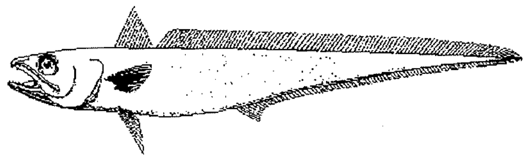
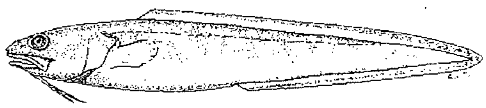
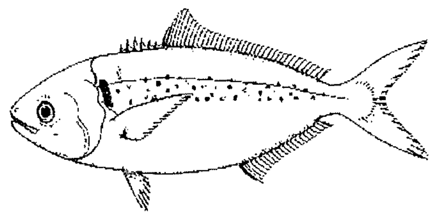
MODELLING THE POPULATION DYNAMICS OF HIGH PRIORITY SEF SPECIES

Principal Investigators:
Robin Thomson and Xi He







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CORPORATION

Final report to the Fisheries Research and Development Corporation

FRDC Project 1997/115

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NON-TECHNICAL SUMMARY

1997/115 Modelling the population dynamics of high priority SEF species

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OBJECTIVES

1. To provide high quality dynamic models and stock assessment advice for three SEF quota species for which there is immediate concern of stock status.
2. To work with industry and managers in developing population dynamics models in a manner that will improve the stock assessment in the SEF and its perception by industry.
3. To use the stock assessments to evaluate stock status against current management performance indicators and to provide advice on alternative performance indicators if necessary.
4. To evaluate the value (in terms of improved assessment) of future data collections and research studies for the assessed species.

SUMMARY

There are 16 species or species groups for which annual TACs are set for the South East Fishery (SEF). Stock assessments synethize the available data for individual species and contribute information to the AFMA management process. This project resulted in stock assessments for three important quota SEF species (blue grenadier, pink ling, and spotted warehou). SEF industry representatives, managers and scientists have contributed to the development of these assessments through meetings of the South East Fishery Assessment Group (SEFAG), the Blue Grenadier Assessment Group (BGAG), the Blue Warehou Assessment Group (BWAG), and two workshops on pink ling.

An age-structured assessment method known as Integrated Analysis was used. This is a very flexible method that allows for gaps in the data and that can be adapted to fit to a variety of data sources.

The Integrated Analysis method was specifically tailored for each species under consideration and a variety of sensitivity tests performed for alternative model structures and datasets. All three models are age-based although some model processes may be length-based. The models all make use of the following data (reported per annum): landed catch; discard rate; catch-per-unit effort – CPUE - (standardized using the General Linear Model technique); age frequency of the catch and of the discards

(calculated using the length frequency of the catch and of the discards and an age length key, ALK, for the same year). Each of the assessments also included other data, specific to that assessment. The blue grenadier assessment made use of age frequency data only while the pink ling and spotted warehou models included length frequency data for years for which no ALK was available. The blue grenadier assessment included estimates of the absolute size of the spawning biomass from surveys of egg abundance. The pink ling assessment included CPUE and age and length frequency data from two research cruises. The spotted warehou assessment included information on the depth for the landed catches and for the length and age frequency data.

During 2000 catches of blue grenadier in the SEF were greater, by mass, than any other species. Concern was expressed when the fishing industry noted declining catch rates in the early 1990s. This was primarily due to several years of poor recruitment and not, apparently, to over-fishing. Two years of exceptionally good recruitment (1994 and 1995) have occurred and are currently sustaining the fishery. Indications so far are that recruitment since 1995 has again been poor. Forward projections indicate that the stock is likely to be able to sustain the current annual catch of approximately 10 000t but this may not be true in the short or medium-term if recruitment continues to be poor. Two surveys of the abundance of blue grenadier eggs were performed (in 1994 and 1995). The assessment is very sensitive to these estimates indicating that the other data included in the model give little information regarding the size of the stock.

Pink ling are taken by the trawl fishery, as a by-catch of gemfish and blue grenadier fishing and, increasingly, as a target species. They are also important to the non-trawl fishery, being one of the three staple species for this fleet. Both the catch and the TAC have increased in recent years, as has the market price for ling, thus increasing targeting on this species. Unfortunately, data are sparse, particularly for the non-trawl fleet. It was necessary for this assessment to lump all non-trawl gear types together so that nets, longlines, droplines and traps were all assumed to have the same selectivity pattern. Pink ling may be susceptible to localized depletions because the adults are sedentary. Catches in the western area of the SEF, where fishing has been lightest, indicate a much older and larger stock in that region than in the east where catches have been heaviest and have been sustained for the longest period. Unfortunately, again, scarcity of data prevented modelling of separate areas.

The assessment for pink ling was very sensitive to the relative weights given to the CPUE and age frequency data. Greater weight given to a particular data source indicates greater confidence in those data and forces the model to try harder to fit to those data than to other sources that have been given less weight. Giving higher weight to the CPUE data, relative to the age data, caused the estimate of depletion (which for ling is defined as the spawning biomass in the most recent year divided by its pristine size, B_0) in the most recent year of the model to change from roughly 20% (no weight given to the CPUE data) to roughly 70% (great weight given to the CPUE). The length frequency data did not contribute a great deal of information to the assessment. A variety of hypotheses that might explain the data were discussed during a workshop on pink ling but no satisfactory conclusions were reached. Forward projections using the base case model indicate that the current level of catch is unsustainable and also that the impact on the stock of a given level of catch will be greater if a greater proportion of that catch is taken by the non-trawl fleet. However these conclusions cannot be given much credibility because the model clearly does not fit the data; and the base case is only one of a suite of possible models all of which could give quite different results and none of which adequately fit the existing data.

The fishery for spotted warehou is relatively recent, large catches have only been taken since the mid-1980s. The fishery is clearly in a 'building-up phase', with catches still increasing. Spotted warehou show a clear length-depth relationship that can be taken account of as part of an Integrated Analysis assessment. Unfortunately this means that some sort of fleet dynamics process is required when forward projections are performed. In this assessment the proportion of the landed catch that was taken in each of four depth classes during 2000/01 (the most recent year included in the assessment) was applied to every future year. This meant that the whole future target catch could not always be taken and that younger fish in the shallower depth classes were 'protected' from large catches. Therefore the risk of depleting the stock was underestimated. Future work should look into more sophisticated fleet dynamics models, or alternatively should ignore depth structure. The model indicates that although the stock is currently only lightly depleted, future catches at the current high level may cause the stock to decline to undesirably low levels.

It will be possible to improve the assessment for pink ling when more data become available from the non-trawl sector and when the dynamics of this fish are better understood. The assessments for blue grenadier and spotted warehou appear to fit the available data sufficiently well to allow their use in providing management advice (including use in Management Strategy Evaluation) although it must be emphasized that the absolute size of the stock, in both cases, is not well estimated.

Outcomes achieved

The results of these stock assessments were used by the South East Fisheries Assessment Group when providing advice on the status of blue grenadier, pink ling and spotted warehou stocks.

Keywords

Stock assessment, blue grenadier, pink ling, spotted warehou, South East Fishery, risk assessment

1 BACKGROUND

The South East Fishery is managed by an Individual Transferable Quota (ITQ) system that requires annual estimates of Total Allowable Catch (TAC) and annual assessments of stock abundance for the 19 stocks for which quotas are set. TACs for the quota stocks are small by world standards and there usually have not been sufficient resources for the biological monitoring that forms the basis for stock assessment in the world's larger fisheries.

Standard stock assessment techniques are readily available or can be programmed with ease when comprehensive data are available: they are basically a sophisticated accountancy, though not without problems in interpretation. However, these standard techniques are dependant on the data (catch by age, fishery independent abundance indices, etc.) being well known and collected annually. Once these data are either not well known or have not been collected then the standard stock assessment techniques fail or, and more dangerously, provide seemingly accurate but actually misleading information.

The basic fishery and biological data in the South East Fishery are poorly understood for all species (with the exception of orange roughy in the Eastern zone) because:

1. Catch (and discards) by age data are not available for all years and all areas for most species;
2. There are no fishery independent estimates of recruitment or biomass for most species;

Therefore catch-per-unit-effort is used as an index of abundance. However:

3. The effects of technological advances on overall fishing effort are poorly understood;
4. The effects of management-induced changes in fishing practices are poorly understood;
5. The effects of environmentally-induced changes on fish distribution are poorly understood;

The lack of basic fishery and biological data for the South East Fishery quota species, requires a more sophisticated stock assessment than would otherwise be the case. The more sophisticated stock assessments require the development of an underlying simulation model of the species, its biology, distribution and the fishery harvesting it. This is followed by a time-consuming process to fit the model to the available verified data to provide the most likely estimate of the stock's current status in absolute terms and relative to its earlier status. It is a powerful technique, and although the general methodology is now well established, its application to a species requires an individual model to be developed.

This is the approach that has been used for orange roughy and is now being used for gemfish. It is the approach that will be necessary for blue grenadier and tiger flathead, and other quota species for which precise assessments are required, but where comprehensive data have not been collected annually. It is an approach that requires considerable time in understanding the dynamics of a stock and the fishery to be assessed and considerable time in model development and data fitting.

We propose here to appoint a stock assessment scientist for a three year term specifically to provide high quality stock assessments for the species of most concern in the South East Fishery. This scientist would work closely with CSIRO's recognized stock assessment specialists and would actively contribute to the SEFAG.

Blue grenadier is an obvious candidate for a high quality stock assessment – new data have become available and some industry sectors have expressed strong concern over the stock condition. Ling is a species for which new data are becoming available, has a high landed value, is of interest to many sectors of industry, and is a species where catches are increasing (in some sectors) to an unknown extent. Spotted warehou has been accorded a high priority status by SEFAG and is becoming an increasingly important species in terms of landed catch.

2 OBJECTIVES

1. To provide high quality dynamic models and stock assessment advice for three SEF quota species for which there is immediate concern of stock status.
2. To work with industry and managers in developing population dynamics models in a manner that will improve the stock assessment in the SEF and its perception by industry.
3. To use the stock assessments to evaluate stock status against current management performance indicators and to provide advice on alternative performance indicators if necessary.
4. To evaluate the value (in terms of improved assessment) of future data collections and research studies for the assessed species.

3 NEED

Nineteen separate ITQ's (Individual Transferable Quotas) are set in the South East Fishery. Many of these are based on historical catches and are raised or lowered in response to current catch levels in the fishery and to indicators of stock abundance (such as CPUE and average length in the catch). However, formal stock assessments based on mathematical modelling techniques are becoming available for many of these species or species groups. These methods allow researches to integrate all (or at least much) available data for the stocks concerned as well as current understanding of life history and the behaviour of the fishery. Perhaps most importantly, they allow quantification of uncertainty regarding stock status. Stock assessment models can be used to project populations into the future, under a range of different future catch levels and given various assumptions and can give probabilities that these catch levels will achieve pre-specified goals. Formal stock assessment models can also form the basis for Harvest (or Management) Strategy Evaluation (HSE or MSE) a powerful technique for managing fish stocks and taking account of uncertainty which is gaining increased support among fisheries scientists and managers (Punt *et al*, 2001; Smith *et al*, 1996; Polacheck *et al*, 2000; Thomson, 2000a; Tuck *et al*, 2001).

The need for special research projects for individual stock assessments is detailed by the South East Fishery Assessment Group (SEFAG) and endorsed and by the South East Trawl Management Advisory Committee (SETMAC). SEFAG has set a high priory for formal stock assessments for blue grenadier and pink ling. They also set high priorities for blue warehou, redfish, blue-eye trevalla and tiger flathead, all of which have assessments currently under development or, in the case of blue-eye trevalla, proposed and awaiting funding.

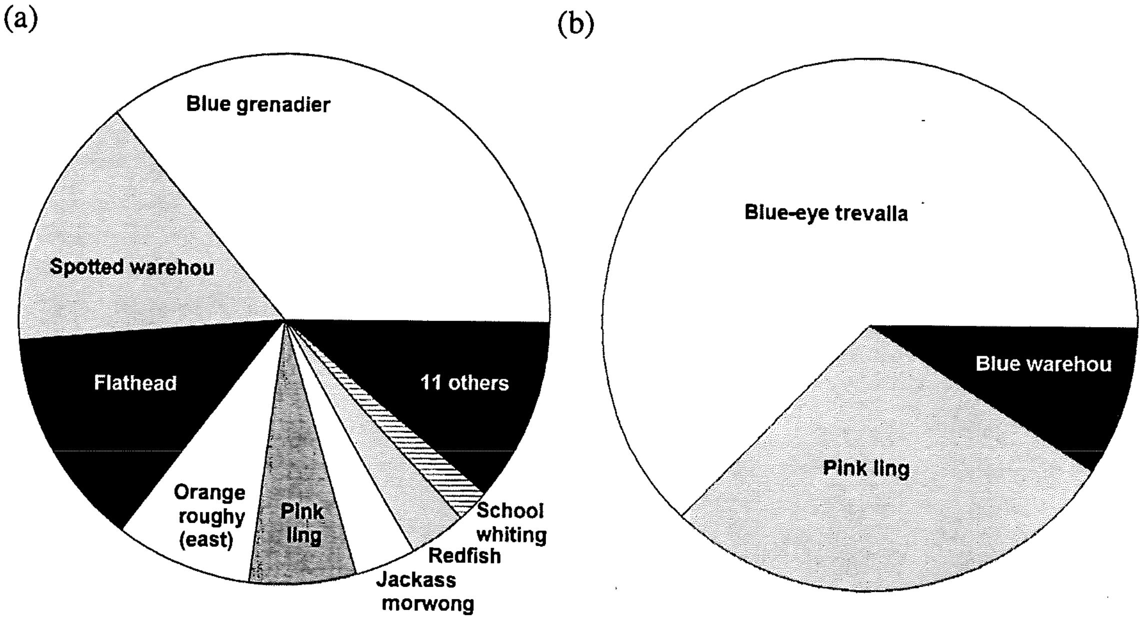


Figure 1. Catches of SEF quota species during 2000 by (a) the trawl fishery and (b) the non-trawl fishery. Data were taken from SEF2 and SAN2 records.

There was considerable controversy regarding the status of blue grenadier stocks in the mid-1990s due to conflict between the relatively optimistic scientific advice (based primarily on acoustic and egg production estimates) and the more pessimistic view of several industry representatives. It has been possible to resolve these views using a stock assessment model which shows that there has been a recent large recruitment event which has lead to an increased number of fish in the stock but which have taken some tie to grow to a size where they can be captured in the spawning run of large grenadier. During 2000 blue grenadier composed the greatest catch (by mass) by the trawl sector of all quota species in the South East Fishery (Figure 1a).

Pink ling are an important species for both the trawl and non-trawl sectors of the South East Fishery (Figure 1). Catches increased substantially during the 80s and 90s in response to increased market value and perhaps to decreases in catches of other fish stocks such as eastern gemfish. An automatic longlining vessel has been permitted to operate in the fishery (Tilzey, 2000). A similar species in South Africa (*Genypterus capensis*) was seriously depleted when a large longline fishery was allowed on top of an already substantial trawl fishery (Punt and Japp, 1994). During 2000 pink ling composed the fifth largest catch (of all trawl quota groups) by mass for the trawl sector of the SEF and the second largest for the non-trawl sector (Figure 1).

Spotted warehou catches have been increasing since the mid-80s and it now forms the second greatest catch by mass for the trawl sector (Figure 1). In 1998 the (unstandardised) CPUE for spotted warehou fell below the lowest level observed during 1986 to 1994 thus triggering one of AFMAs performance criteria for SEF species (Smith and Wayte, 2001).

4 METHODS

These assessments have been developed and improved through consultation with industry, managers, and fishery scientists. This interaction was facilitated by SEFAG's Species Assessment Groups (the Blue Grenadier Assessment Group, BGAG, and the Blue Warehou Assessment Group, BWAG) and by workshops on pink ling.

4.1 Data

Species summaries have been compiled (see Appendices F-H). These involved literature reviews that compiled biological information and population parameters for blue grenadier, pink ling and spotted warehou as well as related species both in Australia and elsewhere. The aim of these summaries was to allow future refinement of the assessments and possibly to feed into future Harvest Strategy Evaluation. The reports on this work are presented in a similar format to the Fish Species Synopsis produced by the United Nations FAO.

The models used the following data: annual landings, annual discards, catch- and discard-at-age and standardised CPUE. The catch- and discard-at-age data are calculated by multiplying a catch- or discard-at-length vector by an age-length key (ALK). If an ALK is not available for a year in which a length frequency is available, the length frequency could be used by the model, instead of the age frequency. The blue grenadier model also uses estimates of absolute female spawning abundance from egg surveys (Bulman *et al*, 1999).

Data are organised according to the six zones identified by Klaer and Tilzey (1994) (Figure 2).

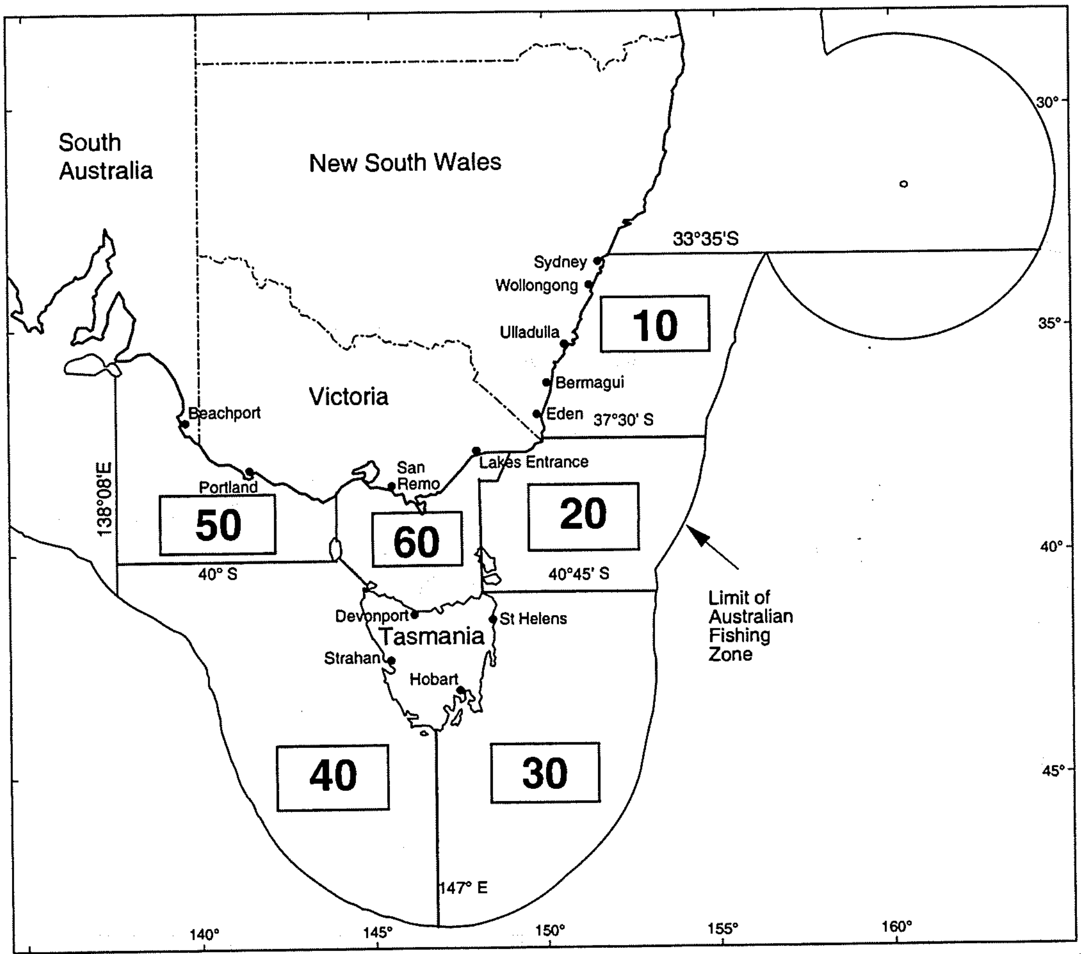


Figure 2. Map of the South East Fishery region showing the six zones identified by Klaer and Tilzey (1994).

4.1.1 Landed catch

Two sources of landed catch data exist for SEF trawl and Danish seine vessels: SEF1 and SEF2. SEF1 is a log-book that is kept onboard fishing vessels that are licensed to fish in Commonwealth SEF waters. In it vessel skippers record several types of data for each deployment of the fishing gear (shot) including the date and time the gear went into the water, the time it was retrieved, the average depth of the water in which is was set, the position of the shot (in latitude and longitude) and their estimate of the mass of the catch by species. When the vessel offloads at a port the landed catch is weighed and its mass (and information on whether or not it was processed onboard) are recorded, by species, in the SEF2 database.

Therefore SEF2 data give an accurate measure of the landed catch (although sometimes the fish are landed in a processed state so that conversion factors need to applied in order to calculate whole weight) but SEF1 gives details such as catch-per-unit-effort (CPUE), depth, and accurate position and date. It has been noted that the SEF1 estimates are always lower than the SEF2 records, possibly because skippers estimate the processed and not the whole weight of the catch.

SEF2 data are ideally used as measures of the landed catch however sometimes it is necessary to disaggregate the data according to some factor that is recorded in the SEF1 and not the SEF2 database. On these occasions the SEF1 data are used but are weighted up by the ratio between the SEF1 and SEF2 totals for that year.

4.1.2 Discarded catch

Data on discarding were collected by the Integrated Scientific Monitoring Program (ISMP; Knuckey & Sporcic, 1999; Knuckey, 2000; Knuckey *et al*, 2001) and its predecessors the Scientific Monitoring Program (Garvey, 1996) and the Interim Integrated Scientific Monitoring Program (Garvey, 1998). These data were provided as the estimated proportion of the catch of a given species that was discarded in each of the SEF zones for a particular year. These discards were then weighted by the landed catch for that species in that SEF zone and combined to give an overall discard rate for the fishery in that year. For blue grenadier the Western Tasmania zone (zone 40, Figure 2) is further broken down into a winter (June-Aug) and a non-winter component in order to distinguish the winter spawning fishery.

4.1.3 CPUE Standardisation

The SEF1 data were used to provide shot-by-shot catch and effort information for trawl vessels. Any investigation of relative annual CPUE for a particular species began by narrowing the SEF1 database down to a dataset that it was hoped would capture the majority of targeted shots for that species. The SEF is a multi-species fishery so it is possible for species to be caught as by-catch when another species or species group was the intended target. The SEF1 logbook has a space for skippers to write down "target species" however it is widely believed that this is done retrospectively (if it is done at all), once the catch is onboard and the dominant species identified. Therefore, unfortunately, it is not possible to identify 'zero shots' when the target species was not caught at all. 'Targetted' shots for a particular species were usually identified for the CPUE analysis by setting a threshold weight for the species in question for each shot. For example, all shots containing more than 30kg of ling were considered to be targeted ling shots. A range of threshold levels are normally evaluated. Another method that was commonly used was to identify the vessels that appeared to concentrate on the species of interest and to include all shots by those vessels in the dataset for CPUE analysis. These vessels were taken to be those that had an average annual landing, of the species under investigation, of greater than some threshold weight (e.g. 1.5 t).

Shots by Danish seine vessels were excluded from the dataset because they do not take a large component of the catches for any of the species considered in this report and are likely to have different dynamics from the trawl vessels.

'Raw' catch-per-unit-effort (CPUE) was calculated by taking the geometric mean of all the shots included in the dataset used for investigation. The geometric mean was preferred to the arithmetic mean because CPUE is thought to follow a log-normal distribution and occasional large CPUE values (which would probably be the result of mistakes during data entry) could have a disproportionate influence on an arithmetic mean.

The General Linear Modelling technique (GLM) was applied to the identified datasets for each species. This was done using the PC-SAS statistical package and Aikake's Information Criterion (AIC) to choose the optimal model. A range of model factors and ways of restricting the dataset were investigated in each case. In some cases a single standardized CPUE series was chosen for use in the stock assessment model, in others one was chosen for use on the base case model and alternative series were included in sensitivity tests.

SEF1 data pertain to trawl and Danish seine vessels only. An equivalent logbook, termed the SAN1, is available for vessels that deploy non-trawl gear (such as lines, traps and mesh nets) and a varified record (similar to the SEF2), termed the SAN2. GN01 records have been kept since 1997 and SAN2 since 1998 whereas SEF1 and SEF2 record keeping began in 1986 (Smith and Wayte, 2000). This time series has therefore been too short to warrant GLM analysis of non-trawl CPUE data.

4.1.4 Length frequencies

Measurements of the length frequency of a particular species in the catch are available from research programs (which typically provide length frequency data for between 1 and 3 years); from State-based monitoring; and since 1992 from the ISMP and its predecessors. ISMP length frequency data take two forms: measurements of the landed catches made at ports and fish markets; and onboard measurements of both the retained and discarded components of the catch.

The port-based measures have greater sample sizes than those made onboard and are therefore used to give the estimated length frequency of the retained component of the catch. The onboard data are used to give the length frequency of the discarded catch. The spotted warehou model, however, uses both the port- and onboard-measured length frequency data for the retained catch.

The length frequency for a particular year was calculated by catch weighting the length data. First, each sample was weighted up to the catch for that shot. Then samples that were taken in the same month, year and SEF zone (and in the case of spotted warehou, depth class) were added together. These were further weighted up to the total SEF1 catch for that month, year, area (and depth class) before being added together to give the estimated length frequency of the entire catch for the fishery for that year.

4.1.5 Age data

The ISMP program takes otoliths from a randomly selected component of the catch, for which length measurements were recorded. These are sent to the Central Aging Facility (CAF) for reading. The resulting age and length measurements are used to construct age-length keys (ALKs) for particular years. These are applied to the length frequency data for corresponding years in order to calculate the age frequency of the catch (or discard).

The ALK data for all years for which otoliths were read are combined in order to calculate the parameters of the von Bertalanffy growth curve for that species. Account is not taken of the effect of fishing selectivity on the sampling process however it is recommended that future work examine this problem.

"Missing lengths" sometimes occur in the ALK; this happens when no fish from a particular length class were sampled and aged. This often reflects poor sample size or problems due to converting from one length measurement to another however sometimes it reflects a real bias such as when fishers do not allow researchers to remove otoliths from large fish because the resulting damage might reduce the value of the fish at the market.

The conventional way of using an ALK results in "missing" length classes being ignored altogether i.e. they are effectively excluded from the length frequency. Clearly this could lead to serious inaccuracies in the calculation of the age frequency of the catch, particularly when the ALK sampling is biased. In order to overcome this problem an algorithm was applied which used the von Bertalanffy growth curve to "fill" in missing length classes. If no sample was recorded for a particular length class then the von Bertalanffy was used to allocate an age to that length class and a single "sample" was added to that length-age cell. Simulation testing has yet to be conducted to investigate the effect of this method on model results and to compare it to other possible ways of dealing with the problem of "missing lengths".

4.2 Stock Assessment Method - Integrated Analysis

4.2.1 Suitability for the SEF

The stock assessment method that has been applied to the three SEF species is the Integrated Analysis method (Methot, 1989, 1990; Fournier and Archibald, 1982). This method is highly suited to SEF assessments because it does not require unbroken time series of data and because it is very flexible.

