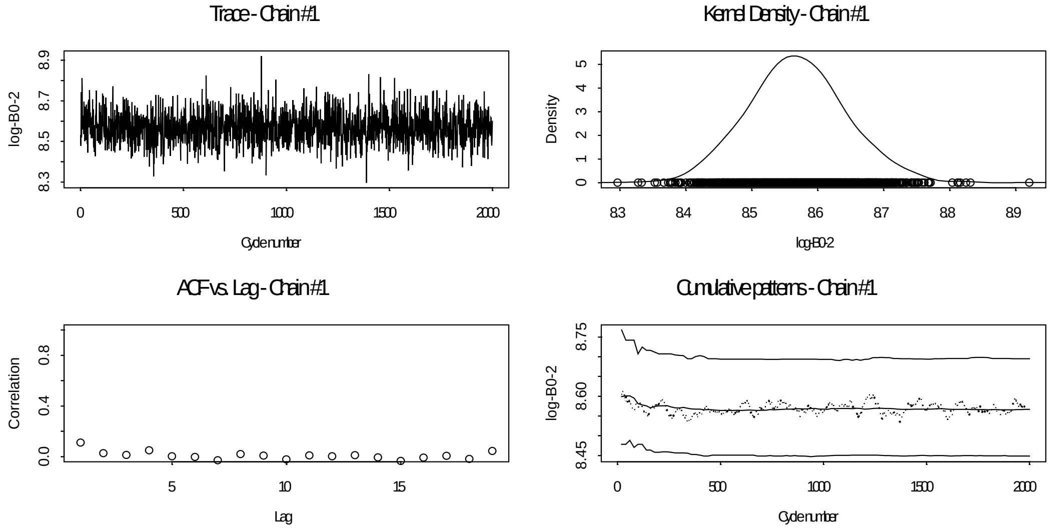

Figure 7.15(c): Convergence statistics for the logarithm of SB_0 for South Australia.

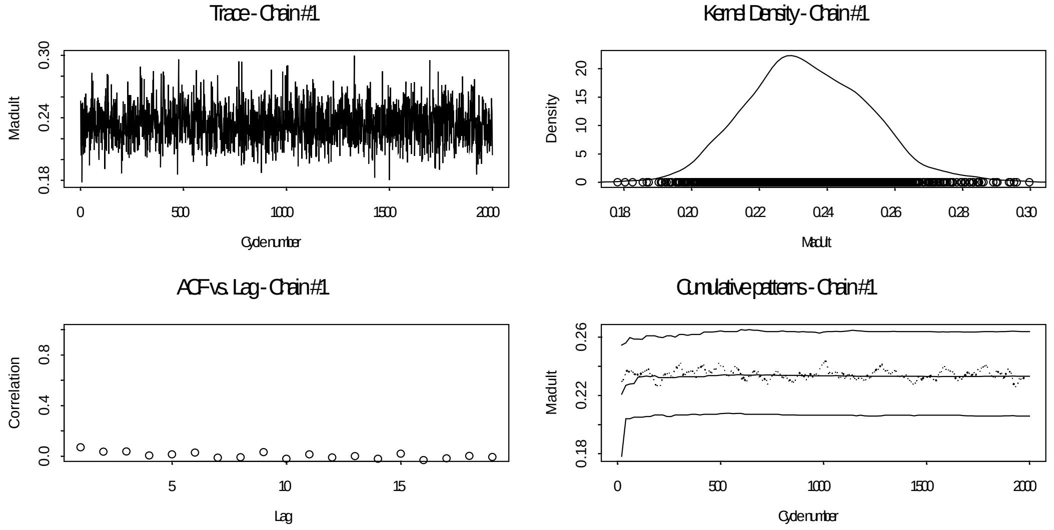

Figure 7.15(d): Convergence statistics for M_2.

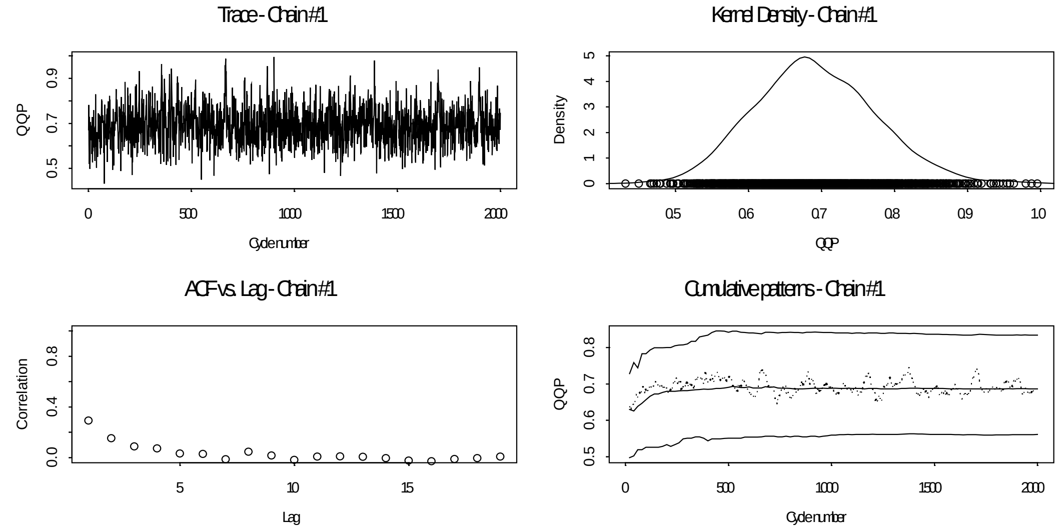

Figure 7.15(e): Convergence statistics for *V*.

None of diagnostic statistics for the five quantities exhibit any evidence that the MCMC algorithm failed to converge adequately to posterior distribution although a larger number of cycles would have reduced the auto-correlation in the chain even further

It is not feasible to produce figures summarizing the convergence statistics for all of the very many parameters of the model. Figures 7.16 and 7.17 summarize the values of five statistics (the ratio of the batch standard deviation to the naive standard deviation, the extent of lag-1 auto-correlation, the *p*-value computed from the Geweke statistic, whether the Heidelberger and Welch test is passed or not, and the value of the single-chain Gelman statistic) for the recruitment residuals and the estimates of pup production. Ideally, the value of the first statistic should be close to 1, the value of the second statistic should be close to zero, the value of the third statistic should be greater than 0.05, and the value of the last statistic should be less than 1.05. The results in Figures 7.16 and 7.17 suggest that the sample from the posterior is close to ideal. The *p*-value for the Geweke statistic is less than 0.05 reasonably often. However, this is not a major concern because this statistic can be triggered at random and the other statistics suggest that convergence has been achieved very successfully. The lag-1 autocorrelations for the estimates of pup production are all positive.

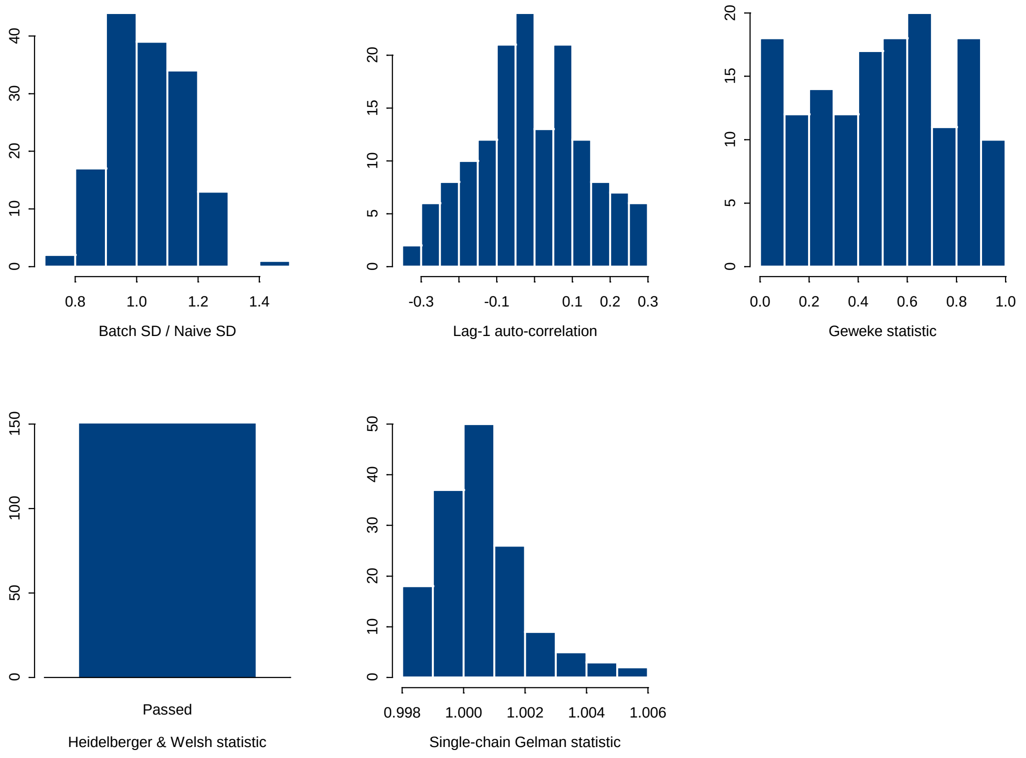

Figure 7.16 : Diagnostic statistics for the recruitment residuals.

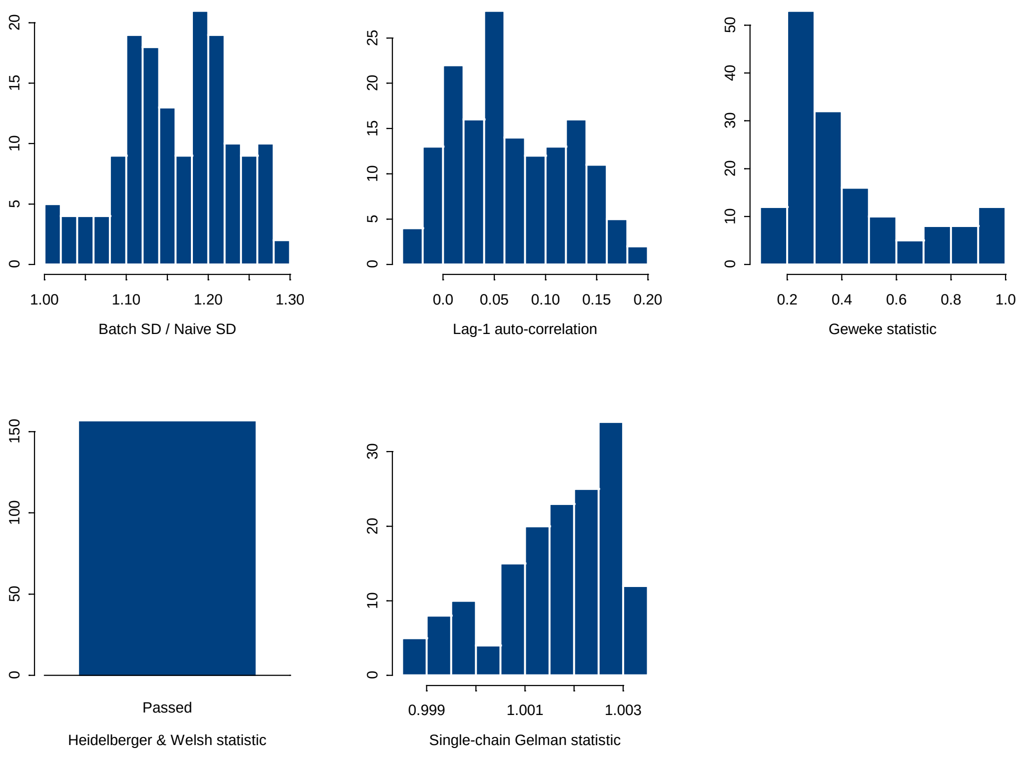

Figure 7.17 : Diagnostic statistics for the estimates of pup production.

7.4.3 The base-case assessments

The results of the assessment are summarized by the values for 12 quantities of interest to management:

a) SB_0	the pup production in a virgin state (separately for Bass Strait and South Australia),
b) M_2	the instantaneous rate of natural mortality for fish of age 2 (at pre-exploitation equilibrium when natural mortality is density-dependent),
c) $MSYR$	the MSY rate (the ratio of MSY to the biomass at which MSY is achieved – Appendix C), separately for Bass Strait and South Australia.
d) SB_{73}/SB_0	the ratio of the pup production at the start of 1973 to that in a virgin state, expressed as a percentage (separately for Bass Strait and South Australia),
e) SB_{99}/SB_0	the ratio of the pup production at the start of 1999 to that in a virgin state, expressed as a percentage (separately for Bass Strait and South Australia),
f) SB_{04}/SB_0	the ratio of the pup production at the start of 2004 to that in a virgin state, expressed as a percentage (separately for Bass Strait and South Australia),
g) $-\ell nL$	the negative of the logarithm of the likelihood function (ignoring constants independent of the model parameters).

The pup production ratios are reported for 1999 along with those for 1973 and 2003 to allow the results for the present assessment to be compared with those from the 2000 assessment.

The base-case results of the present assessment are listed in Table 7.11. Compared to the 2000 assessment (Tables 2.17 and 2.18 of Punt *et al.* (2001)), the present assessment is less optimistic. The 1999 depletion of the pup production is 43.6% and 42.3% for Bass Strait and South Australia respectively in Table 7.11 compared with 73.6% and 76.3% for these two areas in the 2000 assessment. Much of this difference can, however, be attributed to the 2000 assessment basing its estimate of *MSYR* on the data for Bass Strait only. Punt *et al.* (2001) Table 3.3 reports assessment results based on the same data as their Tables 2.17 and 2.18 except that *MSYR* is estimated using data for both South Australia and Bass Strait (i.e. the same approach as applied in this paper). The 1999 depletions of the pup production for Bass Strait and South Australia are 57.8% and 53.7% respectively - values much more similar to those obtained in the present assessment. The comparisons between the 2000 and the present assessment are henceforth based on the analyses that estimated *MSYR* using data for both South Australia and Bass Strait.

The estimate of M_2 (0.231yr^{-1}) for this assessment is higher than the estimate of M_2 obtained by Punt *et al.* (2001) (0.192yr^{-1}). This assessment is, however, less optimistic in terms of the values for *MSYR* (0.172 yr^{-1} for the 2000 assessment, and 0.153 and 0.164 yr^{-1} for Bass Strait and South Australia respectively for this assessment). The estimate of M_2 is fairly precise (95% probability interval: [0.202yr^{-1}, 0.272yr^{-1}]).

Figure 7.18 shows the time-trajectories of exploitable biomass and exploitation rate (by gear-type) for the gummy shark populations in Bass Strait and off South Australia. The most noteworthy result in Figure 7.18 is that the exploitable biomass in Bass Strait was relatively stable from 1980 to the mid-1990s, dropped substantially and has recovered somewhat. In contrast, the exploitable biomass for the gummy shark population off South Australia dropped substantially in about 1994 and there are some signs of recovery.

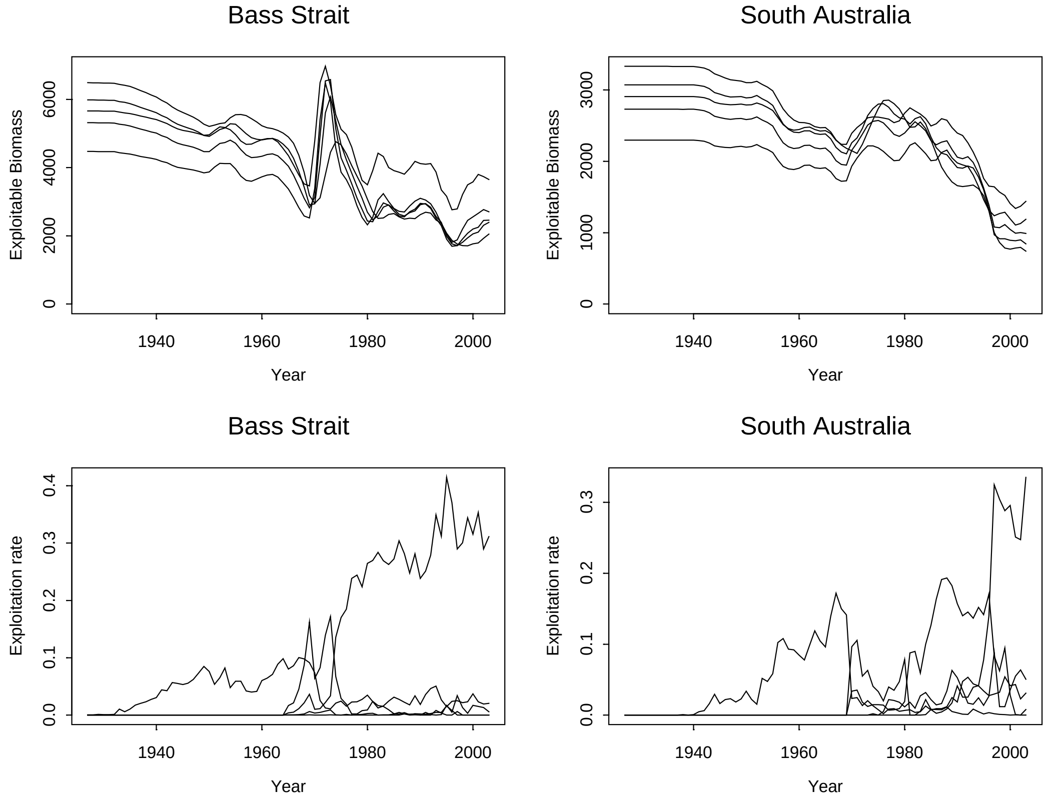

Figure 7.18 : Time-trajectories of exploitable biomass and exploitation rate for Bass Strait and South Australia by gear-type.

The exact reasons for the reduced spawning biomass in recent years are not totally clear, but various factors point in this direction: a) increasing exploitation rate in the data (Figure 7.5), b) increasing estimated exploitation rates for 6” and 6.5” mesh gear in recent years (Figure 7.18), and c) a reduced mean length of the catch in recent years in Bass Strait. The lack of evidence for good recruitment off South Australia remains a feature of the present assessment.

Figures 7.19 and 7.20 show time-trajectories (with asymptotic 90% probability intervals) for the pup production, the total (1+) biomass, the number of 1-year-olds, and the number of 3-year-olds for the gummy shark populations in Bass Strait and off South Australia respectively. The narrow 90% probability intervals for 1927 (age-1 abundance) and 1927–1929 (age-3 abundance) in Figures 7.19 and 7.20 arise because the population is assumed to be in deterministic equilibrium at the start of 1927.

There is a gradual reduction in the number of pups produced by gummy shark in Bass Strait over the period 1927–2003 (Figure 7.19). In contrast, the time-trajectory of (1+)

biomass is more stable due to a large increase from 1970 to 1980. This increase is a consequence of a large 1968 year-class (Figure 7.21). Such a year-class is needed to fit the high mean catch lengths during the early 1970s, as these can only be explained by a strong cohort passing through the population. The oscillations in total (1+) biomass are mirrored in the time-trajectories of age 1 and age 3 abundance (Figure 7.19). The combination of variation in pup survival (Figure 7.21) and density-dependence implies that recruitment to the fishery in Bass Strait has been relatively constant (Figure 7.19 bottom left panel). A consequence of this is that exploitable biomass from 1976–2003 has been more stable than total biomass or pup production (Figure 7.18). The marked increase in exploitable biomass from 1970 to 1973 is due to recruitment to the fishery of the strong 1968 cohort. The exploitable biomass in Bass Strait is estimated to have declined from 1990 to 1996 but then to have recovered due to lower catches. Although imprecisely determined, recruitment has been stronger than would have been expected from the deterministic stock-recruitment relationship for the years 1995–2000 (Figure 7.21). The pup survival for 2001 is estimated to be average because the data provide no information on the size of the recruitment for 2001 as it has yet to enter the fishable component of the population.

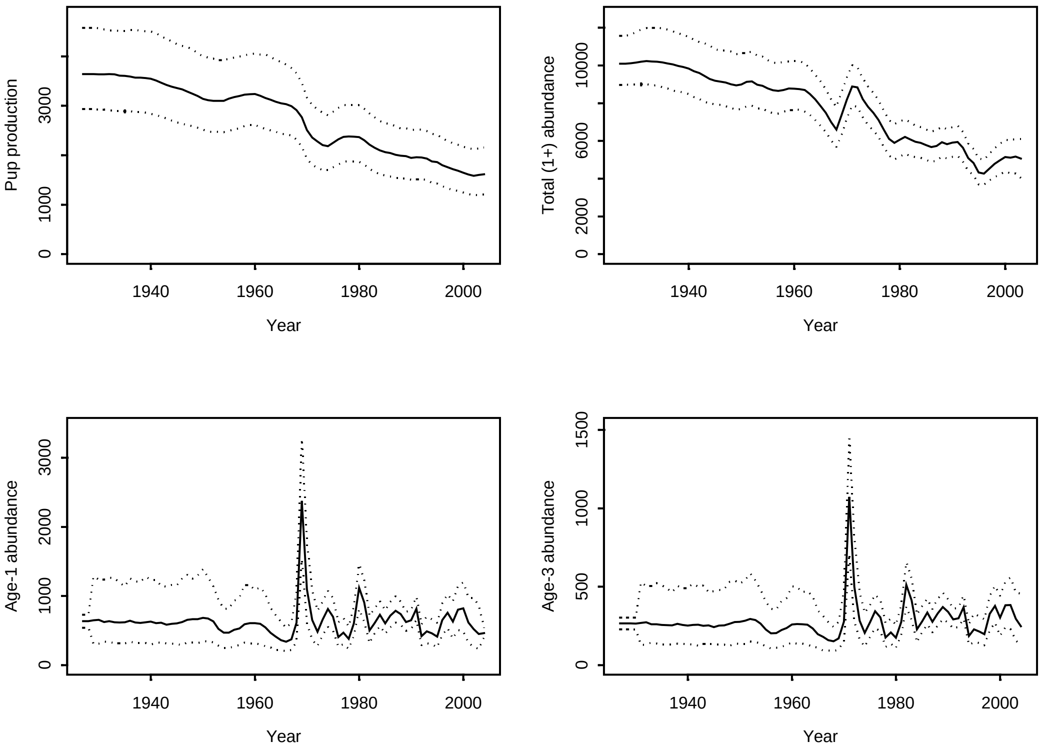

Figure 7.19 : Time-trajectories for Bass Strait (with 90% probability intervals) for: pup production, 1+ biomass, number of 1-year-olds, and number of 3-year-olds.

Generally poor pup survival from 1989 off South Australia has meant that recruitment in this region during the mid-to-late 1990s has been weak (Figure 7.20). This has lead to a marked decline in total (1+) biomass over recent years (upper right panel of Figure 7.20) and in recruited biomass (Figure 7.18) in recent years. The impact of poor recruitment is evident from the length-frequency data – the mean length of the catch increased markedly from 1992. The estimates of pup survival and consequently of recruitment are, however, highly imprecise (essentially equal to the assumed default level of variation) until the late 1970s. This is due to a lack of length-frequency data prior to 1984 (Table 7.8).

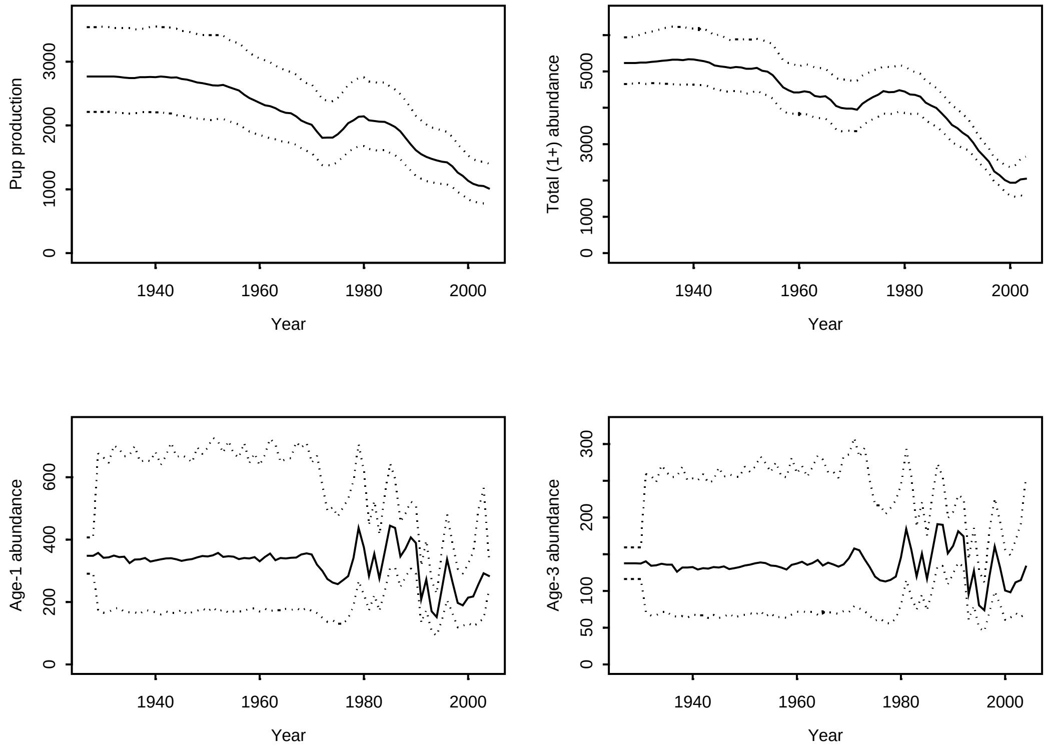

Figure 7.20 : Time-trajectories for South Australia (with 90% probability intervals) for: pup production, 1+ biomass, number of 1-year-olds, and number of 3-year-olds.

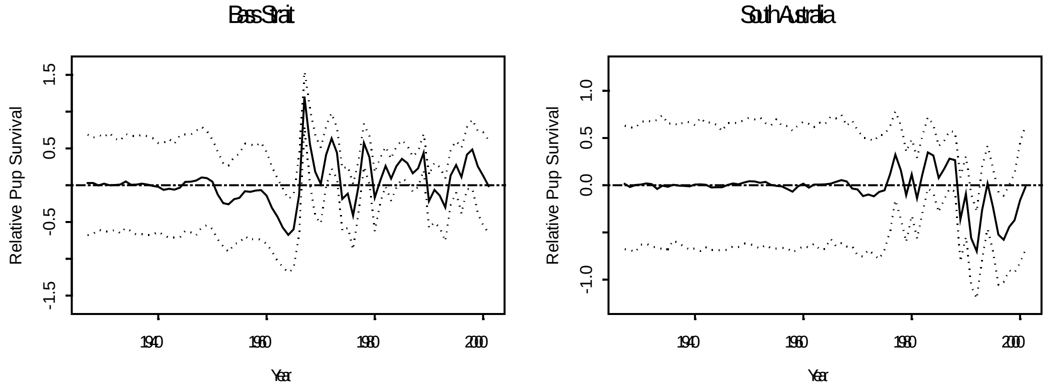

Figure 7.21 : Annual pup survival for Bass Strait and South Australia expressed as fractions of those expected under the deterministic stock-recruitment relationship (with 90% probability intervals).

7.4.4 Sensitivity tests

Table 7.11 lists the values of the 12 summary statistics for the base-case analysis and the 14 sensitivity tests. The estimates of the ratio of the pup production at the start of 2004 to that in 1927, SB_{04} / SB_0, are highly sensitive to changes to how density-dependence is modeled. Reducing the range of ages over which density-dependent natural mortality operates leads to a more depleted population (Figure 7.22, Table 7.11 rows “Dens-dep-pups” and “Dens-dep M (ages 0-4)”),

Ignoring the length-frequency and age-composition data when conducting the assessment has a marked impact on the estimate of SB_{04} / SB_0 for South Australia (Figure 7.22); the effect of ignoring these data on the status of the resource in Bass Strait is less. Ignoring the tagging data has the large impact on the estimate of SB_{04} / SB_0 for Bass Strait (reducing it from 40.7% to 32.3%).

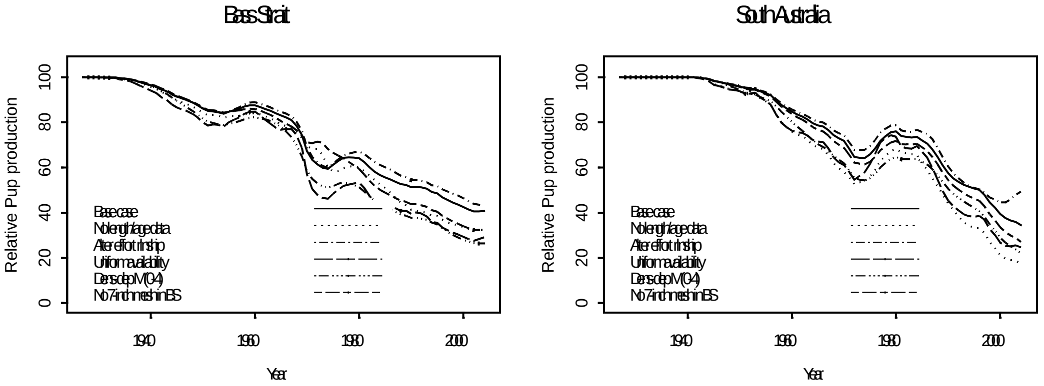

Figure 7.22 : Time-trajectories of pup production (expressed relative to that in 1927) for the base-case analysis and a subset of the 14 sensitivity tests.

The results are sensitive to assumptions about availability and the relationship between effort and exploitation rate (Figure 7.22, Table 7.11 rows “Alter effort relationship” and “Uniform availability”). However, these two sensitivity tests fit the data significantly poorer than the base-case analysis.

Ignoring the early 7-inch mesh data for Bass Strait (Figure 7.22, Table 7.11 row “No “ mesh lengths in BS”) leads to lower values for the estimates of SB_{04} / SB_0 because the 1968 cohort is no longer estimated to be extremely strong.

7.4.5 Projections

20-year projections (2004-2023) were conducted for a range of future catch levels (900-1200t in Bass Strait and 350-500t off South Australia). The projections assume the split of the catch among gear-types is the same as that for 2003, the last year for which data are available, and are based on a random sample of 2,000 parameter vectors from the Bayesian posterior distribution.

The results of the projections are summarized in Figure 7.23 by the probability that the pup production in each of the 20 future years exceeds two threshold levels (40% of the 1927 pup production, upper panels; the 2003 pup production, lower panels). The catch levels which keep the pup production above the thresholds are, respectively for Bass Strait and South Australia, 1000t and 450t (40% of the 1927 level) and 900t and 450t (2003 pup production). The catch level is higher for Bass Strait for the 40% threshold because the stock in Bass Strait is estimated to be currently above 40% of the 1927 level.

The results in Figure 7.23 are based on pup production. Somewhat different levels of catch would be appropriate had other population components been considered (e.g. total population size, exploitable biomass). However, pup projection has formed the basis for projections in the past.

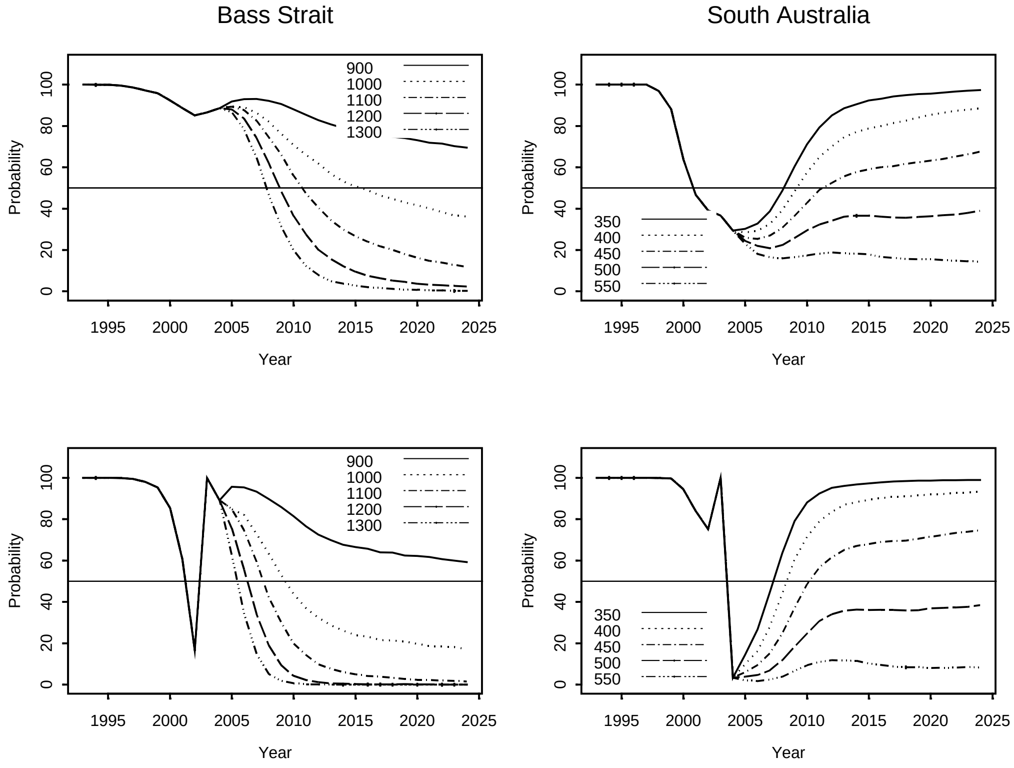

Figure 7.23. Probability of the pup production in Bass Strait and off South Australia exceeding each of two threshold levels (40% of the 1927 pup production, upper panels; the current 2003 pup production, lower panels) for various levels of future catch. Results are shown for the base-case analysis.

The results in Figure 7.23 are based on the Bayesian posterior distribution for the base-case analysis. The results in Table 7.11 and Figure 7.22 suggest that the results of the assessment (in terms of status and productivity) are sensitive to some changes to the specifications of the assessment; the results of the projections would consequently also be sensitive to these changes.

7.4.6 General discussion

7.4.6.1 Stock status

The populations of gummy shark in Bass Strait and off South Australia are both estimated to be currently slightly above the proxy for the level at which *MSY* would be achieved, SB_{MSY}, of $0.4SB_0$[7] and recruitment to the fisheries in Bass Strait is estimated to better than expected given the number of mature females, while that off South Australia has generally been poorer than expected. However, although this qualitative appraisal of the status of the populations is robust to the specifications of the assessment, this is not the case for the actual quantitative results. In particular, the

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[7] The actual point estimates of SB_{MSY} are $0.41SB_0$ (Bass Strait) and $0.37SB_0$ (South Australia).

results are very sensitive to assumptions about density-dependent processes, and the extent to which gummy sharks are unavailable to the fishing gear (Table 7.11). Furthermore, two of the key data sources included in the assessment (the tagging and length-frequency data) appear to be in conflict to some extent (Pribac *et al*., in press).

One consequence of a significant size-specific availability effect (see Figure 7.4) is that the fishery is more susceptible to periods of good and poor recruitment than would be a fishery that had access to all age- and length-classes. Furthermore, the apparent resilience of the population to (over)fishing can be attributed in no small part to this effect. If the fishery changes its behavior so that non-traditional grounds become fished with increasing frequency, this resilience may be substantially reduced.

It is well-known that catch-rates may not index abundance adequately, but the extent to which catch-rates may be inadequate indicators of abundance is unknown. Cooke and Beddington (1984) and Cooke (1985) describe various scenarios in which catch rate is unlikely to be linearly related to abundance. Cooke and Beddington (1984) highlight the possibility that catch rates may decline more slowly than abundance (“hyperstability”) and this expectation is supported by the meta-analysis conducted by Harley *et al.* (2001). However, the opposite problem (“hyperdepletion”) can also occur (e.g. Prince and Hilborn, 1998).

7.4.6.2 Changes in methodology

The major difference between the present assessment and the assessment of Pribac *et al.* (in press) is that the latter assessment based the estimates of some key population dynamics parameters (e.g. M_2 and *MSYR*) on the data for Bass Strait only and then assumed that the “best” estimates of these quantities also apply to gummy shark off South Australia, when conducting assessments of gummy shark off South Australia. This approach implicitly assumes that the data for South Australia contain no information about *MSYR*, availability and M_2 and also ignores any uncertainty about the values for these parameters when constructing probability intervals and making projections. This could lead to the paradoxical situation in which uncertainty is assessed to be less for South Australian gummy shark than for Bass Strait gummy shark.

The approach taken in this paper is conceptually the same as that of Pribac *et al.* (in press), i.e. the values for some of the parameters of the model are the same for Bass Strait and South Australia, but is statistically more justified because the values for the parameters are based on the entire data set and the uncertainty associated with the values for these parameters is reflected in the estimates for both South Australia and Bass Strait rather than for Bass Strait only.

7.5 Future development

The analyses of this document could be extended in future in several ways.

1) The data for Tasmania could be included in the assessment and the values for *MSYR*, M_2, etc. assumed to be the same for Tasmania, South Australia and Bass Strait.
2) The values for *MSYR*, M_2, etc., could be assumed to differ between South Australia and Bass Strait (with a constraint on the extent of difference).

7.6 Acknowledgements

This assessment was conducted through the SharkFAG process and many of the assumptions / model scenarios considered arose during discussions at meetings of SharkFAG. The SharkFAG process also provided a forum within which the realism of some of the model assumptions and results could be discussed. Had the assessment been conducted without this input, it seems likely that the extent of uncertainty would have been under-estimated as some key model assumptions may not have been examined to the extent they were.

Lauren Brown (PIRVic) is thanked for supplying the tagging data, and John Garvey (AFMA) is thanked for supplying the data for SEF and GAB fisheries.

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Table 7.1 : Estimates of catch (carcass weight, tonnes) by sub-region, year and gear-type for 1927–72 for the directed shark fisheries and the Commonwealth non-trawl fishery (estimates for the four gill-net mesh sizes used in the fishery have been pooled).

(a) Longline catches

Year	Sub-region								Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	
1927				1		1			1
1928				1		1			1
1929				4		4			8
1930				2		2			3
1931				2		2			5
1932				3		3			6
1933				30		30			61
1934				17		17			34
1935				30		30			60
1936				57	5	35			97
1937		0	0	64	12	39			116
1938		1	1	54	15	59			129
1939		0	0	48	40	64			153
1940		1	1	71	40	57			171
1941		7	7	76	50	114			254
1942		9	9	58	77	94		15	260
1943		23	23	60	133	112		14	364
1944	8	39	37	46	126	120		31	407
1945	16	16	14	65	107	107		47	372
1946	42	12	8	67	79	144		55	406
1947	26	21	18	75	88	161		76	465
1948	27	13	12	63	128	189		63	495
1949	31	23	11	52	105	282		48	552
1950	22	45	29	53	123	216		24	511
1951	27	30	6	30	90	160		18	361
1952	29	11	4	40	129	182		41	436
1953	115	17	17	49	148	248		41	635
1954	110	12	12	26	96	129		31	415
1955	136	17	10	49	108	146		25	490
1956	181	60	41	60	112	119		13	586
1957	84	109	94	38	80	83	5	39	533
1958	70	91	79	41	69	83	3	26	462
1959	69	89	77	36	84	82	5	44	486
1960	63	82	71	42	147	111	12	97	623
1961	58	76	66	51	148	125	11	89	623
1962	75	98	85	80	120	158	5	37	658
1963	90	117	102	106	134	201	3	26	779
1964	78	101	88	117	138	217	3	20	762

(Table 7.1 Continued)

(a) Longline catches

Year	Sub-region								Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	
1965	153	60	32	37	116	212	0	13	624
1966	223	88	47	82	135	151	4	13	743
1967	269	106	56	52	142	206	23	25	879
1968	227	89	47	55	145	163	15	41	782
1969	212	83	45	47	194	92	2	26	701
1970	13	24	20	24	193	149	7	23	453
1971	14	26	22	13	47	109	19	7	256
1972	8	14	12	3	34	49	13	6	138

(b) Mesh catches

Year	Sub-region								Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	
1965					28	64			92
1966				0	31	79			111
1967				0	68	148			217
1968				3	84	290	0	24	400
1969				43	88	495	3	125	753
1970	161	107	28	48	41	151	3	20	558
1971	173	116	30	56	133	241	4	15	768
1972	94	62	16	90	396	526	11	15	1211

Table 7.2 : Estimates of catch (carcass weight, tonnes) by sub-region, year and gear-type for 1973–2003 for the directed shark fisheries and the Commonwealth non-trawl fishery (estimates for the four gill-net mesh sizes used in the fishery have been pooled).

(a) Longline catches

Year	Sub-region								Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	
1973	20	17	17	0	23	47	1	8	133
1974	15	18	2	1	81	36	7	53	213
1975	2	14	4	11	106	11	24	40	211
1976	0	3	2	11	52	15	0	24	108
1977	10	7	5	8	43	54	14	26	168
1978	12	11	0	3	40	53	2	9	131
1979	10	2	1	4	50	47	5	13	132
1980	8	9	1	3	58	63	8	13	163
1981	9	12	1	2	33	60	5	12	132
1982	3	7	0	2	31	23	2	17	85
1983	8	5	0	4	26	39	16	8	105
1984	2	28	3	9	25	66	17	41	191
1985	4	11	3	10	53	57	16	37	193
1986	4	10	6	5	34	56	15	28	159
1987	4	14	5	2	18	63	15	34	155
1988	8	16	6	6	15	49	25	37	160
1989	11	25	23	13	48	76	30	25	251
1990	12	24	2	4	30	37	23	44	175
1991	23	53	24	17	56	72	8	47	300
1992	20	64	30	20	77	83	77	22	392
1993	23	45	23	9	97	78	76	39	389
1994	15	55	6	2	48	26	31	31	213
1995	9	35	4	3	5	28	1	0	86
1996	10	22	3	8	15	25	2	4	88
1997	14	21	2	2	15	36	1	4	93
1998	16	23	2	1	19	24	1	9	95
1999	31	38	3	0	4	49	2	5	131
2000	16	21	2	1	2	101	1	4	148
2001	21	16	2	0	7	52	1	3	102
2002	2	7	6	2	9	33	3	2	64
2003	1	8	7	1	15	31	2	6	72

(Table 7.2 Continued)

(b) Mesh catches

Year	Sub-region								Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	
1973	30	135	25	95	350	942	15	67	1658
1974	44	73	36	87	206	748	10	84	1286
1975	23	86	24	108	190	559	0	12	1002
1976	7	68	33	101	178	550	3	54	995
1977	13	114	53	69	275	567	8	53	1154
1978	18	100	43	46	295	472	3	81	1058
1979	21	132	40	32	234	401	9	67	937
1980	46	213	28	25	282	434	17	99	1145
1981	36	196	41	35	317	508	9	83	1226
1982	49	196	22	50	461	546	15	51	1389
1983	48	169	18	27	335	689	21	39	1348
1984	62	313	15	15	260	661	31	106	1463
1985	47	302	50	19	219	659	70	107	1473
1986	24	363	55	20	275	698	40	83	1559
1987	58	398	51	29	331	547	48	82	1543
1988	46	474	43	30	268	523	20	109	1514
1989	58	464	60	28	289	682	14	104	1699
1990	55	394	77	22	299	525	21	77	1470
1991	75	265	71	54	348	493	18	69	1393
1992	74	281	37	36	355	572	21	84	1460
1993	46	283	72	36	408	727	36	118	1726
1994	64	286	69	45	335	515	34	112	1460
1995	49	308	42	84	494	559	17	97	1650
1996	96	355	46	43	280	526	14	124	1484
1997	111	446	62	63	252	394	23	77	1428
1998	95	339	26	50	166	587	14	79	1356
1999	76	368	37	53	214	760	19	85	1611
2000	85	319	27	55	146	794	13	66	1505
2001	79	236	33	51	154	973	15	54	1595
2002	70	236	50	72	228	672	18	88	1435
2003	116	295	36	53	238	679	21	81	1519

Table 7.3 : Reported catches (kg) by SEF and GAB trawlers of gummy shark by year and sub-region. Source: John Garvey (AFMA).

(a) SEF

Year	Sub-region								Total
	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	NSW	
1985	0	131	154	214	2309	0	0	2023	4831
1986	0	2875	1649	310	9329	80	298	9829	24370
1987	0	215	15	0	3001	0	65	9798	13094
1988	0	60	0	0	2561	60	650	6924	10255
1989	0	241	0	90	6179	0	50	7077	13637
1990	0	240	635	30	4306	0	1012	6700	12923
1991	0	141	122	35	4682	190	281	8548	13998
1992	9	4195	2203	772	10979	890	3642	5900	28590
1993	0	2542	1324	1290	12932	683	2240	8297	29306
1994	9	4905	2916	464	10791	587	1634	11367	32674
1995	246	3294	1159	583	8031	1277	1218	7745	23553
1996	47	3103	1949	395	14664	69	1701	11591	33520
1997	20	3383	1953	470	15379	107	1488	10891	33691
1998	0	2975	1838	307	21420	76	889	9823	37328
1999	5	4920	1645	478	24373	65	1180	7322	39988
2000	0	10792	1751	530	26155	500	1915	8832	50475
2001	1	8695	958	173	25952	393	3535	7064	46771

(b) GAB

Year	Sub-region								Total
	WA	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WBas	
1987	0	0	205	0	0	0	0	0	205
1988	1255	0	1591	0	0	0	0	0	2846
1989	1472	1744	120	0	0	0	0	0	3336
1990	1510	6386	285	0	0	0	0	0	8181
1991	4864	12055	170	0	0	0	0	0	17089
1992	2365	5115	10	0	0	0	0	0	7490
1993	2546	2446	40	0	0	0	0	0	5032
1994	2351	2320	27	0	0	0	0	0	4698
1995	6460	8065	18	0	0	0	0	0	14543
1996	10267	7361	35	0	0	0	0	0	17663
1997	11401	8089	17	0	0	0	0	0	19507
1998	7167	6231	16	0	0	0	0	0	13414
1999	5668	6111	213	0	0	0	0	0	11992
2000	4107	8015	36	0	0	0	0	0	12158
2001	11649	9904	0	0	0	0	0	0	21583

(Table 7.3 Continued)

(c) SEF and GAB

Year	Sub-region										Total
	WA	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	NSW	
2002	11048	7965	12	6953	898	674	25934	698	9508	10970	74658
2003	17760	21049	56	3721	1366	770	20932	1306	10293	13026	90277

Table 7.4 : The base-case catch rate indices for Bass Strait and South Australia.

Year	Bass Strait	South Australia
1976	100.00	
1977	92.25	
1978	90.23	
1979	75.84	
1980	76.55	
1981	74.06	
1982	92.94	
1983	78.55	
1984	67.06	89.18
1985	58.17	100.00
1986	66.06	70.43
1987	54.81	44.92
1988	61.85	66.08
1989	73.03	68.19
1990	75.11	45.72
1991	71.97	45.11
1992	96.94	42.21
1993	95.48	47.47
1994	77.71	51.59
1995	92.42	42.79
1996	68.15	68.38
1997	48.18	57.97
1998	58.08	48.01
1999	65.93	48.15
2000	61.28	51.91
2001	78.39	72.85
2002	64.04	66.04
2003	60.19	55.20

Table 7.5 : The tag-types represented in the tagging database. The column ‘direct’ indicates whether the double-tagging experiments can be used to estimate tag-shedding rates for the tag-type concerned. The columns ‘#rel’ and ‘#rec’ contain the total number of gummy sharks released and recaptured respectively. Note that the total number of releases in this table exceeds the actual number (see row ‘total’) because some fish were double-tagged. An asterisk indicates a tag-type for which the tag-shedding rate is assumed to be 1.

Tag-type	Years	Details	#Rel	#Rec	Direct
Nesbit (S-tag)	1942-56	Internal — 35mm long, 10mm wide	98	5	Yes*
Nesbit (L-tag)	1942-56	Internal — 50mm long, 22mm wide	488	52	Yes*
W-tag	1942-56	External — white Peterson disc (16mm diameter, 1mm thick)	58	2	No
G-tag	1942-56	External — gray Peterson disc (16mm diameter, 1mm thick)	306	26	No
Roto	1987-02	External — 36 mm long, 9 mm wide	3057	763	Yes
Jumbo	1993-96	External — 45 mm long, 18 mm wide	1869	707	Yes
Mini	1995-96	External — 21 mm long, 5 mm wide	78	3	No
Dart – muscle	1991-96	External — 95 mm long, 2 mm diameter	1779	354	Yes
Dart – fin	1991-96	External — 95 mm long, 2 mm diameter	1252	194	Yes
Steel	1993-96	External — 140 mm long, 2 mm diameter	78	7	No
T-Bar	1986-90		84	7	No
A-Int	1994-96	Dummy archival tag – internal	5	1	No
A-Block	1994-96	Dummy archival tag – block	1	1	No
A-Torp	1994-96	Dummy archival tag – torpedo	4	1	No
Nesbit (MAFRI)	1973-76	Internal – white (equivalent to S-tag)	89	7	Yes*
Nesbit (MAFRI)	1973-76	Internal – yellow (equivalent to J / L tags)	1436	373	Yes*
Total			9581	2177	

Table 7.6 : Tag-shedding rates for gummy shark (yr^{-1}) with asymptotic standard errors in parenthesis. Results are shown separately for males and females. The column ‘$-\ell nL$’ lists the negative of the logarithm of the likelihood function corresponding to the estimates provided.

	N	Jumbo / Roto / Dart (fin)	Dart (muscle)	$-\ell nL$
Males	136	0.135 (0.036)	0.589 (0.091)	125.65
Females	156	0.066 (0.026)	0.811 (0.106)	120.28
Both	294	0.106 (0.023)	0.712 (0.070)	252.60

Table 7.7 : Length-frequency sample sizes for gummy shark (1970–2003).

(a) Females

Sub-region	Gear-type	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
WSA	Longline	0	0	0	82	170	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	8	0	28	0	0	0	0	0	0	0	0	0	0
WSA	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84	187	130	0	0	127	85	0
WSA	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88	0	0	303	1041	1362	854	618	0	109
WSA	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	98	222	41	0	90	2	1137	2928	706	906	706	1638	0	0	0	0	0	0
WSA	8	0	0	0	392	1015	0	76	0	0	0	0	0	0	0	0	0	73	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSA	Longline	0	0	0	0	65	395	0	0	0	0	0	0	0	0	0	6	171	38	50	42	0	22	0	0	0	0	0	0	0	0	0	733	0	9
CSA	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	592	642	168	240	58	284	0	140	0	235	199	0	110	0	0	336	495
CSA	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96	336	720	29	339	2690	5580	1833	2516	2813	1172
CSA	7	0	0	0	0	0	354	8	0	0	0	0	0	0	0	0	36	291	2858	1048	80	525	218	397	329	623	445	232	124	0	0	34	12	0	0
CSA	8	0	0	0	186	46	1131	603	0	0	0	0	0	0	0	0	0	0	25	4	0	0	0	80	0	28	0	0	0	0	0	0	0	0	0
SAV-W	Longline	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	11	29	105	139	0	0	45	0	0	0	43	0	0	0	0	0	118	0	0
SAV-W	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	173	226	53	172	0	387	37	0	0	0	74	0	0	0	180	605	130
SAV-W	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	406	19	0	0	71	925	305	0	454	1045
SAV-W	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76	994	472	76	114	5	247	5	224	40	0	0	0	0	0	0	0	0
SAV-W	8	0	0	0	0	8	0	1	0	0	0	0	0	0	0	0	0	0	0	180	0	0	0	0	0	136	0	0	0	0	0	0	0	0	0
WBas	Longline	0	107	0	49	86	324	388	0	0	0	103	26	0	20	0	5	25	0	15	77	25	0	17	110	128	40	0	0	0	0	10	0	0	0
WBas	6	0	0	0	577	1504	2407	3255	1996	1635	1927	1688	2374	4040	2268	272	959	432	590	801	476	586	559	264	883	919	435	487	247	1304	1182	342	516	110	219
WBas	6.5	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WBas	7	594	1039	1797	2702	332	71	2	0	0	103	74	175	246	77	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
WBas	8	0	0	0	0	0	0	330	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EBas	Longline	150	768	234	1114	2057	537	522	0	178	72	17	0	0	0	0	73	56	19	43	57	0	66	134	451	457	0	40	45	0	0	0	0	0	6
EBas	6	0	0	0	517	7878	11675	9580	4616	2878	2557	3688	6422	2974	2678	207	1968	1254	1042	2037	1676	2067	1848	1373	2950	1244	753	2017	1601	5231	3643	2575	3114	1007	725
EBas	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
WTas	Longline	2737	4464	4516	14666	1484	53	0	0	0	53	29	298	44	67	0	88	0	0	0	24	0	0	0	0	0	0	26	0	0	0	0	0	0	0
WTas	6	0	0	0	95	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	0	118	17	22	11	0	0	0	0	0	0	0
WTas	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	153	0	35	8	0	0	0	0	9
ETas	Longline	0	0	0	167	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	0	0	0	0	0	0	0
ETas	6	7	0	0	11	16	0	0	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	343	1	4	0	20	0	0	0	0	0	0	0
ETas	7	0	0	0	0	0	113	0	39	0	0	0	67	0	0	0	0	0	0	0	0	0	0	33	0	2	293	0	0	0	40	17	0	14	133
SAV-E	Longline	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	351	0	0	0	0	0	0	0
SAV-E	6	0	0	0	135	0	43	45	0	7	20	1	0	83	92	0	1	1	0	0	0	0	53	38	10	0	0	3	0	0	21	0	0	0	10
SAV-E	6.5	0	0	0	216	0	0	144	13	51	115	67	415	225	328	28	0	0	18	81	0	44	23	0	0	0	0	27	0	0	40	222	352	62	888
SAV-E	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
SAV-E	8	0	0	0	1033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0

(Table 7.7 Continued)

(a) Males

Sub-region	Gear-type	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
WSA	Longline	0	0	0	44	43	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	9	0	18	0	0	0	0	0	0	0	0	0	0
WSA	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	214	41	0	0	88	62	0
WSA	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84	0	0	190	805	883	454	340	0	41
WSA	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44	86	220	41	0	19	40	526	1354	703	959	497	529	0	0	0	0	0	0
WSA	8	0	0	0	438	179	0	59	0	0	0	0	0	0	0	0	0	147	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSA	Longline	0	0	0	0	22	337	0	0	0	0	0	0	0	0	0	1	102	37	51	7	0	17	0	0	0	0	0	0	0	0	0	243	0	6
CSA	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	420	830	269	177	40	179	0	185	0	123	84	0	30	0	0	131	132
CSA	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68	84	273	27	200	1346	2388	693	1265	1139	360
CSA	7	0	0	0	0	0	483	24	0	0	0	0	0	0	0	0	38	505	1745	692	192	561	144	250	153	498	679	181	17	0	0	28	0	0	0
CSA	8	0	0	0	77	9	298	297	0	0	0	0	0	0	0	0	0	0	5	7	0	0	0	13	0	17	0	0	0	0	0	0	0	0	0
SAV-W	Longline	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	3	15	22	140	0	0	9	0	0	0	22	0	0	0	0	0	24	0	0
SAV-W	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	187	103	243	0	170	9	0	0	0	31	0	0	0	37	177	19
SAV-W	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	119	8	0	0	30	271	104	0	128	266
SAV-W	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	235	368	132	95	9	57	0	70	6	0	0	0	0	0	0	0	0
SAV-W	8	0	0	0	0	7	0	2	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0
WBas	Longline	0	228	0	91	139	456	442	0	0	0	101	4	0	23	0	1	21	0	41	54	31	0	25	66	160	3	0	0	0	0	6	0	0	0
WBas	6	0	0	0	339	1940	2517	3021	2601	1673	1598	1414	1926	3298	1822	309	1188	883	1051	1359	970	934	1144	393	1514	1219	607	1029	253	2318	1780	1009	552	148	251
WBas	6.5	0	0	0	0	0	0	0	0	0	0	0	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WBas	7	1047	2673	4809	4038	266	46	9	0	0	88	55	104	186	65	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0
WBas	8	0	0	0	0	0	0	118	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EBas	Longline	285	1797	152	1660	3429	689	827	0	215	67	0	0	0	0	0	45	31	24	58	86	0	36	116	525	514	0	79	10	0	0	0	0	0	5
EBas	6	0	0	0	1292	9744	13411	10320	4699	2851	2163	3121	5300	2417	2170	205	1890	1198	1141	2255	1771	2376	1966	1579	3356	1380	734	2335	2361	6753	5067	3778	3078	1756	702
EBas	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
WTas	Longline	3325	4954	5881	16770	1663	48	0	0	0	43	19	237	32	47	0	51	0	0	0	29	0	0	0	13	0	0	42	0	0	0	0	0	0	0
WTas	6	0	0	0	22	44	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	0	112	2	25	18	0	0	0	0	0	0	0
WTas	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44	115	0	54	11	0	0	0	0	16
ETas	Longline	0	0	0	127	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	130	0	0	0	0	0	0	0
ETas	6	15	0	0	8	1	0	0	56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	323	0	6	0	19	0	0	0	0	0	0	0
ETas	7	0	0	0	0	0	227	0	58	0	0	0	54	0	0	0	0	0	0	0	0	0	0	118	0	6	701	0	0	0	24	38	0	130	93
SAV-E	Longline	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	466	0	0	0	0	0	0	0
SAV-E	6	0	0	0	96	0	15	9	0	5	9	1	0	68	74	0	0	0	0	0	0	0	34	5	2	0	0	9	0	0	9	0	0	0	3
SAV-E	6.5	0	0	0	56	0	0	102	7	23	76	31	293	178	259	0	0	0	22	38	0	27	35	0	0	0	0	18	0	0	34	86	380	78	460
SAV-E	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0
SAV-E	8	0	0	0	473	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0

Table 7.8 : Length-frequency information (parts per ten thousand) for gummy shark in Bass Strait and South Australia. Results are shown separately for males and females. The row 'No' indicates the number of animals measured for length in the year concerned.

(a) Bass Strait - Females – 6-inch mesh

Length	Year																													
Class	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
70	35	45	24	0	4	0	17	32	1	28	457	29	7	0	9	6	9	33	40	25	75	13	0	6	14	15	0	8	8	0
75	55	71	46	28	12	4	46	92	51	4	139	164	9	9	1	32	73	40	67	49	81	41	29	65	93	69	55	30	32	0
80	130	146	147	137	169	77	166	336	290	128	696	201	26	31	71	98	122	127	244	169	235	207	159	455	424	358	268	223	235	218
85	266	393	485	397	408	221	391	769	819	591	1592	291	142	473	443	659	575	416	668	469	630	653	473	1429	1172	849	682	861	951	796
90	416	778	1110	949	1130	760	788	1339	1525	1325	1625	758	657	952	1102	1794	1186	1269	1107	1092	1361	1593	1246	1903	1693	1541	1622	1779	1852	1624
95	803	1222	1506	1674	1391	1484	1217	1725	1916	1898	1297	1080	1355	1756	1816	2449	1923	1683	1776	1621	1891	1974	1922	2153	1662	1666	1859	2135	2152	1955
100	938	1416	1536	1813	1690	1692	1567	1779	1957	2057	779	1236	1633	1781	2050	2173	1821	1851	1740	1772	1760	1996	1889	1368	1498	1522	1764	1687	1793	1697
105	1168	1409	1291	1658	1500	1539	1514	1681	1565	1845	369	970	1622	1529	1535	1263	1430	1467	1399	1425	1314	1177	1492	945	1122	1221	1305	1102	1151	1403
110	1228	1191	992	1184	1180	1334	1343	956	957	1138	700	792	1275	1158	1004	666	1027	1009	1053	1057	909	830	943	556	775	870	811	765	670	731
115	1130	974	780	686	788	1065	953	533	476	593	685	690	868	689	718	289	522	707	685	823	595	515	762	302	506	646	467	514	482	537
120	987	783	667	527	549	683	693	264	202	231	791	428	552	481	475	206	441	448	342	534	299	372	453	227	315	402	293	279	220	308
125	812	534	461	332	417	431	514	191	84	111	566	529	374	368	299	92	220	288	252	375	274	191	276	169	215	282	223	167	124	262
130	591	364	388	225	243	332	300	94	44	33	157	610	321	306	172	67	132	140	196	218	174	157	109	142	177	200	149	128	90	136
135	508	244	287	155	168	161	197	67	39	18	109	452	228	150	79	36	129	116	156	135	145	123	72	91	143	136	155	97	16	104
140	386	160	127	98	114	99	133	55	37	0	6	374	212	77	52	17	116	80	100	84	102	55	52	63	69	51	85	78	32	126
145	246	129	68	52	71	76	57	37	14	0	24	327	149	54	74	11	64	66	57	62	47	15	29	58	41	37	78	30	50	47
150	148	67	34	40	75	17	40	15	21	0	0	302	167	32	29	32	55	78	54	26	52	68	23	6	20	35	70	47	32	12
155	77	33	23	30	43	13	28	11	1	0	0	278	114	56	15	28	29	49	13	16	9	14	25	10	29	24	15	17	8	12
160	44	25	17	4	32	12	12	9	1	0	0	227	68	47	23	28	19	40	27	23	32	2	8	15	15	23	27	14	17	7
165	16	6	8	5	6	0	10	6	1	0	0	88	96	10	25	50	26	26	3	3	2	2	15	30	7	23	18	29	42	0
170	10	4	1	7	10	1	10	6	1	0	2	73	55	1	4	0	9	9	7	10	0	1	14	0	6	21	15	3	25	0
175	7	2	0	0	0	0	2	1	0	0	6	43	22	1	0	6	31	19	13	13	7	0	5	0	6	6	24	6	0	24
180	1	1	1	1	0	0	0	1	0	0	0	57	48	38	4	0	41	38	0	0	7	1	2	8	0	3	15	3	17	0
No	9382	14082	12835	6612	4513	4484	5376	8796	7014	4946	479	2927	1686	1632	2838	2152	2653	2407	1637	3833	2163	1188	2504	1848	6535	4825	2917	3630	1117	944
Ave Length	111.6	105.6	103.7	102.5	103.4	104.7	104.7	98.4	97.3	98.3	96.1	112.5	108.5	103.3	101.6	97.4	101.4	102.3	100.8	102.1	99.8	98.9	100.6	95.8	97.8	99.6	99.9	98.3	97.4	99.2

(Table 7.8 Continued)

(b) Bass Strait - Males – 6-inch mesh

Length	Year																													
Class	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
70	24	44	25	3	6	5	3	22	0	0	1893	66	17	0	4	1	0	36	12	15	64	13	0	8	10	24	0	0	0	12
75	53	60	48	28	38	8	24	68	8	0	0	125	20	17	9	32	27	47	95	40	48	39	44	40	73	52	19	22	46	30
80	125	168	175	136	191	67	142	287	158	22	231	167	31	42	91	49	132	185	252	108	163	147	118	361	274	236	141	168	274	139
85	218	415	547	377	406	311	454	747	681	347	877	262	162	387	297	415	508	421	474	353	535	640	430	974	904	730	505	806	761	574
90	435	846	1151	962	1245	954	986	1456	1600	1297	1674	699	742	997	1049	1548	1141	940	1213	812	1116	1088	1213	1721	1506	1351	1230	1419	1557	1375
95	796	1307	1591	1715	1529	1668	1403	1774	2144	2082	2424	1018	1099	1731	1662	2290	1689	1686	1856	1368	1603	1875	1782	1919	1745	1572	1749	1912	1937	2100
100	1008	1495	1550	1878	1782	1583	1539	1903	2161	2263	1341	1298	1714	1795	1969	2182	1878	1798	1781	1659	1636	1871	1806	1562	1625	1488	1578	1652	1765	1931
105	1318	1509	1346	1661	1689	1509	1647	1704	1693	2009	619	1163	1824	1406	1660	1392	1653	1790	1374	1550	1490	1440	1364	1127	1245	1278	1484	1417	1282	1427
110	1407	1232	990	1216	1066	1481	1378	1018	882	1222	256	1148	1459	1175	1278	909	1065	1126	1130	1237	1022	1052	1020	819	924	995	1033	861	977	886
115	1349	982	828	734	782	958	897	431	363	517	239	992	1069	799	781	485	731	765	690	1020	788	719	765	553	577	711	741	686	572	674
120	1104	749	629	542	528	632	636	260	133	175	185	485	718	660	526	297	425	459	404	746	537	394	583	447	445	573	566	445	382	444
125	887	521	477	379	386	378	471	145	71	41	48	575	371	462	287	138	293	271	387	485	380	337	426	255	291	382	434	308	186	281
130	607	294	284	210	199	286	211	91	46	26	46	535	229	226	172	53	138	190	133	227	265	158	224	122	149	286	224	158	109	102
135	304	194	219	79	85	100	129	50	40	0	46	404	189	140	118	26	99	104	104	189	166	103	132	37	112	162	153	86	89	6
140	169	95	83	51	37	25	48	29	10	0	46	335	74	88	53	30	79	95	60	118	61	80	55	33	66	83	84	31	54	6
145	99	50	37	18	20	16	15	13	4	0	62	210	68	46	26	50	34	48	28	56	54	40	14	6	31	41	20	22	0	12
150	50	16	10	9	13	9	11	1	4	0	5	146	102	18	6	48	52	15	0	14	15	1	13	2	15	11	19	3	5	0
155	33	12	3	1	1	0	3	1	0	0	0	104	30	8	12	38	27	16	0	3	0	0	9	4	2	9	12	6	5	0
160	6	4	3	1	0	1	3	0	4	0	0	104	42	1	1	7	12	9	6	0	20	1	2	6	3	12	2	0	0	0
165	7	4	3	0	0	8	0	0	0	0	2	69	17	0	0	5	0	0	0	0	26	0	0	2	1	1	2	0	0	0
170	2	2	0	0	0	1	0	0	0	0	3	35	8	0	0	5	8	0	0	0	7	0	0	0	0	0	0	0	0	0
175	0	1	0	0	0	0	0	0	0	0	3	25	15	0	0	0	8	0	0	0	0	0	0	0	0	0	4	0	0	0
180	0	1	0	0	0	0	0	0	0	0	0	35	0	0	0	0	0	0	0	0	7	1	0	0	0	3	0	0	0	0
No	11684	15928	13341	7300	4524	3761	4535	7226	5715	3992	514	3078	2081	2192	3614	2741	3310	3110	1972	4870	2599	1341	3364	2614	9071	6847	4787	3630	1904	953
Ave Length	109.4	103.9	102.2	101.7	101.2	102.9	102.7	97.8	97.1	98.6	89.9	109.5	105.8	102.8	101.8	98.9	101.3	101.5	100.1	104.0	101.9	100.4	101.5	97.5	98.9	101.0	101.8	99.3	98.3	98.9

(Table 7.8 Continued)

(c) Bass Strait – 7-inch mesh

	Males					Females				
Length	Year									
Class	1970	1971	1972	1973	1974	1970	1971	1972	1973	1974
70	61	54	7	6	3	32	68	8	6	7
75	143	90	11	8	0	149	109	22	15	3
80	359	265	24	15	6	347	255	58	31	21
85	561	471	88	85	43	556	418	97	77	63
90	862	751	195	204	344	685	809	217	182	405
95	992	862	339	399	556	965	1031	361	377	571
100	1064	1021	607	648	813	1129	1302	662	587	844
105	1116	1144	839	932	1126	1144	1377	937	868	1139
110	1057	1219	1203	1316	1489	1071	1299	1316	1211	1200
115	860	1080	1490	1520	1337	862	1100	1401	1312	938
120	875	988	1614	1627	1392	646	932	1401	1247	889
125	754	774	1482	1383	938	518	464	1200	1120	1052
130	513	590	1067	955	844	385	371	795	905	773
135	285	359	584	524	497	370	163	608	765	624
140	192	196	269	247	185	298	98	378	540	396
145	113	63	94	86	138	220	86	261	339	338
150	87	41	43	34	43	196	52	123	188	247
155	49	15	22	8	117	185	35	65	110	148
160	43	11	14	2	65	121	14	48	65	203
165	14	0	2	1	65	68	12	27	36	110
170	0	0	6	0	0	33	3	14	12	25
175	0	6	0	0	0	19	0	0	2	3
180	0	0	0	0	0	0	4	1	6	0
No	4372	7627	10690	20808	1929	3331	5503	6313	17368	1816
Ave length	105.9	107.0	115.4	114.5	113.7	108.5	104.9	115.7	117.7	116.5

(Table 7.8 Continued)

(d) South Australia (7-inch mesh catches)

Length Class	Females									Males								
	1986	1987	1988	1990	1992	1993	1994	1995	1996	1986	1987	1988	1990	1992	1993	1994	1995	1996
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	0	0	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	32	27	17	97	19	0	16	18	0	0	10	39	120	0	0	0	0	0
85	96	33	69	129	101	0	0	0	0	0	40	105	135	65	1	0	12	36
90	32	164	260	772	731	1	56	82	28	0	115	263	572	336	1	113	80	0
95	128	356	555	885	832	0	135	122	24	37	354	539	783	1003	4	170	30	86
100	71	633	1119	981	1315	130	452	366	114	18	488	1051	925	1059	294	411	188	216
105	128	952	1275	970	1191	219	740	781	176	37	812	1406	1007	1380	706	681	772	266
110	158	974	1266	1203	1077	397	1071	1076	492	100	957	1301	1194	1420	834	1105	1615	857
115	714	1004	1124	884	938	1017	1072	1047	778	701	1032	1131	1291	1418	1662	1829	1809	1711
120	2351	1004	1108	1113	859	889	1331	1015	1601	1948	1287	1368	975	1348	1703	1617	1968	1922
125	1966	1300	976	963	768	1363	1183	1357	1489	1764	1771	967	1007	1015	2550	1689	1626	1922
130	760	1274	682	611	454	705	806	1220	1623	809	1390	602	602	400	995	915	1119	1560
135	900	819	495	384	461	835	680	1033	875	1274	720	612	271	167	529	250	563	722
140	380	455	293	278	445	934	575	512	963	944	393	171	456	124	546	204	85	502
145	758	284	222	197	316	1046	441	616	920	1036	216	210	196	82	57	260	71	136
150	451	293	191	113	171	889	375	249	404	627	223	131	166	88	57	173	23	64
155	426	148	121	66	121	727	294	151	391	348	45	66	120	40	0	198	25	0
160	398	94	121	97	57	337	329	147	86	229	21	26	105	28	1	148	7	0
165	67	55	87	80	30	180	234	150	20	24	11	13	30	9	0	94	7	0
170	35	55	17	80	81	195	72	18	15	16	25	0	0	19	53	94	0	0
175	60	33	0	32	20	55	88	20	0	16	48	0	45	0	0	47	0	0
180	90	42	0	17	13	81	50	20	0	71	45	0	0	0	6	3	0	0
No	389	3080	1089	615	1534	3257	1329	1351	938	591	1965	733	580	776	1507	1201	1638	678
Ave length	127.8	119.8	114.6	112.1	112.5	132.8	124.2	122.8	127.5	130.1	119.2	112.8	112.7	110.1	119.5	119.5	117	120.2

(Table 7.8 Continued)

(e) South Australia (6.5-inch mesh catches)

Length Class	Females							Males						
	1997	1998	1999	2000	2001	2002	2003	1997	1998	1999	2000	2001	2002	2003
70	0	0	0	4	0	4	0	0	0	2	11	6	0	0
75	0	0	3	0	0	4	0	0	0	8	11	6	0	0
80	0	3	19	8	11	36	17	0	6	22	11	17	35	0
85	0	96	80	34	74	146	133	0	57	115	56	74	132	38
90	23	267	330	202	303	530	503	40	238	355	166	372	413	264
95	0	660	719	611	641	1120	775	277	525	675	549	681	1001	433
100	348	1108	1153	987	1064	1610	949	501	1112	1115	997	1014	1501	414
105	328	1260	1354	1359	1275	1671	1012	534	1251	1397	1371	1366	1554	772
110	599	1248	1335	1296	1158	1482	1199	1139	1528	1452	1807	1572	1484	1510
115	1190	1201	1093	1212	1070	953	1049	2009	1603	1494	1501	1444	1282	1504
120	1755	937	887	857	816	651	716	1978	1196	1288	1352	1483	966	1237
125	1441	802	691	713	628	487	438	1749	1151	859	1010	883	667	1438
130	1098	640	593	644	577	320	580	839	766	581	641	667	465	1595
135	980	445	462	459	526	263	374	367	346	300	242	245	263	443
140	874	349	327	458	631	220	533	444	132	182	110	87	79	254
145	565	265	267	265	343	128	146	123	51	80	48	51	44	19
150	393	282	230	251	364	121	529	0	34	38	82	23	61	79
155	111	220	160	235	216	92	565	0	0	25	33	0	35	0
160	158	112	111	141	94	57	223	0	6	12	0	6	18	0
165	77	62	72	94	87	53	176	0	0	0	0	0	0	0
170	60	14	47	57	89	18	76	0	0	0	0	6	0	0
175	0	11	27	35	18	18	6	0	0	0	0	0	0	0
180	0	17	42	76	14	18	0	0	0	0	0	0	0	0
No	642	3731	6942	2687	3134	2813	1281	390	2151	3271	1147	1605	1139	401
Ave length	124.9	114.9	114.2	116.5	116.5	108.4	117.3	116.7	111.7	110.4	111.4	110.3	108.0	115.4

Table 7.9 : Number of gummy sharks collected and aged (1973–93).

(a) Males

Region	Mesh size	Year 1973	1974	1975	1986	1987	1990	1991	1992	1993
Bass Strait	6	18	10	15	76	27	83	141	70	184
Bass Strait	6.5	3	0	19	143	90	0	0	0	0
Bass Strait	7	13	11	4	27	7	0	0	0	6
Bass Strait	8	2	0	0	7	2	0	0	0	0
South Australia	6	0	0	0	29	5	35	11	37	12
South Australia	6.5	0	0	0	53	15	5	0	25	33
South Australia	7	0	0	0	23	4	10	0	81	69
South Australia	8	0	0	0	8	0	0	0	0	0
Tasmania	6	0	0	0	0	0	11	11	0	17

(b) Females

Region	Mesh size	Year 1973	1974	1975	1986	1987	1990	1991	1992	1993
Bass Strait	6	24	7	12	72	39	43	179	68	190
Bass Strait	6.5	0	0	7	139	114	0	0	0	0
Bass Strait	7	36	30	4	20	11	0	0	0	10
Bass Strait	8	6	0	7	19	4	0	0	0	0
South Australia	6	0	0	0	93	11	77	58	113	14
South Australia	6.5	0	0	0	97	20	12	0	28	59
South Australia	7	0	0	0	56	6	54	0	79	76
South Australia	8	0	0	0	46	5	0	0	0	0
Tasmania	6	0	0	0	0	0	5	10	0	14

Table 7.10 : Age-composition data for gummy shark. Results are shown separately for males and females. The row ‘No’ indicates the number of animals aged in the year concerned.

(a) Bass Strait – 6-inch mesh

	Females						Males					
Year / Age	1986	1987	1990	1991	1992	1993	1986	1987	1990	1991	1992	1993
1	0	2	0	0	1	0	0	0	0	0	2	0
2	13	8	4	4	12	11	10	1	5	6	9	11
3	18	12	11	28	19	75	28	8	24	31	12	51
4	22	13	5	31	15	54	23	9	19	37	17	60
5	7	2	9	28	10	29	12	5	17	34	11	33
6	6	2	6	24	4	10	1	3	7	13	11	21
7	2	0	4	17	3	6	1	0	7	8	6	6
8	3	0	0	23	1	2	0	1	1	6	1	1
9	0	0	1	10	1	2	0	0	1	5	0	1
10+	1	0	3	14	2	1	0	0	2	1	1	0
No	72	39	43	179	68	190	76	27	83	141	70	184

(b) South Australia – 7-inch mesh

	Females					Males				
Year / Age	1986	1987	1990	1992	1993	1986	1987	1990	1992	1993
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	1	1
3	1	0	1	3	0	1	0	1	18	5
4	6	0	2	19	9	1	0	0	14	19
5	11	1	11	10	14	4	0	1	19	24
6	8	0	8	18	18	2	0	3	13	12
7	12	0	15	13	11	2	0	0	6	3
8	7	1	8	8	8	6	4	3	6	2
9	3	3	5	6	4	4	0	2	4	2
10+	8	1	4	2	12	3	0	0	0	1
No	56	6	54	79	76	23	4	10	81	69

Table 7.11 : Results of the base-case assessment and those of the sensitivity tests.

Scenario	SB_0		M_2	*MSYR*		SB_{73}/SB_0 (%)		SB_{99}/SB_0 (%)		SB_{04}/SB_0 (%)		$-\ell nL$
	BS	SA	(yr^{-1})	BS	SA	BS	SA	BS	SA	BS	SA	
Base-case	3819	2891	0.231	0.153	0.164	60.0	64.3	43.6	42.3	40.7	34.5	730.9
Alt catches	4425	3233	0.229	0.137	0.147	57.8	60.2	40.8	40.0	38.5	32.0	730.3
$\sigma_j = 0.3$	3896	2942	0.234	0.144	0.154	59.9	64.6	42.4	42.1	37.7	33.9	714.3
No length / age data	3845	2383	0.243	0.147	0.157	65.4	53.4	34.4	24.2	32.3	17.4	205.8
No tagging data	3896	2942	0.234	0.144	0.154	59.9	64.6	42.4	42.1	37.7	33.9	714.3
$\sigma_R = 0.3$	4091	2942	0.227	0.149	0.161	63.3	63.7	43.1	41.4	40.0	35.0	747.0
$\sigma_R = 0.5$	3605	2868	0.234	0.155	0.167	56.8	65.0	44.0	42.9	41.4	34.0	719.4
30 day early recaptures	3480	2618	0.237	0.164	0.176	59.0	63.1	42.0	39.9	39.6	33.5	708.3
120 day early recaptures	4378	3323	0.222	0.138	0.148	61.3	66.0	46.7	45.6	43.2	36.1	759.4
Alter effort relationship	3679	3022	0.222	0.184	0.199	60.6	67.7	47.7	45.8	43.1	49.4	759.2
Uniform availability	1958	1547	0.300*	0.197	0.212	46.5	56.3	30.3	30.0	29.1	24.7	797.8
Dens-dep M (ages 0-4)	5744	4321	0.179	0.141	0.154	51.6	54.6	29.0	32.0	26.4	22.0	735.4
Dens-dep pups	5271	4296	0.172	0.099	0.091	54.0	58.5	31.6	33.3	27.5	21.6	732.7
Deterministic recruitment	3333	2465	0.246	0.162	0.174	58.7	62.4	43.7	41.5	39.4	33.3	744.6
No 7” mesh lengths in BS	4877	3355	0.219	0.120	0.128	70.8	61.7	35.1	36.6	32.5	27.0	664.7

* Bound

APPENDIX 7.A : Revised Standardized Catch-Rate Series for School and Gummy Shark

7.A.1 Introduction

One of the key inputs to the assessments of school and gummy shark are time-series of standardized catch-rate data. The approach of Punt *et al.* (2000) is used to standardize the SSF catch and effort data to remove the impact of changes over time in the spatial distribution of the fishery, seasonal changes in availability, and changes over time in the composition of the fleet.

The methodology on which this standardization exercise is based is described in several previous SharkFAG documents and has evolved over time. This document therefore first summarizes the current methodology, and then applies it to determine catch-rate indices for school and gummy shark based on data until the end of 2003.

The nature of catch-effort standardization is such that inclusion of new data can lead to changes in historical indices of abundance. For example, when determining the probability of obtaining a zero catch, it is assumed that there is a “statistical cell effect” and that this effect has not changed over time relative to how this effect has changed over time for other statistical cells. Furthermore, additional data may mean that the standardized catch-rate series is based on a different set of vessels because some vessels no longer satisfy the criteria for inclusion while other vessels that did not before now do. To examine whether changes to the data have led to notable changes to the catch-rate indices, the updated catch-rate series are contrasted with the results from previous catch-effort standardization exercises.

7.A.2 Methodology

The approach of Punt *et al.* (2000) involves first developing a set of criteria to identify those operators whose catch and effort data should provide useful information about trends in the abundance of gummy or school shark. For example, the catch-rates for operators who catch shark during periods when rock lobsters are unavailable to them or incidentally take school or gummy shark as part of other targeted fishing operations are unlikely to provide reliable information about changes over time in abundance. The criteria selected by SharkFAG to identify ‘indicative’ shark fishers are summarized in Table 7.A.1. Table 7.A.2 lists the further restrictions imposed on the data at the level of monthly catch and effort (by statistical cell, depth zone, and vessel). The data are generally analyzed at the level of statistical cell but some statistical cells are combined with other statistical cells due to lack of detailed catch and effort data or are excluded altogether (e.g. the cells in the South Australian Gulfs are ignored when standardizing the catch and effort data for school shark). Table 7.A.3 lists all the statistical cells for which data are available and how each is treated during the standardization procedure.

The data for the selected vessels are standardized using a “delta” approach (Lo *et al.*, 1992; Stefánsson, 1996; Punt *et al.*, 2000). The questions of whether a catch rate is zero or not, and the size of a non-zero catch rate are therefore treated separately. The non-zero catch rates are modeled using a negative binomial error model and whether the catch rate is zero or not is modeled as a Bernoulli random variable. The factors considered when modeling whether the catch is zero are year, statistical cell, vessel and month. The factors considered when modeling the non-zero catch rates are year, depth[8], statistical cell, vessel, month and the interaction between year and statistical cell. Other factors and interactions (e.g. the factor 'region' and the interaction between year and month) were examined in the past, but found not to be significant. The results from fitting these models are used to compute time-series of standardized catch rate for each statistical cell and these are combined by weighting them by a proxy for the shark 'habitat area' of each statistical cell (the area of each cell between 20 and 80m for gummy shark and the area shallower than 200m for school shark) to obtain a single catch-rate time-series for each species for Bass Strait and South Australia.

There are some combinations of year and statistical cell for which data are unavailable (because, for example, none of the selected vessels fished in them during those years). Rules were therefore used to interpolate missing values for the catch-rate index for year y and statistical cell b, $I_{y,b}$ [9]:

a) For gummy shark and for school shark except in the western South Australia region[10], the rule used to specify $I_{y,b}$ if catch-rate estimates are not available for statistical cell b for any year prior to year y is:

$$I_{y,b} = \frac{\sum_{y^* \in highest 3} I_{y_*,b}(y_* - y)^{-2}}{\sum_{y^* \in highest 3} (y_* - y)^{-2}} \qquad \text{(A.1)}$$

where $\sum_{highest\ 3}$ indicates summation over the three highest catch rates.