Unbroken time series of data are available for considerable periods for many of the important fish stocks in the Northern Hemisphere and various forms of Virtual Population Analysis (VPA) are commonly used to assess them. SEF work is often project-driven, data may have been collected for a period of up to three years and then not again until several years later during the course of a second project. The ISMP and its predecessors have been collecting an unbroken time series of catch- and discard-at-length and -at-age data for quota species since the early 1990's (Knuckey & Sporcic, 1999; Knuckey, 2000; Knuckey *et al*, 2001; Garvey, 1996, 1988). However most SEF quota species were already heavily exploited by the 1990's. Were VPA techniques to be applied to SEF data it would be necessary to use data from only the early 1990's to the present, making it difficult to assess current stock status relative to early, unfished or almost unfished, levels. Alternatively, the gaps between the earlier data collections and the SMP/ISMP data would have to be filled by some form of educated guesswork. VPA techniques assume that catch-at-age data are collected without error, therefore any incorrect assumptions that are made when 'filling in the gaps' could have a profound influence on the results of the VPA assessment.

Another advantage of the Integrated Analysis framework is that it is relatively easy to incorporate a variety of types of data into the assessment. Therefore data that have been collected during the course of various projects can be made use of in order to improve the assessment model. More rigid stock assessment frameworks, such as VPA, might be forced to ignore these data or to use them in an informal manner only when evaluating the results of the assessment. Thus the ling assessment, presented here, was able to use length data that were collected by research cruises; the blue grenadier assessment uses the results of two egg abundance surveys; and the spotted warehou assessment uses both port and onboard-measures of catch-at-length and makes use of the catch-at-depth recorded for the onboard data.

The Integrated Analysis approach is perceived to provide a better basis for the evaluation of alternative harvest strategies (Punt and Hilborn, 1997). Simulation testing has shown that these models perform well relative to other widely-used methods (Punt *et al,* 2001). This technique has been applied to a number of SEF species besides the three dealt with here: eastern gemfish (Smith and Punt, 1998), blue warehou (Punt, 1999a), school whiting (Punt, 1999b), orange roughy and tiger flathead (Smith and Wayte, 2000).

4.2.2 Application to three SEF species

It has already been stated that Integrated Analysis is a highly flexible method that can be tailored to suit the biology and available data for each species and fishery considered. Appendix A describes a generic form of this model and the models used for each of the three species dealt with here is a special case of this model. The chapters dealing with those species individually describe, in the 'Modelling Methods' sections, how the generic model in Appendix C has been tailored for that species.

4.2.3 Base case and sensitivity tests

For each of the three assessments conducted a base case stock assessment model was chosen. The base case model consists of a particular set of estimable model parameters; various functional forms (such as logistic selectivity curves); the values of biological and other non-estimated parameters (such as L_∞ and the steepness of the stock-recruit relationship); the weighting given to each data source; and the dataset used.

The sensitivity of the model to different functional forms, parameter values, weightings and to the exclusion of certain data are investigated by changing one aspect of the base case model and then comparing the specific result of the altered model to those of the base case model.

The AD Model Builder package (Otter Research, 2000) was used to implement and run these models. Probability intervals for parameters and derived quantities of interest were calculating using the Markov Chain Monte Carlo (MCMC) algorithm (Gelman *et al.*, 1995; Punt and Hilborn, 1997) that is part of the AD Model Builder package.

The models are Bayesian in that prior distributions are assumed for all model parameters. These are always chosen to be uniform or uniform on a log-scale.

Data sources (such as landed catch and catch-at-age) are weighted either by an assumed sample size if a multinomial error structure is assumed for the residuals) or by a c.v. value (if a log-normal is assumed). An effort is made to ensure that the c.v.s that weight the data are similar to those of the residuals (i.e. the 'input' and 'output' c.v.s) for the base case model. An additional parameter (σ_{all}) is estimated during exporation of the base case model. This parameter is applied as a multiplier to the weighting c.v.s. These are adjusted until the estimate for σ_{all} is approximately 1.0.

4.2.4 Risk analysis / projections

The risk to the stock of various levels of future catches is investigated by projecting the base case model into the future, assuming a fixed level of future catch. This catch is divided among fleets according to a fixed proportion (usually equal to the recently observed split of landings between these fleets).

When the population is projected forwards future recruitment residuals are drawn randomly from a log-normal distribution with median zero and c.v. equal to the value that is assumed (as a weight) when fitting the base case model to the data. The values of the model parameters are not held to be constant but are drawn with replacement from the posterior distribution of these parameters (this is done using the MCMC algorithm and AD Model Builder, as mentioned above). A large number of iterations are performed, each with a different set of recruitment residuals and model parameters, and the median and 90%-ile calculated from the results.

The projections are based on fixed levels of *TAC* and hence should over-estimate risk because such projections implicitly assume that future data will be ignored.

5 BLUE GRENADIER (*Macronurus novaezelandiae*)

A.E. Punt, R.B. Thomson, D.C. Smith, M. Haddon, X. He, and J. Lyle

5.1 History of the fishery

Catches of blue grenadier in the SEF were not large until the late 1970s when catches increased in Tasmanian waters (Last *et al*, 1983). Large blue grenadier aggregate off the west coast of Tasmania (in zone 40, Figure 2) during winter in order to spawn. Large catches have been made at this time and this is termed the winter spawning fleet. Catches by the non-spawning fleet primarily comprise sub-adult and small adult fish whereas the spawning fleet concentrates on mature fish, including large adults that are poorly represented in the catches by the non-spawning fleet.

Catches of non-spawning grenadier (i.e. those taken at other times and places) were greater than those taken during the spawning run between 1986 when monitoring began and 1995. Catch rates in the non-spawning fleet declined almost continuously from 1990 to 1997, a period when catches in the spawning fleet increased by over 300%, even though they never reached the Total Allowable Catch, *TAC*, which was raised in 1994 to 10,000*t* (Figure 3). This led to concern amongst some fishers who operate primarily in the non-spawning fleet that the *TAC* for the fishery was too high and that their reduced catches were a consequence of overexploitation by, or competition with, the spawning fleet. This view was in stark contrast to those of fishers who operated primarily in the spawning fleet whose catch rates had been stable over the 1990s. Large numbers of juvenile grenadier began appearing, first in the discards and later in the catches, indicating good recruitment in the past. In 1997 the Blue Grenadier Assessment Group (BGAG; Tilzey, 1998) was formed in order to help guide management of this fishery.

Since 1997 several large factory trawling vessels from New Zealand have participated in the winter fishery. With the entry of these vessels into the fishery the quantity of fish taken by mid-water trawl rather than demersal trawl has increased. Concern regarding the accidental drowning of seals and sea lions by factory trawlers lead to the trialling of seal excluder devices on the nets of these vessels during the 2000 and 2001 winter fishery (Smith and Wayte, 2001).

Prior to the establishment of BGAG in 1997, assessments were based primarily on inferences from swept area trawl surveys and egg production estimates of abundance (Bulman *et al.*, 1999). These inferences combined with an investigation based on stock reduction analysis implied that the fishery had little impact on the resource as a whole (Punt *et al*, in press). Several sources of data (e.g. catch rates, age-composition data) were, however, not explicitly considered in past assessments.

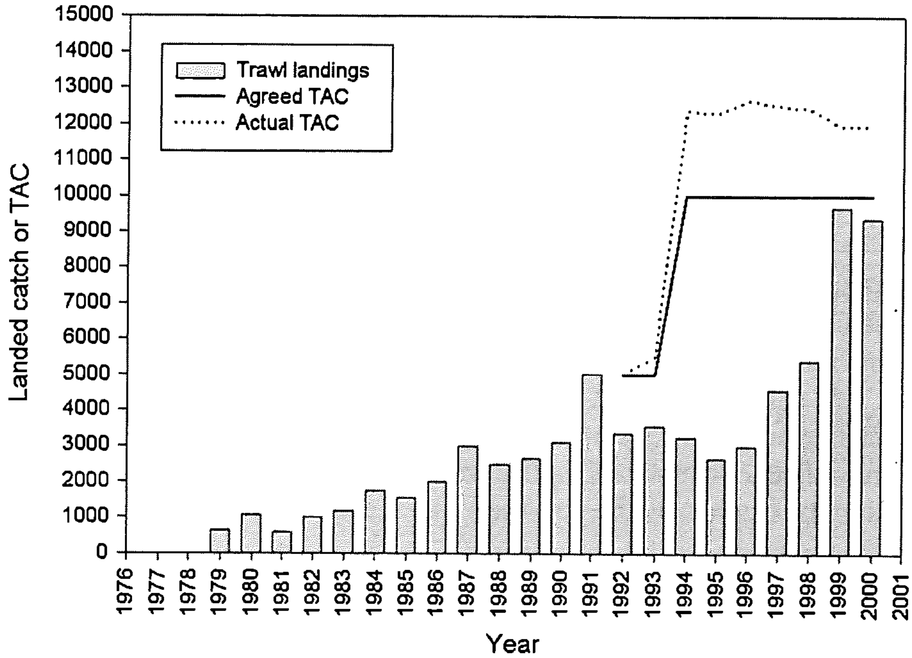


Figure 3 Estimated landed catches of blue grenadier for the period modelled, and allocated and actual TACs for the SEF. The actual TAC is the allocated TAC adjusted for carry-over and carry-under from the previous year.

5.2 Biological Background

5.2.1 Habitat and related species

Blue grenadier (*Macruronus novaezelandiae*) are found from mid-New South Wales to southern Western Australia, including the coasts of Tasmania and across the Great Australian Bight (Smith, 1994a). Most blue grenadier are taken between 300 and 600m with a peak in catches occurring in the 450 – 550m depth range (Smith, 1994a; Smith, 1998).

5.2.2 Stock structure

No evidence has been found to suggest stock structure in blue grenadier in the SEF from investigations using biochemical genetic techniques (Milton and Shaklee, 1987); morphometrics and meristics (Kenchington, 1989); or parasite loads (Milton and Shaklee, 1987). Gunn *et al.* (1989) and Thresher *et al.* (1989) found no evidence from egg and larval surveys however, more recently, Bruce *et al* (in press) have found some evidence of larval blue grenadier hatching east of Bass Strait. It is not known, as yet, whether this is a regular or periodic phenomenon.

5.2.3 Biological parameters

Natural mortality is estimated by the model but is constrained to lie between 0.2 and $0.3y^{-1}$. This choice and those for the recruitment parameters (Table 1) are based on selections made in New Zealand (e.g. McAllister *et al.*, 1994; Ballara *et al.*, 1997). The values for the von Bertalanffy growth curve (Table 1) were derived by combining all age-length information and fitting a von Bertalanffy. The length-weight relationship was provided by David Smith (*pers comm*) (Table 1). Other parameters were chosen by BGAG.

Table 1. Values for biological parameters used in the stock assessment of blue grenadier

Description	Value
Length-weight relationship:	
a	$0.00375\ g^{-1}.cm$
b	3.013
von Bertalanffy growth curve:	
L_∞	107.66 cm
K	$0.135\ y^{-1}$
$t0$	-2.570 y
Natural mortality rate:	
M	estimated $(0.2, 0.3)\ y^{-1}$
Other:	
length-at-maturity (l_m)	70 cm
steepness (h)	0.9
μ	0.77

5.3 Data

5.3.1 Landed catch

Blue grenadier landings were not closely monitored prior to 1986 but members of BGAG, using Tasmanian records (Lyle, 1989), and expert judgement have been able to estimate the catch history prior to this date (Table 2). Annual landings data for 1986 onwards are taken from the SEF1 log-book database and are separated into spawning (all catches taken in zone 40 during June, July and August of each year) and non-spawning (all other times and places). SEF1 catches are always found to be underestimates of the catches recorded by SEF2, therefore figures are multiplied by 1.2 for the spawning and 1.4 for the non-spawning fleets in order to reflect this under-estimate. This factor is lower for the spawning than for the non-spawning fleet because some fish, landed in a headed-and-gutted state, were recorded as having been landed whole. These factors were chosen by BGAG. An additional correction factor is applied to the landings for the spawning fleet to correct for losses due to over-full fishing nets bursting while being hauled on board ('burst bags'). Percentage losses due to 'burst bags' were estimated by the assessment group up to 1996, thereafter the assumption is made that non-factory vessels lose 5% of their catch to burst bags but that the factory vessels that entered the spawning fishery in 1997 do not suffer any burst bags. For 1997-2000 the 'burst bags' factor is therefore 95% of the proportion of the spawning catch that was taken by the Australian fleet (Table 2).

Table 2. Landed and discarded catches for the winter spawning and non-spawning fleets, by calendar year. The landings data have been adjusted as described in the text; blanks indicate unknowns.

Year	"Burst bags" correction for spawning	Landings (tonnes)		Discards (tonnes)	
		Spawning	Non-spawning	Spawning	Non-spawning
1979	1	294.0	343.0		
1980	1	492.0	574.0		
1981	1	270.0	315.0		
1982	1	468.0	546.0		
1983	1	540.0	630.0		
1984	1	810.0	945.0		
1985	1	720.0	840.0		
1986	1	296.6	1698.2		
1987	1	938.8	2052.8		
1988	1	382.8	2105.2		
1989	1	43.3	2601.5		
1990	0.95	719.5	2380.0		
1991	0.95	1122.1	3891.4		
1992	0.95	901.6	2459.5		
1993	0.80	1218.4	2334.4		
1994	0.85	1375.4	1873.9		
1995	0.90	1214.5	1425.5		111.3
1996	0.95	1515.1	1485.0		1364.7
1997	0.9944	3165.1	1407.1		5201.8
1998	0.9939	3319.0	2078.3		1860.6
1999	0.9974	6563.1	3114.6		172.9
2000	0.9976	6898.6	2458.0		97.0

5.3.2 Discarded catch

Discard rates for the non-spawning fleet were measured by the ISMP. The estimated tonnages of fish discarded are shown in Table 2.

5.3.3 CPUE

CPUE data were standardised using GLM analysis (Haddon, 2001a), (Table 3). Two standardised CPUE series were made available, one used catch and effort information from all vessels in the fishery ("big boats" CPUE series) and the other excluded the information from two of the large factory vessels that have operated in the spawning fishery recently (Haddon, 2001a). This CPUE series did include data from three other factory vessels which had operated in different years, treating these three as a single vessel for the purposes of the standardisation ("No big boats" CPUE series). In future a third CPUE series will be calculated, one that excludes data from all factory vessels. The "big boats" CPUE was used in the base case.

Table 3. Standardised CPUE (Haddon, 2001a) for the spawning and non-spawning fleets. The results for the spawning fleet include all the factory vessels that have taken the bulk of the catches in recent years (With "big boats") or exclude them ("No big boats")

Year	Spawning (With "big boats")		Spawning ("No big boats")		Non-spawning	
	CPUE	number of shots	CPUE	number of shots	CPUE	number of shots
1986	1.009	79	0.981	79	1.937	2240
1987	0.931	196	0.906	196	2.550	2400
1988	1.625	91	1.621	91	2.665	2674
1989	0.590	30	0.548	30	2.572	3154
1990	0.882	140	0.848	140	2.764	2711
1991	2.462	135	2.377	135	1.982	3679
1992	1.286	173	1.227	173	1.773	3155
1993	2.275	159	2.234	159	1.258	3750
1994	1.699	310	1.646	310	1.104	4010
1995	0.732	474	0.729	474	0.781	4585
1996	1.100	490	1.116	490	0.681	4774
1997	0.917	535	0.897	417	0.695	5041
1998	0.963	572	0.999	572	1.225	5187
1999	0.913	861	1.000	625	1.356	6778
2000	1.000	948	0.949	750	1.000	6219

5.3.4 Catch-at-age

Information on the length and age composition of the catches are available from research surveys (which used commercial gear and vessels) performed during 1984 and 1985 (Wankowski, 1987; Moulton and Wankowski, 1985) and during 1987-1989 (Smith *et al*, 1995). Monitoring of the catches by the ISMP and its predecessors provide continuous information from 1992. Sample sizes for these data are shown in Table 4 and the length- and age-frequencies themselves in Appendix D. Age-length keys (ALKs) are available for each of these years although those for 1984 and 1985 had to be combined due to poor sample size (Table 4, Figure 4).

Absolute estimates of the female spawning biomass in 1994 and 1995 are available from egg surveys (Bulman *et al*, 1999) (Table 4).

Table 4. Sample sizes for ALKs and absolute estimates of spawning biomass from egg surveys. 'Y' indicates that a sample is available but size is unknown due to prior weighting of the sample. The s.e.s of the egg estimates are shown in parentheses.

Year	Spawning fleet		Non-spawning fleet		ALK	Egg estimates (tonnes)
	Catch-at-length	Discard-at-length	Catch-at-length	Discard-at-length		
1984	Y		1935		278*	
1985	Y		1829		278*	
1986						
1987			Y		513	
1988	Y		Y		561	
1989			Y		529	
1990						
1991	Y		Y			
1992	Y		Y		813	
1993	Y		Y		1178	
1994	Y		Y		1270	57772 (10386)
1995	Y		Y	(Y)+	1088	41409 (11949)
1996	Y		Y	Y	1313	
1997	Y		Y	Y	1836	
1998	Y		Y	Y	2466	
1999	Y		Y	Y	1526	
2000	3223		Y	Y	2385	

* these are combined sample size (see text)
+ this sample was not used in the assessment model

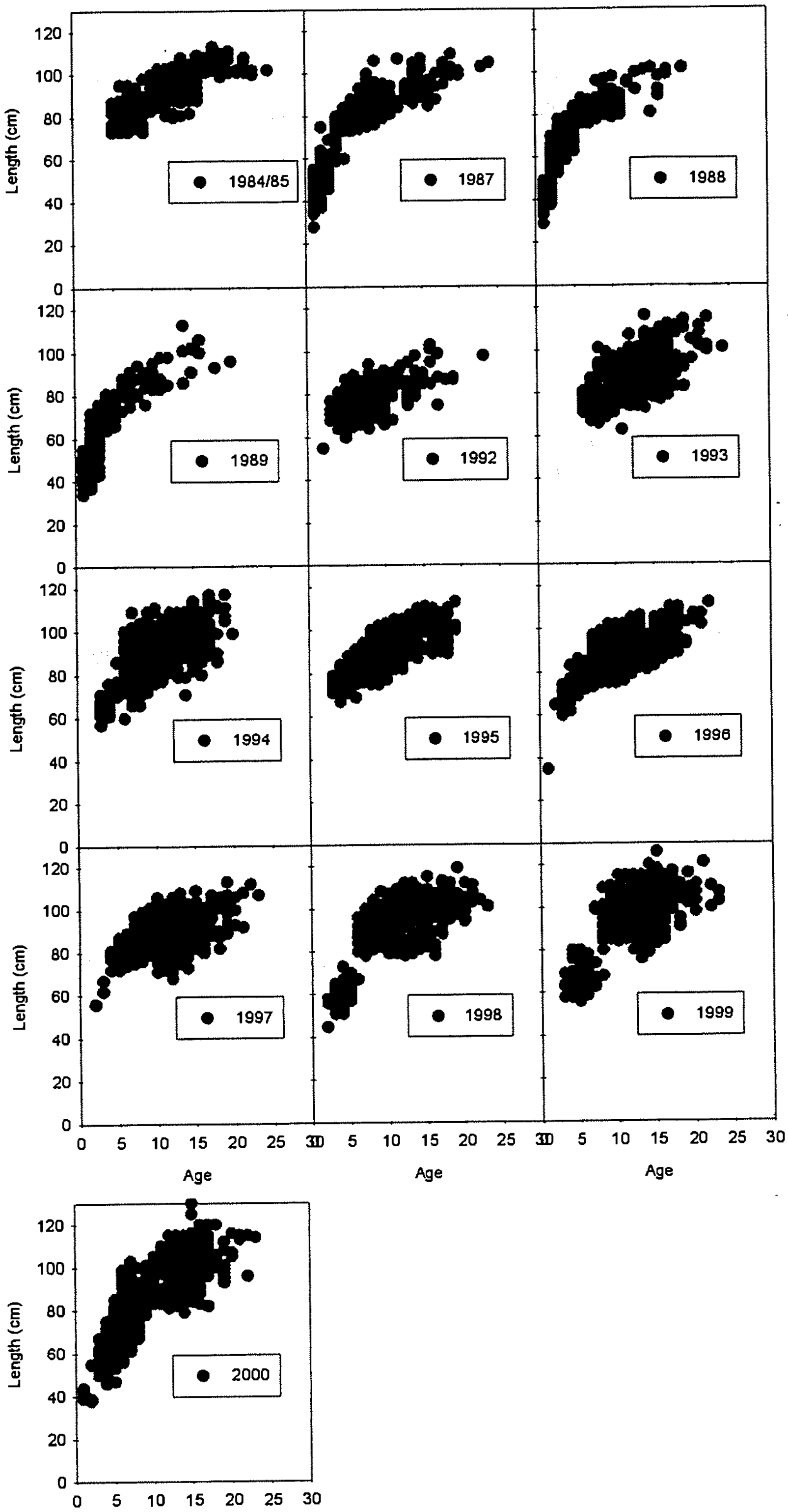


Figure 4. Age-length key (ALK) data for blue grenadier

An ageing error matrix was calculated by the Central Ageing Facility by re-reading a sub-set of the otoliths and recording both ages (Table 5).

Table 5. The ageing error matrix for blue grenadier. The columns are the age originally allocated to the otolith and the rows are the ages that were assigned to the otolith when it was re-read. The numbers in the table indicate the number of samples. Note that the 'total' shown in the last row may not be equal to the sum of the samples in that column as some of the otoliths were allocated an age greater than 15.

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	88	11	0	0	0	0	0	0	0	0	0	0	0	0
3	0	25	171	37	4	0	0	0	0	0	0	0	0	0	0
4	0	1	39	155	22	1	0	1	0	0	0	0	0	0	0
5	0	0	2	19	73	25	2	0	0	0	0	0	0	0	0
6	0	0	0	2	41	236	70	6	4	1	0	0	0	0	0
7	0	0	0	1	3	33	82	40	17	6	1	0	0	0	0
8	0	0	0	0	1	2	39	88	30	10	5	3	0	0	0
9	0	0	0	0	0	2	3	44	140	41	9	1	1	0	0
10	0	0	0	0	0	0	3	10	48	124	43	15	1	0	0
11	0	0	0	0	0	0	1	1	7	30	68	33	10	1	0
12	0	0	0	0	0	0	0	1	1	5	26	65	25	8	3
13	0	0	0	0	0	0	0	0	0	2	6	28	45	20	5
14	0	0	0	0	0	0	0	0	0	0	1	7	31	50	14
15+	0	0	0	0	0	0	0	0	0	0	0	3	7	16	24
Tot	12	118	223	214	144	299	200	191	247	219	159	155	121	101	68

5.3.5 Discard-at-age

Discard-at-length data are available for the non-spawning fleet from 1996 (from the ISMP) (Table 4). A sample is also available for 1995 but has been excluded from the dataset due to poor sample size and peculiar pattern (Appendix D). The length composition and ALK data were used to calculate catch-at-age, discard-at-age (see Appendix D), and mean length-at-age data (Table 6).

Table 6. Calculated length-at-age (cm) for all years included in the model. Blank cells indicate that data were not available, average length-at-age (the row marked "mean") is used for years or age classes for which ageing data were not available. These average values were used for all age classes in all years for the "Method 1" sensitivity test.

	Age																			
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mean	44.8	53.6	60.4	66.1	71.6	76.6	79.7	82.7	84.6	87.4	88.9	91.3	92.8	93.4	95.5	95.8	99.1	99.7	100.2	101.8
1979																				
1980																				
1981																				
1982																				
1983																				
1984	43.4	49.9	55.4	62.6	75.5	77.9	80.5	80.3	79.8	91.7	92.3	92.9	93.3	92.6	95.0	95.9	103.3	106.4	103.5	105.2
1985	42.6	49.6	56.3	63.1	73.7	78.5	81.2	80.9	80.8	90.3	91.5	91.7	91.7	91.1	94.5	96.8	102.3	105.1	104.1	105.5
1986																				
1987	51.3	58.3	58.2	70.6	77.6	79.1	80.7	83.4	83.2	84.3	84.8	86.3	90.9	91.7	93.4	90.5	91.3	99.6	100.4	99.7
1988	46.3	57.4	65.9	69.7	73.6	81.1	79.9	84.2	86.8	85.2	85.2	95.3	95.8	101.0	92.1	93.8	99.5	99.7	102.0	
1989	50.9	59.9	67.7	72.4	74.7	77.9	80.7	82.9	81.4	87.3	86.4	88.8	92.8	92.6	97.1	102.1	99.0	93.0		96.0
1990																				
1991																				
1992		53.3	66.0	68.5	70.9	72.3	73.9	75.0	78.1	76.2	82.6	88.6	92.0	95.2	93.1	97.1	94.7	98.2	92.6	102.2
1993	43.6	49.2	56.3	59.6	65.3	74.7	74.6	76.0	78.7	83.2	84.2	84.4	85.7	89.5	93.6	93.2	96.0	96.4	95.0	100.9
1994	43.5	47.8	59.3	63.7	68.5	77.9	78.9	78.3	82.3	86.6	87.0	92.1	93.7	91.8	97.2	95.4	98.6	93.9	103.5	99.4
1995	41.3	66.2	70.4	71.4	76.6	78.6	82.8	82.9	83.4	87.3	90.1	92.9	95.5	95.7	99.9	97.1	96.3	98.5	102.2	
1996	45.8	54.5	66.7	72.8	77.5	76.1	80.0	84.6	83.4	84.6	86.5	89.8	91.0	90.9	94.0	95.9	98.9	101.1	97.2	97.7
1997	45.4	49.4	54.0	70.9	79.5	80.2	85.2	87.5	87.8	85.9	87.1	88.8	90.8	89.4	93.7	92.4	99.2	99.1	98.6	101.3
1998	42.5	54.1	55.6	56.9	58.9	81.3	84.9	92.8	94.7	93.0	93.1	92.6	95.8	97.2	98.3	94.8	102.0	101.7	103.2	101.2
1999	42.9	49.7	56.5	60.8	61.9	64.8	78.2	87.0	93.9	91.6	94.5	94.7	91.9	91.7	95.4	94.2	101.1	97.7	98.9	101.6
2000	42.3	51.7	57.6	62.5	68.3	72.5	74.2	81.6	89.7	96.3	99.6	98.5	97.6	97.6	99.4	102.6	104.8	105.8	101.2	110.7

5.4 Modelling Methods

5.4.1 Base case model

A single stock of blue grenadier is assumed by the base case model. Two fleets, or in this case, sub-fisheries are modelled – the spawning fleet operating during June-August in Western Tasmania (zone 40) and the non-spawning fleet operating at other times and places. Male and female fish are modelled separately although the only difference between them is that the natural mortality rate for males is 1.2 times that of females, based on assumptions made in New Zealand (e.g. McAllister *et al.*, 1994; Ballara *et al.*, 1997). Depth structuring is not considered (i.e. a single depth class is used). Estimates of female spawning biomass from egg surveys conducted during 1994 and 1995 are used in the model as absolute estimates. This model is a variant of the model described in Appendix A (Table 7).

Table 7. Some of the choices made for the base case Integrate Analysis model applied to blue grenadier.

Aspect of model	Choice	Details
Stocks	1	
Fleets	2	Spawning and non-spawning trawl
Selectivity pattern	Spawning	Logistic
	Non-spawning	Logistic with a decreasing right-hand side
Sexes	2	
Depth classes	1	
Years	1979-2000	
Ages	1-15 or 1-20	20 is a plus group for the population
		15 is a plus group for the estimator
Lengths	not modelled	only used as mean length-at-age
Initial conditions	Unfished at the start of 1979	$F_{f,0} = 0$ for all fleets (see Appendix C)
Egg data	Yes	1984 and 1985
Stock-recruit relationship	Yes	Beverton-Holt
Method for fitting age frequencies	Multi-nomial	

Data were formulated by calendar year (i.e. 1 Jan to 31 Dec). The population is considered to be in an unfished state at the start of 1979. A plus group is modelled at age 20 but catch- and discard-at-age data are further summed into a plus group at 15 when used to calculate the negative log-likelihood. The model is age-structured and length is only considered as mean length-at-age i.e. catch- and discard-at-length data are not used in the model and selectivity and discarding are functions of the mean length-at-age. Discarding is considered to be density dependant (more discarding of larger cohorts) and a parameter is estimated which controls the strength of this density dependence.

Fishing mortality rates are estimated for each fleet and each year modelled. Recruitment residuals are estimated for each age in the first year (except for the plus group at 20) and for the first age in each year. The weights that were applied to the data are shown in Table 8.

Table 8. Weighting factors used in the base case model.

Parameter	Description	Value
$N^{c/da}$	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
σ_c'	c.v. for the age composition of the landings	0.2
σ_d'	c.v. for the age composition of the discards	0.2

The model has 97 parameters: 2 catchability co-efficients; 1 female natural mortality, 1 average recruitment at unfished level R_0; 22 annual fishing mortality rates for each of the two fleets; recruitment residuals for 21 years and 19 age classes in the first year; 2 selectivity parameters for the spawning fleet and 3 for the non-spawning; and 4 parameters for the probability of discarding-at-length function (Table 9).

Table 9. Parameters of the base case model for blue grenadier.

Parameter	Description	Number
q	Catchability	2
M	Natural mortality	1
R_0	Average recruitment at the unfished level	1
F_y^f	Fully-selected fishery mortality	44
ε_y, ε_a	Recruitment residuals	40
S_a^f	Selectivity	5
d_a	Discarding (including 1 density dependence parameter)	4
		97

5.4.2 Risk analysis / projections

One thousand draws were made from the posterior distributions for the parameters of the model as well as certain quantities of interest (such as B_0 and spawning biomass in the last year included in the model). These 1000 draws were used to project the population into the future, assuming log-normal errors in recruitment (with c.v. of 1.0) and some fixed future TAC. Previous calculations (Thomson, 2000b) have assumed that all fish will revert to the average length-at-age in future. This has been amended so that the von Bertalanffy equation is used to project the length-at-age one year into the future, starting at the length estimated for 2000 (Table 2). Cohorts entering the fishery after 2000 are, however, assumed to have the mean length-at-age despite the size of future recruitments i.e. future density dependant growth is not considered.

Future TACs are divided between the spawning and non-spawning stock in a ratio of 0.72 : 0.25.

5.5 Results and Discussion

5.5.1 Base-case analysis

The estimated natural mortality figure for females is 0.20 and consequently that for males is 0.24 (= 1.2*female natural mortality). The estimated numbers of grenadier in each age class in each year is shown in Table 10.

Table 10. Estimated number of blue grenadier (males and females) at age for each year included in the base case model.

	Age														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1979	54.52	25.96	15.64	10.21	5.28	6.95	9.41	9.92	7.91	3.23	2.50	1.94	1.55	1.25	5.18
1980	36.51	43.70	20.80	12.52	8.17	4.23	5.56	7.53	7.94	6.34	2.59	2.00	1.56	1.24	5.17
1981	14.27	29.24	34.96	16.62	10.00	6.52	3.37	4.43	6.01	6.35	5.07	2.07	1.60	1.25	5.15
1982	16.01	11.44	23.44	28.01	13.31	8.01	5.22	2.70	3.55	4.82	5.09	4.07	1.66	1.29	5.15
1983	20.02	12.83	9.16	18.75	22.39	10.63	6.39	4.17	2.16	2.84	3.86	4.08	3.26	1.33	5.18
1984	20.54	16.04	10.26	7.32	14.97	17.87	8.48	5.10	3.33	1.72	2.27	3.09	3.26	2.61	5.23
1985	39.41	16.44	12.82	8.19	5.83	11.88	14.18	6.73	4.05	2.64	1.37	1.81	2.46	2.61	6.27
1986	51.04	31.55	13.14	10.23	6.53	4.63	9.43	11.27	5.35	3.22	2.11	1.10	1.45	1.97	7.11
1987	57.23	40.70	25.05	10.40	8.08	5.15	3.65	7.44	8.93	4.25	2.56	1.68	0.88	1.16	7.28
1988	40.25	45.47	32.22	19.83	8.18	6.33	4.04	2.87	5.87	7.04	3.36	2.03	1.33	0.69	6.71
1989	15.14	32.10	36.08	25.48	15.66	6.46	5.01	3.19	2.28	4.67	5.60	2.67	1.62	1.06	5.95
1990	4.72	12.05	25.45	28.54	20.15	12.38	5.10	3.98	2.54	1.81	3.73	4.47	2.14	1.30	5.64
1991	7.95	3.76	9.56	20.13	22.51	15.85	9.73	4.01	3.14	2.01	1.44	2.96	3.56	1.70	5.55
1992	10.13	6.31	2.96	7.49	15.68	17.48	12.27	7.54	3.13	2.46	1.58	1.13	2.34	2.81	5.76
1993	7.38	8.07	5.00	2.33	5.87	12.28	13.68	9.60	5.90	2.45	1.92	1.24	0.89	1.85	6.81
1994	9.31	5.87	6.40	3.94	1.83	4.60	9.54	10.64	7.46	4.58	1.91	1.50	0.97	0.70	6.84
1995	115.59	7.42	4.67	5.04	3.09	1.43	3.57	7.42	8.27	5.83	3.59	1.50	1.18	0.77	5.96
1996	72.51	92.30	5.85	3.66	3.96	2.42	1.12	2.81	5.83	6.51	4.60	2.84	1.19	0.94	5.35
1997	19.57	57.71	73.06	4.59	2.86	3.07	1.88	0.87	2.19	4.56	5.09	3.60	2.23	0.93	4.96
1998	15.78	15.54	45.69	57.54	3.53	2.17	2.34	1.44	0.67	1.68	3.48	3.89	2.76	1.71	4.53
1999	3.21	12.48	12.10	35.46	44.58	2.73	1.62	1.76	1.09	0.51	1.27	2.64	2.95	2.10	4.76
2000	2.49	2.54	9.80	9.37	27.19	34.09	2.07	1.16	1.25	0.77	0.36	0.90	1.88	2.10	4.89

The low sigma (σ_c) value assigned to the landings data give these data great weight, forcing the model to fit these data extremely well (Figure 5). It is able to fit the recent drop in the mass of the discards however the large discard measured in 1998 is not well estimated despite the ability of the model to allow for density dependant discarding (Figure 5).

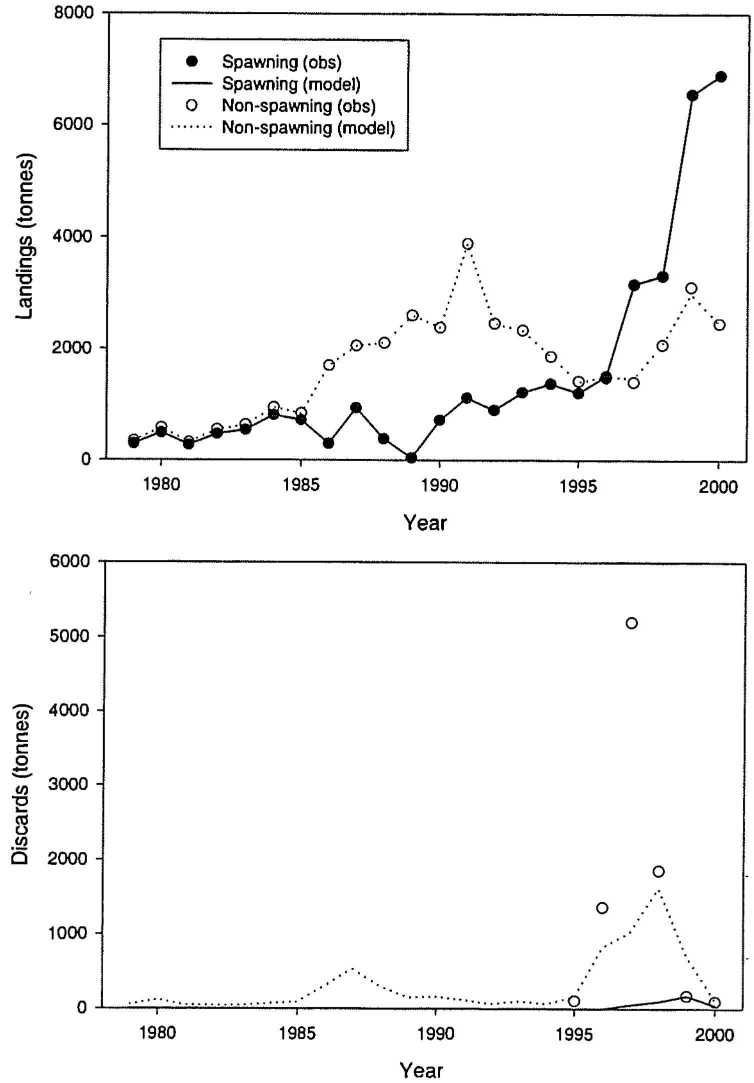


Figure 5. Annual landings of blue grenadier from log books (obs) and estimated by the base case model (model) in the top plot; and discards measured by the ISMP (obs) and estimated by the model (model). The spawning and non-spawning fleets are shown.

The model is not able to fit the early fluctuations in the CPUE for the winter spawning fleet but it is able to achieve a reasonably good fit to the CPUE for recent years (Figure 6). The fit to the CPUE for the non-spawning fleet 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 for this year, consistent with the growth of a large cohort of grenadier spawned in 1994.

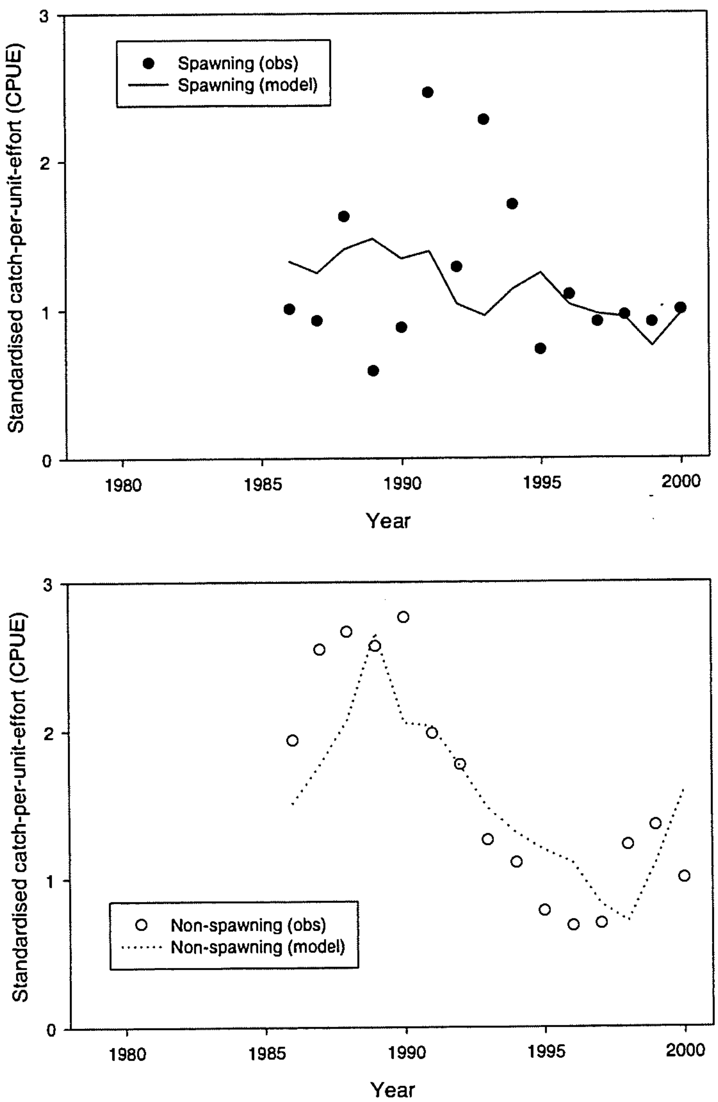


Figure 6. Catch-per-unit-effort (CPUE) calculated using a GLM to standardise CPUE from log-books (obs) and model estimated CPUE (model) for the winter spawning fleet (top plot); and the non-spawning fleet (bottom plot).

The fits to the age-composition data are adequate in that the model is generally able to follow the patterns of strong and weak year-classes (Figure 7). In particular, the model is able to fit the two periods of above average recruitment and the period (1990-94) of poor recruitment. However the 1994 cohort is consistently under-estimated for the non-spawning fishery. The primary reason for this seems to be the lower than expected CPUE for the non-spawning fleet in 2000, a sensitivity test that ignores the non-spawning CPUE data predicts a larger recruitment residual for the 1994 cohort. Previous applications of this model (Thomson, 2000b; Punt *et al*, in press) have been able to fit the data from that cohort more precisely. Other reasons are explored further through sensitivity tests that exclude or down-weight certain sources of data; these are discussed below.

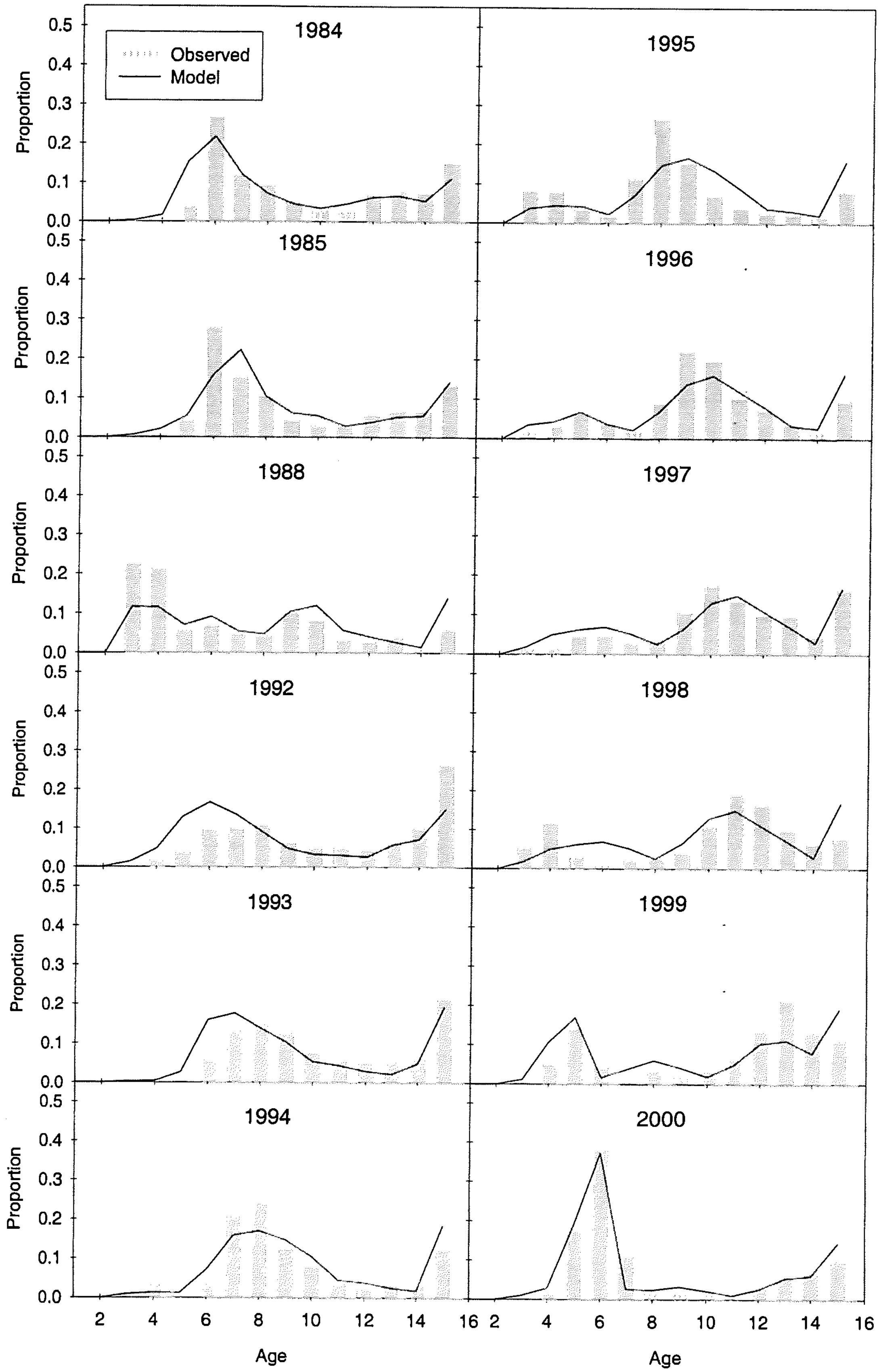


Figure 7a. Observed (bars) and model estimated (lines) proportion caught-at-age for the spawning fleet.

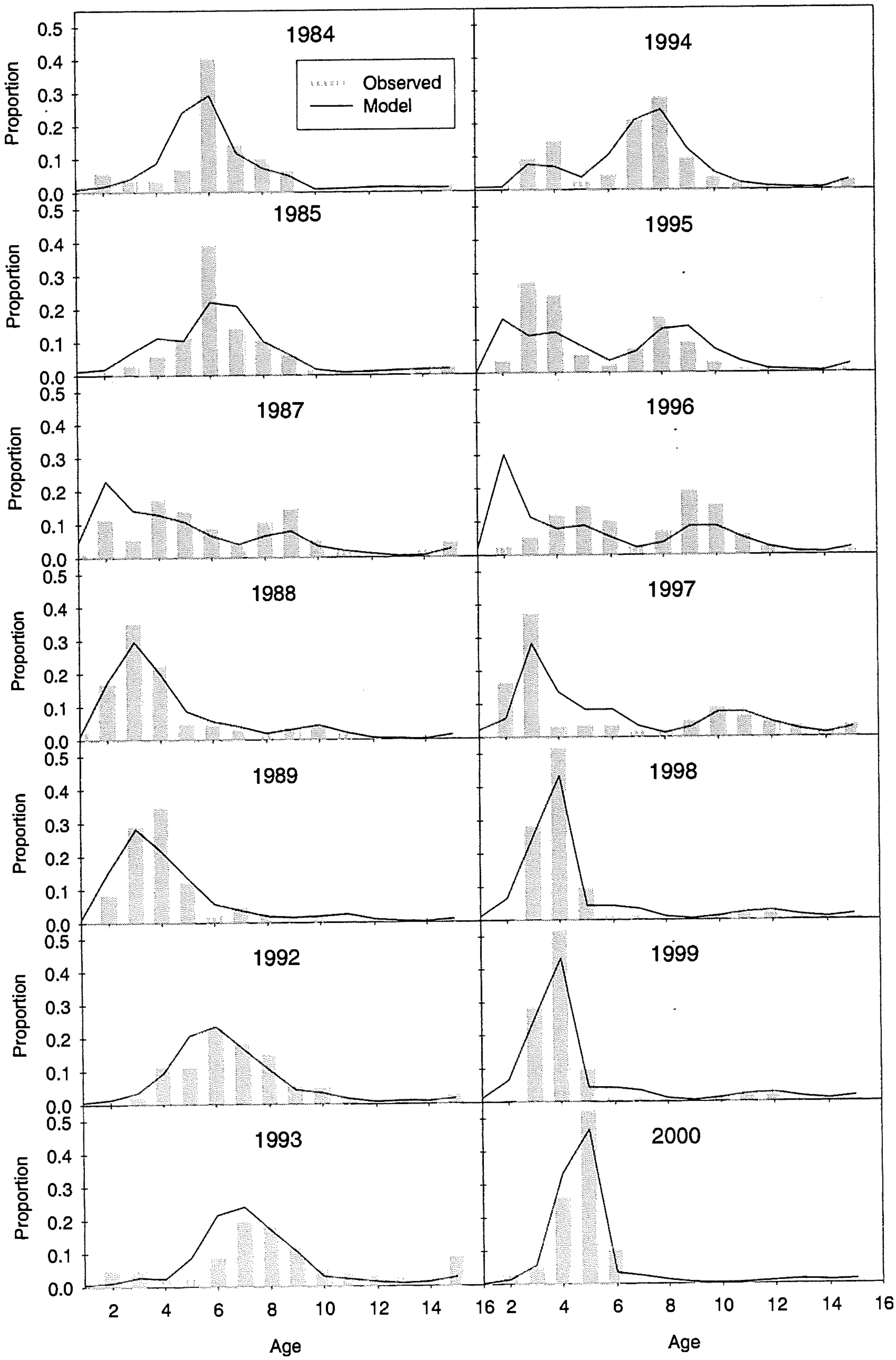


Figure 7b. Observed (bars) and model estimated (lines) proportion caught-at-age for the non-spawning fleet.

The discard-at-age data are based on fewer samples than the catch-at-age data and trends are consequently not as clear (Figure 8).

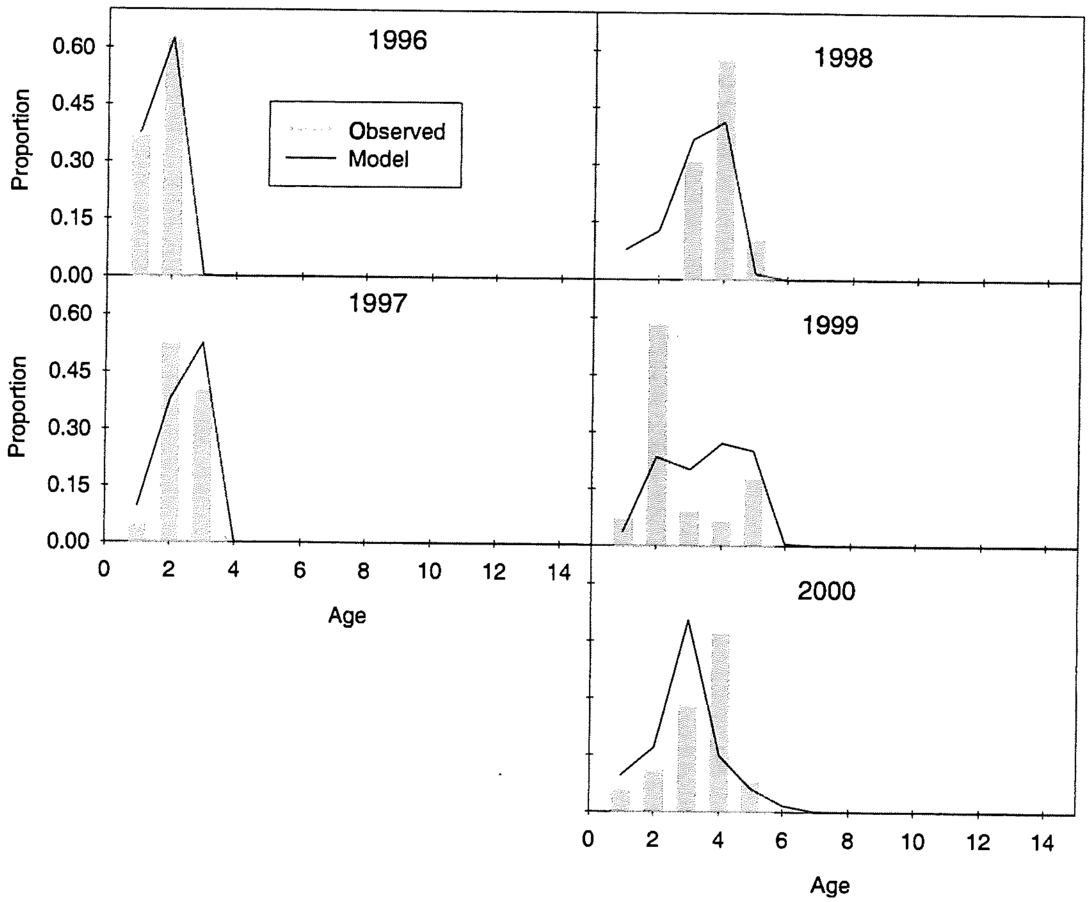


Figure 8. Observed (bars) and model estimated (lines) proportion discarded-at-age for the non-spawning fleet.

The model indicates that the spawning and non-spawning fleets have notably different selectivity patterns (Figure 9, top plot) and that selectivity drops off with age / length for the non-spawning fishery. The selectivity pattern for the spawning fleet increases quite slowly with length, which is perhaps surprising as this implies that many fish capable of spawning are not available to the spawning fleet. As expected, the probability of discarding is relatively high for fish of 60cm or less but is virtually zero after a length of roughly 70cm (Figure 9, bottom plot). This result indicates that relatively high levels of discarding will take place when large year-classes enter the population.

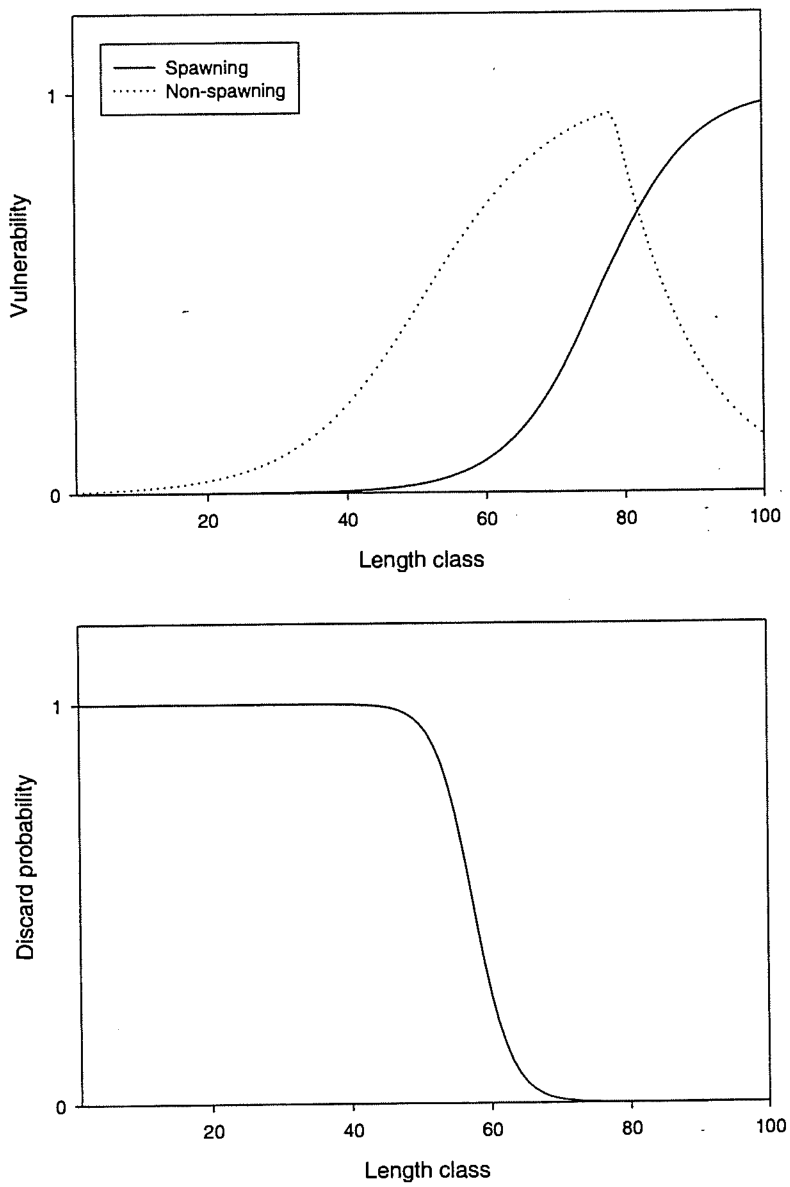


Figure 9. Vulnerability of blue grenadier to being caught (but not necessarily landed) by the two fleets (top plot); and probability of being discarded if caught (bottom plot) as a function of length class.