$I_{y,b}$ is set to the maximum catch-rate if catch-rates are missing for all years prior to year y for school shark for the cells in the western South Australia region.

b) If catch-rate estimates are available for statistical cell b for at least one year prior to year y but not thereafter, $I_{y,b}$ is set equal to the arithmetic average standardized catch rate for the last three years for which catch-rate estimates are available.

c) If neither rule a) nor b) is applicable then standardized catch-rate estimates are available for earlier and later years than year y. The value for $I_{y,b}$ is then set using linear interpolation of the standardized catch-rates for the nearest years before and after year y for which data are available.

7.A.3. Results and discussion

7.A.3.1 The updated catch-rate standardization

Tables 7.A.4 and 7.A.5 summarize the selection of records in terms of whether the raw data are reported at a sufficient level of resolution for possible inclusion in the catch-

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[8] For gummy shark in Bass Strait only.

[9] This set of rules is that currently employed. These rules have been modified over time based on comments by SharkFAG.

[10] This exception was selected by SharkFAG.

effort standardization[11]. Results are shown separately for school and gummy shark *inter alia* because the catch-effort standardization for school shark ignores the SAV region (Table 7.A.3). As expected from previous catch-effort standardizations, the vast bulk of the data from 1995 can be included in the catch-effort standardization exercise[12]. It is noteworthy that the data for South Australia were poorer in 2000 than in 1999, 2001, 2002 and 2003. The bulk of the data for Tasmania since 1995 are reported at a sufficient level of resolution for inclusion in a catch-effort standardization.

Table 7.A.6 summarizes the selection of vessels for use in the catch-rate standardization. This table provides information on the total number of (monthly) records considered, how many vessels were included, their total catch and (average across vessel) median annual catch (of the species for which catch and effort data are being standardized), and the fraction that the total catch included in the catch-effort standardization constitutes of the total catch over all the years included in the catch-effort standardization. Two sets of results are supplied for gummy shark. This is because, in contrast to the case for South Australia, when selecting vessels for Bass Strait, the 60% constraint (see Table 7.A.1) is applied.

The number of indicative vessels for the current catch-effort standardization for school shark is the same as that on which the analyses of Punt and Pribac (2002) are based although the average number of years in the fishery is higher. The number of vessels on which the gummy shark catch-effort standardization is based is higher than for the last two analyses (Punt *et al.*, 2001; Punt and Pribac 2002). The percentage of the total catch of gummy shark included in the standardization is also higher than in the previous analysis – this probably reflects the increasing (average) quality of the data.

Table 7.A.7 lists the frequency with which it was necessary apply rules a) – c) to specify catch-rates for cell-year combinations for which data are missing. Consistent with the results from previous catch-effort standardizations, these rules are used most for the cells in the SAV region and those in the South Australian Gulfs.

The updated standardized catch-rate indices are shown in Figures 7.A.1 and 7.A.2 (school and gummy shark respectively). Standardized catch-rates for school shark have been relatively stable over the last six years (WSA, CSA and EBas regions). However, the catch-rate indices for the last six years are only a few percentage points of the catch-rates in the 1980s (Figure 7.A.1).The standardized catch-rate for gummy shark for western South Australia in 2001 is the highest on record while the standardized catch-rates for central South Australia have remained stable (Figure 7.A.2). The net effect of the trends in western and central South Australia is an increase in standardized catch-rate for gummy shark over 1999–2003 for South Australia overall. There is little evidence for increasing or decreasing trends since 1995 in western Bass Strait and eastern Bass Strait, which is reflected in the standardized catch-rate index for the whole of Bass Strait.

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[11] The results in Tables 7.A.4 and 7.A.5 for 2003 are restricted to data for Commonwealth-licensed operators only.

[12] But may, of course, be excluded if the vessels which took the catches do not satisfy the criteria in Table 7.A.1.

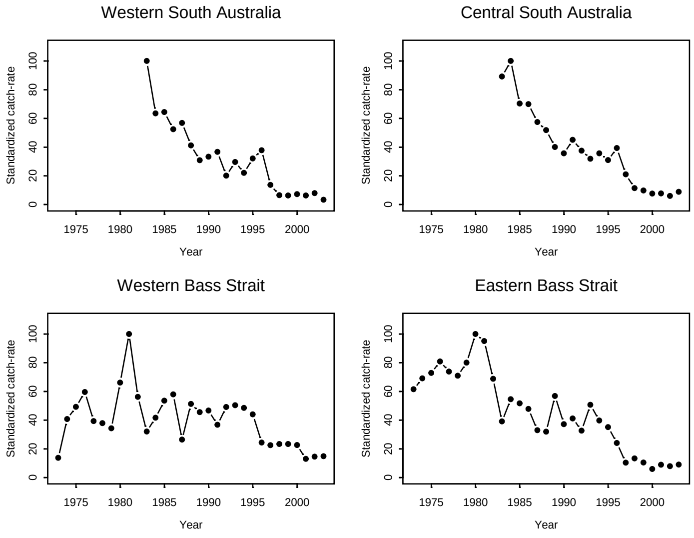

Figure 7.A.1 : Standardized catch-rate series for school shark based on data for 1973–2003.

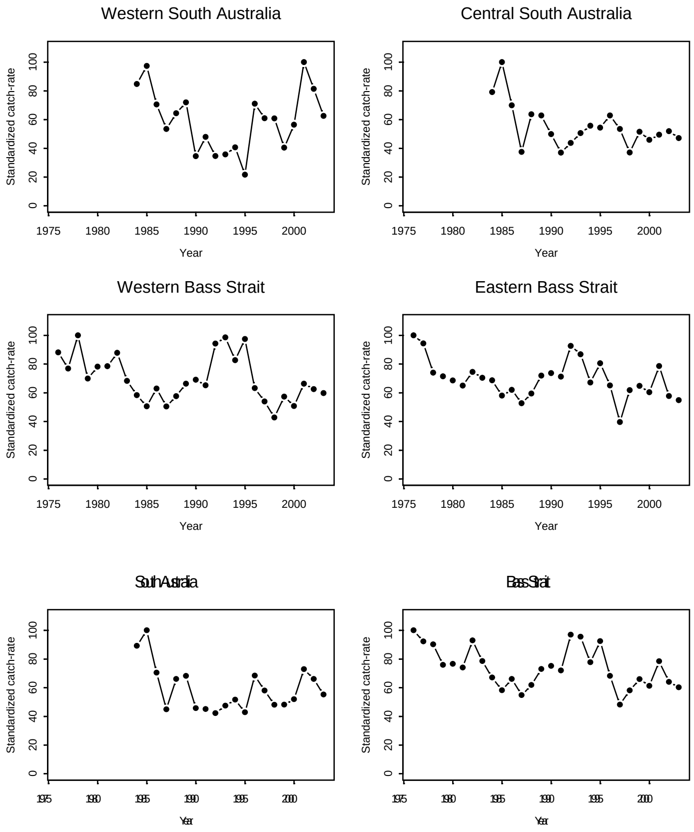

Figure 7.A.2 : Standardized catch-rate series for gummy shark based on data for 1976–2003.

7.A.3.2 Retrospective analysis

Figure 7.A.3 shows the time-trajectories of standardized catch-rate for school shark from the present analysis, those based on the analyses of Punt and Pribac (2002), and those on which the 1999 and 2001 assessments of school shark were based. Figure 7.A.4

shows the time-trajectories of standardized catch-rate for gummy shark from the present analysis, those based on the analyses of Punt and Pribac (2002) and those on which the 2000 assessment of gummy shark were based. The final years for which data were available for the 1999 and 2001 school shark assessments were 1997 and 1999 and the final year for which data were available for the 2000 gummy shark assessment was 1998. The final year for the analyses of Punt and Pribac (2002) was 2001.

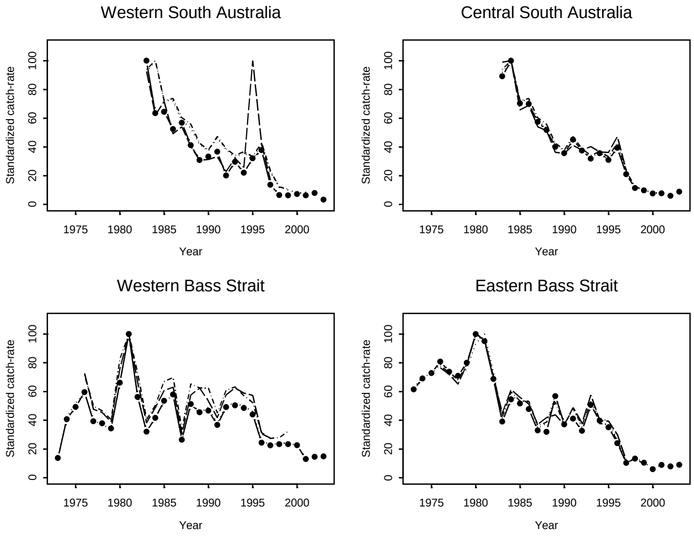

Figure 7.A.3 : Retrospective evaluation of the results of standardizing the catch and effort data for school shark (analyses based on data for 1973–1997, 1973–1999, 1973–2001, and 1973–2003; dashed, dotted and solid lines respectively).

With the notable exception of the 1995 point for school shark in western South Australia (which was eventually shown to be an error in the database) and the impact of the 2001 data point for gummy shark in western South Australia being the largest on record (and hence rescaling the series), there is little evidence for restrospective patterns in the time-series of standardized catch-rate.

The lack of inconsistency in the time-series of standardized catch-rate is pleasing. It suggests that the addition of new data (in this case for 2002 and 2003) is not leading to changes to the values for parameters for the years prior to 2001 and that the new data are not updating the values for parameters that are common across years markedly. The analyses for 2003 are based on the new database, and the similarity of the indices up to 2001 with those up to 2003 indicate that the new and old databases are highly comparable.

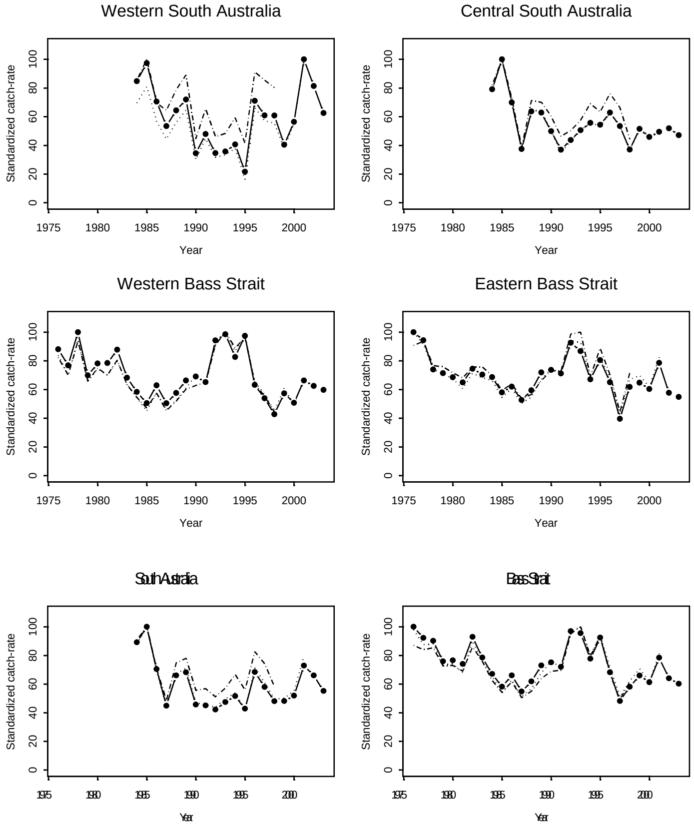

Figure 7.A.4 : Retrospective evaluation of the results of standardizing the catch and effort data for gummy shark (analyses based on data for 1976–1998, 1976–2001, 1976–2003; dashed, dotted and solid lines respectively).

Table 7.A.1. The criteria used to select 'indicative' shark fishers.

Criterion	School shark	Gummy Shark
Years included		
South Australia	1983–2003	1984–2003
Bass Strait	1973–2003	1976–2003
Tasmania	N/A	N/A
Minimum median annual catches		
Total (school and gummy) shark	10 t	10 t
School shark	5 t	N/A
Gummy shark	N/A	5 t
Minimum years with data	5	5
Minimum percentage gummy shark		
South Australia	N/A	0
Bass Strait	N/A	60%
Maximum fraction gummy=school catches		
South Australia	25%	25%
Bass Strait	99%	99%
Minimum usable monthly records per vessel [A]	20	20

A – after excluding records for the reasons outlined in Table 7.A.2.

Table 7.A.2. The criteria used to select records for use in the catch effort standardization.

Criterion	School shark	Gummy Shark
Years included		
South Australia	1983–2003	1984–2003
Bass Strait	1973–2003	1976–2003
Tasmania	N/A	N/A
Gear types	6-, 6.5-, 7-inch mesh	6-, 6.5-, 7-inch mesh
Must have a depth		
Bass Strait	No	Yes
South Australia	No	No
Use 0 school shark catches between 20 and 40m	No	Yes
Minimum effort (gillnet m-lifts)	N/A	1000m

Table 7.A.3. Statistical cells and their treatment in the catch-effort standardization. The symbol '& x' indicates that the data for the cell concerned are pooled with those for cell x.

Cell	**School Shark**	**Gummy Shark**	**Cell**	**School Shark**	**Gummy Shark**
4	Not used [A]	Used	101	& 104	& 104
5	Not used [A]	Used	102	& 105	& 105
6	Used	Used	103	& 106	& 106
7	Used	Used	104	Used	Used
8	& 7	Used	105	Used	Used
9	& 7	Used	106	Used	Used
10	Used	Used	107	Used	Used
11	& 10	Used	108	& 107	& 107
12	& 10	& 10	112	Used	Used
13	& 10	& 10	113	& 112	& 112
18	Used	Used	114	& 112	& 112
19	& 18	Used	115	Used	Used
20	Used	Used	122	Not Used	Used
21	Used	Used	126	Used	Used
22	Used	Used	128	Used	Used
23	& 22	Used	129	& 139	Used
30	Used	Used	132	Not used	Used
31	& 30	Used	136	Not used	Used
32	Used	Used	138	Used	Used
33	Used	Used	139	Used	Used
34	Used	Used	140	Not used	Used
35	Used	Used	144	Not used	Used
41	Not used [B]	Not used [B]	148	Used	Used
42	Not used [B]	Not used [B]	149	Used	Used
48	Not used [B]	Not used [B]	150	Used	Used
49	Not used [B]	Not used [B]	151	Not used [A]	Used
54	Not used [B]	Not used [B]	155	Not used [A]	Used
55	Not used [B]	Not used [B]	158	Not used [A]	Used
56	Not used [B]	Not used [B]			

A: The data for the SAV region are not used when standardizing the catch and effort data for school shark.
B: The data for Tasmania are excluded from consideration in the analyses of this document.

Table 7.A.4. Reported catches of gummy shark, total number of catch-effort records, and the percentage of the reported catch of gummy shark rejected for use in the standardization of the catch and effort data for the three reasons listed in the text.

(a) South Australia (WSA, CSA and SAV-W)

Year	Number of records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1976	845	71.3	0.00	0.00	4.90	95.10
1977	897	162.5	20.51	0.00	68.16	31.81
1978	808	176.6	19.20	0.00	79.99	19.92
1979	557	207.0	11.27	0.00	92.86	7.14
1980	664	305.2	5.10	0.00	93.82	6.18
1981	694	293.6	7.99	0.00	92.80	7.20
1982	649	276.6	7.43	0.00	96.32	3.68
1983	697	246.2	15.42	0.00	53.76	37.17
1984	1001	417.7	8.72	0.00	0.10	91.17
1985	1131	415.9	22.04	0.00	0.06	77.90
1986	1523	462.2	7.68	0.00	0.04	92.29
1987	2153	520.8	4.13	0.00	0.00	95.87
1988	2131	584.1	3.06	0.00	0.00	96.94
1989	1947	640.8	2.54	0.00	0.05	97.45
1990	2279	529.7	6.00	0.00	1.24	92.80
1991	2406	460.3	6.99	0.00	0.89	92.93
1992	2364	412.4	7.35	0.00	0.42	92.48
1993	2117	413.7	1.81	0.00	0.27	97.92
1994	1937	431.7	2.70	0.00	0.14	97.17
1995	1937	385.0	1.53	0.00	1.53	98.47
1996	1748	500.4	0.80	0.00	0.80	99.20
1997	6924	637.5	6.16	0.00	14.19	80.68
1998	9944	480.0	3.89	0.00	1.01	96.02
1999	8350	546.2	2.36	0.00	1.09	97.53
2000	6596	469.3	18.12	0.00	1.03	81.87
2001	6540	386.7	3.53	0.00	2.62	95.91
2002	5539	372.0	0.48	0.00	2.03	97.78
2003 *	6152	463.2	0.00	0.00	0.22	99.78

* Excludes State catches

(Table 7.A.4 Continued)

(b) Bass Strait (EBS, WBS and SAV-E)

Year	Number of records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1976	3795	758.1	3.07	0.00	23.55	76.17
1977	4019	872.9	7.07	0.00	17.78	82.06
1978	4206	791.8	9.17	0.00	14.97	80.81
1979	4165	673.8	21.18	0.00	13.60	73.23
1980	4652	761.5	22.94	0.00	12.07	73.47
1981	4319	851.7	35.94	0.00	27.28	62.35
1982	5229	972.2	24.93	0.00	22.45	72.39
1983	5435	1007.5	37.17	0.00	31.46	62.80
1984	5241	973.1	42.96	0.00	35.26	57.03
1985	5769	942.6	46.72	0.00	38.12	52.55
1986	6148	1013.2	39.63	0.00	36.45	55.09
1987	6342	900.6	45.35	0.00	38.54	52.85
1988	7143	802.2	26.43	0.00	28.70	65.57
1989	6642	993.0	36.12	0.00	40.56	52.15
1990	5568	849.5	32.36	0.00	27.90	66.42
1991	7740	944.5	21.48	0.00	24.26	66.28
1992	7255	1060.2	16.30	0.00	13.13	76.87
1993	7088	1213.8	19.23	0.00	16.78	71.79
1994	6633	870.3	19.15	0.00	18.27	75.19
1995	7734	1073.9	1.82	0.00	0.00	98.18
1996	9748	836.9	0.54	0.00	0.54	99.46
1997	9752	752.3	4.41	0.00	2.47	94.47
1998	8856	845.6	2.48	0.00	2.29	97.52
1999	10313	1075.7	1.89	0.00	1.65	98.11
2000	9801	1098.9	1.35	0.00	1.45	98.33
2001	8350	1236.6	1.04	0.00	0.75	98.96
2002	7404	1015.7	0.17	0.00	1.09	98.77
2003 *	7954	1017.1	0.00	0.00	0.03	99.97

* Excludes State catches

(Table 7.A.4 Continued)

(c) Tasmania

Year	Number of records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1976	247	77.0	24.33	0.00	45.14	54.86
1977	443	99.3	20.20	0.00	39.25	60.75
1978	382	94.0	49.36	0.00	60.52	36.70
1979	512	93.9	97.49	0.00	78.75	2.51
1980	577	137.0	92.21	0.00	77.13	7.79
1981	298	109.7	93.10	0.00	77.45	6.90
1982	188	84.6	92.71	0.00	70.27	7.29
1983	176	83.0	97.53	0.00	69.52	2.47
1984	463	195.0	99.06	0.00	69.32	0.94
1985	983	230.4	97.92	0.00	74.68	2.05
1986	942	162.4	98.38	0.00	72.03	1.62
1987	1384	178.8	98.33	0.00	71.02	1.67
1988	1683	185.3	91.84	0.00	61.75	7.27
1989	1714	173.2	88.09	0.00	63.19	5.86
1990	2143	161.1	84.78	0.00	46.59	14.98
1991	903	140.3	80.29	0.00	52.76	17.35
1992	1168	201.0	76.65	0.00	38.42	21.49
1993	901	268.4	92.72	0.00	51.15	7.01
1994	650	208.2	96.05	0.00	66.63	3.80
1995	1565	111.2	0.22	0.00	0.22	99.78
1996	4915	142.6	1.56	0.00	1.56	98.44
1997	1606	104.2	6.22	0.00	6.81	93.19
1998	1923	103.1	7.16	0.00	6.66	92.84
1999	2368	109.2	3.33	0.00	3.33	96.67
2000	2193	83.6	3.35	0.00	3.45	96.55
2001	1586	73.8	3.97	0.00	3.83	95.93
2002	1376	111.4	1.17	0.00	1.47	98.53
2003 *	1382	110.4	0.00	0.00	1.24	98.76

* Excludes State catches

Table 7.A.5. Reported catches of school shark, total number of catch-effort records, and the percentage of the reported catch of gummy shark rejected for use in the standardization of the catch and effort data for the three reasons listed in the text.

(a) South Australia (WSA and CSA)

Year	Number of records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1973	1203	158.4	5.46	0.00	5.54	94.46
1974	1265	188.8	0.00	0.00	1.88	98.12
1975	1158	231.8	0.00	0.00	2.48	97.52
1976	590	158.5	0.26	0.00	9.08	90.92
1977	705	270.1	11.19	0.00	64.85	35.15
1978	704	333.8	17.94	0.00	83.19	16.67
1979	509	334.5	14.33	0.00	92.38	7.62
1980	572	458.7	4.98	0.00	87.28	12.72
1981	650	607.0	4.58	0.00	79.48	20.52
1982	626	608.8	2.18	0.00	89.37	10.63
1983	614	481.5	8.25	0.00	54.66	41.34
1984	865	540.7	4.46	0.00	0.00	95.54
1985	960	612.6	9.03	0.00	0.10	90.87
1986	1342	693.8	2.67	0.00	0.22	97.12
1987	1936	828.3	2.36	0.00	0.01	97.63
1988	1910	809.6	1.94	0.00	0.43	97.64
1989	1781	688.8	2.29	0.00	0.23	97.57
1990	2002	555.2	1.18	0.00	0.11	98.72
1991	2118	520.2	1.42	0.00	0.10	98.50
1992	2125	319.5	0.45	0.00	0.00	99.55
1993	1902	375.0	0.83	0.00	0.00	99.17
1994	1740	383.4	2.27	0.00	0.00	97.73
1995	1695	361.2	0.16	0.00	0.16	99.84
1996	1565	419.3	0.06	0.00	0.06	99.94
1997	6041	418.2	6.05	0.00	6.49	88.22
1998	9268	231.7	2.77	0.00	0.71	97.22
1999	7457	166.3	1.31	0.00	1.22	98.67
2000	5873	93.9	7.87	0.00	1.88	92.13
2001	5950	91.6	2.01	0.00	1.49	97.38
2002	4917	64.4	0.53	0.00	1.84	98.09
2003 *	5593	98.6	0.00	0.00	0.06	99.94

* Excludes State catches

(Table 7.A.5 Continued)

(b) Bass Strait (EBS and WBS)

Year	Number of records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1973	3670	153.7	0.18	0.00	6.55	93.45
1974	3466	248.6	3.32	0.00	13.81	86.19
1975	3523	422.1	6.47	0.00	11.70	88.23
1976	3273	403.5	0.94	0.00	10.68	89.29
1977	3595	316.9	8.05	0.00	18.39	81.56
1978	3902	277.2	17.00	0.00	6.01	79.09
1979	3885	354.6	47.81	0.00	14.20	43.33
1980	4418	537.6	49.73	0.00	12.20	45.56
1981	4145	453.6	53.25	0.00	25.70	45.11
1982	4925	398.9	40.55	0.00	24.40	58.69
1983	5179	428.3	45.80	0.00	34.33	54.20
1984	4915	518.1	51.49	0.00	40.73	48.51
1985	5445	621.3	47.76	0.00	38.84	51.59
1986	5761	633.2	42.66	0.00	30.89	52.75
1987	5875	471.9	49.66	0.00	30.59	48.67
1988	6659	494.6	26.09	0.00	26.44	65.09
1989	6183	474.7	32.57	0.00	35.31	51.91
1990	5238	365.1	36.77	0.00	25.72	59.28
1991	7025	414.9	32.49	0.00	24.77	53.78
1992	6677	348.8	34.75	0.00	17.87	55.81
1993	6643	348.8	21.29	0.00	13.69	71.98
1994	6208	281.8	22.91	0.00	14.18	75.04
1995	7058	223.2	0.08	0.00	0.01	99.92
1996	9308	174.2	2.48	0.00	2.48	97.52
1997	8979	129.3	8.14	0.00	2.33	91.42
1998	8221	195.9	2.98	0.00	2.95	97.02
1999	9560	125.4	3.46	0.00	3.46	96.54
2000	9000	85.4	4.17	0.00	3.42	95.13
2001	7625	52.6	2.81	0.00	2.96	96.89
2002	6631	78.7	0.32	0.00	0.47	99.39
2003 *	7165	64.9	0.00	0.00	0.53	99.47

* Excludes State catches

(Table 7.A.5 Continued)

(c) Tasmania

Year	Number of records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1973	396	70.9	24.85	0.00	24.85	75.15
1974	513	159.1	18.78	0.00	25.73	74.27
1975	219	91.9	33.74	0.00	33.83	66.17
1976	247	127.7	18.90	0.00	24.26	75.74
1977	443	196.7	12.33	0.00	17.67	82.33
1978	382	104.8	29.26	0.00	25.82	61.12
1979	512	183.3	96.84	0.00	25.64	3.16
1980	577	207.6	96.34	0.00	23.77	3.66
1981	298	259.8	94.65	0.00	31.32	5.35
1982	188	162.5	99.39	0.00	53.91	0.61
1983	176	111.0	100.00	0.00	59.33	0.00
1984	463	442.2	99.63	0.00	47.31	0.37
1985	983	584.4	95.91	0.00	59.58	4.03
1986	942	500.5	96.59	0.00	46.67	3.41
1987	1384	470.7	99.40	0.00	43.42	0.60
1988	1683	221.8	77.07	0.00	50.93	22.29
1989	1714	167.4	52.22	0.00	34.46	41.05
1990	2143	242.6	73.83	0.00	19.23	25.88
1991	903	156.6	64.65	0.00	26.86	22.66
1992	1168	253.2	80.93	0.00	15.10	15.44
1993	901	207.4	80.45	0.00	32.82	17.69
1994	650	119.6	77.96	0.00	15.53	21.97
1995	1565	117.4	1.12	0.00	1.12	98.88
1996	4915	91.3	1.41	0.00	1.41	98.59
1997	1606	86.2	1.25	0.00	3.79	96.21
1998	1923	88.4	3.23	0.00	3.23	96.77
1999	2368	79.1	6.19	0.00	3.62	93.81
2000	2193	59.1	2.87	0.00	2.91	97.09
2001	1586	15.3	8.30	0.00	8.30	91.70
2002	1376	32.5	4.77	0.00	4.77	95.23
2003 *	1382	19.6	0.00	0.00	9.96	90.04

* Excludes State catches

Table 7.A.6. Statistics related to the vessels included in the catch-effort standardization. Results are shown separately for the vessels chosen to standardize the gummy shark data for South Australia and Bass Strait.

Quantity	**School shark**	**Gummy shark**	
		Bass Strait	South Australia
Number of records	18,124	26,481	31,559
Number of vessels	62	66	87
Total catch (t)	9,422	17,482	20,383
Average # of years in the fishery	16.9	16.0	15.8
Median annual catch per vessel	11,769 kg	5,227 kg	7,541 kg
Percentage of the potential catch			
South Australia	61.7%		54.0%
Bass Strait	34.0%	50.9%	

Table 7.A.7. Diagnostic statistics by statistical cell.

(a) Gummy shark

Bass Strait (28 years - 1976–2003)				**South Australia (20 years - 1984–2003)**			
Cell	**Rule a**	**Rule b**	**Rule c**	**Cell**	**Rule a**	**Rule b**	**Rule c**
4	0	0	11	101	3	0	1
5	0	0	3	102	5	0	0
6	1	0	0	103	0	0	0
7	0	0	0	107	0	0	0
8	0	0	0	112	0	0	0
9	0	0	0	115	0	0	0
10	0	0	0	122	8	2	6
11	0	0	0	126	0	0	0
18	0	0	1	128	0	0	0
19	0	0	0	129	0	3	1
20	0	0	0	132	1	3	4
21	0	0	0	136	2	4	7
22	0	0	0	138	0	0	0
23	0	0	0	139	0	0	0
30	2	0	0	140	0	0	0
31	0	0	0	144	0	0	0
32	0	0	0	148	0	0	1
33	4	0	1	149	0	0	0
34	0	0	0	150	0	0	0
34	0	0	0	151	0	0	0
				155	0	0	0
				158	1	0	0

(b) School shark

Bass Strait (31 years – 1973–2003)				**South Australia (21 years – 1983–2003)**			
Cell	**Rule a**	**Rule b**	**Rule c**	**Cell**	**Rule a**	**Rule b**	**Rule c**
6	4	0	0	101	0	0	2
7	0	0	0	102	0	0	3
10	0	0	0	103	0	0	0
18	0	0	0	107	0	0	0
20	0	0	0	112	0	0	0
21	0	0	0	115	0	0	0
22	0	0	0	126	0	0	0
30	0	0	0	128	1	0	0
32	0	0	0	138	1	0	0
33	7	0	1	139	1	0	0
34	0	0	0	148	1	0	0
35	0	0	0	149	0	0	0
				150	0	0	0

APPENDIX 7.B : The population dynamics model

7.B.1 Basic Dynamics

The population dynamics of gummy shark are assumed to be governed by the equation:

$$N_{g,t+1,a} = \begin{cases} N_{g,t+1,0} & a = 0 \\ (N_{g,t,a-1} e^{-M_{t,a-1}/2} - C_{g,t,a-1}) e^{-M_{t,a-1}/2} & 1 \le a < x \\ N_{g,t,x-1} e^{-M_{t,x-1}} - C_{g,t,x-1} e^{-M_{t,x-1}/2} + N_{g,t,x} e^{-M_{t,x}} - C_{g,t,x} e^{-M_{t,x}/2} & a = x \end{cases} \qquad (7.B.1)$$

where $N_{g,t,a}$ is the number of fish of age *a* and sex *g* (*g*=1 for females; *g*=2 for males) at the start of year *t*,

$M_{t,a}$ is the instantaneous rate of natural mortality on fish of age *a* during year *t*,

$C_{g,t,a}$ is the catch (in number) during year *t* of fish of age *a* and sex *g*:

$$C_{g,t,a} = \sum_j C_{g,t,a,j} \qquad (7.B.2)$$

$C_{g,t,a,j}$ is the catch (in number) during year *t* by gear-type *j* of fish of age *a* and sex *g*, and

x is the maximum age considered (treated as a plus group) - taken to be 30.

7.B.2 Pup production

The expected number of pups in a given year depends on the number of mature females, the frequency of pregnancy, and the number of pups (taken here to be the same as the number of embryos) per pregnant female. The latter two quantities are taken to be functions of age. The total number of pups of sex *g* at the start of year *t*+1 is given by:

$$N_{g,t+1,0} = 0.5 Q_{t+1} \Gamma_{t+1} e^{\varepsilon_{t+1} - \sigma_r^2/2} \qquad (7.B.3)$$

where Q_t is the density-dependent factor that multiplies the number of births during year *t*,

$$Q_t = 1 + \max\{(Q_0 - 1)[1 - D_t / D_0], 0\} \qquad (7.B.4)$$

Q_0 is the parameter that determines the magnitude of density dependence,

Γ_t is the number of pups produced during year *t*:

$$\Gamma_t = \sum_{a=1}^{x} P_a^{'} P_a^{''} N_{1,t,a} \qquad (7.B.5)$$

D_t is the size of the component of the population on which density-dependence acts, assumed to be the total (1+) biomass at the start of year *t*, B_t^{1+}:

$$B_t^{1+} = \sum_{a=1}^{x} \sum_{L} \sum_{g} w_{g,L}\, \Phi(g, a+1/2, L)\, N_{g,t,a} \qquad (7.B.6)$$

ε_t is the logarithm of the ratio of the expected and actual number of pups,

$$\varepsilon_t \sim N(0; \sigma_r^2)$$

σ_r is the standard deviation of ε_t (assumed to be 0.4),
$P_a^{'}$ is the number of pups per pregnant female of age *a*,
$P_a^{''}$ is the proportion of females of age *a* that become pregnant each year,
$w_{g,L}$ is the mass of a fish of sex *g* in length-class *L*, and
$\Phi(g, a, L)$ is the fraction of animals of age *a* and sex *g* that are in length-class *L*.

The subscript 0 in Equation (7.B.4) indicates an evaluation of *D* at the pre-exploitation equilibrium level. Equation (7.B.4) assumes that all of the density dependence occurs on the mortality between birth and age one, in which case Q_0 is the expected ratio of the pup survival rate in the limit of zero population size to that at unexploited equilibrium.

The number of pups (actually embryos) per pregnant female of age *a* (total length $\ell_{1,a}$) is given by:

$$P_a^{'} = \begin{cases} 0 & \ell_{1,a} < 995\text{mm} \\ e^{a'+b'\ell_{1,a}} & \text{otherwise} \end{cases} \qquad (7.B.7)$$

where *a'* and *b'* are the parameters that govern the relationship between total length and number of pups per pregnant female.

The proportion of female sharks of age *a* (total length $\ell_{1,a}$) that are pregnant each year is given by:

$$P_a^{''} = P_{\max}^{''} \left(1 + \exp(-\ell n(19) \frac{\ell_{1,a} - \ell_{50}^{''}}{\ell_{95}^{''} - \ell_{50}^{''}}) \right)^{-1} \qquad (7.B.8)$$

where $P_{\max}^{''}$ is the proportion of very large ($\ell_{1,a} \to L_{\infty,1}$) females that are pregnant each year,
$\ell_{50}^{''}$ is the length at which half of the maximum proportion of females are pregnant each year, and
$\ell_{95}^{''}$ is the length at which 95% of the maximum proportion of females are pregnant each year.

Table A.1 lists the values assumed for the parameters of Equations (7.B.7) and (7.B.8).

7.B.3 Catches

The annual catches are assumed to be taken in a pulse in the middle of the year (after 50% of the natural mortality) and the fisheries are assumed to be sequential (gauntlet)[13]. The catch (in number) during year *t* by gear-type *j* of fish of age *a* and sex *g* is calculated from the total catch (in mass) during year *t* by gear-type *j*, $\tilde{C}_{t,j}$:

$$C_{g,t,a,j} = F_{t,j} \sum_L A_L \, S_{g,j,L} \, \Phi(g, a+1/2, L) \left(N_{g,t,a} e^{-M_{t,a}/2} - \sum_{i=1}^{j-1} C_{g,t,a,i} \right) \qquad (7.B.9)$$

where $S_{g,j,L}$ is the selectivity of gear-type *j* on fish of sex *g* in length-class *L*,

A_L is the availability of a fish of sex *g* in length-class *L*, and

$F_{t,j}$ is the fully-selected exploitation rate by gear-type *j* during year *t*:

$$F_{t,j} = \tilde{C}_{t,j} \Big/ \left(\sum_g \sum_{a=1}^{x} \sum_L w_{g,L} \, A_L \, S_{g,j,L} \, \Phi(g, a+1/2, L) \left(N_{g,t,a} e^{-M_{t,a}/2} - \sum_{i=1}^{j-1} C_{g,t,a,i} \right) \right) \qquad (7.B.10)$$

7.B.4 Length and mass

The (mean) total length of a fish of age *a* and sex *g* at the start of the year, $\ell_{g,a}$, is described by the von Bertalanffy growth equation:

$$\ell_{g,a} = L_{\infty,g}(1 - e^{-\kappa_g (a - t_{0,g})}) \qquad (7.B.11)$$

and the mass by the allometric equation:

$$w_{g,L} = a_g (\bar{L}_L)^{b_g} \qquad (7.B.12)$$

where $\bar{L}_L$ is the mid-point of length-class *L*.

The values assumed for the parameters of Equations (7.B.11) and (7.B.12) are listed in Table 7.B.1.

The probability that a fish of age *a* and sex *g* lies in length-class *L* (length-class *L* is defined to be $[L - \Delta L, L + \Delta L]$) is given by:

$$\Phi(g, a, L) = \int_{L-\Delta L}^{L+\Delta L} \frac{1}{\sqrt{2\pi}\, \sigma_{g,a} l} e^{-\frac{(\ell n l - \ell n \ell_{g,a})^2}{2\sigma_{g,a}^2}} \, dl \qquad (7.B.13)$$

where ΔL is half the width of a length-class (25 cm), and

$\sigma_{g,a}$ is (approximately) the coefficient of variation of the length of an animal of age *a* and sex *g*.

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[13] The impact of assuming that the fisheries act sequentially is unlikely to be large because the annual exploitation rates are relatively small.

7.B.5 Gear selectivity

Different selectivity patterns are assumed for the two major gear-types (longlines and gill-nets). The catch by longlines is assumed to be taken uniformly from the 2+ component of the population (Walker, 1983), i.e.:

$$S_{g,j,L} = \begin{cases} 0 & \overline{L}_L < \ell_{g,2} \\ 1 & \text{otherwise} \end{cases} \tag{7.B.14}$$

The selectivity pattern for gill-nets is assumed to follow a gamma function (Kirkwood and Walker, 1986):

$$S_{g,j,L} = \left(\frac{\overline{L}_L}{\alpha_{g,j}\, \beta_{g,j}} \right)^{\alpha_{g,j}} e^{\alpha_{g,j} - \frac{\overline{L}_L}{\beta_{g,j}}} \tag{7.B.15}$$

where $\alpha,\ \beta$ are the parameters of the selectivity pattern.

The values for the parameters α and β are determined from the mesh size of the gear, i.e.:

$$\beta = \tfrac{1}{2}\left(\theta_1 m - \sqrt{(\theta_1 m) + 4\theta_2} \right) \qquad \alpha = \theta_1\, m / \beta \tag{7.B.16}$$

where θ_1, θ_2 are parameters (184.2841 and 29736.96 respectively), and
m is the mesh size (in inches).

7.B.6 Availability

Availability as a function of length is either assumed to be independent of length or governed by a normal equation:

$$A_L = A_L^{'} / \max_{L'}(A_{L'}^{'}) \tag{7.B.17a}$$

$$A_L^{'} = \exp(-[\overline{L}_L - \mu_L]^2 / \sigma_L^2) \tag{7.B.17b}$$

where μ_L, σ_L are the parameters of the availability function.

7.B.7 Initial conditions

The population is assumed to have been at pre-exploitation equilibrium at the start of 1927 (the assumed start of harvesting) because there are no data to estimate deviations for the equilibrium age-structure at that time:

$$N_{g,y_1,a} = \begin{cases} 0.5\ R_0\, e^{-\sum\limits_{a'=0}^{a-1} M_{a'}} & 0 \le a \le x-1 \\ 0.5\, R_0\, e^{-\sum\limits_{a'=0}^{x-1} M_{a'}} / (1 - e^{-M_x}) & a = x \end{cases} \tag{7.B.18}$$

where R_0 is the number of pups at the (deterministic) equilibrium that corresponds to an absence of fishing, and

y_1 is the first year considered (1927).

The value for R_0 is calculated from the value assumed for the virgin total (1+) biomass at the start of the year, B_0:

$$R_0 = 2B_0 / \sum_g \left(\sum_{a=1}^{x-1} w_{g,a} e^{-\sum_{a'=0}^{a-1} M_{a'}} + w_{g,x} \frac{e^{-\sum_{a'=0}^{x-1} M_{a'}}}{1-e^{-M_x}} \right) \qquad (7.B.19)$$

$$w_{g,a} = \sum_L w_{g,L}\, \Phi(g, a+1/2, L) \qquad (7.B.20)$$

7.B.8 Natural Mortality

Natural mortality-at-age is assumed to be governed by the equation:

$$M_{t,a} = \begin{cases} M_a(1-V(1-D_t/D_0)) & 0 \le a \le a_d \\ M_a & \text{otherwise} \end{cases} \qquad (7.B.21)$$

where M_a is the rate of natural mortality on fish of age a at pre-exploitation equilibrium:

$$M_a = \begin{cases} M_0\, e^{\ell n(M_2/M_0)a/2} & 0 \le a \le 2 \\ M_2 & 2 < a \le x \end{cases} \qquad (7.B.22)$$

V is the parameter that determines the extent of density-dependence in natural mortality,

a_d is the oldest age at which density-dependent natural mortality applies,

M_2 is the rate of natural mortality on animals aged two and older, and

M_0 is the rate of natural mortality on pups.

This formalism implies that natural mortality decreases exponentially between age 0 and age 2, and is constant thereafter. The value for M_2 is either estimated or pre-specified while the value for M_0 is calculated so that, in the absence of harvesting, the population satisfies the balance equation:

$$2 = \sum_{a=1}^{x-1} P_a^{'} P_a^{''} e^{-\sum_{a'=0}^{a-1} M_{a'}} + P_x^{'} P_x^{''} \frac{e^{-\sum_{a'=0}^{x-1} M_{a'}}}{1-e^{-M_x}} \qquad (7.B.23)$$

Table 7.B.1: Values for the parameters of the population dynamics model.

(a) Biological parameters

	Bass Strait		South Australia		
Quantity	Female	Male	Female	Male	Source
L_∞ (mm)	2019	1387	2019	1387	Moulton *et al.,* (1992)
κ (yr^{-1})	0.123	0.253	0.123	0.253	Moulton *et al.,* (1992)
t_0 (yr)	-1.55	-0.90	-1.55	-0.90	Moulton *et al.,* (1992)
a (x10^{-9})	1.22	4.38	1.22	4.38	Walker (1994a)
b	3.18	2.97	3.18	2.97	Walker (1994a)
a' (yr)	-1.8520		-2.521		Walker (1994a)
b' (yr^{-1})	0.0032		0.00358		Walker (1994a)
$P''_{\max}$	0.6060		1.0000		Walker (1994a)
ℓ''_{50} (mm)	1273.15		1356.5		Walker (unpublished data)
ℓ''_{95} (mm)	1593.20		1624.1		Walker (unpublished data)

b) Gill-net selectivity parameters (Kirkwood and Walker, 1986)

Mesh-size	α	β
6 in	42.09	26.27
7 in	56.95	22.65
8 in	74.08	19.90

APPENDIX 7.C: The contributions to the likelihood function

7.C.1 Catch rate data

The contribution of the catch-rate data to the likelihood function is based on the assumption that effective effort for gear-type *j* is lognormally distributed about the exploitation rate:

$$F_{t,j} = q_j\, f(\tilde{C}_{t,j} / I_{t,j})\, e^{\phi_{j,t}} \qquad \phi_{j,t} \sim N(0;\sigma_j^2) \qquad (7.C.1)$$

where $f(E)$ is relative exploitation rate as a function of actual fishing effort, modeled by one of three alternatives:

$$f(E) = E \qquad (7.C.2a)$$

$$f(E) = E^{\gamma} \qquad (7.C.2b)$$

$$f(E) = E/(1+\gamma_1 E) \qquad (7.C.2c)$$

q_j is the catchability coefficient for gear-type *j*,

γ, γ_1 are control parameters (constrained to be positive), and

$I_{j,t}$ is the catch-rate index for gear-type *j* and year *t*.

The negative of the log-likelihood function (ignoring constant terms) is

$$-\ell\text{n}L_j = \sum_{t(j)} \left(\ell\text{n}\sigma_j + \frac{1}{2\sigma_j^2} \Big(\ell\text{n}(q\, f(\tilde{C}_{t,j} / I_{j,t})) - \ell\text{n}(F_{t,j}) \Big)^2 \right) \qquad (7.C.3)$$

where σ_j is the residual standard deviation (assumed to be 0.15 based on preliminary analyses) and the summation over *t* is taken over all years for which catch rates are available for gear-type *j*.

7.C.2 Length-frequency data

The contribution of the length-frequency data (by gear-type) to the negative of the logarithm of the likelihood function is based on the assumption that the observed proportion of the catch by gear-type *j* in length-class *L* is multinomially distributed about the model prediction:

$$-\ell\text{n}L = -O_j^{\text{len}} \sum_g \sum_t \frac{N_{g,t,j}^{\text{len}}}{\overline{N}_{g,j}^{\text{len}}} \sum_L \rho_{g,t,L,j}\, \ell\text{n}(\hat{\rho}_{g,t,L,j} / \rho_{g,t,L,j}) \qquad (7.C.4)$$

where $\rho_{g,t,L,j}$ is the observed fraction of the catch of animals of sex *g* during year *t* by gear-type *j* that lies in length-class *L*,

$N_{g,t,j}^{\text{len}}$ is the number of animals of sex *g* caught by gear-type *j* measured during year *t*,

$\overline{N}_{g,j}^{\text{len}}$ is mean of $N_{g,t,j}^{\text{len}}$,

O_j^{len} is the weight assigned to the length-frequency data for gear-type *j* (the average annual effective sample size; assumed to be 50 per sex for Bass Strait and 25 per sex for South Australia), and

$\hat{\rho}_{g,t,L,j}$ is the model-estimate of the fraction of the catch of animals of sex *g* during year *t* by gear-type *j* that lies in length-class *L*:

$$\hat{\rho}_{g,t,L,j} = F_{t,j}\, A_L\, S_{g,j,L} \sum_a \Phi(g,a+1/2,L)\left(N_{g,t,a}\, e^{-M_a/2} - \sum_{i=1}^{j-1} C_{g,t,a,i} \right) / \sum_{a'} C_{g,t,a',j} \qquad (7.C.5)$$

7.C.3 Age-composition data

The contribution of the age-composition data (by gear-type) to the negative of the logarithm of the likelihood function is identical to Equation 7.C.4, except that the observed and model-predicted fractions by age rather than by length are included in Equation 7.C.4. The effective sample size for the age-composition data is assumed to be 25 per sex. The age-composition data are a small subset of the length-frequency data. Therefore, the impact of the double-counting of the fish that were aged by including both the age- and length-frequency in the assessment simultaneously should not be marked.

7.C.4 Tagging data

The information for each release includes year-of-release, age-at-release (calculated from the growth curve and the length-at-release) and tag-type. The information for each recapture includes year- and age-at-recapture. The latter is calculated by adding the time-at-liberty to the age-at-release. Any releases for which complete information is not available are discarded (irrespective of whether they were recaptured or not). Ignoring constants, the contribution of the tagging data to the negative of the log-likelihood function is (Hilborn, 1990; Xiao, 1996):

$$-\ell\text{n}L = \sum_t \sum_g (\hat{R}_{g,t} - R_{g,t}\, \ell\text{n}\hat{R}_{g,t}) \qquad (7.C.6)$$

where $R_{g,t}$ is the actual number of recaptures of animals of sex *g* during year *t*, and

$\hat{R}_{g,t}$ is the expected number of recaptures of animals of sex *g* during year *t*.

The equation that governs the dynamics of tags is defined analogously to that which governs the dynamics of the population itself, except that 'births' to the tagged population occur when a tag is released, and account needs to be taken of tag shedding and 'early' recaptures[14]:

$$T^z_{t+1,a+1} = (T^z_{t,a}\, e^{-(M_{t,a}+\lambda^z)} + (I^z_{t,a} - \tfrac{1}{\theta^z_t} E^z_{t,a})\, e^{-(M_{t,a}+\lambda^z)/2}) \prod_j \left(1 - F_{t,j}\, S_{g,j,a}\right) \qquad (7.C.7)$$

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[14] An 'early recapture' is defined as a recapture that occurs before it is reasonable to assume that the tagged animal has been at liberty sufficiently long for it to have 'fully mixed' into the population.

where $T_{t,a}^z$ is the number of fish of age *a* with tag-type *z* at the start of year *t*,

$I_{t,a}^z$ is the number of fish of age *a* which were released with tag-type *z* during year *t*,

$E_{t,a}^z$ is the number of fish of age *a* that were recaptured with tag-type *z* ‘early’ during year *t*,

θ_t^z is the tag recapture reporting rate (defined as the product of a year- and tag-type-specific factor),

$S_{g,j,a}$ is the selectivity of gear-type *j* on fish of sex *g* and age *a*:

$$S_{g,j,a} = \sum_L A_L \, S_{g,j,L} \, \Phi(g, a+1/2, L) \qquad (7.C.8)$$

λ^z is the instantaneous (long-term) rate of tag shedding for tag-type *z*.

The tagging data included in the assessment are restricted to tag-types for which estimates of tag shedding are available. Table 7.C.1 lists the five tag-types considered in the analyses of this report, the number of releases and recaptures for each tag-type and the tag-loss rates assumed when including the tagging data in the analyses. The expected number of fish of sex *g* recaptured during year *t* is given by:

$$\hat{R}_{g,t} = \sum_z \theta_t^z \sum_a \left(1 - \prod_j \left(1 - F_{t,j} \, S_{g,j,a}\right)\right) \left(T_{t,a}^z \, e^{-(M_{t,a}+\lambda^z)/2} + I_{t,a}^z - \tfrac{1}{\theta_t^z} E_{t,a}^z\right)$$

(7.C.9)

Table 7.C.1 : The five tag-types. Double-tagged animals are treated differently from animals tagged using a single tag because of differences in the rate of tag loss.

Tag-type(s)	Bass Strait		South Australia		Tag loss rate	
	# Releases	# Recoveries	# Releases	# Recoveries	Females	Males
Jumbo, Roto, Dart (fin) – single tag	1460	413	1454	501	0.106	0.106
Dart (muscle) – single tag	958	116	137	14	0.712	0.712
Dart (muscle) and Jumbo	372	149	195	54	0.075	0.075
Jumbo, Roto, Dart (fin) – double tagged	56	21	143	55	0.011	0.011
Internal	1658	370	77	9	0	0

APPENDIX 7.D: Calculating the Maximum Sustainable Yield Rate

The Maximum Sustainable Yield Rate (*MSYR*) is defined as:

$$MSYR = MSY / B_{MSY} \tag{7.D.1}$$

MSY is determined by expressing the yield as a function of the exploitation rate, and then solving for the value of *F* which gives:

$$\left.\frac{dY(F)}{dF}\right|_{F=F_{MSY}} = 0 \tag{7.D.2}$$

where F is the exploitation rate,

Y is the yield, which is the following function of *F*,

$$Y(F) = \tilde{Y}(F)\,P(F) \tag{7.D.3}$$

$\tilde{Y}(F)$ is yield-per-recruit given *F*,

$$\tilde{Y}(F) = F\sum_{a=a_m}^{x}\sum_{L}\sum_{g} w_{g,L}\,\Phi(g,a+0.5,L)\,\bar{N}_a(F)\,e^{-M_a(F)/2} \tag{7.D.4}$$

$P(F)$ is the number of pups given *F*, divided by the number of pups in the absence of fishing,

a_m is the age-at-maturity,

$$M_a(F) = M_a(1 - V(1 - P^*))\ ^{15}$$

M_a is the rate of natural mortality in the absence of fishing (see Equation 7.B.21),

$\bar{N}_a(F)$ is the number of fish of age *a* relative to the number of pups when the exploitation rate on mature animals is *F*, i.e.:

$$\bar{N}_a(F) = \begin{cases} 1 & \text{if } a = 0 \\ \bar{N}_{a-1}(F)\,e^{-M_{a-1}(F)} & \text{if } 1 \le a \le a_{am} \\ \bar{N}_{a-1}(F)\,e^{-M_{a-1}(F)}(1-F) & \text{if } a_m < a < x \\ \bar{N}_{x-1}(F)\,e^{-M_{x-1}(F)}(1-F)/(1-e^{-M_x(F)}(1-F)) & \text{if } a = x \end{cases} \tag{7.D.5}$$

P^* is the “sustainable depletion” parameter.

For the case in which density dependence is assumed to affect natural mortality, $P(F)$ is defined as:

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[15] *V* is zero when density-dependence impacts pup survival.

$$P(F) = P^* \, \tilde{\Gamma}(F) \tag{7.D.6}$$

where $\tilde{\Gamma}(F)$ is the number of pups-per-recruit given F, i.e.:

$$\tilde{\Gamma}(F) = 0.5 \sum_{a=1}^{x} P_a' \, P_a'' \, \bar{N}_a(F) \tag{7.D.7}$$

The value of P^* is chosen so that the population remains in balance (i.e. each female pup produces, in expectation, one female pup over her lifespan) given an exploitation rate of F.

For the case in which density dependence impacts fecundity, $P(F)$ is defined as:

$$P(F) = \frac{Q_0 \, \tilde{\Gamma}(F) - 1}{\tilde{D}(F) \, \tilde{\Gamma}(F) \, \left(Q_0 - 1\right)} \tag{7.D.8}$$

where $\tilde{D}(F)$ is the total (age 1+) biomass-per-recruit given F, i.e.:

$$\tilde{D}(F) = \sum_{a=1}^{x} \sum_{L} \sum_{g} w_{g,L} \, \Phi(g,a,L) \, \bar{N}_a(F) \tag{7.D.9}$$

8. Stock Assessment for Jackass Morwong (*Nemadactylus macropterus*) based on data up to 2002

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8.1 Background

Jackass morwong (*Nemadactylus macropterus*), one of 16 species under quota in Australia's southeast fishery (SEF), is managed using a total allowable catch (TAC), which is allocated among the different participants of the fishery. An assessment of the status and trends of jackass morwong populations off southern Australia is necessary to determine the impact of the fishery and to provide a basis for evaluating alternative management strategies.

8.1.1 History of the fishery

Jackass morwong have been landed in southern Australia since the inception of the steam trawl fishery off New South Wales in the early twentieth century. Jackass morwong were not favoured during the initial years of this fishery, with the main target species being tiger flathead (*Neoplatycephalus richardsoni*). Declines in flathead catches led to increased targeting of jackass morwong during the 1930s - the later years of the steam trawl fishery (Klaer, 2001). Annual estimates of landings of jackass morwong from the steam trawl fishery between 1915 and 1957 reached a peak of about 2,000 t during the late 1940s (Table 8.1).

The fishery expanded greatly during the 1950s, with Danish seine vessels becoming the main vessels in the trawl fleet. Landings of jackass morwong in NSW and Eastern Victoria increased following WWII, and, at their peak in the 1960s, annual landings were of the order of 2,500 t (Table 8.1). The fishery shifted southwards during this time, with the majority of the landed catches coming from Eastern Zone B (East Victoria). Landings of morwong then dropped to around 1,000 t by the mid-1980s, with landings in Eastern Tasmania becoming an increasing proportion of catches. By the mid-1980s, the majority of jackass morwong were being landed by modern otter trawlers, with small landings by Danish Seine vessels in Eastern Victoria and East Bass Strait (Smith and Wayte, 2002).

Following the establishment of the SEF, the recorded catch of jackass morwong ranged between 802 t (2001) to 1,724 t (1989). In 1992, an initial TAC was set at 1,500 t (Smith and Wayte, 2002). The TAC has since remained at that level, with some additions due to carryovers. Landings of jackass morwong in the eastern zones continued to decline during the 1990s, and annual catches in these areas are currently of the order of 500 t (Table 8.2). Catches from the western zones within the SEF have historically been minimal, with some trawling off Western Tasmania and West Victoria. However, catches in the western zones increased substantially in 2001, and now represent ~35% of the total landings of morwong in the SEF (Table 8.2).

Quantities of morwong are also caught by the non-trawl sector of the fishery, although these landings are not large. Reported catches of morwong in 2001 were around 2.2 t, compared to 85 t in 2000. This assessment does not consider landings from vessels in the non-trawl sector.

8.1.2 Previous Assessments

Smith (1989) analysed catch and effort data for the Eden fishery (1971-72 to 1983-84), finding a significant decline in catch-per-unit-effort (CPUE) to 1980. Lyle (1989) analysed logbook data for Tasmania and western Bass Strait from 1976-84. No trends were apparent in these data.

The biomass of jackass morwong in the eastern zone was estimated using a combination of trawl surveys and VPA to be about 10,000 t in the mid-1980s, (Smith, 1989). Age-structured modelling of the NSW component of the fishery indicated that Maximum Sustainable Yield (*MSY*) is approached with a fishing mortality (*F*) between 0.2 and 0.3 yr^{-1}, and that the fishery was at optimum levels in the mid-1980s (Smith, 1989).

At the 1993 meeting of SEFSAG, then recent age data (from the Central Ageing Facility, CAF) and length data were presented together with new age and length data from southeastern Tasmania. Estimates of total mortality from catch curve analyses were similar to previous estimates in the early 1980s. Length and age data from southeastern Tasmania were characterised by a greater proportion of larger and older fish. Preliminary ageing data from sectioned otoliths were tabled at SEFAG in 1994 which suggested that morwong were longer lived (35 years) than previously thought (20 years).

In 1995, catch and unstandardised effort by major area in the fishery were derived from logbook records for the period 1986-94. Whereas the 1994 assessment stated that catch rates had remained relatively stable for the previous 4 years, GLM-standardized trawl catch rates exhibited a slow decline from 1987. Indeed, Smith and Wayte (2002) note that the mean unstandardised catch rate of jackass morwong has continued to decline, and, since 1996, has triggered AFMA’s catch rate performance criterion.

An assessment in 1997 was based on the collation and analysis of catch and effort data, combined with new biological information on growth rates of jackass morwong. Information on length frequencies and the retained and discarded catch of jackass morwong was obtained from SMP data and the FRDC report by Liggins (1996). Further length-frequency data were available from NSW and Tasmanian state projects. Catch curve analysis on fish between 5 and 26 years old produced an estimate for total mortality of 0.18 yr^{-1}. This was considerably lower than previous estimates of 0.6 to 0.77 yr^{-1} and was a direct result of the “new” maximum age. It is also lower than the values obtained by applying the 1993/94 age-length key (0.3 yr^{-1}) to length composition data. Using a value for *M* of 0.09 yr^{-1}, a fishing mortality (*F*) of 0.09 $yr^{-1}$was estimated.

Recently, Klaer (MS) used a stock reduction analysis (SRA) method to model the population of jackass morwong off NSW using catch history data from 1915-61. This analysis lead to a point estimate of virgin biomass of 21,600 tonnes, with a 1962 depletion level of 71%.

This 2004 assessment uses a generalised age-structured modelling approach to assess the status and trends of the jackass morwong trawl fishery in the eastern zones, using data from the period 1915-2002. Although data are provided for the western areas of the SEF, these data were not included in the assessment, as it is not clear these landings are from the same stock as that from which the landings in the east are taken. The following sections outline the biological parameters used, the data available for assessment purposes, the modelling approach and estimation framework, and the results of the assessment.

8.2 Biological Background

Jackass morwong spawn during late summer and early autumn, and individuals may spawn more than once during the spawning season (Tong and Vooren, 1972). They have pelagic postlarvae which metamorphose to the adult form at 9-12 months old (Vooren, 1972). Icthyoplankton studies have shown such larvae to be widely distributed (up to 250 km offshore, Vooren, 1972). Juveniles (< 20 cm. LCF (caudal fork length), ages 1-2) are found in inshore nursery areas in Bass Strait and around Tasmania. These juveniles are almost absent from the major fishery however, with the majority of landed fish throughout the history of the fishery being of length greater than 25 cm. No migrations of adult morwong have been reported in Australian waters, although extensive movements of adults have been reported from New Zealand (Annala, 1993).

8.2.1 Habitat and associated species

Jackass morwong are distributed around the southern half of Australia (including Tasmania), New Zealand, the St Paul and Amsterdam Islands (Indian Ocean), and off south-eastern South America and southern Africa (Smith, 1989). They occur to depths of 450 m and, in Australian waters, are most abundant between 100 and 200 m (Smith and Wayte, 2002). Analyses of SEF1 logbook data (1986-2002) show that the majority of morwong catches are made in shelf waters of depth less than 200 m (Figure 8.1). Morwong are caught at greater depth off west Victoria (Figure 8.1) than in the eastern zones, probably reflecting the fact that much of the waters in shallower depths have largely been inaccessible to trawl fishing, and a lack of targeting of morwong in the west. Recent (2001-02) large catches of jackass morwong have been taken off western Victoria (Table 8.2) at similar depths to the catches in eastern zones (Figure 8.2).

Analyses of the catch composition of shots (tows) containing jackass morwong from SEF1 logbook data show that this species is caught with the majority of the other quota shelf species in the SEF (Appendix 8.A). Among others, greater than 20% of the annual landed catches of tiger flathead, redfish (*Centroberyx affinis*), blue warehou (*Seriolella brama*), eastern gemfish (*Rexea solandri*), and the shallow form of ocean perch (*Helicolenus sp.*) have been consistently caught in shots which caught jackass morwong (Table 8.A.1), and these associations unsurprisingly tend to be both regional- and depth-specific (Tables 8.A.2 and 8.A.3). Of these species, the percentage of the annual catch of tiger flathead that is caught in shots also catching morwong is one of the most consistently large (Table 8.A.1). Annual catches of jackass morwong are thought to be inversely correlated with those of tiger flathead (Smith and Wayte, 2002, Knuckey, Fishwell, pers. comm. 2004).

8.2.2 Stock structure

Genetic studies conducted by the CSIRO have found no evidence of separate stocks in Australian waters. New Zealand and Australian stocks are however, distinct (Elliott *et al.*, 1992). Analysis of otolith microstructure (Proctor *et al.*, 1992) found differences between jackass morwong from southern Tasmania and those off NSW and Victoria, but it is unclear if such differences indicate separate stocks. Differences among jackass morwong in the western and eastern zones have been suggested (D.C. Smith, PIRVic, pers. commn. 2004; Knuckey, Fishwell, pers. comm. 2004). The modelling approach employed is based on the assumption that the data are for a single stock so the landings and other data from the areas west of Bass Strait were not included in the assessment.

8.2.3 Biological parameters

Growth

A von Bertalanffy growth curve fitted to all available data from sectioned otoliths of jackass morwong (both sexes, Appendix 8.B) resulted in estimates for L_∞, K, and t_o of 38.04 cm, 0.188 yr^{-1}, and -3.552 yr respectively (Table 8.B.1). Fixing the value of t_o at zero lead to estimates of L_∞ and K of 35.65 and 0.419 yr^{-1} (Table 8.B.1). These values are slightly different from those published in the 2002 SEF Fishery Assessment Report (Smith and Wayte, 2002), which reports values for L_∞, K and t_o of 35.18 cm, 0.41 yr^{-1} and -0.2 yr, respectively, for males and 36.39 cm, 0.34 yr^{-1} and -0.45 yr for females.

The resulting growth curves from the new estimation (Figure 8.B.1) indicates that, despite being long-lived, initial growth rate of jackass morwong is rapid, with fish reaching about 30 cm LCF at five years of age. Growth then slows markedly, with little growth occurring after 10 years. There was little difference in the updated estimates of mean length at age (Tables 8.B.2 and 8.B.3) estimated in this report and those reported previously.

Natural mortality

There are several estimates of the rate of natural mortality, M, for jackass morwong. M was estimated to be 0.09 yr^{-1} based on a maximum age of 35 years for both males and females (Smith and Wayte, 2002), while Smith and Robertson (1995) report a value for M of 0.2 yr^{-1}. This assessment considers cases where this parameter is pre-specified to different fixed values, and where M is treated as an estimated parameter of the model.

Maturity and fecundity

Jackass morwong become sexually mature at about three years of age, with estimates of egg production ranging from 100,400 for three year olds to 1,419,000 for a 14 year old[16] (Smith and Robertson, 1995). Ageing studies by the CAF using sectioned otoliths show a maximum observed age in Australia of 39 years. An age of maturity of 3 was chosen for the assessment model and fecundity assumed to be proportional to mass, because insufficient information was available to determine how fecundity changes with age over

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[16] This age was obtained using whole-otoliths. Given that results from sectioned-otoliths have revealed that morwong are longer-lived than previously thought, this animal was likely underaged.

the lifespan of the species. Given that jackass morwong are long-lived, it is unlikely that this assumption will have a marked impact on the results of the assessment.

Table 8.3 shows the values and ranges for the biological parameters discussed above which were used in this assessment. Also included in Table 8.3 are the values for the parameters of the length-weight relationship for jackass morwong, taken from Smith and Robertson (1995), and the range over which the parameter determining stock productivity, steepness (*h*), was considered in the absence of other information.

8.3 Data

The data available for assessment purposes include landed catches by fleet / gear-type (1915–2002), estimates of discarded catches (1993-2002), catch-rates (numerous indices covering years from 1918–2002), length-frequency data (1947-66, 1991–2002), and age-composition data (1991–94, 1996-97, 1999-2002). Each of these data sources is described in turn below. Logbook data, and the resulting annual estimates of catch, were not available for 2003. For this reason, length-composition data for 2003 are not included in the data summary

The data are presented for six regions off southern Australia: i) New South Wales (NSW), ii) eastern Victoria (EVic), iii) Bass Strait (BS), iv) eastern Tasmania (ETas), v) western Tasmania (WTas), and vi) western Victoria (WVic). Data for WTas and WVic were not used in the assessment, and data from NSW EVic and BS were aggregated into a single region for the purposes of separating the data by fleet, as outlined below.

8.3.1 Landed catches

A landed catch history for jackass morwong is available for all years from 1915 to 2002. This catch history is separated into six "fleets", which represent one or more gear, regional, or temporal differences in the fishery for assessment purposes.

Klaer (MS) recently used a compilation of catch data from historical steam trawlers (fleet 1) (Klaer and Tilzey, 1996) to recreate a catch history for jackass morwong for this sector of the fishery from 1915 to 1962 (Table 8.1). Estimates of total annual landings of jackass morwong from the eastern zones by Danish seine vessels and other boats (primarily diesel trawlers) during 1947-85 were compiled from Klaer (MS), Klaer (pers. commn. 2004) and Allen (1989). Although this fleet consisted primarily of Danish seine vessels until the mid 1970s, no separation of landings by gear type is available for the later years of this period. For the purposes of this assessment, therefore landings during 1947-85 were treated as coming from one fleet ('other boats', fleet 2) with one selectivity pattern.

Annual landings data from 1986 to 2002 are taken from the SEF1 logbook database and are separated into the following four fleets: 3) otter trawlers from NSW, EVic, and BS, 4) Danish seine vessels from the same areas, 5) otter trawlers from ETas, and 6) otter trawlers from WVic and WTas. As mentioned above, the latter time series was not used in the assessment because there is a possibility that the catches by this fleet are from a different stock to those from the east. Landings by Danish seine vessels in areas other than those specified above are minimal and are not included in the assessment.

Landings data from eastern Tasmania were separated from the catches from the other regions in the east, because the length composition of catches from this area indicate a landing of larger fish. This may reflect a difference in availability of certain length classes rather than actual gear selectivity. There are differences in the catch rates and landings of jackass morwong among the eastern areas depending on the time of year. However, there is no obvious difference in the size composition of the catches by month and/or season.

SEF1 logbook data were used as these data include the necessary regional information. However, SEF1 catches are always underestimates of the landings recorded in the SEF2 database. To accommodate this, the regional annual SEF1 catches were multiplied by a scaling factor of 1.128. This was calculated from the average relative difference between total (all regions) annual SEF1 and SEF2 catches for those years (1995-2002) for which both were available (Table 8.4).

8.3.2 Discarded catches

Information on the discarding rate of jackass morwong were available from the ISMP for 1993-2002. These data are summarised in Table 8.5. Discards of jackass morwong in recent years are not very large, with a maximum estimated discard rate of 12.8% of the landings from ETas in 2002. However, the total discard rate for that year over all regions was just 2% of the total landings (Table 8.5). The data from the ISMP also provides information on the size composition of the discards relative to that of the retained catch for the years 1996-2002, and this information is presented as length frequencies (Table 8.6) and as the percentage by number of fish of given lengths that were discarded over this period (Table 8.7).

The assessment does not formally allow for discarding, as the software used requires the modelling of discards as a separate fleet. As only small amounts of recent data on discards are available, and from this information, discarding appears to be low for this species, discards were not considered in the assessment. It is known that jackass morwong were discarded during the early years of the steam trawl period, due to a preference in the fishery for other species (Klaer, 2001). Klaer (MS) considered the impact of such discarding, given available data, and showed that the discards, while affecting CPUE standardisation, did not appear to impact estimates of stock status.

8.3.3 Catch rate indices

A standardised catch rate (CPUE) index is available for the historical steam trawl fleet (fleet 1) for the years 1920-21, 1937-42, and 1952-57 (Klaer, pers. comm. 2004; Table 8.8). Smith (1989) provided a standardised CPUE index for all vessels for the period 1977-84 (Table 8.9). This index corresponds to the ‘other boats’ fleet (fleet 2).

Catch and effort information from the SEF1 logbook database from the period 1986-2002 were standardised using GLM analysis to obtain indices of relative abundance for the NSW, EVic, and BS otter trawl fleet, and the ETas otter trawl fleet (fleets 3 and 5). The standardised indices are given in Table 8.10. The methodology employed in the derivation of these indices is outlined in Appendix 8.C.

Smith (1989) also presented a standardised CPUE index for jackass morwong for the period 1948-66 (Table 8.11). This index standardises for gear type during a period of overlap between the steam trawl fishery and the onset of Danish seine vessels. The assessment method used requires that CPUE indices be specific to a particular fleet, and so this latter index of abundance was not used.

8.3.4 Length- and age- composition data

Monitoring of catches by the SMP/ISMP provided length composition data for jackass morwong for 1992-2002, for fleets 3-6. The data used when fitting the population dynamics model are those collected during port sampling because the samples sizes are larger for the port-based data than for the length-frequencies collected onboard fishing vessels. These data are used to calculate the length frequency of the retained component of the catch. Onboard data were used to calculate the length frequency of the discarded component of the catch (Tables 8.6 and 8.7). However, as stated in Section 8.3.2, these data were not included in the assessment.

The numbers of morwong measured in port and onboard fishing vessels by fleet for the period 1991-2002 are listed in Table 8.12, along with the number of trips (port data) sampled. The length data for jackass morwong are usually not disaggregated to sex, and so length data for fish of both sexes were lumped together for the purposes of the assessment. The length-composition data from port sampling for fleets 3, 4, 5 and 6 are given in Tables 8.13-8.16.

Length composition information from market sampling (Blackburn, 1978) is also available for the steam trawl fleet (fleet 1) for 1947-68 (Table 8.17) and for the other boats fleet (fleet 2) for 1947-66 (Table 8.18). These data are assumed to be representative of the retained catch. Sample sizes were available for these data in terms of the total numbers of fish measured, which are frequently one or more orders of magnitude greater than those for the recent port-sampling data (Table 8.12).

Age and length measurements, based on sectioned otoliths, provided by the CAF, were available for the years 1991-94, 1996-97, and 2000-2002 (see Table 8.12 for sample sizes). These data were used to construct an age-length key (ALK) for each of these years (Figure 8.3). The ALKs were then applied to the length-frequency information for the relevant years to obtain estimates of the age composition of the catch. The resulting age-composition data for fleets 3-5 are listed in Tables 8.19-8.21.

An ageing error matrix was not available for jackass morwong, and so a default identity matrix was used in the assessment, which assumed that otoliths were aged without error (i.e. the probability that an otolith aged as X came from an X-year-old fish was assumed to be 1).

8.4 Analytical Approach

8.4.1 Population dynamics model

A single-sex stock assessment for jackass morwong was conducted using the software package Coleraine (version 3.2; Hilborn *et al.*, 2003). Coleraine is a statistical age-structured model with a very general structure which can allow for multiple fishing fleets, and can be fitted simultaneously to the types of information available for jackass morwong. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, is outlined fully in the Coleraine user manual (Hilborn *et al.*, 2003) and is not reproduced here. Some key features of the population dynamics model underlying Coleraine which are pertinent to this assessment are discussed below.

A single stock of jackass morwong was assumed for the assessment, with an assumption of an unfished (virgin) biomass and equilibrium (unfished) age structure at the start of 1915 when the steam trawl fishery is assumed to have started. Catches from western Tasmania and west Victoria are assumed to come from a separate stock and are therefore not included in the bulk of the scenarios considered in the assessment. The assessment therefore modelled the impact of five fishing fleets on the morwong population, corresponding to fleets 1-5 (See Section 8.3.1).

Selectivity was assumed to vary among fleets, but the selectivity pattern for each fleet was modelled as being time-invariant. Coleraine models selectivity as being a function of age for commercial fishing fleets, with the function for the selectivity ogive being double-normal, facilitating the modelling of a wide range of possible selectivity patterns.

The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. Recruitment to the stock is assumed to follow a Beverton-Holt type stock-recrutiment relationship, parameterised by the average recruitment at virgin spawning biomass, R_0, and the steepness parameter, h. Deviations from the average recruitment at a given spawning biomass (recruitment residuals) are estimated for all years of the historical projection from 1915 to 2002. Coleraine estimates recruitment residuals for all years, and cannot be parameterized so that recruitment residuals are estimated for only a subset of the years for which catches are available.

A plus-group is modelled at age 20, and discarding is not considered in the model. Growth of morwong is assumed to be time-invariant, in that there is no change over time in the mean size-at-age within the model, with the distribution of size-at-age being determined from the fitting of the growth curve (See Appendix 8.B). These assumptions are slightly inconsistent with those used to determine the age-composition data for fitting, as the age data were derived from measurements of length-at-age which were year-specific. However, the fact that the growth curve was estimated using data pooled across all years for which data were available goes some way to correcting for this. No differences in growth related to gender are modelled, as the stock is modelled as a single-sex.

8.4.2 The base-case analyses

The base-case analyses reflect a ‘most’ likely’ set of assumptions. Sensitivity tests then examine the sensitivity of the model outputs to changes to these assumptions. Several versions of the base-case model were run, using different fixed values for the rate of natural mortality, M, and steepness, h. Base-case analyses which treated one or both of these quantities as estimated parameters within the model were also considered. The following are the base-case assumptions (assumptions indicated with asterisks are examined further in sensitivity tests):

a) Selectivity for all five fishing fleets is modelled as being asymptotic - there is therefore no decline in the selectivity pattern with age. To achieve this, the variance of the right-hand-side of the selectivity pattern is fixed at a very large value (in excess of 10^{10}).*

b) The value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, was set equal to 0.3.*

c) The CV's of the CPUE indices were assumed to be 0.2, and any CVs obtained from bootstrapping the GLMs were ignored.*

d) For those years for which the length-composition data had been used to calculate the age-composition of the landings, the length-composition data were omitted from the likelihood function.

d) The sample sizes used for the length-composition data were the number of fish measured.*

e) The sample sizes used for the age-composition data were the number of otoliths aged in the relevant year.

e) The length-composition data for the historical steam trawl fishery (fleet 1) and the 'other boats' fishery (fleet 2) were down-weighted compared to the more recent length-composition data obtained from the SMP/ISMP by dividing the number of fish measured by 10 to reduce the sample size. This reflects less certainty in these data owing to the information coming from market samples.*

8.4.3 Parameter and variance estimation

Parameter estimation within Coleraine is conducted using the AD Model Builder (ADMB) Package (Otter Research, Ltd.) to obtain the maximum likelihood estimates of the model parameters for given estimation scenarios. The use of the AMDB package for stock assessment purposes is desirable because the derivatives of the objective function with respect to the model parameters are calculated analytically (as opposed to numerically), and the package provides a means of obtaining Bayesian posterior distributions using the Markov Chain Monte Carlo (MCMC) technique, facilitating quantification of uncertainty regarding model parameters and stock status.

The parameters of the population dynamics model estimated during the model-fitting process for the base-case analyses were: average recruitment at virgin spawning biomass (R_0), recruitment residuals for each year in the period 1915-2002, the catchability coefficients (q's) of the four CPUE indices, the fleet-specific ages at maximum selectivity (S_{full}), and the natural logarithms of fleet-specific variances of the left-hand limb of the selectivity function (S_{Left}). Some versions of the base-case analyses also estimated the rate of natural mortality, M, and the steepness parameter, h. The values for all of the other parameters of the population dynamics model were fixed using ancillary information (Table 8.3).

Values for the estimated parameters were determined by maximizing a likelihood function which includes contributions from the catch-rate, length-frequency, and age-composition data. The mathematical specifications for the contributions to the likelihood function for the various data sources are provided in the Coleraine manual (Hilborn *et al.*, 2003). Coleraine provides the means of assuming different error structures for the various types of data. The CPUE observations were assumed to be log-normally distributed, while the fits to the length- and age- composition data were obtained by assuming the robust lognormal distribution for proportions (*e.g.* Fournier *et al.*, 1998), which is more robust to outliers than the traditional multinomial error model (Fournier *et al.*, 1990).

The variances for the estimates of the model parameters and derived variables of interest were determined using Bayesian methods. The Metropolis-Hastings variant of the Markov-Chain Monte Carlo (MCMC) algorithm (Hastings, 1970; Gilks *et al.*, 1996; Gelman *et al.*, 1995) with a multivariate normal jump function was used to sample 1,000 equally likely parameter vectors from the joint posterior density function. This sampling process implicitly considers uncertainty in all dimensions of parameter space, and accounts for correlation among model parameters. The samples on which inference is based were generated by running 4,500,000 cycles of the MCMC algorithm, discarding the first 500,000 as a burn-in period and selecting every 4,000th parameter vector thereafter. The initial parameter vector was taken to be the vector of maximum posterior density (MPD) estimates. A potential problem with the MCMC algorithm is how to determine whether convergence to the actual posterior distribution has occurred. Diagnostic statistics developed by Geweke (1992), Heidelberger and Welch (1983), and Raftery and Lewis (1992), and the extent of auto-correlation among the samples in the chain were used to determine whether there was a lack of convergence in the chain. The large number of cycles of the MCMC algorithm used to determine the variance estimates was due to non-convergence of several of the selectivity parameters over shorter chains. This was unsurprising as the two selectivity parameters for each fleet were very highly correlated with each other (Figure 8.4).

8.5 Results and discussion

8.5.1 Fits to the data

The fits to the length-composition data for the historical steam trawl fleet (fleet 1) and the ‘other boats’ fleet (fleet 2) are shown in Figures 8.5 and 8.6 for one version of the base-case analysis. The data are generally mimicked very well, and this was true across all of the analyses. There appears to be some difficulty in mimicking some of the finer scale detail in the data for some of the years (e.g. fleet 2, 1947, 1948, 1951, Figure 8.6), where there appears to be some evidence for stronger year classes moving through the size composition data. However, the mean length of the catch and the overall annual distributions of catch-at-length are mimicked very well. The number of years’ worth of length-composition data for the fleets operating in the modern era of the fishery (fleets 3, 4, and 5) included in the likelihood function for the base-case analyses is not very large, because the majority of these data are used to calculate the age-composition data for these fleets. The fits to the remaining years' data are shown in Figure 8.7. Again, the general patterns in the data are mimicked well, although the estimates for fleets 3 and 4 underestimate the relative abundance of fish of lengths 30-35cm (which generally represents the modal size of the landed catch), and over-estimate the proportions of smaller fish (Figure 8.7). It should be noted that some of these years' data have relatively small sample sizes (Tables 8.12-8.14).

The fits to the age-composition data for fleets 3-5 are generally adequate, and are shown in Figures 8.8-8.10 for one of the base-case analyses (M=0.15, h =0.7). However, although the model seems able to mimic the general distribution of ages in the landed catch, the fits tend to be quite poor for some of the years. In particular, the model seems unable to mimic the observation of an apparently strong year-class moving through the age composition in the later years of the data, which are considered to be four-year olds in 1998 (Figures 8.8-8.10). There also seems to be no way for the model to reconcile the appearance and disappearance in the data of a large proportion of the catch in the plus group (Figures 8.8-8.10). The age composition data for the NSW/EVic/BS Danish Seine fleet (fleet 4) in 1996 appears to be somewhat inconsistent with the distribution of ages in the catch for other years (Figure 8.9). Examination of Table 8.14 reveals that the sample size for the length frequency data used to derive the age-composition for that year was very low (33 fish).

The contribution to the likelihood function of fits to the CPUE data are included in the summary of the assessment results (Table 8.22 column $-\ell\text{nCPUE}$), as the fits to the two recent CPUE indices change appreciably with the values chosen for M and h. The CPUE data are fitted better with lower values for these parameters (Table 8.22), although the overall change in the value for the objective function is only slight. The two recent CPUE indices both indicate a declining trend in biomass during the late 1980s and 1990s, although landings of jackass morwong reduced during this time. Only the least productive scenarios of the base-case analyses (i.e. the lowest values for h in Table 8.22) are able to mimic this trend. As there is no obvious trend in the age-composition data, the model generally appears unable to reconcile the decline in CPUE with the reduced catches, and fits the CPUE data best by predicting a relatively stable trend during the 1990s, thus not matching the decline in the observed catch rate data (Figure 8.11).

8.5.2 Markov Chain Monte Carlo diagnostics

Bayesian posteriors were obtained for one version of the base-case analysis (M=0.15, h=0.7) and for two of the sensitivity analyses which, based on the results in Table 8.23, provided a more pessimistic prediction of 2003 stock status than the base-case: a) the analysis which increased recruitment variability (σ_r =0.5), and b) that in which the CVs of the recent CPUE indices were taken to be 10%.

Figures 8.12 and 8.13 summarise the convergence statistics for the objective function and the average recruitment at the unfished level (R_0) for the three analyses. The panels for each quantity show the trace, the posterior density function (estimated using a normal kernel density), the correlation at different lags, the 50-point moving average against cycle number (dotted line in the rightmost panels), and the running mean and running 95% probability intervals (solid lines in the rightmost panels). None of the diagnostic statistics for these two quantities exhibit any evidence that the MCMC algorithm failed to converge adequately to the posterior distribution.

It is not sensible to produce figures such as those in 8.12-8.13 which summarise the convergence statistics for all of the very many parameters of the model. Figures 8.14, 8.15 and 8.16 summarise the values of five statistics (the ratio of the batch standard deviation to the naive standard deviation, the extent of lag-1 auto-correlation, the *p*-value computed from the Geweke statistic, whether the Heidelberger and Welch test is passed or not, and the value of the single-chain Gelman statistic) for the parameters associated with estimating selectivity and catchability, and the recruitment residuals, for all three Bayesian analyses. Ideally, the value of the first statistic should be close to 1, the value of the second statistic should be close to zero, the value of the third statistic should be greater than 0.05, and the value of the last statistic should be less than 1.05. The results in Figure 8.14 suggest that the sample from the posterior for the base-case analysis is close to ideal. However, there is some evidence for a lack of convergence among the selectivity parameters, which is more so for the two sensitivity analyses (Figures 8.15 and 8.16). This is not surprising given the high correlation between the two selectivity parameters for each fleet (Figure 8.4), and perhaps indicates that it is necessary to run the MCMC algorithm for longer and increasing the thinning coefficient. A chain of length 10,500,000 with a burn-in of 500,000 and sampling every 10,000th cycle resulted in fewer of the selectivity parameters failing some of the diagnostics for the base-case model. However there was little change in the estimates of the posterior distributions of the model parameters. In principle, the efficiency of the ADMB MCMC algorithm could be improved by re-parameterising the model to reduce the correlation between the selectivity parameters.