Spawning biomass is estimated to have been steady until about 1992, implying that catches were not having much impact on the population (Figure 10, top plot). After 1992 the spawning biomass fell continuously until 1999 despite the fact that fishing mortality rates generally remained well below 10% (Table 11). This fall was primarily due to the weak recruitment that occurred from 1990 to 1994 (Figure 10, bottom plot).

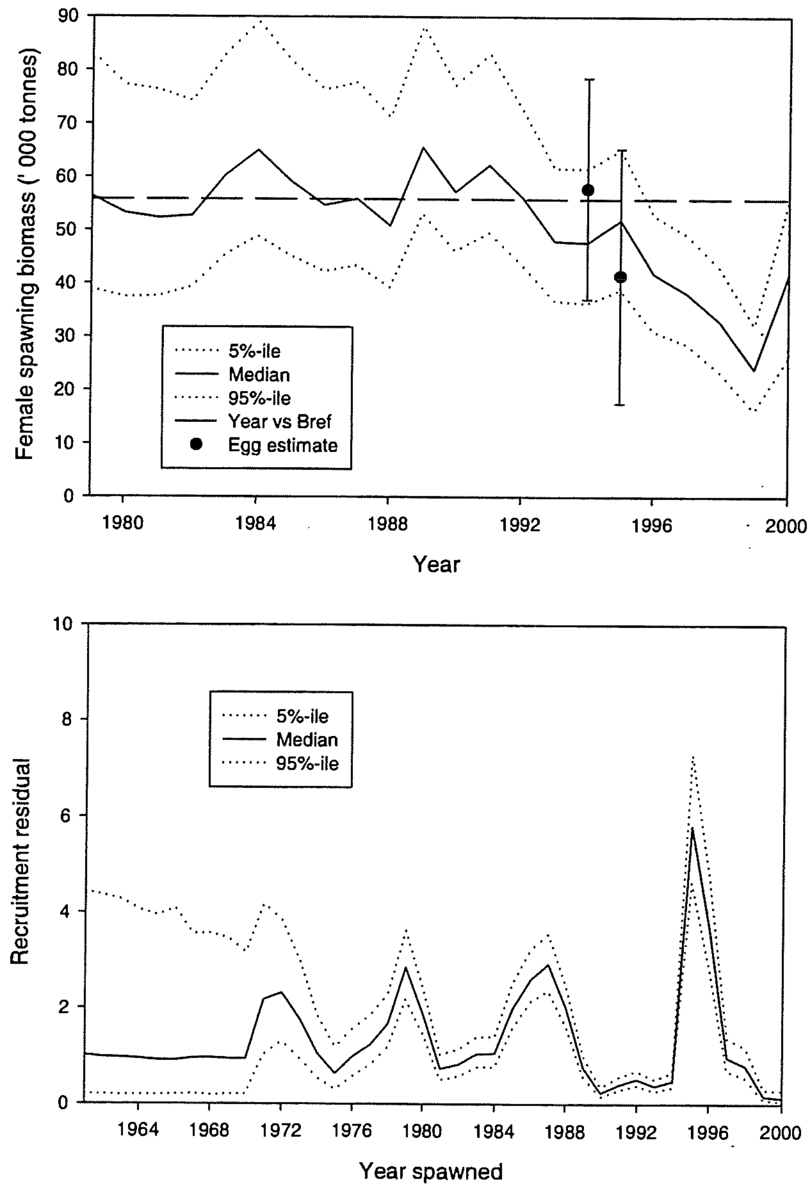


Figure 10a. Estimated median and 90%-ile for the female spawning biomass (top plot). Absolute estimates of female spawning biomass from egg surveys are shown, with error bars indicating 2 standard errors. The dashed line indicates B_0. Recruitment residuals (the amount by which the recruitment deviated from that predicted by the stock-recruit relationship) versus year of spawning are shown (bottom plot). The dotted lines on both plots indicate the 90% probability interval (estimated using the Markov Chain process).

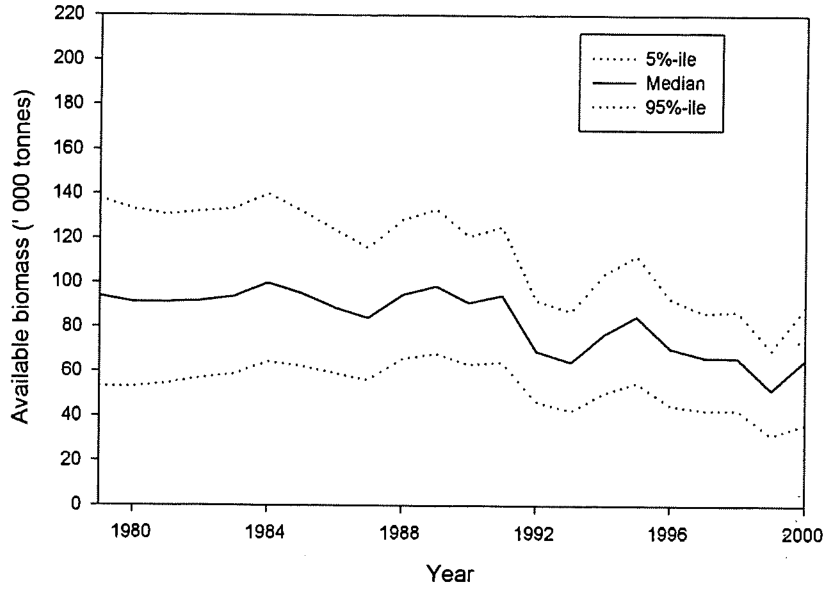
Table 11. Estimated fishing mortality rates for the base case model

Year	Spawning	Non-spawning
1979	0.003	0.004
1980	0.005	0.007
1981	0.003	0.003
1982	0.005	0.005
1983	0.006	0.006
1984	0.008	0.010
1985	0.007	0.010
1986	0.003	0.020
1987	0.011	0.021
1988	0.004	0.018
1989	0.000	0.018
1990	0.008	0.021
1991	0.011	0.035
1992	0.012	0.025
1993	0.018	0.029
1994	0.017	0.026
1995	0.014	0.021
1996	0.021	0.025
1997	0.046	0.032
1998	0.049	0.053
1999	0.122	0.049
2000	0.100	0.028

The large 1994 and 1995 cohorts are growing more slowly than the average (Table 6) and consequently have entered the fishery later than might otherwise have been expected. The biomass of fish available to the spawning fishery declined still further between 1999 and 2000 because these fish, although thought to be mature (greater than 70cm) are still too small to be available to the spawning fishery. The available biomass for the non-spawning fleet has begun to increase (Figure 10b).

5.5.2 Sensitivity tests

Table 12 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}) which is the average spawning biomass over the 1979 to 1988 period; the spawning biomass in 1979 ($\tilde{B}_{79}$) and in 2000 ($\tilde{B}_{2000}$) and its size in 1986, 1993, and 2000 relative to the reference level (depletion, $\tilde{B}_y / B_{\text{ref}}$); the estimated fishing mortality rate for the spawning (F^1_{2000}) and non-spawning (F^2_{2000}) fleets during 2000; and the negative log likelihood (-ln L) value from the model.



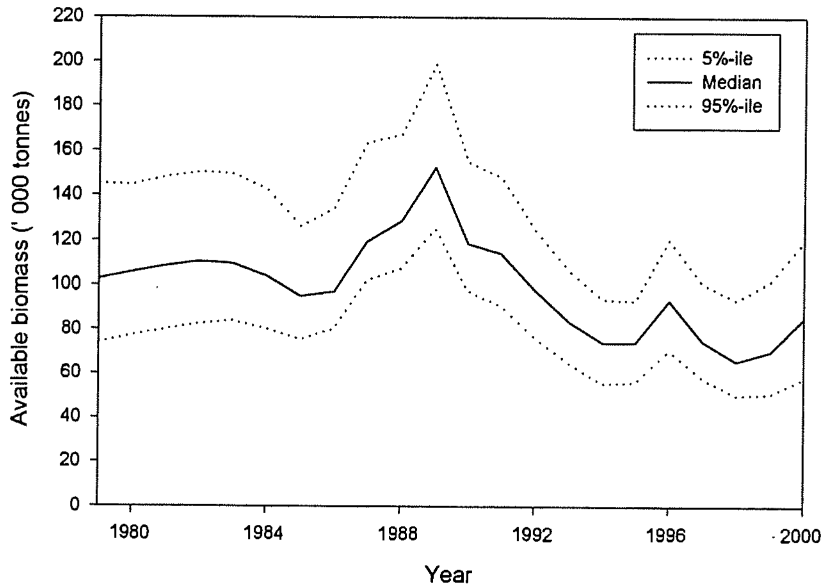


Figure 10b. Estimated available biomass for the spawning fleet (top plot), and the non-spawning fleet (bottom plot) The dotted lines on both plots indicate the 90% confidence interval (estimated using the Markov Chain process).

The overall shape of the spawning biomass trajectories is similar for the base-case and the sensitivity tests that examine the implications of bias in the egg-production estimates, but there are considerable differences in scale (Figure 11). The sensitivity tests that examine possible bias in the results of the egg surveys ("Half" and "Double" egg estimates) produce the lowest and highest estimated spawning biomass values. It is sensible therefore to consider the implications of either of these cases being true. The "no egg" case which ignores the results of the egg surveys gives estimates of spawning biomass that are between those of the base case and the "double" case Table 12. This is reassuring as it indicates that the –at-age data are consistent with a population that is at least as large as that estimated by the base case. However, the spawning biomass is not well estimated by the "no egg" case: the value of B_0 for this model is extremely sensitive to small changes in the data (not shown).

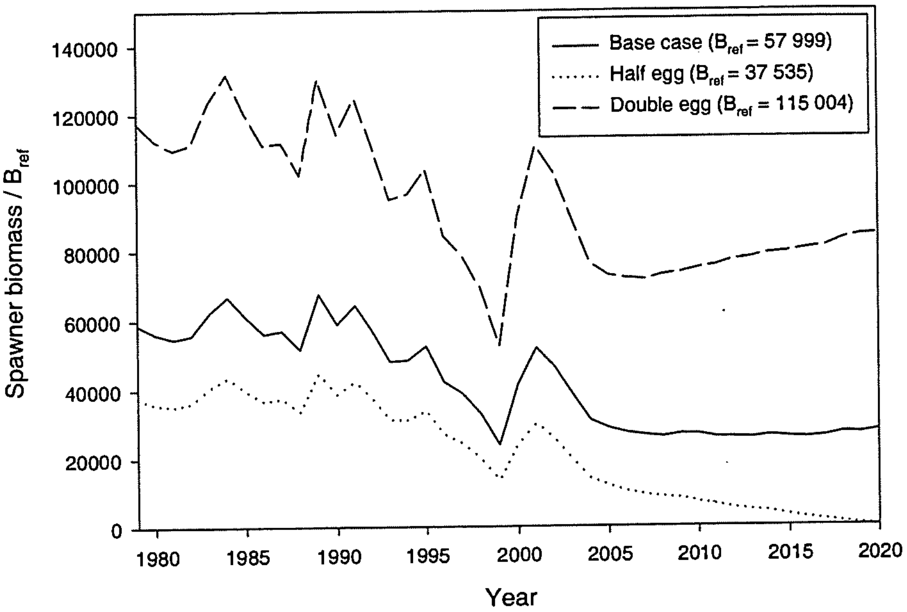


Figure 11. Estimated female spawning biomass divided by the reference biomass (B_{ref}) for the base case model and models that assume that the true spawning biomass is half ("Half egg") or double ("Double egg") that indicated by the egg surveys.

Except for the sensitivity tests that deal with bias in the egg estimates of biomass the only test that substantially alters the results is the one that uses 'Method 1' for calculating length-at-age. This highlights the importance of taking account of the fact that cohorts are not all growing at the same rate (Table 6) as would be the case in a standard stock assessment.

If the weight given to the discard-at-age data is reduced (from 50 to 10) the estimated size of the 1994 cohort is somewhat greater and this under-estimate becomes less severe (Table 12) but there is still some under-estimation. When the CPUE series for the non-spawning fishery is ignored, the estimated cohort strength for the 1994 cohort is greater. The drop in the size of this cohort is likely to be an attempt by the model to improve the fit to the lower than expected CPUE figure for the non-spawning fleet in 2000.

When the ageing error matrix is used to adjust the expected catch- and discard-at-age distributions to resemble those that might be observed, the estimated size of the 1994 recruitment is greatly increased whereas that of the 1995 cohort (not shown) is almost unchanged. The model is able to achieve a better fit to the data in this case Table 12.

Table 12. Estimated values for several parameters of interest. The base case model is shown as well as sensitivity tests.

Specification	B_0	B_{ref}	$\tilde{B}_{79}$	$\tilde{B}_{2000}$	$\tilde{B}_{86} / B_{ref}$	$\tilde{B}_{93} / B_{ref}$	$\tilde{B}_{2000} / B_{ref}$	F^1_{2000}	F^2_{2000}	R_{94}	-ln L
Base-case	44416	56845	55835	43396	98.1%	85.7%	76.3%	0.100	0.028	5.59	295.26
"no big boats" CPUE	44630	56969	55924	43830	98.1%	86.0%	76.7%	0.099	0.028	5.61	296.06
Half egg	29016	35313	34230	23885	98.5%	86.2%	67.6%	0.203	0.045	5.83	295.75
Double egg	83024	111422	110361	92751	97.8%	85.4%	83.2%	0.043	0.014	5.38	297.64
No egg	49914	63802	62547	51123	98.2%	86.5%	80.1%	0.084	0.024	5.66	294.39
CPUE ∝ √biomass	44894	56952	56710	43719	97.4%	84.5%	76.8%	0.099	0.027	5.66	301.3
Catch-at-age method 1	42530	54821	53130	49397	100.2%	112.8%	90.1%	0.169	0.027	3.88	331.06
Use ageing error	39584	56984	58130	58100	0.968	83.3%	102.0%	0.085	0.021	11.25	219.02
$\sigma_q = 0.2$	43889	56987	55085	42935	98.8%	86.8%	75.3%	0.1	0.029	5.49	324.16
$\sigma_q = 0.4$	44728	56658	55926	44015	97.8%	85.6%	77.7%	0.099	0.027	5.69	285.00
$N^{ca} = 40$	44496	56383	55067	44051	98.3%	86.1%	78.1%	0.099	0.027	5.76	249.00
$N^{ca} = 60$	44381	57259	56500	42834	97.8%	85.3%	74.8%	0.1	0.028	5.44	341.18
$N^{da} = 10$	45754	57028	56349	45566	97.8%	84.6%	79.9%	0.097	0.026	6.16	243.48
Ignore discard-at-age data	47884	57958	57613	46171	97.4%	83.2%	79.7%	0.096	0.025	6.08	225.44
Ignore spawning catch rate	43624	56835	56244	41134	97.7%	82.9%	72.4%	0.105	0.029	5.45	279.55
Ignore non-sp' catch rate	45505	55072	54105	47570	98.0%	89.3%	86.4%	0.095	0.024	6.17	287.02

5.5.3 Retrospective analysis

Retrospective analysis further reveals the importance of taking account of the slow growth of the 1994 cohort (Figure 12). The estimate of recruitment strength for this cohort, and the estimated spawning biomass of the stock, tends to drop over time if mean length-at-age is assumed to be the same for all cohorts ("Method 1", Punt and Smith, *in press*). The base case method ("Method 2") does not show any retrospective pattern although the estimated sizes of the 1994 and 1995 cohorts is different in different years, reflecting uncertainty due to conflicting signals from various catch- and discard-at-age samples.

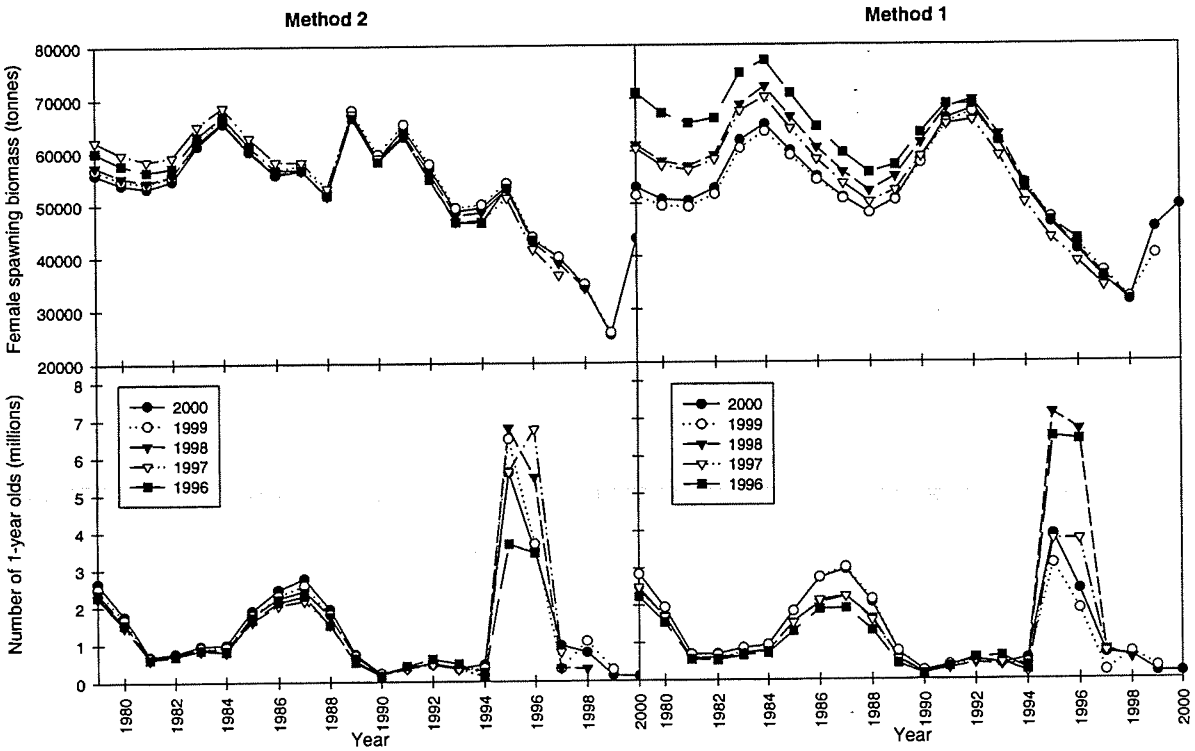


Figure 12. Results of retrospective analysis of the base case model (which uses 'Method 2' for calculating mean length-at-age for all cohorts) and the model that assumes that all cohorts have the same mean length-at-age ('Method 1').

5.5.4 Risk analysis / projections

It is predicted that the spawning biomass of blue grenadier will peak in 2001 (Figure 13) when the 1994 cohort will have grown larger and the 1995 and 1996 cohorts will mature simultaneously (Table 13). The wide probability interval around the spawning biomass in 2001 reflects uncertainty in the sizes of the large cohorts (1994 and 1995), in particular the 1994 cohort. Beyond 2001 the spawning biomass is extremely uncertain due to the potentially large variation in recruitment. Given median recruitment in future years the model predicts that the future population will remain at roughly 50% of B_{ref} under a fixed TAC of 10 000t. However, future poor recruitments of the kind observed prior to 1994 would cause the population to decline well below this level over the next 5 to 10 years.

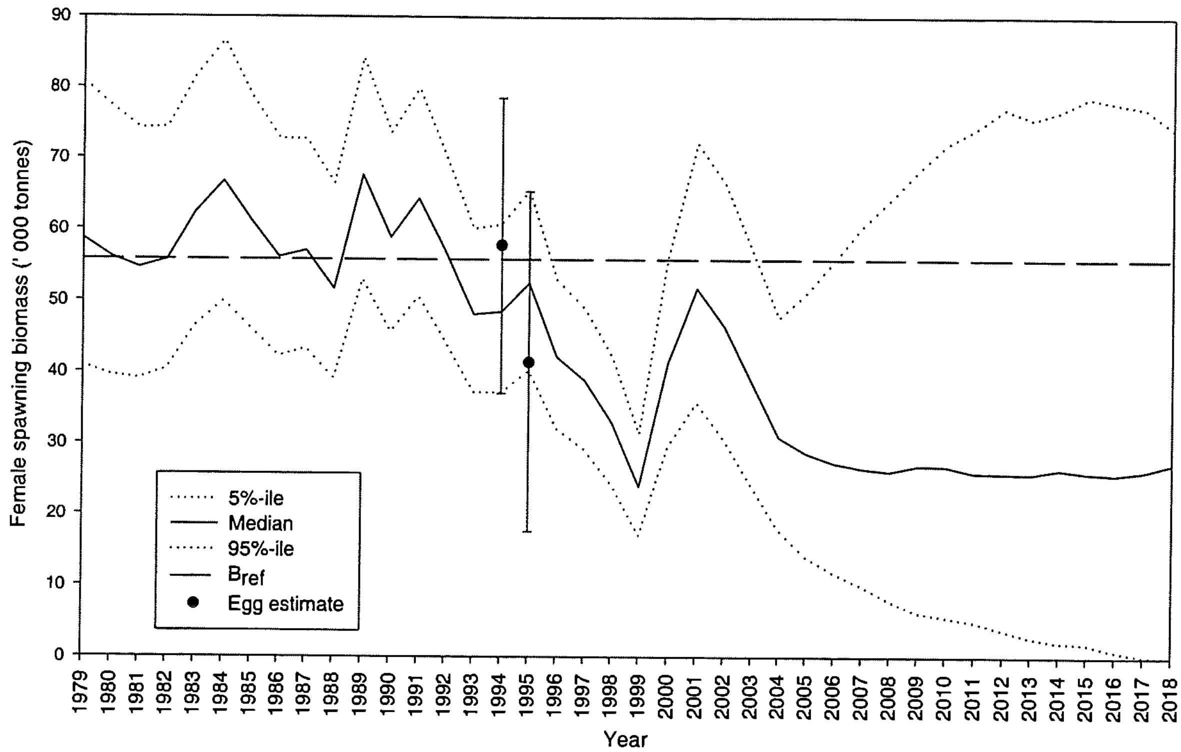


Figure 13. Estimated female spawning biomass and future predicted female spawning biomass. Estimates from egg surveys are shown with error bars indicating 2 standard errors; the dashed line indicates B_0. The dotted lines indicate the 90% probability interval (estimated using the Markov Chain process and mutiple future projections).

Table 13. Estimated female spawning biomass (tonnes) at age for each year included in the base case model.

	Age														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1979	0	0	0	0	3062	4947	7692	9179	7995	3652	3031	2578	2185	1832	9682
1980	0	0	0	0	4732	3002	4537	6958	8018	7159	3139	2652	2202	1823	9656
1981	0	0	0	0	5801	4642	2754	4104	6079	7180	6153	2747	2266	1838	9629
1982	0	0	0	0	7715	5692	4261	2493	3588	5447	6175	5388	2347	1892	9621
1983	0	0	0	0	12969	7557	5215	3850	2176	3209	4676	5398	4597	1957	9646
1984	0	0	0	0	10011	13105	7006	4256	2784	2216	3027	4280	4647	3709	10447
1985	0	0	0	0	3640	8931	12001	5726	3523	3251	1780	2417	3346	3528	12038
1986	0	0	0	0	3759	3273	7655	10372	5388	3630	2551	1450	2040	2886	12738
1987	0	0	0	5514	5741	3933	3025	6900	8377	4214	2630	1844	1139	1581	11656
1988	0	0	0	0	5027	5235	3237	2753	6284	7221	3504	2995	2037	1261	12158
1989	0	0	0	14485	9898	4764	4168	2918	2013	5153	6124	3224	2288	1533	10456
1990	0	0	0	0	11588	8736	4137	3653	2550	2037	4505	5902	3006	1903	10715
1991	0	0	0	0	12862	11101	7829	3668	3136	2249	1727	3895	4985	2482	10455
1992	0	0	0	0	8544	10264	7794	5149	2453	1842	1561	1386	3232	4352	10440
1993	0	0	0	0	0	7874	8898	6745	4683	2336	1950	1281	982	2373	11586
1994	0	0	0	0	0	3392	7386	8181	6842	4976	2165	2021	1396	977	11993
1995	0	0	2398	2767	2104	1075	3187	6792	7914	6485	4480	2072	1793	1195	11066
1996	0	0	0	2101	2770	1635	911	2726	5512	6564	5031	3541	1565	1243	9630
1997	0	0	0	2559	2142	2412	1822	931	2392	4750	5625	4327	2896	1175	8918
1998	0	0	0	0	0	1794	2236	1810	908	2201	4669	5231	4173	2722	8605
1999	0	0	0	0	0	0	1285	1770	1400	616	1723	3656	3822	2734	8279
2000	0	0	0	0	0	19981	1323	1002	1427	1103	579	1430	2954	3342	10254

The results of the risk analysis are summarised by giving the probability that spawning biomass will drop below 20% (Figure 14a) or 40% (Figure 14b) of B_{ref} after 5, 10 and 20 years for a range of future *TAC*s. Sensitivity is explored to changing the assumed level of bias associated with the egg production estimates.