8.5.3 The base-case analyses

The results of the base-case analyses are summarised in Table 8.22 by the values for the following quantities of interest:

a) SB_0 the (unfished) virgin spawning biomass in 1915,
b) SB_{2003} the spawning biomass at the start of 2003,
c) SB_{03} / SB_0 the depletion level at the start of 2003, i.e. the 2003 spawning biomass expressed as a percentage of the 1915 (virgin) spawning biomass,
d) SB_{62} / SB_0 the depletion level at the start of 1962, i.e. 1962 spawning biomass expressed as a percentage of the 1915 (virgin) spawning biomass,
e) $-\ell\text{n}L$ the negative of the logarithm of the likelihood function (ignoring constants independent of the model parameters), and
f) $-\ell\text{nCPUE}$ the contribution to the negative of the logarithm of the likelihood function (ignoring constants independent of the model parameters) of the four CPUE indices.

Table 8.22 shows the results for a large number of versions of the base-case assessment model based on different values for the rate of natural mortality, *M*, and the steepness parameter, *h*. The results of the assessment are very sensitive to the values specified for these parameters. Lower fixed values of *M* and *h* lead to less optimistic results, with the lowest estimates of both 2003 spawning biomass (5,165 tonnes) and 2003 depletion (19%) occurring with a steepness of 0.6 and a *M* of 0.1 yr^{-1}. Versions of the base-case model which estimated steepness provided even less optimistic estimates of 2003 stock status (Table 8.22), although these results should be interpreted with caution because the models with an *M* of 0.15 yr^{-1} and 0.2 yr^{-1} both resulted in an estimate of steepness of 0.2, which is the lower bound for this parameter. Attempts to estimate the rate of natural mortality also lead to implausible results for fixed values of steepness of 0.7 and 0.8 (Table 8.22). The model predictions obtained when estimating natural mortality ($M = 0.159\ \mathrm{yr}^{-1}$) when steepness was fixed at 0.6 is more consistent with the results of the other base-case models (Table 8.22). It was possible to obtain estimates for the model parameters when both *M* and *h* were treated as estimable parameters. However as with the other analyses that estimated the steepness parameter, the estimate of *h* deemed as providing the best fit was at the lower bound, at 0.2.

The depletion level in 1962 is presented in Table 8.22, because Klaer (MS) calculated estimates of morwong biomass based on the NSW catch history to this point. The point estimate obtained by Klaer (MS) for 1962 depletion was 71%. The values obtained for the base-case assessments for 1962 depletion (Table 8.22) are generally higher (more optimistic regarding 1962 stock status) than that obtained by Klaer. This is probably due to the fact that the current assessment is estimating biomass trends for all the eastern zones, as opposed to just NSW. Other eastern regions were only lightly exploited by 1962. Another factor contributing to these higher estimates of 1962 depletion could also be the estimation of good recruitments for the years prior to 1962 - the analysis by Klaer assumed recruitment to be related deterministically to spawning biomass according to a Beverton-Holt stock-recruitment relationship.

Figure 8.17 shows the median and central 95% probability interval of the estimated trend in spawning biomass for the base-case model with M=0.15yr^{-1} and h=0.7, along with the posterior probability distributions for virgin spawning biomass (SB_0), and the 2003 depletion level.

The estimates of the time-trajectory of exploitation rate for the five fleets are shown in Figure 8.18 for two versions of the base-case assessment. Unsurprisingly, the more pessimistic of the two scenarios (M=0.1 yr^{-1}, h=0.6) estimates current exploitation rates to be higher than the analysis which assumes that the stock is more productive (M=0.15 yr^{-1}, h=0.7).

The selectivity patterns estimated for each fleet are shown in Figure 8.19 for one version of the base-case model (M=0.15 yr^{-1}, h=0.7). The selectivity ogive did not differ all that much among the five fleets. The assumption of asymptotic selectivity, in addition to the decision to only use the port-sampled length-composition data when fitting the model (thus only considering retained catch) may be the cause for this result. As noted in Section 8.5.2, the two estimated selectivity parameters for each fleet were very highly correlated (Figure 8.4). Length frequency information indicates that most of the retained catch is of fish greater than 25cm in length, which, given the estimates of mean length-at-age used, and no ageing error, suggests that the majority of the catch is from fish four and older. Given the values assumed for the distribution of size-at-age (Table 8.B.1), it seems quite reasonable to expect the estimates of selectivity to be fairly rigorously defined as changing very rapidly between ages 3 and 4 as is evident in Figure 8.19.

The version of Coleraine used in the assessment estimates recruitment residuals for every year from 1915-2002. Figure 8.20(a) plots the estimated recruitments from 1915-2002 for the base-case analysis with M=0.15 yr^{-1} and h=0.7, and also plots the recruitment residuals over this period. The model estimates that most of the recruitments in recent years have been below average, i.e. the recruitment residuals during the past 20 years are largely negative. This is contrasted with high variability in recruitment (both positive and negative residuals) during the period from the mid 1940s – 1960s, when historical length frequency data are available. Estimates of recruitment residuals prior to this period show a progressive negative trend, and there is a run of correlated positive residuals during the 1970s (Figure 8.20(a), right panel). Both of these periods correspond to years for which no length composition data are available.

8.5.4 Sensitivity analyses

Table 8.23 shows the results of sensitivity analyses which investigate the sensitivity of the model predictions when some of the assumptions of the base-case model are changed. The negative trend in the standardised CPUE data is mimicked better when more weight is assigned to these data ("CPUE CV=0.1" in Table 8.23; Figure 8.21). It is perhaps unrealistic to assume that the CV of the logbook CPUE data would be as low as 10%. However, it is also desirable to produce a fit to the CPUE indices that is adequate, given that these data are assumed to reflect changes in stock abundance. Assuming a CV of 10% results in a more pessimistic estimate of 2003 stock status than does the base case (Table 8.23). As expected given these results, the analysis which placed less weight on the CPUE data ("CPUE CV=0.3" in Table 8.23), produced a more optimistic appraisal of stock status. The assessment results are only slightly less optimistic than those for the base-case analysis when the bootstrap estimates of the CVs from the GLM analyses are used when fitting to the catch-rate data ("CV=bootstrapping estimates" in Table 8.23).

Decreasing the sample size assigned to the historical length-frequency data further (sensitivity test "Downweight historical length frequencies" in Table 8.23) results in a slight increase in the estimate of current depletion. This is because the model estimates a much lower degree of variability in recruitment during the historical period, and, as a result, the estimates of recruitment during the late 1930s, early 1940s, and 1960s, to be more tightly distributed about the average (Figure 8.20(b)). Interestingly, although changes in the contributions to the negative log-likelihood function of these data are not comparable with the base-case analyses because the sample size is changed, there is no visual depreciation in the model fits to the length data.

Increasing the extent of recruitment variability ("σ_r = 0.5" in Table 8.23) produces a more pessimistic appraisal of 2003 stock status (Table 8.23). The recruitment residuals from 1985 are generally negative (Figure 8.20(c)), although more so than is the case for the base-case analysis (Figure 8.20(a)). This results in a larger decline in spawning biomass from 1985 (Figure 8.22(b)). Unsurprisingly, increasing the amount of recruitment variability also increases the uncertainty associated with the estimates of historical spawning biomass (Figure 8.22(b)).

8.5.5 Projections

The projections into the future were based on the three Bayesian analyses (a - base-case, b - CPUE CV =0.1, and c - increased recruitment variability; Figures 8.17 and 8.22). These analyses all assume M=0.15 yr^{-1} and h=0.7. Each set of projections involved 1,000 draws from the joint posterior probability distribution for the model parameters. The projections assumed fixed levels of future catch, and that the relative proportions by fleet of the total catch equalled that for 2002 (fleet 3- 69.1%, fleet 4 – 8.5%, fleet 5 – 22.4%, Table 8.2).

Figures 8.23-8.25 show the median and central 95% probability intervals of projected spawning biomass to 2014, the distribution for 2014 spawning biomass, and the distribution for 2014 depletion, for the three analyses for which Bayesian posteriors were obtained, for six different levels of future annual TAC (it is assumed that the catch equals the TAC). The base-case projections (Figure 8.23) show that there is very little probability that the depletion level in 2014 is less than 25% under a future TAC of 1,200 t. This level of catch is much greater than that landed in the eastern zones in 2002 and for several years prior to 2002. Unsurprisingly, catches higher than 1,200 t result in the probability distribution for expected 2014 depletion shifting lower, with catches approximating current (late 1990s / early 2000s) eastern zone landings resulting in an increase in spawning stock biomass over the projection period. Results for a less productive version of the base-case analysis (M=0.1 yr^{-1}, h=0.6) indicate that a TAC of 1,200 t would probably not be sustainable owing to the lower productivity of the population, and the fact that this version of the model estimates the stock to be more heavily depleted in 2003 than suggested by the base-case analysis with M=0.15yr^{-1} and h=0.6 (Table 8.22).

A similarly pessimistic scenario regarding 2003 spawning stock status was predicted by the sensitivity analysis which fixed the CVs of the data from the two recent CPUE indices at 10%. However, projections from the posterior distribution for this analysis with future annual catches of 1,200 t or less produced predictions of 2014 depletion only slightly more pessimistic than those for the base-case analysis, given the same parameter values for natural mortality and steepness (Figure 8.24). The distributions for 2014 spawning biomass were of course lower than those observed in the base-case analysis, with there being some probability that spawning biomass would be less than 10,000 t in 2014 even with a future TAC of 600 t. This, and indeed the prediction of extinctions with a future TAC of 1600 t, is not surprising because the distribution for 2003 spawning biomass is lower for this sensitivity analysis than for the base-case analysis (Figure 8.22).

Increasing the variability in recruitment increases the uncertainty around the predictions of future stock status under all of future fixed catch levels considered (Figure 8.25). If σ_r is set at 0.5, then all six levels of TAC have some probability that the spawning stock biomass will be less than 10,000 t in 2014. The results in Figure 8.25 show that TACs in excess of 800 t lead to distributions with some probability that the 2014 depletion will be below 20%.

8.5.6 General discussion

The model predictions, in terms of estimates of stock status, are very sensitive to assumptions about the amount of recruitment variability, and the weight assigned to the historical length-frequency information. Unsurprisingly, the model predictions are also sensitive to the values chosen for the steepness parameter and the rate of natural mortality. It was not possible to obtain variance estimates for those analyses in which these parameters were estimated because effective sampling from the posterior distribution for these parameters was not possible even if the MCMC algorithm was initialised at a parameter vector with ‘reasonable’ values for these parameters. The sampling-importance-resampling (SIR) algorithm (Gelman *et al.*, 1995; Punt and Hilborn, 1997) may have provided a more effective means of sampling the posterior distribution in this case. It was therefore necessary to examine a wider range of scenarios than may otherwise be the case given the lack of information for these two parameters.

The population dynamics model is confronted with negative trends in the CPUE data during a period when catches were much lower than previously in the history of the fishery and no obvious trend in the age- or length-composition data. The model attempts to reconcile these pieces of information by estimating that annual recruitments have largely been below average since the mid-1980s, thus enabling the stock to continue to decline even though removals are low. The CPUE data can be mimicked by either reducing the productivity of the stock, increasing the variability in recruitment, or by forcing the model to fit the CPUE data by increasing the relative weight assigned to those data.

Problems with assuming a relatively unproductive stock appear to be associated with the fact that recruitment residuals were estimated within the model for all years in the time series, with the result that a series of negative residuals were estimated in the historical phase of the fishery (prior to the 1940s), when there are no length-composition data. This results in the model estimating the stock to have declined far more over this early period than would be sensible given the removals data.

Similarly, assuming a highly productive stock resulted in estimates which indicate that the fishery has had little impact on the jackass morwong population - the data are then mimicked by stochastic processes attributed to recruitment variability rather than changes in the distribution and extent of the fishery.

The posterior distributions for 2003 stock status obtained would indicate that jackass morwong in the eastern areas appear to be somewhere around 25-45% of 1915 spawning biomass. The three analyses chosen for the Bayesian analyses largely typify the estimates of stock status shown in the results tables. The projection results presented would indicate that, given the assumptions in the base-case scenario, current removals from the eastern areas are perhaps sustainable. The sensitivity analyses which provided a more pessimistic prediction of 2003 stock status unsurprisingly suggest that a lower TAC than that suggested by the base-case analysis may be more appropriate.

It is important to acknowledge the lack of inclusion of the removals from the western areas in the assessment. As noted above, landings from western Victoria in particular have become a substantial component of the annual total of morwong taken in recent years. The implications of changes in the distribution of the fishery to and from these areas, whether landings there represent an additional stock or not, should be considered when determining potential removals. If fish landed in the western areas are from the same stock as those landed from eastern areas then it is likely that the exploitation rate in recent years is under-estimated by the analyses in this assessment. Determining the relatedness of fish in western areas to those caught in eastern zones may therefore be a priority.

8.6 Future Development

The analyses of this document could be extended in future in several ways.

1) Explicitly allow for discarding through the use of the onboard length frequency data from the SMP.
2) Estimation of recruitment residuals should be limited to those years for which appropriate data are available.
3) The parameters of the growth curve could be estimated within the assessment model, reducing the impact of selectivity bias on the parameter estimates.
4) Selectivity could be modelled as being a function of length.
5) Re-parameterisation of the selectivity functions to reduce correlation among the parameters.
6) The relationship between the jackass morwong caught in the western zones and those in the eastern zones included in this assessment warrants attention. If fish from the western zones are part of the same spawning stock as those in the east, then the implications of including the catches from west Tasmania and west Victoria should be considered. This issue will continue to be of increasing importance if future composition of the catch by area continues to follow recent trends.
7) Inclusion of additional length frequency data from years prior to the establishment of the SEF, which exist but were not available for this assessment.
8) Inclusion of the catch rate index produced by Smith (1989) for the overlap years between the steam trawl and ‘other boats’ fleets.
9) Separation of landings by gear type and/or area in the years prior to establishment of the SEF. The similarities in the estimates of the selectivities for the different fleets in this assessment suggests that this may not be of major importance.

Implementing the majority of the points listed above would necessitate the use of an alternative software package to the version of Coleraine used in this assessment.

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Table 8.1 : Landed catches (metric tonnes) of jackass morwong by steam trawlers and other boats in New South Wales and East Victoria (fleets 1 and 2) from 1915–1985. Time series of catches derived from Klaer (MS) and Allen (1989).

Year	Steam Trawl	Other Boats
1915	49	0
1916	50	0
1917	58	0
1918	89	0
1919	99	0
1920	145	0
1921	143	0
1922	102	0
1923	98	0
1924	162	0
1925	235	0
1926	259	0
1927	327	0
1928	391	0
1929	449	1
1930	398	4
1931	420	0
1932	380	5
1933	352	0
1934	326	4
1935	361	3
1936	390	12
1937	419	8
1938	421	9
1939	413	17
1940	74	18
1941	79	21
1942	20	0
1943	2	5
1944	67	189
1945	305	260
1946	1538	275
1947	2096	221
1948	1472	273
1949	1182	334
1950	819	299

(Table 8.1 Continued)

Year	Steam Trawl	Other Boats
1951	867	322
1952	971	535
1953	740	612
1954	754	920
1955	489	1088
1956	709	1430
1957	540	1668
1958	501	1257
1959	253	1249
1960	95	993
1961	16	1185
1962	0	2489
1963	0	1950
1964	0	1472
1965	0	2210
1966	0	2709
1967	0	1237
1968	0	1846
1969	0	1442
1970	0	1362
1971	0	1582
1972	0	1525
1973	0	1925
1974	0	1843
1975	0	1969
1976	0	1841
1977	0	1361
1978	0	1624
1979	0	1649
1980	0	2556
1981	0	2347
1982	0	1789
1983	0	1806
1984	0	1733
1985	0	1096

Table 8.2 : Adjusted landed catches (metric tonnes) of jackass morwong by fleet for the years 1986-2002. Landings information for west Tasmania and west Victoria is presented for completeness. These catches were not included in the assessment.

Year	NSW, BS & East Vic. (otter trawl)	NSW, BS & East Vic. (Danish seine)	East Tasmania	West Tasmania	West Victoria
1986	873	7	33	0	171
1987	1038	14	90	15	52
1988	1265	41	241	18	57
1989	1123	23	569	57	38
1990	757	46	178	15	77
1991	898	28	254	16	37
1992	550	24	149	31	46
1993	667	4	388	5	23
1994	622	10	208	5	21
1995	525	4	211	76	12
1996	626	28	183	12	30
1997	747	72	232	31	29
1998	506	71	217	50	13
1999	526	31	280	72	16
2000	559	51	141	121	13
2001	289	73	126	147	167
2002	382	47	124	111	176

Table 8.3 : Values for biological parameters used in the assessment.

Parameter	Value(s)
Length-weight relationship	
a	1.7×10^{-5}
b	3.031
Growth curve	
L_∞	35.65cm
K	0.419 yr^{-1}
t_0	0
Rate of natural mortality, M	0.1, 0.15, 0.2 yr^{-1}
Steepness, h	0.6, 0.7, 0.8

Table 8.4 : Annual totals (all regions) of SEF1 logbook catches of morwong and reported SEF2 landings, with ratio of SEF2/SEF1 totals for the years in which both sources of data are available. The scaling factor applied to the SEF1 logbook data prior to use in the assessment is derived from the difference between totals for all years (bold type).

Year	SEF1	SEF2	SEF2/SEF1
1992	714.4	742.9	1.04
1993	969.7	1045.1	1.08
1994	771.7	887.8	1.15
1995	736.6	856.8	1.16
1996	781.8	892.2	1.14
1997	987.7	1132.5	1.15
1998	761.4	882.7	1.16
1999	821.3	935.1	1.14
2000	787.0	881.1	1.12
2001	714.3	816.2	1.14
2002	748.9	846.4	1.13
Total	8794.7	9918.7	**1.128**

Table 8.5 : Percent by weight of jackass morwong which were discarded. A dash indicates that no samples were available for the area / year combination concerned.

	% by weight of retained samples which were discarded				
Year	NSW	EVic	ETas	WTas	WVic
1993	11.1	5.4	3.1	-	-
1994	-	3.8	5.9	-	1.8
1995	-	8.9	100	0	0
1996	-	7.4	1.3	-	0.5
1997	-	5.7	1.1	-	0
1998	0.3	3.9	10.3	-	0.4
1999	0.2	1.4	12.2	-	0
2000	1.6	5.8	1.8	-	1.8
2001	0.2	3.3	3.7	0	0.1
2002	0.1	0.2	12.8	0	0.2

Table 8.6 : Length composition data for the discarded component of the catch for fleets 3, 4, and 5 from the period 1996-2002. The row ‘Number’ indicates the number of fish sampled in the discard data for that year.

Length (cm)	fleet 3						fleet 4			fleet 5			
	1996	1997	1998	1999	2000	2001	2000	2001	2002	1997	1998	1999	2001
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.235	0.500	0.002	0.000	0.000	0.004	0.000
18	0.005	0.000	0.000	0.000	0.000	0.000	0.294	0.167	0.020	0.000	0.000	0.004	0.000
19	0.006	0.000	0.000	0.009	0.024	0.000	0.206	0.167	0.009	0.000	0.000	0.000	0.000
20	0.040	0.000	0.000	0.078	0.207	0.000	0.235	0.000	0.050	0.000	0.000	0.004	0.013
21	0.132	0.017	0.006	0.039	0.415	0.003	0.029	0.000	0.068	0.000	0.012	0.002	0.012
22	0.263	0.037	0.000	0.024	0.281	0.038	0.000	0.167	0.095	0.146	0.013	0.005	0.020
23	0.241	0.182	0.000	0.000	0.073	0.152	0.000	0.000	0.091	0.000	0.039	0.017	0.054
24	0.158	0.229	0.050	0.098	0.000	0.321	0.000	0.000	0.128	0.164	0.067	0.037	0.082
25	0.121	0.254	0.038	0.093	0.000	0.476	0.000	0.000	0.194	0.309	0.172	0.054	0.111
26	0.027	0.174	0.106	0.231	0.000	0.010	0.000	0.000	0.155	0.218	0.186	0.072	0.197
27	0.002	0.079	0.239	0.245	0.000	0.000	0.000	0.000	0.120	0.164	0.185	0.112	0.225
28	0.006	0.016	0.278	0.125	0.000	0.000	0.000	0.000	0.068	0.000	0.171	0.139	0.172
29	0.000	0.013	0.283	0.039	0.000	0.000	0.000	0.000	0.001	0.000	0.101	0.176	0.111
30	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.042	0.171	0.003
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.145	0.000
32	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.045	0.000
33	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000
34	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000
35	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Number	244	342	147	57	82	118	34	6	131	10	427	588	419
Mean length	22.8	24.7	27.5	25.6	21.2	24.3	18.5	18.3	24.3	24.9	26.5	28.4	26.3

Table 8.7 : Percentage of jackass morwong of given lengths (CFL) that were discarded, from samples taken in all years for which onboard length composition data were available (1996-2002). Zeroes indicate a retained catch and no discarding, and a dash indicates that no samples (retained or discarded) were available for that length.

Length (cm)	NSW, EVic, BS trawl	NSW, EVic, BS Danish seine	ETas trawl	WVic
15	-	-	-	-
16	-	-	-	-
17	-	100	100	-
18	100	100	100	-
19	100	100	-	-
20	97.1	100	59.2	0
21	88.6	100	54.4	0
22	76.5	100	70.3	0
23	68.4	100	73.4	0
24	50.9	86.3	74.9	0
25	35.2	89.1	73.5	0
26	11.8	95.8	73.7	0
27	5	97.3	60.7	0
28	1.9	100	35.3	0
29	1.5	11.1	21.9	0
30	0.1	0	9.6	0
31	0	0	6.4	0
32	0	-	2.2	0
33	0	-	0.5	0
34	0	-	0.1	0
35	0	-	0.1	0
36	0	0	0	0
37	0	-	0	0
38	0	-	0	0
39	0	-	0	0
40	0	-	0	0
41	0	-	0	0
42	0	-	0	0
43	0	-	0	0
44	0	-	0	0
45	0	-	0	-
46	0	-	0	-
47	0	-	0	-
48	-	-	0	-
49	0	-	0	-
50	-	-	-	-

Table 8.8 : Standardised time series of catch-per-unit-effort (CPUE) for jackass morwong by steam trawlers (1920-57). Source: (Klaer, MS).

Year	CPUE
1920	1.54
1921	1.09
1937	1.25
1938	1.06
1939	1.14
1940	1.35
1941	1.12
1942	0.96
1952	0.98
1953	0.79
1954	0.82
1955	1.02
1956	0.89
1957	0.84

Table 8.9 : Standardised time series of catch-per-unit-effort (CPUE) for jackass morwong off New South Wales and east Victoria (1977-83). Source: (Smith, 1989).

Year	CPUE
1977	19.7
1978	20.3
1979	18.9
1980	17.1
1981	19.6
1982	16.3
1983	13.9

Table 8.10 : Standardised time series of catch-per-unit-effort (CPUE) in kg.hr^{-1} with bootstrapped estimates of coefficients of variation (CVs) for otter trawlers off New South Wales, Bass Strait and eastern Victoria (fleet 3) and east Tasmania (fleet 5). The standardisation procedure is outlined in Appendix 8.C.

	NSW, Bass Strait, and East Vic.		East Tasmania	
Year	CPUE	CV	CPUE	CV
1986	23.7	0.16	63.8	0.26
1987	28.4	0.15	78.3	0.22
1988	25.2	0.15	125.9	0.22
1989	24.7	0.15	135.6	0.20
1990	19.8	0.14	92.2	0.21
1991	19.4	0.15	92.4	0.19
1992	17.8	0.15	71.3	0.19
1993	17.7	0.15	72.3	0.19
1994	16.9	0.15	47.3	0.20
1995	14.8	0.15	45.4	0.19
1996	13.7	0.15	46.3	0.19
1997	16.3	0.15	55.8	0.20
1998	14.6	0.14	52.2	0.18
1999	14.6	0.15	58.6	0.20
2000	15.2	0.15	42.1	0.20
2001	12.6	0.15	38.3	0.20
2002	13.6	0.15	34.5	0.20

Table 8.11 : Standardised time series of catch-per-unit-effort (CPUE) for jackass morwong off New South Wales and east Victoria (1948-66). Source: (Smith, 1989).

Year	CPUE (t / st. v/yr)
1948	123.7
1949	105.4
1950	84.4
1951	74.2
1952	92.8
1953	116.1
1954	92.6
1955	71.6
1956	99.2
1957	90.1
1958	63.3
1959	79.3
1960	77.6
1961	85.0
1962	79.7
1963	89.5
1964	89.8
1965	89.6
1966	82.4

Table 8.12 : Number of port samples (N_{samp}), and number of fish sampled in port samples (N_{port}) and onboard data ($N_{onboard}$)contributing to length composition information for fleets 3, 4, 5, and 6 for the period 1991-2002.

	fleet 3			fleet 4			fleet 5			fleet 6		
Year	$N_{samp.}$	N_{port}	$N_{onboard}$	$N_{samp.}$	N_{port}	$N_{onboard}$	$N_{samp.}$	N_{port}	$N_{onboard}$	$N_{samp.}$	N_{port}	$N_{onboard}$
1991	8	1181	0	0	0	0	0	0	0	0	0	0
1992	9	1355	0	1	51	0	0	0	0	0	0	0
1993	11	2359	0	0	0	0	0	0	0	0	0	0
1994	14	1124	0	0	0	0	0	0	0	0	0	0
1995	10	531	0	0	0	0	0	0	0	0	0	0
1996	42	2990	1108	1	33	0	1	87	0	3	364	0
1997	46	3190	3441	5	340	0	4	282	267	4	505	245
1998	113	8078	3431	17	1070	0	12	835	1941	1	2	373
1999	187	12659	3653	4	295	0	35	2384	2094	3	341	412
2000	118	8089	2043	7	259	58	11	762	934	5	572	124
2001	76	5588	3301	7	330	6	11	664	2300	21	2232	1434
2002	60	5856	2172	9	388	131	13	2116	647	12	1918	859

Table 8.13 : Port length frequency information for jackass morwong caught by otter trawlers off NSW, Bass Strait, and East Victoria (fleet 3). The row 'Number' indicates the number of fish measured.

Length (cm)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003
22	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.002	0.001	0.007	0.015
23	0.002	0.001	0.001	0.000	0.002	0.004	0.000	0.007	0.003	0.002	0.013	0.042
24	0.002	0.010	0.002	0.000	0.000	0.011	0.001	0.014	0.006	0.003	0.022	0.052
25	0.014	0.015	0.007	0.001	0.013	0.021	0.009	0.033	0.017	0.011	0.025	0.054
26	0.046	0.029	0.014	0.008	0.019	0.036	0.014	0.071	0.039	0.027	0.038	0.066
27	0.109	0.087	0.016	0.019	0.034	0.056	0.042	0.085	0.067	0.060	0.056	0.080
28	0.175	0.121	0.026	0.054	0.028	0.073	0.067	0.097	0.102	0.095	0.095	0.097
29	0.189	0.107	0.048	0.064	0.065	0.095	0.103	0.112	0.138	0.135	0.106	0.139
30	0.179	0.117	0.058	0.114	0.077	0.099	0.084	0.111	0.131	0.134	0.124	0.090
31	0.115	0.115	0.067	0.116	0.074	0.109	0.105	0.091	0.131	0.128	0.117	0.078
32	0.070	0.088	0.088	0.107	0.087	0.109	0.107	0.087	0.102	0.109	0.099	0.068
33	0.045	0.054	0.099	0.106	0.085	0.090	0.096	0.061	0.079	0.088	0.081	0.055
34	0.018	0.087	0.099	0.076	0.103	0.080	0.094	0.056	0.058	0.059	0.058	0.043
35	0.011	0.070	0.091	0.060	0.091	0.064	0.091	0.046	0.041	0.043	0.052	0.036
36	0.007	0.033	0.075	0.058	0.099	0.052	0.067	0.036	0.030	0.031	0.034	0.023
37	0.006	0.032	0.064	0.040	0.083	0.035	0.047	0.028	0.021	0.023	0.022	0.018
38	0.005	0.016	0.069	0.057	0.054	0.016	0.029	0.022	0.015	0.017	0.017	0.014
39	0.003	0.011	0.053	0.035	0.046	0.013	0.022	0.012	0.010	0.015	0.013	0.011
40+	0.004	0.009	0.121	0.084	0.039	0.036	0.023	0.029	0.011	0.021	0.019	0.015
Number	1181	1355	2359	1124	595	3088	3293	8078	13048	8393	5588	5856
Mean length	29.6	31.0	34.4	33.3	33.4	31.8	32.4	30.8	30.8	31.2	30.8	29.5

Table 8.14 : Port length frequency information for jackass morwong caught by Danish seine vessels off NSW, Bass Strait, and East Victoria (fleet 4). The row 'Number' indicates the number of fish measured.

Length (cm)	1992	1995	1996	1997	1998	1999	2000	2001	2002
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.004	0.007	0.000	0.004	0.000	0.000
23	0.000	0.000	0.000	0.015	0.015	0.000	0.000	0.000	0.000
24	0.000	0.014	0.000	0.062	0.036	0.000	0.011	0.000	0.013
25	0.000	0.028	0.000	0.116	0.075	0.000	0.035	0.005	0.043
26	0.000	0.064	0.000	0.116	0.092	0.000	0.045	0.009	0.081
27	0.000	0.064	0.000	0.126	0.209	0.054	0.042	0.049	0.098
28	0.059	0.106	0.000	0.125	0.126	0.147	0.135	0.048	0.139
29	0.000	0.113	0.000	0.143	0.144	0.146	0.165	0.148	0.172
30	0.078	0.106	0.000	0.086	0.119	0.197	0.157	0.150	0.100
31	0.118	0.121	0.000	0.054	0.075	0.215	0.174	0.168	0.145
32	0.216	0.135	0.061	0.041	0.062	0.105	0.048	0.175	0.079
33	0.235	0.135	0.000	0.036	0.017	0.063	0.125	0.089	0.047
34	0.137	0.085	0.061	0.035	0.010	0.029	0.049	0.075	0.041
35	0.118	0.021	0.121	0.013	0.005	0.025	0.005	0.033	0.020
36	0.020	0.007	0.091	0.017	0.003	0.007	0.003	0.029	0.006
37	0.020	0.000	0.242	0.004	0.002	0.006	0.001	0.011	0.006
38	0.014	0.000	0.000	0.182	0.003	0.001	0.003	0.001	0.007
39	0.012	0.000	0.000	0.152	0.003	0.000	0.002	0.001	0.002
40+	0.014	0.000	0.000	0.091	0.000	0.000	0.002	0.001	0.003
Number	51	141	33	340	1070	295	259	330	388
Mean length	32.5	30.3	37.1	28.3	28.2	30.4	29.9	31.1	29.5

Table 8.15 : Port length frequency information for jackass morwong caught by otter trawlers off Eastern Tasmania (fleet 5). The row 'Number' indicates the number of fish measured.

Length (cm)	1996	1997	1998	1999	2000	2001	2002
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.001	0.001	0.000
23	0.000	0.000	0.002	0.002	0.001	0.002	0.005
24	0.000	0.000	0.007	0.003	0.002	0.004	0.014
25	0.034	0.000	0.028	0.009	0.007	0.009	0.023
26	0.011	0.014	0.030	0.032	0.029	0.011	0.054
27	0.069	0.021	0.056	0.059	0.055	0.023	0.080
28	0.034	0.073	0.106	0.122	0.090	0.048	0.105
29	0.057	0.111	0.166	0.122	0.096	0.071	0.106
30	0.126	0.096	0.139	0.131	0.114	0.103	0.113
31	0.138	0.093	0.136	0.134	0.126	0.109	0.090
32	0.103	0.114	0.066	0.114	0.189	0.089	0.091
33	0.057	0.124	0.108	0.079	0.099	0.097	0.068
34	0.103	0.086	0.055	0.052	0.061	0.106	0.064
35	0.057	0.092	0.033	0.042	0.046	0.105	0.035
36	0.069	0.042	0.026	0.033	0.033	0.066	0.037
37	0.057	0.044	0.015	0.023	0.021	0.037	0.025
38	0.000	0.000	0.011	0.036	0.015	0.015	0.019
39	0.003	0.000	0.023	0.026	0.006	0.012	0.005
40+	0.008	0.000	0.046	0.030	0.007	0.016	0.008
Number	87	282	835	2390	762	664	2116
Mean length	32.3	32.5	30.6	31.0	31.3	32.9	31.2

Table 8.16 : Port length frequency information for jackass morwong caught by otter trawlers off Western Tasmania and West Victoria (fleet 6). The row ‘Number’ indicates the number of fish measured.

Length (cm)	1980	1981	1996	1997	1999	2000	2001	2002
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.002	0.002	0.000	0.000	0.000	0.000
22	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.015	0.005	0.000	0.000	0.002	0.000
24	0.000	0.000	0.026	0.007	0.002	0.000	0.003	0.001
25	0.000	0.000	0.045	0.017	0.002	0.000	0.009	0.000
26	0.028	0.000	0.059	0.034	0.006	0.004	0.011	0.001
27	0.000	0.000	0.098	0.052	0.020	0.002	0.017	0.007
28	0.042	0.000	0.128	0.033	0.023	0.002	0.043	0.012
29	0.070	0.017	0.165	0.039	0.043	0.004	0.075	0.021
30	0.014	0.017	0.103	0.060	0.074	0.002	0.095	0.032
31	0.084	0.017	0.110	0.036	0.105	0.017	0.150	0.044
32	0.042	0.025	0.082	0.063	0.120	0.040	0.163	0.065
33	0.084	0.034	0.057	0.085	0.103	0.018	0.148	0.072
34	0.084	0.034	0.053	0.088	0.104	0.056	0.095	0.121
35	0.084	0.059	0.022	0.077	0.085	0.108	0.072	0.121
36	0.084	0.076	0.006	0.106	0.062	0.110	0.055	0.135
37	0.028	0.059	0.009	0.059	0.084	0.134	0.024	0.116
38	0.070	0.102	0.006	0.073	0.056	0.116	0.015	0.091
39	0.070	0.076	0.006	0.055	0.040	0.103	0.008	0.062
40+	0.211	0.483	0.003	0.107	0.070	0.281	0.016	0.101
Number	71	118	364	2106	2036	572	869	1918
Mean length	34.9	37.8	29.5	33.8	33.8	37.2	32.2	35.3

Table 8.17 : Market length frequency information for jackass morwong caught by steam trawlers off NSW and East Victoria (fleet 1). The row 'Number' indicates the number of fish measured.

Length (cm)	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.002	0.000	0.005	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.010	0.001	0.012	0.009	0.002	0.000	0.001	0.001	0.002	0.001	0.000
22	0.004	0.018	0.004	0.018	0.021	0.008	0.002	0.004	0.003	0.003	0.001	0.001
23	0.012	0.019	0.013	0.033	0.038	0.018	0.007	0.007	0.015	0.011	0.004	0.004
24	0.022	0.027	0.026	0.037	0.051	0.035	0.016	0.011	0.032	0.026	0.017	0.009
25	0.018	0.040	0.039	0.041	0.052	0.059	0.032	0.017	0.046	0.039	0.033	0.019
26	0.022	0.053	0.044	0.052	0.052	0.072	0.056	0.025	0.057	0.057	0.054	0.021
27	0.035	0.058	0.063	0.086	0.051	0.080	0.078	0.050	0.055	0.074	0.079	0.034
28	0.062	0.069	0.086	0.084	0.061	0.089	0.089	0.076	0.055	0.082	0.111	0.052
29	0.084	0.078	0.094	0.088	0.070	0.084	0.098	0.109	0.074	0.077	0.114	0.091
30	0.096	0.092	0.097	0.105	0.080	0.084	0.102	0.125	0.090	0.102	0.123	0.112
31	0.113	0.107	0.106	0.097	0.088	0.081	0.100	0.117	0.098	0.091	0.085	0.113
32	0.119	0.096	0.109	0.082	0.090	0.080	0.084	0.104	0.093	0.088	0.073	0.105
33	0.118	0.090	0.086	0.072	0.074	0.071	0.079	0.077	0.083	0.079	0.070	0.089
34	0.094	0.075	0.075	0.065	0.077	0.063	0.065	0.067	0.075	0.064	0.059	0.079
35	0.077	0.060	0.056	0.048	0.055	0.052	0.055	0.053	0.060	0.053	0.053	0.070
36	0.055	0.043	0.039	0.032	0.042	0.039	0.042	0.046	0.050	0.045	0.048	0.057
37	0.031	0.029	0.028	0.021	0.030	0.031	0.032	0.032	0.039	0.032	0.031	0.052
38	0.020	0.018	0.015	0.012	0.022	0.021	0.023	0.030	0.028	0.029	0.019	0.037
39	0.011	0.010	0.008	0.007	0.014	0.013	0.016	0.018	0.019	0.016	0.012	0.025
40+	0.009	0.008	0.010	0.005	0.021	0.019	0.022	0.030	0.029	0.029	0.014	0.031
Number	4836	13960	8577	8823	9721	9456	7956	8033	12010	7997	6351	3243
Mean length	31.6	30.6	30.8	29.8	30.4	30.4	31.0	31.6	31.3	31.1	30.7	32.3

Table 8.18 : Market length frequency information for jackass morwong caught by ‘other boats’ (primarily Danish Seine) in NSW and East Victoria (fleet 2). The row ‘Number’ indicates the number of fish measured.

Length (cm)	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.003	0.000	0.003	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
21	0.002	0.015	0.000	0.018	0.003	0.002	0.000	0.004	0.003	0.001	0.000	0.003	0.003	0.002	0.001	0.001	0.001	0.000	0.000	0.001
22	0.008	0.018	0.003	0.029	0.006	0.012	0.001	0.011	0.008	0.006	0.002	0.007	0.007	0.009	0.004	0.003	0.004	0.002	0.001	0.003
23	0.021	0.018	0.006	0.030	0.021	0.016	0.003	0.014	0.018	0.019	0.007	0.012	0.012	0.019	0.012	0.006	0.008	0.004	0.003	0.008
24	0.022	0.018	0.010	0.036	0.045	0.027	0.010	0.028	0.028	0.034	0.014	0.018	0.019	0.030	0.025	0.010	0.018	0.013	0.006	0.012
25	0.009	0.028	0.016	0.037	0.057	0.052	0.020	0.019	0.055	0.054	0.026	0.027	0.032	0.038	0.037	0.016	0.030	0.023	0.011	0.017
26	0.018	0.039	0.033	0.046	0.056	0.060	0.030	0.028	0.064	0.076	0.050	0.034	0.038	0.045	0.049	0.033	0.047	0.038	0.024	0.030
27	0.016	0.045	0.040	0.060	0.057	0.077	0.060	0.033	0.059	0.084	0.084	0.051	0.046	0.058	0.055	0.055	0.054	0.058	0.046	0.051
28	0.038	0.046	0.066	0.086	0.068	0.080	0.090	0.061	0.057	0.089	0.094	0.072	0.067	0.063	0.058	0.074	0.070	0.081	0.071	0.068
29	0.058	0.050	0.077	0.090	0.081	0.088	0.092	0.085	0.048	0.076	0.103	0.097	0.068	0.066	0.060	0.090	0.090	0.093	0.104	0.086
30	0.082	0.087	0.124	0.093	0.078	0.093	0.125	0.113	0.079	0.089	0.115	0.130	0.099	0.084	0.086	0.094	0.102	0.102	0.117	0.107
31	0.091	0.103	0.127	0.098	0.092	0.090	0.107	0.121	0.096	0.076	0.088	0.114	0.104	0.090	0.088	0.087	0.097	0.103	0.125	0.117
32	0.130	0.124	0.131	0.079	0.087	0.097	0.090	0.113	0.110	0.077	0.087	0.103	0.113	0.094	0.091	0.094	0.096	0.099	0.124	0.118
33	0.133	0.121	0.107	0.072	0.084	0.082	0.093	0.099	0.107	0.075	0.083	0.082	0.100	0.092	0.091	0.090	0.088	0.098	0.108	0.106
34	0.109	0.100	0.098	0.066	0.080	0.071	0.084	0.080	0.087	0.066	0.072	0.069	0.080	0.085	0.092	0.089	0.076	0.079	0.081	0.086
35	0.091	0.071	0.060	0.053	0.065	0.053	0.060	0.068	0.063	0.059	0.061	0.059	0.062	0.069	0.077	0.077	0.065	0.066	0.061	0.065
36	0.077	0.046	0.044	0.036	0.052	0.043	0.042	0.050	0.046	0.046	0.042	0.045	0.054	0.058	0.060	0.063	0.050	0.053	0.045	0.046
37	0.039	0.031	0.027	0.026	0.028	0.024	0.036	0.028	0.033	0.033	0.029	0.030	0.035	0.039	0.044	0.046	0.039	0.036	0.031	0.031
38	0.024	0.020	0.015	0.017	0.018	0.014	0.025	0.015	0.019	0.019	0.020	0.018	0.025	0.025	0.030	0.030	0.026	0.021	0.018	0.022
39	0.016	0.009	0.006	0.010	0.009	0.007	0.015	0.013	0.011	0.012	0.012	0.012	0.018	0.014	0.015	0.018	0.015	0.014	0.011	0.011
40+	0.016	0.009	0.009	0.014	0.012	0.010	0.015	0.018	0.010	0.013	0.013	0.016	0.017	0.019	0.024	0.025	0.023	0.017	0.014	0.016
Number	1590	5070	3882	5511	1933	3779	2749	2231	8627	8769	4826	6205	8569	10660	10038	15498	17887	24744	16586	19328
Mean length	32.2	31.2	31.5	30.1	30.6	30.4	31.4	31.3	30.9	30.5	30.9	31.1	31.4	31.2	31.6	31.9	31.4	31.5	31.6	31.6

Table 8.19 : Age composition of jackass morwong retained by otter trawlers off NSW, Bass Strait, and east Victoria (fleet 3). The row 'N' indicates the number of fish aged in that year.

Age	1991	1992	1993	1994	1996	1997	1998	2000	2001	2002
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.004	0.001	0.021	0.023	0.000	0.007	0.003	0.006	0.000
3	0.060	0.043	0.008	0.013	0.086	0.028	0.086	0.023	0.040	0.009
4	0.403	0.203	0.043	0.151	0.156	0.105	0.245	0.102	0.213	0.114
5	0.205	0.212	0.130	0.283	0.171	0.117	0.099	0.112	0.070	0.166
6	0.101	0.095	0.148	0.141	0.105	0.168	0.055	0.251	0.093	0.116
7	0.060	0.060	0.103	0.154	0.050	0.184	0.080	0.190	0.146	0.075
8	0.057	0.065	0.089	0.111	0.063	0.075	0.055	0.071	0.138	0.081
9	0.020	0.062	0.106	0.021	0.087	0.050	0.017	0.075	0.039	0.076
10	0.050	0.042	0.082	0.026	0.044	0.066	0.036	0.033	0.051	0.078
11	0.007	0.042	0.045	0.023	0.031	0.044	0.099	0.030	0.044	0.050
12	0.014	0.032	0.055	0.016	0.033	0.012	0.040	0.010	0.021	0.042
13	0.005	0.036	0.028	0.000	0.030	0.010	0.005	0.008	0.007	0.010
14	0.005	0.031	0.017	0.023	0.017	0.020	0.018	0.041	0.040	0.027
15	0.001	0.028	0.033	0.000	0.019	0.026	0.061	0.026	0.009	0.082
16	0.005	0.003	0.016	0.009	0.018	0.014	0.014	0.002	0.006	0.017
17	0.000	0.011	0.009	0.006	0.015	0.016	0.011	0.024	0.016	0.016
18	0.003	0.004	0.010	0.004	0.013	0.014	0.004	0.000	0.006	0.007
19	0.003	0.008	0.009	0.000	0.005	0.004	0.038	0.000	0.003	0.004
20+	0.000	0.021	0.069	0.000	0.033	0.046	0.027	0.000	0.052	0.030
N	343	340	596	114	510	230	196	389	384	377

Table 8.20 : Age composition of jackass morwong retained by otter trawlers off Danish seiners off NSW, Bass Strait, and east Victoria (fleet 4). The row 'N' indicates the number of fish aged in that year.

Age	1992	1996	1997	1998	2000	2001	2002
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.014	0.005	0.006	0.000
3	0.029	0.004	0.065	0.155	0.048	0.013	0.009
4	0.130	0.005	0.440	0.384	0.111	0.133	0.092
5	0.166	0.016	0.167	0.112	0.121	0.074	0.202
6	0.092	0.036	0.110	0.060	0.268	0.105	0.050
7	0.063	0.019	0.097	0.060	0.208	0.189	0.086
8	0.065	0.054	0.035	0.033	0.068	0.175	0.105
9	0.071	0.058	0.024	0.020	0.069	0.047	0.095
10	0.069	0.093	0.020	0.035	0.019	0.061	0.088
11	0.074	0.056	0.017	0.055	0.032	0.041	0.050
12	0.062	0.067	0.001	0.028	0.010	0.028	0.053
13	0.049	0.071	0.001	0.004	0.003	0.008	0.011
14	0.030	0.035	0.003	0.002	0.010	0.028	0.030
15	0.049	0.074	0.004	0.008	0.017	0.010	0.043
16	0.001	0.085	0.004	0.007	0.003	0.004	0.022
17	0.018	0.096	0.001	0.001	0.009	0.016	0.016
18	0.001	0.043	0.002	0.000	0.000	0.010	0.010
19	0.008	0.043	0.000	0.008	0.000	0.003	0.007
20+	0.023	0.144	0.009	0.013	0.000	0.049	0.031
N	340	510	230	196	389	384	377

Table 8.21 : Age composition of jackass morwong retained by otter trawlers off east Tasmania (fleet 5). The row ‘N’ indicates the number of fish aged in that year.

Age	1996	1997	1998	2000	2001	2002
1	0.000	0.000	0.000	0.000	0.000	0.000
2	0.009	0.000	0.003	0.003	0.003	0.000
3	0.075	0.030	0.068	0.020	0.012	0.006
4	0.140	0.086	0.240	0.093	0.121	0.071
5	0.157	0.115	0.098	0.118	0.051	0.150
6	0.107	0.182	0.054	0.233	0.086	0.051
7	0.053	0.188	0.087	0.202	0.154	0.090
8	0.064	0.076	0.067	0.074	0.154	0.084
9	0.077	0.048	0.024	0.080	0.041	0.082
10	0.049	0.061	0.049	0.038	0.058	0.087
11	0.034	0.046	0.112	0.038	0.064	0.061
12	0.033	0.014	0.043	0.011	0.026	0.049
13	0.036	0.011	0.008	0.008	0.010	0.011
14	0.017	0.022	0.013	0.037	0.068	0.030
15	0.022	0.028	0.058	0.025	0.016	0.142
16	0.018	0.016	0.015	0.002	0.012	0.020
17	0.046	0.018	0.008	0.019	0.024	0.019
18	0.011	0.014	0.001	0.000	0.006	0.009
19	0.003	0.003	0.029	0.000	0.007	0.004
20+	0.050	0.045	0.023	0.000	0.086	0.037
N	510	230	196	389	384	377

Table 8.22 : Results of the base-case variants of the assessment model, with different pre-specified and estimated values for the rate of natural mortality, *M*, and the steepness parameter, *h*.

Scenario	M (yr^{-1})	h	SB_0	SB_{2003}	SB_{03} / SB_0 (%)	SB_{62} / SB_0 (%)	$-\ell n L$	$-\ell$nCPUE
Base Case	0.1	0.6	27,223	5,165	19.0	69.6	-1400.2	23.4
- fixed M and h	0.1	0.7	25,511	5,505	21.6	66.7	-1397.9	24.9
	0.1	0.8	24,489	5,958	24.3	66.2	-1396.5	27.1
	0.15	0.6	27,643	9,236	33.4	79.1	-1420.4	30.4
	0.15	0.7	26,413	9,635	36.5	79.2	-1418.0	31.3
	0.15	0.8	25,740	10,400	40.4	78.9	-1413.2	32.0
	0.2	0.6	42,063	24,668	58.6	90.4	-1420.3	41.5
	0.2	0.7	42,125	26,190	62.2	90.3	-1419.9	43.0
	0.2	0.8	42,126	27,124	64.4	90.3	-1419.8	43.9
Estimated h	0.1	0.471	29,627	4,421	14.9	71.1	-1402.4	21.6
	0.15	0.261	42,466	5,102	12.0	79.9	-1442.5	20.2
	0.2	0.2	79,211	7,693	9.7	73.8	-1454.1	18.4
Estimated M	0.159	0.6	28,401	10,487	36.9	81.0	-1420.6	32.2
	0.247	0.7	3968,250	3126,030	78.8	1.03	-1424.5	40.8
	0.248	0.8	4021,730	3261,470	81.1	1.02	-1421.0	38.7

Table 8.23 : Results of the sensitivity tests.

Scenario	M (yr^{-1})	h	SB_0	SB_{2003}	SB_{03} / SB_0 (%)	SB_{62} / SB_0 (%)	$-\ell nL$	$-\ell$nCPUE
Base-case	0.15	0.7	26,413	9,635	36.5	79.2	-1418.0	31.3
σ_r = 0.2	0.15	0.7	28,041	14,344	51.2	78.1	-1350.7	51.2
σ_r = 0.5	0.15	0.7	26,514	6,364	24.0	73.0	-1474.1	20.8
CPUE CV=0.1	0.15	0.7	25,181	7,053	28.0	79.9	-1370.7	56.7
CPUE CV=0.3	0.15	0.7	28,404	14,215	50.0	78.1	-1437.5	28.0
CPUE CV=bootstrapped estimates	0.15	0.7	25,972	8,656	33.3	79.5	-1415.3	30.8
Down-weight Historical Length frequencies	0.15	0.7	27,495	10,705	38.9	66.2	-1789.3	29.8

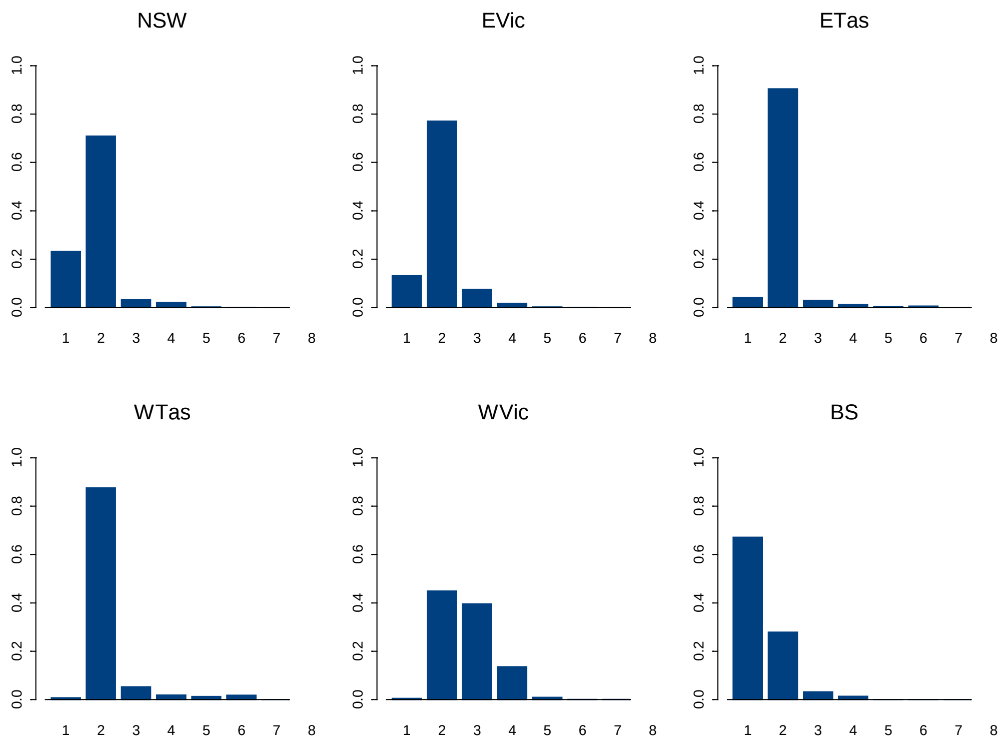
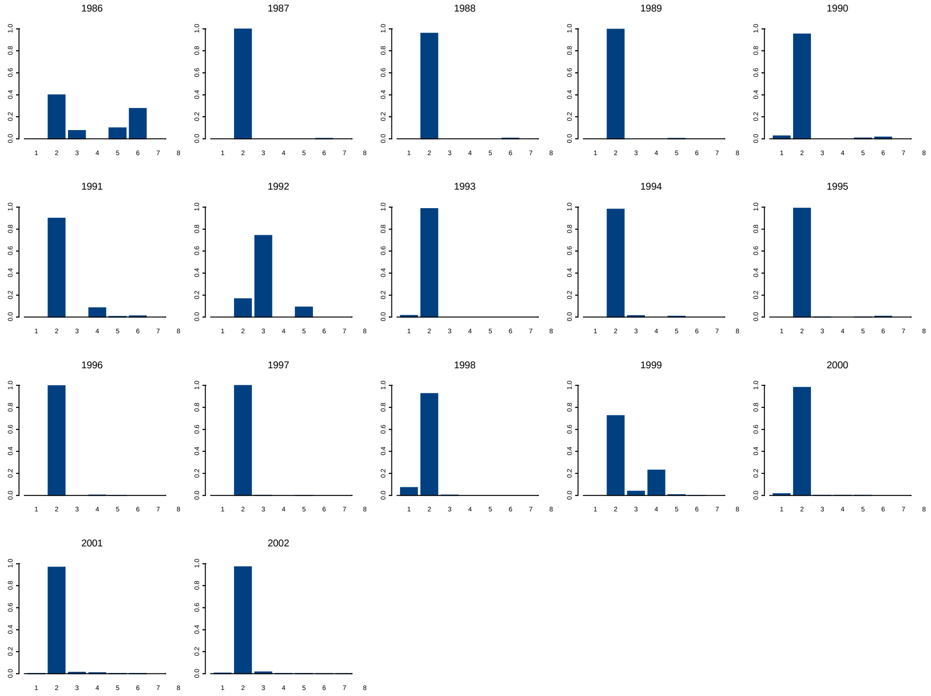


Figure 8.1 : Proportions by depth bin and area of total SEF1 logbook catches of jackass morwong for the years 1986-2002. Each depth bin covers 100m, so bin 1= 0-100m, 2= 100-200m, 3= 200-300m, etc.

a) WTas



b) WVic

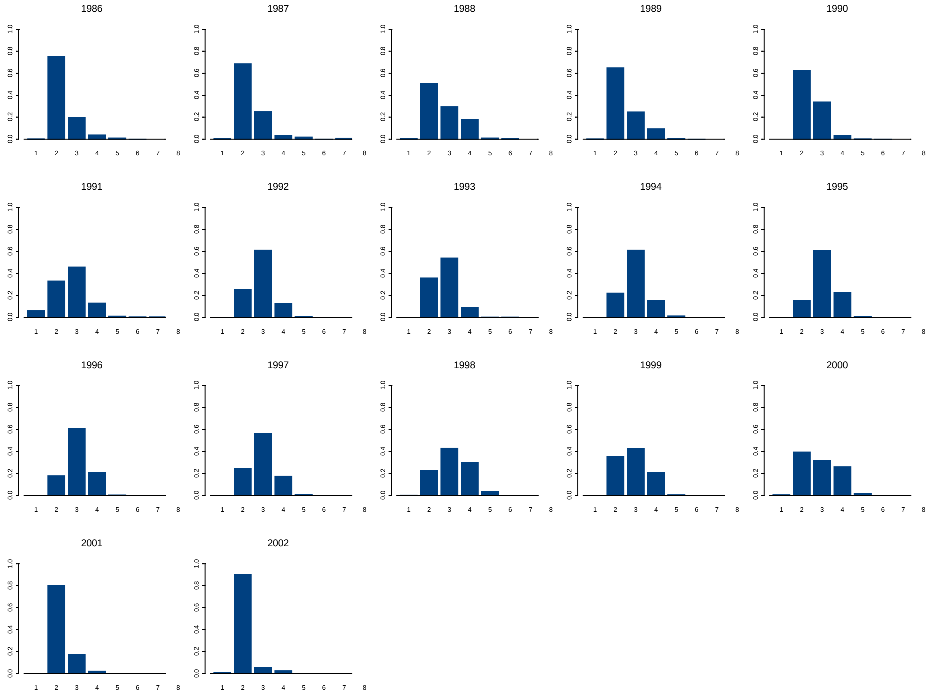


Figure 8.2 : Proportions by depth bin and year of SEF1 logbook catches of jackass morwong for WTas and WVic. Each depth bin covers 100m, so bin 1= 0-100m, 2= 100-200m, 3= 200-300m, etc.

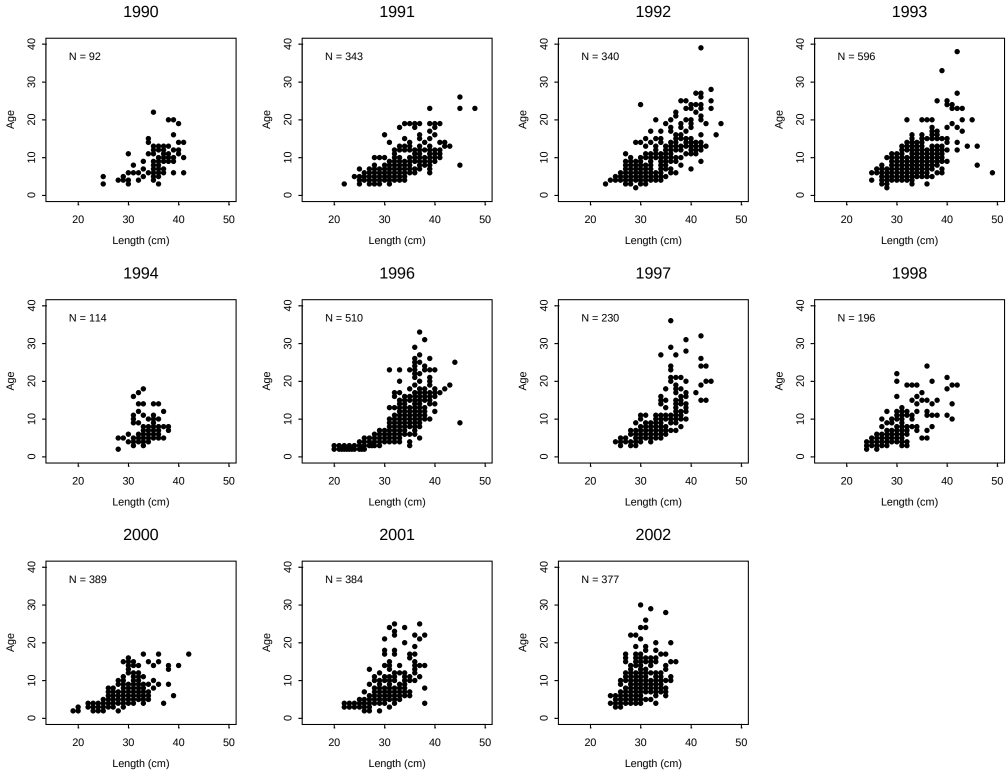


Figure 8.3 : Age length keys (ALKs) for the years in which observations of length and ages from sectioned otoliths were available. The legend in each panel indicates the number of length-age observations.

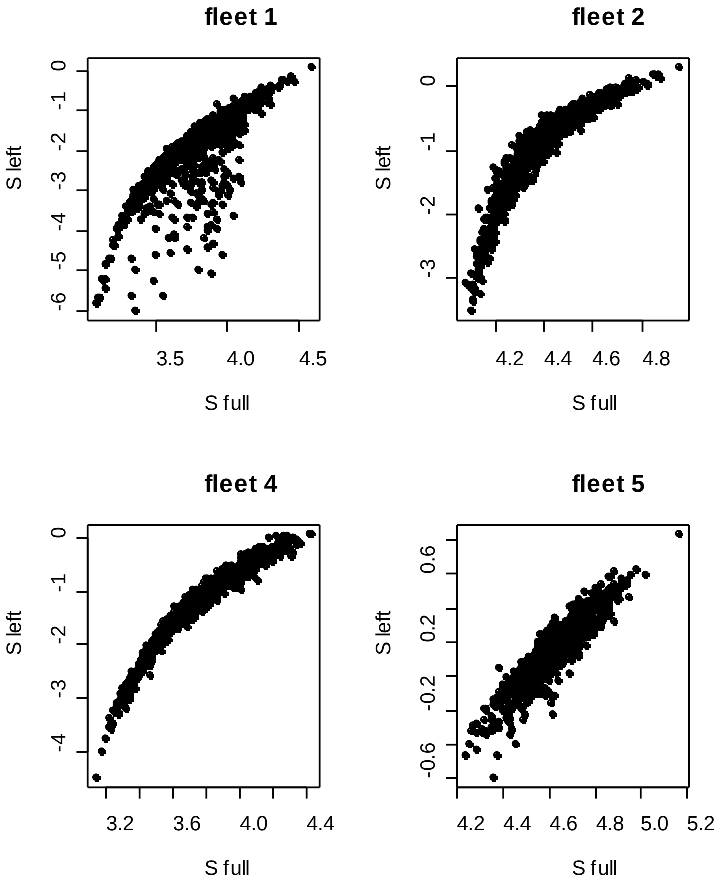


Figure 8.4 : Correlations among parameter values for the two estimated selectivity parameters for the five fleets, taken from 1,000 draws from the posterior distribution. Results shown are from the Bayesian analysis of the base-case model with M=0.15 yr^{-1} and h=0.7. 'S full' is the age at full selectivity, and 'S left' is the natural logarithm of the variance of the left-hand (ascending) limb of the selectivity function.

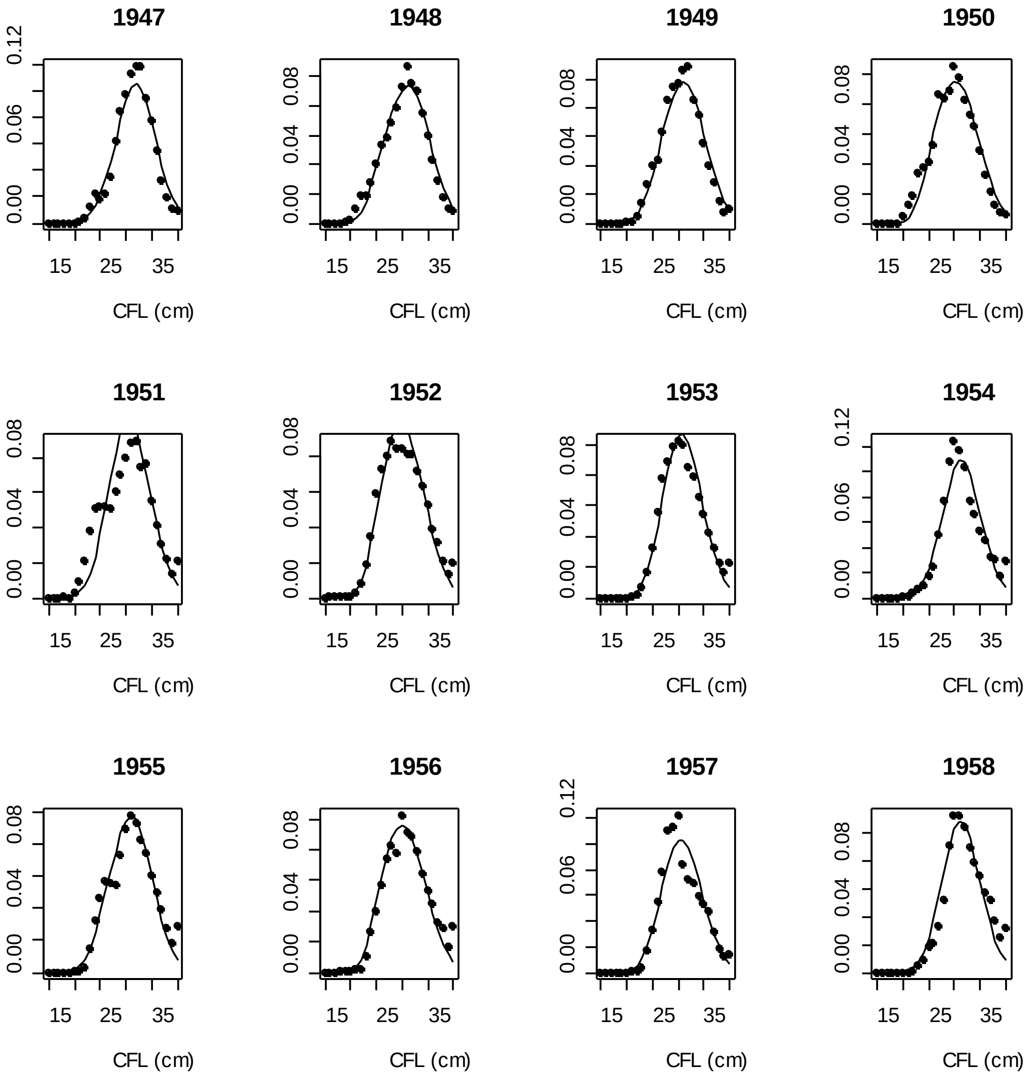


Figure 8.5 : Fits to the length frequency data for fleet 1 (historical steam trawlers). Fits shown are from the base-case model with *M*=0.15 yr^{-1} and *h*=0.7.

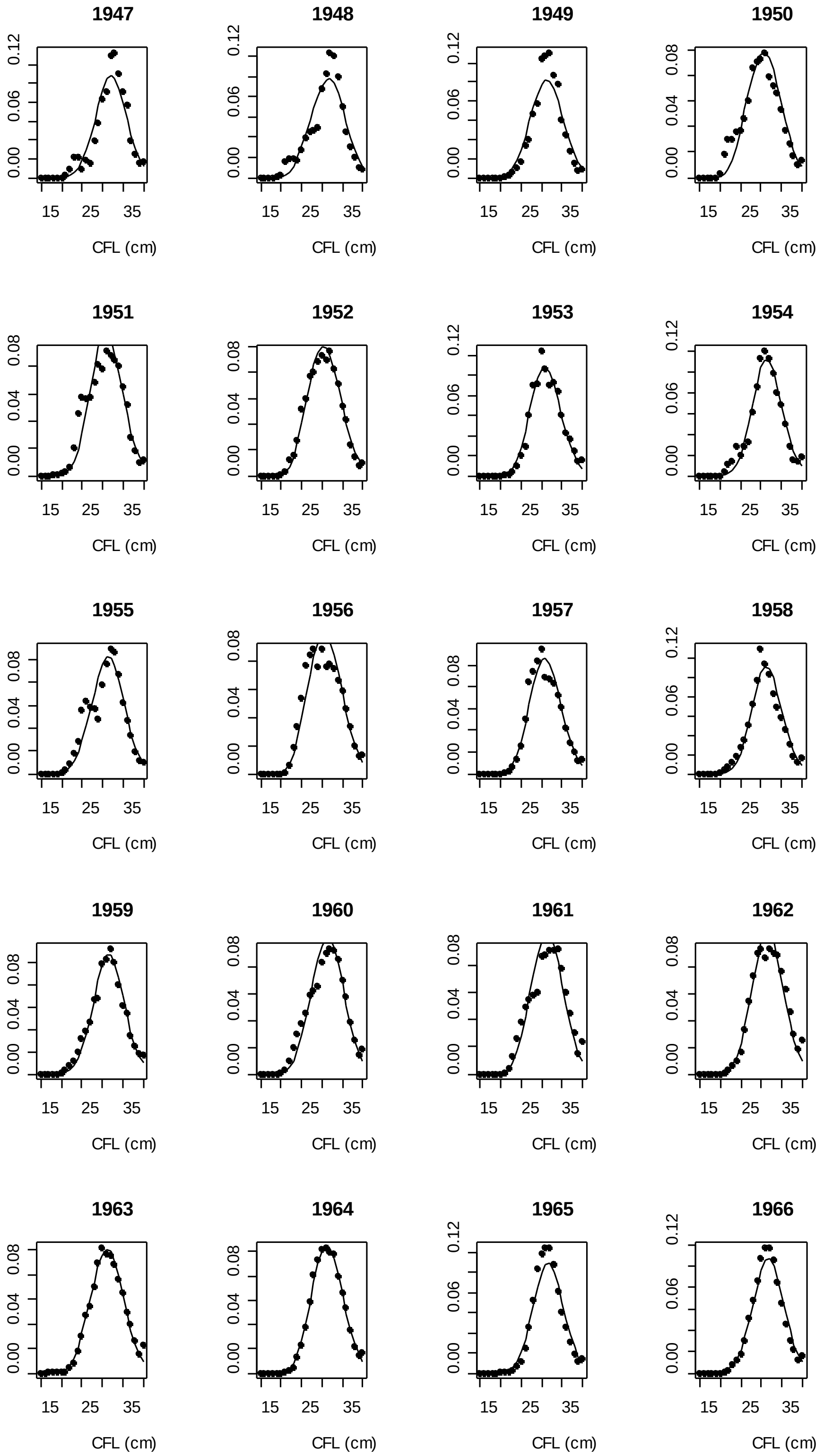


Figure 8.6 : Fits to the length frequency data for fleet 2 (‘Other Boats’). Fits shown are from the base-case model with M=0.15 yr^{-1} and h=0.7.

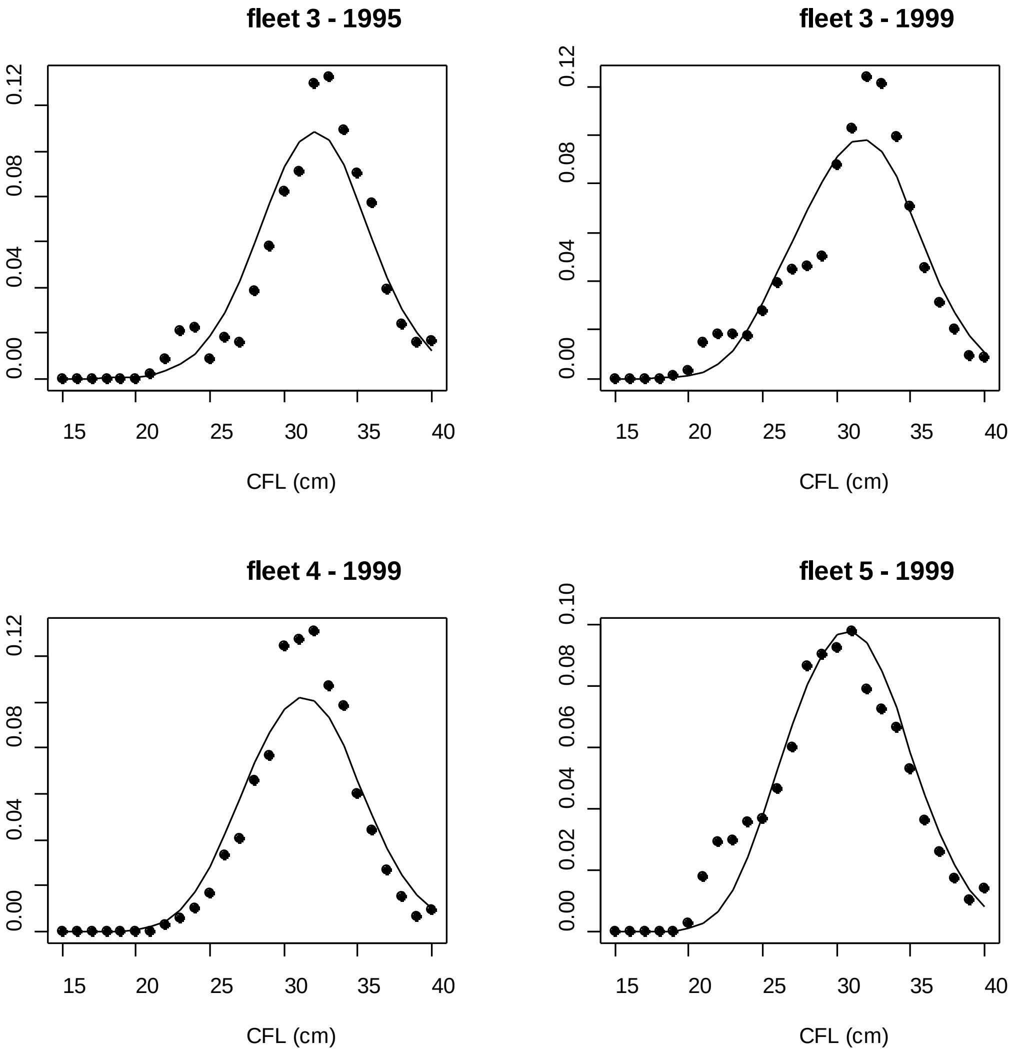


Figure 8.7 : Fits to the length frequency data for fleets 3, 4, and 5. Fits shown are from the base-case model with *M*=0.15 yr^{-1} and *h*=0.7. The paucity of years for which length data are available in this figure is a result of these data for other years being used to calculate the catch-at-age data.

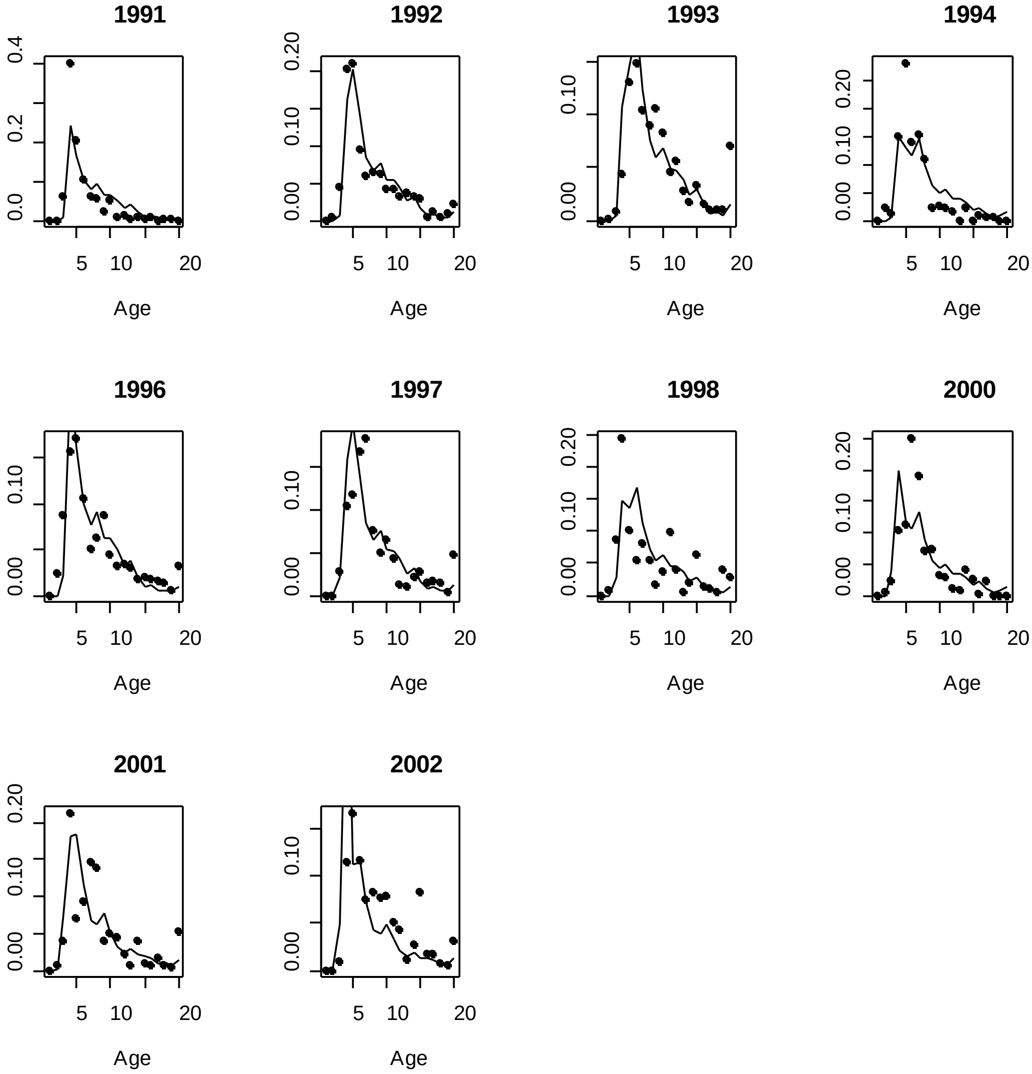


Figure 8.8 : Fits to the catch-at-age data for fleet 3 (otter trawlers in NSW, EVic and Bass Strait). Fits shown are from the base-case model with M=0.15 yr^{-1} and h=0.7.

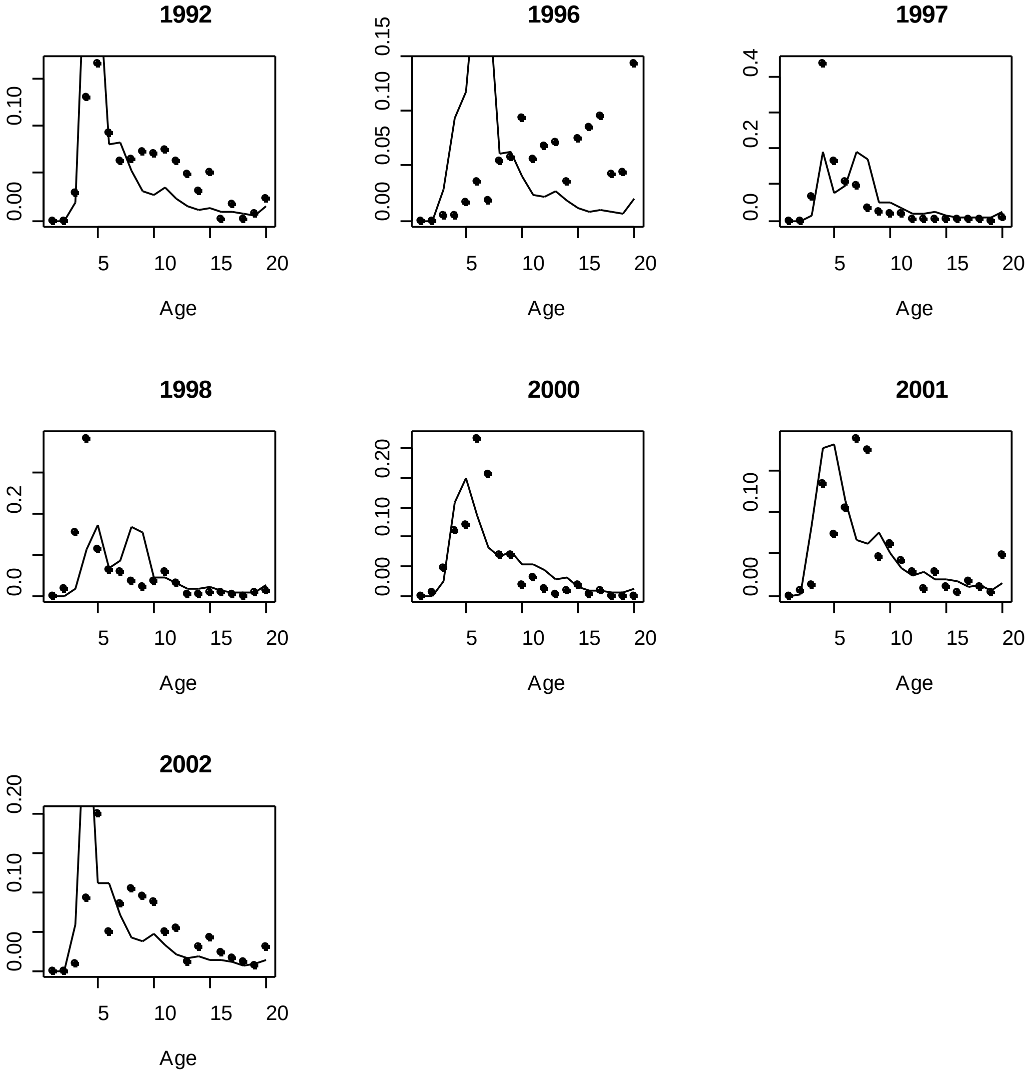


Figure 8.9 : Fits to the catch at age data for fleet 4 (Danish seine vessels off NSW, EVic and Bass Strait). Fits shown are from the base-case model with $M = 0.15$ yr^{-1} and h=0.7.

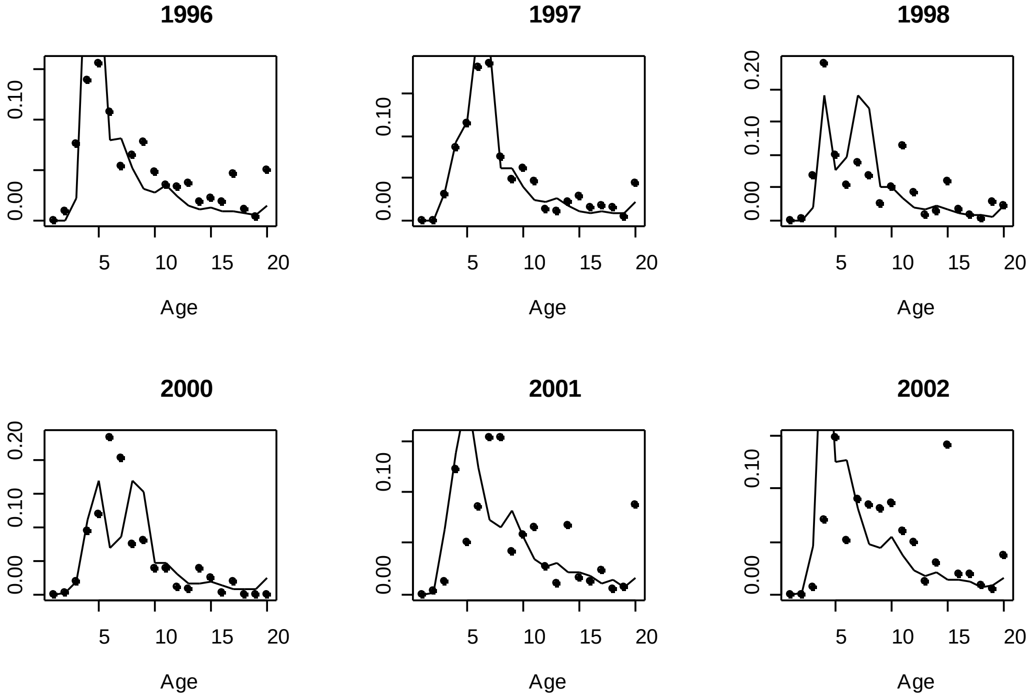


Figure 8.10 : Fits to the catch at age data for fleet 4 (otter trawlers off east Tasmania). Fits shown are from the base-case model with M = 0.15 yr^{-1}and h=0.7.

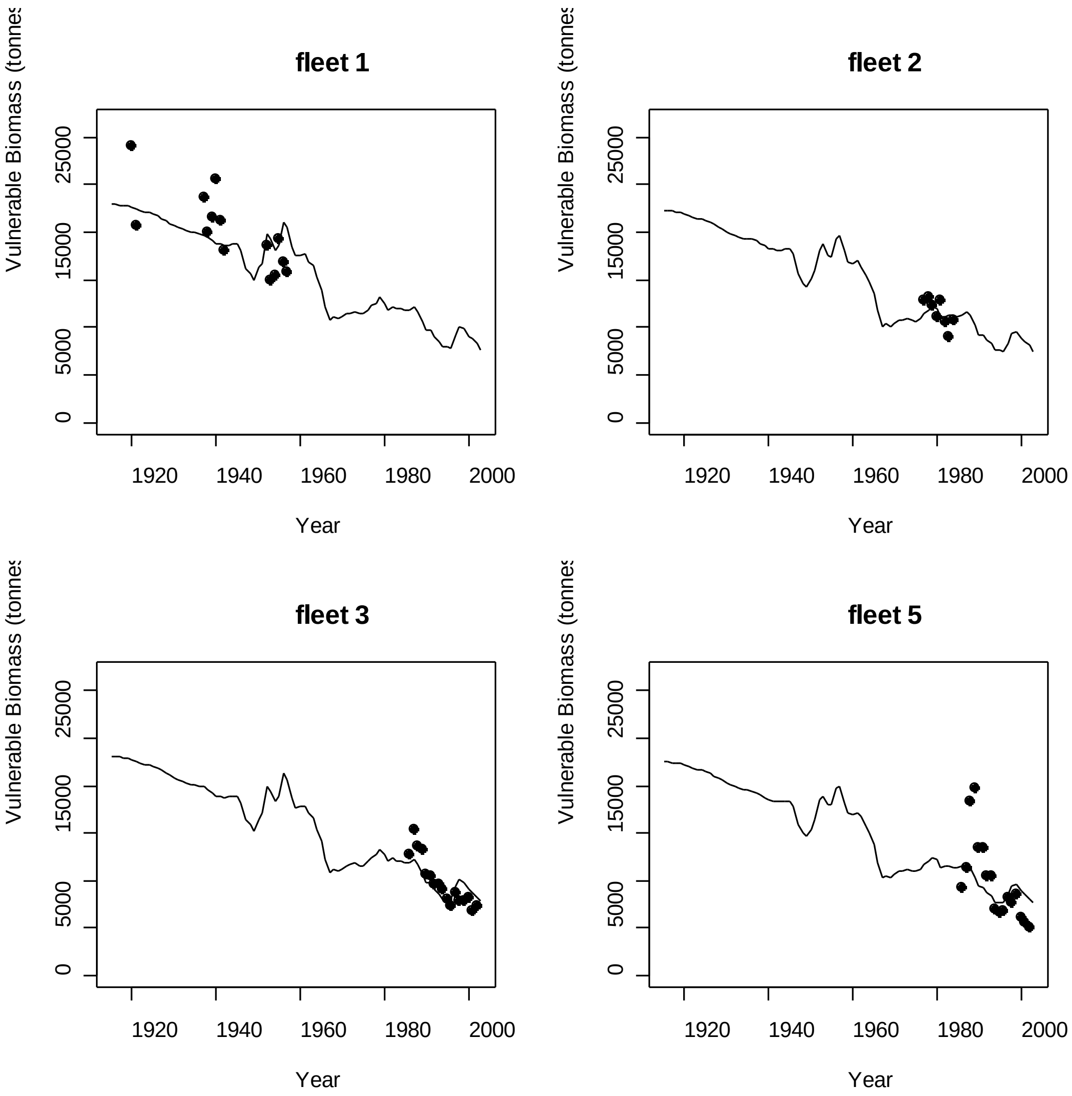
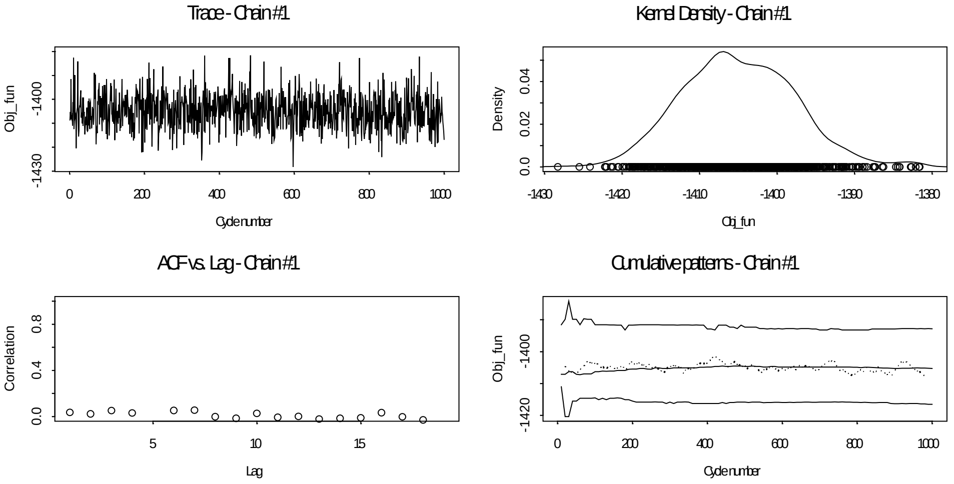
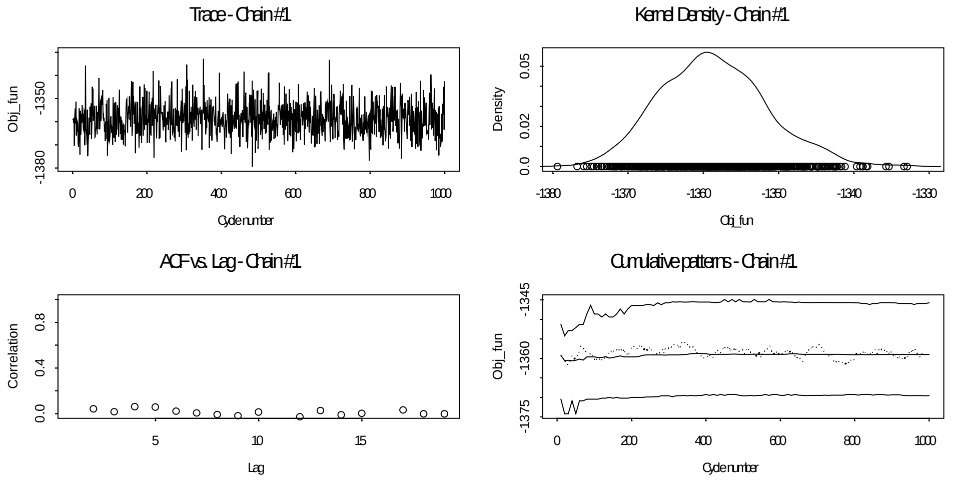


Figure 8.11 : Estimated vulnerable biomass through time for fleets 1, 2, 3, and 5 for the base-case model with *M*=0.15 yr^{-1} and *h*=0.7. The points correspond to the estimates of vulnerable biomass determined from the CPUE data given the maximum likelihood estimates of the catchability coefficients for each of the four catch rate indices.

a) Base-case



b) CPUE CV=0.1



c) $\sigma_r = 0.5$

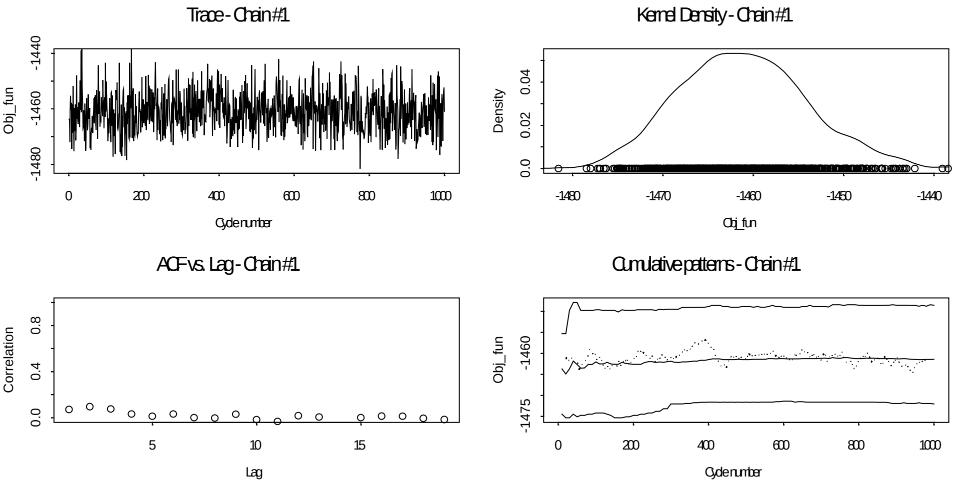
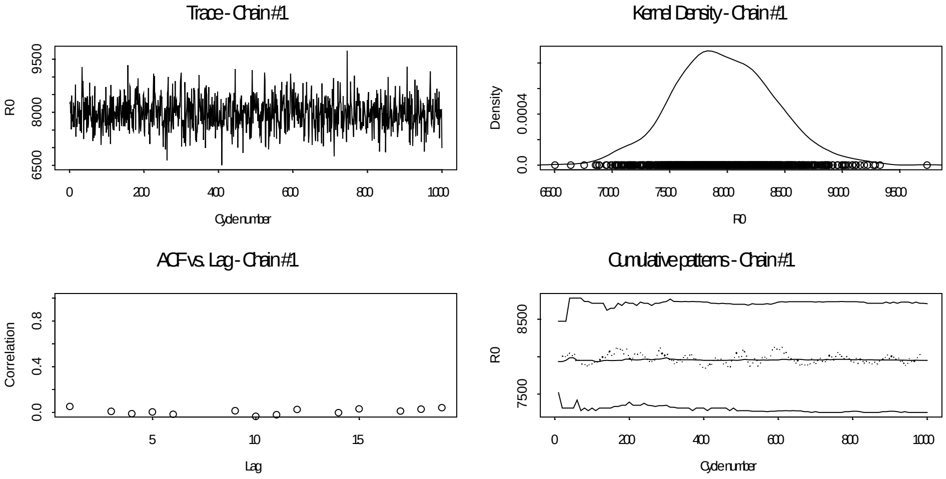
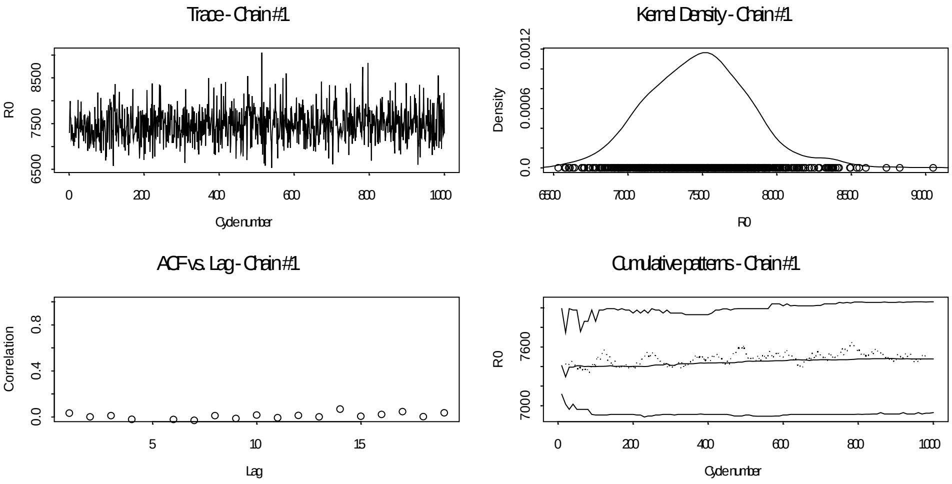


Figure 8.12 : Convergence statistics for the value of the objective function for the three Bayesian analyses.

a) Base-case



b) CPUE CV=0.1



c) $\sigma_r = 0.5$

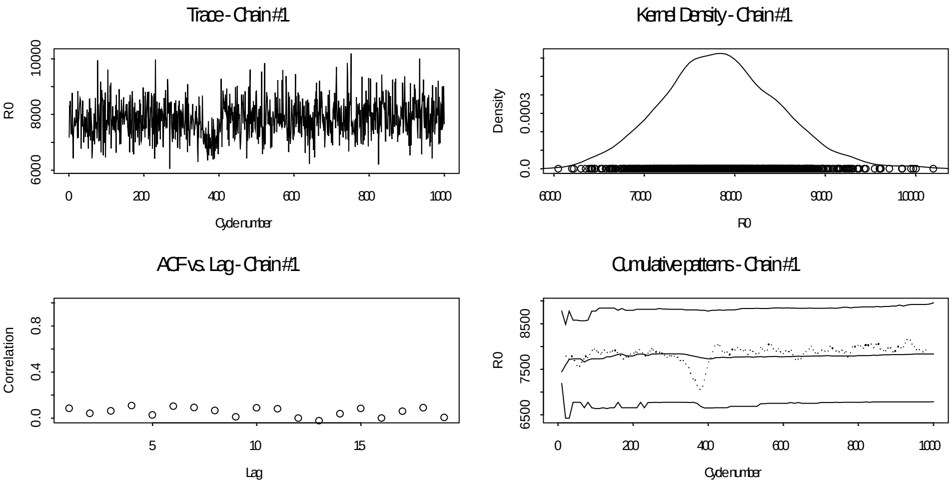
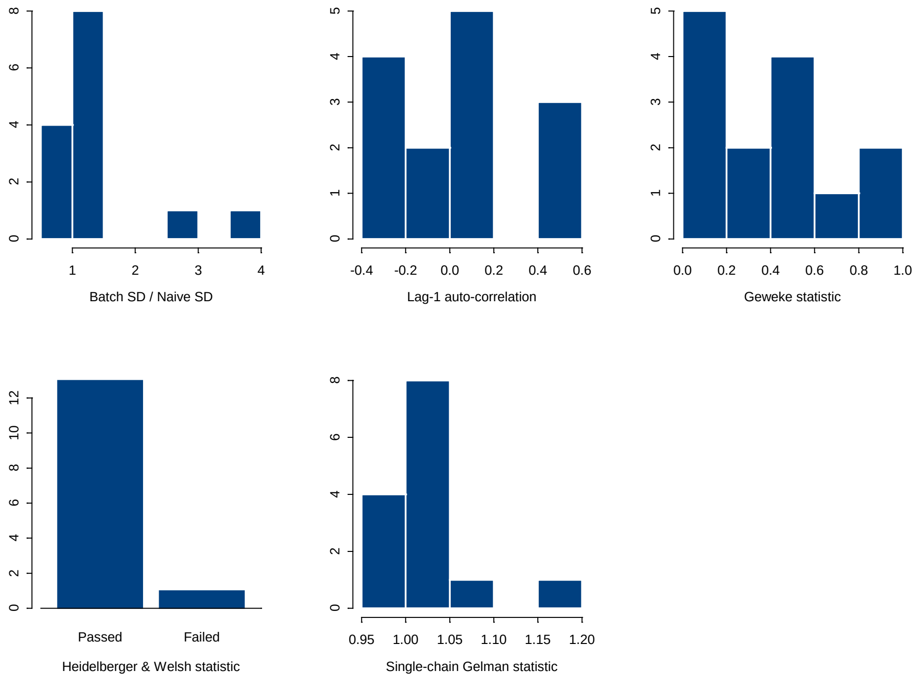


Figure 8.13 : Convergence statistics for R_0 for the three Bayesian analyses.

a) Selectivity and catchability parameters



b) Recruitment residuals

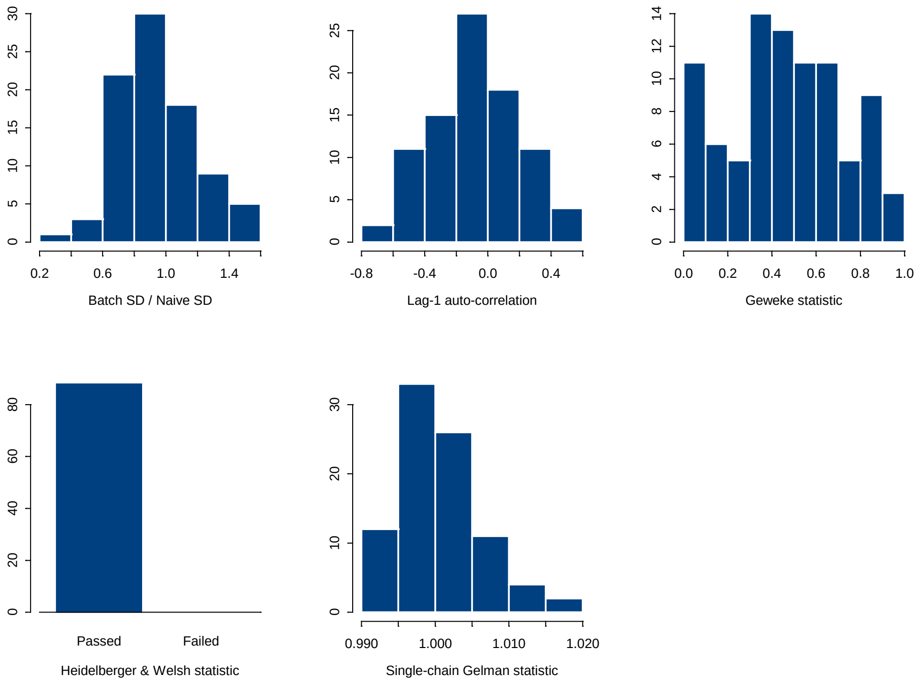
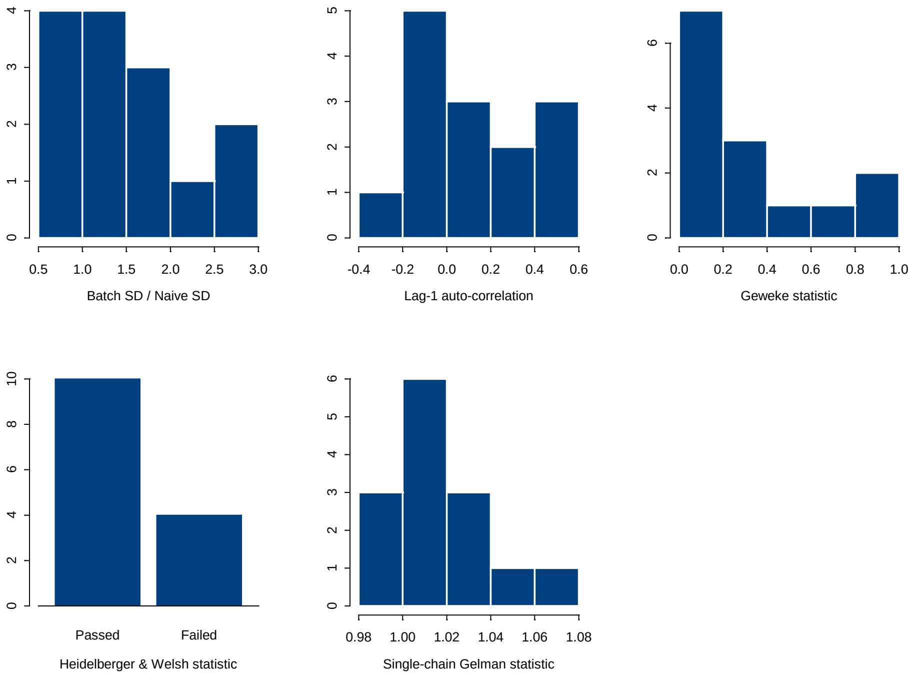


Figure 8.14 : Diagnostic statistics for: a) the parameters determining selectivities and catchabilities, and b) the recruitment residuals for the base-case model with M=0.15yr^{-1} and h=0.7.

a) Selectivity and catchability parameters



b) Recruitment residuals

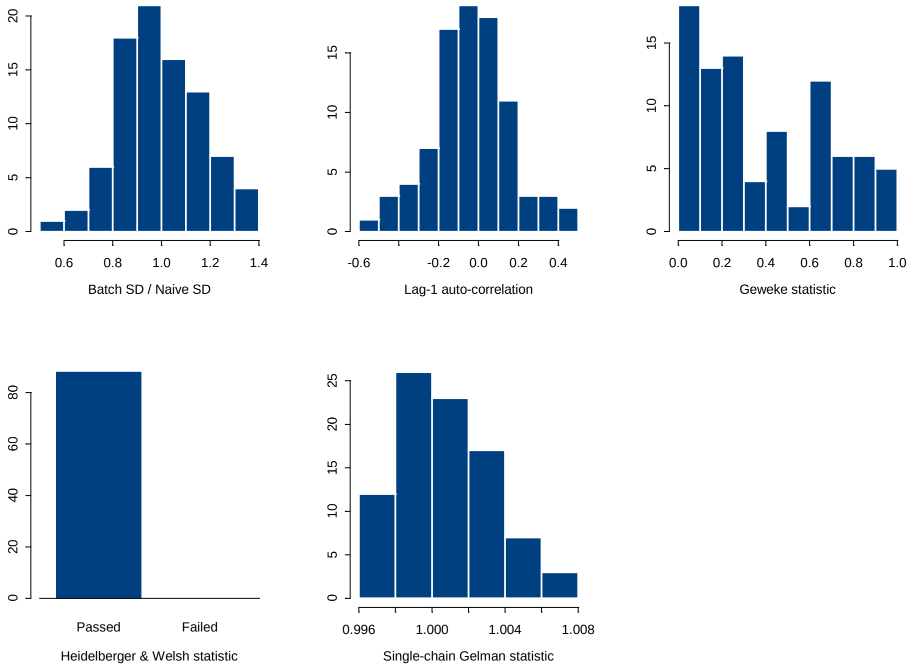
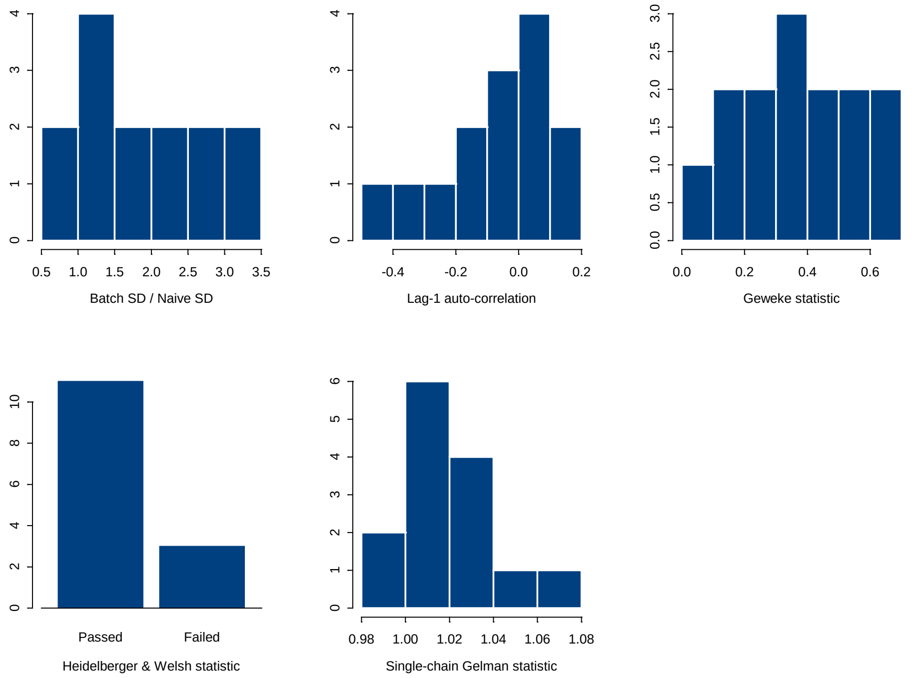


Figure 8.15 : Diagnostic statistics for: a) the parameters determining selectivities and catchabilities, and b) the recruitment residuals for the sensitivity test with CPUE CV=0.1, M=0.15yr^{-1} and h=0.7.

a) Selectivity and catchability parameters



b) Recruitment residuals

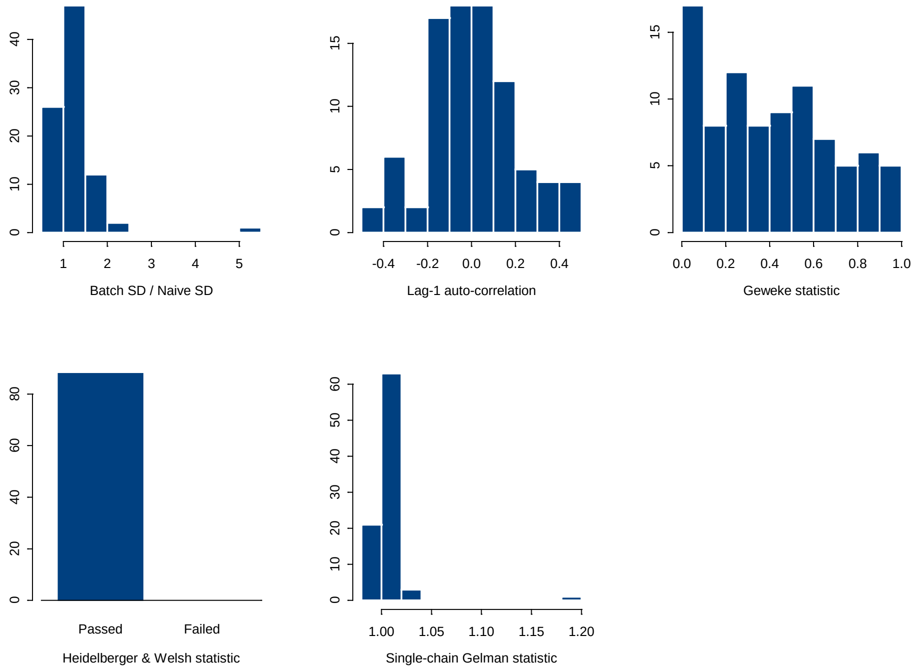


Figure 8.16 : Diagnostic statistics for: a) the parameters determining selectivities and catchabilities, and b) the recruitment residuals for the sensitivity test with $\sigma_r = 0.5$, *M*=0.15yr^{-1} and *h*=0.7.

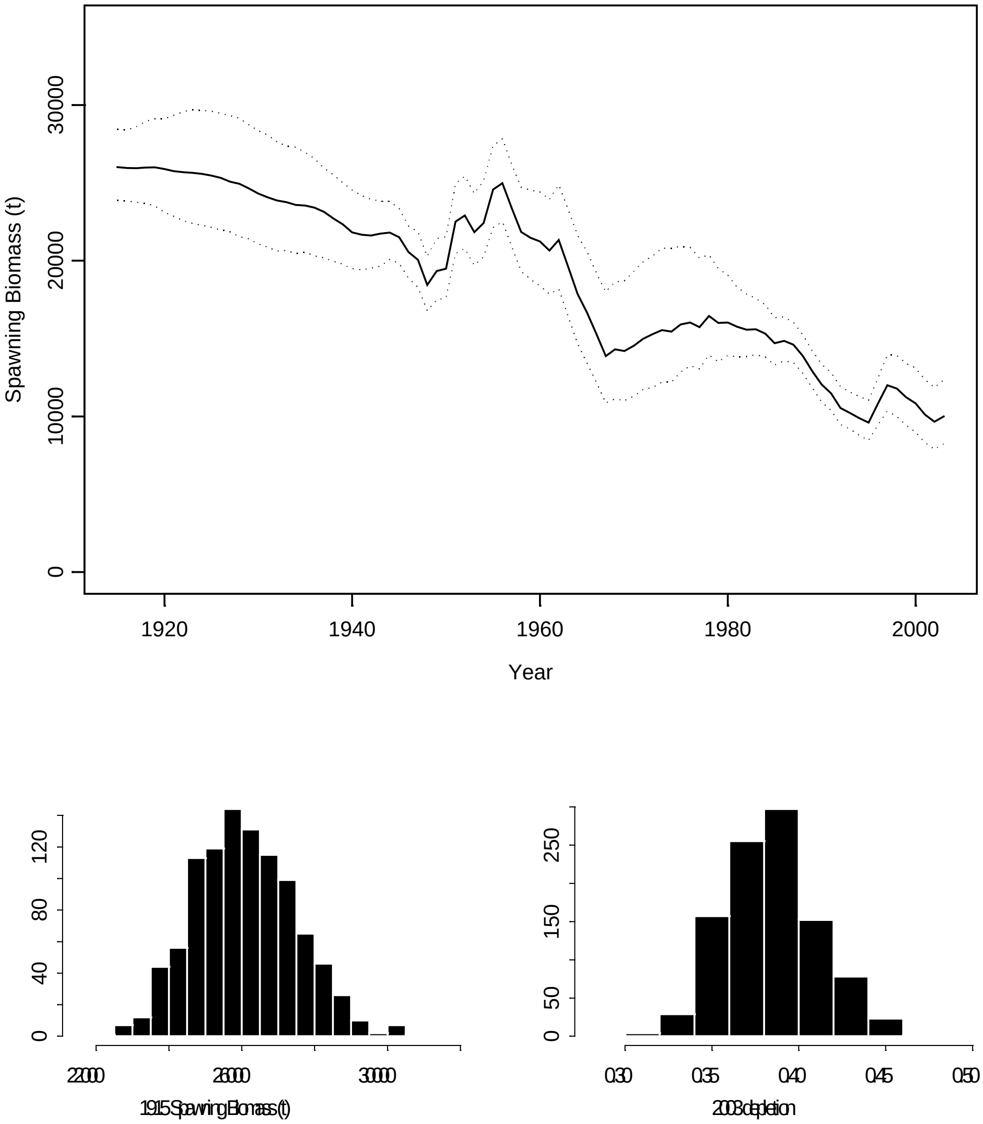
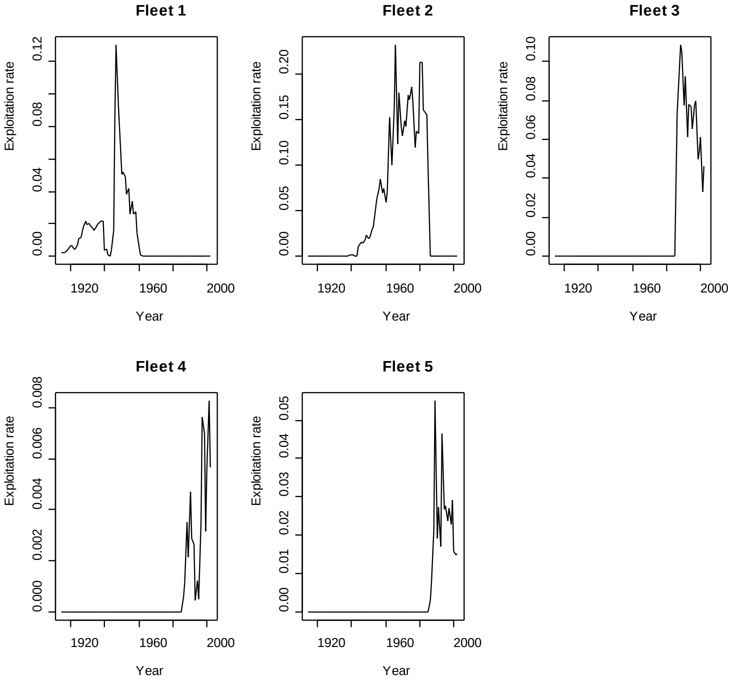


Figure 8.17 : Median and central 95% probability intervals of the time-trajectory of the spawning biomass of jackass morwong for the base-case model with M=0.15yr^{-1} and h=0.7, and the posterior probability distributions for the 1915 (virgin) spawning biomass and the 2003 depletion level.

a) M = 0.15 yr^{-1}, h = 0.7



M = 0.1 yr^{-1}, h = 0.6

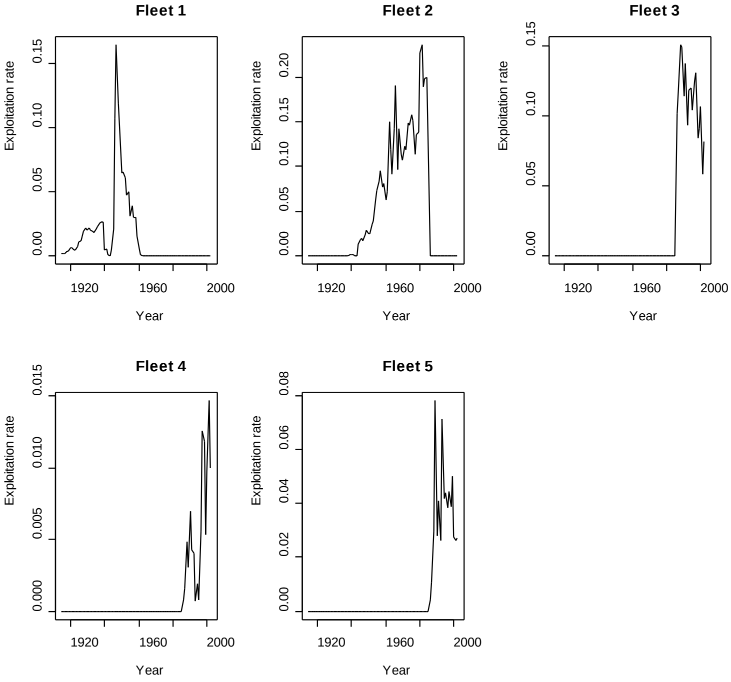


Figure 8.18 : Estimated time-trajectories of exploitation rate for the five fleets for two versions of the base-case assessment which differ in terms of the values pre-specified for *M* and *h*.

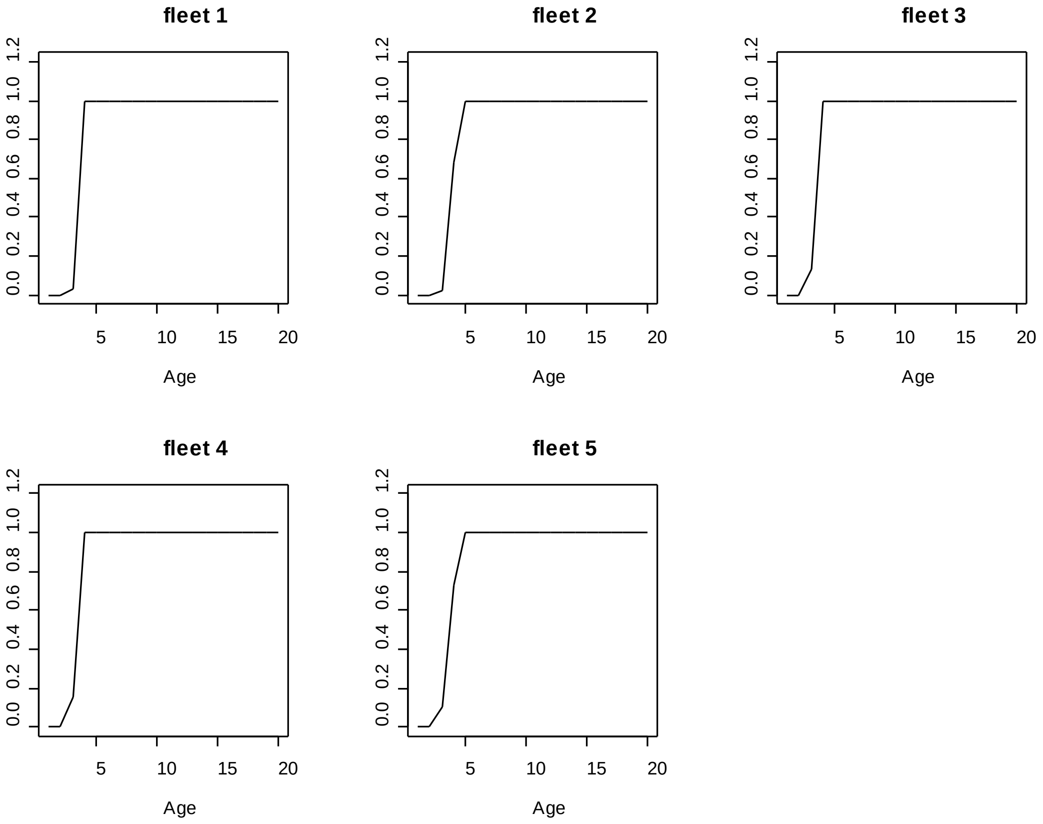
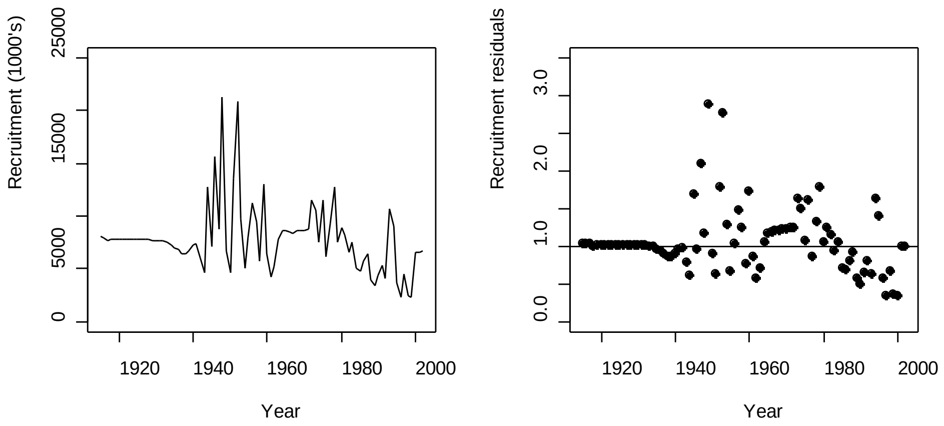
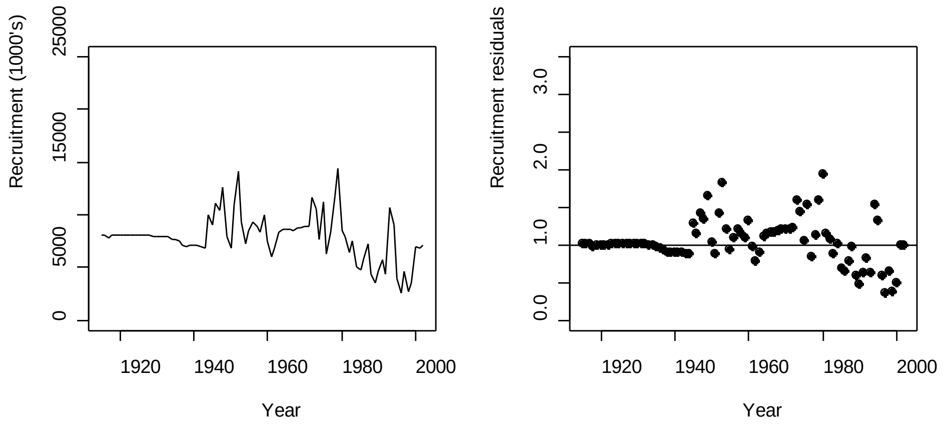


Figure 8.19 : Estimated selectivity patterns for the five fleets for the base-case model with *M*=0.15 yr^{-1} and *h* = 0.7.

a) Base-case



b) Decreased weight to historical length frequencies



c) $\sigma_r = 0.5$

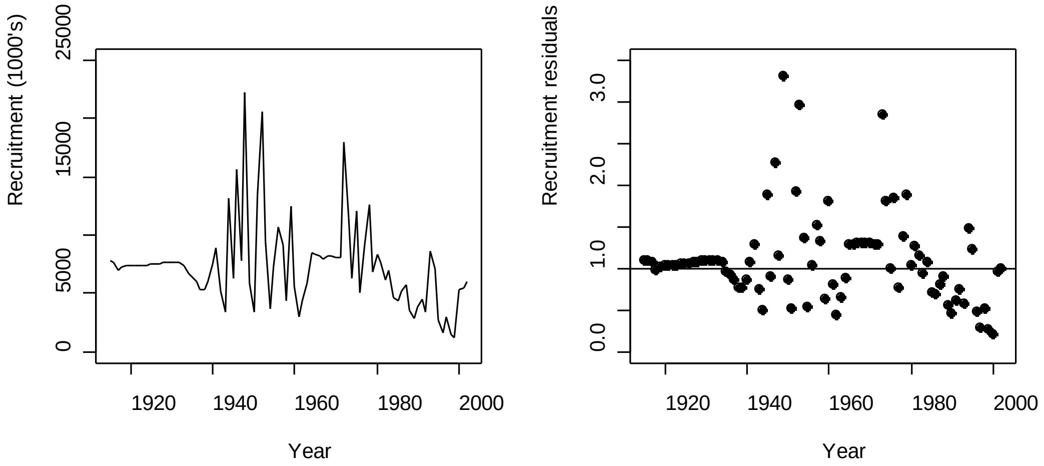


Figure 8.20 : Estimated recruitments and recruitment residuals (in terms of the fraction of the average recruitment given the appropriate spawning biomass), for a base-case analysis and two of the sensitivity tests. All three analyses assumed $M = 0.15$ yr^{-1} and $h = 0.7$.

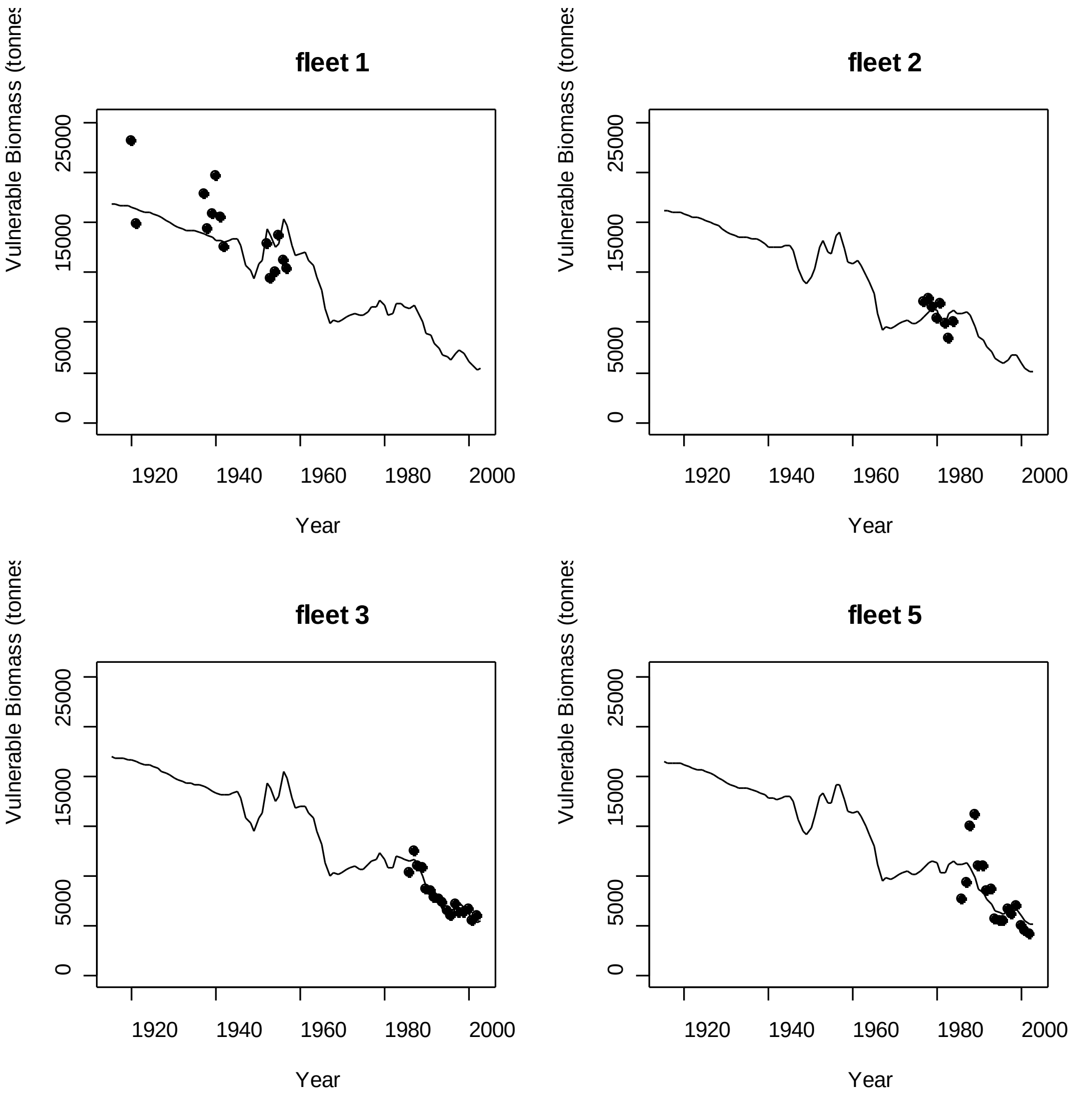
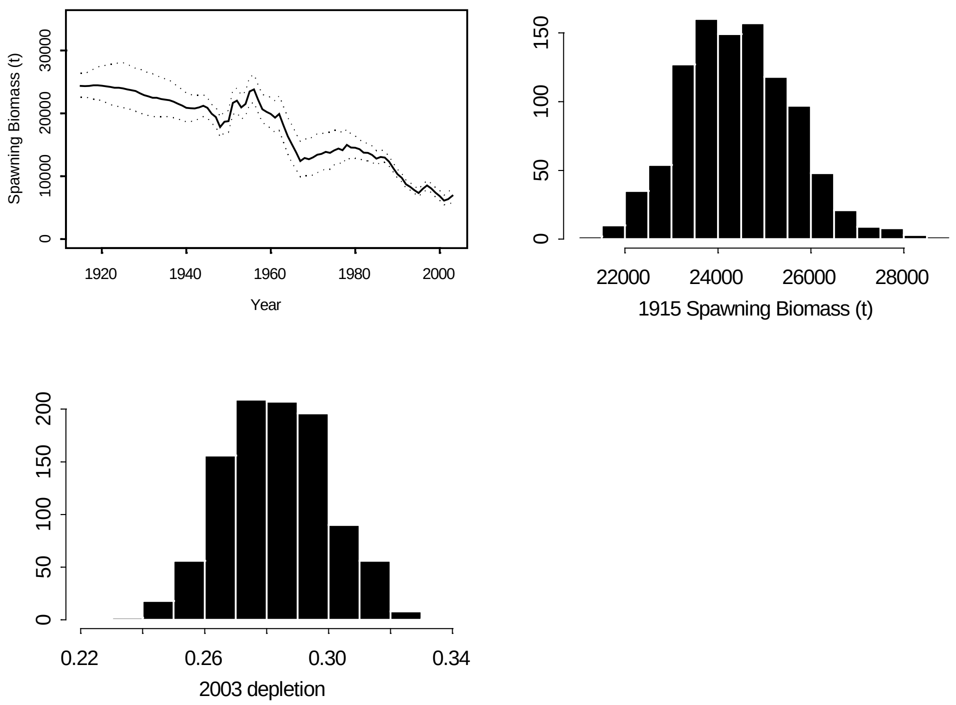


Figure 8.21 : Estimated vulnerable biomass through time for fleets 1, 2, 3, and 5 for the sensitivity analysis in which the recent CPUE data were given more weight than in the base-case (CPUE CVs = 0.1, M=0.15 yr^{-1}, h=0.7). The points correspond to the estimates of vulnerable biomass determined from the CPUE data given the maximum likelihood estimates of the catchability coefficients for each of the four catch rate indices.

a) CPUE CV = 0.1



b) $\sigma_r = 0.5$

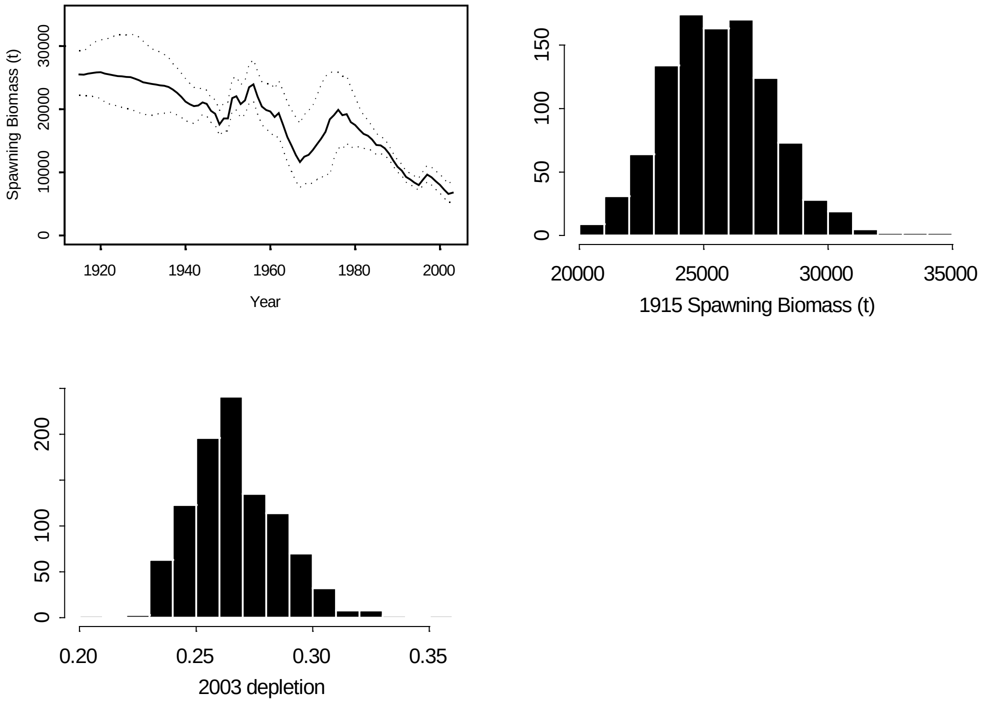


Figure 8.22 : Median and central 95% probability intervals of the time-trajectory of the spawning biomass of jackass morwong, and the posterior probability distributions for the 1915 (virgin) spawning biomass and the 2003 depletion level. Results are shown for two of sensitivity tests.

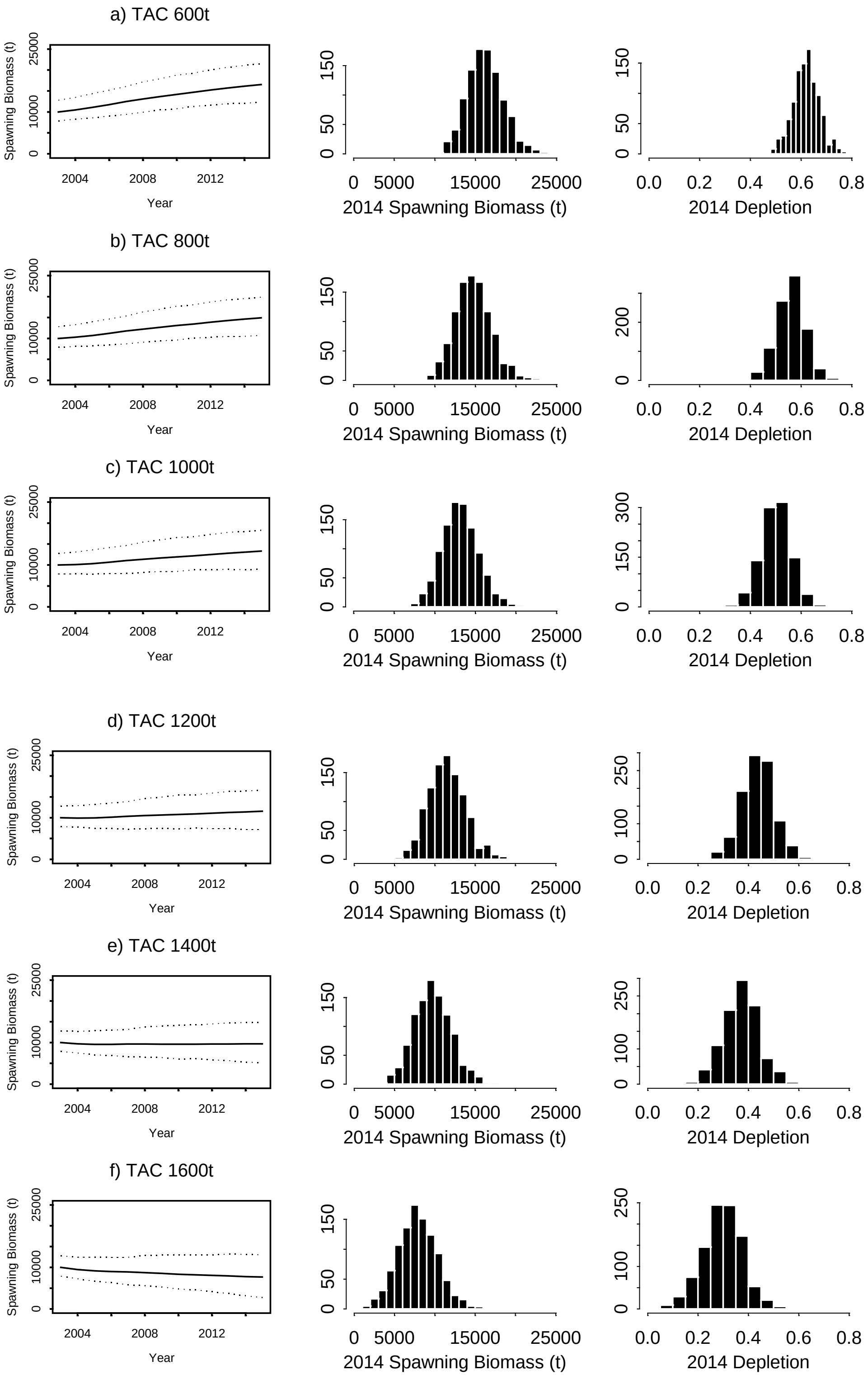
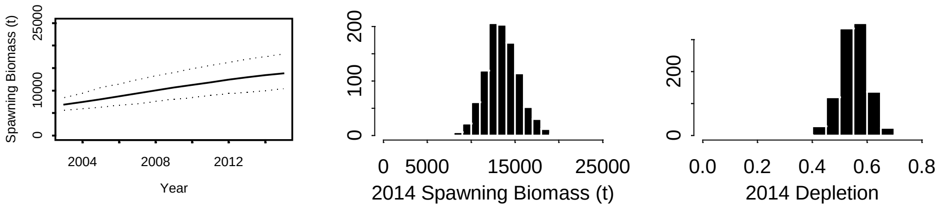
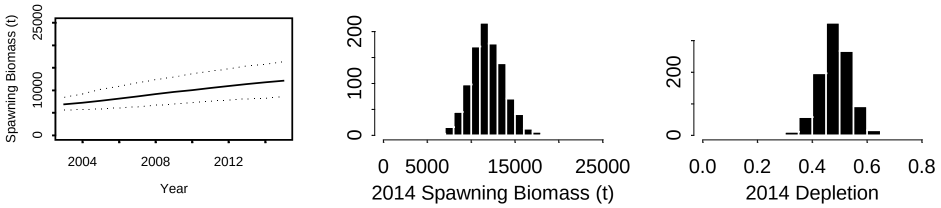


Figure 8.23 : Median and central 95% probability interval of projected spawning biomass and projected distributions for 2014 spawning biomass and 2014 depletion for six fixed levels of future catches. Projections were based on the Bayesian posterior obtained for the base-case model with M=0.15 yr^{-1} and h =0.7.

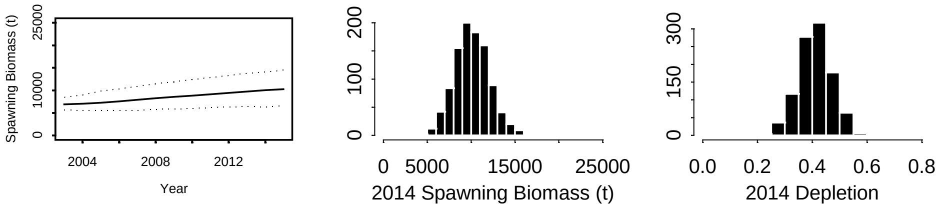
a) TAC 600t



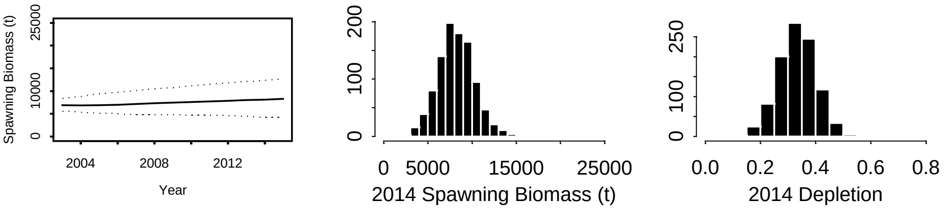
b) TAC 800t



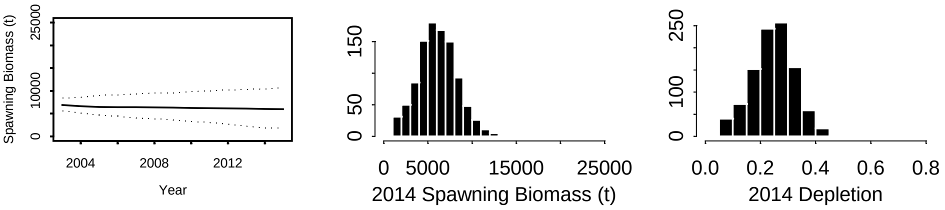
c) TAC 1000t



d) TAC 1200t



e) TAC 1400t



f) TAC 1600t

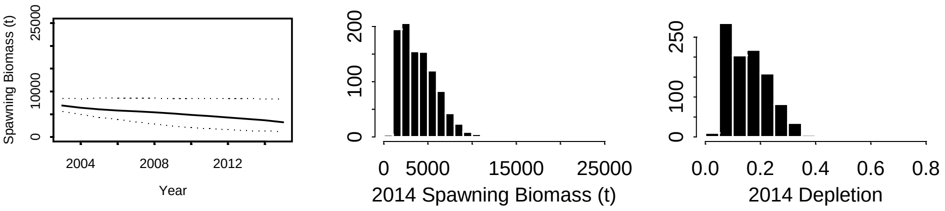
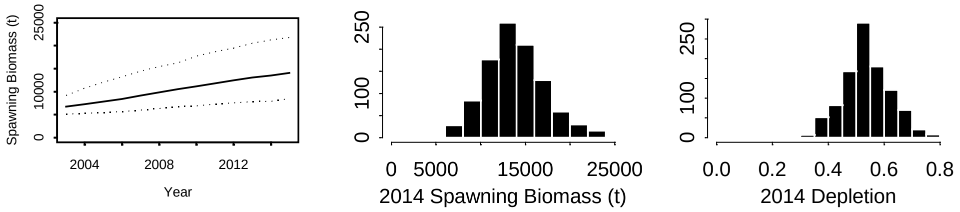
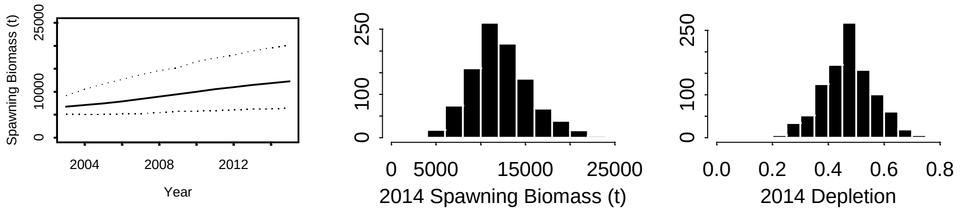


Figure 8.24 : Median and central 95% probability interval of projected spawning biomass and projected distributions for 2014 spawning biomass and 2014 depletion for six fixed levels of future catches. Projections were based on the Bayesian posterior obtained for the sensitivity analysis where the recent CPUE indices were given a CV of 0.1 (M=0.15 yr^{-1}, h =0.7).

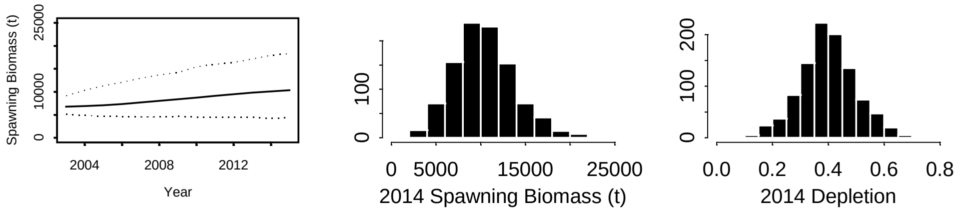
a) TAC 600t



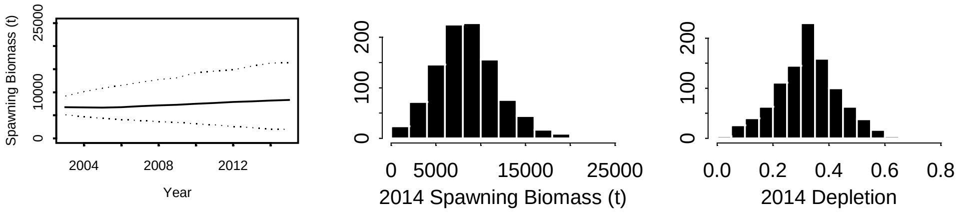
b) TAC 800t



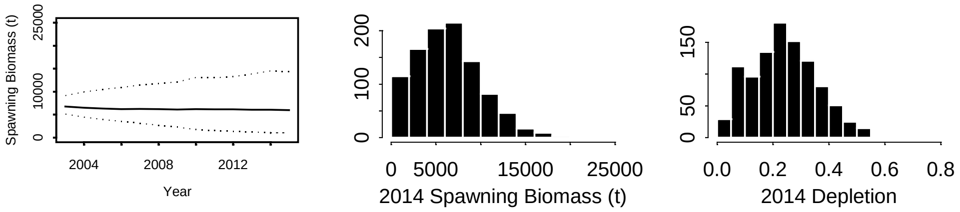
c) TAC 1000t



d) TAC 1200t



e) TAC 1400t



f) TAC 1600t

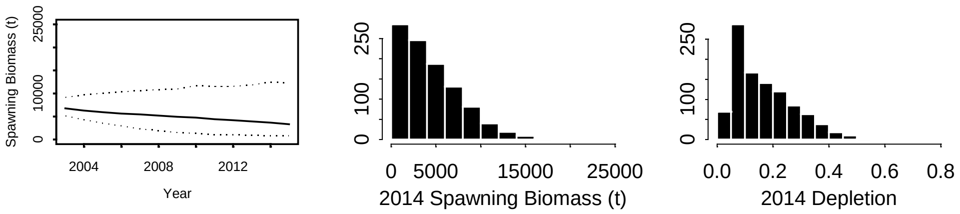


Figure 8.25 : Median and central 95% probability interval of projected spawning biomass and projected distributions for 2014 spawning biomass and 2014 depletion for six fixed levels of future catches. Projections were based on the Bayesian posterior obtained for the sensitivity analysis which increased the variability in recruitment (σ_r = 0.5, M=0.15 yr^{-1}, h =0.7).

APPENDIX 8.A : Within-tow associations of jackass morwong with other species

Table 8.A.1 : Percentage of the annual SEF1 catch of nine species which was caught in tows that also caught jackass morwong

	% of annual SEF1 catch								
Year	blue warehou	tiger flathead	eastern gemfish	john dory	ocean perch (shallow)	redfish	silver trevally	spotted warehou	western gemfish
1986	26.6	41	4.9	32.1	59	30.4	12.4	31.5	9.2
1987	29.7	37.2	7.7	35.2	64.9	36.7	20.2	21.1	11.1
1988	51.7	45.1	13.7	36	70.2	45.2	14.2	38.3	24.1
1989	64.1	41.3	8.6	36.5	71.3	29.1	14.1	38	17.2
1990	49.6	45.4	7.3	49.7	67.4	45.2	25.1	38.6	26.3
1991	29.6	44.8	13	45.6	66.3	47	30.8	26.2	13.9
1992	34.5	32.2	5.1	38.7	57.8	36	28.3	28.3	37.5
1993	42.2	36.5	13.4	33.5	60.5	25.2	38.3	20.1	21.3
1994	37.1	41.9	20.7	36.7	50	28.3	42.5	25.4	34.7
1995	32.4	35.5	27.3	39.1	59.2	25.4	20.9	23.4	21.2
1996	53.8	38.9	12.9	50.7	84.8	42.8	38.1	28.3	30.5
1997	43.2	45.8	10.8	54.2	85.1	38.9	27.1	26.4	30.6
1998	30.9	39.6	8.1	43.8	72.6	38.7	17.1	15	18.7
1999	28.8	35.7	15.4	38.7	70.3	37.2	16.4	15.1	15.2
2000	38.2	31.7	25.7	47.9	76.9	43.3	19.6	10.4	14.7
2001	31.3	40.8	30.4	52.1	82.9	44.6	22.1	9.8	9.1
2002	39.2	48.9	29.8	66.6	85	39	23.4	9.6	10.4

Table 8.A.1 : Percentage of the total SEF1 catch of nine species for the period 1986-2002 which was caught in tows that also caught jackass morwong by area.

	% of 1986-2002 SEF1 catch								
Area	blue warehou	tiger flathead	eastern gemfish	john dory	ocean perch (shallow)	redfish	silver trevally	spotted warehou	western gemfish
NSW	3.8	8.1	2	23.9	32.1	29.3	15.8	1.1	0
EVic	21.2	28.4	6.5	18.6	37.4	7.3	9	14.3	0
ETas	10	3.6	1	0.1	1.1	0	0	3.2	0
WTas	1.4	0.1	0	0	0	0	0	0.9	0.4
WVic	3.6	0.4	0	0	0.3	0.1	0.4	1.8	19.8

Table 8.A.3 : Percentage of the total SEF1 catch of nine species for the period 1986-2002 which was caught in tows that also caught jackass morwong by depth.

	% of 1986-2002 SEF1 catch								
Depth bin	blue warehou	tiger flathead	eastern gemfish	john dory	ocean perch (shallow)	redfish	silver trevally	spotted warehou	western gemfish
1–100m	26.6	41	4.9	32.1	59	30.4	12.4	31.5	9.2
101–200m	29.7	37.2	7.7	35.2	64.9	36.7	20.2	21.1	11.1
201–300m	51.7	45.1	13.7	36	70.2	45.2	14.2	38.3	24.1
301–400m	64.1	41.3	8.6	36.5	71.3	29.1	14.1	38	17.2
401–500m	49.6	45.4	7.3	49.7	67.4	45.2	25.1	38.6	26.3
501–600m	29.6	44.8	13	45.6	66.3	47	30.8	26.2	13.9
601–1200m	39.2	48.9	29.8	66.6	85	39	23.4	9.6	10.4

APPENDIX 8.B : Estimation of von Bertalanffy growth curve for Jackass Morwong (Nemadactylus macropterus)

8.B.1 Methods

Growth of jackass morwong was modelled according to a von Bertalanfy growth curve with mean length-at-age given by:

$$\bar{L}_a = L_\infty\left(1-\exp\left(-k\left[a-t_0\right]\right)\right) \tag{8.B.1}$$

where $\bar{L}_a$ is the mean length (in centimetres) of a fish of age a, and
L_∞, k, and t_0 are the parameters of the growth curve.

The distribution of length-at-age was assumed to be log-normal with standard deviation σ_a, given by:

$$\sigma_a^2 = \left(\frac{sd_a}{\bar{L}_a}\right)^2 \tag{8.B.2}$$

with

$$sd_a = \sigma_{L_1} + \left(\frac{\sigma_{L_x}-\sigma_{L_1}}{\bar{L}_x-\bar{L}_1}\right)\left(\bar{L}_a-\bar{L}_1\right) \tag{8.B.3}$$

where σ_{L_1} is the standard deviation of the mean length of fish of age 1, and
σ_{L_x} is the standard deviation of the mean length at the maximum age x.

The mean weight-at-age of animals was determined by the weight-length power function:

$$\bar{w}_a = \alpha\left(\bar{L}_a\right)^\beta e^{\left(\frac{\beta\sigma_a^2(\beta^2-1)}{2}\right)} \tag{8.B.4}$$

where α and β are the parameters of the weight-length relationship.

The exponential term in Equation (8.B.4) is a correction for the variance of the log-normal distribution of size-at-age.

The values for the parameters of the weight-length relationship were obtained from the CAF (1998), and are shown in Table 8.B.1. The values for the other parameters of the model (L_∞, k, t_0, σ_{L_1}, and σ_{L_x}) were estimated by minimizing the negative of the logarithm of the likelihood function, which, ignoring constants which are independent of the values for the model parameters, is defined as:

$$-\ln L = \sum_{i=1}^{n}\left(\ln\sigma_i + \frac{\left[\ln(L_i)-\ln(\bar{L}_i)\right]^2}{2\sigma_i}\right) \tag{8.B.5}$$

where $\overline{L}_i$ is the model-estimate of the expected length of the ith fish in the sample,

σ_{a_i} is the standard deviation of the logarithm of the mean length of the ith fish in the sample, and

n is the total number of age-length observations.

The model was fitted using the AD Model Builder software package (Otter Consulting). The data set of age-length observations provided by the CAF consisted of data for six years (1990, 1991, 1992, 1993, 1994, 1996), totalling 1995 pairs of observations, with a maximum age (x) in the sample of 39 yr.

8.B.2 Results and discussion

The maximum likelihood estimates (MLEs) of the model parameters are given in Table 8.B.1. The impact of the selectivity of the sampling method can lead to biased estimates of the size at age (REF), (often particularly true for young ages), as the samples only represent a fraction of the true distribution of size-at-age. Over-observation of size-at-age for young fish frequently leads to unrealistically low estimates of the t_0 parameter when fitting von Bertalanffy growth curves, which leads to an estimation of minimal growth during the observed lifespan. Table 8.B.1 therefore also provides the maximum likelihood estimates of the model parameters obtained from a fit to the model which fixed the value of t_0 at zero, and the values for the parameters determining the standard deviation of the mean length at ages 1 and x when the values for the three von Bertalanffy parameters were fixed at values provided by the CAF (1998) for female jackass morwong.

Tables 8.B.2, 8.B.3, and 8.B.4 list the estimates of mean length-at-age, standard deviation of length-at-age, and mean weight-at-age for the three estimation scenarios.

All of the three estimation scenarios produce consistent estimates of the standard deviations of the mean lengths-at-age (Tables 8.B.2, 8.B.3 and 8.B.4). Irrespective of the estimation scenario, the standard deviation of the natural logarithm of the mean length at the lowest age was estimated to be lower than that at the maximum age. It is usually assumed that the CV of the distribution of log-length at age decreases with increasing age, as the majority of growth occurs when fish are younger, and so it is at this time when factors affecting growth rate are most likely to be expressed in the size distribution of the population. The lack of a large number of otoliths from older individuals in the age-length data set may have contributed to the estimated increase with age in standard deviation of the log of the mean length-at-age.

Table 8.B.1 : Values used for the parameters of the weight-length relationship (CAF, 1998) and maximum likelihood estimates of the parameters for the von Bertalanfy growth curve, for scenarios when all parameters were estimated, and the estimates obtained when the value of t_0 was fixed at zero.

Parameter	Value		
α	0.00017		
β	3.031		
	MLE	MLE for t_0 =0	MLE (fixed VB)
L_∞	38.04	35.65	36.39
k	0.188	0.419	0.34
t_0	-3.552	0	-0.45
σ_{L_1}	2.16	2.10	2.18
σ_{L_x}	3.13	3.12	3.08

Table 8.B.2 : Estimates of mean length-at-age, standard deviation of the mean length-at-age, and mean weight-at-age corresponding to the MLEs of the model parameters given in Table 8.B.1 when all parameters are estimated.

Age	$\bar{L}_a$ (cm)	sd_a	$\bar{w}_a$ (kg)
1	21.88	2.16	0.22
2	24.65	2.33	0.31
3	26.95	2.46	0.41
4	28.85	2.58	0.50
5	30.43	2.67	0.59
6	31.73	2.75	0.66
7	32.81	2.81	0.73
8	33.71	2.87	0.79
9	34.45	2.91	0.85
10	35.07	2.95	0.89
11	35.58	2.98	0.93
12	36.00	3.00	0.97
13	36.35	3.03	0.99
14	36.64	3.04	1.02
15	36.88	3.06	1.04
16	37.08	3.07	1.06
17	37.24	3.08	1.07
18	37.38	3.09	1.08
19	37.49	3.09	1.09
20	37.58	3.10	1.10
21	37.66	3.10	1.11
22	37.73	3.11	1.11
23	37.78	3.11	1.12
24	37.82	3.11	1.12
25	37.86	3.12	1.12
26	37.89	3.12	1.13
27	37.92	3.12	1.13
28	37.94	3.12	1.13
29	37.95	3.12	1.13
30	37.97	3.12	1.13
31	37.98	3.12	1.13
32	37.99	3.12	1.13
33	38.00	3.12	1.14
34	38.00	3.12	1.14
35	38.01	3.13	1.14
36	38.01	3.13	1.14
37	38.02	3.13	1.14
38	38.02	3.13	1.14
39	38.02	3.13	1.14

Table 8.B.3 : Estimates of mean length-at-age, standard deviation of the mean length-at-age, and mean weight-at-age corresponding to the MLEs of the model parameters given in Table 8.B.1 when the value of t_0 is set to zero.

Age	$\bar{L}_a$ (cm)	sd_a	$\bar{w}_a$ (kg)
1	12.19	2.10	0.05
2	20.22	2.45	0.18
3	25.50	2.68	0.36
4	28.97	2.83	0.52
5	31.26	2.93	0.64
6	32.76	2.99	0.74
7	33.75	3.04	0.81
8	34.40	3.07	0.85
9	34.83	3.08	0.88
10	35.11	3.10	0.90
11	35.30	3.10	0.92
12	35.42	3.11	0.93
13	35.50	3.11	0.93
14	35.55	3.12	0.94
15	35.59	3.12	0.94
16	35.61	3.12	0.94
17	35.62	3.12	0.94
18	35.63	3.12	0.95
19	35.64	3.12	0.95
20	35.65	3.12	0.95
21	35.65	3.12	0.95
22	35.65	3.12	0.95
23	35.65	3.12	0.95
24	35.65	3.12	0.95
25	35.65	3.12	0.95
26	35.65	3.12	0.95
27	35.65	3.12	0.95
28	35.65	3.12	0.95
29	35.65	3.12	0.95
30	35.65	3.12	0.95
31	35.65	3.12	0.95
32	35.65	3.12	0.95
33	35.65	3.12	0.95
34	35.65	3.12	0.95
35	35.65	3.12	0.95
36	35.65	3.12	0.95
37	35.65	3.12	0.95
38	35.65	3.12	0.95
39	35.65	3.12	0.95

Table 8.B.4 : Estimates of mean length-at-age, standard deviation of the mean length-at-age, and mean weight-at-age corresponding to the MLEs of the model parameters given in Table 8.B.1 when the value of t_0 is set to zero.

Age	$\bar{L}_a$ (cm)	sd_a	$\bar{w}_a$ (kg)
1	14.16	2.18	0.07
2	20.56	2.44	0.19
3	25.12	2.63	0.34
4	28.37	2.76	0.48
5	30.68	2.85	0.61
6	32.32	2.92	0.71
7	33.49	2.97	0.78
8	34.32	3.00	0.84
9	34.92	3.03	0.89
10	35.34	3.04	0.92
11	35.64	3.05	0.94
12	35.85	3.06	0.96
13	36.00	3.07	0.97
14	36.11	3.07	0.98
15	36.19	3.08	0.99
16	36.24	3.08	0.99
17	36.28	3.08	0.99
18	36.31	3.08	0.99
19	36.33	3.08	1.00
20	36.34	3.08	1.00
21	36.35	3.08	1.00
22	36.36	3.08	1.00
23	36.37	3.08	1.00
24	36.37	3.08	1.00
25	36.37	3.08	1.00
26	36.37	3.08	1.00
27	36.38	3.08	1.00
28	36.38	3.08	1.00
29	36.38	3.08	1.00
30	36.38	3.08	1.00
31	36.38	3.08	1.00
32	36.38	3.08	1.00
33	36.38	3.08	1.00
34	36.38	3.08	1.00
35	36.38	3.08	1.00
36	36.38	3.08	1.00
37	36.38	3.08	1.00
38	36.38	3.08	1.00
39	36.38	3.08	1.00

APPENDIX 8.C : Standardisation of Catch-per-unit-effort (CPUE) information

8.C.1 Methods

The 2002 SEF Fishery Assessment Report (FAR) suggested that the data included in a standardisation of CPUE for jackass morwong should be limited to those from Eastern Zone B, in effect East Victoria. The standardisation procedure described here utilised data from New South Wales, east Victoria and Bass Strait, as trawling activities in all three of these zones were considered to be one fleet in the stock assessment. The majority of the landings of jackass morwong during the period for which SEF1 logbook data are available were from these areas. A separate analysis was conducted which used SEF1 logbook data from east Tasmania, to develop a standardised index of abundance for the fishing fleet (fleet 5) for this area.

Logbook records included in the analysis were limited to tows which were able to be identified as trawls (as opposed to those tows using the Danish seine method). Only shots in which at least 30 kg of jackass morwong were caught were considered to remove shots from the analysis which clearly reflected non-targeting of jackass morwong. In addition, shots were only used from vessels which had at least a five-year history in the fishery over the time period of the SEF1 logbook database, and which had a median annual catch of jackass morwong of at least 5 t. Removal of data from vessels which did not meet this criterion was exclude vessels which have not consistently fished for morwong, with the assumption that catch records for vessels that do fish consistently for morwong would more likely reflect trends in the abundance of morwong.

A general linear modelling (GLM) approach with a log-link was used to relate the natural logarithm of catch rate to a wide suite of factors also recorded in the SEF1 logbooks, with the log of the catch rates of jackass morwong assumed to be normally distributed. The intent of CPUE standardisation procedure is to extract the information in the catch data related to relative annual abundance (the year effect) by accounting for variation in the data set due to other, known factors. A large number of models were considered, which utilised different combinations of factors and interaction terms. Factors considered in the analyses in addition to year included: zone (fishing area), month, depth (treated as a factor with 100 m depth bin categories), vessel, and the natural logarithms of the catches of eight other species (again factorised); tiger flathead, spotted warehou, blue warehou, eastern gemfish, ocean perch (shallow), redfish, silver trevally and john dory.

Akaike's information criteria (AIC) was used as a means of model selection to identify the 'best' model from the full range of those considered. In addition, models which contained factors or interaction terms which accounted for variance in the data which was less than 1% of the model deviance were ignored. This was to remove from consideration models which were excessively complicated, in that given the large size of the data set, terms may indeed be significant, but make little or no contribution to the model fit.

Following the selection of a suitable GLM, 50 bootstraps of the residuals to the model fits were obtained. The 'best' GLM was then fitted to each of these bootstrapped data sets in order to estimate the coefficients of variation (CVs) of the estimated year effects.

8.C.2 Results

Figure 8.C.1 and Table 8.C.1 show the unstandardised geometric mean catch-rates for jackass morwong the period for which SEF1 logbook data are available (1985-2002), for the analysis which used data from NSW, EVic, and BS, corresponding to fleet 3. The geometric mean is used as this method is known to be less sensitive to outliers than the arithmetic mean. As a result, the geometric mean is probably more robust to any obvious recording errors or small numbers of erroneously high catches in the database. The geometric mean CPUE (Figure 8.C.1) shows a dramatic reduction from 1985 to the mid-1990s, followed by stability.

The catch rates obtained from the best model obtained from the standardisation procedure for this fleet is also shown in Figure 8.C.1. This model had the form:

$$\begin{aligned}\ln(\text{CPUE}) \sim\ & \text{Year}+\text{Month}+\text{Zone}+\text{Depth}+\text{Vessel}+\\ & \text{Depth:Vessel}+\text{Month:Vessel}+\text{FHFac:Depth}\end{aligned} \qquad (8.C.1)$$

where FHFac is the categorised natural logarithm of the catch of flathead caught with jackass morwong. The flathead factor was dropped from the model as the majority of the variance explained by this factor could be accounted for by the flathead:depth interaction term. Indeed, a model which contained both terms would have been rejected given the selection criteria.

Figure 8.C.1 also shows several diagnostic plots for this model. There is little evidence for model mis-specification, although there are fewer negative residuals at lower fitted values – which, given the exclusion of small catches from the dataset, is perhaps not surprising. There is also no evidence of heteroscedascity; the variance does not appear to change as a function of the predicted variable. The q-q plot in Figure 8.C.1 also supports the assumption of normality in the distribution of the residuals.

The extracted year effects from the fitted model, that is, the standardised catch rates, are given in Table 8.C.1, and are plotted in the upper-left panel of Figure 8.C.1. As with the geometric mean, the standardised CPUE declines from 1985 to the mid-1990s and then stabilizes. However, the magnitude of the reduction in standardised CPUE is lower than that suggested by the geometric means. Table 8.C.2 lists the geometric mean catch-rates and the standardised index, both expressed relative to 2002. Standardized catch rates in the late 1980s and early 1990s are proportionately lower relative to that for 2002 compared to those for the geometric means.