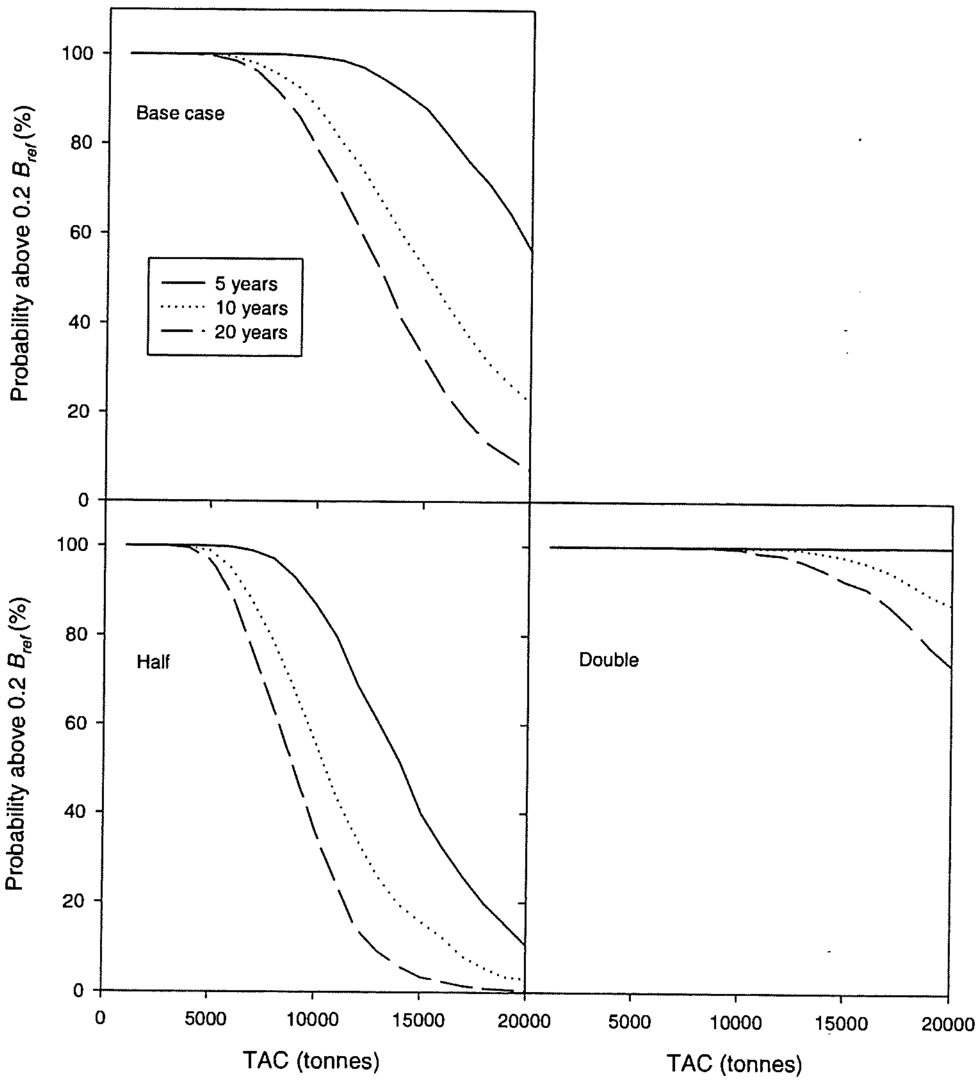


Figure 14a. The probability that the female spawning biomass of blue grenadier will remain above 20% B_{ref} after 5, 10 or 20 years of fishing at a fixed TAC. The plots show the base case and the sensitivity tests that assume spawning biomass is half; or double that estimated from egg surveys.

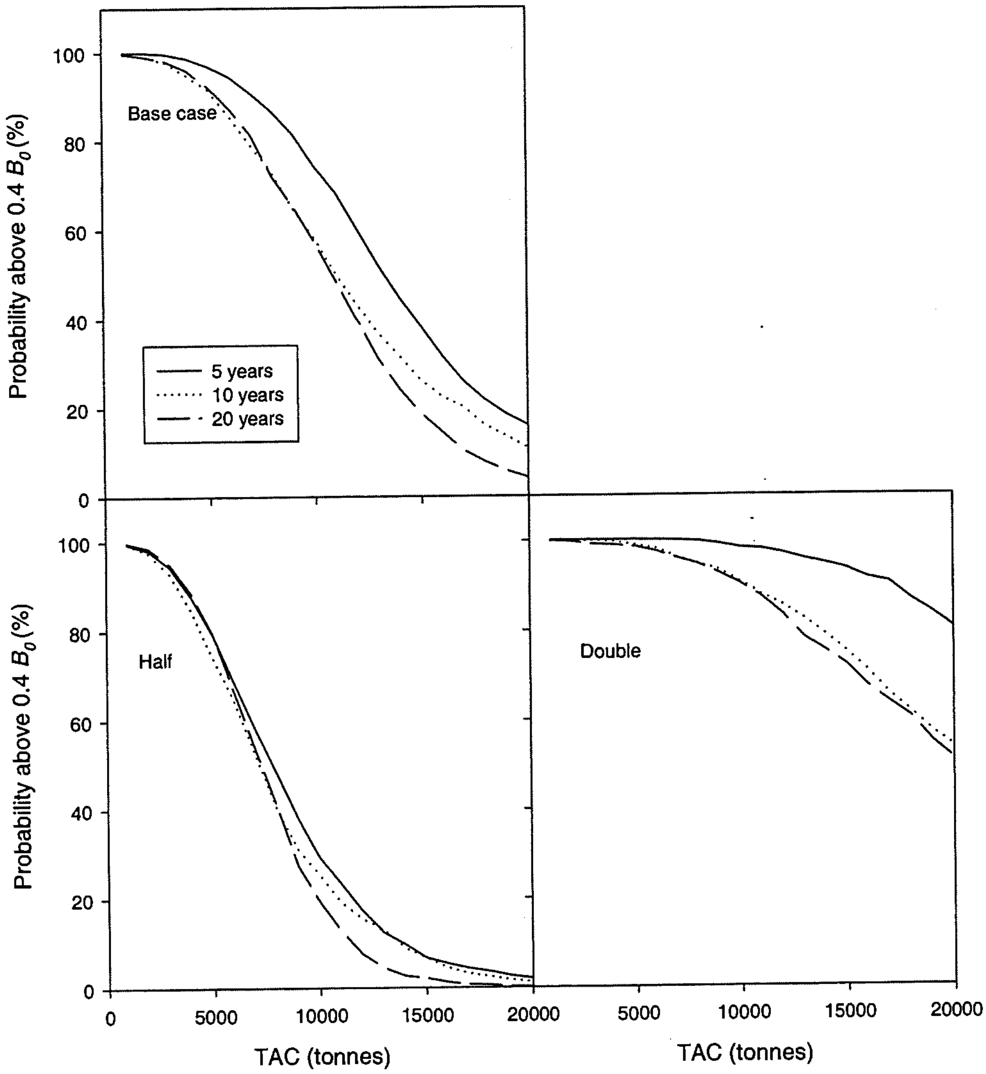


Figure 14b. The probability that the female spawning biomass of blue grenadier will remain above 40% B_{ref} after 5, 10 or 20 years of fishing at a fixed TAC. The plots show the base case and the sensitivity tests that assume spawning biomass is half; or double that estimated from egg surveys.

5.5.5 Summary and implications

Although the fits to some of the data sources are relatively imprecise, the model is nevertheless able to reconcile the differing trends in catch rate for the two fleets. In particular, because the non-spawning fleet concentrates principally on 4-5 age-class of juveniles and sub-adults, the biomass available to it is subject to considerable variation due to variation in recruitment. The spawning fleet, which targets more than 10 age-classes is less subject to this variation. Given the marked trends in recruitment from 1986 to 1994, declines would have occurred in the biomass available to the non-spawning fleet even in the absence of a fishery although these would not have been as marked as those evident from the base-case analysis.

The results for the sensitivity tests that change how the age-composition data are calculated indicate that the method of determining length-at-age can have a substantial impact on the results of the assessment. The current approach of using the empirical length-at-age information has several problems, not least of which is that it is necessary to assume that length-at-age will be equal to the average value for years for which age-composition data are unavailable (Punt and Smith, in press). Although beyond the scope of the current paper, it would seem that a better way to deal with this problem would be to use the model to predict length-at-age. This would permit the model to be used *inter alia* to examine hypotheses such as that the growth rate is a function of the strength of a cohort.

6 PINK LING (*Genypterus blacodes*)

R.B. Thomson, D. Furlani, and X. He

6.1 History of the fishery

Relatively large catches of pink ling (*Genypterus blacodes*) have been made since the mid-1970s when the South East Fishery moved into waters of 200m or deeper (Tilzey, 1994a). Pink ling were primarily a by-catch of trawlers targeting blue grenadier and gemfish and of gillnet fishers operating in the southern shark fishery. However, since the early 1980s the market value for pink ling has risen and they have become increasingly targeted (Tilzey, 1994a). Ling is now an important species for both the trawl and non-trawl sectors of the South East Fishery.

An ITQ was introduced for trawl sector catches of pink ling in 1992 and this has been increased several times in order to allow expansion in the fishery (Figure 15). Landings of pink ling by the trawl sector increased between 1992 and 1995 but seem to have stabilised since then.

In the non-trawl sector pink ling are caught by gillnets, traps, drop-lines and bottom-lines. Catches of pink ling by the non-trawl sector increased dramatically in 1992 and 1993 with the introduction of automatic longlining and because of increased targeting by gillnet fishers operating in the southern shark fishery (Smith and Tilzey, 1995). The ITQ for pink ling in the trawl sector was extended to include the non-trawl component in 1998. Pink ling was one of only three species for which a quota was set for the non-trawl fishery, before this was expanded to include other trawl quota species in 2001. Ling quota is transferable between the trawl and non-trawl sectors.

A formal stock assessment has not previously been conducted for pink ling.

6.2 Biological Background

6.2.1 Habitat and related species

Pink ling are caught mainly at 200-900m depth (Tilzey, 1994a) off the east and south coasts of Australia (including Tasmania), and off New Zealand (Colman, 1995). A closely related species, rock ling (*Genypterus tigerinus*) occurs in the same areas but mainly at depths shallower than 60m (Last *et al*, 1983). Other related species occur off southern Africa (*Genypterus capensis*) and South America (*Genypterus chilensis*).

Pink ling show a distinct size-depth relationship with smaller ling being found in shallower waters (Bax & Williams, 2000).

6.2.2 Stock structure

The stock structure of pink ling in SEF waters has been investigated recently by Daley *et al* (2000) using allozyme, genetic, morphometric and meristic techniques. Although certain of their tests may indicate significant differences between some regions these differences are not consistent and the majority of their investigations do not show significant differences between pink ling in different areas. The base case hypothesis used here therefore assumes a single pink ling stock. A possible east-west stock separation is considered by fitting the model separately to data from the east of Bass Strait only (zones 10-30), and from west of Bass Strait only (zone 40-60).

Table 14. Values for biological parameters used in the stock assessment of pink ling

Description	Value
Length-weight relationship:	
a	0.00293 $g.cm^{-1}$
b	3.139
Length-at-age	
σ_a (for ages 1-10)	0.210, 0.162, 0.118, 0.125, 0.110, 0.109, 0.102, 0.104, 0.105, 0.095
σ_a (for age 11+)	0.092
von Bertalanffy growth curve:	
L_∞	101.335 cm
K	0.179 y^{-1}
$t0$	-2.045 y
Natural mortality rate:	
M	estimated (0.05, 0.5)
Other:	
length-at-maturity (l_m)	67* cm
steepness (h)	0.75
μ	1.0

* This is roughly the average of two lengths-at-50%-maturity that have been reported in the literature: 60 cm (Smith and Tilzey, 1995) and 72 cm (Lyle and Ford, 1993). It corresponds to an age of roughly 4 years.

6.2.3 Biological parameters

Analyses of catch curve data have indicated that ling older than 10 years may have a lower natural mortality rate than those of 10 or younger (Smith *et al*, 1996; Morison *et al*, 1999).

The biological parameters used in this model are listed in Table 14. The parameters for the length-weight relationship were calculated using pooled length and weight data collected by CSIRO and TAFI as well as that used by Withel and Wankowski (1989). Those of the von Bertalanffy growth curve were calculated using data collected by the Central Ageing Facility (CAF), all available data held by the CAF were used. The values for the steepness of the Beverton-Holt stock-recruit relationship (h) and the proportion of mature fish that spawn each year (μ) were the same as those used by a New Zealand study (Horn & Cordue, 1996). However, they describe these choices as "precautionary" because the true parameter values are unknown. The mean for the length-at-age relationship is given by the von Bertalanffy growth curve and the c.v.s for length-at-age for each age (σ_a) were calculated from the ALK data.

6.3 Data

6.3.1 Landed catch

The landed catches of pink ling increased steadily from 1977 to 1997 after which they appear to have stabilized (Figure 15). Landings for 1977 to 1990 were estimated by Tilzey (1994a), (Table 15). Subsequent figures were obtained from the SEF2 database as reported by Smith and Wayte (2000). It is possible that some rock ling (*Genypterus tigerinus*) were landed and recorded as pink ling however rock ling occur in relatively shallow waters (60m) and are caught in small numbers by the SEF so this is unlikely to be an important factor (Tilzey, 1994a).

Catches of pink ling have been greatest off the east coasts of NSW and Victoria (Figure 16) but these appear to have stabilized during the 1990s whereas those in the west increased sharply in the early 1990s. Recent catches in the west have shown some decrease.

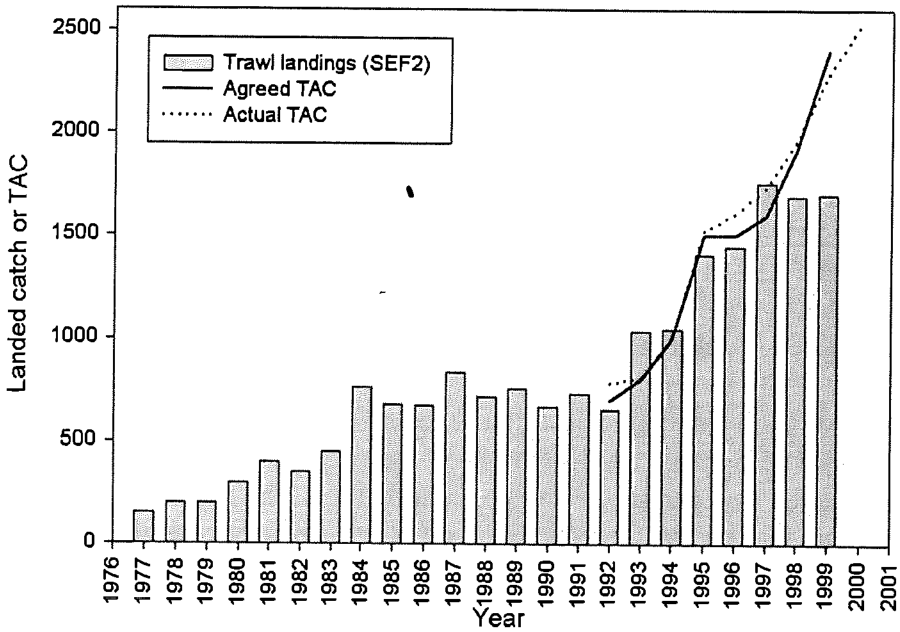


Figure 15. Estimated landed catches of pink ling for the period modelled, and allocated and actual TACs for the SEF. The actual TAC is the allocated TAC adjusted for carry-over and carry-under of quota from the previous year.

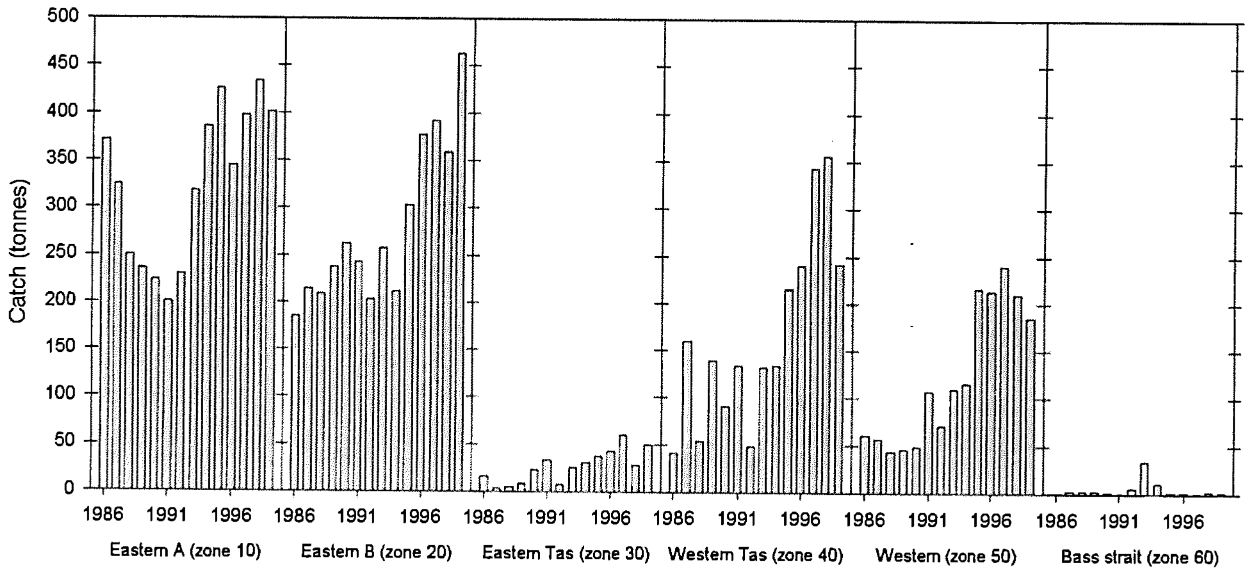


Figure 16. Landed catches (from SEF1) of pink ling in each of the SEF zones.

6.3.2 Discarded catch

Discarding by the trawl fishery was measured by the ISMP from 1993 onwards (Table 15). Industry members advised that discards by the non-trawl fishery were negligible

(Thomson, 2000c) so these were ignored in the model. Recent sampling on non-trawl vessels by the ISMP has supported this approach (Knuckey and Gason, 2001). Discarding for the east and west trawl fleets was calculated separately.

Table 15. Landed catches, discards, and CPUE for pink ling for the period modelled. The trawl CPUE has been standardized using GLM techniques but the two data points for the Kapala have not ("raw"). Blanks indicate no data.

Year	Landed catches (tones)			Discard ratio (%)			Standardised CPUE		"Raw" CPUE
	Trawl East	Trawl West	Non-trawl	East	West	All trawl	Trawl East	Trawl West	Kapala
1977	127.24	22.76	0						26.1
1978	169.66	30.34	0						
1979	169.66	30.34	0						
1980	254.49	45.51	0						
1981	339.32	60.68	0						
1982	296.9	53.1	0						
1983	381.73	68.27	0						
1984	646.4	115.6	11						
1985	576.84	103.16	54						
1986	574.3	102.7	86				0.887	0.864	
1987	597.36	240.64	88				0.916	1.043	
1988	590.07	126.93	103				0.847	0.846	
1989	547.59	212.41	115				0.808	0.881	
1990	522.83	145.17	82				0.988	0.817	
1991	487.69	247.31	82				0.922	0.795	
1992	510.13	144.87	274				0.862	0.672	
1993	711.15	324.85	615	0.22	0.00	0.18	0.929	0.908	
1994	740.6	306.4	496	0.92	0.01	0.66	0.916	0.998	
1995	900.96	509.04	415	1.46	0.35	1.06	1.091	1.101	
1996	908.05	540.95	591	2.16	16.38	6.11	1.014	1.107	
1997	1040.32	715.68	224	8.22	4.13	6.85	0.97	1.213	25.0
1998	999.82	692.18	202	1.13	1.83	1.41	1.033	1.161	
1999	1212.55	488.45	271	0.01	3.19	0.75	1	1	

6.3.3 Standardised CPUE

The standardization CPUE data from the SEF1 log-book showed very little trend over time (Table 15, Figure 17, Appendix E). The CPUE data were analysed as one stock (all data combined), and as two stocks (east and west data analysed separately). In addition the dataset was divided into records from shallower, and deeper than 200m because examination of the ISMP onboard data indicated that ling shallower than 200m were likely to be aged 1 or 2 while older ling were more likely to have been caught in deeper water (Appendix E). It was hoped that the CPUE trend in 0-200m might therefore serve as an index of recruitment strength. There were insufficient data from the 0-200m depth range to perform this assessment separately for records from the east and west, particularly in the west where little shallow water fishing occurs. There are very few records even when all data are combined, so these results must be regarded as unreliable. It is also notable that the number of records from 0-200m is much greater during 1993-1995, presumably as a result of the 'OCS loophole' that existed in NSW waters during this time when fishers reported a large number of catches in shallow waters because these fish were not deducted from their SEF quotas.

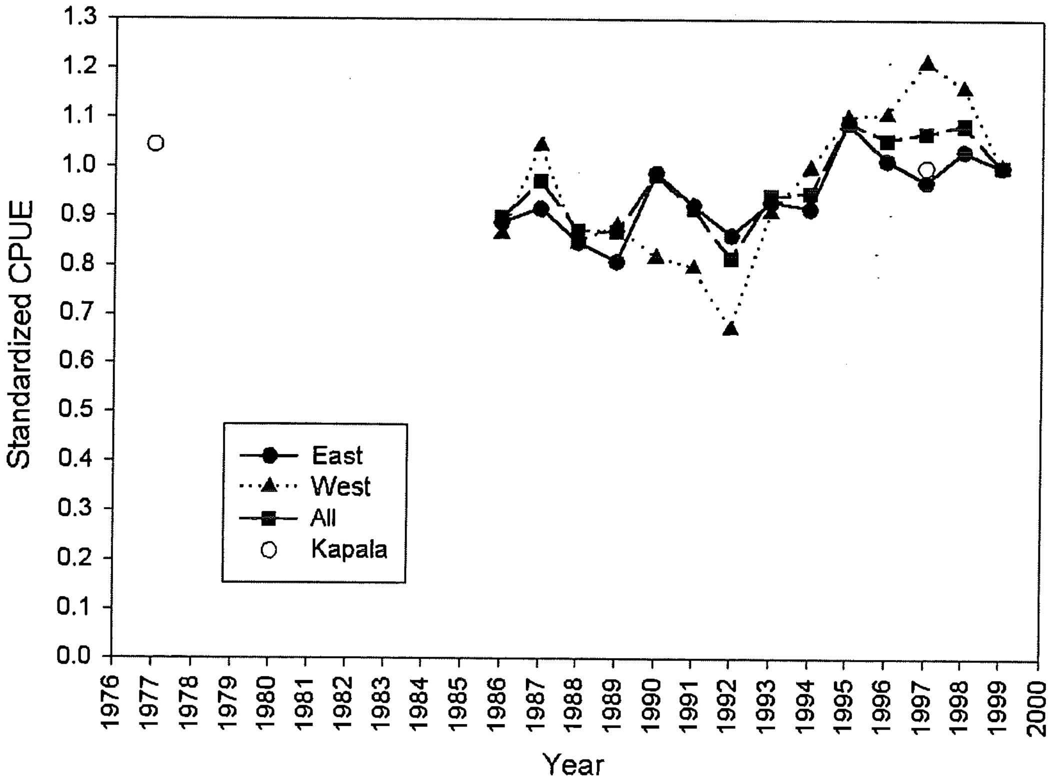


Figure 17. Standardised CPUE for trawl catches in the East (zones 10-30) and West (zones 40-60) and in all areas combined. The two CPUE values obtained by the Kapala cruises are also shown (they have both been divided by the 1997 value).

Unstandardised CPUEs were also available for two research surveys that were conducted off NSW using the vessel *Kapala* in 1976/7 and 1996/7 (Andrew *et al*, 1997, Table 15, Figure 17). These were assigned to 1977 and 1997. The second survey attempted to use the same methods as the first and to trawl the same areas and depths so that the data collected are directly comparable and no standardization is necessary.

6.3.4 Catch-at-length

Catch-at-length data were available from the ISMP and its predecessors for the trawl fleet for a number of years (Table 16, Appendix D and Figure 18). A limited amount of non-trawl data were also available but unfortunately data for all non-trawl gear types had to be pooled due to small sample sizes. Non-trawl data will become available in greater quantity from 2001 onwards due to the extension of the ISMP to cover the non-trawl sector.

Three length frequencies are also available from NSW, two from the *Kapala* survey mentioned above and a third from a period that falls between the two *Kapala* surveys. This intermediate length frequency was calculated by combining length frequency data for three years (1979-1981; Andrew *et al*, 1997) and is therefore not necessarily reliable; it was assigned to 1980.

Table 16. Sample sizes for length frequency and ALK data for pink ling. 'Y' indicates that a sample is available but that the sample size is unknown.

Year	ALK	Retained catch length-frequencies				Discarded catch length-frequencies	
		East trawl	West trawl	Non-trawl	Research (*Kapala*)	Trawl East	Trawl West
1977					1848		
1978							
1979	399		114		2568		
1980			86				
1981			602				
1982			120				
1983							
1984							
1985							
1986							
1987	567						
1988	328						
1989	190						
1990							
1991							
1992		54	399				141
1993							695
1994	484					857	1290
1995	792	248	784	78		135	4430
1996	1005	Y	1180*	322		310	1516
1997	970	102*	2340*	178	2655	242	363
1998	881	1417	1311	251		Y	Y
1999	550	1413	853			Y	Y

* These are under-estimates because the sample sizes for some of the data were unknown

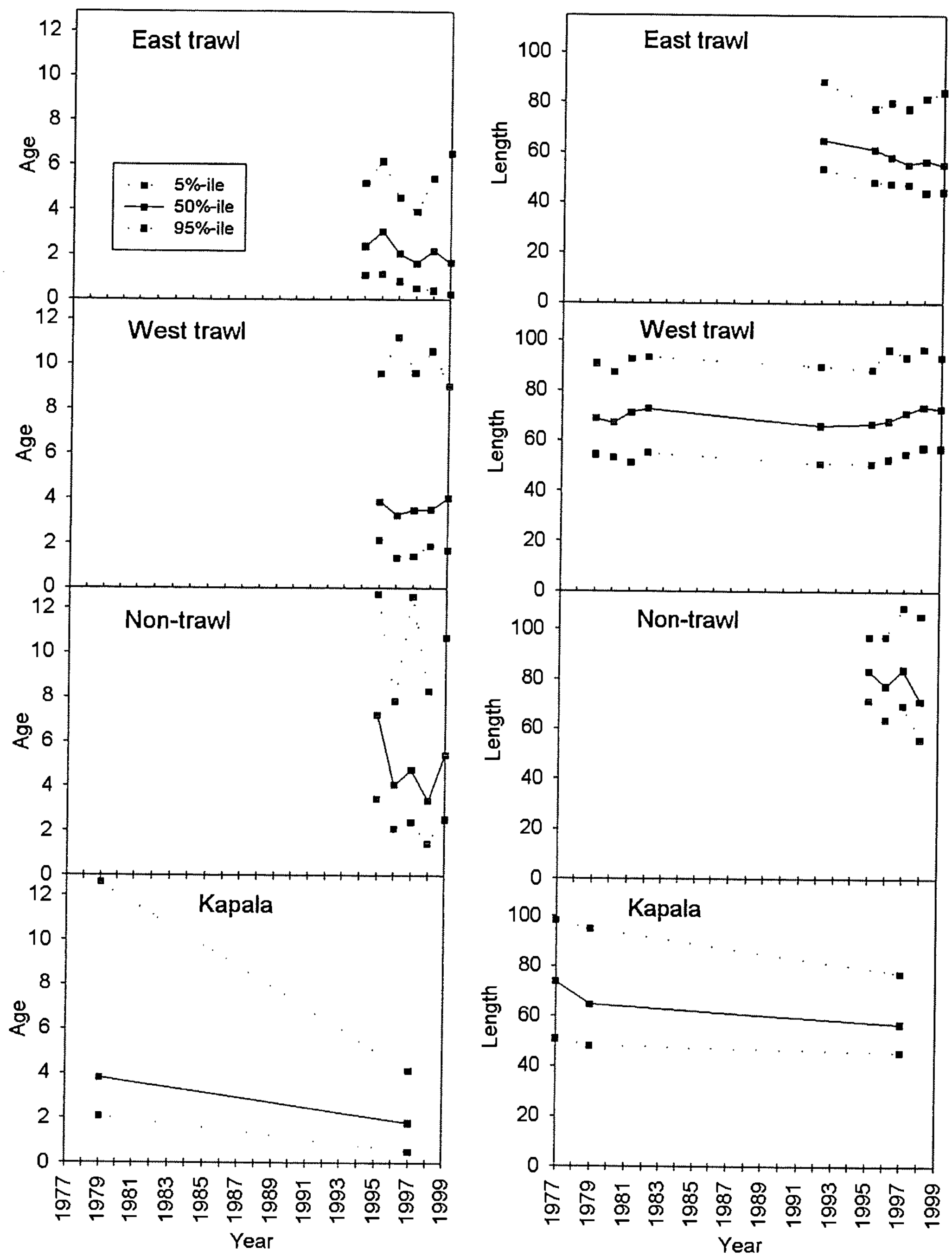


Figure 18. Median and 90%-iles for length and age in pink ling catches.