Figure 8.C.2 shows the unstandardised geometric mean catch-rates for east Tasmania (fleet 5). In the standardisation procedure for this fleet, the best model differed to that obtained for the fleet 3 analysis. The catch rates obtained from the best model obtained from the standardisation procedure for fleet 5 is also shown in Figure 8.C.2. This model had the form:

$$\begin{aligned}\ln(\text{CPUE}) \sim\ & \text{Year}+\text{Month}+\text{Depth}+\text{Vessel}+\\ & \text{Depth:Month}+\text{Month:Vessel}\end{aligned} \qquad (8.C.2)$$

The diagnostic plots in Figure 8.C.2 again show little evidence for model mis-specification or for heteroscedascity. The standardised catch rates for this fleet are not as different from the geometric mean catch rates as those in the fleet 3 analysis, showing a substantial decline in CPUE over the timer period. This could be a reflection of the fact that the number of data points used in the fleet 5 analysis is about 20% that for the fleet 3 analysis, meaning that there are less observations to determine effects attributable to the various factors.

Table 8.C.1 : Geometric mean and standardised catch-per-unit-effort (CPUE) for jackass morwong (1985 – 2002).

Year	Geometric mean CPUE (kg/hr)	Standardised CPUE (kg/hr)	CV of standardised CPUE
1985	44.0	25.5	0.154
1986	44.7	23.7	0.157
1987	54.2	28.4	0.147
1988	47.2	25.2	0.148
1989	48.0	24.7	0.151
1990	36.4	19.8	0.144
1991	38.0	19.4	0.148
1992	33.6	17.8	0.151
1993	33.0	17.7	0.151
1994	30.5	16.9	0.148
1995	26.3	14.8	0.151
1996	26.2	13.7	0.149
1997	30.3	16.3	0.148
1998	27.9	14.6	0.144
1999	27.4	14.6	0.145
2000	28.7	15.2	0.150
2001	23.8	12.6	0.150
2002	24.0	13.6	0.149

Table 8.C.2 : Geometric mean and standardised CPUE relative to 2002 catch rates.

Year	Geo. mean CPUE (relative to 2002)	Standardised CPUE (relative to 2002)
1985	1.83	1.88
1986	1.86	1.74
1987	2.26	2.09
1988	1.97	1.85
1989	2.00	1.81
1990	1.52	1.46
1991	1.58	1.42
1992	1.40	1.31
1993	1.38	1.30
1994	1.27	1.24
1995	1.09	1.09
1996	1.09	1.01
1997	1.26	1.20
1998	1.16	1.07
1999	1.14	1.08
2000	1.19	1.12
2001	0.99	0.93
2002	1.00	1.00

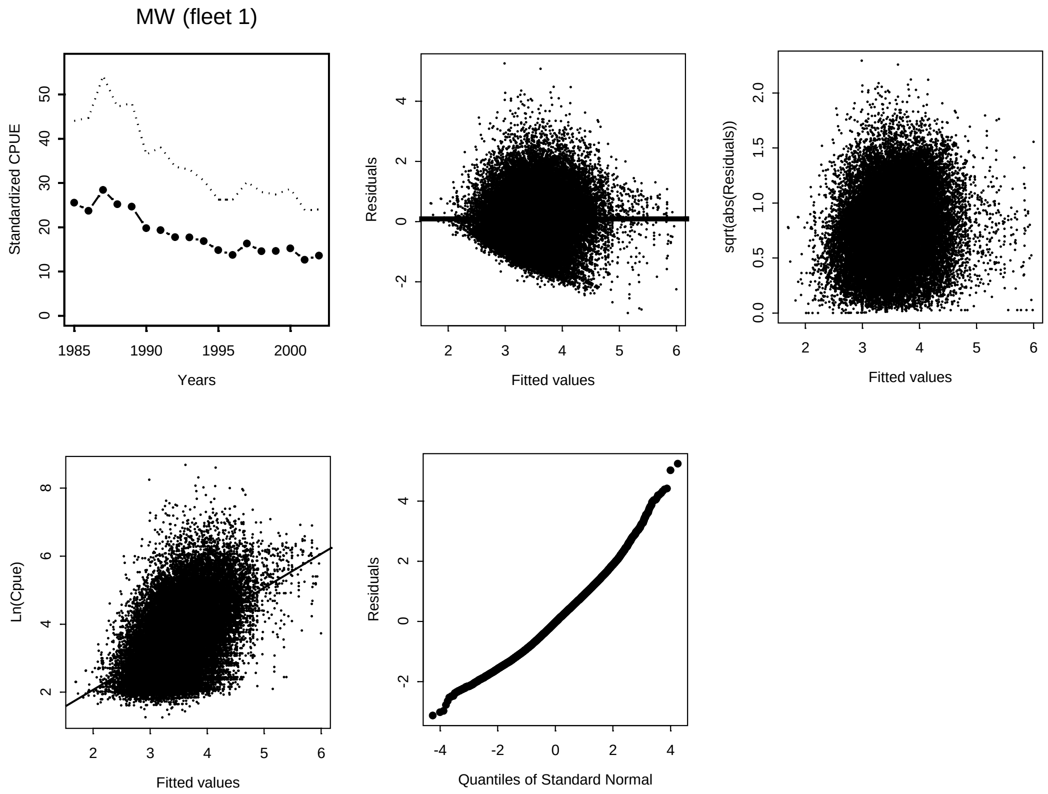


Figure 8.C.1 : Plot of geometric mean (upper left panel, dotted line) and standardised (upper-left panel, solid line) catch-per-unit-effort (CPUE) from the ‘best’ model for jackass morwong, and diagnostic plots from the fitting of the ‘best’ GLM used in the standardisation procedure for the analysis for fleet 3 logbook data (NSW, EVic & BS).

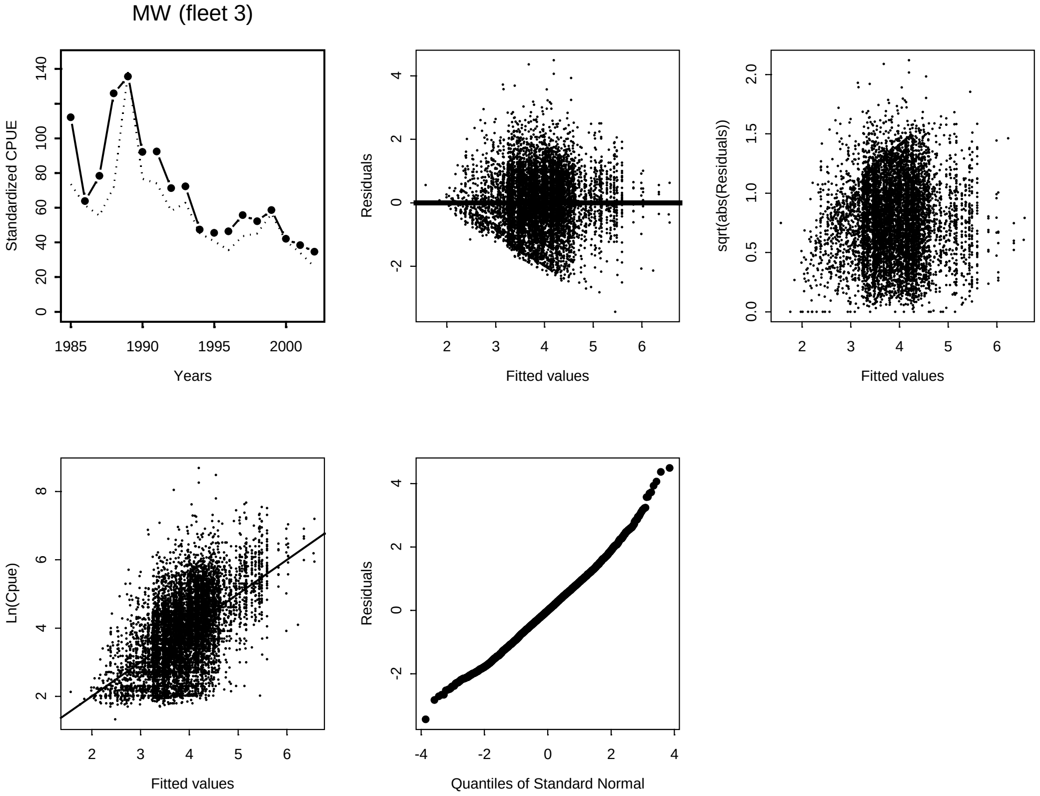


Figure 8.C.2 : Plot of geometric mean (upper left panel, dotted line) and standardised (upper-left panel, solid line) catch-per-unit-effort (CPUE) from the 'best' model for east Tasmania, and diagnostic plots from the fitting of the 'best' GLM used in the standardisation procedure for the analysis for fleet 5 logbook data (otter trawlers ETas).

9. Stock Assessment for Pink Ling (*Genypterus blacodes*) based on data up to 2002

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9.1 Background

This document summarises and examines South East Fishery (SEF) data for pink ling (*Genypterus blacodes*) to the end of December 2002. The data were collected and processed in the weeks prior to the workshop. An effort was made to collect as much available data as possible to the end of the 2002 calendar year. Logbook information for the trawl and non-trawl sectors of the fishery was provided by the Australian Fisheries Management Authority (AFMA) to Primary Industries Research Victoria (PIRVic), and after some processing by PIRVic to CSIRO. Central Ageing Facility (CAF) Victoria provided age-length information collected though the Independent Scientific Monitoring Program (ISMP), and ISMP length-frequency data collected in port and on-board were provided to CSIRO via PIRVic. Data processed through PIRVic followed formatting protocols proposed by Thomson (2002c) and endorsed by a workshop on SEF data held at PIRVic in April 2003.

The assessment update including yield analysis, catch curve analysis and integrated analysis follows from earlier work in these areas detailed in Thomson (2000a, 2000b, 2002a, 2002b) and Thomson and Smith (2002).

9.1.1 The Fishery

9.1.1.1 Fishing Method

Ling are caught by trawl, longline, drop-line, traps and mesh nets. Ling were caught as a by-catch of gemfish and blue grenadier fishing but are increasingly targeted across the fishery.

9.1.1.2 2002 Catch

The total landing of ling during 2002 was 1,611t. The 2002 SEF2 landed weight by the trawl sector was 1,074t (1,073t in Commonwealth waters and 1t in State waters). The Commonwealth catch was 20% lower than in 2001 (1,347t) and represents 55% of the 2002 allocated trawl TAC of 1,946t. The 2002 SAN2 landed weight by the non-trawl sector was 522t, which was 38% higher than in 2001 (377t) and represents 71% of the 2002 allocated non-trawl TAC of 735t.

9.1.1.3 2003 TAC

In 2003 the agreed global TAC for ling was 2,160t (1,886t trawl and 274t non-trawl). The actual TAC (including carryover/under and leasing) for 2003 was 2,681t (1,946t trawl and 735t non-trawl).

9.1.1.4 Current situation

The total catch of ling in 2002 of 1,611 t continues a decline since a peak of 1,986 t in 1999. This catch was well below the 2002 actual TAC for all sectors of 2,681 t. Raw CPUE from trawl in the East (SEF statistical zones 10, 20 and 30) and West (zones 40, 50 and 60) show a continuous decline of about 40% since 1998.

A steadily increasing proportion of the trawl landings are being taken from the western area of the fishery (Western Tasmania, the Western Victoria). In 1986 only 15% of pink ling recorded in SEF1 logbooks were taken in the west, but during 2002, catches in this region accounted for more than half of the total trawl catch. Trawl catches off NSW are the lowest on record (132t in 2001, 112t in 2002 from preliminary figures). The median size of ling caught in the west in recent years has been greater than that in the east, and the median age in the west has been roughly 3 years as opposed to roughly 2 years in the east.

Catches of ling are seasonal, with the greatest trawl catches in the east during May and June whereas those in the west are greatest between August and October.

An increasing percentage of the ling catch (30% in 2002) is being taken by non-trawl methods, particularly by longlines, but traps, mesh nets and droplines also catch ling. These methods generally catch larger fish than trawlers in areas outside the historical trawl grounds. There is general concern about the impact that this may have on ling stocks.

9.1.2 Previous assessments

Prior to 1999, assessments have consisted largely of examination of catch and effort data, and catch composition data including catch curve analysis. Biological parameters such as growth parameters, length-weight parameters and length at first maturity have been estimated.

During 1992 and 1994 Wankowski and Moulton (1986) used demersal trawling and swept area techniques to estimate the standing stocks of several species in eastern Bass Strait (essentially Eastern B and part of Bass Strait). Their estimate of mean annual biomass of pink ling was 3,200 t with a standard error of 63 t. Smith *et al* (1995) estimated the annual standing stock of pink ling in western Bass Strait (essentially the western zone) during 1987 and 1988 to be 1,055 t with a standard error of 97 t. Both studies found that ling biomass, although relatively steady during the year, peaks during summer.

Two FRDC-funded projects into the ageing and mortality rates of pink ling both showed that older ling (more than 10 or 12 years of age) showed lower mortality rates than younger ling. Mortality rates of 0.3 y^{-1} for ling aged 3-10 and 0.1 y^{-1} for those older than

10 years were obtained by Smith *et al* (1996). Morison *et al* (1999) found mortality rates of between 0.12 and 0.42 y^{-1}, depending on which ages and years were included in the catch curve analysis, and estimates between 0.16 and 0.22 y^{-1} when basing their calculations on longevity.

A workshop on pink ling was held during 1995 to synthesise available data and comment on the status of the stock (see Smith & Tilzey, 1995). Estimates of landed catches between 1976 and 1995 were compiled and the catch composition of commercial and research data were examined. An inconsistency was noted between the stable catch-rates observed for this stock and the increased mortality shown by catch curve analyses applied to aged samples of the catch landed at Eden and Ulladulla. It was also noted that landings had increased markedly over the time period considered. Possible reasons that were discussed to explain the improved catches included changes in fish abundance, changes in catchability, and improved targeting practices. Industry explained that ling were being increasingly targeted due to declines in gemfish catches. It was considered that the high mortality rates measured in the east might be due to unrepresentative sampling. It was hoped that sampling during 1995/96 would resolve this conflict. It was also noted during the workshop that industry reported considerable discards of small pink ling but that this was not seen in the SMP data.

Following the collection of further data on pink ling another workshop was held, in December 1998. CPUE standardisations were performed (Haddon, 1999) and the stable to increasing trend noted during the 1995 workshop was still evident. Factors were discussed that might possibly bias the catch-per-unit-effort (CPUE) trend: expansion of the fishery into new areas, changes in gear, increased targeting, and different targeting methods being applied to fish of different sizes. However, for the area off NSW spatial analysis did not support the theory of expansion of the fishery into new areas.

A formal stock assessment for pink ling was conducted during 1999 and presented at a workshop during February 2000 (Thomson, 2000). The model was an integrated assessment using age-structured data but also estimated the length structure of the population and of the catch. A single stock of pink ling was assumed and the model included three sub-fisheries: east trawl (zones 10-30), west trawl (zones 40-60) and non-trawl. The model begins in 1977 when the stock is thought to have been close to pristine. The model estimates two values for natural mortality – one for animals aged less than 10 and one for those aged greater than 10. Selectivity for the trawl sub-fisheries were assumed to be dome-shaped and that for the non-trawl fishery was assumed to be logistic. Discarding of small fish was modelled but it was assumed that the non-trawl sub-fishery does not discard ling.

The data used included landings by the trawl fishery in the east and west and estimated landings for the non-trawl sector. Data on the age and length-composition of the catch and discards were used where available. Age-length keys were prepared separately for the east and west however data from all areas were applied to the non-trawl length composition data. The CPUEs were standardised using GLM analysis.

The model was unable to resolve the conflicting signals from the standardised CPUE data and the catch composition data. The estimate of spawning biomass in 1998 as a proportion of virgin spawning biomass (B0) was strongly dependent on the relative weighting given to the CPUE and the catch-at-age data. The only explanation consistent with a stable stock biomass and an increasing mortality rate is an increase in the number of smaller/younger animals. There was no indication in the data, however, of an increasing proportion of 1-year old animals in the catch or in the discards.

The reasons for the conflicting signals from the CPUE and the catch-composition data were discussed at a ling workshop (Thomson, 2000). Some possible factors that might have biased the observed trends included: that ling might be cannibalistic; individual growth rates of ling may have changed over time; poor early data may have unduly influenced model results; quota induced changes in fishing practices and targeting may have biased the observed trends in data; and, vessel power may have increased in recent years due to technological improvements in fishing gear.

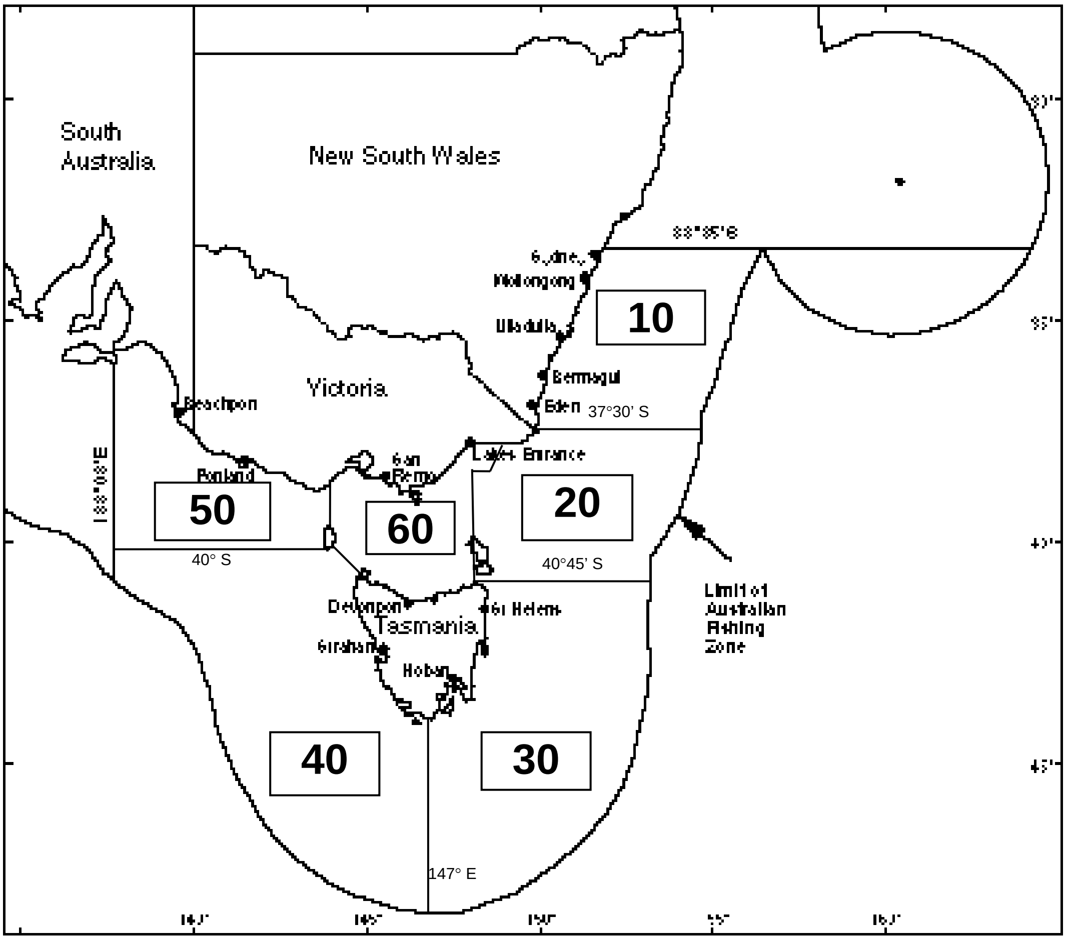
9.2 Analytical approach

9.2.1 Total Catch

Total actual TAC and landed catch values for the SEF for 1992 to 1997 were taken from figures given in Thomson (2002b). Actual TAC and landings figures for the trawl and non-trawl fishery components for 1998 to 2002 were obtained from AFMA (Shane Spence, per. comm.).

Where statistics are broken down by zone, the zones described by Klaer and Tilzey (1994) have been used, as shown in Figure 9.1. The 'east' fishery is defined as zones 10, 20 and 30, while the 'west' fishery is defined as zones 40, 50 and 60.

Figure 9.1. Map of the South East Fishery region showing the six zones



As the number of vessels operating in different components of the non-trawl fishery is below 5 in many cases (annually by area), catch and effort statistics are not presented here because of commercial confidentiality. Although not presented, statistics for these fleet components have been examined, and some aspects of the methods used should be discussed. For demersal longline it is recognised that some vessels have automated setting gear allowing upwards of 5000 hooks to be set per fishing operation. Vessels with a gear code of “BL” and more than 5000 hooks per set were located and assigned a new method of “AL” for auto-longline to allow statistics for those vessels to be examined separately. The vessel ID numbers for these vessels were 12157, 12145 (both with the same vessel name), 6411, 6335 and 6396.

9.2.2 Raw CPUE

The effort measure used for various fishing methods are given in Table 9.1.

Table 9.1. Effort measures used for CPUE calculations for various fishing methods

Method	Method code	Effort measure	Unit formula	Unit formula description
Otter trawl	27	Hours trawled		
Demersal longline	BL (and AL)	Total hooks	THS	Total hooks set
Dropline	DL	Total hooks	NLD x AHL	Number of line lifts per day times average hooks per line
Gillnet	GN	Operations	Operation	Per fishing operation record
Fish trap	FP	Trap lifts	NFL	Number of fish trap lifts
Trotline	TL	Total hooks	NLS x THL	Number of lines per shot times hooks per line

For presentation of results, only those methods and years where more than 10t of ling was caught are shown. Detailed checking of effort values, particularly in the GN01 logbook has not been carried out. Simple tests were applied for some fishing methods to discard records with suspect effort values – demersal longline with less than 100 hooks, auto-longline with less than 1000 hooks, dropline with less than 100 hooks or more than 5000 hooks. These tests were only applied when examining CPUE, and do not affect total catch and record number statistics.

9.2.3 Standardised CPUE

Only otter trawl CPUE has been standardised, firstly because there are many more years covered by this fishing method, secondly because there are far fewer annual records by other fishing methods even in recent years and thirdly because the effort measures for the non-trawl have not been checked in any detail.

The GLM procedure has difficulty fitting the full otter trawl record set where each observation is a single trawl. To reduce the number of observations to a more manageable level, catch and effort were pooled within a single vessel, month, 50m depth stratum and 1 degree square.

The form of log-linear model is the same as that used by Haddon *et al.* (2000) as follows:

$$\mathrm{Ln(CE)} = \mathrm{Const} + a.\mathrm{Year} + b.\mathrm{Month} + c.\mathrm{Zone} + d.\mathrm{Depth} + e.\mathrm{VesselNo}$$

Interactive terms were not examined - they were only significant in some model variations in Haddon *et al.* (2000). All model parameters were examined as discrete factors, with depth classified into 50m strata.

Three levels of data inclusion were examined:

All records that caught ling – GLM1
All records that caught greater than 30kg of ling – GLM2
Records from standard ling vessels that caught greater than 30kg of ling – GLM3

A vessel was considered to be a standard ling vessel if, within the defined region, it caught ling for more than 2 years, caught an average of more than 10t per year, and the coefficient of variation (CV) for the annual catch was less than 0.8. This resulted in 40 standard ling otter trawl vessels for the SEF region, 29 for the eastern fishery and 9 for the western fishery.

Models were run for east and west regions for GLM1 – GLM3, and for all regions for GLM3 only.

9.2.4 Catch Length Distributions

Catch length frequency samples collected in port and on-board were examined separately for the east and west areas by trawl and non-trawl fishing methods.

9.2.5 Yield Analysis

The information required for this calculation were: selectivity-at-age, length-at-age, weight-at-age; age-at-maturity; and natural mortality. The parameters used are shown in Table 9.2.

Table 9.2. Population parameters used for yield analysis

a' (kg.cm)	b'	Linf	k	t0	length	M	S50	S95	lmat (cm)	steepness	age of plus group
2.93E-03	3.139	103.731	0.16	-2.309	TOT	0.2	39.9	43	67	0.75	20

9.2.5.1 Length- and weight-at-age

Length-at-age was calculated using the von Bertalanffy growth equation (parameters are Linf, k and t0) and the weight-at-age using the allometric length-weight relationship (parameters are a' and b'). The von Bertalanffy was calculated using length and age data supplied by the Central Ageing Facility. The type of length measurement (e.g. standard length or total length) used was specified, and for ling was normally total length. It is assumed the parameters of the length-weight relationship (Wayte and Smith, 2002) use the same measures. The units for these parameters are not specified and do not all appear to use the same units. These were manipulated until the results appeared to be in kg per cm.

9.2.5.2 Female length-at-maturity

Length-at-maturity for females (which is converted into a knife-edged function of age using the calculated lengths-at-age) was obtained from Wayte and Smith (2002).

9.2.5.3 Natural mortality

The natural mortality values presented by Bax and Knuckey (in prep) for ling were 0.12, 0.18 and 0.22. A value of 0.2 has been used in the models presented here.

9.2.5.4 Selectivity

A logistic selectivity curve is assumed. Selectivity parameters were drawn from Bax and Knuckey's calculated selectivity factors. Parameters used in the present investigation apply to a 90mm trawl mesh and non-trawl gear types are not considered.

The selectivity parameters used in this study have been estimated from an empirical relationship between fish size and mesh size derived from covered codend (or trouser haul) experiments on a subset of the species.

9.2.5.5 Stock-recruit relationship

A Beverton-Holt stock-recruit relationship is assumed using the single-parameter formulation suggested by Francis (1992a). The value of this parameter (steepness) was investigated by Koopman *et al* (2001) using meta-population analysis. The histograms presented by Koopman *et al.* were examined and likely figures for steepness chosen. The default figure of 0.75 suggested by Francis (1992b) is used when the results of Koopman *et al.* do not suggest a clear pattern.

9.2.6 Catch Curve Analysis

9.2.6.1 Data

This investigation used length frequency data from three sources: the NSW Sydney Fish Market measurement program; the *Kapala* slope cruises of 1976/7 and 1996/7 (Andrew *et al*, 1997); and the ISMP port measurement data (eg Knuckey *et al*, 2001). For a given year, fleet and population (see below for further detail) length frequencies from each zone by season cell are catch-weighted and summed to give annual length frequencies. The methodology is described in detail in Thomson (2002b).

Age and length data were obtained from the Central Ageing Facility. These age and length data were used to calculate the parameters of a von Bertalanffy growth curve for each species (see Thomson (2002b) for details). Age-length keys (ALKs) were also constructed from these data.

Two methods were used to convert length frequencies data into age frequencies: ALKs and chopping. The ALK method was used, where possible, to generate age frequencies data by multiplying the length frequency for a given year by the ALK for that same year. No allowances were made for inadequate sampling of an ALK so that, if no age samples were taken from a particular length class then all samples from this length class in the length frequency were ignored. This occurs because the ALK has a zero for all ages for that length class so that the length frequency is always multiplied by zero. 'Chopping' involves using the von Bertalanffy to chop the length frequency into age classes. Catch curve analysis was applied to all resulting age frequencies.

9.2.6.2 Fleets and Populations

The difference between a fleet and a population is that although the length frequency data are separated for both, the ALK data are separated into populations but are combined across fleets.

The length frequency data were separated into trawl and non-trawl (including Danish seine) fleets - *Fleet* 1 is trawl fleet and *Fleet* 2 non-trawl. Ling was divided into two populations *Population* 1 is eastern and *Population* 2 western.

9.2.6.3 Automated catch curve analysis

Catch curve analysis involves fitting a straight line to log-transformed data from age classes that are thought to be fully selected by the fishery. The underlying principle is that cohorts diminish in number, over time, through a process that can be described by exponential decay:

$$N_{y+1} = N_y e^{-Z_y} \tag{1}$$

where N_y is the number of animals in a cohort at the start of year y, and
Z_y is the overall instantaneous mortality rate - incorporating natural mortality (M_y), and fishing mortality (F_y) multiplied by selectivity (S which is a function of age and or length):

$$Z_y = M + F_y \; S \tag{2}$$

Log-transforming equation 1 gives:

$$\ln(N_{y+1}) = \ln(N_y) - Z_y \tag{3}$$

Therefore the slope of a straight line fitted to log-transformed age frequency data for a single cohort for consecutive years would be equal to $-Z_y$. However, data are seldom sufficiently accurate to allow the calculation of Z_y for each pair of N_y, N_{y+1} figures. The assumption is usually made that the Z_y (and therefore F_y) has been constant for the lifetime of each cohort. A straight line is fitted to the age data for several cohorts in a single year. The line is confined to ages that are thought to be fully selected (so that S in equation 2 can be taken to be 1 for all ages). This usually involves choosing, by eye, a section of the log-transformed data for which the plotted points seem to lie in a straight line. The youngest ages are assumed to be affected by selectivity and the oldest by a breakdown in the assumption of a constant F_y and possibly also by selectivity.

The method of selecting, by eye, the age classes to be considered was not practicable as roughly 500 catch curves were performed. A computer algorithm was therefore developed for selecting the 'best' of all possible ranges of age classes. It was found that simply selecting the line that gave the greatest value of the squared correlation coefficient (r^2; Zar, 1984) often resulted in the selection of ranges of only 2 or 3 ages because these points happened to be very closely in line (2 consecutive points will always lie exactly in line). Often these points were from a part of the plot that clearly ought not to have been used at all as the resulting slope was positive. After much trial and error, which included attempts to restrict the range of ages that was considered eligible for consideration, the following simple rules were used. Select the range of ages that gives the greatest value for the quantity ρ, where ρ is given by:

$$\rho = \begin{cases} 0 & \textit{for } n <= 2 \\ \sqrt{n}\, r^2 / 100 & \textit{for } n > 2;\ \textit{slope positive} \\ \sqrt{n}\, r^2 & \textit{otherwise} \end{cases} \tag{4}$$

where n is the number of ages included in the age range, and
r^2 is the squared correlation coefficient (see e.g. Zar, 1984).
"slope positive" indicates that the slope of a line fitted to this age range has a slope that is greater than or equal to zero.

All possible age ranges were considered.

9.2.7 Integrated Analysis

A generalised age-structured stock assessment developed at the University of Washington by a group headed by Ray Hilborn called Coleraine was used. Coleraine is a statistical age-and (potentially) sex-structured model. It allows several fisheries to be modelled at once and can be simultaneously fitted to many different sources of information, like catch-at-age and/or size data from the fishing fleet, and surveys and several indices of abundance (commercial fishery and survey). The estimation is performed using maximum likelihood theory in a first step and a Bayesian approach in a second (Hilborn *et al.,* 2000).

Prior information on the parameters that can be estimated may be readily incorporated, given the Bayesian framework of this statistical approach. Uncertainty around the estimates of the derived parameters of interest can be assessed directly from the Bayesian posteriors (Hilborn *et al*., 2000). The details of the fitting procedure are given in Appendix B.

A base case total (east plus west) population assessment used the prior parameter values and data files as given in Appendix A. The primary components are catch at age from trawl and non-trawl sectors, raw CPUE from trawl and non-trawl, selectivity curve for trawl in Thomson (2000b) by Knuckey that incorporates a decrease for older individuals, and a selectivity curve for non-trawl that assumes all but very young fish are equally selected, and total catch by fishing fleet in tonnes. The total catch was assumed to be otter trawl alone for trawl, and all other methods (including Danish seine) were assumed to be non-trawl.

Standardised CPUE for trawl flattens the recent declining trend, so an alternative to the base case was constructed that only fitted to standardised trawl CPUE .

Port length-frequency samples were used to construct catch at age information for the assessment presented at the workshop. It was noted during the workshop that the 2002 scaled length-frequency contained a large number of small fish. Investigation has shown that these came from a small number of fish incorrectly identified as ling in the 2002 sample that were scaled to large numbers due to the large numbers of fish in the catches they were taken from. These mis-identified samples have been removed, but the assessment presented here uses samples taken on-board in any case.

In addition to updates recommended by the workshop, some further adjustments have been made to improve consistency with other analyses presented for ling, and to incorporate additional information into the assessment:

- Estimated total annual landings from SEF2 and SAN2 are used for total catch instead of total catches recorded in SEF1 and GN01 logbooks
- Age of full selection by trawl changed from 4 to 3 with steeper left-hand transition to more closely match selectivity given by Knuckey in Thomson (2000)
- Initial exploitation rate set to reflect assessment output values from 1985-88 for trawl, 0.1 for raw CPUE and 0.07 for standardised.
- Raw CPUE was assigned a CV of 0.3. Average CV values for standardised CPUE were about 0.1 from the GLM presented in Klaer (2003), so a CV of 0.1 was assigned to those

9.2.8 Projections

Projections were made from Coleraine results using standard forward catch equations in an Excel spreadsheet, with fisheries assumed to take place in the middle of the year as in Coleraine. Deterministic future recruitment used fitted stock-recruitment parameters from Coleraine, and the different selectivities for trawl and non-trawl were the same as used in Coleraine.

9.3 Results

9.3.1 Total Catch

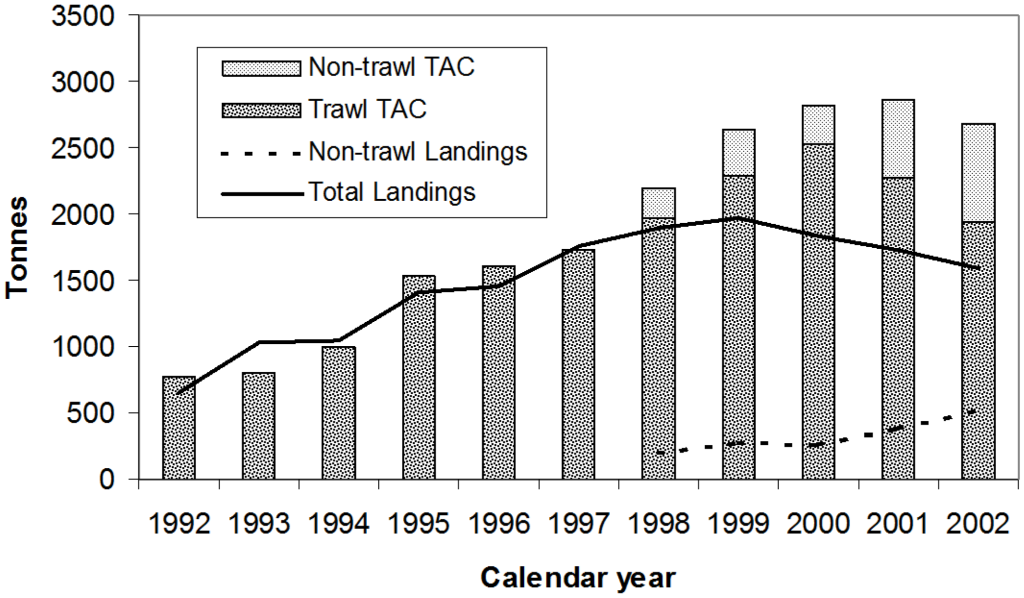


Figure 9.2. SEF Trawl and non-trawl trawl TAC versus total landings.

9.3.2 Raw CPUE

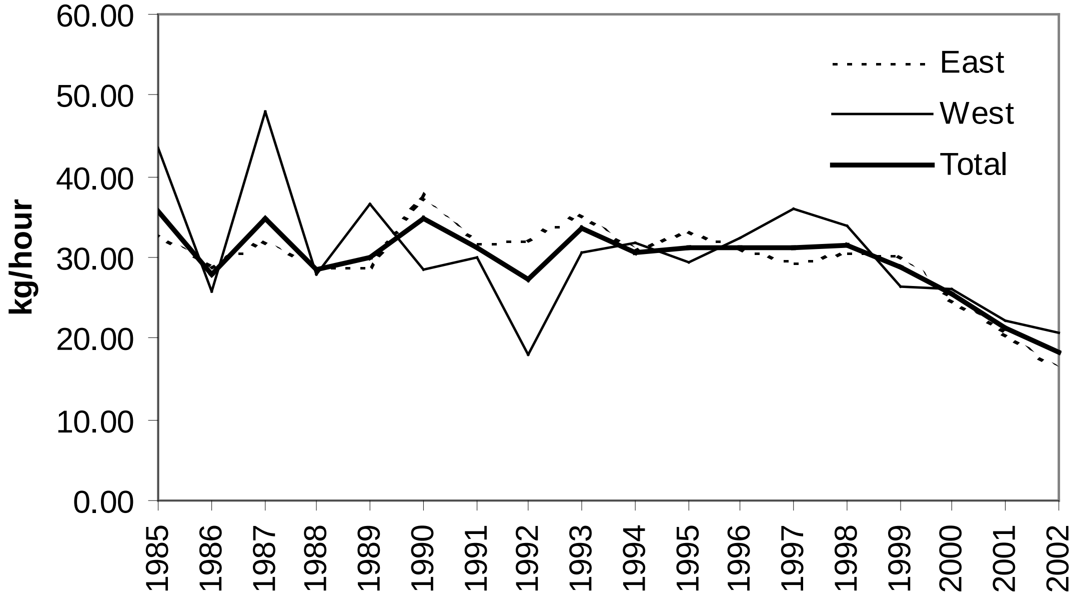


Figure 9.3. Raw CPUE (kg/hour) for otter trawl from SEF1

9.3.3 Standardised CPUE

Statistics applying to the various GLM runs are given in Table 9.3. The percentage of variation explained by the models is best for GLM1 East, which is the only one that appears very different when the data are filtered.

Table 9.3. GLM run statistics.

Model	Pooled Input Records	Null Deviance	Residual Deviance	% Deviance Explained	AIC
GLM1 East	44,501	65646	42639	35.05	361150
GLM1 West	19,593	20553	14130	31.25	158251
GLM2 East	27,490	15821	12262	22.50	250971
GLM2 West	14,136	8732	5882	32.64	121018
GLM3 East	13,725	7575	5861	22.63	126337
GLM3 West	4,595	2820	1882	33.26	39069
GLM3 All	20,820	12429	9629	22.53	189626

Year index results are given in figures 9.4-9.7, with approximate 95% confidence intervals (1.96 x s.d.) also shown. For the east, a slight decline in GLM1 is removed by GLM2 and GLM3. For the west, a dip in 1992, then and increase to 1997 followed by a decrease to 2000 is smoothed by GLM2. GLM3 for the west shows lower annual indices earlier (particularly 1986), and a less pronounced increase and decline from 1992 to 2002, giving the trend a flatter appearance. The GLM3 results for all areas more closely resembles the flat pattern as in the east, influenced by the larger proportion of input data from the east.

Figure 9.4(a) Standardised CPUE – GLM1 East

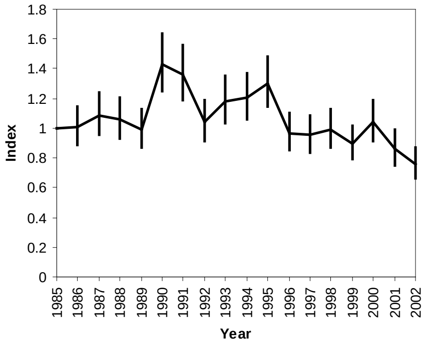


Figure 9.4(b) Standardised CPUE – GLM1 West

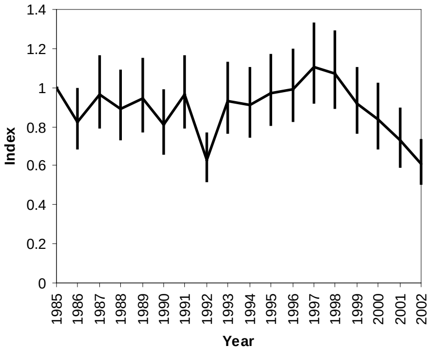


Figure 9.5(a) Standardised CPUE – GLM2 East

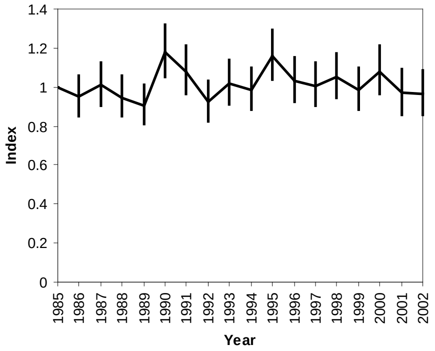


Figure 9.5(b) Standardised CPUE – GLM2 West

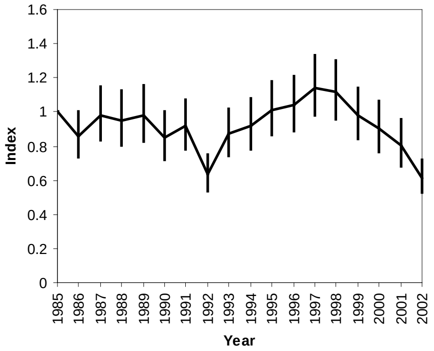


Figure 9.6(a) Standardised CPUE – GLM3 East

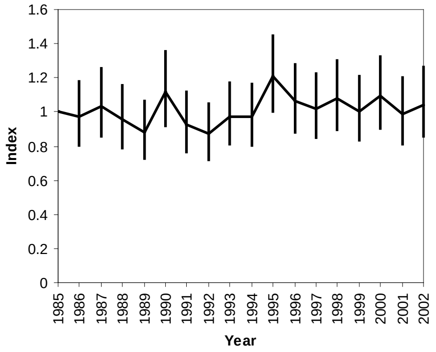


Figure 9.6(b) Standardised CPUE – GLM3 West

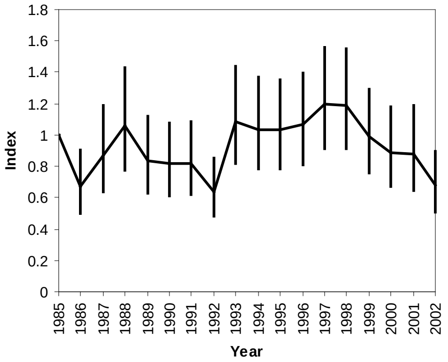
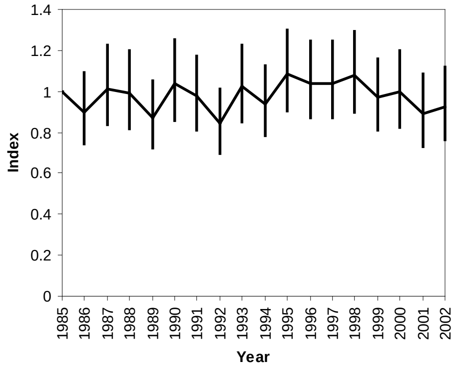


Figure 9.7. Standardised CPUE – GLM3 Total



9.3.4 Catch Length Distributions

Figure 9.8. Port samples – East Trawl

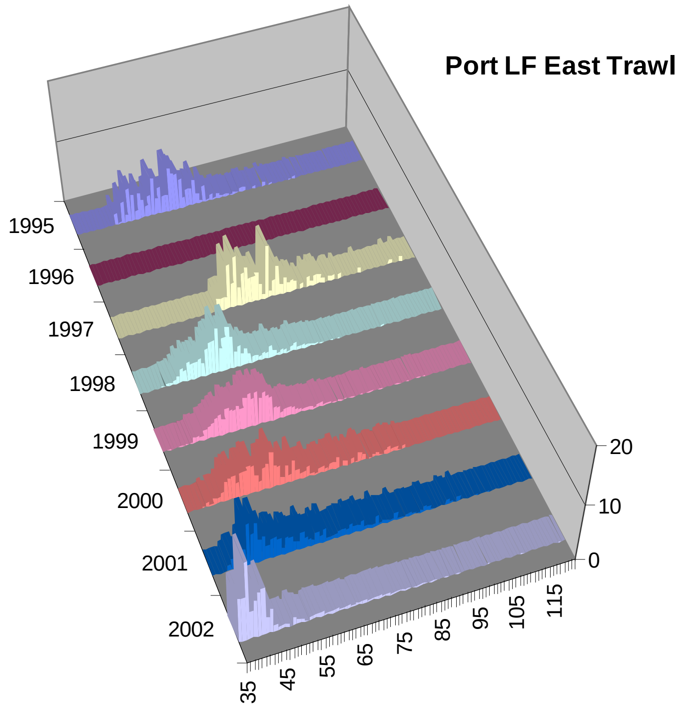


Figure 9.9. Port samples – East Non-trawl

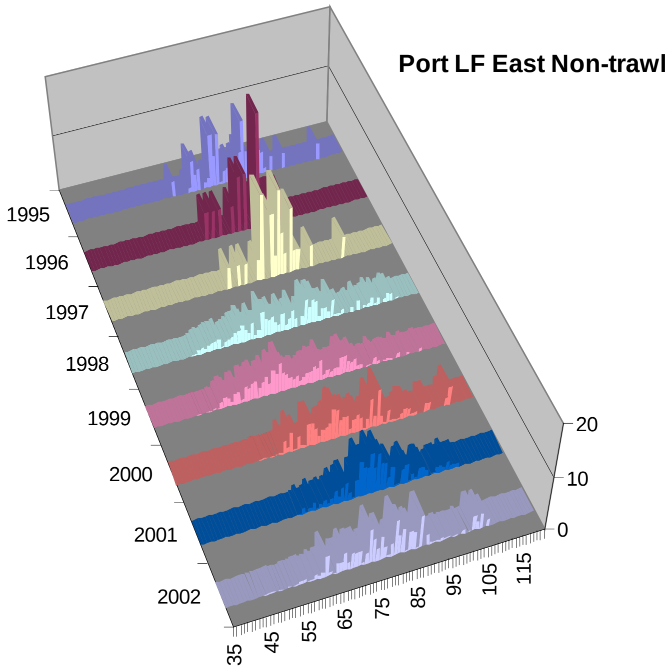


Figure 9.10. Port samples – West Trawl

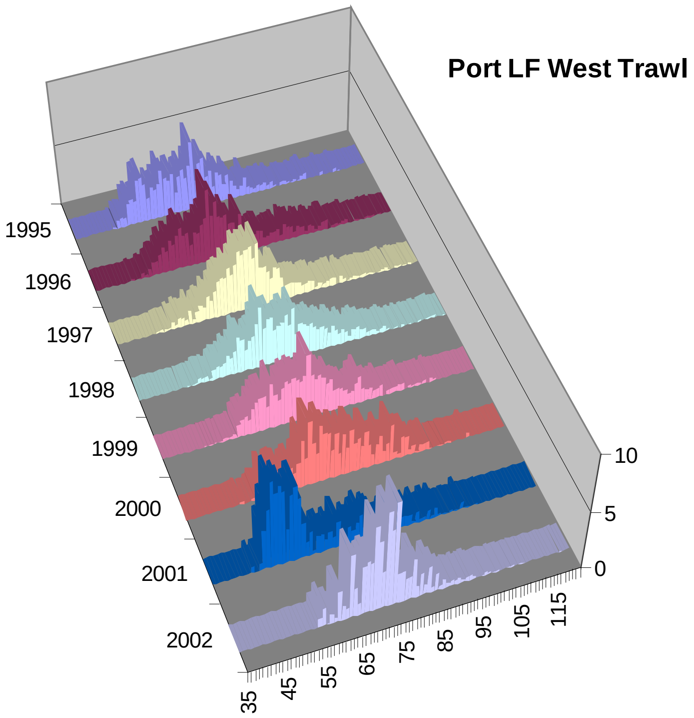


Figure 9.11. Port samples – West Non-trawl

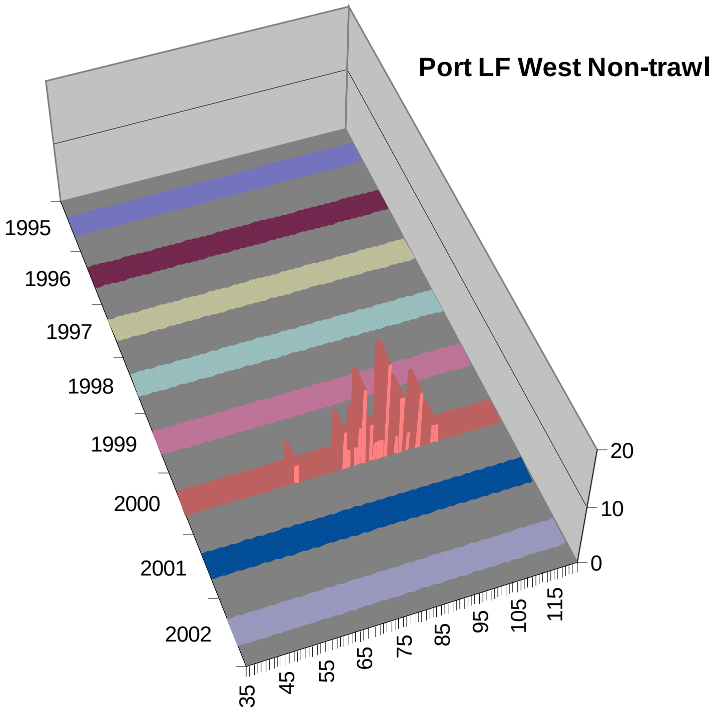


Figure 9.12. On-board samples – East Trawl

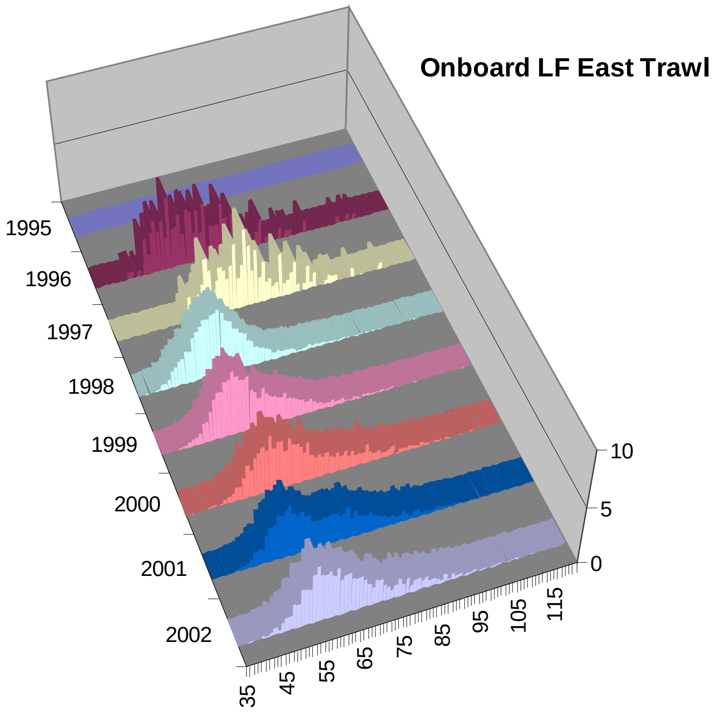


Figure 9.13. On-board samples – East Non-trawl

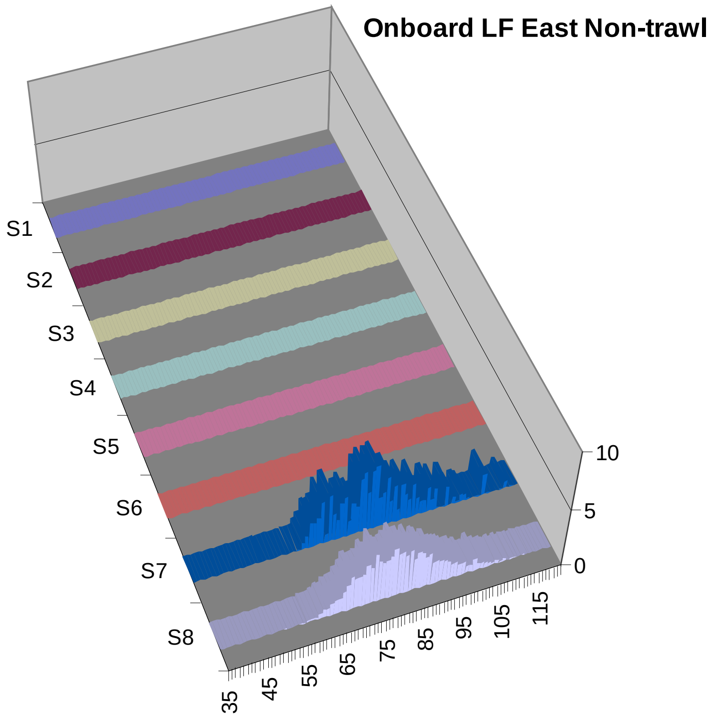
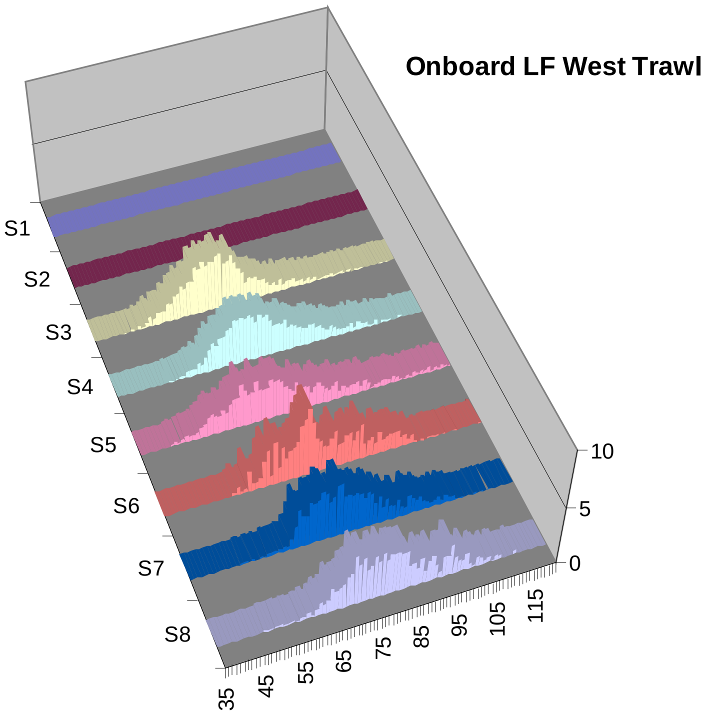


Figure 9.14. Port samples – West Trawl



9.3.5 Yield Analysis

Results of yield analysis are shown in Table 9.4 and Figures 9.15 and 9.16. The difference between results for east and west are only due to differences in fitted growth parameters for each area. Plots on the left show: solid curve - the relative female spawning biomass (spawning biomass divided by pristine spawning biomass); and dotted curve – the yield divided by the maximum sustainable yield, MSY. The horizontal and vertical lines mark the total mortality values (Z) for which female spawning biomass is at 20%, 30% and 40% of its pristine size. The plots on the right show the proportion of the population that is available to the gear that are less than 60 cm (dotted line) and 80cm (solid line) in length (using trawl selectivity alone).

Table 9.4. Yield results – population reference points by region

Value	East	West
Z(Bsp=0.2B0)	0.411	0.415
Z(Bsp=0.3B0)	0.349	0.352
Z(Bsp=0.4B0)	0.308	0.310

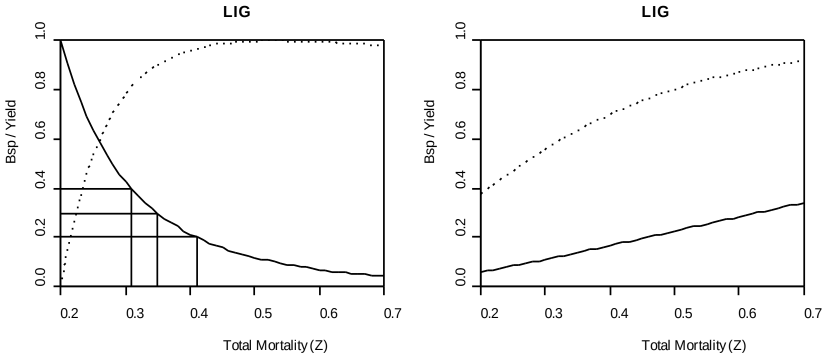


Figure 9.15. Eastern population

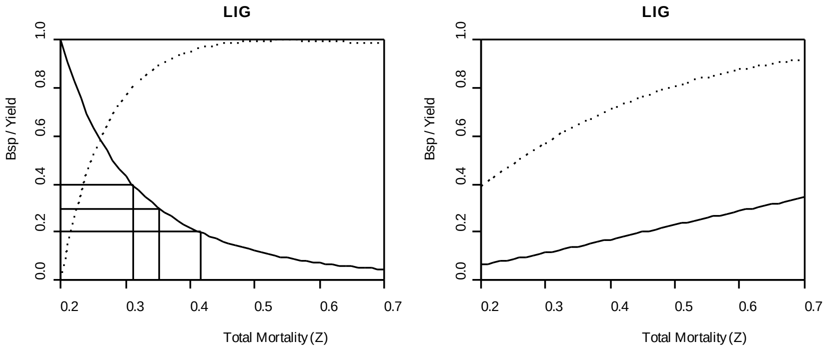


Figure 9.16. Western population.

9.3.6 Catch Curve Analysis

The value of fishing mortality (*F*) can, if all theory and assumptions are believed, be derived from the *Z* values shown in Figures 9.17 and 9.18 by subtracting the natural mortality rate (*M*).

The individual catch curves that gave rise to each point in the plots shown in Figures 9.17 and 9.18 are shown in the Appendix.

The results of catch curve analysis (see Thomson (2002b)) are shown together with the total mortality figures (*Z*) that resulted in spawning biomasses of 20% and 40% of pristine (solid horizontal lines).

Figure 9.17. Total mortality as estimated by catch curves for eastern and western ling populations for trawl from age and length samples.

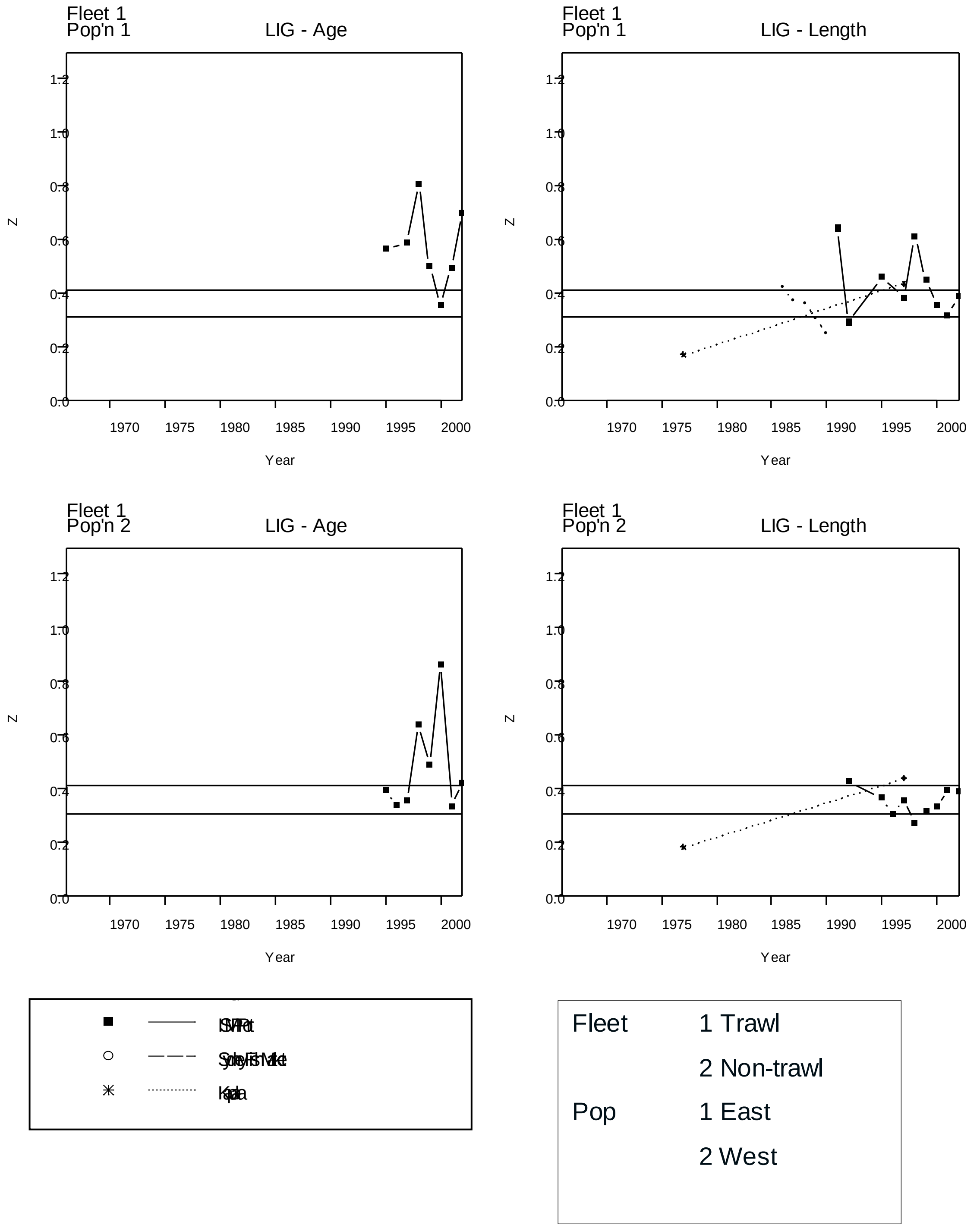
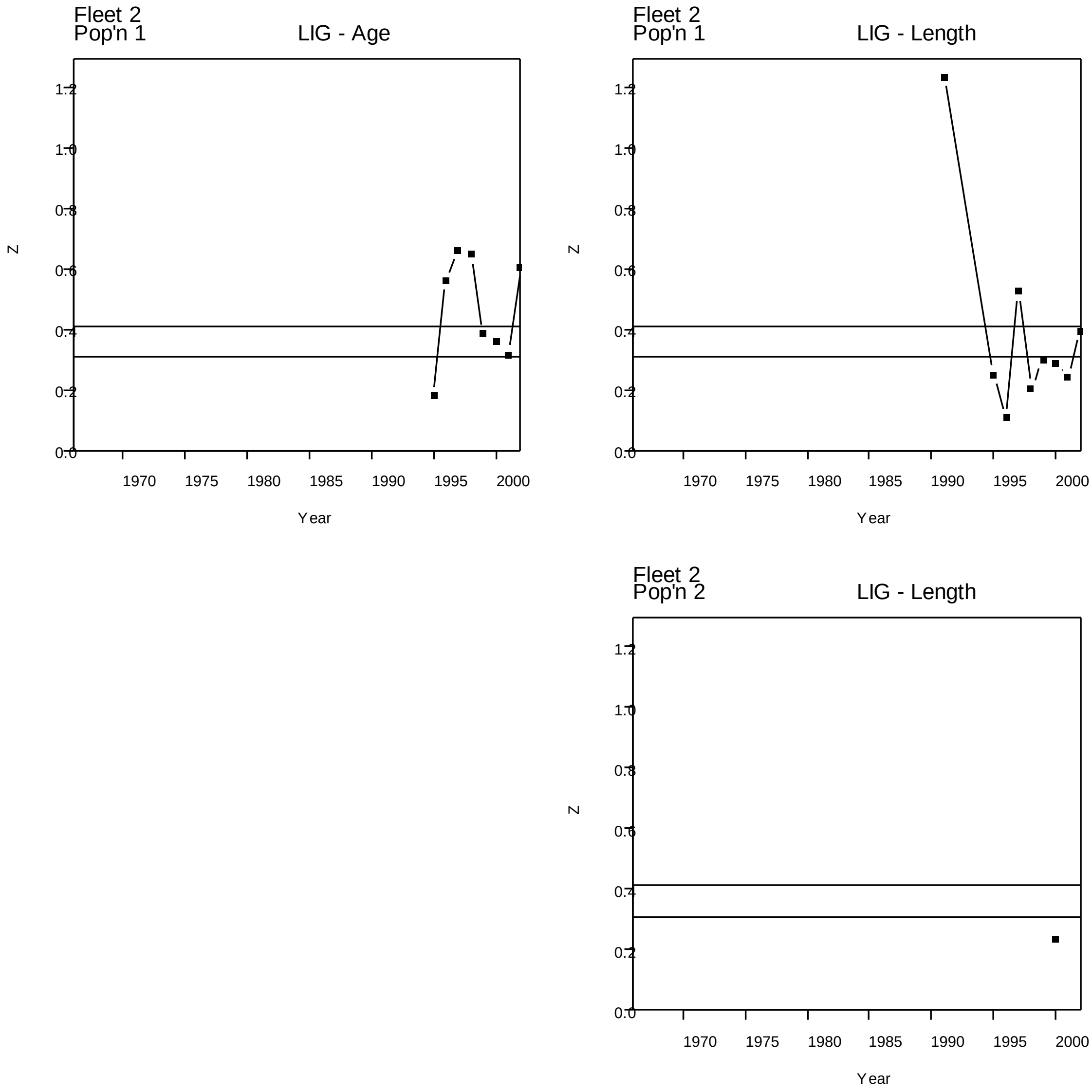
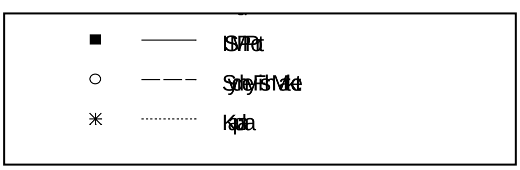


Figure 9.18. Total mortality as estimated by catch curves for eastern and western ling populations for non-trawl from age and length samples.





Fleet	1 Trawl
	2 Non-trawl
Pop	1 East
	2 West

9.3.7 Integrated Analysis

Figure 9.19. Base case general results – raw CPUE

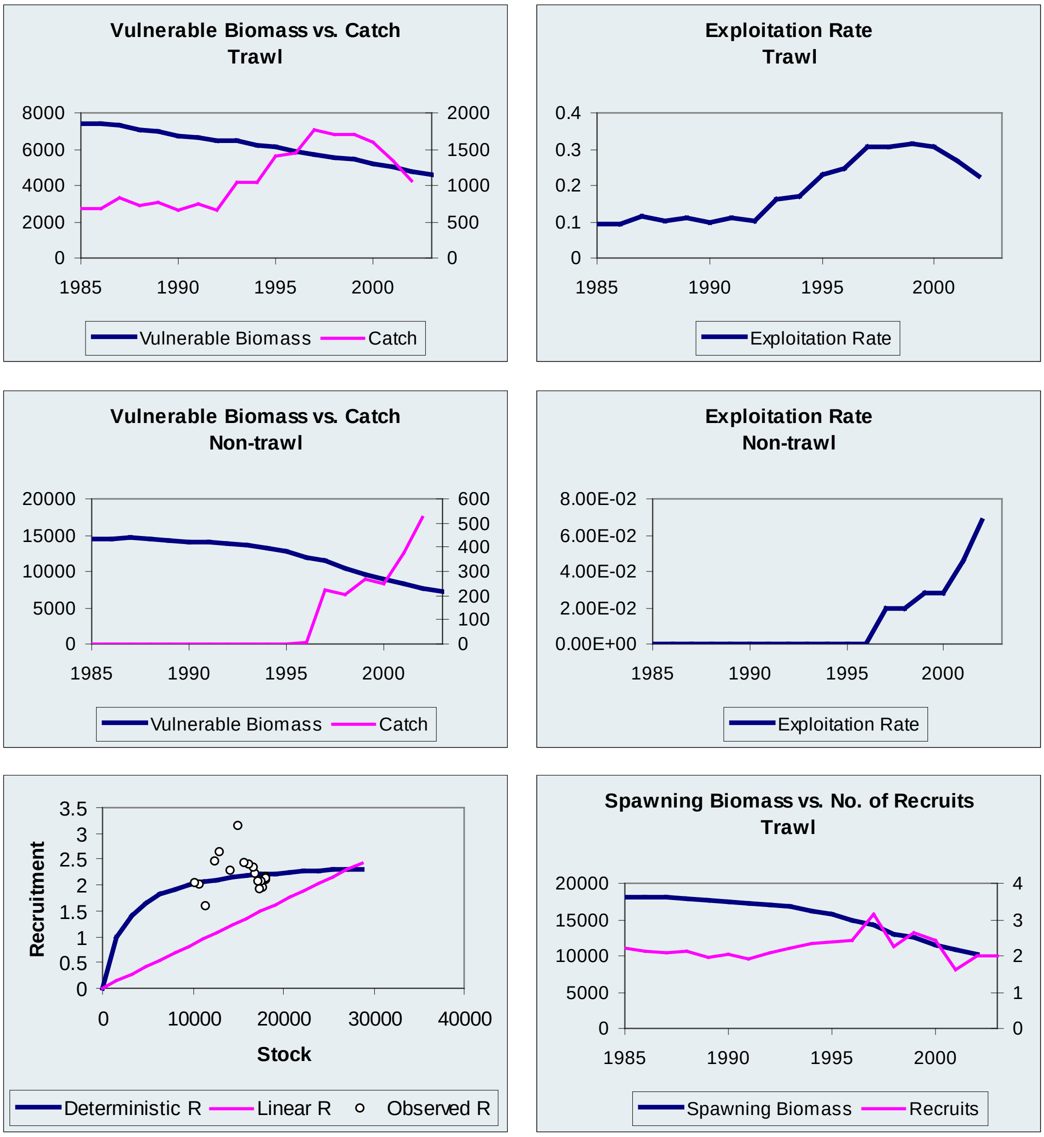


Figure 9.20. Base case CPUE fits – raw CPUE

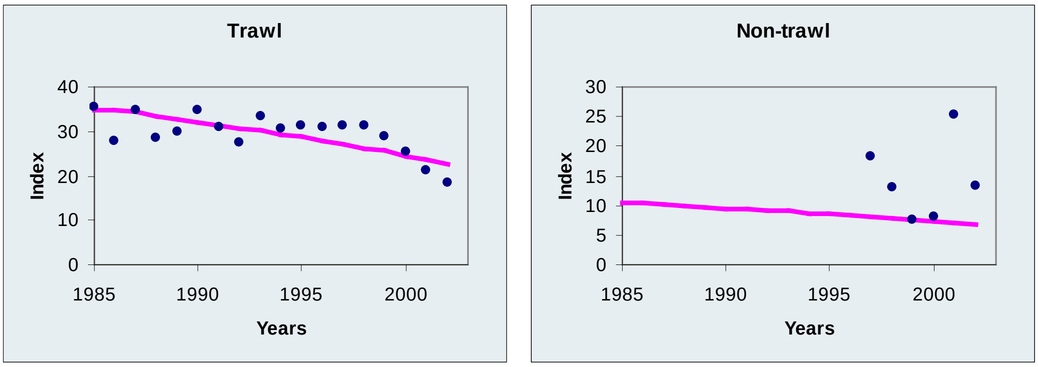


Figure 9.21. Base case catch at age fits – raw CPUE

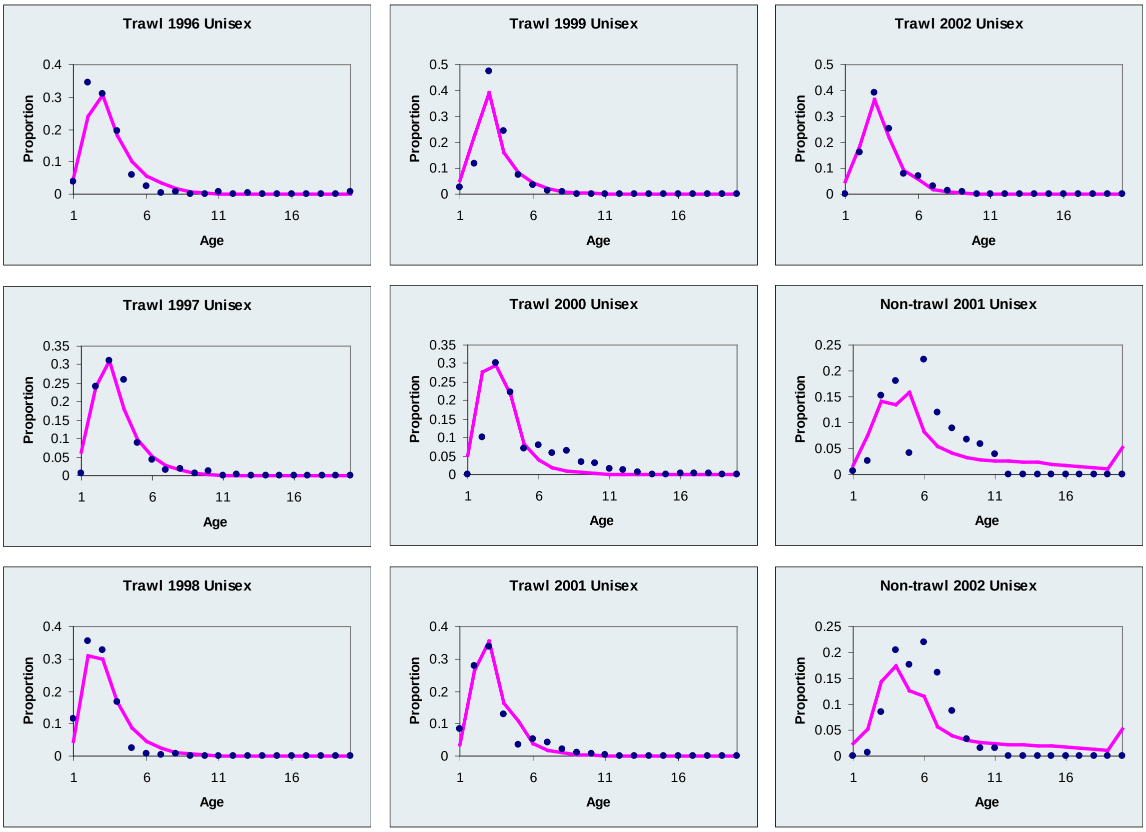


Figure 9.22. Base case general results – standardised CPUE (GLM 3 total)

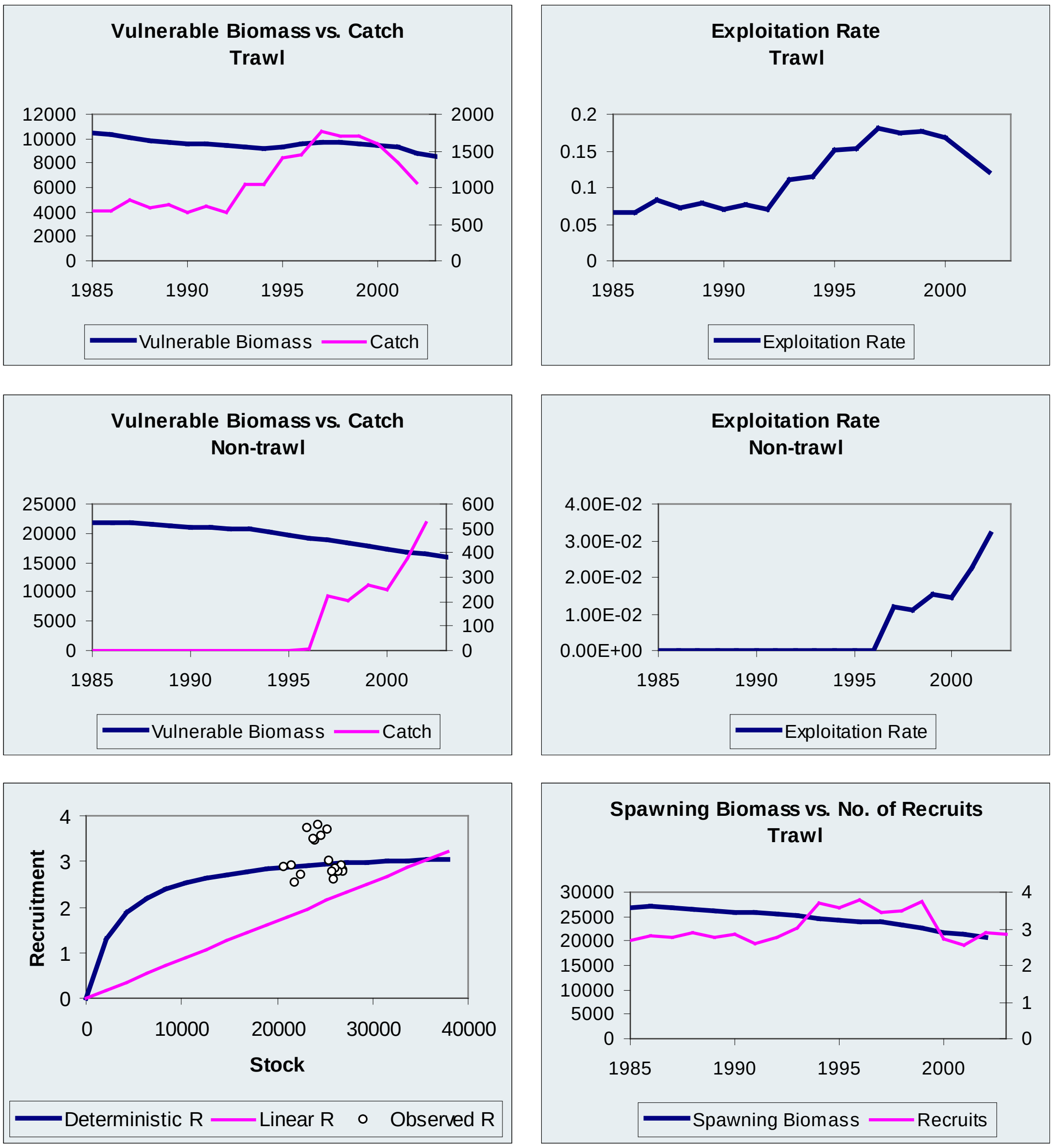


Figure 9.23. Base case CPUE fit – standardised CPUE

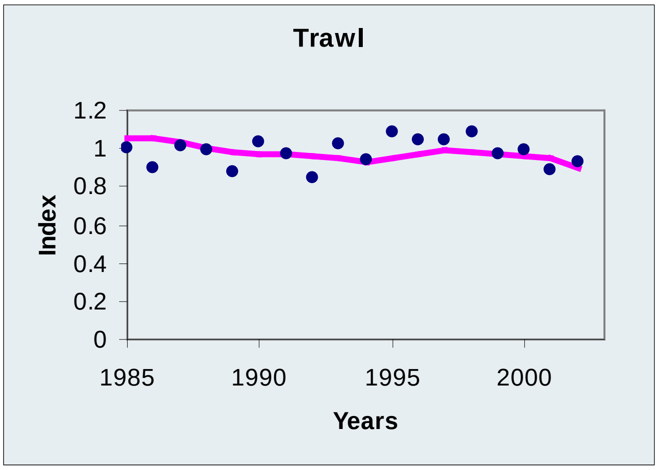
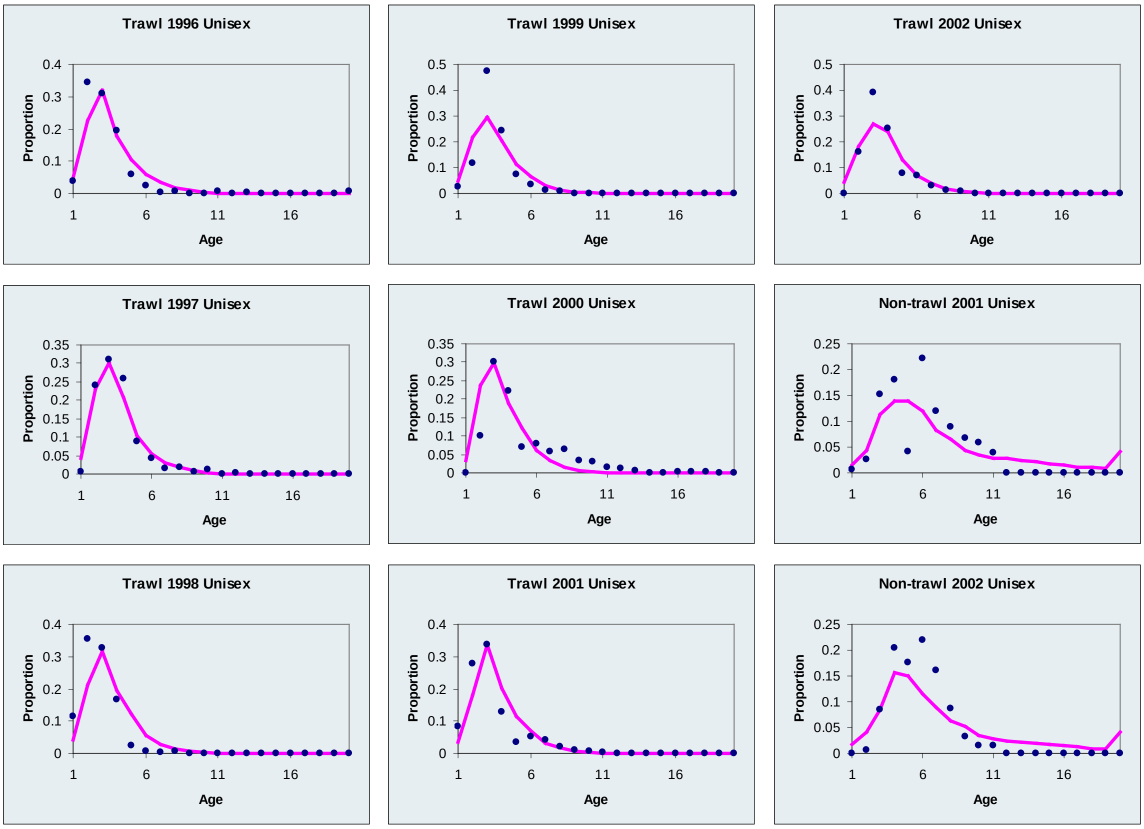


Figure 9.24. Base case catch at age fits – standardised CPUE



9.3.8 Projections

Figure 9.25. Base case raw CPUE: Projection of constant catches of 400t to 2000t to 2020 with current assignment of catch 67% to trawl and 33% non-trawl assumed to continue into the future

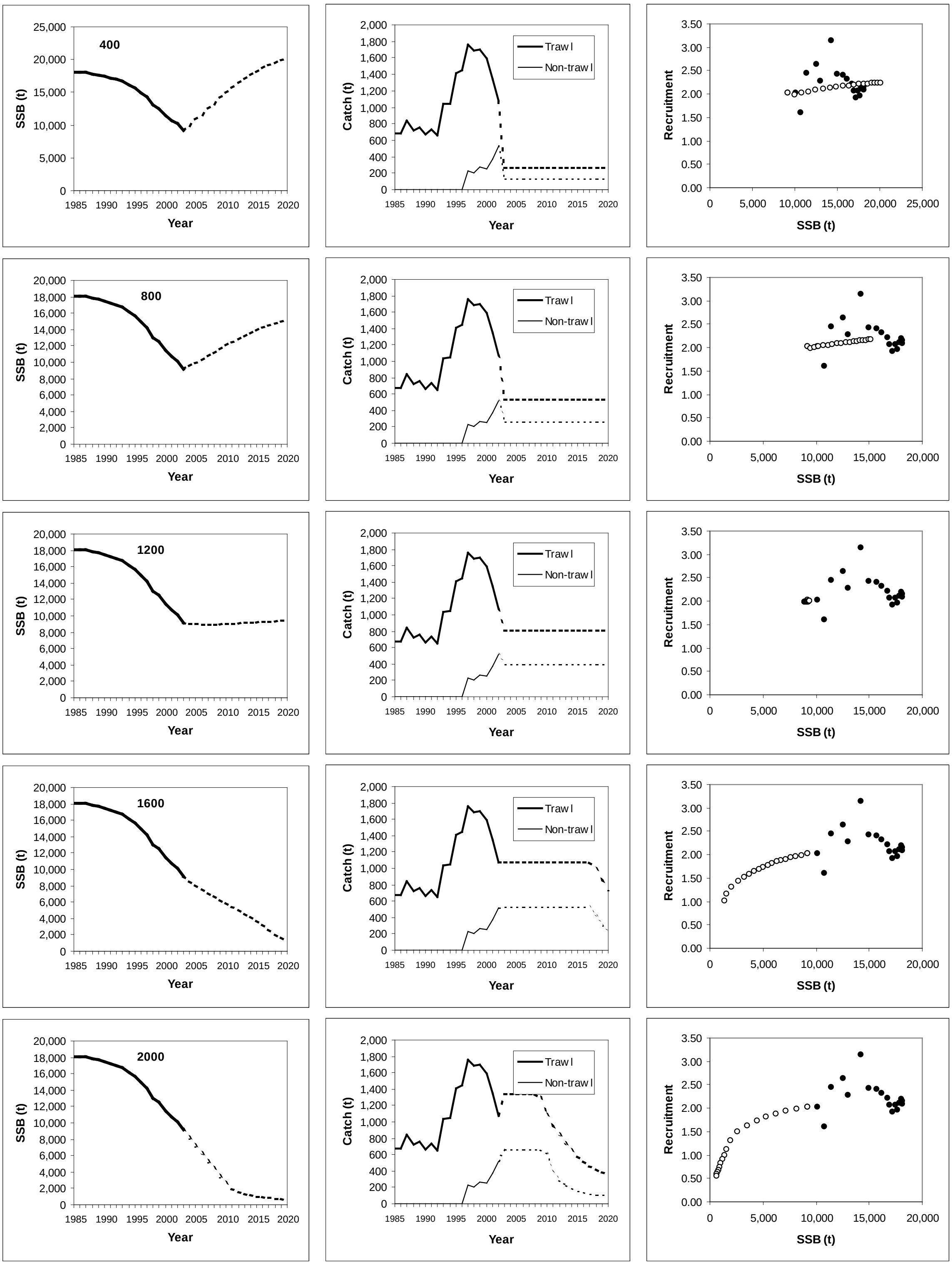


Figure 9.26. Base case standardised CPUE: Projection of constant catches of 400t to 2000t to 2020 with current assignment of catch 67% to trawl and 33% non-trawl assumed to continue into the future

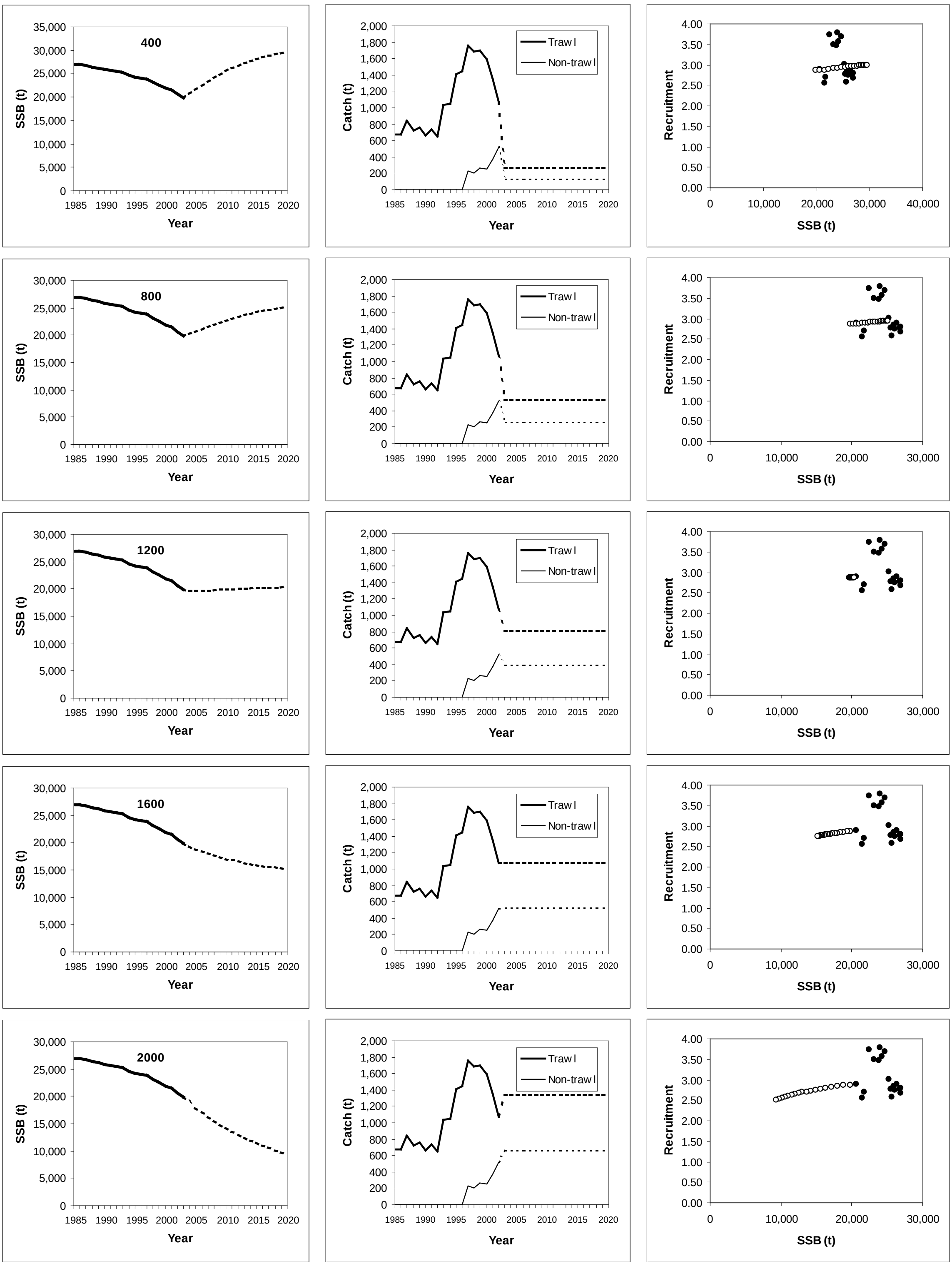


Figure 9.27. Base case raw CPUE: Projection of constant current catches of 1600t to 2020 with proportion taken by trawl and non-trawl modified

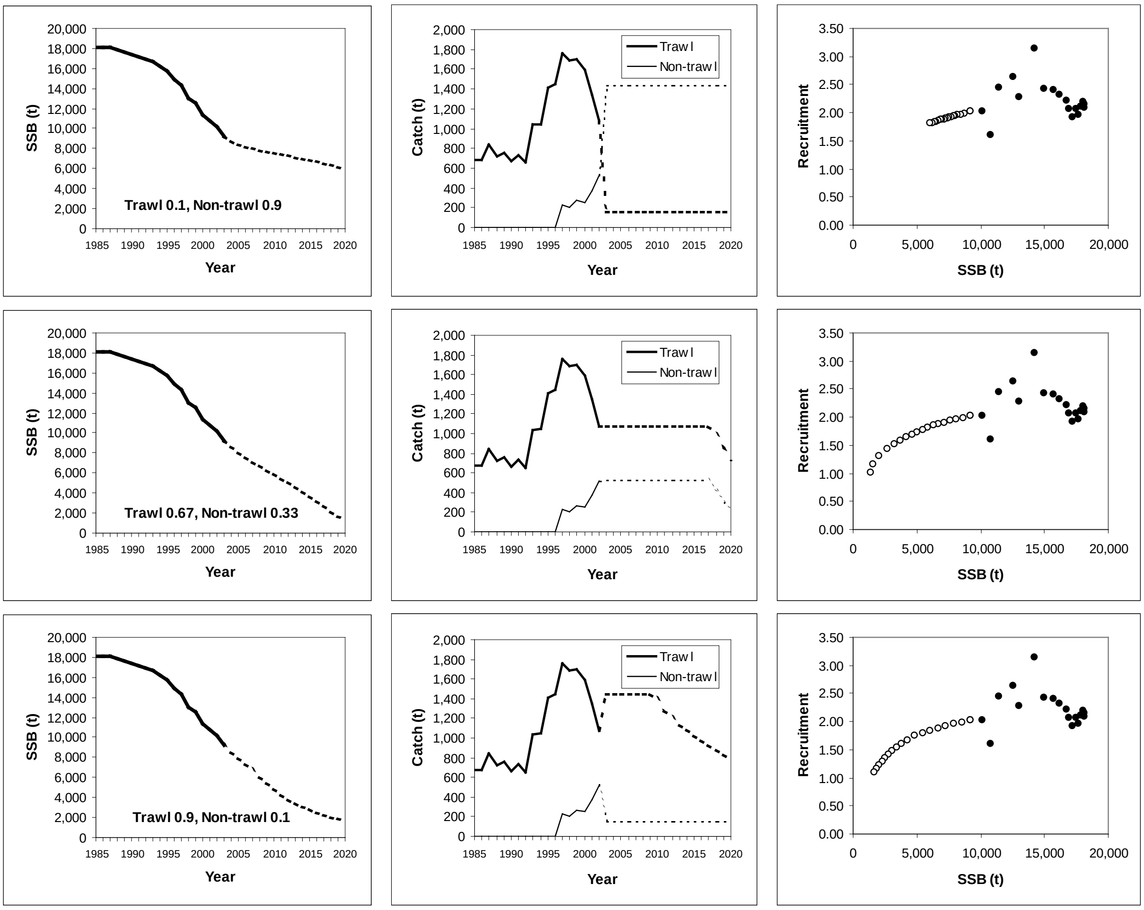
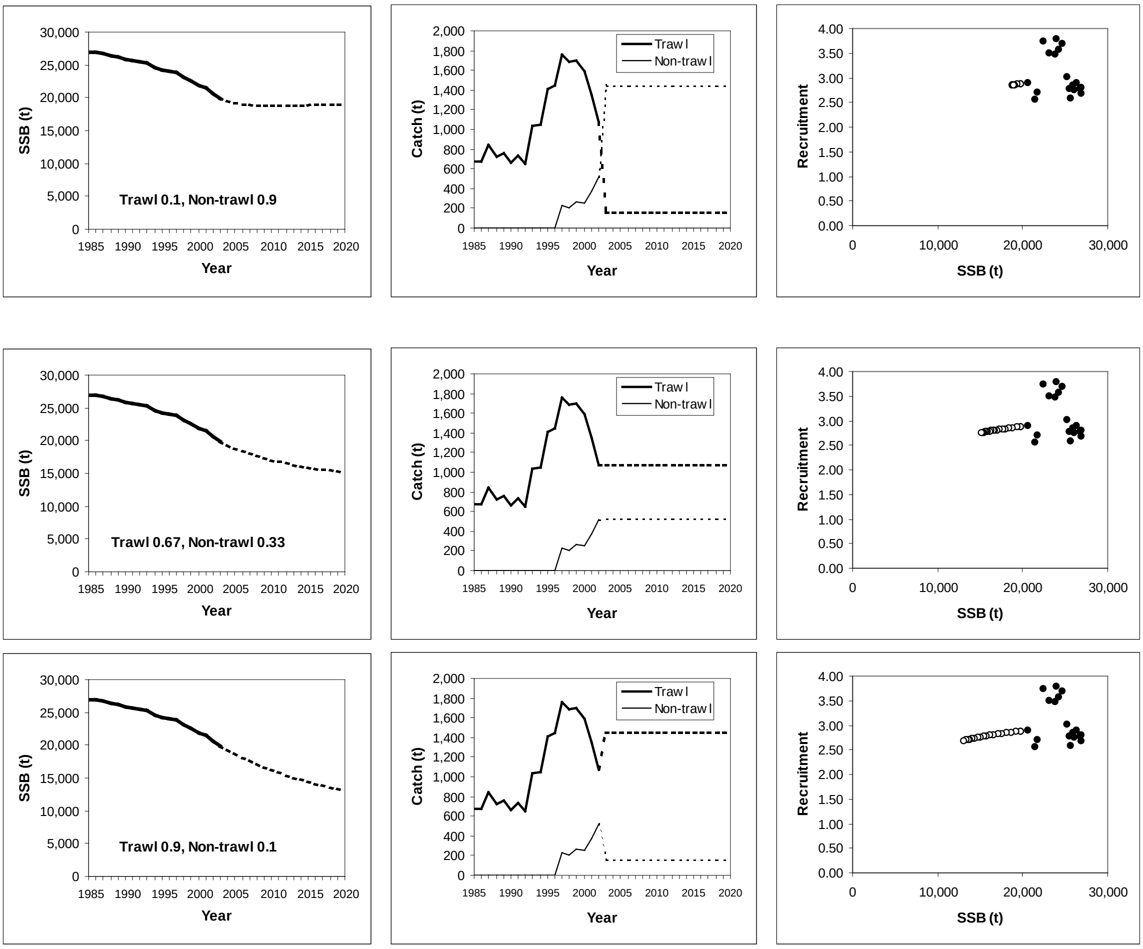


Figure 9.28. Base case standardised CPUE: Projection of constant current catches of 1600t to 2020 with proportion taken by trawl and non-trawl modified



9.4 Discussion

Catch statistics show an overall decrease in landings and unstandardised CPUE, particularly in the east. Standardised CPUE shows less of a decline than unstandardised. Age frequencies for certain years are difficult to fit with a population model. The pattern of selectivity for non-trawl is not well understood or defined

Population model results for standardised CPUE with a larger CV become similar to the raw CPUE results because the model tends to preferentially fit the catch age-structure. The raw CPUE model has a better fit to catch-at-age, whereas the standardised CPUE model fits catch-at-age less well to accommodate the CPUE trend.

The virgin spawning stock biomass (SSB) for raw CPUE is 27,000t, the 1985 SSB is 18,000t and the 2002 SSB is 9,000t. The SSB level in 2002 as a proportion of virgin is estimated to be 34%.

The virgin SSB for standardised CPUE is 36,000t, the 1985 SSB is 27,000t and the 2002 SSB is 20,000t. The SSB level in 2002 as a proportion of virgin is 56%.

Projections for base case raw CPUE for future catches of 400, 800, 1200, 1600 and 2000t using the current proportions of catch by gear of trawl 67% and non-trawl 33% (Figure 9.25) show that the current catch of 1600t is not sustainable in the long-term, while a catch of 1200t is sustainable. The same projections using standardised CPUE (Figure 9.26) indicate that the current catch of 1600t is sustainable in the long-term.

Projections of current catches using different proportions taken by the two gear types for raw and standardised CPUE (Figures 9.27 and 9.28) show that taking a higher proportion of older fish leads to higher SSB levels by 2020. The change in the 2020 SSB level is greater for raw CPUE as this scenario is on the margin of long-term sustainability, and is therefore more sensitive to minor changes in total catch, or selectivity. Large changes in selectivity have less influence than moderate changes to total catch levels.

9.5 Further development

- The uncertainties in the current assessments and projections have not been formally investigated. This should be done for future assessments using standard Markov Chain Monte-Carlo (MCMC) techniques.
- A more rigorous analysis of SEF1 and GN01 logbook data should be made to examine detailed spatial and temporal patterns of ling catches in terms local depletion of spawning areas and interactions with other SEF species. This would have implications for effort standardisation, and also stratification by season, area, or ling life stages in the assessment.
- An improved technique for making more robust estimates of Z from catch curves by pooling years and accounting for some dynamics should be investigated.
- Investigate the reasons why the vessels that do not consistently catch ling drive the unstandardised CPUE downwards.
- The issue of stock structure (east/west) should be revisited by collecting samples from both areas of the fishery (and also the Campbell Plateau in New Zealand) for genetic analysis.

- The selectivity estimates for trawl and non-trawl should be improved.

9.6 Acknowledgements

Central Age Facility data was provided by Corey Green (PIRVic), ISMP and some AFMA logbook data was processed and provided by Anne Gason (PIRVic), and updated non-trawl logbook and vessel identification data was provided by John Garvey (AFMA). Annual TAC and landings figures for trawl and non-trawl were provided by Shane Spence (AFMA). Robin Thomson (CSIRO) assisted with the processing of the data through a generalised system she has developed for processing SEF data, and the calculation of yields and catch curves. Ray Hilborn and Billy Ernst (University of Washington) provided some assistance with the use of Coleraine.

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APPENDIX 9.A – Results and methods details

Total catch

Table A.1. Record summary from SEF1 by calendar year and fishing method

Year	Method	Records	No weight	No effort	Catch(kg)
Otter trawl					
1985	27	2,256	281	260	212,750
1986	27	8,487	659	639	678,678
1987	27	7,365	338	372	764,976
1988	27	6,342	149	217	566,970
1989	27	6,932	71	154	672,084
1990	27	5,887	26	293	667,501
1991	27	7,101	37	426	734,647
1992	27	6,017	0	165	565,561
1993	27	7,817	0	114	890,340
1994	27	9,057	0	150	893,280
1995	27	11,442	0	72	1,208,037
1996	27	11,351	0	113	1,227,618
1997	27	12,939	0	74	1,443,291
1998	27	12,445	0	82	1,393,184
1999	27	13,265	2	22	1,369,090
2000	27	13,886	4	241	1,267,239
2001	27	13,971	4	31	1,362,708
2002	27	12,041	0	117	830,131
Danish seine					
1985	33	17	0	0	79
1986	33	40	0	0	299
1987	33	14	0	1	48
1988	33	49	0	0	386
1989	33	82	0	6	273
1990	33	81	0	0	441
1991	33	93	0	4	391
1992	33	473	1	46	1,365
1993	33	638	0	131	1,556
1994	33	671	0	162	1,640
1995	33	280	0	30	525
1996	33	478	0	41	3,261
1997	33	481	0	66	1,011
1998	33	462	0	21	1,081
1999	33	824	0	133	2,798
2000	33	497	0	57	1,942
2001	33	910	0	103	26,522
2002	33	865	0	32	20,658

Table A.2. Catch summary from SEF1 by calendar year, fishing method and zone

Year	Method	Records	Catch(kg)									
			Zone 10	20	30	40	50	60	Un-known	East	West	Total
Otter trawl												
1985	27	1,975	104,603	29,935	610	46,955	29,425	30	1,192	135,148	76,410	212,750
1986	27	7,828	371,317	185,000	2,380	51,579	62,803	920	4,679	558,697	115,302	678,678
1987	27	7,027	325,171	214,355	2,934	159,708	56,002	2,786	4,020	542,460	218,496	764,976
1988	27	6,193	250,747	209,484	5,108	54,130	43,315	2,326	1,860	465,339	99,771	566,970
1989	27	6,861	235,991	237,019	8,777	139,020	45,925	1,784	3,568	481,787	186,729	672,084
1990	27	5,861	221,740	280,488	11,670	101,409	49,277	1,632	1,285	513,898	152,318	667,501
1991	27	7,064	201,035	242,252	33,136	133,397	107,098	850	16,879	476,423	241,345	734,647
1992	27	6,017	230,226	202,549	7,129	48,295	71,002	5,368	992	439,904	124,665	565,561
1993	27	7,817	313,755	271,791	21,399	130,060	117,684	33,715	1,936	606,945	281,459	890,340
1994	27	9,057	386,429	212,029	30,837	134,460	116,052	9,785	3,688	629,295	260,297	893,280
1995	27	11,442	426,665	302,636	37,367	214,848	216,378	1,510	8,633	766,668	432,736	1,208,037
1996	27	11,351	344,682	375,453	42,604	242,540	214,079	761	7,499	762,739	457,380	1,227,618
1997	27	12,939	397,528	391,804	59,786	342,986	240,185	491	10,511	849,118	583,662	1,443,291
1998	27	12,445	433,816	358,331	28,493	355,841	210,297	1,903	4,503	820,640	568,041	1,393,184
1999	27	13,263	428,090	453,211	49,648	247,551	187,872	1,985	733	930,949	437,408	1,369,090
2000	27	13,882	316,896	391,750	37,989	345,457	171,277	2,765	1,105	746,635	519,499	1,267,239
2001	27	13,967	132,221	343,044	177,146	492,000	142,851	35,199	40,246	652,411	670,050	1,362,708
2002	27	12,041	112,439	236,046	39,396	310,542	130,283	347	1,079	387,881	441,172	830,131
Danish Seine												
1985	33	17	0	4	20	0	36	19	0	24	55	79
1986	33	40	0	3	190	0	5	101	0	193	106	299
1987	33	14	0	5	0	0	0	43	0	5	43	48
1988	33	49	45	0	0	0	0	341	0	45	341	386
1989	33	82	22	65	0	0	0	186	0	87	186	273
1990	33	81	0	171	0	0	0	270	0	171	270	441
1991	33	93	15	74	0	0	0	302	0	89	302	391
1992	33	472	0	861	0	0	0	498	6	861	498	1,365
1993	33	638	9	380	0	0	0	1,150	17	389	1,150	1,556
1994	33	671	0	661	0	0	0	979	0	661	979	1,640
1995	33	280	0	204	0	0	0	321	0	204	321	525
1996	33	478	0	2,170	0	0	559	532	0	2,170	1,091	3,261
1997	33	481	0	394	0	0	124	493	0	394	617	1,011
1998	33	462	0	592	0	0	126	363	0	592	489	1,081
1999	33	824	0	2,297	0	0	45	456	0	2,297	501	2,798
2000	33	497	0	1,593	0	0	5	344	0	1,593	349	1,942
2001	33	910	294	23,532	2,150	0	9	532	5	25,976	541	26,522
2002	33	865	1,081	18,934	0	0	58	584	2	20,015	642	20,658

Table A.3. Record summary from GN01 by calendar year

Year	Method	Records	No weight	No effort	Catch(kg)
All non-trawl					
1997		1,572	35	30	224,711
1998		1,223	10	18	178,040
1999		1,282	5	14	246,720
2000		1,187	4	20	226,061
2001		825	3	6	315,506
2002		822	6	1	464,545

Table A.4. Catch summary from GN01 by calendar year and zone

Year	Method	Records	Catch(kg)									
			Zone 10	20	30	40	50	60	Unknown	East	West	Total
All non-trawl												
1997		1,536	1,484	89,836	1,139	82,636	2,316	45,110	2,192	92,459	130,062	224,713
1998		1,213	4	37,953	7,648	72,389	971	58,691	386	45,605	132,051	178,042
1999		1,277	50	72,245	11,745	91,180	3,164	68,105	231	84,040	162,449	246,720
2000		1,182	0	77,607	31,772	45,823	3,397	67,278	184	109,379	116,498	226,061
2001		822	596	27,559	117,548	129,580	1,301	38,758	163	145,703	169,639	315,505
2002		816	0	47,625	135,129	250,063	15,666	15,703	359	182,754	281,432	464,545

Standardised CPUE

Example data file for GLM input (positions and callsigns changed):

```
"SHOTS","WEIGHT","EFFORT","CPUE","YEAR","MONTH","VESSEL","DEPTH","
ZONE","LAT","LONG"
1,90,2.50,36.00,1985,8,"Boat 1",500,40,40,147
1,50,2.00,25.00,1985,8,"Boat 1",950,40,40,149
8,2470,28.75,85.91,1985,8,"Boat 1",500,40,41,141
1,300,3.50,85.71,1985,8,"Boat 1",550,40,41,142
1,60,4.08,14.71,1985,8,"Boat 2",300,50,38,146
1,84,4.17,20.14,1985,8,"Boat 2",400,50,38,144
2,180,10.08,17.86,1985,8,"Boat 2",400,50,38,143
6,1030,24.35,42.30,1985,9,"Boat 1",500,40,40,142
1,300,5.17,58.03,1985,9,"Boat 1",550,40,40,149
3,900,15.17,59.33,1985,9,"Boat 1",500,40,41,149
```

Example R script for performing GLM (GLM type 3 West):

```
datLING <- read.table("s1glm3w.txt",sep=",",skip=2)
names(datLING) <-

C("shots","weight","effort","CPUE","year","month","vessel","depth","zone","lat","long"
)
datLING$year<-factor(datLING$year)
datLING$month<-factor(datLING$month)
datLING$depth<-factor(datLING$depth)
datLING$zone<-factor(datLING$zone)
sLING.glm <- glm(datLING$CPUE~C(datLING$year,treatment)+
        C(datLING$month,treatment)+C(datLING$vessel,treatment)+
        C(datLING$depth,treatment)+C(datLING$zone,treatment),
        family=Gamma(link=log),data=datLING,maxit=20)
rm(datLING)
attach(sLING.glm)
sink("s1glm3w.lis")
summary(sLING.glm)
sink()
detach()
```

Catch curve analysis

Figure A.1 Detailed catch curve results

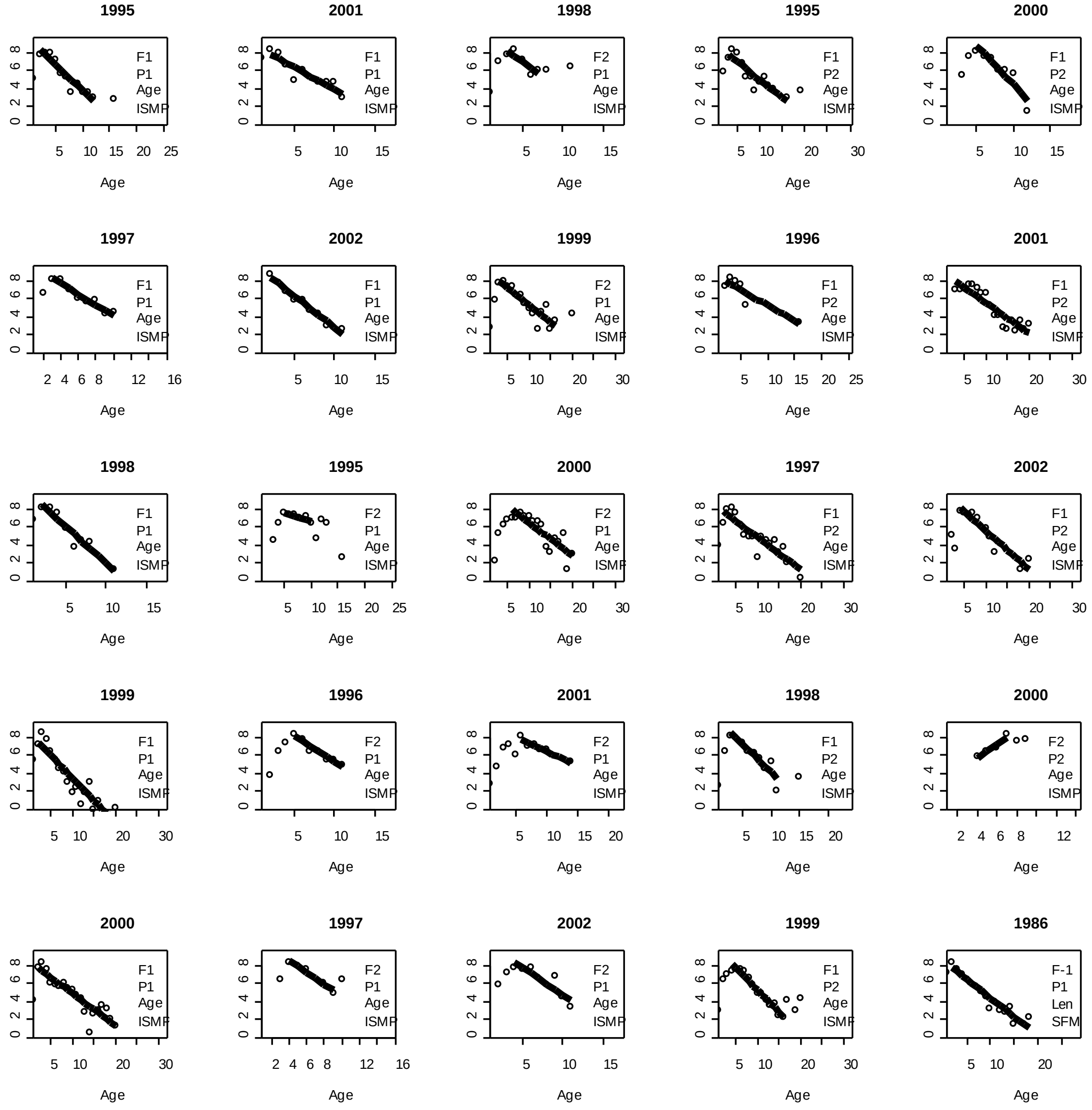


Figure A.2 Detailed catch curve results continued

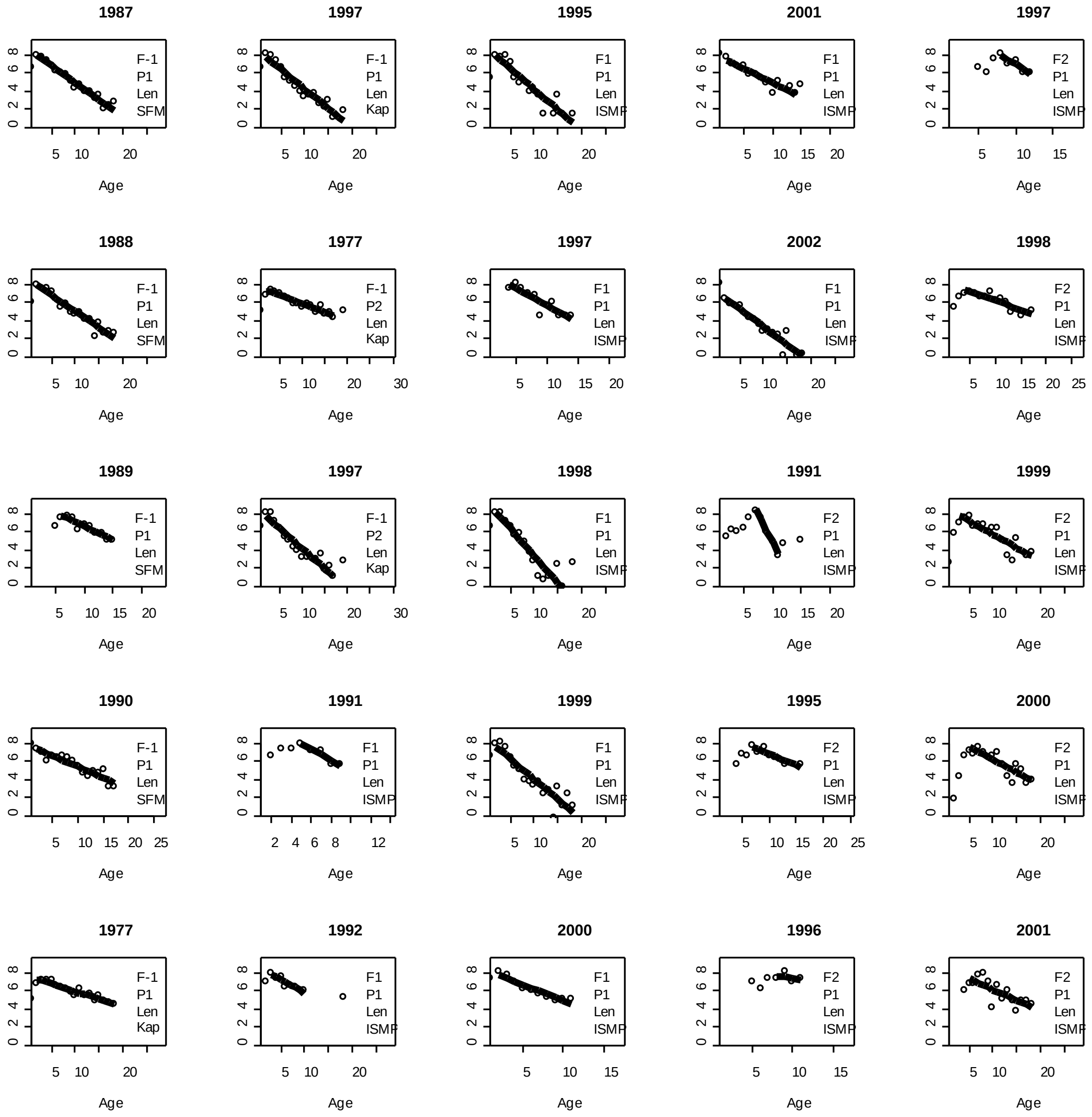
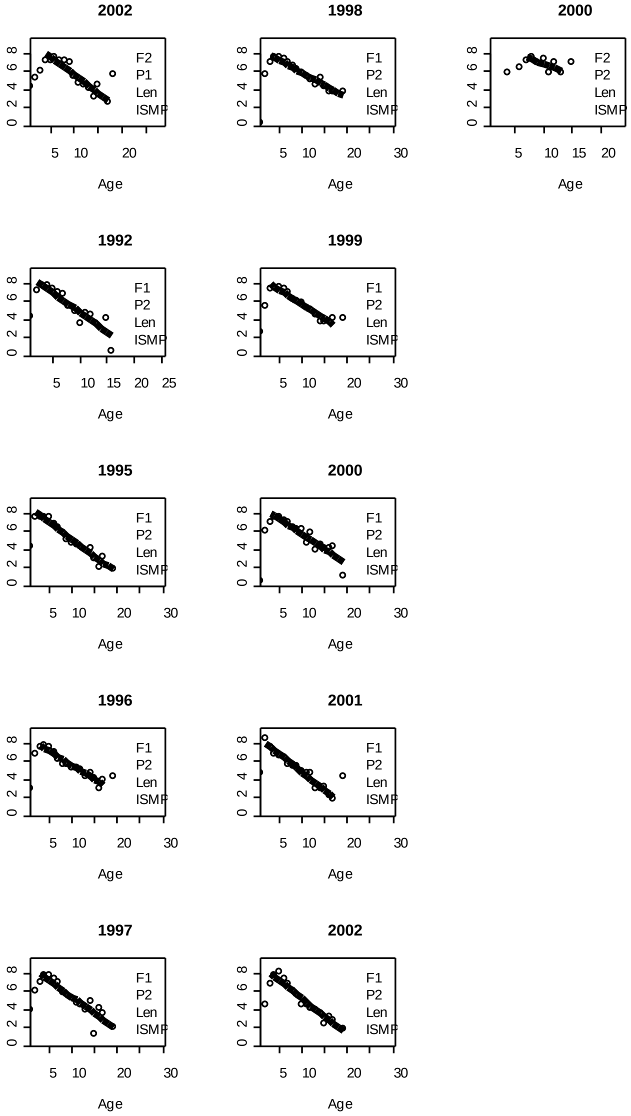


Figure A.3 Detailed catch curve results continued



Integrated Analysis

Table A.5 Base case priors

R0 (Recruitment in virgin condition)						
1	0	20	0	0	0	1.5
h (steepness of spawner-recruit curve)						
-1	0.01	5	0	0.75	0.6	0.75
M (natural mortality)						
-1	0.1	0.3	0	0.2	0.1	0.2
Log init dev prior: deviates for initial age structure: uniform or normal only						
-3	-15	15	1	0	0.1	0
log rec dev prior (uniform or normal only)						
3	-15	15	1	0	0.1	0
Initial R (= # 1-yr olds in yr 1/R0; unfished = 1)						
-1	0	2	0	1	0.1	1
Intial u (exploitation rate for initial age structure; 0=unfished)						
-1	0	0.1	0	0	0.1	0.1
Plus scale						
-1	0	2	0	0	0.6	1
S fullest (for length)						
-1	1	10	0	9	0.1	3
-1	1	10	0	9	0.1	6
S full delta (for males as different from females)						
-1	-3	3	0	0	0.6	0
-1	-3	3	0	0	0.6	0
Log variance of left side of selectivity curve by length (for both sexes)						
-2	-15	15	0	0	0.6	0.5
-2	-15	15	0	0	0.6	2
Log variance of righthand side of double normal selectivity curve (for both sexes)						
-1	-15	15	0	0	0.6	3
-1	-15	15	0	0	0.6	10
Error S full						
-1	-15	15	1	0	0.1	0
-1	-15	15	1	0	0.1	0
Error variance L						
-1	-15	15	1	0	0.1	0
-1	-15	15	1	0	0.1	0
Error variance R						
-1	-15	15	1	0	0.1	0
-1	-15	15	1	0	0.1	0
Log q CPUE						
1	-10	10	0	0	0.6	-5.8
1	-10	10	0	0	0.6	-6
Log q CPUE error						
-1	-5	5	0	0	0.6	0
-1	-5	5	0	0	0.6	0
Log q Survey						
-1	-5	5	0	0	0.6	1
Survey L full						
-1	1	216	0	0	0.6	10
Survey L full delta						
-1	1	216	0	0	0.6	0
Survey variance L						
-1	-15	15	0	0	0.6	1
Survey variance R						
-1	-15	15	0	0	0.6	10
L variance 1						
-1	-15	15	0	0	0.6	1.93
L variance n						
-1	-15	15	0	0	0.6	8.16
Dummy variable--keep for error troubleshooting						
-1	-15	15	0	0	0.6	2

Table A.2 Base case likelihoods and fixed parameters

Likelihoods (0=not used; 1= norm; 2 = lognorm; 12 = robust lognormal for proportions)

CPUE likelihood Type

2	2

Commercial catch at age likelihood type

12	12

Commercial catch at length likelihood type

0	0

Survey likelihood type

0

Survey Index type (1=weight; 2=numbers)

1

Survey vulnerability type (1=age; 2=length)

1

Survey no-sex C@L likelihood type

0

Survey catch at length likelihood type

0

Survey catch at age likelihood type

0

Fixed Parameters

Bi-scalar of length-weight relationship

2.93E-03

bii exponent of length-weight relationship

3.139

L-infinity of the vonBertanlanffy growth equation

109.9611

k of the vonBertanlanffy growth equation

0.134788

t0 of the vonBertanlanffy growth equation

-2.715822

Brody parameter

0.6

Mean length of age 1 fish

40

Length at oldest age

108

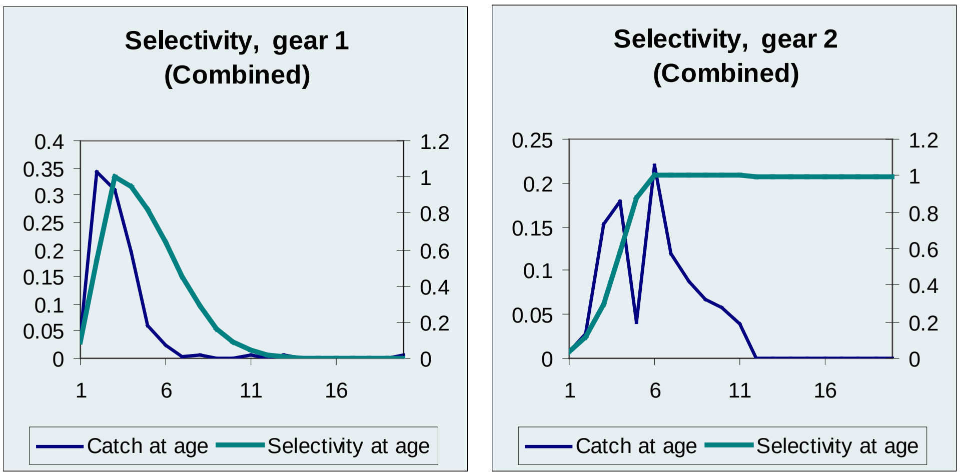
S.d. of length at age of 1-year old fish

8

S.d. of length at age of oldest fish

21

Figure A.1 Trawl and non-trawl selectivity – gear 1 = trawl, gear 2 = non-trawl



APPENDIX 9.B – Coleraine model description

(From Hilborn *et al.*, 2000)

B.1. General Overview of the Program Coleraine

Coleraine is a user-friendly, general age-structured model for fisheries stock assessment. It combines a familiar Excel environment with a general and powerful AD Model Builder application.

Coleraine has a statistical age- and sex-structured model with a very general structure. It allows for several fisheries to be modeled at once and can be simultaneously fitted to many different sources of information, like catch-at-age and/or -size data from the fishing fleet, and surveys and several indices of abundance (commercial fishery and survey). The estimation is performed using maximum likelihood theory in a first step and a Bayesian approach in a second.

Prior information on the parameters which can be estimated may be readily incorporated, given the Bayesian framework of this statistical approach. Uncertainty around the estimates of the derived parameter of interest can be assessed directly from the bayesian posteriors.

Once the model is fitted, this program allows the user to do policy evaluation by assessing the consequences of different harvest strategies (harvest rates or catch levels) on certain statistics of interest (e.g., predicted vulnerable biomass), which are reported as Bayesian posteriors.

Other salient features of this model are as follows:

Temporal changes in the selectivity of the fishing fleet.
Temporal changes in the catchability of the fishing fleet.
Survey selectivity modeled as age-or size-based.
The model simultaneously fitted to length and age data.
Robust multinormal likelihood function incorporated for data expressed as proportions.
Automated process for saving condensed information on different runs.

B.2. General Overview of the Estimation Model

A general description of the different components of the estimation model (Colerain.exe) is presented in the following sections of this manual. The following notation is used throughout Section 1:

Subscripts:		Superscripts:	
a	Age	g	Gear (Fishery or Survey)
l	Length	S	Sex
t	Time		

B.2.1. Abundance dynamics by sex

Abundance at age and sex is propagated according to the following difference equation

$$N^s_{a+1,t+1} = N^s_{a,t}\,\mathrm{e}^{-M^s}\left(1-u^s_{a,t}\right) \qquad \text{for } a=1,\cdots,A$$

where M is the instantaneous rate of natural mortality, age A is a “plus group," and $u^s_{a,t}$ is the exploitation rate for all gears combined, which is obtained by summing over all gear types

$$u^s_{a,t} = \sum_g u^{s,g}_{a,t}$$

The exploitation rate for each gear is a product of its age-specific selectivity, $s^{s,g}_{a,t}$, and the exploitation rate of fully selected fish at a specific time

$$u^{s,g}_{a,t} = s^{s,g}_{a,t}\,u^g_t$$

Formulations below are identical whether g refers to a fishery component or to a survey, except that the mortality induced by the surveys is negligible and can be ignored. The alternative approaches used for the selectivity function are explained in a later section.

Assuming that total commercial catches in biomass for each gear C^g_t are known without error, and that fishing takes place in a short time interval in the middle of the year, the annual exploitation rate by gear is given by

$$u^g_t = \frac{C^g_t}{\mathrm{e}^{-0.5M^s}\sum_s\sum_a s^{s,g}_{a,t}\,N^s_{a,t}\,w^s_{a,t}}$$

which is basically equal to the ratio of total catch to vulnerable biomass in the middle of the year.

B.2.2. Initial conditions

The initial condition assumptions built into the model allow for the estimation of three parameters: $\boldsymbol{R}_0$ (virgin recruitment), $\boldsymbol{\omega}$ (fraction of $\boldsymbol{R}_0$ in the first year), and u_0 (exploitation rate for the first year). The initial vulnerability-at-age pattern by sex has to be incorporated by the user in the "Fixed Parameter Section" (item 13). Also the fraction of $N_{1,1}$ and more generally $N_{1,j}$ (j = year) that recruits to each sex is represented by a user defined constant (λ). Thus the initial population age structure is represented by

$$N^s_{1,1} = \omega\, C^s R_0$$

$$where, \quad C^1 = \lambda\,; \quad C^2 = (1-\lambda)$$

$$N^s_{a,1} = N^s_{1,1}\, \mathrm{e}^{-M^S(a-1)} \prod_{i=1}^{i=a-1} (1 - {}_I v^s_i\, {}_I u^s) \quad \text{for} \quad a = 2,\cdots A-1$$

The plus group for the initial year is given by

$$N^s_{A,1} = N^s_{1,1}\, \mathrm{e}^{-M^S(A-1)} \frac{\prod_{a=1}^{a=A-1} (1 - {}_I v^s_{a\,I} u^s)}{1 - \mathrm{e}^{-M^S(A-1)} \prod_{a=1}^{a=A-1} (1 - {}_I v^s_{a\,I} u^s)}$$

Uncertainty in the initial age structure is incorporated by using log-normal errors:

$$N^s_{a,1} = N^s_{a,1}\, \mathrm{e}^{-({}_I\varepsilon_a - \frac{{}_I\sigma^2}{2})} \quad where \quad {}_I\varepsilon_a \sim N(0, {}_I\sigma^2); \quad \text{for} \quad a = 2,\cdots A-1$$

The plus group has an independent error component ${}_P\varepsilon_A$ (with its own variance) where *P* stands for plus group and *I* for initial.

B.2.3. Stock–recruitment

Recruitment follows a Beverton–Holt stock–recruitment relationship with log-normal error structure

$$N^s_{1,t+1} = \lambda \frac{S_t}{\alpha + \beta\, S_t} e^{\left({}_R\varepsilon_t - {}_R\sigma^2/2\right)}$$

where $\boldsymbol{{}_R\varepsilon_t}$ is the recruitment residual for year *t* (${}_R\varepsilon_t \sim N(0, {}_R\sigma^2)$), and S_t is the spawning biomass in year *t* computed as

$$S_t = \sum_a w^f_{a,t} \Phi_a N^f_{a,t}$$

where Φ_a (maturity ogive) is the fraction of females that have reached maturity at age *a* and $\boldsymbol{w^f_{a,t}}$ is female weight at age and time.

Recruitment at equilibrium in the absence of fishing equals (Mace 1994)

$$R_0 = \frac{SpR - \alpha}{\beta SpR}$$

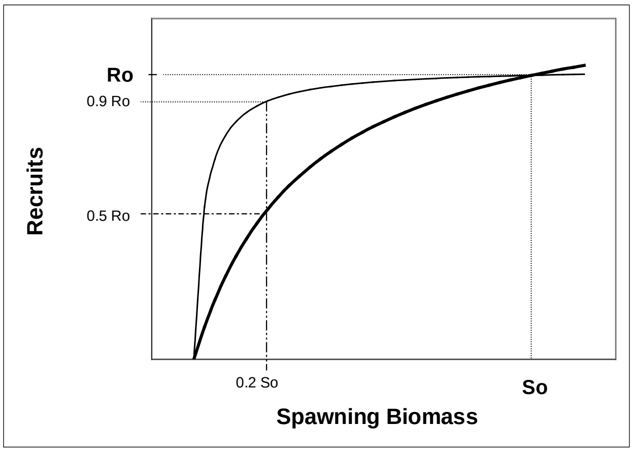
where $SpR = \lambda \sum_a w^f_{a,t} \Phi_a\, e^{(-M^S(a-1))}$ is the spawning biomass per recruit (a function of the surviving proportion, weight at age, and maturity ogive). The model was parameterized with a steepness parameter, *z*, the proportion of the virgin recruitment that is realized at a spawning biomass level of 20% of the virgin spawning biomass (Francis 1992).

Thus both parameters can be formulated as a function of $z, R_0 \; and \; SpR$,

$$\alpha = S_0 \frac{1-z}{4z\,R_0}$$

$$\beta = \frac{5z-1}{4zR_0}$$

$$S_0 = R_0\,SpR$$



This graph shows the Beverton–Holt relationship, formulated as a function of the steepness and virgin recruitment. This parameterization is very convenient because the *z* is clearly defined between [0.2, 1].

B.2.4. Growth

Fish grow according to a von Bertalanfy model with mean size at age given by

$$L_a^S = L_\infty(1+\exp(-k(a-t_0)))$$

We assume that the distribution of size at age is log-normal with standard deviation sd_a^s, which is a linear function of mean size at age

$$sd_a^S = {}_{L_1}\sigma^S + \left\lfloor \frac{{}_{L_n}\sigma^S - {}_{L_1}\sigma^S}{L_n^S - L_1^S} \right\rfloor (L_a^S - L_1^S)$$

This is basically a linear interpolation between the standard deviation of the mean length at the first (L_1^S) and last (L_n^S) age. The distribution of log(*L)* at age (length–age relationship) by sex is symbolized by $\varphi\left(\log(L) \mid \mu_a^s\,\sigma^s{}_a\right)$, and has mean μ_a^s and standard deviation $\boldsymbol{\sigma}_a^s$, respectively equal to:

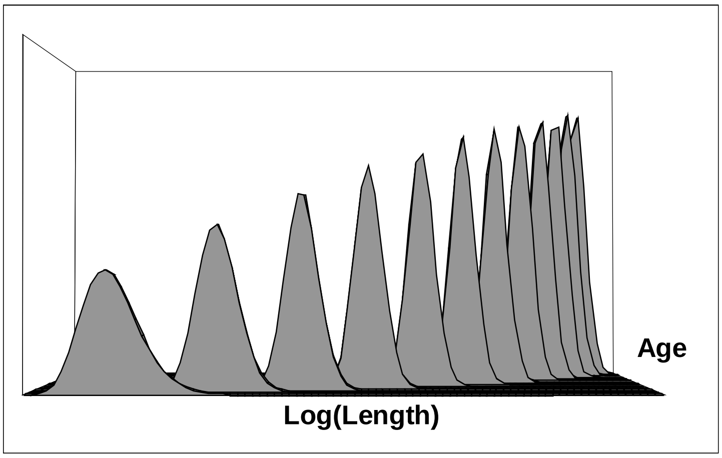
$$\mu_a^s = \log\left(L_a^s\right) - \frac{\sigma_a^{s\,2}}{2}$$

$$\sigma_a^{s2} = \left(\frac{sd_a^S}{L_a^s}\right)^2$$

The length proportions at age can be approximated as

$$f_{l|a}^s = \frac{\varphi\left(\log L_l \mid \mu_a^s, \sigma_a^{s\,2}\right)\Delta_l}{\sum_{l=1}^{n_L} \varphi\left(\log L_l \mid \mu_a^s, \sigma_a^{s\,2}\right)\Delta_l}$$

where Δ_l is the width of the interval in log scale. This relation can be visualized in the following graph:



The proportions of length at age are used in many sections of the model, depending on the nature of available data. They are used to compute the predicted size compositions, to convert a length-based selectivity into a selectivity at age, and to compute the mean weight at age when the selectivity function of the survey is a function of length.

B.2.5. Weight at age relationship

Weight at age is a vital piece of information in the assessment, because it is involved in the vulnerable biomass calculations. It can be directly incorporated into the model as observed data (design-based estimators) or by using a model-based approach (parameters of the weight–length power function).

By default the program uses the observed data. The rest of the temporal weight-at-age information arises from the following calculations:

(a) If selectivity is a function of age, mean weight at age is predicted from the following equation

$$w_{a,t}^{s} = b_i^S (L_a^S)^{b_{ii}^S} e^{\left(\frac{b_{ii}^S \sigma_a^{s\,2} \left(b_{ii}^2 - 1\right)}{2}\right)}$$

where the exponential is a correction for the variance of the log-normal distribution of size at age. If the survey selectivity is based on age, than the weight at age for the commercial fleet is the same as the one for the surveys.

(b) However, selectivity can be modeled as a function of fish size (only for surveys), in which case the mean weight at age for the surveys is affected by selectivity at size and the length–age relationship according to

$$w_{a,t}^{s,g} = \frac{\sum_l b_i^S (L_l)^{b_{ii}^S} s_{l,t}^{s,g} f_{l|a}^{s}}{\sum_l s_{l,t}^{s,g} f_{l|a}^{s}}$$

B.2.6. Selectivity

Selectivity is a process that can be modeled based on age or size. This model supports an age-based selectivity for the fishing fleet and a size- or age-based selectivity for the surveys. In this model the only sex-specific variation in the selectivity function arises from the difference between ages of full recruitment.

B.2.6.1 Selectivity as a function of age

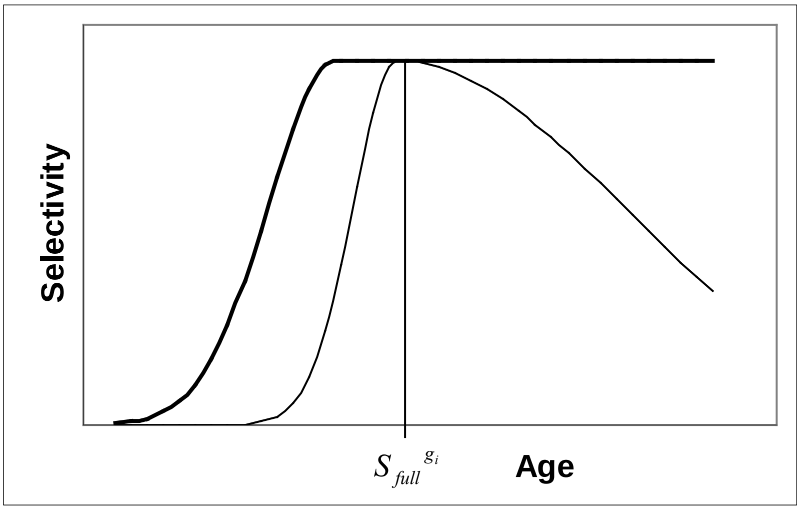
The selectivity function implemented in the model is a double half-Gaussian function of age:

$$s_{a,t}^{s,g} = \begin{cases} \exp\left\{\dfrac{-\left(a - S_{full}^{\;s,g}\right)^2}{{}_L v^g}\right\} & \text{for} \quad a \le S_{full}^{\;s,g} \\ \exp\left\{\dfrac{-\left(a - S_{full}^{\;s,g}\right)^2}{{}_R v^g}\right\} & \text{for} \quad a > S_{full}^{\;s,g} \end{cases}$$

$$\boldsymbol{S_{full}^{\;s,g} = (S_{full}^{\;g} + (1 - j)\Delta_{S_{full}}^{g})}$$

where *j* is a dummy variable with value *1* for females and *0* for males, and $\boldsymbol{\Delta_{S_{full}}^{g}}$ is the sex specific difference in age of full recruitment for each gear.

The next graph shows some of the shapes that this three-parameter model can adopt. The thick line represents a situation with very high right-hand variance, as opposed to the other line, which has a declining right-hand limb.



Survey selectivities are assumed to be constant over time while commercial selectivities are allowed to change over time. Residuals are estimated for the periods when we do have catch at age data

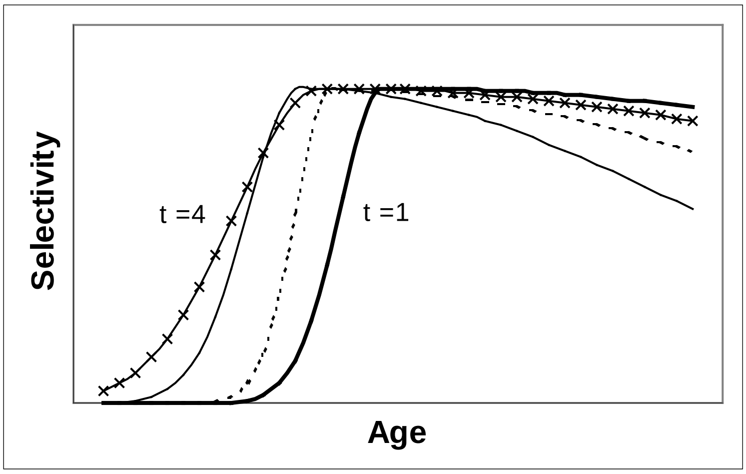
$$S_{full_t}^{S,g} = S_{full_t}^{S,g} e^{{}_{S_{full}}\varepsilon_t^g} \qquad where \ {}_{S_{full}}\varepsilon_t^g \sim N(0\,,\ {}_{S_{full}}\sigma^2)$$

$${}_j v_{t+1}^g = {}_j v_{t+1}^g \ e^{{}_{j^v}\varepsilon_t^{g_i}} \qquad {}_{j\,v}\varepsilon_t^{g_i} \sim N(\,0,\,{}_{L\,v}\sigma^2)$$

where *j* is the right or left side variance.

Trends in selectivity have been associated with changes in spatial allocation of fishing effort (Jacobson *et al.,* 1997), and the variation considered in this approach is independent of sex.

The following figure shows a declining pattern in the right side of the selectivity curve over time. It also shows a decrease in age of full selectivity between the first and the last time period.



B.2.6.2 Selectivity as a function of size

Only the selectivity of the survey is allowed to be size-based. A double-Gaussian function of size, with time invariant parameters, is used. The selectivity at age is computed by integrating the selectivity at size over the size proportions at age. Thus

$$s_{a,t}^{s,g} = \int_{-\infty}^{\infty} s_t^{s,g}(L)\varphi\left(\log L \mid \mu_a^s, \sigma^{2s}_{a}\right) \mathrm{dlog}L$$

The integral above can be approximated by discretizing the size distribution into n_L size classes, denoted as l, as

$$s_{a,t}^{s,g} = \sum_{l=1}^{n_L} s_{l,t}^{s,g} \, f_{l|a}^{s}$$

where $s_{l,t}^{s,g}$ is the size-selectivity function evaluated at L_l, the length at the mid-point of interval l . For converting the size-based selectivity into a selectivity at age, we weight the selectivity at size by the size proportion at the respective age. If we do not rescale the "new" selectivities at age, very likely no age has been fully selected. This would not affect the estimation procedure but would be reflected in the catchability coefficient.

B.3. Data

B.3.1. Predicted abundance indices

Commercial CPUE and survey indices, here denoted as I_t^g , are assumed to be directly proportional to the vulnerable biomass in the middle of the year

$$I_t^g = q_t^g \, e^{-0.5M} \left(\sum_s \sum_a s_{a,t}^{s,g} N_{a,t}^s w_{a,t}^g \right) e^{{}_{I^g}\varepsilon_t}$$

where ${}_{I^g}\varepsilon_t \sim N(0, {}_{I^g}\sigma^2)$ and q_t^g is the gear-specific catchability. The temporal index for the catchability coefficients is incorporated only for the commercial CPUE (catchability coefficients of the surveys are not allowed to have a temporal variation).

A random walk model is used to model the temporal changes, thus

$$\ln\left(q_{t+1}^g\right) = \ln\left(q_t^g\right) + {}_q\varepsilon_t^{CPUE_i}$$

where ${}_q\varepsilon_t^{CPUE_i} \sim N(0, {}_{q^g}\sigma^2)$. The parameter ${}_{q^g}\sigma^2$ is used to control the amount of year-to-year variation allowed in q_t^g . The formulation is identical to that used for selectivity parameters, and results in our estimating residuals for n-1 years for each gear for which CPUE data exist.

B.3.2. Predicted age and size composition

The predicted age composition (in proportions) of the catch at time *t* by *sex* and *gear*, is represented by the following equation

$$P^{s,g}_{a,t} = \frac{s^{s,g}_{i,t} N^{s}_{i,t}}{\sum_{s} \sum_{i} s^{s,g}_{i,t} N^{s}_{i,t}} M^{pool}_{A\,x\,A} \quad \Omega^{S}$$

where Ω^S represents an upper diagonal matrix of age misclassification and $M^{pool}_{A\,x\,A}$ pools the age frequencies for ages $a \geq A_{\text{pool}}$ into a plus group.

Real age

Incorrect age	1	2	3	4	5	6	7	8	9	10
1	**0.8**	0.2	0	0	0	0	0	0	0	0
2	0.1	**0.8**	0.1	0	0	0	0	0	0	0
3	0	0.2	**0.6**	0.1	0.1	0	0	0	0	0
4	0	0	0.2	**0.7**	0.1	0	0	0	0	0
5	0	0	0	0.1	**0.8**	0.1	0	0	0	0
6	0	0	0	0	0.1	**0.8**	0.1	0	0	0
7	0	0	0	0	0	0.1	**0.8**	0.1	0	0
8	0	0	0	0	0	0	0.1	**0.8**	0.1	0
9	0	0	0	0	0	0	0	0.1	**0.8**	0.1
10	0	0	0	0	0	0	0	0	0.1	**0.9**

The above figure shows how to set up the misclassification matrix. If no information on age misclassification is available, an identity matrix has to be used.

Similarly, size compositions are predicted as

$$P^{s,g}_{l,t} = \frac{s^{s,g}_{l,t} \sum_{a} f^{s}_{l|a} N^{s}_{a,t}}{\sum_{s} \sum_{l} s^{s,g}_{l,t} \sum_{a} f^{s}_{l|a} N^{s}_{a,t}}$$

when selectivity is a function of fish size, or as

$$P^{s,g}_{l,t} = \frac{\sum_{a} s^{s,g}_{a,t} f^{s}_{l|a} N^{s}_{a,t}}{\sum_{s} \sum_{a} s^{s,g}_{a,t} \sum_{l} f^{s}_{l|a} N^{s}_{a,t}}$$

when selectivity is a function of mean length at age.

B.4. Objective Function

Different sources of information contribute to the overall objective function. This can be summarized as follows:

- Survey index: *By index*
- CPUE: *By commercial fishing gear index.*
- Catch-at-length: *Survey* (gear, age, time, sex, + undetermined sex); *Commerical fleet* (sex, gear, age, time)
- Catch-at-age: *Survey (*sex, gear, age, time); *Commercial fleet (*sex, gear, age, time)

The objective function includes likelihood components for the different data types, and penalties on the variability of the stochastic parameters as specified by their bayesian *prior* distributions.

B.4.1. Robust normal likelihood for proportions

We use the robust likelihood formulation proposed by Fournier *et al.* (1998) for the age-sex and size-sex catch compositions. The observed frequency data is incorporated to the likelihood function as proportions at age and sex, $\tilde{P}^{s,g}_{a,t}$, or at length, $\tilde{P}^{s,g}_{l,t}$. The robust-normal model was selected instead of the more traditional multinomial error model because there is then no need to specify the effective number of fish sampled.

$$\ln L^{g}_{\text{age}} = -0.5 \sum_{t=1}^{Nyears} \sum_{s} \sum_{a=1}^{A} \ln\left[\left(P^{s,g}_{a,t}(1 - P^{s,g}_{a,t}) + .1/A\right)\right]$$
$$+ \sum_{t=1}^{Nyears} \sum_{s} \sum_{a=1}^{A} \ln\left[\exp\left\{\frac{-(\tilde{P}^{s,g}_{a,t} - P^{s,g}_{a,t})^2}{2(P^{s,g}_{a,t}(1 - P^{s,g}_{a,t}) + .1/A)\tau^g}\right\} + 0.01\right]$$

where A and τ^g are respectively the number of classes and the inverse of the assumed sample sizes. N_{years} is the number of available age-composition samples. A similar formulation is used for the size-sex compositions and is applicable for survey or commercial data.

B.4.2. Abundance indices

Different likelihood functions can be used for the commercial and survey indices. These are normal, log-normal, robust normal and robust log-normal distributions.

The log-normal likelihood function has the following representation:

$$\ln L^{g}_{I} = \sum_{t} \ln\left[\exp\left(-0.5 \frac{{}_{I^g}\varepsilon^2_t}{{}_{I^g}\sigma^2_t}\right) + 0.01\right]$$

In all the cases the variances are entries specified by the user.

B.4.2. Total likelihood

The total log-likelihood corresponds with the sum of the individual log-likelihood components

$$\ln L = \sum_g \ln L_I^g + \sum_g \ln L_{CPUE}^g + \sum_g \ln {}^{Survey}L_{\text{age}}^g + \sum_g \ln {}^{Survey}L_{\text{length}}^g + \sum_g \ln {}^{Comm}L_{\text{age}}^g + \sum_g \ln {}^{Comm}L_{\text{length}}^g$$

B.4.3. Penalties

Several penalties might be affecting the overall objective function, depending on different model assumptions. In general the penalties correspond with prior assumptions made about some of the stochastic processes involved—specifically, recruitment variability and variability in the initial age structure

$$PSS_R = 0.5 \sum_t \frac{{}_R\varepsilon_t^2}{{}_R\sigma^2}$$

$$PSS_I = 0.5 \sum_t \frac{{}_I\varepsilon_a^2}{{}_I\sigma^2}$$

time-series trends in catchability by gear

$$PSS_q^g = 0.5 \sum_t \frac{{}_q\varepsilon_t^2}{{}_q\sigma^2}$$

and time-series trends in the parameters of the age-selectivity functions for the different commercial fisheries,

$$PSS_{S\text{full}}^g = 0.5 \sum_t \frac{{}_{\text{Sfull}}\varepsilon_t^g}{{}_{S\text{full}}\sigma^2},\ PSS_{{}_L v}^g = 0.5 \sum_t \frac{{}_{L}v\,\varepsilon_t^g}{{}_{L}v\,\sigma^2} \text{and}\ PSS_{{}_R v}^g = 0.5 \sum_t \frac{{}_{R}v\,\varepsilon_t^g}{{}_{R}v\,\sigma^2}$$

Hence the overall penalty would be the sum of the individual components

$$\text{penalties} = PSS_R + PSS_I + \sum_g PSS_q + \sum_g PSS_{S\text{full}}^g + \sum_g PSS_{v1}^g + \sum_g PSS_{v2}^g$$

B.4.4. Global objective function

Parameter estimates are obtained by minimizing the overall objective function

$$f = -\ln L + \text{penalties}$$

10. Initial Assessments of Sawshark (*Pristiophorus cirratus* and *P. nudipinnis*) and Elephant Fish (*Callorhinchus milii*)

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10.1 Background

Three species of sawshark and elephant fish (*Callorhinchus milii*) whose distributions have not been precisely described are endemic to waters off southern Australia. Common sawshark (*Pristiophorus cirratus*) is reported to range from Jurien Bay in Weastern Australia to Eden in New South Wales, including Tasmania to depths of 310 m. Southern sawshark (*P. nudipinnis*) is considered to range from the western region of the Great Australian Bight to eastern Gippsland in Victoria, including Tasmania, to depths of 70 m. Eastern sawshark (*Pristiophorus* sp. A) occurs from about Lakes Entrance in Victoria to Coffs Harbour in New South Wales at depths of 100–630 m. The elephant fish is distributed from Esperence in Western Australia to Sydney in New South Wales, including Tasmania, at depths to at least 200 m (Last and Stevens 1994). Elephant fish also occur in New Zealand, but these stocks are assumed to be a separate stock from those in southern Australia.

For assessment purposes, all sawsharks south of the Victoria–NSW border are assumed to be common sawshark and southern sawshark whereas those north of this border are assumed to be eastern sawshark. Only common sawshark and southern sawshark are included in the present stock assessment; the eastern sawshark provides a very small component of the sawshark catch and is excluded from the assessment because there are no biological data available on this species.

These species, along with gummy and school shark, form the primary target and byproduct species of the directed shark fishery off southern Australia. In contrast to gummy and school shark, sawshark and elephant fish are ‘data poor’ with the only stock assessment-related information for these species being species-specific demographic and gillnet selectivity parameters, species-aggregated catch and effort data, and some limited information on the size- and age-structure of the historical catches. This lack of data severely restricts the type of analyses on which stock assessments can be based. This is because, for example, none of the data available for these species permit independent estimation of the rate of natural mortality, *M* (in contrast, it is possible, in principle at least, to estimate *M* for gummy and school shark from the results of tagging experiments).

This chapter first outlines the data available for sawshark and elephant fish and uses these data to develop time-series of catches, catch-rates and catch length-composition for use in population model-based stock assessments. Assessments of sawshark and elephant fish are then undertaken using a population dynamics model tailored to the peculiarities of shark life-history. The final section of this chapter outlines some caveats and identifies future work.

10.2 Data

The data available for assessments of target and byproduct shark species off southern Australia include: catches (in mass), catch-rate-based indices of relative abundance, length-frequency data, age-composition data, and the results of tagging studies. All five of these data-types are included in the assessments of gummy shark (Punt *et al*., 2001; Pribac *et al*., in press; Chapter 7) and school shark (Punt *et al*., 2000a). In contrast to the situation for gummy and school shark, very little information on catch length-frequency is available for sawshark and elephant fish (Walker *et al*., 1997). Few animals of these species have been aged, and the number of animals tagged is much too small to enable reliable estimation of mortality rates (31 common sawshark recaptured, 41 southern sawshark recaptured, and 24 elephant fish recaptured). Therefore, assessments of sawshark and elephant fish must rely primarily on the information from the time-series of catches and from the catch and effort information.

10.2.1 Catch data

Figures 10.1 and 10.2 show the time-trajectories of catch by the directed shark fisheries (by SharkFAG sub-region – see Fig. 7.1) during 1973–2002. The catches of sawshark in Bass Strait (sub-regions SAV-E, western Bass Strait and eastern Bass Strait) make up the vast bulk of the catch of these species by this fishery off southern Australia (90%; Figure 10.1). In contrast to the situation for sawshark, sizeable quantities of elephant fish have been caught off eastern Tasmania (Figure 10.2). Although the catches of elephant fish off eastern Tasmania constitute 24% of the total catch over 1973–2003, the assessments of this chapter are restricted to elephant fish in Bass Strait only. A key reason for this is that, although catch information is available for eastern Tasmania, there are no reliable estimates of effort for this area before 1995 and catch-effort standardizations are not currently based on the catch and effort data for this region (see Appendix 7.A). Sub-region NSW is excluded because the sawshark catch is from a separate species and the catch of elephant fish is negligible.

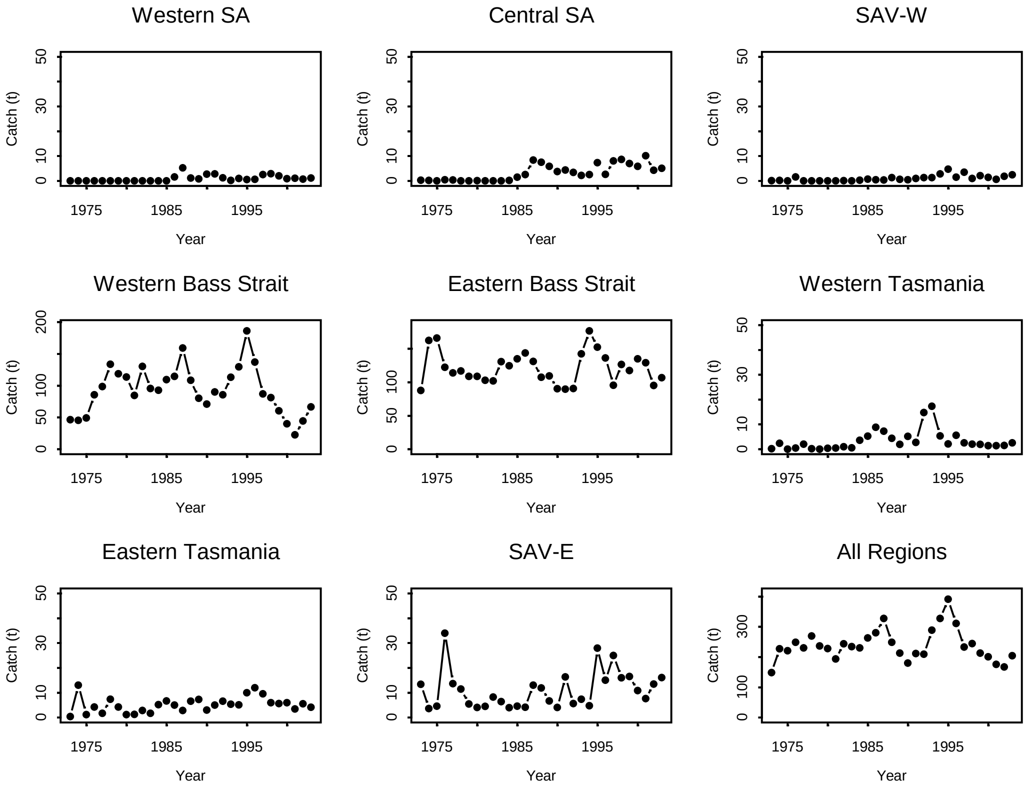

Figure 10.1. Catches (carcass weight, t) of sawshark by the directed shark fisheries by SharkFAG region.

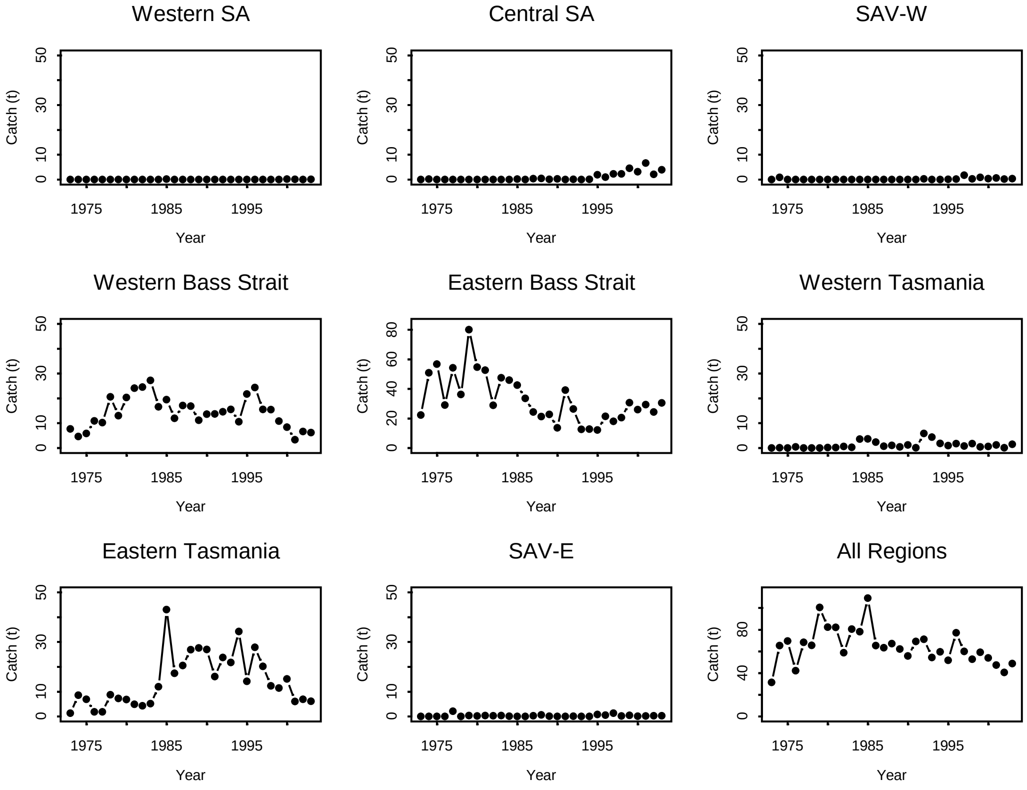

Figure 10.2. Catches (carcass weight, t) of elephant fish by the directed shark fisheries by SharkFAG region.

Table 10.1 lists the annual catches by the directed shark fisheries by gear-type (longlines and four sizes of gill-net) for Bass Strait that were used in the analyses of this chapter. The bulk of the historical catches of sawshark and elephant fish (94%) has been taken by 6” gill-nets although fairly substantial catches were taken during 1973–76 using 7” gill-nets.

It is necessary to estimate the catches by the directed shark fisheries for the years prior to 1973 and to include catches by the trawl sector (otter trawlers and Danish seine vessels) to conduct assessments for sawshark and elephant fish. The remainder of this section therefore uses available information to make estimates of these catches. However, it needs to be recognized that even though the estimates are based on all of the available information, these estimates are still subject to considerable uncertainty.

Table 10.2 lists the catches by the South East Trawl Fishery (SETF) and the Great Australian Bight Trawl Fishery (GABTF) based on logbook data for years 1985–2003 (SETF) and 1988–2003 (GABTF)[17]. The catches of sawshark reported for NSW are excluded from the assessment because the animals landed from this sub-region are a separate species. Table 10.3 lists historical (1950–69) information on catches of sawshark landed in Victoria, which covers the sub-regions of SAV-E, Western Bass Strait and Eastern Bass Strait. The algorithm to estimate catches for those years for which catches are missing using the information in Tables 10.1–10.3 is[18]:

a) The total catches by the directed shark fisheries (all gear-types and sub-regions combined) for years 1969–72 are computed using the formula:

$$C_y^{\mathrm{SSF}} = C_{1973}^{\mathrm{SSF}}\, C_y^{\mathrm{Gummy}} / C_{1973}^{\mathrm{Gummy}} \tag{10.1}$$

where C_y^{SSF} is the catch by the directed shark fisheries during year y, and
C_y^{Gummy} is the catch of gummy shark by the directed shark fisheries during year y.

The rationale for this approach to estimating total catches (suggested at the 2 March 2004 meeting of SharkFAG) is that the effort directed at elephant fish and sawshark should follow that targeted towards gummy shark. Equation 10.1 is not used to estimate the total catch of sawshark for 1968 and 1969 because data from across sub-regions of SAV-E, Western Bass Strait and Eastern Bass Strait are available on these catches (Table 10.3)

b) The catches computed using Equation (10.1) are split to sub-region and gear-type based on the data for 1973. The rationale for this approach is that 1973 is first year for which information on the split to sub-region is available and the data for 1973 should consequently provide the best information on the split for the years prior to 1973.

c) The total catch by trawl (all sub-regions) for each of the years 1950–69 for sawshark is set to the estimates in Table 10.3, whereas the catches by trawl of elephant fish prior to 1970 are assumed to be zero. There is no information on

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[17] Data are presented separately for the SETF and GABTF for 2002 and 2003 even though these two fisheries are now combined for management and reporting purposes.

[18] This algorithm is applied separately to sawshark and elephant fish.

the catches from 1970–84 so the total catch by trawl for 1970–85 is determined by linear interpolation between the catches for 1969 and 1986[19].

d) The total catches by trawl are split to sub-region using the proportion of the catch taken in each sub-region during 1986–88 (the first years for which reliable logbook data are available). The selectivity pattern for the trawl catches is taken to be the same as that for the longline component of the fishery because longline catches the widest size range of fish.

Figure 10.3 shows the time-series of catches of sawshark and elephant fish on which the present assessment is based (i.e. the catches in Bass Strait) compared with the total (southern Australia-wide) catches. This is the breakdown of the catches used in the assessment into those taken using trawl gear and those taken by the directed shark fisheries.

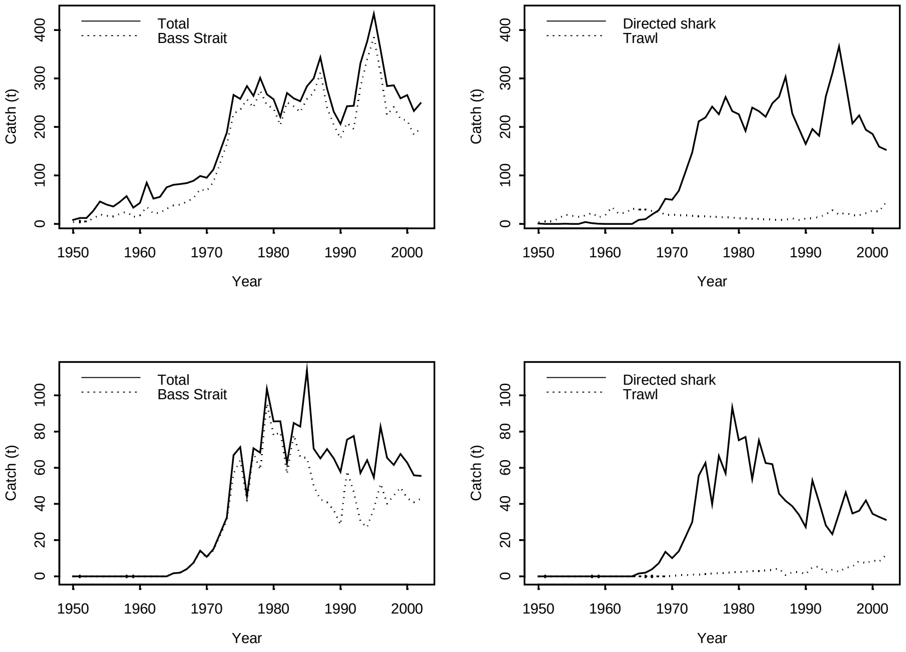

Figure 10.3. Catch series for sawshark (upper panels) and elephant fish (lower panels). The left panels show the catches off southern Australia and those in Bass Strait while the right panel show the split of the catch in Bass Strait between the trawl fisheries and the directed shark fisheries.

It is known that some sawshark and elephant fish are discarded by the trawl sector and that most of the historical catches by otter trawl were recorded in the logbooks as “unspecified species”. It is possible (in principle at least) to estimate the actual trawl catch of sawshark and elephant fish using the data collected by the Scientific Monitoring Programme (SMP) and the Integrated Scientific Monitoring Programme (ISMP) using the formula:

$$C_y^{\mathrm{Trawl}} = \sum_r I_y^r \, E_y^r \tag{10.2}$$

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[19] This process therefore ignores the data from logbooks for 1985. These data are ignored because the otter trawl logbook data for 1985 are incomplete because the logbook programme only started near the end of 1985.

where I_y^r is the catch-rate (either catch-per-haul or catch-per-hour) in sub-region *r* during year *y*, and

E_y^r is the effort (either the number of hauls or the number of hours, depending on how I_y^r is defined) in sub-region *r* during year *y*.

Table 10.4 lists the estimated catches based on Equation 10.2 (with asymptotic coefficients of variation). The estimates of elephant fish catch are very imprecise as are the estimates of sawshark catch for the years prior to 1996. The estimates of the sawshark catches based on Equation (10.2) are generally much larger than those based on the trawl logbooks (compare Tables 10.2 and 10.4). The discrepancy between the catches of sawshark in Table 10.4 and those in Table 10.2 cannot be attributed to discarding (the discard rate for sawshark based on the ISMP data is only 1.7%). Instead, the discrepancy can best be explained by reporting of catches of sawshark as “other”. A sensitivity test is therefore conducted for the sawshark assessment in which the trawl catches in the base-case analysis are increased by 150% to examine the implications of the catches of sawshark in Table 10.4 better representing the removals of sawshark by the trawl sector.