The mean length of ling in the samples has been declining over time (Figure 18) although the most recent data from the west show a slight increase. The non-trawl data show declines in the length and age data.

6.3.5 Catch-at-age

Age length key (ALK) data were collected by the ISMP from 1994 onwards and the 1979 *Kapala* fish were aged (Figure 19). Samples from 1987-1989 are available from research surveys. All the fish aged were caught using trawl gear.

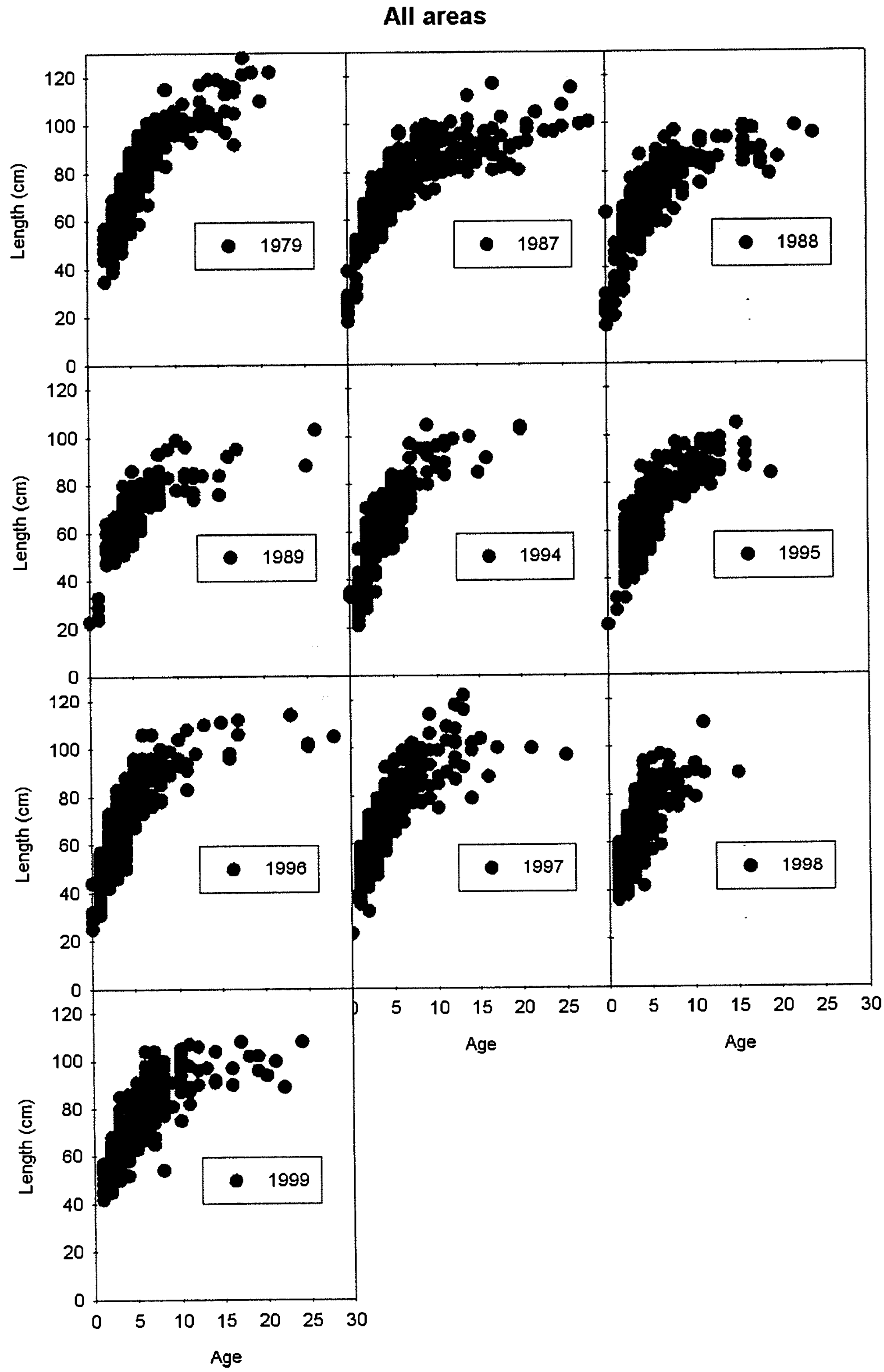


Figure 19. Age-length key (ALK) data for pink ling.

The median and 90%-ile data for the age samples are shown in (Figure 18) and have been discussed above.

6.3.6 Discard-at-age

Discard data are available from the ISMP and discard length frequencies were multiplied by the ALKs for the relevant years in order to calculate discard-at-age frequency data.

6.4 Modelling Methods

6.4.1 Base case model

A variant of the model described in Appendix A was used (Table 17).

Table 17. Some of the choices made for the base case Integrated Analysis model as applied to pink ling.

Aspect of model	Choice	Details
Stocks	1	
Fleets	4	East trawl; West trawl; Non-trawl; Research
Selectivity pattern	East trawl	Dome-shaped
	West trawl	Dome-shaped
	Non-trawl	Logistic
	Research	Dome-shaped
Sexes	1	
Depth classes	1	
Years	1977-1999	
Ages	1-20	20 is a plus group
Lengths	16-133	cm
Initial conditions	stock pristine at start of 1977	
Egg data	None	
Stock-recruit relationship	Yes	Beverton-Holt
Method for fitting age/length frequencies	multinomial	
Method for fitting length-at-age	Method 1	

The base case model assumes a single stock of pink ling but models the east (SEF zones 10-30) and west (SEF zones 40-60) trawl fleets separately. Ideally, the possibility of there being separate east and west stocks would be taken into account by applying the model to data from the east only, and separately to data from the west only. Unfortunately this could not be done, defensibly, because the distribution of non-trawl catches between the east and west, over time is not known. It is known that this distribution has changed– dropline catches in the east are likely to have been dominant in the early years whereas automatic longlining has begun in the west in more recent years. Sensitivity tests have been done to excluding data from various fleets from the model.

Four fleets were assumed – trawl east, trawl west, non-trawl and research (*Kapala*). The model uses the CPUE and catch-at-length data from the *Kapala* but does not consider the effect of the catches made by this fleet on the stock because these were too small to have had much impact. Therefore research landings are ignored and no research fishing mortality rate is calculated. Landings for the remaining fleets were modelled and annual fishing mortality rates estimated (rather than using Pope's approximation and calculating exploitation rates).

The Tasmanian trawl fleet appears to be distinctly different from that in other areas in that it operates in deeper water and consequently takes larger ling. Although Tasmanian catches are included in the data, a separate Tasmanian fleet is not considered because its annual landings are small compared with the rest of the fishery (Lyle *pers comm*).

No depth structuring was assumed – this is equivalent to assuming a single depth class spanning all depths fished. Male and female fish are not distinguished by the model. No egg surveys have been conducted for this species.

The model considers a period of 22 years (1977 to 1998) and assumes that the stock was close to pristine at the beginning of 1977. This is likely to be a reasonable assumption since ling were not targeted in the 1970s and catches of blue grenadier and gemfish were relatively small until the late 1970s (Tilzey, 1994a).

A Beverton-Holt stock-recruit relationship was chosen with the value of the steepness parameter equal to that used by New Zealand (Horn & Cordue, 1996). This is the value recommended by Francis (1992a) when the true value is unknown. The proportion of fish that spawn each year was chosen to be 1 (i.e. all female fish) which is more conservative than the 0.9 value used in the New Zealand assessment (Horn & Cordue, 1996). They state, however, that the value of this parameter is unknown and describe their choice as "precautionary". A value of 1.0 can therefore be regarded as more "precautionary".

The weights assigned to each data source for the base case assessment model are given in Table 18.

Table 18 Weighting factors used in the base case model.

Parameter	Description	Value
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
N^{cl}, N^{dl}	effective sample size for the catch- and discard-at-length data (multinomial)	50
N^{ca}, N^{da}	effective sample size for the catch- and discard-at-age data (multinomial)	25

The model has 101 parameters (Table 19): 3 parameters that relate the catch-rate data to the modelled biomass (for the east and west trawl and the research catches); natural mortality for ling aged 10 or younger and older than 10 (2); the size of the pristine recruitment (1); fishing mortality values for three fleets for in each year in which they operated (23 each for the trawls and 16 for non-trawl because no non-trawl catches are made during the first 7 years modelled); recruitment residuals for each year (23); parameters for the selectivity functions for all fleets (8); and parameters for the discard function (2).

Table 19. Parameters of the base case model for pink ling.

Parameter	Description	Number
q	Catchability	3
M	Natural mortality	2
R_0	Average recruitment at the unfished level	1
F_y^f	Fully-selected fishery mortality	62
ε_y, ε_a	Recruitment residuals	23
S_a^f	Selectivity	8
d_a	Discarding	2
		101

6.4.2 Risk analysis/Projections

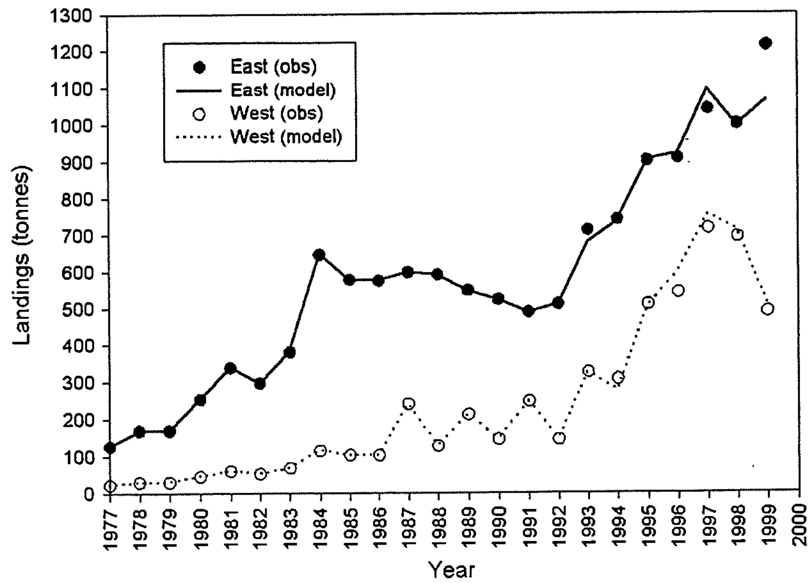
The stock was projected 20 years into the future under a range of possible future TACs. The TAC was split between the trawl and non-trawl fleets according to a pre-specified ratio. In 1998 the non-trawl fleet took 10% of the pink ling catch, however in 1993 before the TAC became 'global', this fleet took 40% of the year's pink ling catch. Therefore non-trawl:trawl catch ratio's of 10:90 and 40:60 were considered.

For each combination of future TAC and non-trawl:trawl catch ratio, 2000 iterations (projections) of 20 years each were performed.

6.5 Results / Discussion

6.5.1 Base case model

The estimated natural mortality for fish aged 10 or younger (0.23 y^{-1}) is the same as that estimated for those older than 10. The greater natural mortality on older fish that was observed in catch curve analyses is likely to be due to the decreasing selectivity for older fish. This was taken account of here by assuming a dome-shaped selectivity pattern.



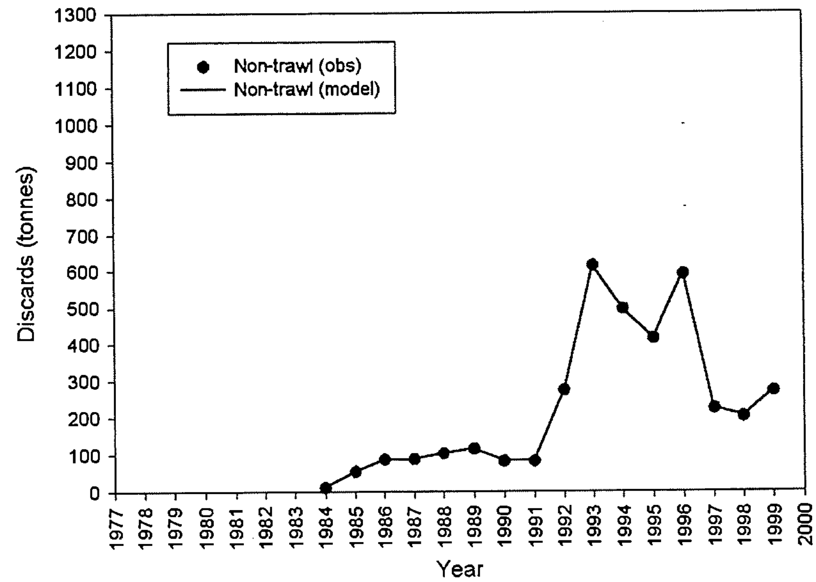


Figure 20. Observed and model estimated landings for the east and west trawl fleets and for the non-trawl fleet. The landings for the research fleet were considered to be negligible.

The model is able to fit the landed catch well (Figure 20) for most years however the fit in 1999 for the east trawl fleet is poor. This appears to be an attempt by the model to improve the fit to the observed discard mass in the most recent year. This was much lower than that observed in previous years and is not well estimated (Figure 21). The high discard rates observed in some years cannot be estimated by the model.

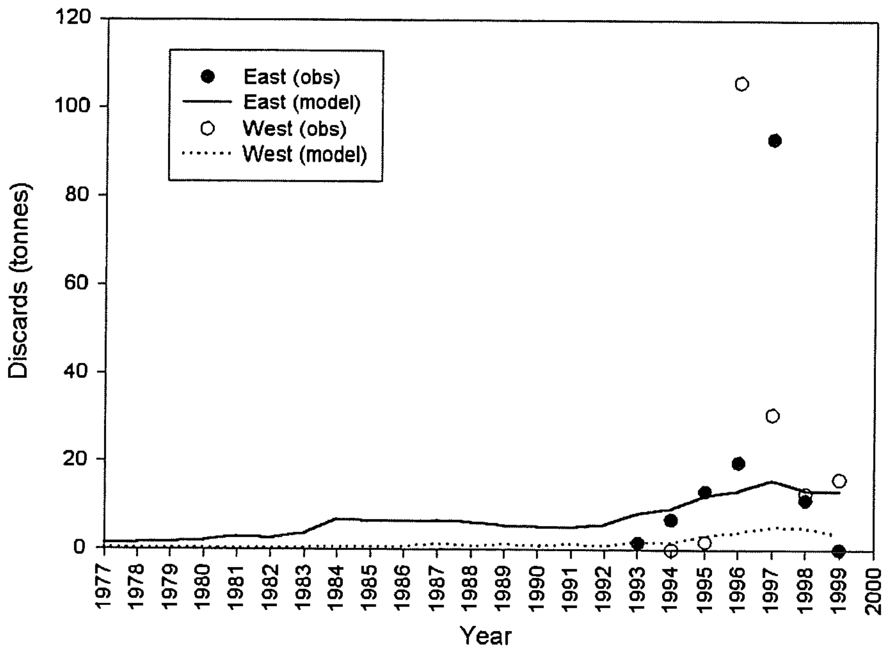
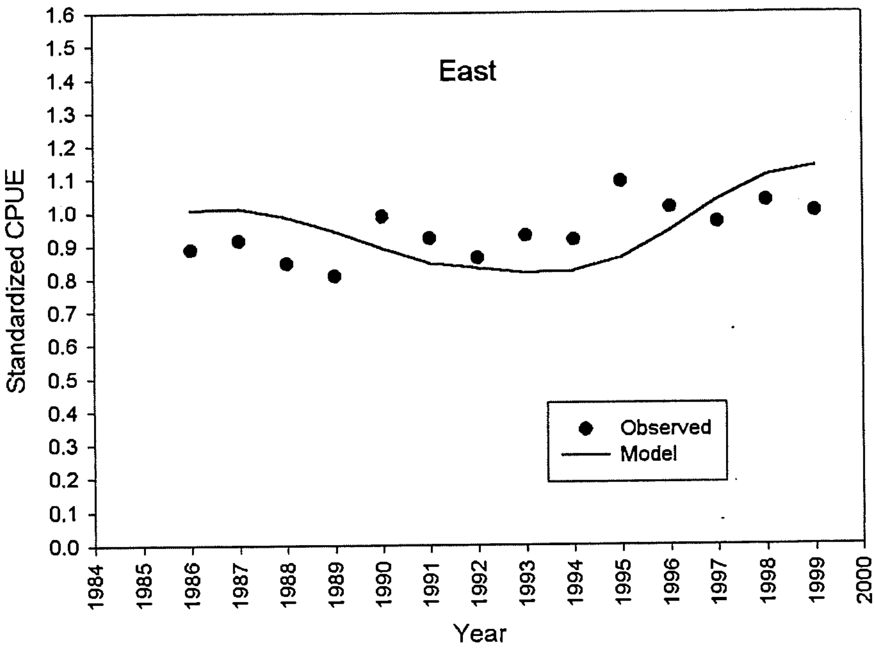


Figure 21. Observed and model estimated discards for the east and west trawl fleets. Those for the non-trawl fleet (and of course the research fleet) were considered to be negligible.



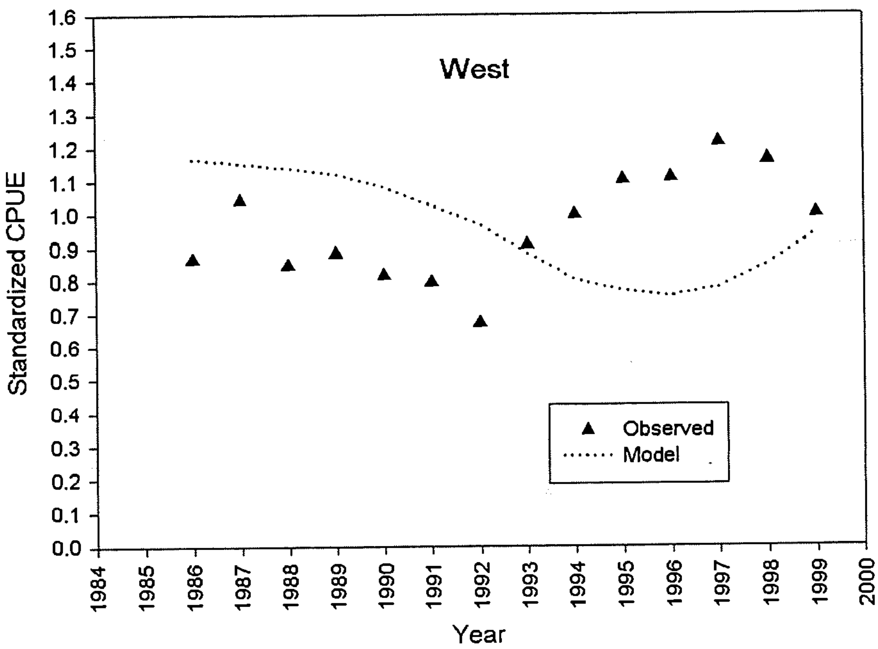


Figure 22. Observed and model expected CPUEs for the two trawl fleets in the base case pink ling model. "East" means trawl catches recorded in zones 10-30 and "West" means trawl catches recorded in zones 40-60.

The model is unable to properly reconcile the flat CPUE data with the declines in mean age and length in the catch (Figure 22). The estimated CPUE for the base case model declines initially and then increases due to larger than average recruitment events during the early and mid-1990s (Figure 23). However, if the CPUE data are given zero weight these estimates are not as large ('no CPUE' Figure 23). Even in this case however recruitment is estimated to have increased to a peak in 1996 after which it declined. This is due to the similar peak and decline in the measured discards (Figure

21). The analysis of CPUE in 0-200m (Appendix E) also shows an increase between 1991 and 1995. There is a sharp decrease in 1996 however and CPUE stays relatively low thereafter. This might indicate good recruitments in the early 1990s however this trend might be due wholly or partially to the "OCS loophole".

The fit to the CPUE data from the *Kapala* is extremely poor; the data values are 26.1 in 1977 and 25 in 1997 and the estimated values are 39.1 in 1977 and 16.7 in 1997.

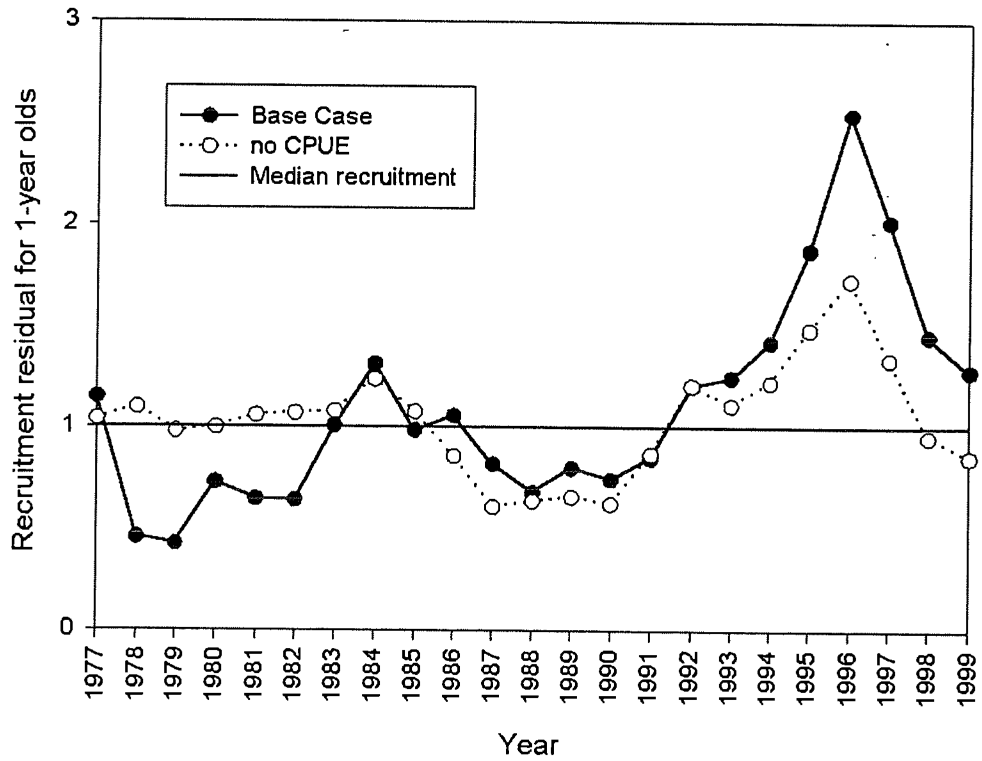


Figure 23. Estimated recruitment residuals for one-year old pink ling from the base case model. Estimated residuals are also shown for a sensitivity test that gives zero weight to the CPUE data.

The estimated vulnerability patterns (selectivity patterns) are similar to what would be expected (Figure 24). The commercial trawl fishery in the west takes larger fish than that in the east and selects a somewhat narrower size range. This reflects the relatively less heavily exploited population of ling in the west as well as the narrower, and deeper, depth rage of fishing in the west. The non-trawl fishery selects larger fish than any of the trawl gears which again reflects the different grounds fished – the non-trawl gears are able to target rocky ground which trawl gears cannot exploit. The *Kapala* research surveys selected a much wider size of fish than any of the commercial fleets and selected more smaller fish as they were designed to survey the area rather than to maximise economic return. However, it was noted that several of the sensitivity tests resulted in very different selectivity patterns (not shown) indicating that these are not well estimated.

The estimated discard selectivity indicates that fish larger than 60cm are unlikely to be discarded however even fish smaller than 60cm have a reasonably low probability of being discarded (Figure 25). Discarding patterns for pink ling are likely to have changed since 1977 as the market price for ling has risen. The model fit may be a compromise between years when juveniles dominate the discards and years when larger fish dominate.

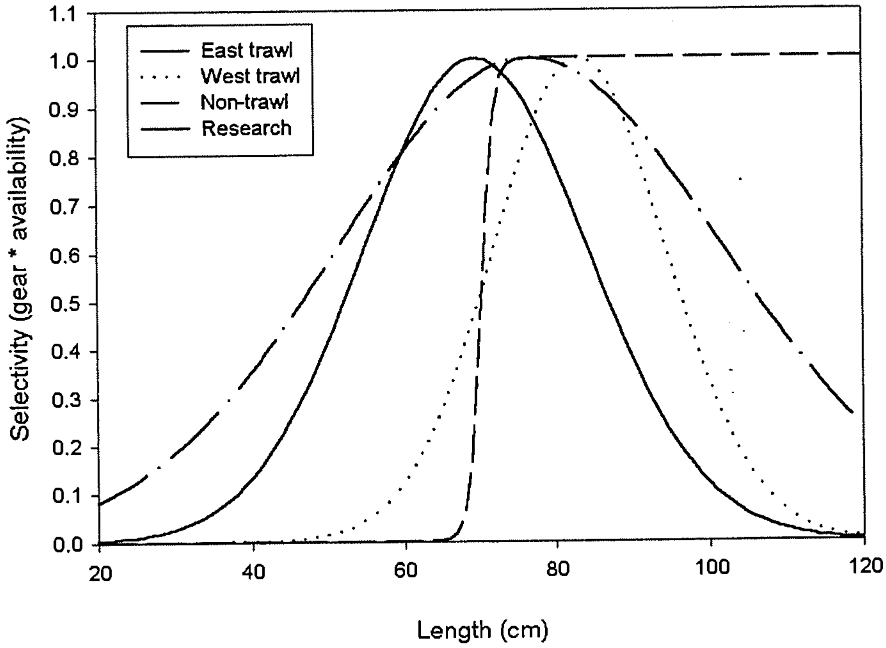


Figure 24. Estimated selectivity patterns (these incorporate gear selectivity and availability of the fish to the gear) for the four fleets considered in the base case model for pink ling.

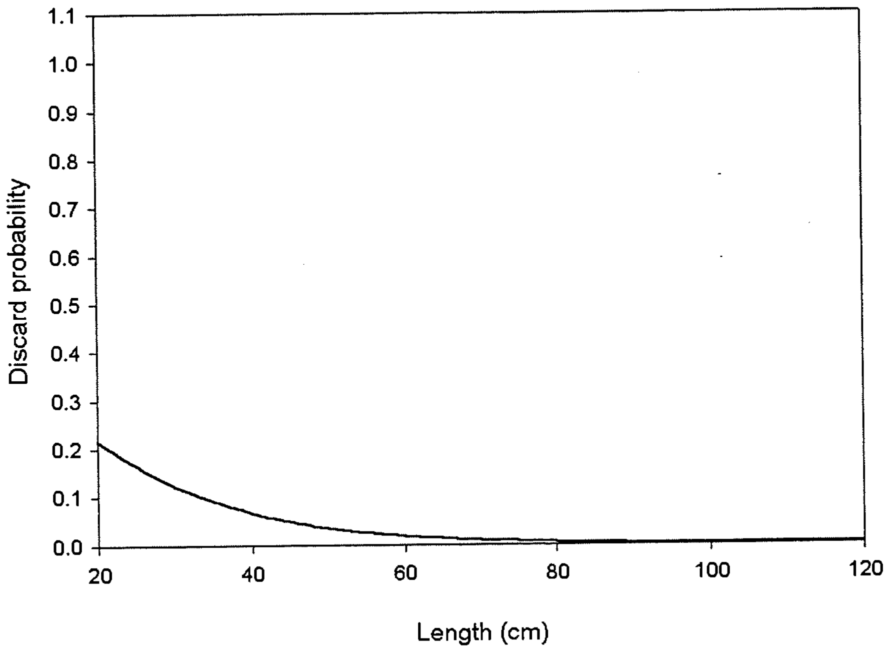
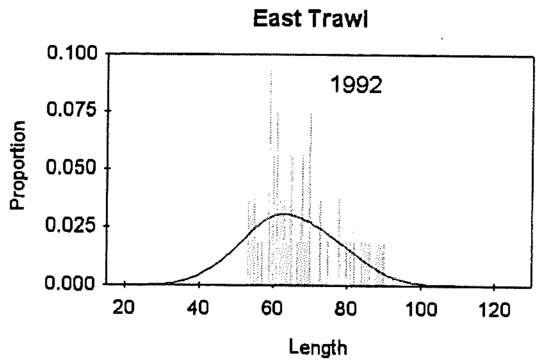


Figure 25. Estimated probability of discarding a ling (this applies to only the east and west trawl fleets).

There are only two catch-at-length frequencies estimated in the model (Figure 26) this is because ALK data are available for most years to convert the length frequencies into age frequencies. The sample size for 1992 is obviously poor but these were included in the model because they give some idea of the size of the catch in the early 1990s. The 1977 sample from the *Kapala* cruises is the only data from that early year.



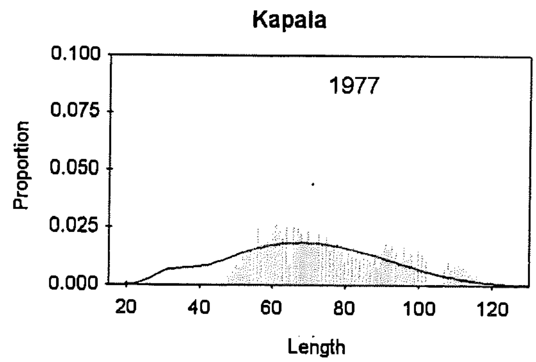


Figure 26. Observed and (base case) expected catch-at-length information for the east trawl fleet and the research fleet ("Kapala").

The east trawl fleet takes smaller fish than all other fleets except the research fleet which has very few catch-at-age data. The number of 1-year old fish caught by this fleet is overestimated in the catch-at-age in most years (Figure 27a). This is due to the relatively large recruitment residuals estimated for those years (Figure 23). These keep the estimated CPUE in the 1990s high, thus improving the model fit to the flat trend in the CPUE data, and improve the fit to the discard data. The number of 1-year olds in the two most recent years however is not overestimated because these young fish do not have a great influence on the available biomass and therefore on the estimated CPUE in those years and because measured discards are relatively low for these years.

The number of one-year olds is also overestimated in the catch-at-age data of the west trawl and non-trawl fleets although these fleets do not select this age group strongly and therefore this signal is not as clear (Figure 27b and c). The shift to younger fish in the catch of the research fleet is not captured well by the model (Figure 27d).

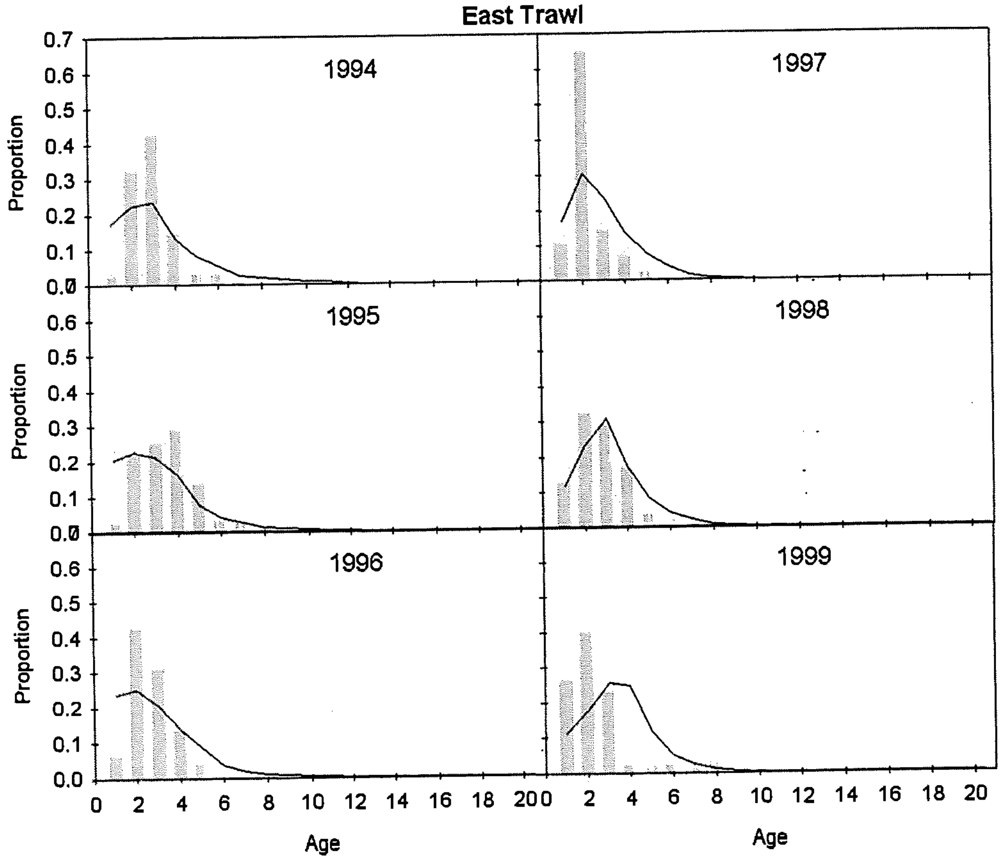


Figure 27a. Observed and (base case) expected catch-at-age information for the east trawl fleet.

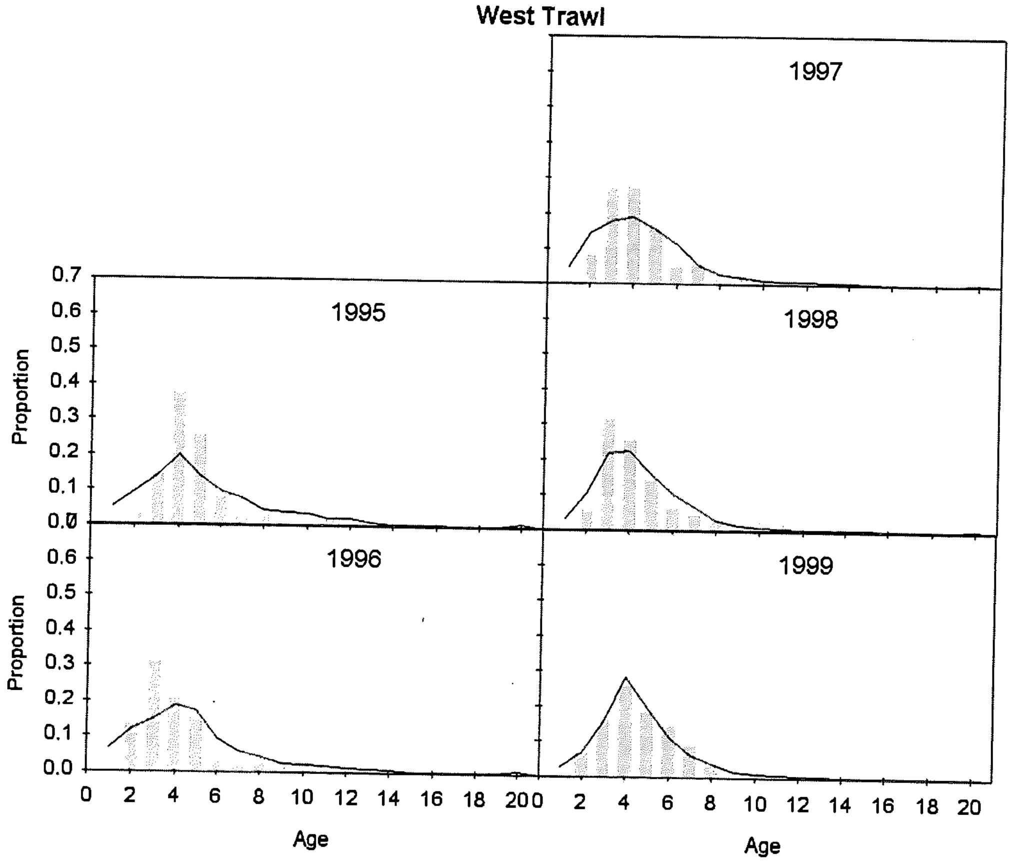


Figure 27b. Observed and (base case) expected catch-at-age information for the west trawl fleet.

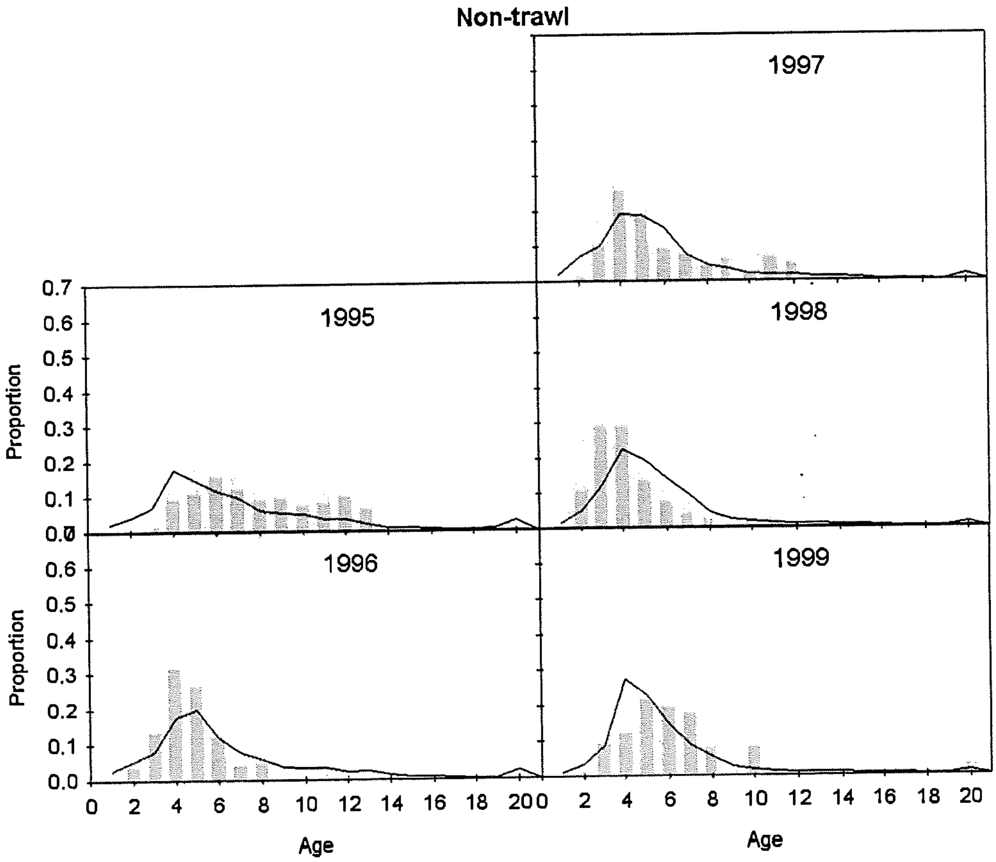


Figure 27c. Observed and (base case) expected catch-at-age information for the non-trawl fleet.

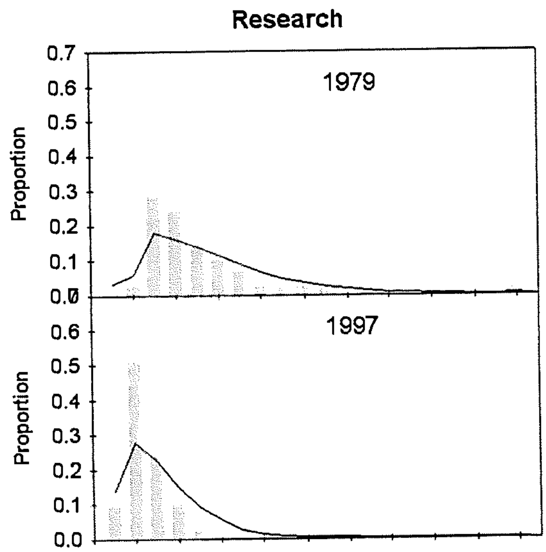


Figure 27d. Observed and (base case) expected catch-at-age information for the research fleet.

Discard-at-length data (in the absence of corresponding ALK data) is available for only the west trawl fleet (Figure 28). The shift to smaller fish is not estimated well.

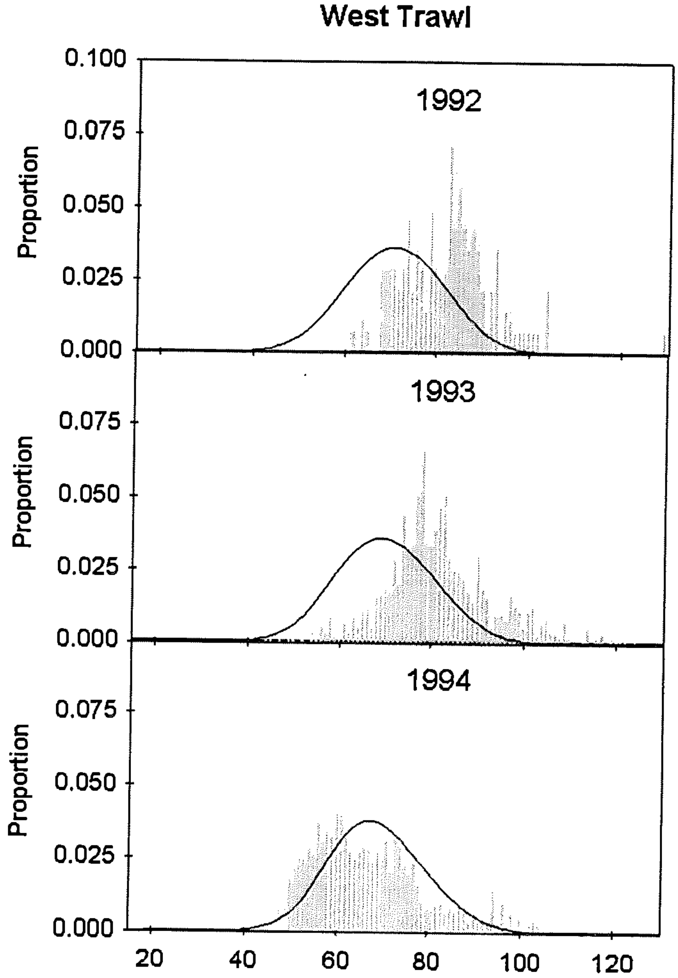


Figure 28. Observed and (base case) expected discard-at-length information for the east trawl fleet.

Discard-at-age data are available for both trawl fleets (and the non-trawl and research fleets are assumed to retain the whole catch). Again the number of one-year old fish is overestimated in most years for the trawl fleet but surprisingly not for the non-trawl fleet (Figure 29). This might indicate different recruitment patterns on the east and west coasts. Alternatively it may indicate that the selectivity pattern for one or other of these fleets is incorrect.

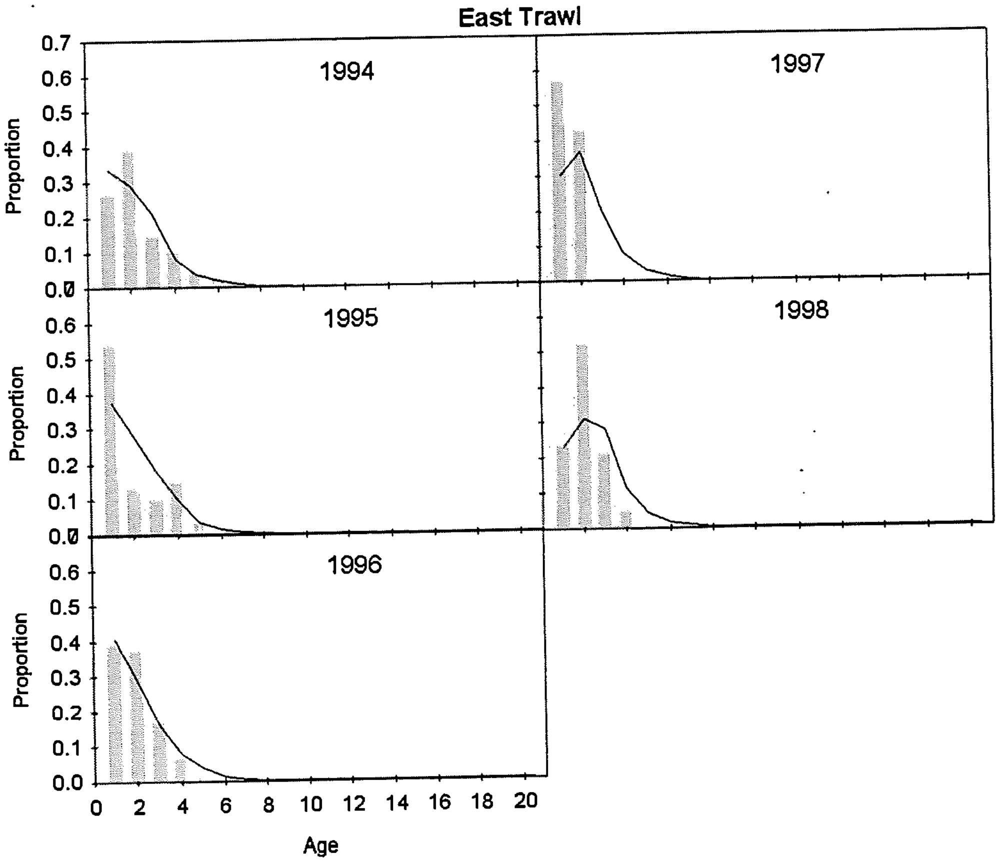


Figure 29a. Observed and (base case) expected discard-at-length information for the east trawl fleet.

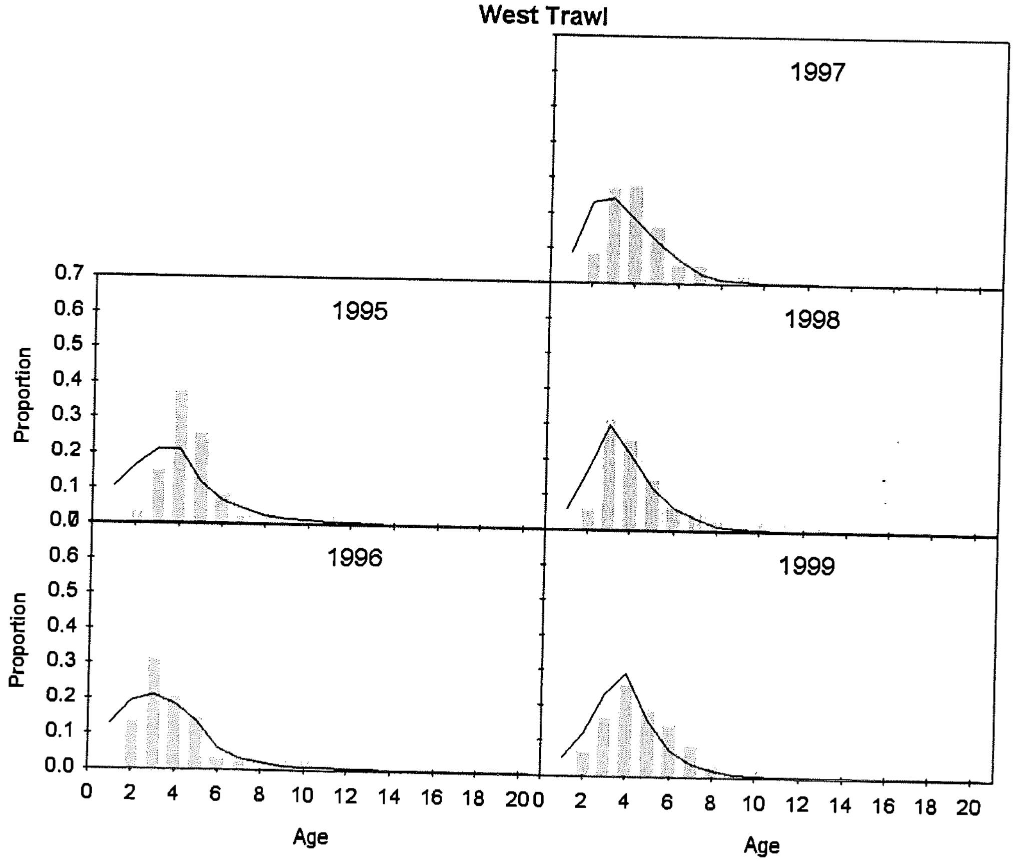


Figure 29b. Observed and (base case) expected discard-at-length information for the west trawl fleet.

The spawning biomass is estimated to have declined steadily until 1996 after which it began to increase due to the good recruitments of the early and mid-1990s (Figure 30).

Fishing mortality rates are estimated to have increased steadily until recently when a decrease has been seen (Figure 31).

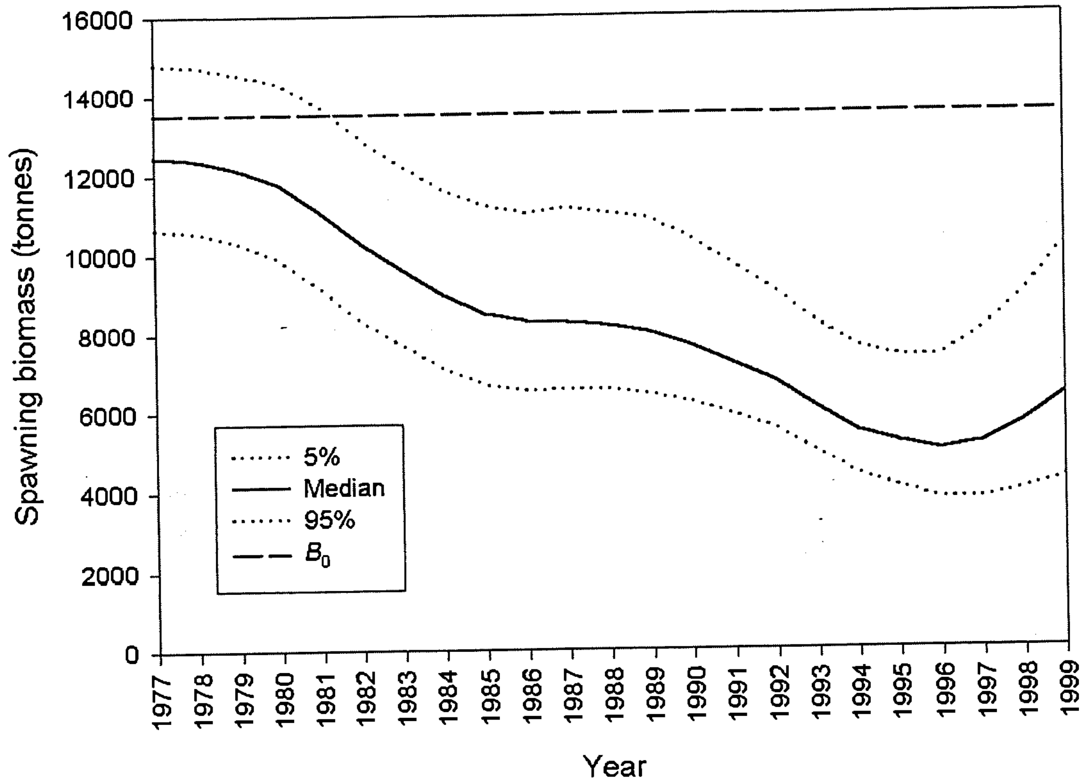


Figure 30. Estimated median spawning biomass and 90%-ile for the base case model for pink ling.

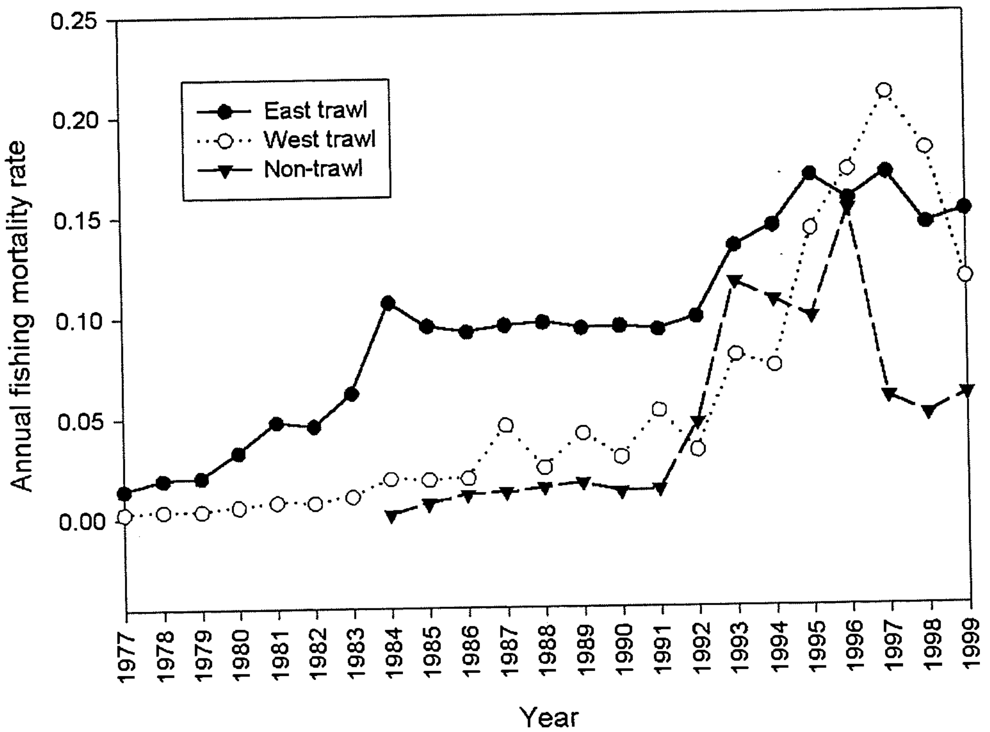


Figure 31. Estimated fishing mortality rates for three fleets for the base case model for pink ling.

6.5.2 Sensitivity to weighting the CPUE data

The model is extremely sensitive to the relative weights chosen for the CPUE and the length- and age-frequency data. This is because these data give quite different signals. The length- and age-frequency data indicate that the population is experiencing increasing mortality rates and that there have been no large recruitment events. The CPUE data on the other hand indicate that the population has not undergone any decline during the 80s and 90s. The influence of the weight chosen for the CPUE data on certain model results is illustrated in Figure 32. Greater values for $(2\sigma_q^2)^{-1}$ correspond to greater weight given to the CPUE data. The base case model uses a σ_q^2 value of 0.3 which corresponds to a $(2\sigma_q^2)^{-1}$ of approximately 5.6. The pristine spawning biomass (B_0) and the spawning biomass in the current year relative to pristine ("Depletion") increase with greater weight given to the CPUE data. The slope of the increase in the recruitment residuals during the 1991-1996 period also increases up to a weight of approximately that of the base case then decreases with greater weight. The natural mortality rate for ages 1-9 shows the reverse trend to that of the slope of the recruitments and that for older ages declines steadily with increasing weight.