10.2.2 Catch-rate indices

In principle, the ideal way to develop catch-rate-based indices of relative abundance is to apply a method of catch-effort standardization (e.g. Gavaris, 1980; Kimura, 1981; Vignaux, 1994; Punt *et al*., 2000b) to the data for sawshark and elephant fish. However, this approach cannot be applied at present because SharkFAG have yet to define ‘indicative’ fishers for sawshark and elephant fish. Instead, the effort estimated from the catch-effort standardization for gummy shark (See Appendix 7.A) estimated to targeted towards gummy shark in Bass Strait (Figure 10.4) is assumed to be an appropriate measure of the effort directed towards sawshark and elephant fish in Bass Strait. The catch-rate for sawshark for year *y* is therefore defined as the catch of sawshark during year *y* divided by the effort estimated to be directed toward gummy shark during year *y* (the ratio of the catch by 6” mesh gill-nets for year *y* to the standardized catch-rate for year *y*). Table 10.5 lists the catch-rate series considered in the analyses of this chapter.

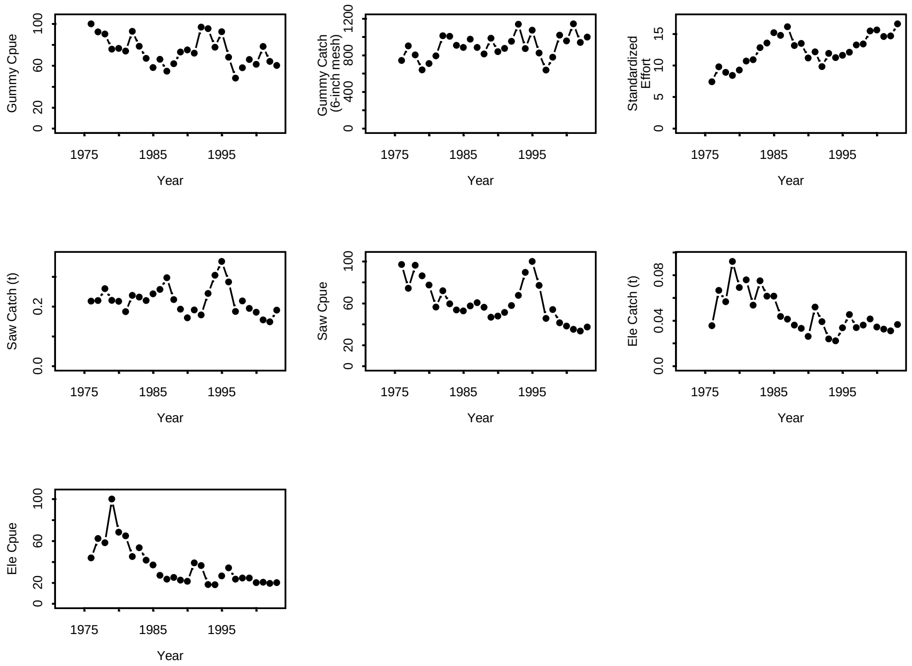

Figure 10.4. Catch and catch-rate indices for sawshark and elephant fish in Bass Strait based on standardized effort for gummy shark.

10.2.3 Length-frequency information

Length-frequency and sex-composition data are available for gummy shark, school shark, sawshark, and elephant fish from commercial and research sampling. The sample sizes for sawshark and elephant fish are, however, very small (Table 10.6 lists the numbers of sharks measured annually by gear-type and sex). The analyses of this chapter are restricted to those combinations of gear-type and sex for which the sample sizes are "reasonable" – these combinations are highlighted in Table 10.6.

10.2.4 Biological parameters

The number of pups (actually embryos) per pregnant sawshark (or number of eggs laid per mature female elephant fish) of age *a* (total length $\ell_{1,a}$) is given by:

$$P'_a = \max(0, a' + b'\ell_{1,a}) \tag{10.3}$$

where *a'* and *b'* are the parameters that govern the relationship between total length and number of pups per pregnant female.

The proportion of female animals of age *a* (total length $\ell_{1,a}$) that are pregnant (or egg laying) each year is given by:

$$P''_a = P''_{\max}\left(1 + \exp(-\ell n(19)\frac{\ell_{1,a} - \ell''_{50}}{\ell''_{95} - \ell''_{50}})\right)^{-1} \tag{10.4}$$

where $P''_{\max}$ is the proportion of very large ($\ell_{1,a} \rightarrow L_{\infty,1}$) females that are pregnant (or egg laying) each year,

ℓ''_{50} is the length at which half of the maximum proportion of females are pregnant (or egg laying) each year, and

ℓ''_{95} is the length at which 95% of the maximum proportion of females are pregnant (or egg laying) each year.

The total length of a fish of age *a* and sex *g* at the start of the year, $\ell_{g,a}$, is described by the von Bertalanffy growth equation:

$$\ell_{g,a} = L_{\infty,g}(1 - e^{-\kappa_g(a - t_{0,g})}) \tag{10.5}$$

and the live mass by the allometric equation:

$$w_{g,L} = a_g(\overline{L}_L)^{b_g} \tag{10.6}$$

where $\overline{L}_L$ is the mid-point of length-class *L*.

The values assumed for the parameters of Equations (10.3)–(10.6) are listed in Table 10.7.

The probability that a fish of age *a* and sex *g* lies in length-class *L* (length-class *L* is defined to be $[L - \Delta L, L + \Delta L]$) is given by:

$$\Phi(g,a,L) = \int_{L-\Delta L}^{L+\Delta L} \frac{1}{\sqrt{2\pi}\sigma_{g,a} l} e^{-\frac{(\ell n l - \ell n \ell_{g,a})^2}{2\sigma_{g,a}^2}} dl \tag{10.7}$$

where ΔL is half the width of a length-class (25 cm), and

$\sigma_{g,a}$ is (approximately) the coefficient of variation of the length of an animal of age *a* and sex *g* (assumed to be 0.1 for all ages).

10.2.5 Selectivity

Different selectivity patterns are assumed for the two major gear-types (hooks and gill-nets). By analogy with the assessments of gummy and school shark, the catch by hooks is assumed to be taken uniformly from the 2+ component of the population, i.e.:

$$S_{g,j,L} = \begin{cases} 0 & \overline{L}_L < \ell_{g,2} \\ 1 & \text{otherwise} \end{cases} \tag{10.8}$$

where $S_{g,j,L}$ is the selectivity of gear-type *j* on fish of sex *g* in length-class *L*.

The selectivity pattern for gill-nets is assumed to follow a gamma function (Kirkwood and Walker, 1986):

$$S_{g,j,L} = \left(\frac{\overline{L}_L}{\alpha_{g,j}\,\beta_{g,j}} \right)^{\alpha_{g,j}} e^{\alpha_{g,j} - \frac{\overline{L}_L}{\beta_{g,j}}} \tag{10.9}$$

where α, β are the parameters of the selectivity pattern, i.e.:

$$\alpha = \tfrac{1}{2}\left(\theta_1 m - \sqrt{(\theta_1 m) + 4\theta_2}\right) \qquad \alpha = \theta_1\, m / \beta \qquad (10.10)$$

where θ_1, θ_2 are parameters (Table 10.7), and
m is the mesh size (in inches).

Figures 10.5–10.7 summarize the biological parameters for common sawshark, southern sawshark and elephant fish in terms of the relationships between length and age, weight and age, pup production (the product of the number of pups per mature female and the proportion of females of each age that are mature) and age. These relationships imply a particular level of natural mortality for pups in order for the population to remain in balance; Figures 10.5–10.7 therefore show natural mortality as a function of age when the natural mortality rate for animals 2 and older is 0.2yr^{-1}. Figures 10.5–10.7 also show selectivity as a function of length (solid line – longlines; dotted lines – gillnets) and age. Finally, these figures include the distributions of length-at-age for ages 3, 8, 11, etc.

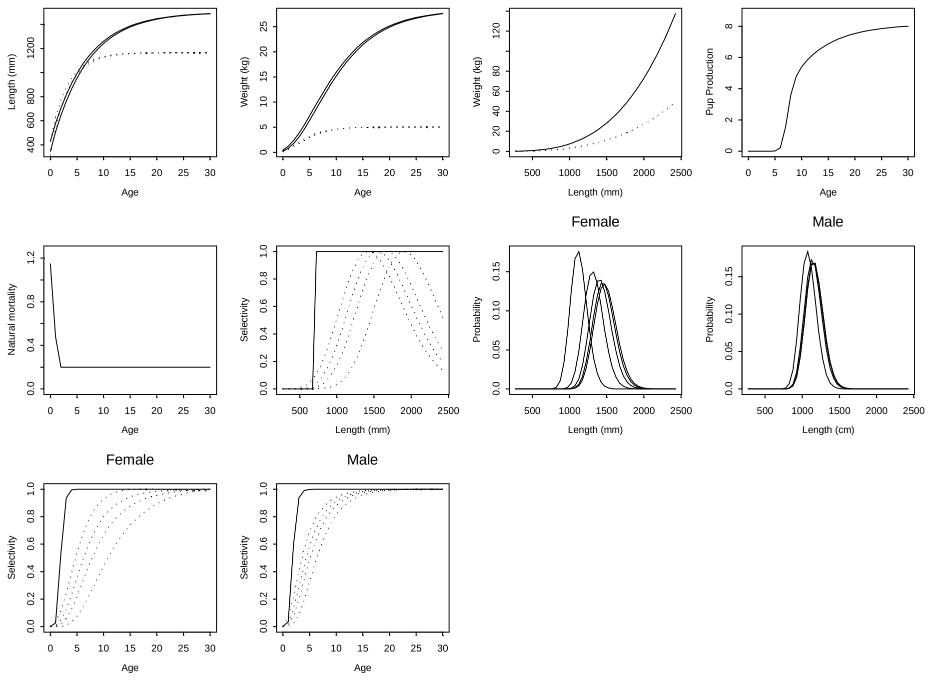

Figure 10.5. Biological and technological parameters for common sawshark. The first two panels on the upper row of panels show length-at-age and mass-at-age at the start and in the middle of year.

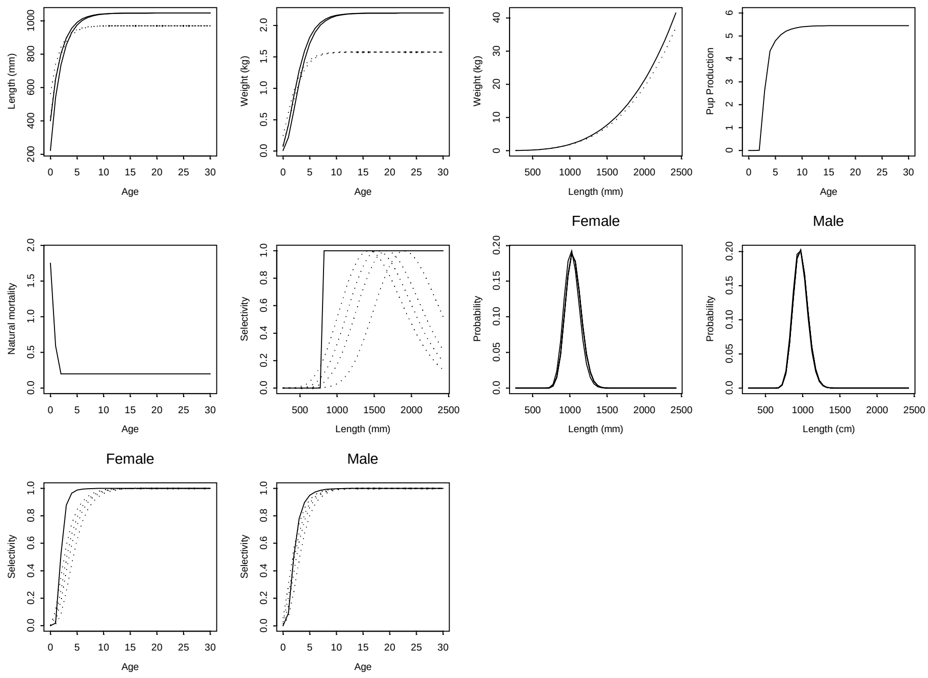

Figure 10.6. Biological and technological parameters for southern sawshark. The first two panels on the upper row of panels show length-at-age and mass-at-age at the start and in the middle of year.

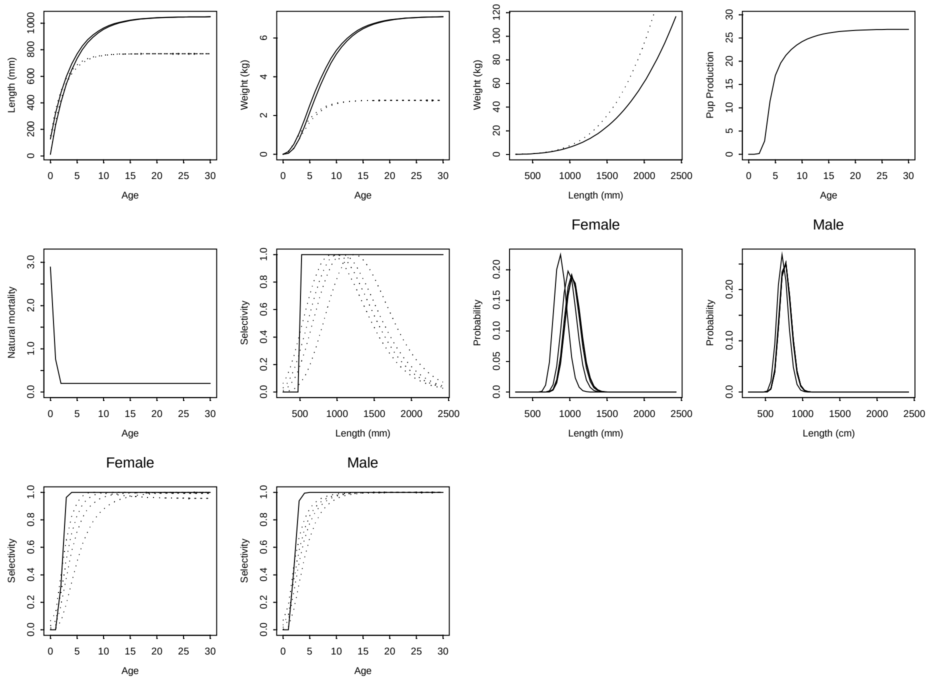

Figure 10.7. Biological and technological parameters for elephant fish. The first two panels on the upper row of panels show length-at-age and mass-at-age at the start and in the middle of year.

10.3 Analytical approach

The assessments of this chapter are based on the approach developed to assess gummy shark in Bass Strait and off South Australia (see Appendices 7.B and 7.C for details), with a few differences:

a) The relationship between length and number of embryos per mature female is assumed to be a linear rather than an exponential function of length.
b) No information is available on the age-structure of the historical catches.
c) Availability is assumed to be independent of length in the absence of data that can be used to determine the relationship between availability and length – this assumption should lead to somewhat more pessimistic results than had availability been assumed to be domed-shaped.
d) Natural mortality is pre-specified (rather than being estimated) in the absence of sufficient tagging, length-, and age-composition data. The base-case value for the natural mortality rate of animals aged 2 and older, M_{2+}, is 0.2yr^{-1}. Sensitivity to the value assumed for M_{2+} is examined in the tests of sensitivity.
e) Catch-rate is assumed to be related linearly to abundance. This assumption is necessitated because of the absence of tagging data and sufficient information on the length- and age-composition of the catches from which the relationship between catch-rate and abundance could potentially be estimated.
f) The population is assumed to be at its unfished equilibrium level at the start of 1950 (the first year for which catches are available – see Section 10.1).
g) Recruitment residuals are estimated for 1951–2000 (for those analyses that allow for changes over time in pup survival).
h) The coefficient of variation of the catch-rate data is assumed to be 0.3 (rather than 0.15) to reflect less confidence in the catch-rate index as an index of abundance.
i) The effective sample size for the length-frequency data is set to 10 to reflect the fact that these data are based on very small sample sizes and few sample locations.

Parameter uncertainty is examined through the use of sensitivity tests and by applying the Markov Chain Monte Carlo (MCMC) algorithm (Hastings, 1970; Gelman *et al*., 1995). Table 10.8 lists the specifications for the base-case analyses and the sensitivity tests. Two sets of analyses are conducted for sawshark, one set in which the values for the biological parameters are set to those estimated for common sawshark (Table 10.7; Figure 10.5) and another set in which the values for the biological parameters are set to those estimated for southern sawshark (Table 10.7; Figure 10.6). The sensitivity in which allowance is made for gear-competition (sensitivity test 10) involves assuming that the relationship between exploitation rate and fishing effort is governed by Equation 7.C.2 where the value of the parameter γ_1 is set equal to 0.1075 – the base-case value for this parameter from the gummy shark assessment.

10.4 Results

The results of the assessments are summarized by the following five quantities:

a) the estimate of the Maximum Sustainable Yield rate (if the fishery operated uniformly on mature animals);

b) the value of the density-dependence parameter (V or Q_0, depending on whether density-dependence impacts natural mortality or the survival rate of pups);
c) the depletion of the pup production in 1973 (relative to that in 1950);
d) the depletion of the pup production in 2004 (relative to that in 1950); and
e) the value of negative log-likelihood function corresponding to the parameter values presented.

Table 10.9 lists the values for these four quantities (and their asymptotic standard errors) for the base-case analyses and the sensitivity tests. One of the sensitivity tests did not converge (the Hessian matrix was not positive definite – indicated in Table 10.8 by an asterisk). The results for this sensitivity tests are consequently omitted from Table 10.9.

10.4.1 The base-case analyses (sawshark)

The fits of the model to the fishing effort data for sawshark (Table 10.9, rows "Base-case"; Figures 10.8 and 10.9) are good. The analysis in which the biological parameters for southern sawshark are assumed fits the change in fishing effort from 1990–95 slightly better than when the biological parameters for common sawshark are assumed. The model is able to capture the central tendency of the length-frequency data. However, the model predicts that a wider range of size-classes should be caught using 6" mesh gill-nets than is actually the case. There are several possible reasons for the inability of the model to adequately capture the size-range of the catch: a) the samples on which the length-frequencies are based (which were collected during surveys) are unrepresentative of the length-frequency of the catch, b) the assumed selectivity curves (which were estimated using data pooled over both species) are in error, c) the values of the parameters of the growth curve (including the extent of variation about that curve) are in error, and d) larger and small animals are not available to the fishing gear. Unfortunately, in the absence of data, it is not possible to determine which of these reasons is most plausible. Clearly, collection of additional length-frequency data would help resolve this issue. Additional length-frequency data should be collected from the catch and an attempt should be made to assemble length-frequencies from the trawl catch.

The productivity of the resource (as measured by *MSYR*) is low (28% or 17% depending on whether the biological parameters are set to those for common or southern sawshark; Table 10.9). These estimates of productivity are, however, very imprecise (standard deviations of 7-8%). The pup production is assessed to be 32% (common sawshark parameters) or 26% (southern sawshark parameters) of its 1950 value. These estimates are also fairly imprecise (standard deviations of ~10%).

10.4.2 The base-case analysis (elephant fish)

The fit of the model to the catch-rate data is again adequate (Figure 10.10). However, the fit to the length-frequency data for females is very poor with the model predicting that there should be a large catch of small females. However, in contrast to the situation for males, few small females are caught. The productivity of elephant fish is estimated to be quite substantially lower than that of sawshark (5%). In common with sawshark, the elephant fish resource in Bass Strait is estimated to be depleted to below 40% of the pup production in 1950 (point estimate 20%). The base-case estimate of the pup production in 2004 of elephant fish is somewhat more precise than those of sawshark (the standard deviation of P_{2004} / P_{1950} is only 3%; a coefficient of variation nevertheless close to 25%).

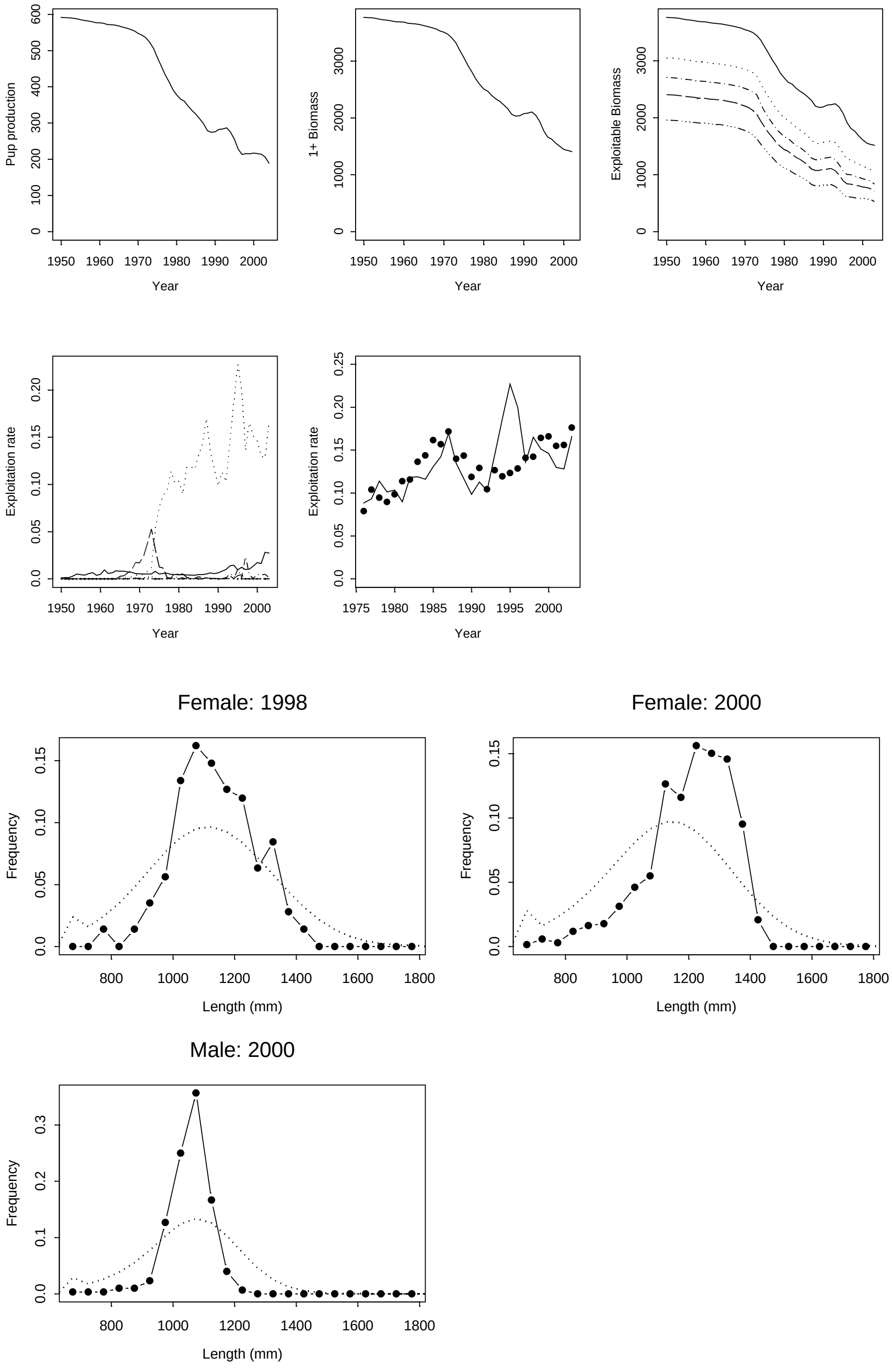

Figure 10.8. Diagnostic statistics for the base-case assessment of sawshark (common sawshark biological parameters).

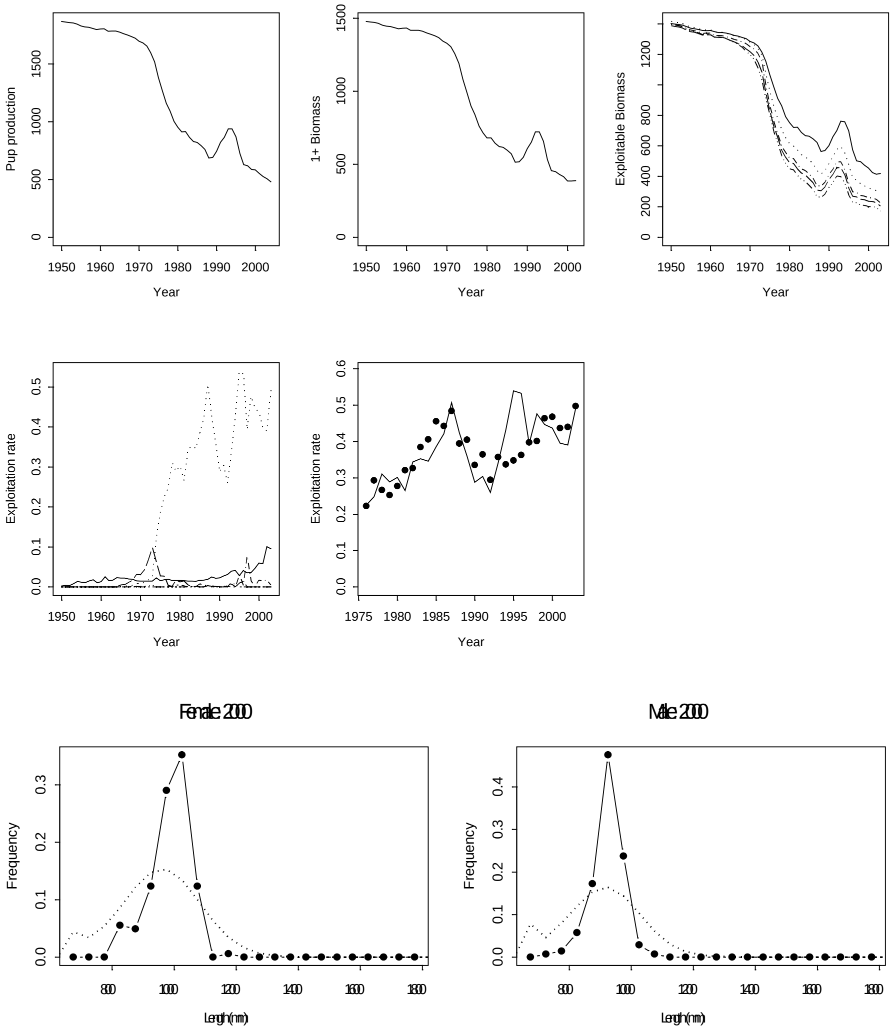

Figure 10.9. Diagnostic statistics for the base-case assessment of sawshark (southern sawshark biological parameters).

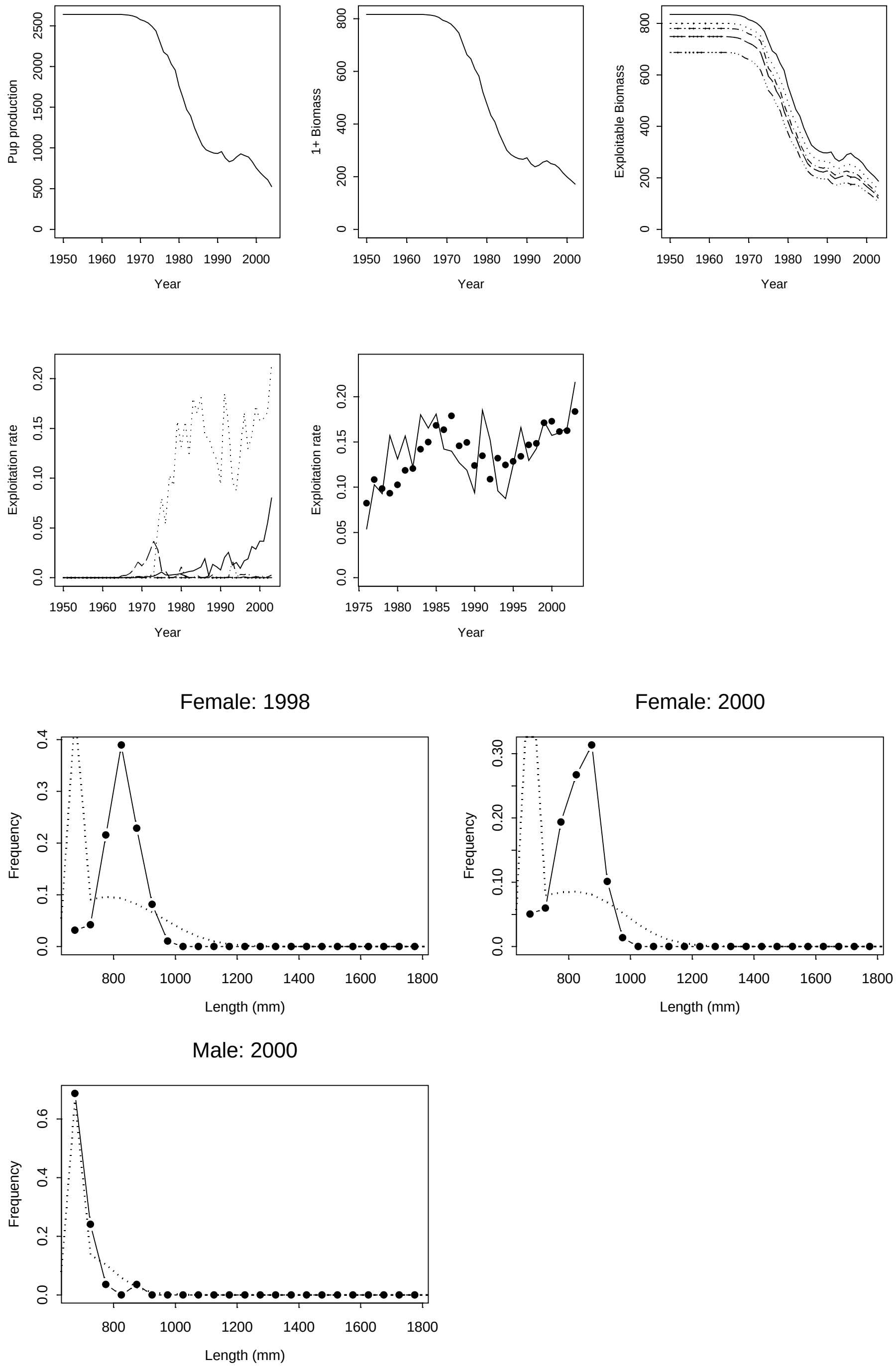

Figure 10.10. Diagnostic statistics for the base-case assessment of elephant fish.

10.4.3 Sensitivity tests

The point estimate of the current depletion of sawshark ranges from 17% (sensitivity test 6) to 39% (sensitivity tests 3 and 10) while productivity (as measured by *MSYR*) ranges from 3% to 23%. The factors that influence the current depletion of sawshark to the greatest extent are: a) whether the biological parameters are set to those for common or southern sawshark, b) the weight assigned to the catch-rate data (increasing this weight leads to a more depleted resource), and c) allowing for some gear-competition. It is perhaps noteworthy that the best fit (of those analyses for which the values for the negative log-likelihood are comparable) is that for which allowance is made for gear competition – note, however, that none of the analyses can be distinguished statistically.

The range of depletion levels is less for elephant fish (14–22%) than for sawshark (17–39%) although the range of *MSYR* values (point estimates: 3–14%) remains very broad.

10.4.4 Bayesian analyses

Bayesian posterior distributions for the parameters and outputs of the model were developed using the Markov Chain Monte Carlo (MCMC) algorithm. The number of cycles was set to 5,000,000, the first 1,000,000 of these were ignored as a burn-in period and the chain was thinned by selecting every 5,000th parameter vector thereafter. Whether the MCMC algorithm had reached convergence was evaluated using standard diagnostic statistics and plots (see section 7.4.2).

The diagnostics (e.g. Figures 10.11a and 10.11b) suggest that convergence had failed to occur for sawshark. The results in Figures 10.11a and 10.11b indicate that this problem is such that convergence of the MCMC algorithm for sawshark cannot be expected unless: a) the model is reparameterized so that all high posterior correlations (e.g. Figure 10.12, a correlation of -0.91) are eliminated, or b) the number of cycles is increased very substantially (by at least an order of magnitude, prossibly by two orders of magnitude). The value of the parameter *V* has substantial posterior probability very near its maximum of 1 (Figure 10.12) – this will also tend cause problems for the convergence of the MCMC algorithm unless a prior is selected for *V* which prevents this. Resolution of the problems with the convergence of the MCMC algorithm for sawshark is beyond the scope of the present preliminary assessment. Detailed Bayesian results are therefore not presented for sawshark in this chapter.

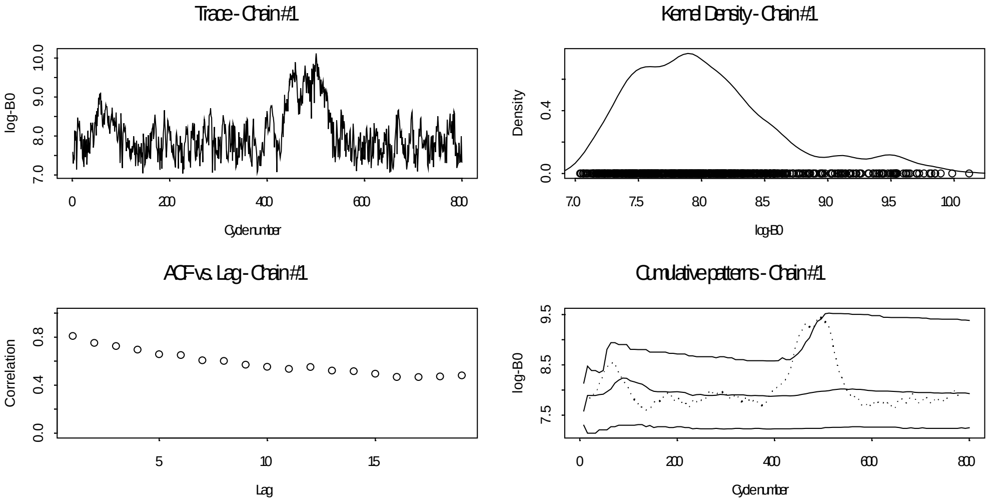

Figure 10.11(a). Convergence statistics for the logarithm of the virgin recruitment for sawshark (common sawshark biological parameters).

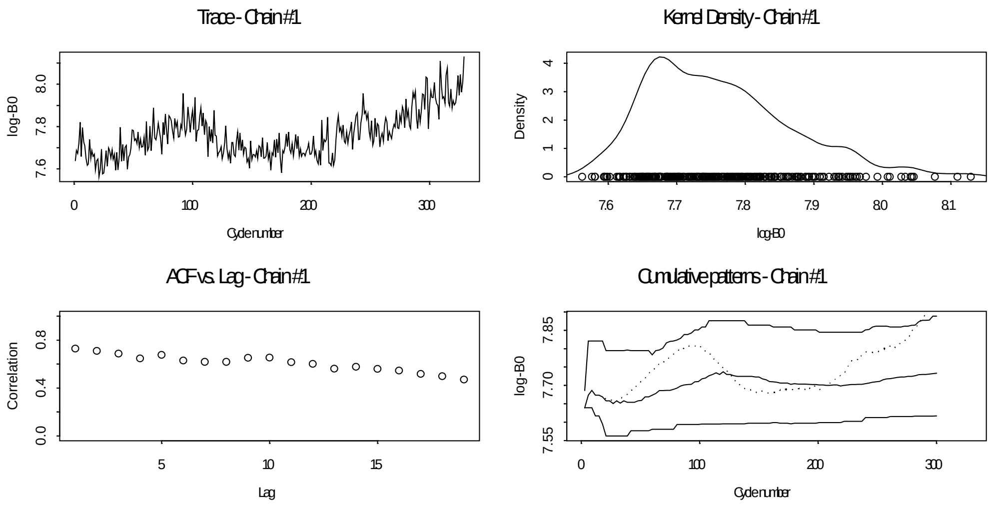

Figure 10.11(b). Convergence statistics for the logarithm of the virgin recruitment for sawshark (southern sawshark biological parameters).

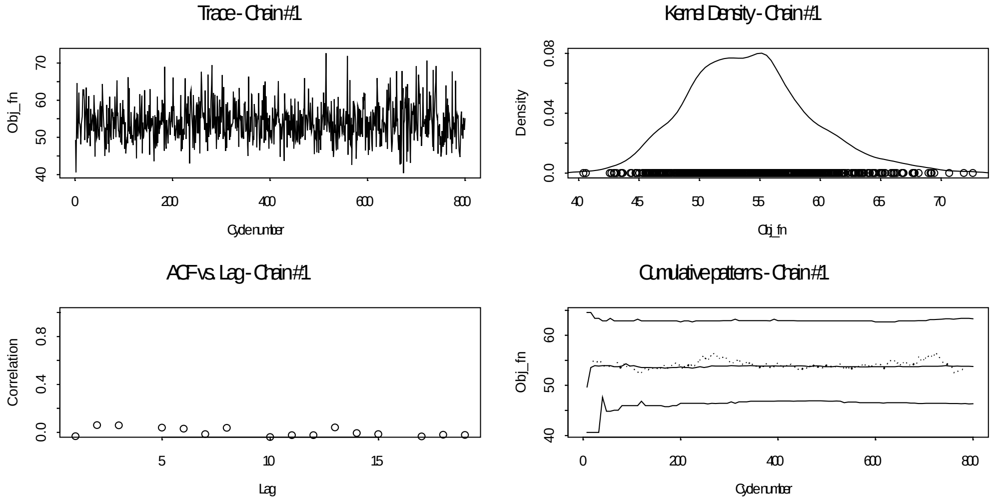

Figure 10.11(c). Convergence statistics for the logarithm of the virgin recruitment for elephant fish.

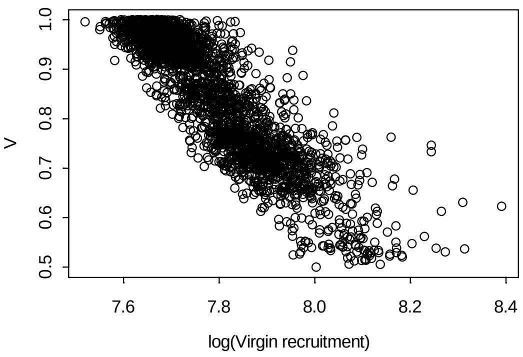

Figure 10.12. Posterior correlation between the value of the density dependence parameter (*V*) and the logarithm of the virgin recruitment for sawshark (common sawshark biological parameters).

Some concerns with the Bayesian results for elephant fish remain although the diagnostics (e.g. Fig 10.11c) provide no evidence for a lack of convergence of the MCMC algorithm. For example, the posterior median for P_{2004} / P_{1950} (0.26) is notably larger than the posterior mode (0.2), although the large imprecision (95% posterior interval [0.13, 0.48]) implies that the posterior mode and median are actually not inconsistent. The bimodal distribution for *MSYR* (modes at 5 and 13%) is also perhaps a cause for some concern.

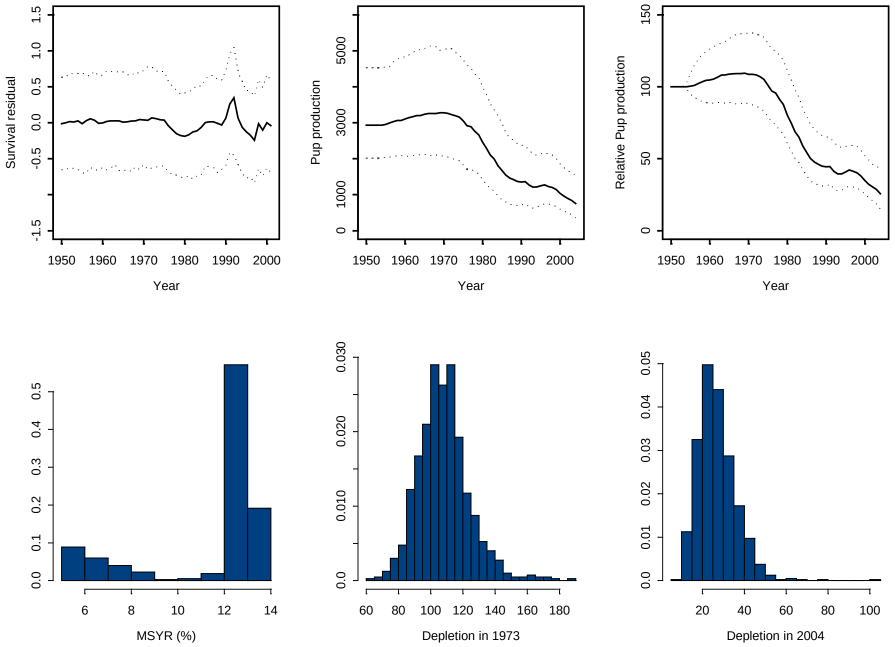

Figure 10.13. Posterior distributions for the time-trajectories of the survival residuals and pup production for elephant fish (posterior medians and posterior 90% intervals) and posterior distributions for *MSYR*, P_{1973} / P_{1950} and P_{2004} / P_{1950}.

10.5 Discussion and further development

10.5.1 Stock status

The results of the assessment suggest that both sawshark and elephant fish are depleted to below 40% of the 1950 pup production (perhaps substantially so in the case of elephant fish). The results are, however, imprecise, particularly those for sawshark. For example, the point estimates of the current depletion of sawshark pup production range from 17–39% depending on the assumptions of the assessment.

The assessment of sawshark combines data for common and southern sawshark. These species differ quite markedly in terms of their biological parameters (Table 10.7; Figures 10.5 and 10.6). It is therefore quite likely that these two species also differ in terms of biological productivity but there are no data to examine this quantitatively. The impact of catches being aggregated across species cannot be assessed at present and the measures of uncertainty do not capture this source of uncertainty.

Changes in targeting practices have occurred over the history of the fishery. This assessment attempts to account for this by basing the effort used to constructed catch-rate-based indices of abundance on that for gummy shark. However, more subtle changes in targeting practices have occurred. In the absence of data to qualify these changes, however, their impacts on the results of the assessment remain unknown.

The fits to the catch-rate data appear good (Figures 10.8–10.10). This is, however, not surprising because these are only the data available to determine trends in population size and the extent of variability in pup survival. The results are therefore completely determined by the trend in historical catch-rates. It is well-known that catch-rates may not index abundance adequately, but the extent to which catch-rates may be inadequate indicators of abundance is unknown for sawshark and elephant fish. Cooke and Beddington (1984) and Cooke (1985) describe various scenarios in which catch rate is unlikely to be linearly related to abundance. Cooke and Beddington (1984) highlight the possibility that catch rates may decline more slowly than abundance (“hyperstability”) and this expectation is supported by the meta-analysis conducted by Harley *et al.* (2001). However, the opposite problem (“hyperdepletion”) can also occur (e.g. Prince and Hilborn, 1998).

Another consequence of an assessment that relies on a single data source is that additional data can lead to marked changes in impressions of stock status and productivity. For example, Punt and Walker (1998) using a model and data set similar to that considered in this paper concluded that the mature biomass of the school shark resource off southern Australia lay between 13 and 45% of its 1927 level at the start of 1995. However, Punt *et al.* (2000a) estimated the pup production to be between 12 and 18% of its 1927 level at the start of 1997 based on a larger data set and a spatially-structured population dynamics model. The two sets of results are not inconsistent, but the additional data did not lead to a narrowing of the uncertainty towards the centre of the range considered initially to be plausible. There is no reason to believe that additional data could not impact the results of the assessments of this chapter in a similar (i.e. non-symmetric) manner.

10.5.2 Further development

The analyses of this paper are clearly preliminary. There are several aspects of the analysis which could be improved.

a) The catch-rate series (Table 10.5) are based on the standardized effort data for gummy shark in Bass Strait. In principle, catch-rate indices could be developed for sawshark (both species combined) and elephant fish based on data for ‘indicative’ fishers chosen by SharkFAG.
b) The analyses are restricted to Bass Strait owing to a lack of data. However, catches of, for example, elephant fish are fairly substantial outside of Bass Strait (e.g. Figure 10.2). SharkFAG need to consider: i) whether consideration needs to be given to attempting to include other regions in future assessments, and ii) how the results for an assessment of a subset of the area fished can be used to provide management advice for the whole fishery.
c) The impact of combining the two sawshark species for assessment purposes should be examined by simulation. Alternatively (or in addition) an assessment framework should be developed that fits two population dynamics models (one

for each of common and southern sawshark) simultaneously and that assesses the relative sizes of the two species using survey data.

d) Availability is assumed to be independent of length in the absence of data. SharkFAG should consider whether sensitivity to the possibility that availability is domed-shaped should be examined. However, given the lack of data, hypotheses for how availability might change with length would need to be developed by SharkFAG based on *a priori* considerations.

e) Assessments of elephant fish have been conducted in New Zealand (e.g. McClatchie and Lester (1994)). The assumptions that underlie those assessments should be compared with those of the present assessments. Such a comparison could lead to a revision to some of the assumptions and / or additional sensitivity tests.

f) The values assumed for the biological parameters should be reviewed by SharkFAG. Specifically, the growth rate of southern sawshark is very rapid with maximum size attained in less than 10 years (Figure 10.6). The gill-net selectivity patterns for sawshark and elephant fish are also such that few animals are “fully selected” because the length-at-full-selection is greater than ℓ_∞ (Figures 10.5–10.7). One of the model inputs is the first size at which a female can be mature (which impacts how *MSYR* is defined). This quantity is assumed to be: 800 mm (common sawshark), 400 mm (southern sawshark), and 90 mm (elephant fish). SharkFAG needs to consider, and possibly revise, these values.

g) The base-case value for the natural mortality rate for animals aged 2 and older is 0.2yr^{-1}. This value is based on the results of the assessment of gummy shark. The growth curves, particularly for southern sawshark, would suggest that this is likely to be an under-estimate.

h) Information of catch-rates of sawshark and elephant fish is available from the Integrated Scientific Monitoring Programme. Once analyzed, these data could be included as an alternative index of abundance.

i) Consideration should be given to reparameterizing the model in an attempt to reduce the extent of correlation among the parameters of the model.

j) Additional length-frequency data (from the catch of gillnetters and trawlers), as well as catch age-composition data, should be collected and included in future assessments.

10.6 References

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Table 10.1. Time-series of historical catches (1973–2002) of sawshark and elephant fish by the directed shark fisheries.

(a) Sawshark

Year	**Gear-Type**				
	Longline	**6” Mesh**	**6.5” Mesh**	**7” Mesh**	**8” Mesh**
1973	1.71	30.69	0.03	111.27	3.82
1974	10.73	139.71	0.00	61.02	0.00
1975	1.81	194.77	0.00	23.01	0.00
1976	3.33	218.49	0.00	19.91	0.20
1977	3.87	220.12	0.00	2.16	0.16
1978	0.58	259.78	0.42	0.91	0.02
1979	0.24	220.52	2.77	9.01	0.00
1980	0.11	217.57	2.45	6.18	0.00
1981	0.10	183.13	1.26	7.40	0.00
1982	0.12	237.76	0.03	2.33	0.00
1983	0.35	231.60	0.29	0.16	0.00
1984	0.26	219.99	0.52	0.49	0.00
1985	2.52	243.01	3.29	0.07	0.00
1986	3.39	257.31	1.44	0.02	0.00
1987	3.84	296.68	1.12	0.95	0.83
1988	2.80	223.66	0.54	0.75	0.02
1989	4.30	191.00	0.49	0.39	0.04
1990	3.09	161.99	0.00	0.00	0.00
1991	5.99	188.82	0.90	0.02	0.00
1992	8.39	172.09	0.25	1.34	0.00
1993	11.41	243.81	0.00	3.35	4.44
1994	3.28	305.19	0.00	0.34	1.85
1995	1.21	351.32	10.83	3.03	0.00
1996	1.06	282.79	1.06	3.56	0.00
1997	0.57	183.22	23.55	0.00	0.00
1998	0.31	219.19	4.27	0.00	0.00
1999	0.39	193.58	0.20	0.00	0.00
2000	0.35	180.86	4.43	0.00	0.00
2001	0.28	155.34	3.62	0.00	0.00
2002	0.06	148.60	4.34	0.00	0.00
2003	0.15	187.84	1.15	0.03	0.00

(Table 10.1 Continued)

(b) Elephant fish

Year	**Gear-Type**				
	Longline	**6” Mesh**	**6.5” Mesh**	**7” Mesh**	**8” Mesh**
1973	0.43	2.21	0.00	25.54	1.78
1974	1.65	35.26	0.00	18.70	0.00
1975	2.92	55.59	0.00	4.15	0.00
1976	0.50	35.58	0.00	3.80	0.00
1977	0.00	66.50	0.00	0.01	0.00
1978	0.00	56.68	0.18	0.01	0.00
1979	0.00	91.96	0.36	1.00	0.00
1980	0.00	69.08	4.79	1.37	0.00
1981	0.00	75.81	0.47	0.74	0.00
1982	0.06	53.62	0.00	0.03	0.00
1983	0.02	74.94	0.03	0.08	0.00
1984	0.24	61.56	0.77	0.00	0.00
1985	0.42	61.53	0.03	0.01	0.00
1986	1.92	43.62	0.12	0.00	0.00
1987	0.07	41.34	0.00	0.00	0.37
1988	1.91	36.14	0.00	0.69	0.00
1989	0.79	33.15	0.00	0.07	0.00
1990	1.14	26.13	0.00	0.00	0.00
1991	1.05	51.89	0.00	0.00	0.00
1992	1.79	39.08	0.08	0.09	0.00
1993	1.35	23.88	0.00	0.00	2.97
1994	0.50	22.30	0.00	0.00	0.52
1995	0.29	33.70	0.75	0.00	0.00
1996	0.28	45.27	0.62	0.18	0.00
1997	0.06	33.85	0.90	0.00	0.00
1998	0.14	36.04	0.04	0.00	0.00
1999	0.35	41.38	0.19	0.00	0.00
2000	0.02	34.31	0.17	0.00	0.00
2001	0.05	32.56	0.23	0.00	0.00
2002	0.11	31.10	0.09	0.00	0.00
2003	0.01	36.62	0.32	0.00	0.00

Table 10.2 : Reported catches (kg) by SETF and GABTF trawlers of sawshark and elephant fish by year and sub-region.

(a) Sawshark

Year	Sub-region									Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	NSW	
South East Trawl Fishery										
1985	0	0	365	81	374	2343	0	349	588	4100
1986	0	0	1257	225	412	7114	150	10	10333	19501
1987	0	0	762	330	36	7804	0	110	7390	16432
1988	0	0	790	60	1325	10043	30	135	18068	30451
1989	0	0	615	0	150	7982	0	25	9408	18180
1990	0	0	1735	1760	595	8383	120	105	4995	17693
1991	0	0	1664	496	70	11661	140	260	9574	23865
1992	0	0	2895	1585	637	11537	0	145	8735	25534
1993	0	0	1795	540	1966	17023	0	247	10120	31691
1994	0	0	2180	770	551	27374	0	267	11999	43141
1995	0	0	7107	1615	835	16432	30	147	6710	32876
1996	0	0	8602	4607	1435	16841	30	217	7234	38966
1997	0	35	11275	4450	1349	11611	0	231	8233	37184
1998	0	99	6695	2955	1020	13981	0	91	5116	29957
1999	0	10	8020	6330	1956	14051	0	36	5771	36174
2000	0	0	20305	5015	3163	19462	91	362	6813	55211
2001	0	40	10155	5710	1556	17978	172	1259	5865	42735
2002	10	55	13138	5682	1628	36460	276	1825	12095	71168
2003	10	43	8517	7398	1721	32702	674	2150	26312	79526

(Table 10.2 Continued)

(a) Sawshark (Continued)

Year	Sub-region									Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	NSW	
Great Australian Bight Trawl Fishery										
1988	0	120	0	0	0	0	0	0	0	120
1989	700	79	0	0	0	0	0	0	0	779
1990	8346	0	0	0	0	0	0	0	0	8346
1991	7217	0	0	0	0	0	0	0	0	7217
1992	8765	0	0	0	0	0	0	0	0	8765
1993	10505	0	0	0	0	0	0	0	0	10505
1994	5322	43	0	0	0	0	0	0	0	5365
1995	9366	50	0	0	0	0	0	0	0	9416
1996	9803	92	0	0	0	0	0	0	0	9895
1997	13695	221	0	0	0	0	0	0	0	13916
1998	11821	156	0	0	0	0	0	0	0	11977
1999	9639	292	0	0	0	0	0	0	0	9931
2000	9520	89	0	0	0	0	0	0	0	9609
2001	14221	169	0	0	0	0	0	0	0	14390
2002	11170	50	0	0	0	0	0	0	0	11220
2003	25395	154	0	0	0	0	0	0	0	25548

(Table 10.2 Continued)

(b) Elephant fish

Year	Sub-region									Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	NSW	
South East Trawl Fishery										
1985	0	0	0	0	124	244	0	330	210	908
1986	0	0	100	0	3549	851	40	455	154	5149
1987	0	0	0	0	200	449	30	55	1056	1790
1988	0	0	90	0	190	2016	140	170	492	3098
1989	0	0	0	0	1110	1398	260	45	94	2907
1990	0	0	0	0	305	895	270	0	373	1843
1991	0	0	0	0	1140	4016	437	255	462	6310
1992	0	0	32	32	2813	2481	555	100	377	6390
1993	0	0	0	0	605	1432	0	467	273	2777
1994	0	0	0	0	1350	2360	62	110	105	3987
1995	0	0	0	0	1140	1325	210	109	75	2859
1996	0	0	15	0	2590	2181	275	177	172	5410
1997	0	0	30	0	2622	2664	170	67	75	5628
1998	0	0	0	0	4747	3755	0	168	15	8685
1999	0	0	60	0	3815	3290	75	175	35	7450
2000	0	0	80	0	3824	4961	20	18	0	8903
2001	0	0	70	30	3314	4751	49	167	93	8474
2002	0	0	1035	119	4384	7040	1238	797	252	14865
2003	0	154	763	291	6135	9245	1538	1388	1134	20648

(Table 10.2 Continued)

(b) Elephant fish (Continued)

Year	Sub-region									Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	NSW	
Great Australian Bight Trawl Fishery										
1988	0	100	0	0	0	0	0	0	0	100
1989	125	14	0	0	0	0	0	0	0	139
1990	45	0	0	0	0	0	0	0	0	45
1991	32	0	0	0	0	0	0	0	0	32
1992	30	0	0	0	0	0	0	0	0	30
1993	0	0	0	0	0	0	0	0	0	0
1994	705	0	0	0	0	0	0	0	0	705
1995	0	0	0	0	0	0	0	0	0	0
1996	220	0	0	0	0	0	0	0	0	220
1997	0	0	0	0	0	0	0	0	0	0
1998	30	0	0	0	0	0	0	0	0	30
1999	965	0	0	0	0	0	0	0	0	965
2000	0	0	0	0	0	0	0	0	0	0
2001	21	0	0	0	0	0	0	0	0	21
2002	127	0	0	0	0	0	0	0	0	127
2003	1384	30	0	0	0	0	0	0	0	1414

Table 10.3 : Historical (1950–69) catches of sawshark in Bass Strait .

Year	Total	Longline	Danish seine	Trawl
1950	8.14	0.70	7.44	7.44
1951	12.48	0.13	12.34	12.34
1952	12.22	0.14	12.08	12.08
1953	26.81	0.08	26.73	26.73
1954	46.48	0.56	45.91	45.91
1955	40.06	0.04	40.02	40.02
1956	36.06	0.06	36.01	36.01
1957	45.68	3.94	41.75	41.75
1958	57.37	1.52	55.84	55.84
1959	33.50	0.56	32.94	32.94
1960	43.43	0.08	43.34	43.34
1961	85.06	0.17	84.89	84.89
1962	52.05	0.09	51.96	51.96
1963	55.92	0.23	55.69	55.69
1964	75.69	0*		75.69
1965	80.89	0*		72.66
1966	82.23	0*		72.39
1967	84.07	0*		64.74
1968	89.19	0.08	37	61.11
1969	98.88	0.11	42	46.77

* assumed value

Table 10.4 : Estimates of trawl catches (otter trawl and Danish seine) based on the data collected by the SMP and the ISMP.

Year	Sawshark				Elephant fish			
	Haul-based		Hour-based		Haul-based		Hour-based	
	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV
1992					11337	0.877	8130	0.721
1993	16239	0.448	19900	0.610	437	0.526	380	0.430
1994	7835	0.359	11488	0.373	18393	0.449	33111	0.537
1995	53413	0.169	63971	0.162	4092	0.244	5536	0.354
1996	40365	0.21	37193	0.393	766	0.617	686	0.542
1997	80332	0.171	68081	0.154	72	0.705	66	0.634
1998	146180	0.172	208190	0.197	5729	0.454	6779	0.427
1999	184399	0.125	176540	0.103	1762	0.481	1369	0.335
2000	231278	0.138	260989	0.147	5942	0.316	7243	0.320
2001	134469	0.184	170217	0.275	346556	0.425	671445	0.462
2002	145765	0.155	164301	0.145	1778	0.452	1978	0.435
2003	178815	0.114	168558	0.145	11331	0.248	8317	0.277

Table 10.5 : Catch-rate series for sawshark and elephant fish.

Year	Sawshark	Elephant fish
1976	97.17	43.92
1977	74.33	62.32
1978	96.44	58.40
1979	86.40	100.00
1980	77.60	68.38
1981	56.51	64.92
1982	72.10	45.12
1983	59.65	53.57
1984	53.67	41.68
1985	52.81	37.11
1986	57.58	27.09
1987	60.69	23.47
1988	56.18	25.19
1989	46.72	22.51
1990	47.85	21.42
1991	51.27	39.10
1992	57.84	36.46
1993	67.56	18.37
1994	89.69	18.19
1995	100.00	26.62
1996	77.18	34.29
1997	45.66	23.41
1998	54.08	24.67
1999	41.35	24.54
2000	38.27	20.15
2001	35.22	20.48
2002	33.46	19.43
2003	37.41	20.24

Table 10.6 : Length-frequency sample sizes for sawshark and elephant fish. The combinations of year, sex, and mesh-size indicated in bold underline are included in the analyses of this document.

		Year											
Sex	Mesh	1973	1974	1975	1976	1986	1987	1994	1995	1998	1999	2000	2001
Elephant fish													
F	6	16	12	23	3	4	0	0	0	**380**	62	**217**	3
F	6.5	0	0	0	0	0	0	0	0	0	1	0	8
F	7	17	5	21	0	9	0	0	0	0	0	0	0
F	8	0	0	2	0	5	0	0	0	0	0	0	0
M	6	8	12	9	5	45	0	0	0	4	40	**83**	0
M	6.5	0	0	0	0	0	0	0	0	1	9	0	2
M	7	5	11	3	2	27	0	0	0	0	0	0	0
M	8	0	1	0	0	17	0	0	0	0	0	0	0
Common sawshark													
F	6	13	6	0	2	39	37	0	0	**142**	23	**672**	96
F	6.5	0	0	0	0	0	0	0	0	2	21	0	0
F	7	9	31	2	1	29	27	16	10	0	0	0	0
F	8	0	1	0	0	20	18	0	0	0	0	0	0
M	6	29	18	3	6	50	26	0	0	94	24	**300**	33
M	6.5	0	0	0	0	0	0	0	0	1	8	0	0
M	7	11	12	1	1	12	12	2	3	0	0	0	0
M	8	1	1	0	0	10	10	0	0	0	0	0	0
Southern sawshark													
F	6	0	0	1	6	13	7	0	0	39	36	**162**	52
F	6.5	0	0	0	0	0	0	0	0	11	3	0	0
F	7	0	0	0	2	8	6	0	0	0	0	0	0
F	8	0	0	0	0	8	3	0	0	0	0	0	0
M	6	0	1	4	3	18	5	0	0	17	15	**139**	48
M	6.5	0	0	0	0	0	0	0	0	2	2	0	0
M	7	0	0	0	1	11	5	0	0	0	0	0	0
M	8	0	0	1	0	6	2	0	0	0	0	0	0

Table 10.7 : Values for the biological parameters (source: PIRVic, unpublished data).

Quantity	Common sawshark		Southern sawshark		Elephant fish	
	Female	**Male**	**Female**	**Male**	**Female**	**Male**
L_∞ (mm)	1502	1165	1047	971	1049	770
κ (yr^{-1})	0.149	0.309	0.488	0.575	0.238	0.400
t_0 (yr)	-1.76	-1.00	-0.49	-1.00	-0.05	-0.04
a (x10^{-9})^A	0.990	1.520	0.060	0.078	0.591	0.063
b	3.292	3.015	3.498	3.450	3.337	3.688
a' (yr)	-14.52		-8.36		-2.37	
b' (yr^{-1})	0.0205		0.0184		0.0279	
$P''_{\max}$	0.5^B		0.5^B		1.0^C	
ℓ''_{50} (mm)	1109		841		602	
ℓ''_{95} (mm)	1199		893		746	
θ_1	237.91		237.91		154.23	
θ_2	185075		185075		185097	

A – Non-pregnant
B – Maternity
C – Maturity

Table 10.8 : The specifications for the base-case analyses and the sensitivity tests.

(a) Sawshark

Abbreviation	**Biological parameters**	M_{2+}	**Recruitment residuals**	**Density-dependence**	**CPUE** σ	**Trawl Catches**	**Length data effective sample size**	**Gear Competition**
Base-A	Common	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	10	No
Base-B	Southern	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	10	No
Sen-1A	Common	0.15yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	10	No
Sen-1B	Southern	0.15yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	10	No
Sen-2A	Common	0.25yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	10	No
Sen-2B	Southern	0.25yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	10	No
Sen-3A	Common	0.2yr^{-1}	None	*M*; ages 0-30	0.3	Base	10	No
Sen-3B	Southern	0.2yr^{-1}	None	*M*; ages 0-30	0.3	Base	10	No
Sen-4A	Common	0.2yr^{-1}	1951–2002	*M*; ages 0-5	0.3	Base	10	No
Sen-4B	Southern	0.2yr^{-1}	1951–2002	*M*; ages 0-5	0.3	Base	10	No
Sen-5A	Common	0.2yr^{-1}	1951–2002	Pup survival	0.3	Base	10	No
Sen-5B	Southern	0.2yr^{-1}	1951–2002	Pup survival	0.3	Base	10	No
Sen-6A	Common	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.15	Base	10	No
Sen-6B	Southern	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.15	Base	10	No
Sen-7A	Common	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	x 2.5	10	No
Sen-7B	Southern	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	x 2.5	10	No
Sen-8A	Common	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	0	No
Sen-8B	Southern	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	0	No
Sen-9A	Common	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	20	No
Sen-9B	Southern	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	20	No
Sen-10A	Common	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	10	Yes
Sen-10B	Southern	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	Base	10	Yes

(Table 10.8 Continued)

(b) Elephant fish

Abbreviation	M_{2+}	**Recruitment residuals**	**Density-dependence**	**CPUE** σ	**Length data effective sample size**	**Gear Competition**
Base	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	10	No
Sen-1	0.15yr^{-1}	1951–2002	*M*; ages 0-30	0.3	10	No
Sen-2	0.25yr^{-1}	1951–2002	*M*; ages 0-30	0.3	10	No
Sen-3*	0.2yr^{-1}	None	*M*; ages 0-30	0.3	10	No
Sen-4	0.2yr^{-1}	1951–2002	*M*; ages 0-5	0.3	10	No
Sen-5	0.2yr^{-1}	1951–2002	Pup survival	0.3	10	No
Sen-6	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.15	10	No
Sen-8	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	0	No
Sen-9	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	20	No
Sen-10	0.2yr^{-1}	1951–2002	*M*; ages 0-30	0.3	10	Yes

* Did not converge

Table 10.9 : Estimates of the output quantities (estimates with asymptotic standard deviations in parenthesis).

(a) Sawshark

Scenario	Common sawshark parameters					Southern sawshark parameters				
	MSYR	$V\,/\,Q_0$	P_{2004}/P_{1950} **(%)**	P_{1973}/P_{1950} **(%)**	$-\ell\mathrm{n}L$	***MSYR***	$V\,/\,Q_0$	P_{2004}/P_{1950} **(%)**	P_{1973}/P_{1950} **(%)**	$-\ell\mathrm{n}L$
Base-case	0.08 (0.08)	0.479 (0.456)	88 (7)	32 (11)	18.01	0.17 (0.07)	0.758 (0.279)	86 (7)	26 (10)	15.32
Sen-1	0.12 (0.08)	0.679 (0.342)	87 (5)	28 (10)	17.47	0.18 (0.07)	0.825 (0.236)	85 (6)	25 (9)	15.06
Sen-2	0.17 (0.11)	0.312 (0.647)	90 (9)	35 (14)	18.71	0.16 (0.07)	0.692 (0.321)	86 (7)	26 (10)	15.57
Sen-3	0.15 (0.07)	0.277 (0.461)	91 (4)	39 (11)	19.17	0.12 (0.08)	0.535 (0.325)	88 (3)	37 (9)	17.77
Sen-4	0.17 (0.01)	0.447 (0.486)	89 (9)	33 (12)	18.09	0.16 (0.07)	0.750 (0.273)	85 (8)	25 (10)	15.22
Sen-5	0.03 (0.06)	1.712 (1.785)	91 (11)	35 (13)	18.37	0.11 (0.05)	3.901 (2.123)	88 (8)	27 (10)	15.97
Sen-6	0.18 (0.00)	1.000 (0.001)	84 (4)	17 (4)	33.32	0.23 (0.00)	1.000 (0.001)	83 (6)	20 (6)	23.11
Sen-7	0.09 (0.08)	0.490 (0.452)	84 (7)	29 (11)	17.94	0.16 (0.07)	0.709 (0.286)	82 (7)	25 (9)	15.45
Sen-8	0.18 (0.00)	1.000 (0.002)	84 (4)	23 (9)	7.27	0.23 (0.00)	1.000 (0.001)	84 (6)	21 (9)	5.06
Sen-9	0.08 (0.06)	0.463 (0.360)	88 (6)	32 (10)	27.66	0.16 (0.06)	0.695 (0.248)	86 (7)	26 (9)	24.70
Sen-10	0.08 (0.09)	0.448 (0.509)	89 (7)	39 (13)	16.92	0.16 (0.08)	0.723 (0.306)	86 (7)	31 (11)	14.92

(b) Elephant fish

Scenario	***MSYR***	$V\,/\,Q_0$	P_{2004}/P_{1950} **(%)**	P_{1973}/P_{1950} **(%)**	$-\ell\mathrm{n}L$
Base-case	0.05 (0.03)	0.195 (0.112)	94 (10)	20 (6)	27.27
Sen-1	0.07 (0.02)	0.269 (0.097)	93 (8)	19 (6)	26.36
Sen-2	0.14 (0.01)	0.127 (0.121)	96 (13)	21 (7)	28.35
Sen-4	0.13 (0.00)	0.197 (0.105)	95 (11)	21 (6)	27.13
Sen-5	0.03 (0.02)	1.540 (0.572)	97 (13)	22 (7)	28.10
Sen-6	0.09 (0.03)	0.340 (0.103)	89 (8)	19 (4)	47.65
Sen-7	0.05 (0.03)	0.195 (0.112)	94 (10)	20 (6)	27.27
Sen-8	0.14 (0.10)	0.510 (0.350)	89 (8)	14 (9)	7.44
Sen-9	0.12 (0.01)	0.160 (0.098)	95 (11)	20 (6)	44.25
Sen-10	0.05 (0.03)	0.185 (0.113)	94 (10)	22 (7)	27.11

11. Stock Assessment for Tiger Flathead (*Neoplatycephalus richardsoni*) based on data up to 2003

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11.1 Background

The fishery for tiger flathead has been one of the main stays of the South East Trawl fishery for almost a century. While catches have fluctuated widely over that period, Commonwealth catches over the past 15 years have averaged 2,640 t, and the actual TAC in 2002 exceeded 4,000 t. Market demand for flathead has been high in recent years, and prices have been strong. This has led to increased targeting of flathead compared with other species (Klaer, 2004a).

Concerns have been expressed in some quarters about whether current catch levels are sustainable. Reasons for this include the important role of flathead in the SETF, and the recent high catch levels, which have exceeded some previous estimates of long term sustainable yield (Allen, 1989). In 2000, SEFAG recommended that a high priority be given to an updated assessment for tiger flathead. Since then, two flathead workshops have been held in Eden, in 2001 and 2002, and two subsequent meetings held in Eden in 2003 and 2004 under the auspices of the SESSF Shelf Assessment Group. During this period, two preliminary assessments were conducted. The assessment in this report is the third quantitative stock assessment for this species over this recent period, with data up to the end of 2003 included in this 2004 assessment. Preliminary results of this assessment were reviewed by the SESSF Shelf Assessment Group in August 2004.

11.1.1 The fishery

11.1.1.1 History

Tiger flathead are endemic to Australia and are caught mainly on trawlable grounds in continental shelf and upper slope waters from northern NSW to Tasmania and through Bass Strait. Historical catch records (Allen, 1989; Klaer, 2004b) show that this stock has been exploited off NSW and in eastern Bass Strait for a long time. The tiger flathead fishery can be traced back to 1915 when tiger flathead formed the primary target species of the Red Funnel Steam Trawlers that operated off NSW (Fairbridge, 1952; Montgomery, 1985; Allen, 1989; Klaer, 2004b). This trawl fleet operated until the early 1960s. The Danish seine fishery started in the 1930s (Allen, 1989) and was the main method of catching tiger flathead during the 1950s and 1960s. The era of modern trawling commenced in the 1960s.

One of the most noteworthy features in the catch history for flathead is that landings in excess of about 3,000 t have rarely been sustained for long periods, with several episodes of catches in excess of this level being followed by subsequent declines in catch rates and catches. This provides some direct empirical evidence that the long term sustainable yield for this stock is not likely to exceed 3,000 t.

11.1.1.2 Current situation

Since 1985, catches of tiger flathead have been taken mainly by Commonwealth-endorsed otter trawl and Danish seine boats, primarily at depths down to 200 m. The trawl catch of flathead is associated with catches of other shelf species including redfish (*Centroberyx affinis*) and jackass morwong (*Nemadactylus macropterus*), while Danish seine catches of tiger flathead show an inverse relationship with catches of school whiting (*Sillago flindersi*).

The total landings of flathead based on SEF2 returns have exceeded 3,000 t in three of the last four years. While the agreed TAC has been steady at 3,500 t over this period, the actual TACs have been closer to 4,000 t, with this figure exceeded in 2002. The flathead TAC includes tiger flathead and several other flathead species, including sand flathead (*Platycephalus bassensis*) and, from 1996 onwards, southern or 'yank' flathead (*Platycephalus speculator*), bluespot flathead (*Platycephalus caeruleopunctatus*) and gold-spot/toothy flathead (*Neoplatycephalus aurimaculatus*). Tiger flathead comprises the bulk of the catch and is the only species being considered in the stock assessment.

The contributions of the Danish seine sector since 1985 to the total SEF flathead landings has averaged 44%, although the annual ratios of Danish seine to otter trawl catches have fluctuated quite widely. The majority of the catch by Danish seine vessels of tiger flathead is taken in Bass Strait and off eastern Victoria. Most of the catch by the otter trawl fishery is taken off NSW and eastern Victoria. While there has been some expansion of the otter trawl flathead fishery into eastern Tasmania in recent years, the current assessment focuses on the main historical part of the fishery (NSW, eastern Victoria and Bass Strait).

Catches of tiger flathead have been cyclical over the past twenty years. Recent catches have been at the upper part of the cycle, with the total catches in 1999 and 2003 reaching levels not recorded since the early 1960s.

11.1.2 Previous assessments

Prior to 2001, the most recent quantitative assessment of tiger flathead was from the late 1980s (Allen, 1989). In that report, the assessment for tiger flathead was conducted based on catch and effort data using a surplus production model. The estimate of MSY for NSW and eastern Bass Strait was about 2,500 t.

Between 1989 and 2001, assessments of tiger flathead involved examination of trends in catches, catch rates, and age and length data, but no quantitative assessments were undertaken during this period. Assessments from 1993 to 2001 can be found in the annual reports of SEFAG (the South East Fishery Assessment Group). For example, the 1993 assessment noted that tiger flathead catches from south-east Tasmanian waters contained higher proportions of larger, older fish than that those from eastern Bass Strait. This suggested that tiger flathead resources off Tasmania were either more lightly fished than those in the main fishing areas, or that there was a separate stock with different population characteristics off Tasmania.

11.1.2.1 2001 Assessment

The 2001 assessment was designed mainly to collate existing data, check the adequacy of the assessment model, and identify priorities for further work. The results were presented and discussed at a special flathead workshop held in Eden in June 2001. This workshop was attended by members of the trawl and Danish seine sectors, scientists, and an AFMA manager. The 2001 workshop identified substantial problems with the logbook data from 1992. It also suggested examining correlations between catch rates and catches and environmental data, and trying to obtain a complete time-series of catches so that virgin biomass could be estimated.

11.1.2.2 2002 Assessment

The 2002 update provided a preliminary report on the status of the stock. Data used for the 2002 assessment included the historical records since 1915, where missing years of catch data were filled in by using a linear interpolation between existing data. No age or length data were found for the years prior to 1985, and catch rate information was available for limited periods in the time series, but with different units for different periods, making comparisons difficult. Therefore, different catchability coefficients were estimated for different record periods.

The catch rate data for the recent period (1985 to 2002) were not fully standardized. The workshop discussed factors to be considered in future standardization of catch rates, including vessel, area, season, depth, minimum shot size, catch of other species, and environmental variables.

Although the preliminary results showed some interesting features, such as cycles in catches and catch rates, industry members at the 2002 workshop questioned the high catches during the 1920s and the suggestion that the stock had been substantially depleted by the early 1930s. However they agreed with the cyclic patterns in the fishery (which seemed to be on about a 10-year period) and suggested how these might be driven by environmental factors. The concerns about the veracity of the early catch history led to a suggestion that the assessment should only consider data for the modern period (since 1985), and that a depletion level in 1985 should be either estimated or assumed.

11.1.2.3 2003 assessment

The 2003 stock assessment (Cui *et al*., 2003) for tiger flathead was improved substantially based on suggestions from the two previous workshops. The improvements to the 2002 assessment included the following changes to the data analysis:

- Records showing depths greater than 400 m and Tasmanian data were excluded from the CPUE standardization.
- An SOI environmental time series was included in the CPUE standardization, which included SEF statistical zone as a factor.

- Only analyses involving 'complete' data (records on both trawl and Danish seine) from 1985–2003 were used for future projections to reduce the data uncertainty among sectors.

Virgin biomass was estimated based on the historical catch records from 1915. The estimated biomass depletion level at the start of 1986 from the historical data series was then used as the "true" relative biomass level at this time in the actual assessment, which was based on the 'complete' set of data from 1986–2003. This assessment was presented at an assessment group meeting for shelf species in 2003, but was not fully accepted.

11.2 Data

As noted in section 1, the main area of the fishery from its inception has included the SETF zones off NSW and eastern Victoria (zones 10 and 20). More recently, substantial catches of tiger flathead have also been taken by the Danish seine fleet in Bass Strait (zone 60). Although catches of tiger flathead have been increasing off eastern Tasmania (zone 30) in recent years, the size distribution of these fish is quite different (larger). This assessment therefore only uses data from zones 10, 20 and 60 of the fishery. Over the past 20 years, these zones account for over 94% of total landings.

11.2.1 Catches

Catches by fleet (otter trawl and Danish seine) of flathead from 1915 to 1984 are listed in Table 11.1, and derive from data compiled by Klaer (2004b). These data include an assumption of 20% discarding for the years prior to 1960 for both fleets. The vast majority of these catches would have come from SETF zones 10, 20 and 60.

Catch data for the period 1985 to 2003 are given in Table 11.2. Deriving agreed catch data for this period proved to be quite difficult. The catch data in Table 11.2 were derived as follows:

- Data were derived initially from SEF1 logbook data. Shots where the vessel name corresponded to a Danish seine vessel were attributed to that fleet. All other shots were attributed to otter trawl.
- Only five months SEF1 logbook data were available for 1985. These were weighted up to a full year based on catch proportions for the corresponding months for the period 1986 to 2003.
- SEF2 data were available from 1992 to 2003. The annual SEF2 to SEF1 ratio for all areas and both fleets was used to weight the annual SEF1 data by fleet for these years. For the period 1985 to 1992, the SEF2 to SEF1 ratio over the entire period 1992 to 2003 was used to weight the SEF1 data.

The SEF2 to SEF1 weighting was necessary because SEF2 data are not available by zone. The total catch history for the fishery is shown in Figure 11.1.

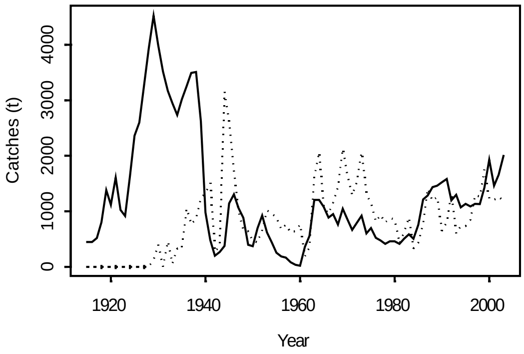

Figure 11.1. Catch time-series (otter trawl – solid line; Danish seine – dotted line) used in the analyses of this chapter.

11.2.2 Catch rates

Catch rates for the historical period (1915 to 1984) derive from Klaer (2004b) and are shown in Table 11.1. These represent standardized catch rates for the trawl fleet (the Red Funnel steam trawlers), but the catch rates are unstandardized for the Danish seine fleet. The standardized catch rates for the trawl fleet are only available for the periods 1919–23, 1937–42 and 1952–57, but are comparable across these periods. The Danish seine catch rates are available for the periods 1950–60 and 1965–78, and derive from Allen (1989).

Standardized catch rates were derived for the trawl and Danish seine fleets for the period 1986 to 2003 from SEF1 logbook data. The data included in the analyses used to standardize the catch and effort information were restricted to records taken by vessels that reported catches of flathead for at least 10 years and had a median annual catch of flathead of 10 t over the years that they were in the fishery. The data were further restricted by excluding all records: a) not taken in SEF zones 10, 20 and 60, and b) in waters deeper than 400 m.

The factors used in the standardization included year, month, week, depth, vessel, zone and catch of jackass morwong. All of these factors (except month which is confounded with week) were found to be statistically significant at the 5% level for both fleets (Table 11.3). The final model (bolded in Table 11.3) was selected using Akaike's Information Criterion (AIC) (Burnham and Anderson, 2002). The final standardized catch-rate indices are listed in Table 11.2. Unlike the 2003 assessment, it did not prove possible to include SOI as a factor in the analysis because these data were not available on a shot by shot basis. Future catch rate standardizations should examine ways to include these data.

11.2.3 Discard rates

Information on the fraction of the catch (in mass) which is discarded annually is available from onboard observers. Two observer programmes, the SMP (Liggins *et al.*, 1997) and the ISMP (Knuckey *et al.*, 1999) have collected onboard data which can be used to estimate discard rates. The data collected by observers are estimates by shot of the mass retained and the mass discarded. The discard rate used here is simply the ratio of the mass discarded (summed over all shots by a given fleet in a given year) to the total mass (retained and discarded combined). The data were validated by excluding any records for which the gear code was not bottom trawl or Danish seine and in which the catch did not occur in one of SEF zones 10, 20, or 60. The resultant discard rates are listed (by year and fleet) in Table 11.2.

11.2.4 Age- and length-frequency data

Length frequency data are available from port measurers and from onboard sampling. The former generally involve much larger sample sizes than the latter (Table 11.4). In contrast, the onboard sampling programmes provide information on the length-frequencies of the discarded as well as the landed catch.

11.2.4.1 Port length-frequencies

The port length-frequencies for a given fleet are constructed from the raw data collected by the measurers using the equation:

$$N^{f}_{y,L} = \sum_{v} \tilde{N}^{f,v}_{y,L} / R^{f,v}_{y} \qquad (11.1)$$

where $N^{f}_{y,L}$ is the number of animals in the component of the landed catch by fleet f during year y that was measured that are in length-class L,

$\tilde{N}^{f,v}_{y,L}$ is the number of animals in the v^{th} sample collected from the landed catch by fleet f during year y that are in length-class L, and

$R^{f,v}_{y}$ is the fraction of the catch of the v^{th} sample collected from the landed catch by fleet f during year y that was measured.

This approach to constructing catch length-frequencies is based on the assumption that the samples for a given fleet are a simple random sample of the catch of that fleet. In principle, this approach to constructing length-frequencies could be generalized so that, for example, port-specific length-frequencies are constructed and these then weighted by the port-specific contribution to the overall catch.

Figures 11.2 and 11.3 plot the port-based length-frequencies from the ISMP database for 1991–2003. Results are shown in Figures 11.2 and 11.3 for three key ports (Eden, Lakes Entrance, and Ulladulla) and for three SEF zones (East A, East B, and Eastern Tasmania). Eden, Lakes Entrance and Ulladulla constitute the bulk of the length-frequency records for the otter trawl and Danish seine fleets. The other ports for which data are available are Hobart, Sydney, Greenwell Point, Triabunna, Wollongong, and Bermagui. The port-based length-frequencies on which the analyses of this chapter are based were constructed by pooling all data for SEF zones 10, 20 and 60 (i.e. the data were not restricted to those landed in specific ports, unlike the situation for blue warehou (see Chapter 6)). The length-frequency data for 1993 and 1994 (otter trawl) and 1994 (Danish seine) were ignored when fitting the model owing to very low sample sizes (see Figures 11.2 and 11.3 and Table 11.4).

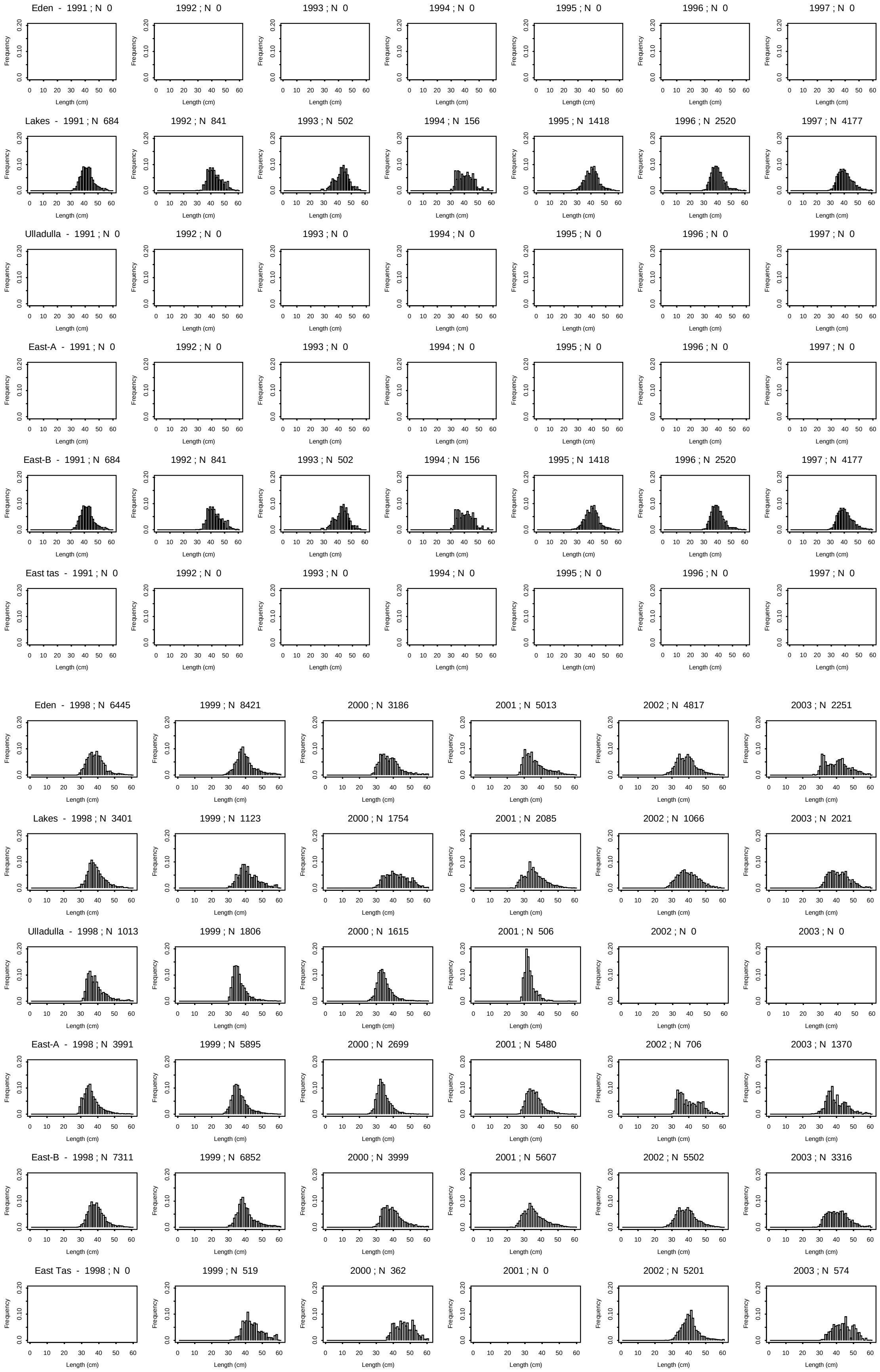

Figure 11.2. Port-based length-frequency data from the SMP and ISMP for flathead caught by otter trawlers. Results are shown by port of landing (Eden, Lake Entrance, Ulladulla) and by SEF zone (East A, East B, and east Tasmania).

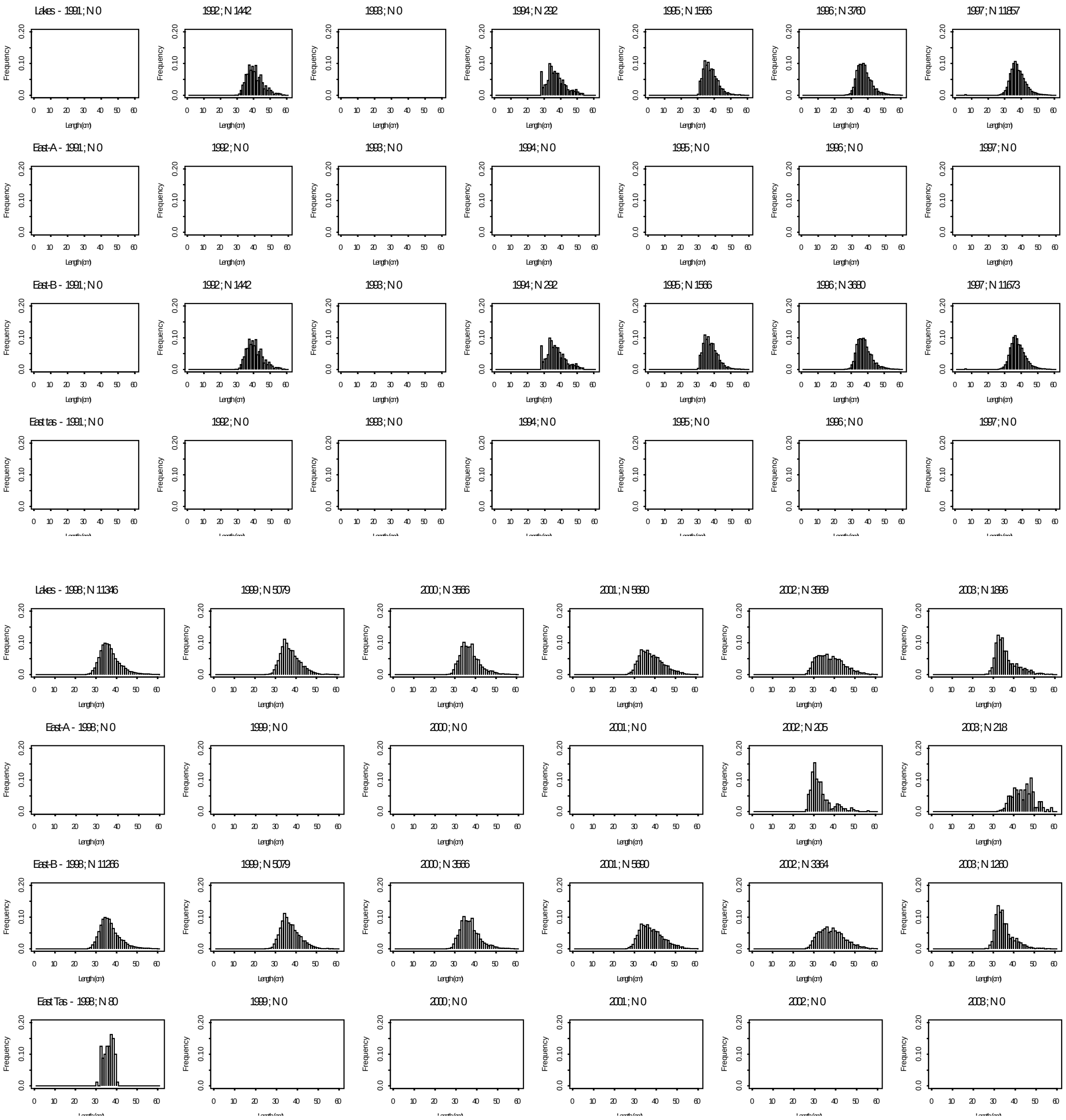

Figure 11.3. Port-based length-frequency data from the SMP and ISMP for flathead caught by Danish seine. Results are shown for Lakes Entrance and by SEF zone (East A, East B, and east Tasmania).

11.2.4.2 Discard length-frequencies

The proportion of the trawl catch which is discarded by length-class can be determined from the onboard length-frequency data using Equation 11.1. Figure 11.4 shows the relationships by fleet between the proportion of the catch which is discarded and length. The solid lines in Figure 11.4 are logistic curves estimated by minimizing the sum of squared residuals.

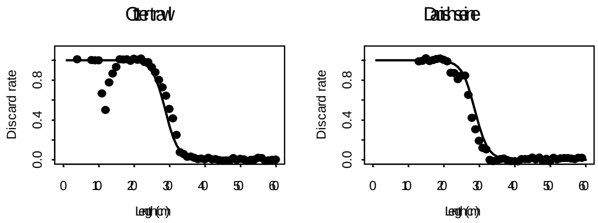

Figure 11.4: Proportion discarded as a function of length for otter trawl and Danish seine.

11.2.4.3 Age-composition data

Flathead have been aged using both surface and break-and-burn techniques. Comparison of age estimates between these two techniques reveals that surface ageing underestimates age compared to the break-and-burn technique. Surface ages are available for 1991–97 while break-and-burn ages are available for 1998–2003. The analyses of this document are based on the break-and-burn data only. Table 11.4 lists the sample sizes for each year.

Age-composition data (port / on board - by fleet and year) have been constructed by multiplying the length-frequencies by the stock- and year-specific age-length keys (length-at-age is assumed to be independent of fleet).

There are cases in which length-frequency data exist for some (2 cm) length-classes for which age data are not available. When this happened, the length-classes adjacent to that for which age data were required were investigated and the age data for these length-classes averaged to obtain age data for the length-class for which this was needed. This process of searching adjacent length-classes was repeated if the length-classes adjacent to that for which age data were needed also had no age data and this process of an expanding search repeated until ageing data were obtained. Ages greater than 15 were pooled into a plus-group at age 15.

11.2.4.4 Growth

Von Bertalanffy growth curves were fitted to age and length data by sex, with the results shown in Figure 11.5. Data were derived from zones 10 and 20 only. Sample sizes were 1,228 males and 1,379 females. The growth curves for males and females are different (females grow larger). Parameter values are given in Table 11.5.

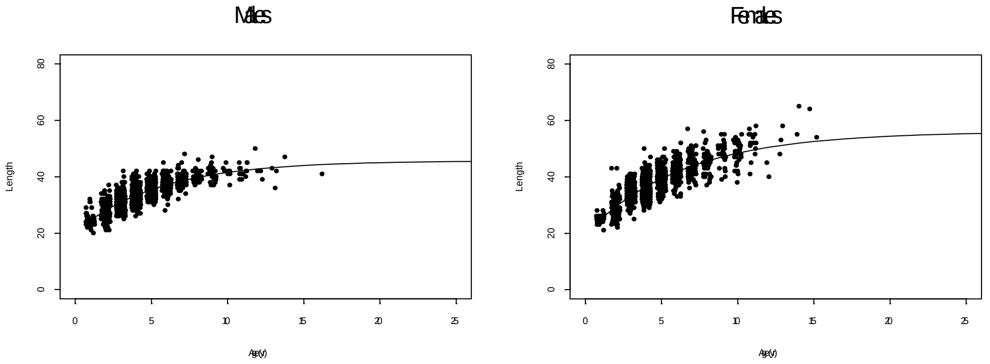

Figure 11.5: Growth curves by sex for tiger flathead.

11.3 Analytical approach

The assessment is based on fitting an age- and sex-structured population dynamics model to a variety of data sources. The model (see Section 11.3.1) includes two “fleets” and accounts for discarding of small fish. The objective function, which is minimized to estimate the values for the parameters of the model that are not fixed based on auxiliary information, includes contributions from the data available for assessment purposes (discard rates, fishery landed age-composition data, fishery landed size-composition data, and catch-rates) and a penalty on the recruitment residuals.

11.3.1 The population dynamics model

11.3.1.1 Basic dynamics

The dynamics of the population assume that the fisheries occur instantaneously in the middle of the year while natural mortality occurs continuously throughout the year, i.e.:

$$N^g_{y+1,a} = \begin{cases} 0.5\,R_y & \text{if } a=0 \\ (N^g_{y,a-1}e^{-M/2} - \sum_{f=1}^{n_f} C^{g,f}_{y,a-1})e^{-M/2} & \text{if } 1 \le a < x \\ ((N^g_{y,x-1} + N^g_{y,x})e^{-M/2} - \sum_{f=1}^{n_f}\{C^{g,f}_{y,x-1} + C^{g,f}_{y,x}\})e^{-M/2} & \text{if } a = x \end{cases} \qquad (11.2)$$

where $N^g_{y,a}$ is the number of animals of sex g and age a at the start of year y,

M is the instantaneous rate of natural mortality (assumed to be independent of age and time and equal to 0.2 yr^{-1}),

$C^{g,f}_{y,a}$ is the catch (in numbers) of fish of sex g and age a by fleet f (f=1 - otter trawlers; f=2 - Danish seine) during year y,

R_y is the recruitment (the abundance of animals aged 0 years) during year y,

n_f is the number of fleets (2), and

x is the maximum age-class (treated as a plus-group and assumed to be 20yr).

11.3.1.2 Stock and recruitment

The number of zero-year-olds added to the population each year is assumed to be governed by a stochastic version of the Beverton-Holt stock-recruitment relationship:

$$R_y = \frac{4h\,R_0\,SB_y}{(1-h)SB_0 + (5h-1)SB_y} e^{\varepsilon_y} \tag{11.3}$$

where R_0 is the expected number of zero-year-olds (of both sexes) in the absence of exploitation,

SB_y is the spawning biomass at the start of year *y*:

$$SB_y = \sum_{a=a_m}^{x} w_a^{\mathrm{f}}\, N_{y,a}^{\mathrm{f}} \tag{11.4}$$

a_m is the age-at-maturity (assumed to be age 3 based on a length-at-50%-maturity of 30cm),

w_a^g is the weight of a fish of sex *g* and age *a* at the start of the year,

h is the steepness of the stock-recruitment relationship (the fraction of R_0 to be expected when the spawning biomass is reduced to 20% of the virgin spawning biomass - $0.2\,SB_0$; set equal to 0.9 for the analyses of this chapter), and

ε_y is the deviation during year *y* about the stock-recruitment relationship (the "recruitment residual" for year *y*).

11.3.1.3 Catches

The total catch (in numbers) by fleet, year, sex and age-class is given by:

$$C_{y,a}^{g,f} = F_y^f\, S_a^{g,f}\,(N_{y,a}^g\, e^{-M/2} - \sum_{f'<f} C_{y,a}^{g,f'}) \tag{11.5}$$

where $S_a^{g,f}$ is the selectivity of fleet *f* on animals of sex *g* and age *a* (assumed to be time-invariant),

F_y^f is the exploitation rate on fully selected (i.e. $S_a^{g,f} \to 1$) animals by fleet *f* during year *y*, i.e.:

$$F_y^f = \tilde{C}_y^f \,/\, B_y^{e,f} \tag{11.6}$$

$B_y^{e,f}$ is the exploitable biomass during year *y* prior to removal of the catch by fleet *f*:

$$B_y^{e,f} = \sum_g \sum_{a=0}^{x} w_{a+1/2}^g\,(1-\phi_{y,a}^{g,f})\,S_a^{g,f}\,(N_{y,a}^g\, e^{-M/2} - \sum_{f'<f} C_{y,a}^{g,f'}) \tag{11.7}$$

$\tilde{C}_y^f$ is total catch (in weight) by fleet and year (see Tables 11.1 and 11.2), and

$\phi_{y,a}^{g,f}$ is the fraction of the catch by fleet *f* of animals of sex *g* and age *a* that is discarded during year *y*.

The model (Equations 11.2 and 11.7) assumes that the catch is taken in a pulse in the middle of the year and that the catches by each fleet are taken sequentially (i.e. gauntlet fisheries). These assumptions are made to avoid having to treat the fully-selected exploitation rate for each year and fleet as estimable parameters.

The landed and discarded total catches (in numbers and weight respectively) are:

$$C_{y,a}^{\mathrm{L},g,f} = (1-\phi_{y,a}^{g,f})C_{y,a}^{g,f}\ ; \qquad C_{y,a}^{D,g,f} = \phi_{y,a}^{g,f}\, C_{y,a}^{g,f} \qquad (11.8a)$$

$$\tilde{C}_{y}^{\mathrm{L},f} = \sum_{g}\sum_{a=1}^{x} w_{a+1/2}^{g}\, C_{y,a}^{\mathrm{L},g,f}\ ; \qquad \tilde{C}_{y}^{\mathrm{D},f} = \sum_{g}\sum_{a=1}^{x} w_{a+1/2}^{g}\, C_{y,a}^{\mathrm{D},g,f} \qquad (11.8b)$$

where $C_{y,a}^{\mathrm{L},g,f}$ is the model estimate of the number of animals of sex *g* and age *a* landed by fleet *f* during year *y*,

$C_{y,a}^{\mathrm{D},g,f}$ is the model estimate of the number of animals of sex *g* and age *a* discarded by fleet *f* during year *y*,

$\tilde{C}_{y}^{\mathrm{L},f}$ is the model estimate of the mass of fish landed by fleet *f* during year *y* ($\tilde{C}_{y}^{\mathrm{L},f} = \tilde{C}_{y}^{f}$ unless $F_y^f > 0.95$ in which case $\tilde{C}_{y}^{\mathrm{L},f} = 0.95\, B_y^{e,f}$), and

$\tilde{C}_{y}^{\mathrm{D},f}$ is the model estimate of the mass of fish discarded by fleet *f* during year *y*.

11.3.1.4 Selectivity and discarding

Selectivity as a function of length is governed by the equation:

$$S_a^{g,f} = \begin{cases} \exp[-(L_{a+1/2}^{f} - \overline{L}^{f})^2 / \Omega_L^f] & \text{if } L_{a+1/2}^{f} \le \overline{L}^{f} \\ \exp[-(L_{a+1/2}^{f} - \overline{L}^{f})^2 / 100] & \text{otherwise} \end{cases} \qquad (11.9)$$

where $\overline{L}^f$ is the length corresponding to maximum selectivity for fleet *f*,

L_a^g is the expected length of a fish of sex *g* and age *a* (given by a von Bertalanffy growth equation), and

Ω_L^f is the parameter that determines how rapidly selectivity for fleet *f* increases with length.

This formulation for selectivity assumes that the probability of capture is a function primarily of the length (rather than the age) of an animal. It also assumes that selectivity is only sex-specific to the extent that growth is sex-specific. The parameter that determines how rapidly selectivity for fleet *f* drops off with length is set to 100 as this parameter is inestimable given that data available for tiger flathead.

The probability of fleet *f* discarding an animal of sex *g* and age *a* during year *y* is assumed to be a function of length, i.e.:

$$\phi_{y,a}^{g,f} = \begin{cases} 0 & \text{if } y \le 1960 \\ [1 + \exp(-\ell n 19 \frac{L_a^g - \phi_{50}^f}{\phi_{95}^f - \phi_{50}^f})]^{-1} & \text{otherwise} \end{cases} \tag{11.10}$$

where ϕ_{50}^f is the length at which 50% of animals are retained by fleet *f*, and

ϕ_{95}^f is the length at which 95% of animals are retained by fleet *f*.

The analyses of this chapter are based on the assumption that the probability of a fish being discarded as a function of length is independent of fleet. The values for ϕ_{50}^f and ϕ_{95}^f are set to 28.78 cm and 23.37 cm respectively based on preliminary analyses (see Figure 11.4). Discarding is ignored for the years prior to 1960 because the catches in Table 11.1 were increased by 20% to account for discarding.

11.3.1.5 Initial conditions

The initial conditions correspond to a population at its deterministic unfished level with the corresponding age-structure, i.e.:

$$N_{y_1,a}^g = \begin{cases} 0.5\, R_0\, e^{-aM}\, e^{\sigma_R^2/2} & \text{if } 0 \le a < x \\ 0.5\, R_0\, e^{-xM} e^{\sigma_R^2/2} /(1 - e^{-M}) & \text{if } a = x \end{cases} \tag{11.11}$$

where y_1 is the first year for which catches are available (1915 for the calculations of this chapter), and

σ_R is the extent of variability in recruitment about the deterministic stock-recruitment relationship (assumed to be 0.6).

11.3.2 The objective function

The equations listed below assume that data for each data-type are available for every year and for both fleets. This is not the case in reality and the equations are modified appropriately in the absence of data for specific years and fleets.

11.3.2.1 Discard rates

The contribution of the estimates of discard rate (in mass) by fleet and year to the negative of the logarithm of the likelihood function is based on the assumption that the errors in when measuring discard rate are log-normal, i.e.:

$$\ell n L_1 = \sum_f \sum_y \left(\ell n \sigma_d^f + \tfrac{1}{2(\sigma_d^f)^2} [\ell n D_y^f - \ell n D_y^{obs,f}]^2 \right) \tag{11.12}$$

where D_y^f is the model-estimate of the fraction of the catch by fleet *f* that was discarded during year *y*:

$$D_y^f = \frac{\tilde{C}_y^{D,f}}{\tilde{C}_y^{L,f} + \tilde{C}_y^{D,f}} \tag{11.13}$$

$D_y^{obs,f}$ is the observed fraction of the catch (in mass) by fleet *f* that was discarded during year *y* (Table 11.2), and

σ_d^f is (approximately) the coefficient of variation of the discard rates for fleet *f* (set to 0.3 for the analyses of this chapter).

Initial analyses suggested that there are considerable problems fitting the discard rate data (owing perhaps to a mis-specified growth curve and value of natural mortality for juveniles) so the contribution to the objective function by the discard data is down-weighted by 100 to avoid the model estimating unrealistic values for the model parameters simply to mimic the discard data (and hence not mimic the remaining information).

11.3.2.2 Age- and size-composition data

The contribution of the age- and size-composition data (the proportion of the catch that is landed by age-/size-class by fleet and year) to the negative of the logarithm of the likelihood function is based on the robust likelihood formulation of Fournier *et al.* (1990). The contribution of the age-/size-composition data for fleet *f* and year *y* to the negative of the logarithm of the likelihood function is therefore given by:

$$\ell n L_2^{f,y} = -\sum_i \ell n \left[\exp\left\{ \frac{-(\rho_i - \rho_i^{obs})^2}{2[(1-\rho_i^{obs})\rho_i^{obs} + \frac{0.1}{N_I}](\tau_i^f)} \right\} + 0.01 \right] \qquad (11.14)$$

where ρ_i^{obs} is the observed proportion of the landed catch in age-/size-class *i*,

ρ_i is the model-estimate of the proportion of the landed catch in age-/size-class *i*,

N_I is the number of age-/size-classes,

$$\tau_i^f = \bar{N}^f / (N^{f,E} N_y^f)$$

N_y^f is the number of animals aged / sized during year *y* for fleet *f*,

$\bar{N}^f$ is the mean over years of N_y^f, and

$N^{f,E}$ is the effective sample size for fleet *f* (taken to be 100 for the analyses of this chapter).

The model-estimates used in Equation 11.14 depend on whether the data are age- or size-composition data:

$$\begin{aligned} \rho_{y,a}^{g,f} &= C_{y,a}^{\mathrm{L},g,f} / \sum_{a'} C_{y,a'}^{\mathrm{L},g,f} && \text{age-composition data} \\ \rho_{y,l}^{g,f} &= \sum_a X_{a,l}^g \, C_{y,a}^{\mathrm{L},g,f} / \sum_{a'} C_{y,a'}^{\mathrm{L},g,f} && \text{size-composition data} \end{aligned} \qquad (11.15)$$

where $X_{a,l}^g$ is the probability that an animal of sex *g* and age *a* is in size-class *l*,

$$X_{a,l}^{g} = \int_{\bar{L}_l-\Delta L/2}^{\bar{L}_l+\Delta L/2} \frac{1}{\sigma_a^g \ell\sqrt{2\pi}} e^{-\frac{(\ell-L_{a+1/2}^{g})^2}{2(\sigma_a^g)^2}} d\ell \qquad (11.16)$$

$\bar{L}_l$ is the midpoint of the l^{th} length-class,

ΔL is the width of each length-class (1cm), and

σ_a^g is the coefficient of variation of the length of a fish of sex g and age a (σ_a^g is calculated by assuming that $(\sigma_a^g)^2$ changes linearly with length and specifying the values of σ_a^g for lengths of 0 and 50 cm based on the results of fitting a von Bertalanffy growth curve to the data on age and length).

The upper and lower limits of the summation in Equation 11.14 are not necessarily the youngest and oldest age-classes and the smallest and largest size-classes. Rather, age- and size-classes are pooled to increase sample size. Specifically, all animals 15 and older are pooled into a 15^+ group when fitting to the age-composition information for the landed catches.

11.3.2.3 Catch-rate series

The contribution of the catch-rate data to the negative of the logarithm of the likelihood function is based on the assumption that fluctuations in catchability are independent and log-normally distributed with a coefficient of variance of σ_q^f:

$$\ell\text{n}L_3 = \tfrac{1}{2(\sigma_q^f)^2}\sum_f\sum_y (\ell\text{n}I_y^f - \ell\text{n}[q^f\, B_y^{e,f}(1-F_y^f/2)])^2 \qquad (11.17)$$

where q^f is the catchability coefficient for fleet *f*,

I_y^f is the catch-rate index for fleet f and year y, and

σ_q^f is (approximately) the coefficient of variation of the random fluctuations in catchability (assumed to be 0.3 for the analyses of this chapter).

11.3.2.4 Recruitment residuals

The recruitment residuals are assumed to be normally distributed, i.e.:

$$\ell\text{n}L_4 = \tfrac{1}{2\sigma_R^2}\sum_y \varepsilon_y^2 \qquad (11.18)$$

11.3.3 Parameter estimation

Table 11.6 lists the parameters of the population dynamics model. The free parameters of the population dynamics model are: R_0, the parameters that define the selectivity pattern (two for each fleet), and the recruitment residuals for 1916–2002 (i.e. there are a total of 92 free parameters). The values for the parameters that maximize the objective function are determined using the AD Model Builder package[20]. This assessment quantifies the uncertainty of the estimates of the model parameters and of the other

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quantities of interest using Bayesian methods. The Metropolis-Hastings variant of the Markov Chain Monte Carlo (MCMC) algorithm (Hastings, 1970; Gelman *et al.*, 1995; Gilks *et al.*, 1996; Punt and Hilborn, 1997) with a multivariate normal jump function was used to sample 800 equally likely parameter vectors from the joint posterior density function. The samples on which inference is based were generated by running 5,000,000 cycles of the MCMC algorithm, discarding the first 1,000,000 as a burn-in period and selecting every 5,000th parameter vector thereafter. The initial parameter vector was taken to be the vector of maximum posterior density (MPD) estimates. A potential problem with the MCMC algorithm is how to determine whether convergence to the actual posterior distribution has occurred, and the selection of 5,000,000, 1,000,000 and 5,000 was based on generating a sample that showed no noteworthy signs of lack of convergence to the posterior distribution. Whether convergence had occurred was examined by applying the diagnostic statistics developed by Geweke (1992), Heidelberger and Welch (1983), and Raftery and Lewis (1992) and by examining the extent of auto-correlation among the samples in the chain.

11.3.4 Projections

Projections are conducted to assess the risk associated with different future levels of catch. All of the projections are based on fixed levels of catch and hence will tend to over-estimate risk because such projections implicitly assume that future data will be ignored. The risk analysis involves projecting the population ahead 10 years (i.e. from 2004 to 2014) under different alternative future levels of total catch (2000 t, 2500 t, 3000 t, and 3500 t). The future catch of flathead is assumed to be split 50:50 between the Danish seine and otter trawl sectors.

The projections are based on the 800 random samples from the Bayesian posterior distribution. The recruitment residuals for 2003 onward are generated from $N(0;\sigma_R^2)$ for consistency with the approach used when estimating the historical (pre-2003) recruitment residuals. The outcomes of the projections are quantified by the probability that the spawning biomass (see Equation 11.4) exceeds 40% and 20% of the virgin spawning biomass (i.e. $0.4SB_0$ and $0.2SB_0$).

11.4 Results

11.4.1 MPD estimates

Diagnostic statistics (see Appendix 11.A for a summary) provide no evidence that the MCMC algorithm failed to converge adequately to the posterior distribution. Results are presented first for the “best fit” of the model to the data (i.e. the MPD fits). These results can be examined to assess whether the model is able to mimic the data available for assessment purposes adequately. Figure 11.6 shows the fits of the model to the historical and more recent catch rate data. The model is able to mimic the historical data very well for both fleets. It has a little more trouble fitting the cyclical trends in recent catch rates, particularly where they are not quite in synchrony between the two fleets.

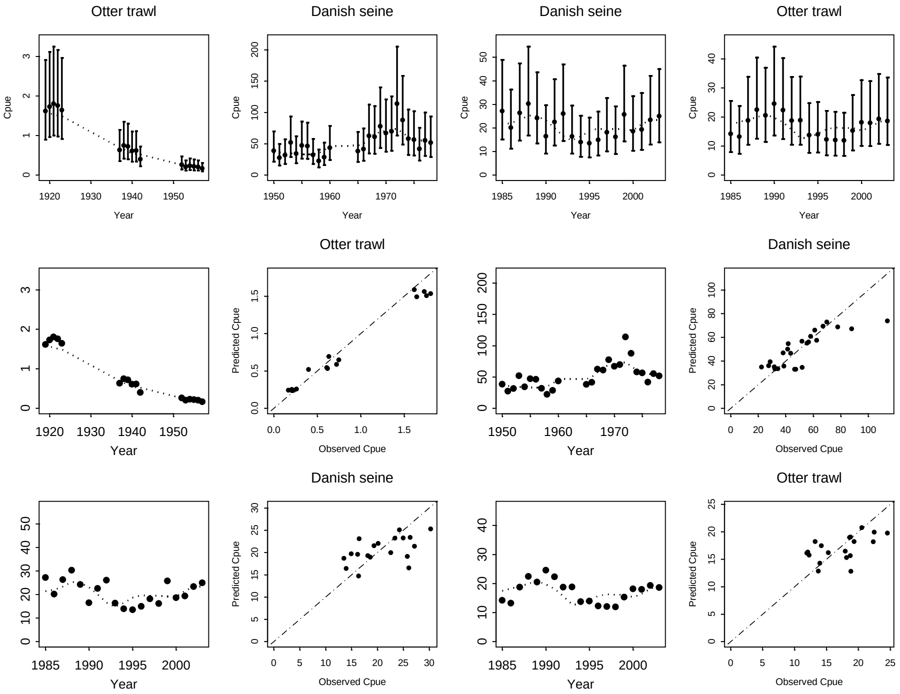

Figure 11.6. Diagnostics related to fit of the population dynamics model to the four catch-rate series. The upper panels plot observed (solid dots) and model-predicted catch rates (dotted lines) versus time. The vertical lines in the upper panels indicate approximate 95% confidence intervals for the data. The second and third row of panels repeats the information in the upper panels (omitting the confidence intervals for improved clarity) as well as observed versus model-predicted catch rates. The dotted lines are 1:1 lines – the expectation if the model fitted the data perfectly.

Figure 11.7 shows the fits to the age-composition data since 1998 (the years for which age-length keys are available based on the break and burn methods). Results are not shown for 2003 because the sample on which the age-length key for 2003 is based is very small (103 fish – Table 11.4). In general, the model fits these data very well. The value of *N* in Figure 11.7 denotes the effective sample sizes estimated within the model. These are generally smaller than the 100 assumed when fitting the model, although the average value is sufficiently close to 100 that the assumption of an effective sample of 100 should not lead to bias.

The model is also able to mimic the length-frequency data adequately (Figure 11.8). Note that length frequency data were only fitted for those years for which age-composition data are not included in the assessment.

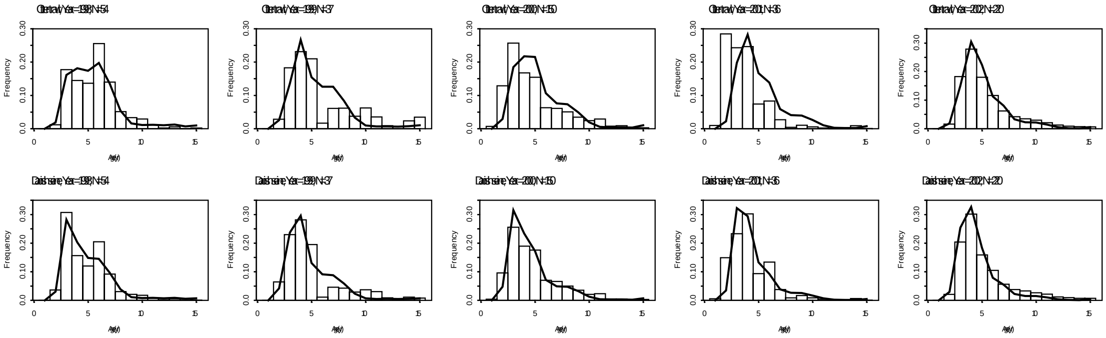

Figure 11.7. Fits to the catch age-composition data. Results are shown for the otter trawl fleet and the Danish seine fleet.

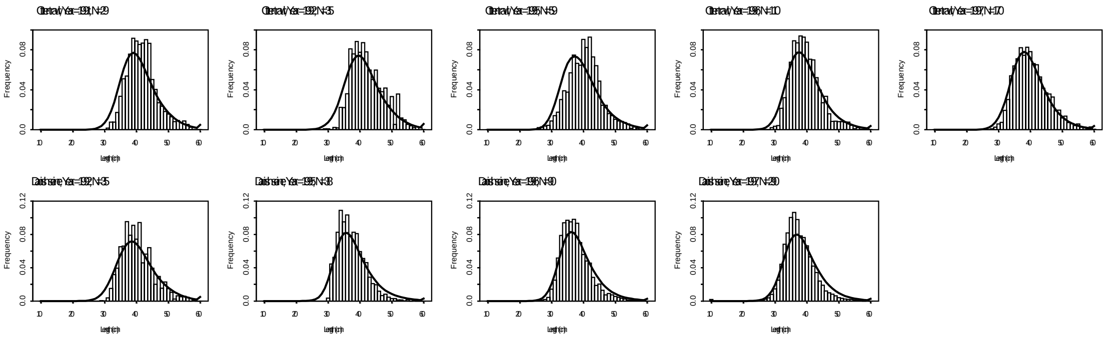

Figure 11.8. Fits to the catch length-composition data. Results are shown for the otter trawl fleet and the Danish seine fleet.

The fits to the discard rate data (Figure 11.9) are very poor. The model is unable to fit these data given the assumed discard selectivity ogive input to the assessment even though this ogive fits the proportions of each length-class discarded adequately (Figure 11.4).

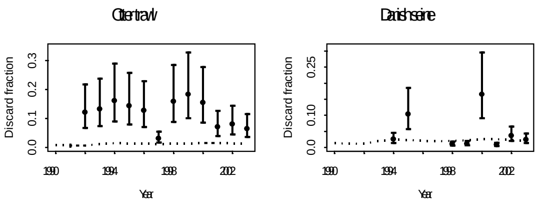

Figure 11.9. Observed (solid dots) and model-predicted discard rates (dotted lines) versus time. The vertical lines indicate approximate 95% confidence intervals for the data

The results corresponding to the MPD estimates are summarized in Figure 11.10. The top left panel of Figure 11.10 shows the time series of spawning biomass (1915–2003). Spawning biomass shows an initial decline driven by the high catches by the steam trawlers. This is followed by a recovery during the 1950s. Spawning biomass has been largely constant (although fluctuating) since 1960. The current (2004) spawning biomass is slightly lower than 40% of SB_0. Recruitment has been variable over the period considered in the assessment (Figure 11.10 middle panel, top). It should be noted however, that the estimates of recruitment for the years prior to about 1980 are driven only by catches and catch rates, and not by age- and length-composition information. Exploitation rate (centre left panel) has also been variable, but rising in recent years.

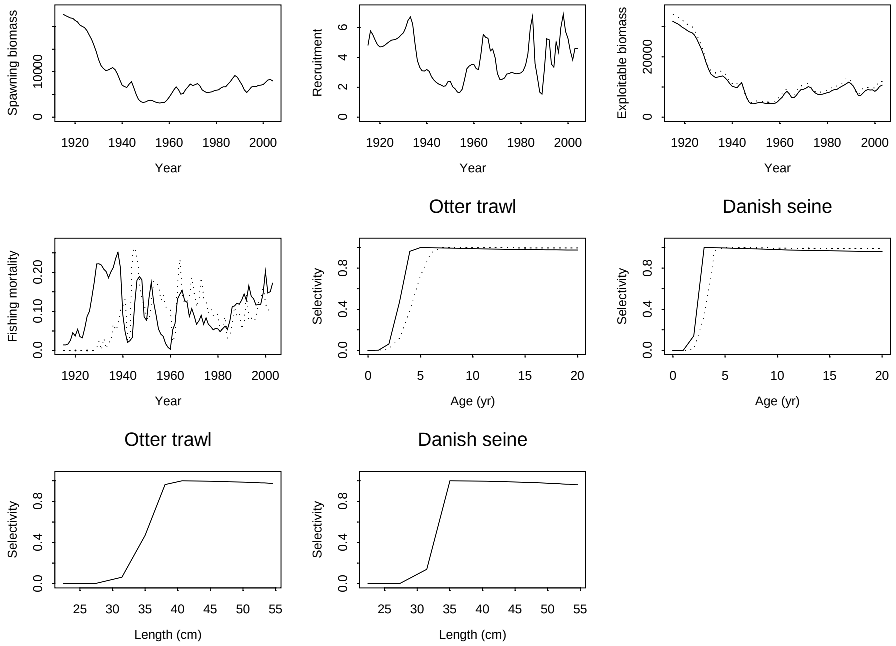

Figure 11.10. Diagnostic statistics for the fit corresponding to the maximum posterior density estimates.

Figure 11.11 shows the MPD estimates for the recruitment residuals since 1985. Recruitment has been above expected levels (i.e. those based on the assumed stock recruitment relationship) on average over the past fourteen years.

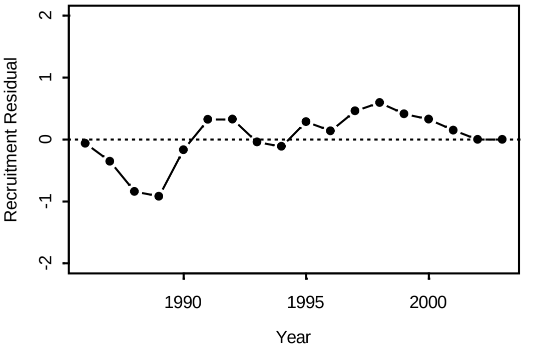

Figure 11.11. MPD estimates of the recruitment residuals (1985–2002).

11.4.2 Bayesian results and stock projections

Bayesian posteriors for the model run are shown for spawning biomass and recruitment in Figure 11.12. Uncertainty is highest during the historical period, and for the estimates of recruitment for the most recent years.

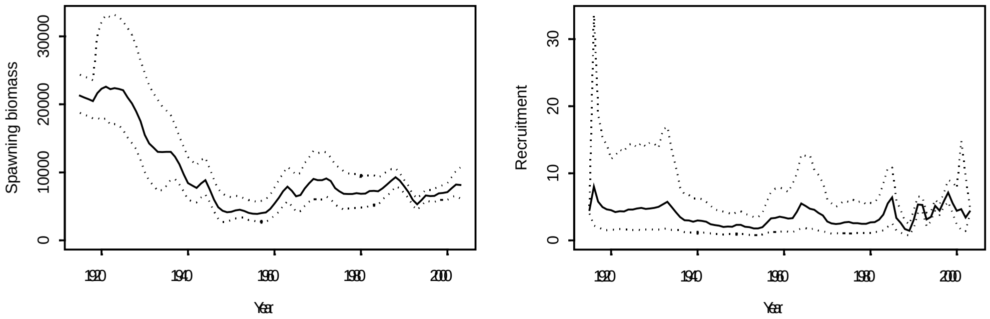

Figure 11.12. Posterior distributions (medians and 90% probability intervals) for spawning biomass and recruitment.

Figures 11.13 and 11.14 show the probability that the stock is above the target and limit reference levels of 40% and 20% of SB_0 respectively, under a range of future fixed catch levels. The annual probabilities are given in Table 11.7. These results, together with those in Figure 11.15, suggest that for this portion of the stock (SEF zones 10, 20 and 60), longer term sustainable catch levels lie in the range 2000 to 2500 t.

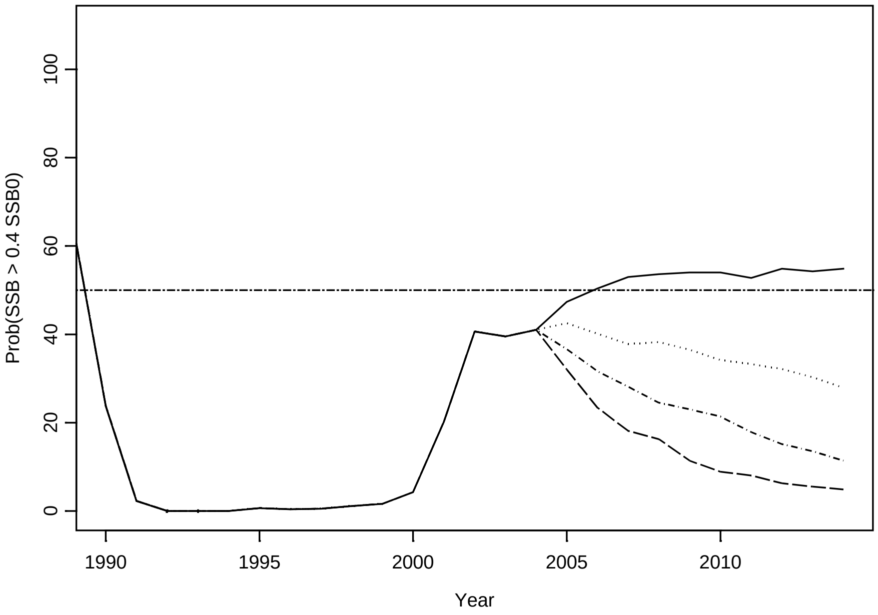

Figure 11.13. Probability of the spawning biomass being above 40% of the unfished spawning biomass for four levels of future catches (2,000, 2,500, 3,000, and 3,500 t).

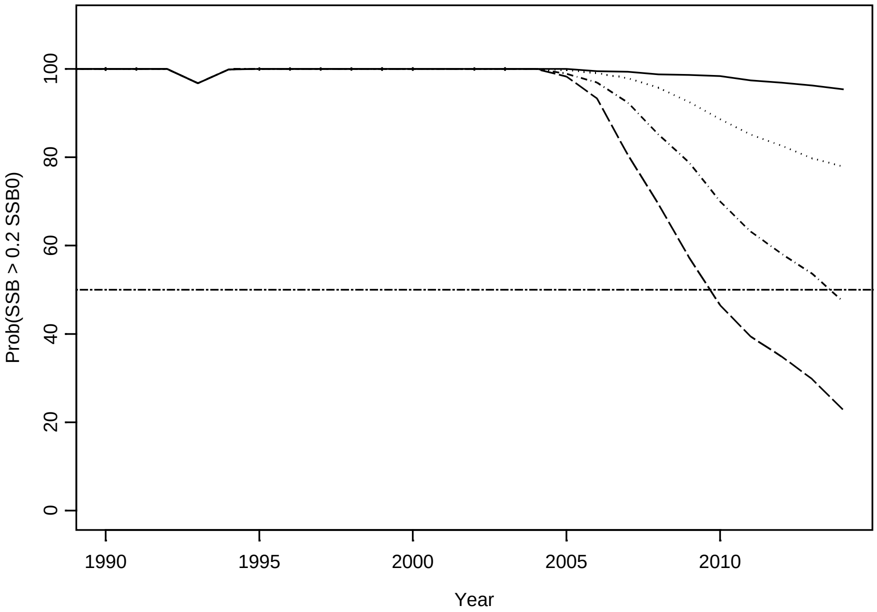

Figure 11.14. Probability of the spawning biomass being above 20% of the unfished spawning biomass for four levels of future catches (2,000, 2,500, 3,000, and 3,500 t).

Figure 11.15. The ratio of the spawning biomass to the 1915 spawning biomass (expressed as a percentage) for four levels of future catches (2,000, 2,500, 3,000, and 3,500 t).

11.5 Discussion

11.5.1 General discussion

Overall, the results of this quantitative assessment of tiger flathead in zones 10, 20 and 60 appear to be in agreement with those from previous assessments, and with empirical observations on the catch history. The results suggest that the longer term sustainable yield from this part of the stock lies somewhere between 2000 and 2500 t. Landings from this region since 1986 have averaged just over 2400 t, and the stock appears to have been fairly stable over that period (allowing for cyclical fluctuations). The current state of the stock is close to the target reference level of 40% of the unfished spawning biomass, so there are no immediate concerns about current catch levels. However the catch levels are at a current high point in the cycle, and at the highest levels since the 1960s, so current catch levels are unlikely to be sustainable indefinitely, and average catch levels of less than 2500 t should be the aim in the longer term.

Figure 11.16 shows the time-trajectories of spawning biomass, catches, and recruitment over the 89-year period (1985–2003). The slight rise in spawning biomass over the last 10 years may be due to higher levels of recruitment, and Figure 11.11 suggests that these recent recruitments are above the long term expected average.

It should be emphasized that there are still several sources of uncertainty associated with the assessment, and there has not yet been a full analysis of the sensitivity of the assessment to data inputs and model assumptions. However, the conclusions about longer term yields are likely to be fairly robust. What is still uncertain is how to set TACs given that only part of the stock has been assessed. Although the catches in zones 10, 20 and 60 account for 94% of total Commonwealth flathead catches since 1986, the percentage is lower in recent years, following expansion of the trawl fishery off eastern Tasmania. Although the fish off Tasmania are unlikely to represent a separate biological stock, it is clear that they do not fully mix with the fish to the north. Thus the sustainable yield estimate from the three zones assessed represents a lower bound on sustainable yields for the entire stock.

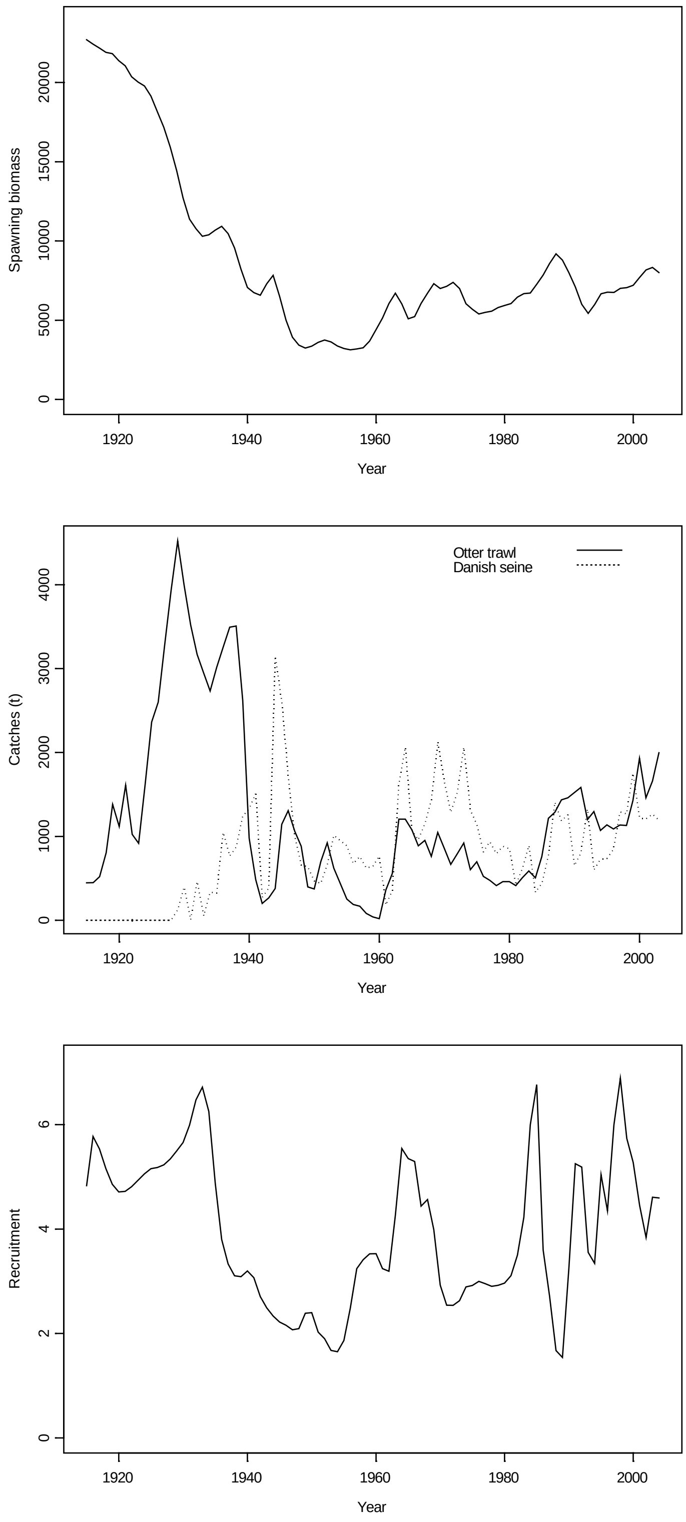

Figure 11.16. Time-trajectories of spawning biomass, catch by sector, and recruitment (1915–2003).

11.6 Further development

The following are ways in which future assessments of tiger flathead could or should be improved.

General sensitivity analyses

- Examine sensitivity to the value assumed for the plus-group age, *M*, and steepness
- Investigate sensitivity to the values assumed for σ_q, σ_d, and the effective sample sizes.
- Examine sensitivity to the plus- and minus-groups when fitting to the length and age-composition data.
- Try to estimate *M* and steepness.

Data

- Document historical changes in gear and size limits.
- Obtain pre-1998 age-length keys.
- Obtain historical (Sydney fish market, 1940 and 50s data) length data.
- Investigate whether it is feasible to construct additional CPUE series (e.g. a CPUE index for the trawl sector for 1960–84).
- Revise the standardized CPUE index for the period 1985 onwards (e.g. delta-type approach, MacCall subsetting method).
- Investigate ways to incorporate environmental data (such as SOI) into catch rate standardizations.
- Include the catch of school whiting as a factor when standardizing the catch and effort data for the Danish seine fleet.
- Obtain readings that compare ageing based on the surface versus the break-and-burn method to enable a comparison to be made between these ageing techniques (this may require additional otoliths to be read using both methods).
- Obtain multi-reader data for surface and break-and-burn ageing (to determine age-reading error matrices)
- Estimate a more realistic maturity ogive (maturity as a function of length rather than of age).
- Estimate year- and fleet-specific CVs for the discard rate estimates.

Population model

- Modify the population dynamics model (e.g. age-specific *M*) to improve the fit to the discard data.
- Revise the growth curve by integrating the estimation of the growth curve with that of the free parameters of the population dynamics model – this should lead to more smaller fish-at-age and hence (perhaps) to an improved ability to mimic the discard data
- Include the Tasmanian component of the population by either:
  - another fleet; or
  - a separate population – perhaps with some parameters shared with the population in zones 10, 20 and 60
- Revisit the definitions of the fleets.

Likelihood function

- Include the ability to fit biased age-composition data (i.e. the data collected using the break and burn method).
- Include age-reading error when fitting to the age-composition data.

MCMC

- Start the MCMC algorithm from several alternative starting parameter vectors.
- Determine if it is possible to improve the speed of convergence of the MCMC algorithm by reprarametrizing the selectivity patterns.

11.7 Acknowledgements

We are indebted to the participants in the flathead workshops and the Shelf Assessment Group for constructive comments on the various stages of this assessment over the past three years. We are also grateful to Sonia Talman (PIRVic), Sally Wayte (CMR) and Kyne Krusic Golub (PIRVic) for provision of data.

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Table 11.1. Reported catches (tonnes) and catch-rates by fleet (1915–84).

	Catch (t)		Catch-rate			Catch (t)		Catch-rate	
Year	Otter trawl	Danish seine	Otter trawl	Danish seine	Year	Otter trawl	Danish seine	Otter trawl	Danish seine
1915	446	0	-	-	1950	372	467	-	38.7
1916	447	0	-	-	1951	699	438	-	27.6
1917	519	0	-	-	1952	923	661	0.262	31.8
1918	806	0	-	-	1953	620	1012	0.208	52.0
1919	1381	0	1.618	-	1954	439	949	0.232	34.4
1920	1117	0	1.732	-	1955	253	886	0.219	47.4
1921	1609	0	1.806	-	1956	188	674	0.208	46.5
1922	1024	0	1.758	-	1957	167	759	0.169	32.1
1923	916	0	1.646	-	1958	81	621	-	22.5
1924	1628	0	-	-	1959	39	640	-	28.7
1925	2363	0	-	-	1960	18	762	-	43.6
1926	2600	0	-	-	1961	360	180	-	-
1927	3282	0	-	-	1962	555	350	-	-
1928	3933	0	-	-	1963	1205	1622	-	-
1929	4522	122	-	-	1964	1205	2064	-	-
1930	3994	396	-	-	1965	1078	1067	-	38.2
1931	3518	5	-	-	1966	888	957	-	41.5
1932	3170	462	-	-	1967	952	1150	-	62.5
1933	2947	52	-	-	1968	761	1436	-	61.2
1934	2734	332	-	-	1969	1047	2127	-	77.8
1935	3016	325	-	-	1970	856	1645	-	67.1
1936	3255	1046	-	-	1971	666	1285	-	69.9
1937	3494	765	0.635	-	1972	793	1525	-	114.0
1938	3509	870	0.749	-	1973	920	2064	-	88.0
1939	2622	1241	0.723	-	1974	603	1312	-	58.1
1940	978	1329	0.611	-	1975	698	1142	-	56.6
1941	483	1506	0.618	-	1976	523	813	-	41.9
1942	201	270	0.401	-	1977	476	935	-	55.5
1943	267	381	-	-	1978	412	794	-	51.9
1944	378	3149	-	-	1979	460	881	-	-
1945	1144	2602	-	-	1980	460	851	-	-
1946	1306	1710	-	-	1981	412	418	-	-
1947	1061	998	-	-	1982	507	615	-	-
1948	881	657	-	-	1983	587	889	-	-
1949	396	638	-	-	1984	505	331	-	-

Table 11.2. Reported catches (tonnes), discard rates and catch-rates by fleet (1985–2003). Catches and catch rates are based on data from zones 10, 20 and 60 for otter trawl, and zones 20 and 60 for Danish seine.

	Catch (t)		Catch-rate		Discard rate	
	Otter trawl	Danish seine	Otter trawl	Danish seine	Otter trawl	Danish seine
1985	759.6	436.6	27.173	14.203	-	-
1986	1215.2	771.2	20.165	13.229	-	-
1987	1286.4	1405.0	26.342	18.798	-	-
1988	1434.9	1184.3	30.292	22.487	-	-
1989	1460.3	1257.9	24.245	20.544	-	-
1990	1522.9	650.6	16.475	24.577	-	-
1991	1583.9	798.2	22.584	22.353	-	-
1992	1199.4	1324.3	26.085	18.752	0.121	-
1993	1296.4	598.0	16.377	18.850	0.132	0
1994	1070.7	722.8	13.975	13.746	0.161	0.025
1995	1136.5	733.8	13.523	13.984	0.143	0.103
1996	1088.4	845.4	14.941	12.284	0.127	-
1997	1134.6	1290.8	18.164	12.092	0.030	-
1998	1129.3	1266.2	16.201	11.930	0.158	0.010
1999	1427.4	1752.3	25.772	15.301	0.182	0.011
2000	1931.3	1219.3	18.620	18.156	0.154	0.164
2001	1460.3	1206.2	19.342	17.969	0.070	0.008
2002	1660.2	1262.1	23.385	19.339	0.080	0.036
2003	1997.3	1191.2	24.990	18.639	0.064	0.024

Table 11.3. Diagnostic statistics for the GLM analyses. The rows indicated in bold typeface are the 'best' models.

(a) Otter trawl

Model	AIC	Deviance
Year	385814	151865
Year+Month	385442	151400
Year+Depth	380587	145785
Year+Vessel	380586	145785
Year+Week	385309	151146
Year+Zone	381921	147323
Year+JM	385400	151333
Year+Month+Depth	380063	145166
Year+Month+Vessel	376068	140648
Year+Month+Zone	381478	146789
Year+Month+JM	384970	150802
Year+Depth+Vessel	371412	135643
Year+Depth+Week	379916	144907
Year+Depth+Zone	378187	143080
Year+Depth+JM	380359	145486
Year+Vessel+Week	375933	140411
Year+Vessel+Zone	374268	138709
Year+Vessel+JM	376370	140965
Year+Week+Zone	381323	146519
Year+Week+JM	384824	150435
Year+Month+Depth+Vessel	370913	135094
Year+Month+Depth+Zone	377650	142457
Year+Month+Depth+JM	379849	144884
Year+Month+Vessel+Zone	373876	138262
Year+Month+Vessel+JM	375987	140520
Year+Depth+Vessel+Week	370775	134861
Year+Depth+Vessel+Zone	369953	134105
Year+Depth+Vessel+JM	371194	135374
Year+Vessel+Week+Zone	373727	138013
Year+Vessel+Week+JM	375850	140281
Year+Week+Zone+JM	381094	146216
Year+Month+Depth+Vessel+Zone	369466	133574
Year+Month+Depth+Vessel+JM	370742	134875
Year+Month+Vessel+Zone+JM	373759	138098
Year+Depth+Vessel+Week+Zone	369317	133334
Year+Depth+Vessel+Week+JM	370611	134651
Year+Depth+Vessel+Zone+JM	369666	133768
Year+Depth+Week+Zone+JM	377249	141883
Year+Month+Depth+Vessel+Zone+JM	369233	133294
Year+Depth+Vessel+Week+Zone+JM	**369093**	**133064**

(Table 11.3 Continued)

(b) Danish seine

Model	AIC	Deviance
Year	318937	207726
Year+Month	315489	199477
Year+Depth	294102	155405
Year+Vessel	314042	196106
Year+Week	315069	198312
Year+Zone	299691	165906
Year+JM	315396	199229
Year+Month+Depth	288166	144961
Year+Month+Vessel	310231	187524
Year+Month+Zone	292978	153358
Year+Month+JM	311773	190926
Year+Depth+Vessel	291309	150359
Year+Depth+Week	287839	144269
Year+Depth+Zone	292658	152800
Year+Depth+JM	293777	154752
Year+Vessel+Week	309797	18696
Year+Vessel+Zone	297852	162317
Year+Vessel+JM	311216	189661
Year+Week+Zone	292582	152506
Year+Week+JM	311367	189841
Year+Month+Depth+Vessel	284998	139640
Year+Month+Depth+Zone	286229	141712
Year+Month+Depth+JM	287769	144230
Year+Month+Vessel+Zone	291175	150103
Year+Month+Vessel+JM	307361	181266
Year+Depth+Vessel+Week	284640	138924
Year+Depth+Vessel+Zone	290455	148859
Year+Depth+Vessel+JM	291136	149992
Year+Vessel+Week+Zone	290772	149256
Year+Vessel+Week+JM	306941	180207
Year+Week+Zone+JM	291910	151248
Year+Month+Depth+Vessel+Zone	283812	137712
Year+Month+Depth+Vessel+JM	284813	139281
Year+Month+Vessel+Zone+JM	290555	148958
Year+Depth+Vessel+Week+Zone	283456	137011
Year+Depth+Vessel+Week+JM	284456	138567
Year+Depth+Vessel+Zone+JM	290346	148608
Year+Depth+Week+Zone+JM	285708	140658
Year+Month+Depth+Vessel+Zone+JM	283712	137495
Year+Depth+Vessel+Week+Zone+JM	**283357**	**136795**

Table 11.4. Sample sizes for age-length keys and the length-frequencies for the landed catches.

	Length-frequency (samples)		Length-frequency (# Fish)		Age-length keys
Year	Otter trawl	Danish seine	Otter trawl	Danish seine	
1991	7	-	684	-	-
1992	9	21	841	1442	-
1993	5	-	502*	-	-
1994	2	6	156*	292*	-
1995	18	20	1418	1566	-
1996	31	47	2520	3680	-
1997	49	145	4177	11857	-
1998	152	139	11302	11266	314
1999	196	61	12747	5079	219
2000	105	47	6698	3566	879
2001	170	75	11087	5690	211
2002	83	48	6208	3569	1302
2003	63	22	4686	1896	103

* Not included when estimating the parameters of the model owing to small sample size.

Table 11.5. Specifications for the parameters of the growth curve.

Quantity	Females	Males
ℓ_∞ (cm)	56.04	45.70
κ (yr^{-1})	0.156	0.180
t_0 (yr)	-2.783	-3.322
$\tilde{\sigma}_0$	0.149	0.080
$\tilde{\sigma}_{50}$	0.104	0.085
Length-weight – a	0.00588	0.00588
Length-weight – b	3.310	3.310

Table 11.6. The parameters of the population dynamics model.

Parameter	Treatment
Natural mortality, M	Pre-specified (0.2 yr^{-1})
Virgin recruitment, R_0	Estimated
Stock-recruitment steepness, h	Pre-specified (0.9)
Age-at-maturity, a_m	Pre-specified (3 yr)
Recruitment deviations, ε_y	Estimated (y=1916, 17, …, 2002)
Extent of variation in recruitment, σ_R	Pre-specified (0.6)
Weight-at-age, w_a^g	Pre-specified (see Table 11.5)
Length-at-age, L_a^g	Pre-specified (see Table 11.5)
Selectivity-at-age, $\overline{L}^f$, Ω_L^f	Estimated
Retention probability, ϕ_{50}^f , ϕ_{95}^f	Computed from auxiliary information
Maximum age, x	Pre-specified (20 yr)

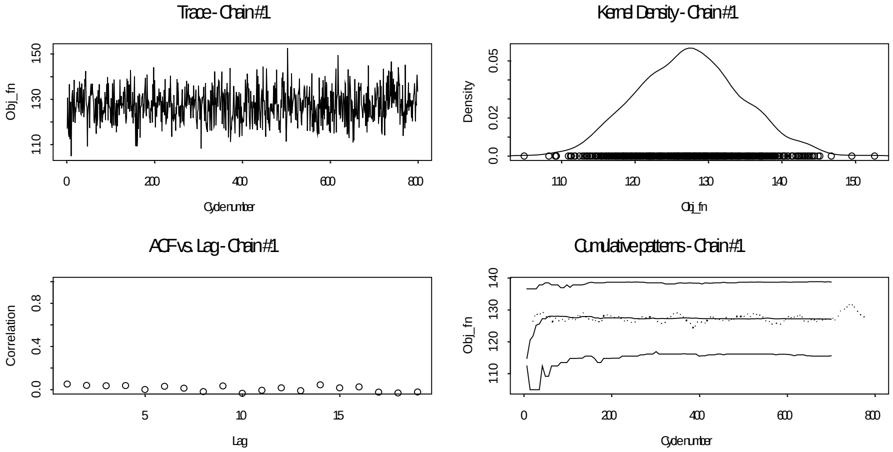
Table 11.7. Results from catch projections to 2014.

Future Catch	Year										
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
$P(SB_y > 0.4SB_0)$											
2000 *t*	41.00	47.38	50.38	53.00	53.63	54.00	54.00	52.75	54.88	54.25	54.88
2500 *t*	41.00	42.50	40.13	37.75	38.25	36.50	34.13	33.25	32.13	30.25	27.88
3000 *t*	41.00	36.63	31.63	28.13	24.50	23.00	21.38	17.88	15.13	13.50	11.38
3500 *t*	41.00	32.00	23.38	18.13	16.25	11.38	8.88	8.00	6.25	5.50	4.88
$P(SB_y > 0.2SB_0)$											
2000 *t*	100.00	100.00	99.50	99.38	98.75	98.63	98.38	97.38	96.88	96.25	95.38
2500 *t*	100.00	99.75	99.00	97.88	95.75	92.50	88.63	85.13	82.63	79.75	77.88
3000 *t*	100.00	98.88	96.88	92.38	85.13	78.75	70.00	63.13	58.13	53.63	47.38
3500 *t*	100.00	98.25	93.25	80.50	69.38	57.25	46.50	39.38	34.88	29.75	22.88

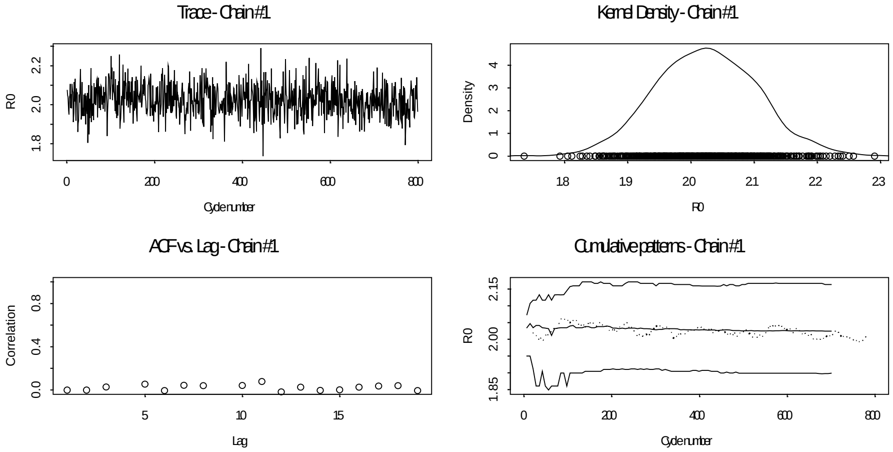
APPENDIX 11.A : Diagnostics statistics for the Bayesian analyses

The panels for each quantity in this Appendix show the trace, the posterior density function (estimated using a normal kernel density estimator), the correlation at different lags, the 50-point moving average against cycle number (dotted line in the rightmost panels), and the running mean and running 95% probability intervals (solid lines in the rightmost panels).

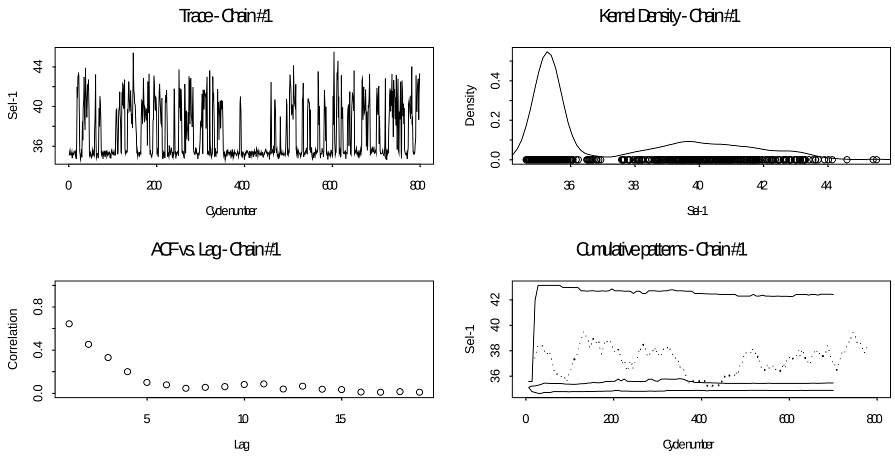
a) Objective function



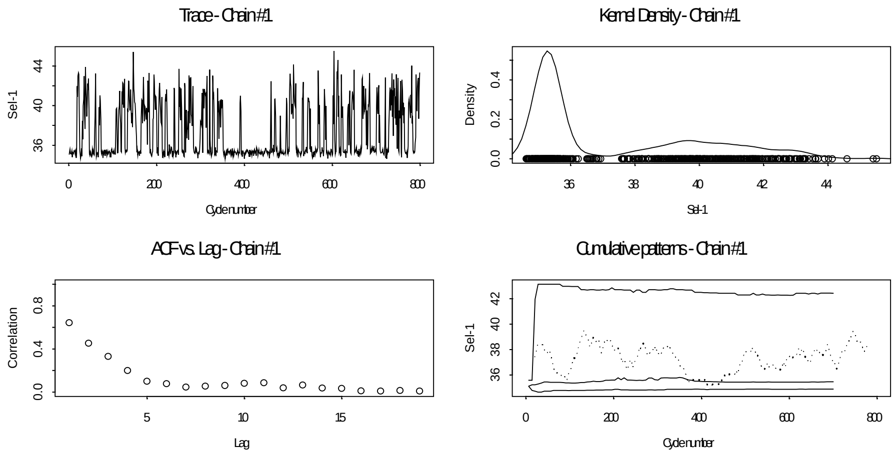
b) Virgin recruitment



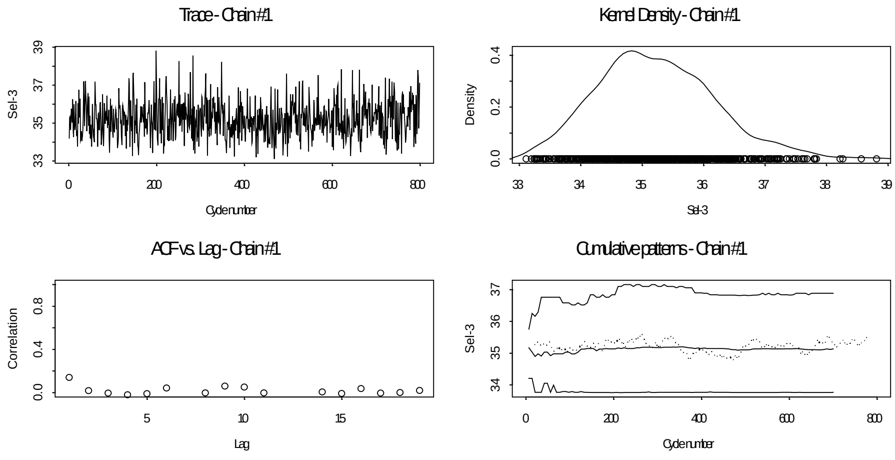
c) Length-at-50%-selectivity for the otter trawl fishery



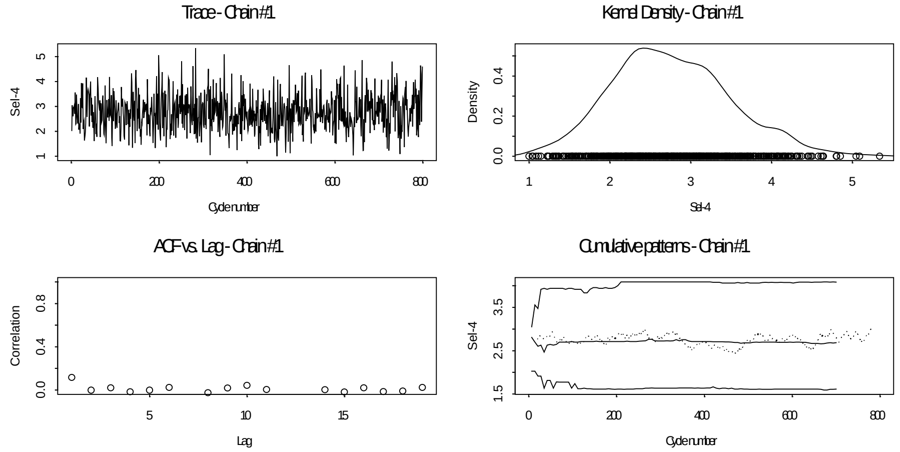
d) Left standard deviation for selectivity for the otter trawl fishery



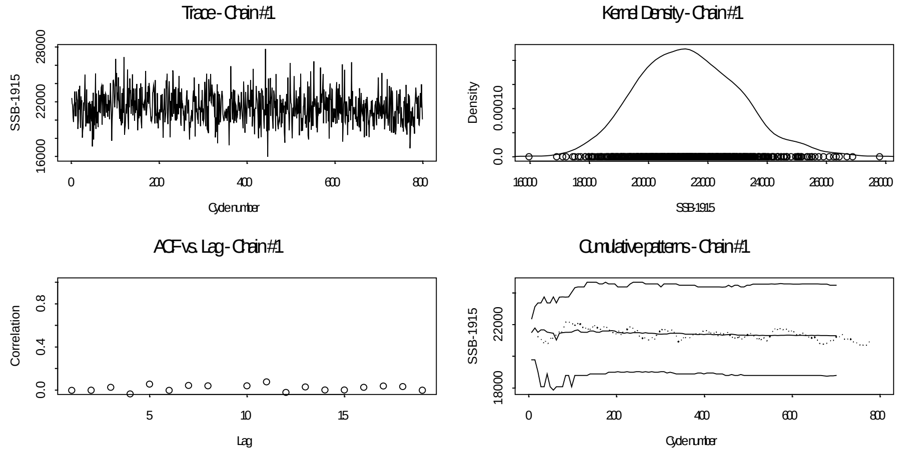
e) Length-at-50%-selectivity for the Danish seine fishery



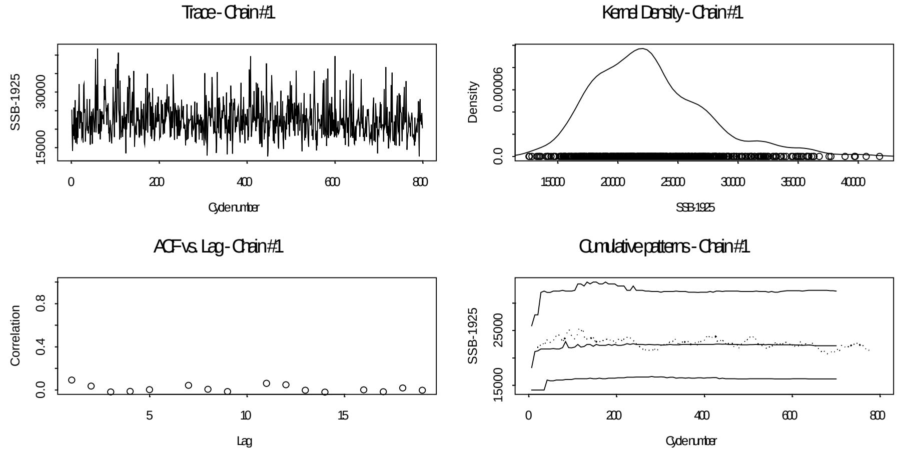
f) Left standard deviation for selectivity for the Danish seine fishery



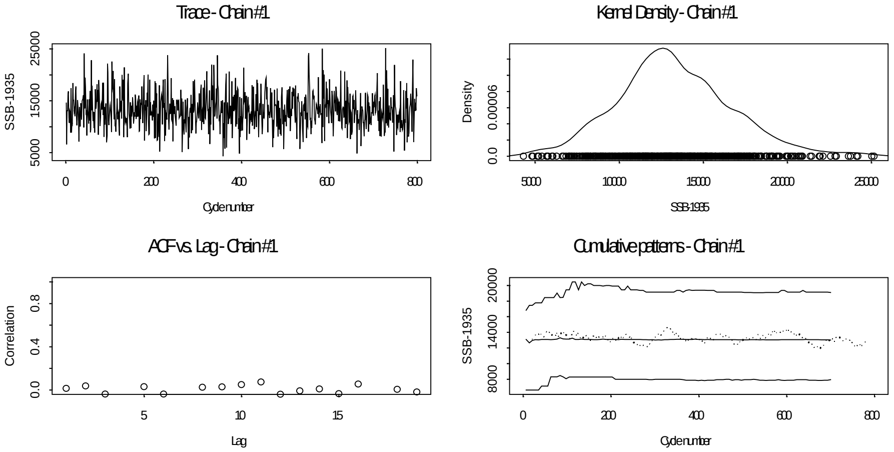
g) 1915 spawning biomass



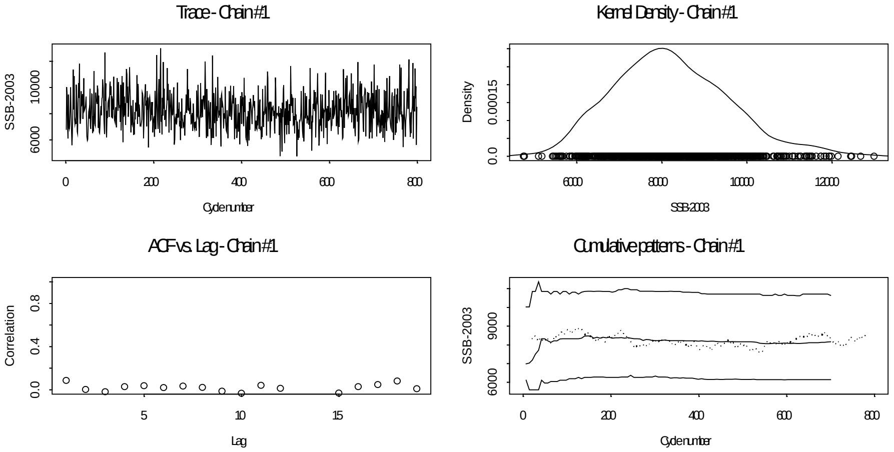
h) 1925 spawning biomass



i) 1935 spawning biomass



j) 2003 spawning biomass



12. Benefits

The results of this project have had a direct bearing on the management of the South East Scalefish and Shark Fishery (formally known as the South East and Southern Shark Fishery). Direct benefits to the commercial fishing industry in the SESSF have arisen from improvements to, or the development of, stock assessments for selected quota and non-quota species. Information from the stock assessments has fed directly into the TAC setting process for SEF quota species. As specific and agreed harvest strategies are being developed for SESSF species (a process required by and agreed to under EPBC approval for the fishery – already initiated by SHSWG and to be completed by SESSFAG), improvements in the assessments developed under this project have had direct and immediate impacts on quota levels or other fishery management measures (in the case of non-quota species)

13. Planned outcomes

1. Benefits from this project will accrue to the fishers in the South East Fishery as the information provided from assessments feeds directly into the TAC setting process.

2. Benefits will also accrue to the fishers of the expanded Southern Shark Fishery.

The results of this project have had a direct bearing on the management of the South East Scalefish and Shark Fishery. The species stock assessments documented in this report have provided critical information for resource status evaluation, while the risk assessments have provided an evaluation of the likely impact of future exploitation. These elements are vital inputs to the TAC setting process for SESSF quota species, and assist commercial operators in better planning their businesses. Assessments of gummy shark, elephantfish and saw shark have also been instrumental in the management of these species and have facilitated the decision making processes of the Shark Assessment Group. Participation by the project's staff on SESSF Assessment Groups has enabled not only the production of critical assessment reports, but also a clear communication of the report's results to a wide audience (managers, industry). Project staff's scientific advice on quantitative and qualitative matters is also clearly valued.

3. The precision of estimates of management related quantities should increase as additional information is included in assessments.

The stock assessments presented in this report have provided managers and industry greater confidence when making key commercial and sustainability decisions for species in the SESSF. Some species did not have any (or recent) full quantitative assessments (e.g. elephantfish, saw shark, jackass morwong), others required the inclusion of major new population dynamic assumptions (e.g. two stocks instead of one for blue warehou; cyclic recruitment for blue grenadier), while others could now utilize improved or new information regarding stock size (e.g. acoustic estimates for blue grenadier). Clearly, these assessments have provided the most up-to-date information, in terms of data and methods, to facilitate the management of the South East Scalefish and Shark Fishery.

14. Conclusion

1. Provide new or updated quantitative assessments for SEF species based on SEFAG priorities

2. Provide new or updated quantitative assessments for southern shark species based on SharkFAG priorities

The 2003/2004 assessment of stock status of the key South East Scalefish and Shark fishery species is based on the methodologies presented in this report. Documented are the latest quantitative assessments for five of the key non-shark quota species (blue grenadier, blue warehou, pink ling, tiger flathead and jackass morwong) and three of the major shark species (gummy shark, elephant fish and saw shark). Typical assessment results provided indications of current stock status, in addition to risk assessments that allow an evaluation of future impacts under different catch strategies and biological scenarios. These assessment outputs are a critical component of the management and TAC setting process for these fisheries. The results from these studies are being used by SEFAG, industry and management to help manage the fishery in accordance with agreed sustainability objectives.

Stock status conclusions:

For blue grenadier (*Macruronus novaezelandiae*), results of the 2004 assessment are less optimistic than that conducted in 2003, continuing the trend seen in recent years, primarily due to continuing poor recent recruitment. The risk analysis indicates that for all scenarios, there is a very high probability that the spawning biomass will reduce below 40% of the reference spawning biomass. In addition, preliminary models of future cyclic recruitment indicate that the spawner biomass may continue to decline beyond that predicted by the base-case model.

In contrast to previous stock assessments, the present stock assessment of blue warehou (*Seriolella brama*) is based on there being two stocks off southern Australia (east and west of Bass Strait). This change in assessment assumption was made based on evidence from a variety of methods of identifying stock structure. The projections suggest that increased catches to the east of Bass Strait are sustainable while the implications of different levels of future catch for the stock to the west of Bass Strait are highly uncertain. The results for the eastern stock, however, depend critically on whether estimates of recent strong recruitment are reliable.

The populations of gummy shark (*Mustelus antarcticus*) in Bass Strait and off South Australia are both estimated to be currently slightly above the proxy for the level at which *MSY* would be achieved, and recruitment to the fisheries in Bass Strait is estimated to better than expected given the number of maternal females, while that off South Australia has generally been poorer than expected.

Assessment results for jackass morwong (*Nemadactylus macropterus*) in eastern areas appear to be somewhere around 25-45% of 1915 spawning biomass. The projection results presented would indicate that, given the assumptions in the base-case scenario, current removals from the eastern areas are perhaps sustainable. The sensitivity analyses which provided a more pessimistic prediction of 2003 stock status unsurprisingly suggest that a lower TAC than that suggested by the base-case analysis may be appropriate.

For pink ling (*Genypterus blacodes*), two different stock assessments were produced – one using raw catch rates and the other using standardised catch rates. The current proportion of spawning stock biomass relative to virgin levels was estimated to be 34% for the assessment using raw catch rates, and 56% for standardised catch rates. Simple deterministic projections to 2020 using the current selectivity pattern for raw catch rates showed that current catch levels are not sustainable, while the results for standardised catch rates showed that this catch is sustainable. Both assessments showed that a catch of 1,200 t was sustainable, while 2,000 t was not.

The results of the assessments for sawshark (*Pristiophorus cirratus* and *P. nudipinnis*) and elephantfish (*Callorhinchus milii*) suggest that they are both depleted to below 40% of the 1950 pup production (perhaps substantially so in the case of elephantfish). These results are, however, imprecise, particularly those for sawshark. The analyses in this report suggest that it is possible to conduct assessments of sawshark and elephantfish. However, the analyses also highlight several research topics which, if addressed, could lead to more reliable assessments.

The 2004 assessment for tiger flathead (*Neoplatycephalus richardsoni*) suggests that the current stock size in the historical area of the fishery (NSW, eastern Victoria, and Bass Strait) is well above the limit reference level of 20% of unfished spawning stock size. The assessment also confirms that recent catch levels in excess of 3,000 t, if maintained, would drive the stock down towards this limit level over time. This is consistent with the observation that catch levels in this part of the fishery have averaged 2,400 t over the past 20 years, during which time the stock has remained fairly stable. The longer term sustainable yield for the three zones assessed appears to lie between 2,000 t and 2,500 t.

15. Appendix A - Intellectual Property

No intellectual property has arisen from the project that is likely to lead to significant commercial benefits, patents or licenses.

16. Appendix B – Staff

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