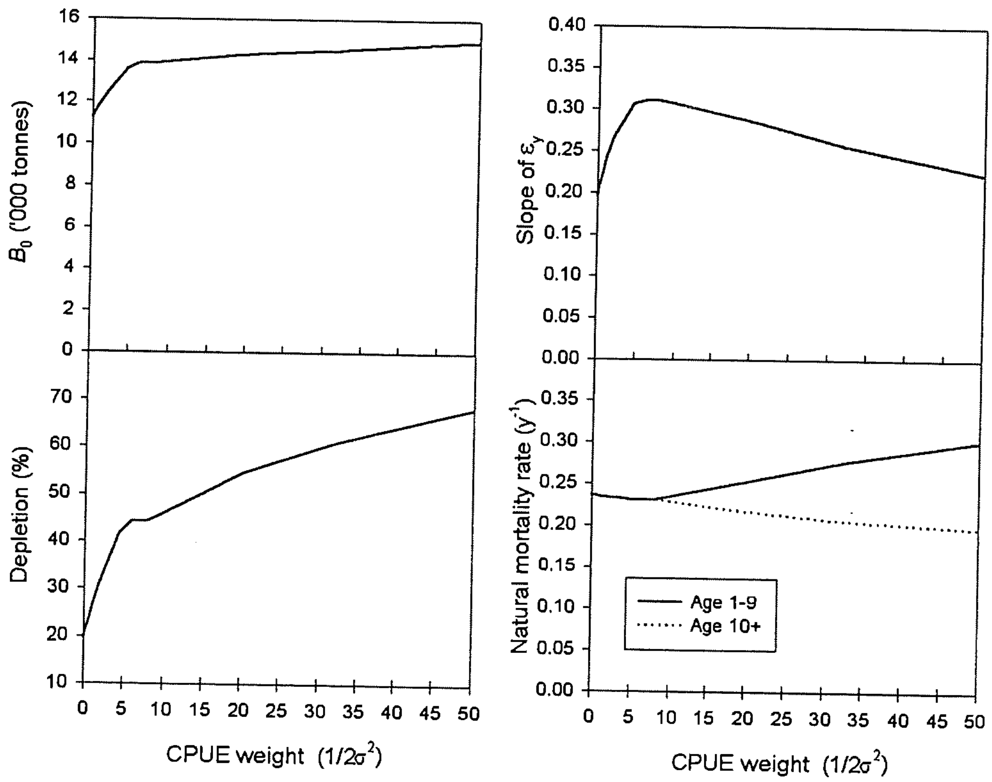


Figure 32. The effect of changing the weight assigned to the CPUE data ($1/2\sigma^2$) on the estimates of pristine spawning biomass (B_0); current depletion (spawning biomass in 1999 divided by B_0); the slope of the recruitment residuals between 1991 and 1996; and the estimated values of M (instantaneous natural mortality rate).

6.5.3 Other sensitivity tests

The results of the sensitivity tests are shown in Table 20. If the CPUE data are given no weight at all the estimated depletion (spawning biomass in 1999 divided by the pristine spawning biomass) is 19.5% whereas if the CPUE are given a relatively high weight ($\sigma_q = 0.1$) depletion is 68.1%. If recruitment residuals are not used (so that the model cannot use these to inflate the biomass and discard figures during the 1990s) the depletion is 35.8%. Estimates of natural mortality vary enormously among sensitivity tests but are never greater than 0.38 (the upper limit was 0.5 y^{-1}) and in only one instance is lower than 0.2 (the lower limit was 0.1y^{-1}). It would probably be best to fix the value of *M* for future assessments and to run the model for a range of plausible values.

If the length data are not used in the assessment the results are similar to those of the base case indicating that the length data are providing similar information to that given by the age data.

A range of tests were done in which data from one or more fleets were ignored in order to assess what sort of information each fleet was providing regarding the relative depletion of the stock in 1999. The estimates of absolute spawning biomass for these tests are not of interest as each test (except for the one that ignores the *Kapala* research fleet) ignores a large component of the annual catch.

Ignoring the *Kapala* research fleet does not greatly effect on the results, indicating that the east trawl data are giving much the same signal as the *Kapala* data does. Ignoring the non-trawl data has little effect except on the estimates of *M*, which are clearly poorly estimated.

Not surprisingly, the tests that use the west trawl fleet and ignore the east trawl ('No east trawl fleet' and 'West trawl only') result in a much less depleted stock in 1999 than the tests that ignore the west trawl ('No west trawl fleet' and 'East trawl only'). This is to be expected because of the larger size and greater age of ling in the west.

The tests that assume that CPUE is related to the square-root of the biomass and that vary the value of the steepness parameter (*h* in the stock-recruit relationship) alter the results little, relative to many of the other tests. Not surprisingly, lowering the length-at-maturity (l_m) results in a large, less depleted stock, and raising it has the reverse effect. If the model is forced to fit the catch data more closely the stock is found to be less depleted than the base case and, as mentioned above, the selectivity curves are altered.

Table 20. Quantities of interest and the negative log-likelihood (-lnL) for the base case model for pink ling and for a range of sensitivity tests. B_0 is the pristine spawning biomass, B_y^{sp} is spawning biomass in year y, F_y^f is fishing mortality for fleet f in year y, "c.v. R" is the c.v. of the estimated recruitment residuals, 'slope' is the slope of the spawning biomass during 1991-1996.

Model specification	B_0	B_{77}^{sp}	B_{99}^{sp}	B_{77}^{sp}/B_0	B_{99}^{sp}/B_0	F_{99}^1 (east trawl)	F_{99}^2 (west trawl)	F_{99}^3 (non-trawl)	c.v R	slope (ε_y '91-'96)	M (a < 10y)	M (a<=10y)	-ln L
Base-case	13489	13427	5530	99.5%	41.0%	0.151	0.117	0.060	0.47	0.21	0.23	0.23	743.61
$\sigma_q = \infty$ (CPUE data ignored)	11212	11151	2185	99.5%	19.5%	0.343	0.295	0.159	0.33	0.20	0.24	0.24	727.78
$\sigma_q = 0.1$	14955	14898	10177	99.6%	68.1%	0.088	0.064	0.029	0.40	0.22	0.30	0.20	778.49
$\varepsilon_y = 0$ (no recruitment residuals)	10890	10838	3899	99.5%	35.8%	0.194	0.168	0.081	-	0	0.38	0.20	789.95
No length data	14113	14055	5865	99.6%	41.6%	0.165	0.138	0.050	0.39	0.17	0.24	0.24	588.72
No non-trawl fleet	10237	10176	3984	99.4%	38.9%	0.203	0.174	-	0.45	0.20	0.28	0.17	679.68
No Kapala fleet	13482	13421	5721	99.5%	42.4%	0.147	0.113	0.057	0.39	0.19	0.25	0.25	713.36
No east trawl fleet	6657	6647	3915	99.8%	58.8%	-	0.158	0.077	0.53	0.29	0.20	0.20	429.90
No west trawl fleet	8001	7951	1078	99.4%	13.5%	0.751	-	0.312	0.36	0.19	0.24	0.24	335.29
East trawl fleet only	7261	7211	1290	99.3%	17.8%	0.882	-	-	0.37	0.08	0.26	0.14	247.41
West trawl fleet only	3806	3795	1765	99.7%	46.4%	-	0.357	-	0.46	0.30	0.20	0.20	336.83
CPUE $\propto \sqrt{B}$	12673	12611	4345	99.5%	34.3%	0.185	0.150	0.080	0.42	0.20	0.24	0.24	739.26
$h = 0.6$	14343	14282	5959	99.6%	41.5%	0.142	0.109	0.054	0.50	0.33	0.24	0.24	745.28
$h = 0.9$	12960	12898	5271	99.5%	40.7%	0.157	0.123	0.063	0.45	0.29	0.22	0.22	742.47
l_m = 60 cm	14784	14715	7235	99.5%	48.9%	0.152	0.118	0.060	0.46	0.21	0.23	0.23	743.30
l_m = 72 cm	12289	12236	4236	99.6%	34.5%	0.150	0.116	0.059	0.47	0.21	0.23	0.23	743.88
$\sigma_c = 0.005$	13479	13417	5512	99.5%	40.9%	0.172	0.112	0.060	0.47	0.31	0.23	0.23	753.37
$M = 0.2$ (for all ages)	14200	14135	4802	99.5%	33.8%	0.176	0.134	0.066	0.51	0.33	0.20	0.20	745.05
$M = 0.25$ (for all ages)	13235	13175	6058	99.5%	45.8%	0.137	0.107	0.056	0.45	0.30	0.25	0.25	744.00

6.5.4 Risk analysis / Projections

Figure 33 shows the estimated spawning biomass and 90%-ile for the base case, projected 20 years into the future assuming a TAC of 2000t, 10% of which is taken by the non-trawl fleet. The predicted spawning biomass declines steadily after 1999 when the recent large recruitments move out of the fishery.

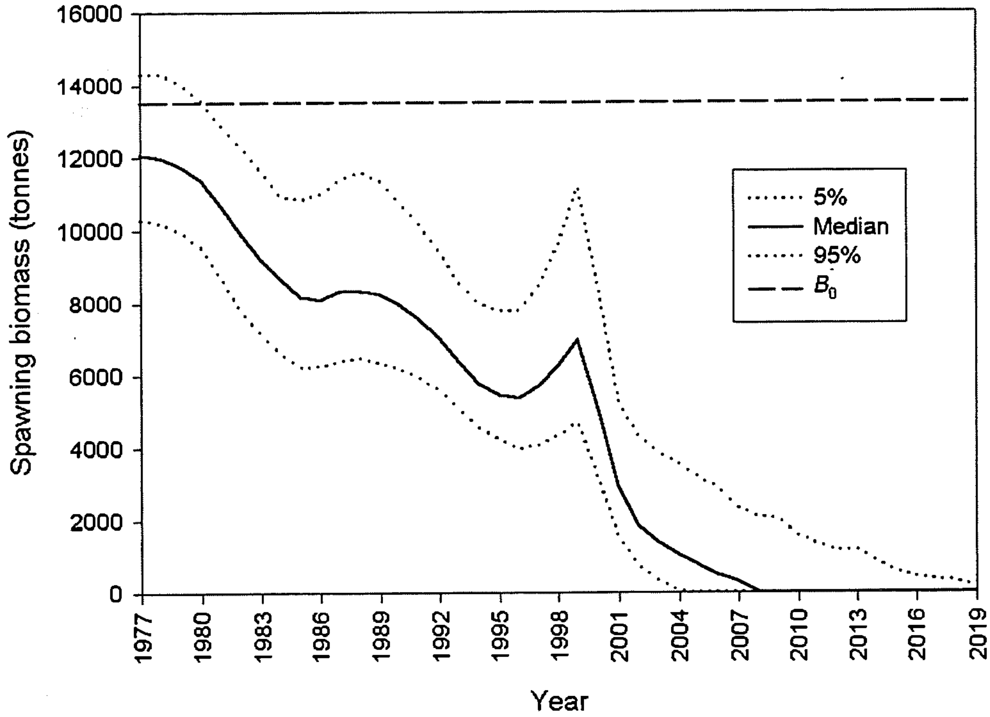


Figure 33. Future projected spawning biomass (with 90%-iles) for the base case model with a fixed future TAC of 2000t, 90% of which is taken by the trawl fleets.

The probability of depleting the stock below 20% of its pristine level (B_0) over a 20 year projection period for a range of TACs is shown in Figure 34 for two possible future splits of the TAC between the trawl and non-trawl fleets (10:90 and 40:60; trawl:non-trawl). The 40:60 split has a greater probability of depleting the stock below 20% of B_0 than the 10:90 split but this result is dependant on the selectivity curves that were calculated by the base case model and, as has been mentioned, these are not well determined - they can change sufficiently with the addition of a single year's data to reverse this result (cf Thomson, 2000c).

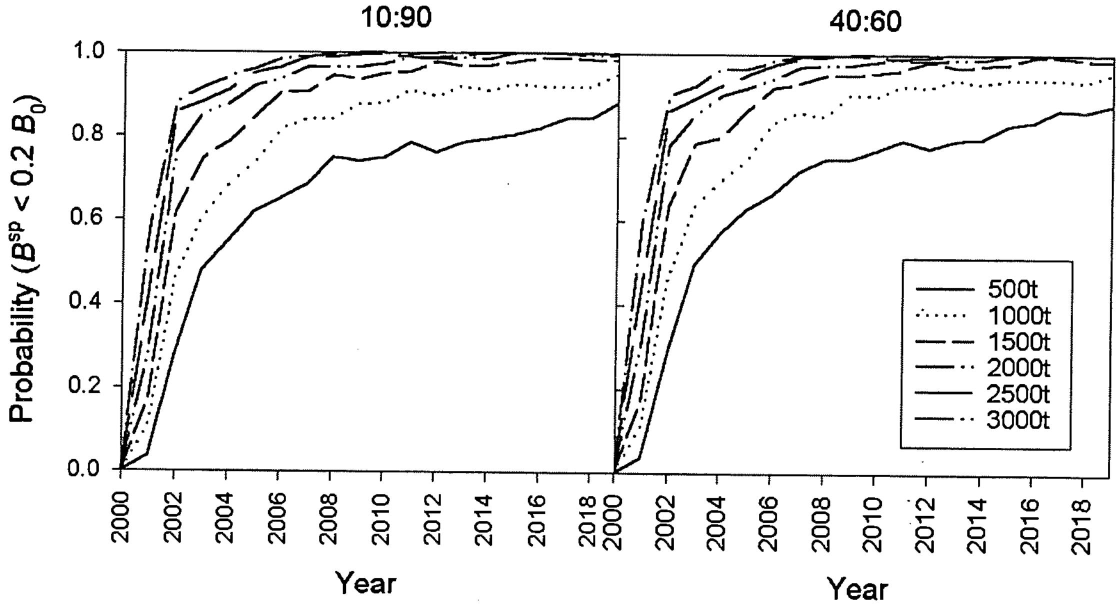


Figure 34. The probability that the spawning biomass will drop below 20% of pristine (B_0) given fixed future catches which are split between the trawl and non-trawl fleets in a ratio of either 10:90 or 40:60.

The size of the stock is not at all certain and neither, therefore, is its current size in relation to pristine. The sustainability of future catches is therefore not easily assessed.

The model is clearly unable to explain all the pink ling data and its qualitative results therefore cannot defensibly be used to recommend future TACs. A number of model improvements suggest themselves (e.g. including data from the 2000 fishing year; weighting the length and age samples by their sample sizes) however it is very unlikely that any of these will be able to solve the essential problem that the CPUE data give a different signal to that given by the age and length data. The reasons for these differing signals must been identified and modelled before other, less important, improvements to the model are considered.

6.5.5 Hypotheses that could explain the existing data

A workshop on pink ling was held in early 2000 (Thomson, 2000c) where a range of hypotheses were identified and discussed by all stakeholders (industry, research and management).

Pink ling adults are not known to show much movement (Tilzey, 1994) therefore it may be possible for localised depletions to take place. The fishery could maintain high catch rates by sequentially fishing down the populations on several grounds. Some evidence for this is seen in the relatively larger and older population in the west relative to the east, which has been subject to greater fishing pressure in the past. However, the decline in the mean age and length of the catch must still be explained - if each fishing ground represented a separate population of ling then the age and length frequency, like the CPUE, of the catches ought to remain unchanged as the fishery moves to new grounds.

The behaviour of the trawl fishery has changed since the introduction of ITQs in 1992 (Prince, *et al*, 1997). Typical trawl shots before 1992 used to target specific depths but since 1992 a wider depth range is exploited in the search for a more mixed catch. Such changes in the behaviour of the fishery could have distorted the CPUE or the age and length data. CPUE may not be a good indicator of abundance for this species because of changes in fishing practices and the behaviour of this species. Ling have increased in value since the early 1980s (Tilzey, 1994a) and this has lead to increased targeting of this species. This might, at least in part, mask a simultaneous reduction in stock biomass. However, the *Kapala* research data are not subject to these changes and yet these also showed no change in CPUE and a decline in overall catch-at-length.

It may be that ling productivity has increased over recent years. This could result from their feeding on offal discarded from fishing vessels or due to reduced competition with other, exploited, demersal species (such as deep sea dogfish and gemfish). This could result in increased recruitment (although.this is not strongly supported by the age data), or decreased mortality rates, or faster individual growth. The individual growth hypothesis can be examined using ALK data.

It has been observed that ling catches on particular grounds increase after these grounds have been trawled. This has been attributed to ling moving onto those grounds to feed on discarded waste from the fishing vessels (Smith and Tilzey, 1995). A tendency for ling to move onto trawl grounds would keep the CPUE for this species high, even if the stock size were reduced. The *Kapala* data is also likely to be affected by this behaviour, if it does take place.

The suggestion was made that ling might be cannibalistic but the literature indicate that this is not the case (Blaber and Bulman, 1987; Clark, 1985; Mitchell, 1984)

6.5.6 Summary and implications

This assessment has revealed two, apparently irreconcilable signals in the data. Firstly the CPUE data indicate a steady, or perhaps slightly increasing, biomass of pink ling over the time period considered. Secondly, the catch-at-age and -length data indicate an increase in total mortality rate over this period with little indication of a compensating increase in year-class strength of one-year olds (i.e. recruitment), and consequently a decline in the stock size. CPUE and age and length data collected during *Kapala* research surveys off NSW in 1976/77 and 1996/97 show the same trends despite effectively identical survey design and gear in both years of the survey. This implies that the trends observed in the commercial fishery do reflect trends in the ling population and are not the result of changes in the behaviour of the fishery.

This assessment indicates that current catches of ling are not sustainable and that it would be detrimental for the non-trawl fleet to take a greater proportion of the current TAC. However these findings depend on the results of the base case assessment model. These are highly sensitive to the relative weighting given to the CPUE and catch-at-age data. The spawning biomass of the population during 1999 could have been as little as 20% of the pristine size, or as great as 70%. The selectivity curves that give rise to the result that greater non-trawl catches are more detrimental are not at all well determined, they are subject to large changes when assumptions are altered or new data introduced. Therefore the results of this model cannot be regarded as reliable.

7 SPOTTED WAREHOU (*Seriolella punctata*)

7.1 History of the fishery

Large catches of spotted warehou were first taken in the late 1970s (Smith, 1994b). Catches of spotted warehou (*Seriolella punctata*) in the South East Fishery have increased substantially during the 1990s (Figure 35) and, in the absence of evidence that these catches are not sustainable, the TAC has also been increased (Figure 35). In 1998 the (unstandardised) CPUE for spotted warehou fell below the lowest level observed during 1986 to 1994 thus triggering one of AFMAs performance criteria for SEF species (Smith and Wayte, 2000).

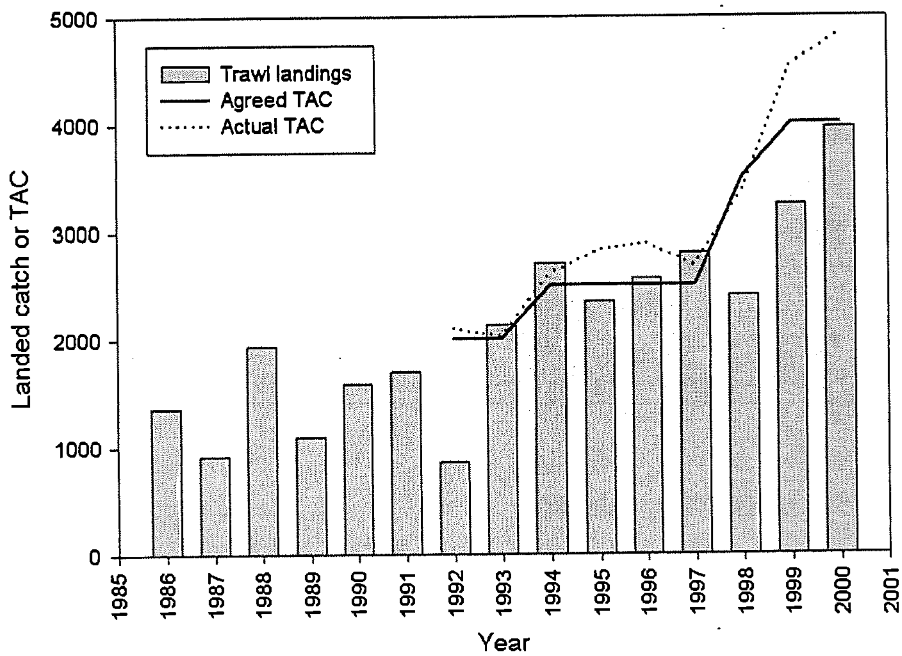


Figure 35. Estimated landed catches of spotted warehou for the period modelled (by calendar year), and allocated and actual TACs for the SEF. The landed catches are taken from SEF1, have been multiplied by 1.1725, and pertain to calendar year (see text for further details).

Spotted warehou are caught using trawl and non-trawl gear (in particular gill-nets). They are also taken as a by-catch of the winter spawning grenadier fishery and this may, at least in part, account for the increased landings in zone 40 (western Tasmania); Figure 36. In the past spotted warehou have been recorded in the SEF2 database as blue warehou due to the greater value of blues on the market. SEF1 records are regarded, however, as being reliable (David Smith, *per comm*).

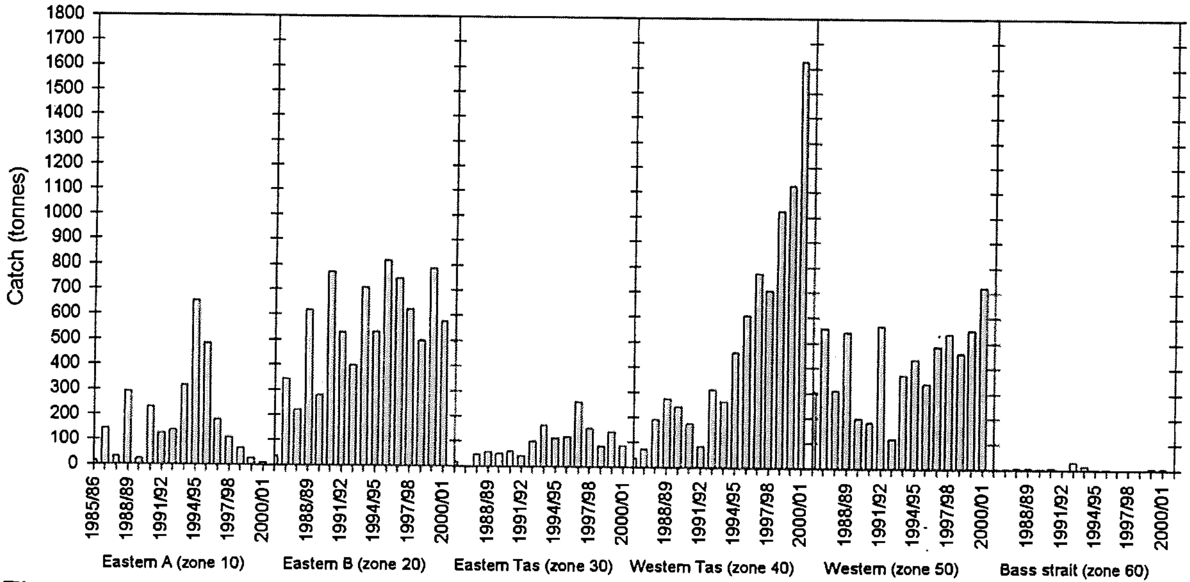


Figure 36. Landed catches of spotted warehou (form SEF1 records) in each of the SEF zones. 1985/86 indicates 1 May 1985 - 30 April 1986.

A formal stock assessment for this species is necessary to gauge whether or not the TAC is sustainable. A preliminary stock assessment model, using the Integrated Analysis approach, was presented to a workshop on spotted warehou in June 2000. It was then decided that the Blue Warehou Assessment Group (BWAG) would take on responsibility for spotted as well as blue warehou. BWAG have met a number of times since then and several improvements have been made to the preliminary model presented at the June workshop.

7.2 Biological Background

7.2.1 Habitat and related species

Spotted warehou are found in the south-east corner of Australia (including Tasmania), their distribution coinciding closely with the northern border of the SEF although they also occur in the Great Australian Bight, to the east of the SEF region. A fishery for spotted warehou exists in New Zealand (where they are named silver warehou) taking roughly 10 thousand tonnes in recent years. The closest relative of spotted warehou in the SEF are blue warehou (*Seriolella brama*).

A strong length-depth relationship has been observed (Bax and Williams, 2000) with smaller fish occurring in shallower water. The larvae are pelagic and young spotted warehou are often found in association with pelagic salps (Smith, 1994a). Spawning occurs during later winter or early spring (Smith and Wayte, 2001).

7.2.2 Stock structure

No studies have been done on the stock structure of spotted warehou in Australian waters (Smith and Wayte, 2000) nor is there strong anecdotal evidence of any stock structure. The species is managed in the SEF as a single stock.

7.2.3 Biological parameters

The parameters of the length-weight relationship and the length-at-maturity (Table 21) were provided by David Smith (*unpublished data*). The von Bertalanffy parameters were calculated using the pooled ALK data for this species and the value for the steepness of the stock-recruit relationship was chosen to reflect the lack of knowledge for this parameter (Francis, 1992; Koopman *et al*, 2000). Early versions of this model estimated the value of the natural mortality rate (*M*) but it was found that it was poorly estimated and also that the model is very sensitive to the value of this parameter. The value of *M* for the base case is the same as that used by New Zealand (Annala *et al*, 2000).

Table 21 Values for biological parameters used in the stock assessment of blue grenadier

Description	Value
Length-weight relationship:	
a	0.0065 g^{-1}.cm
b	3.270
von Bertalanffy growth curve:	
L_∞	52.92 cm
K	0.299 y^{-1}
t0	-0.960 y
Natural mortality rate:	
M	0.25 y^{-1}
Other:	
length-at-maturity (l_m)	37 cm
steepness (*h*)	0.75
μ	1

7.3 Data

7.3.1 Landed catch

Landings of spotted warehou prior to the start of SEF1 record-keeping in 1986 are not considered to have been large. The model uses a 'biological year' (1 May to 30 April) in preference to a calendar year to better reflect the biology of the stock (because spotted warehou are hatched close to the middle of the calendar year).

Table 22. Catch, discard and catch-per-unit effort (CPUE) data for spotted warehou for the trawl and non-trawl fleets. The trawl landings figures used in the base case model were adjusted upwards (by 1.1725, the ratio of logbook to verified catches) and were divided by 1 minus the proportion discarded. CPUE and discard proportion data were not available for the non-trawl fleet. The landings for the non-trawl fleet (David Smith *pers comm*) are not adjusted in any way.

Year	Trawl fleet				Non-trawl fleet
	Landed catch (tonnes)	Proportion discarded (%)	Adjusted landed catch (tonnes)	Standard-ised CPUE	Landed catch (tonnes)
1986/87	1131.7	-*	1407.6	0.565	1
1987/88	810.9	-	1008.6	0.980	1
1988/89	1791.0	-	2227.6	1.090	6
1989/90	805.4	-	1001.7	1.277	21
1990/91	1429.5	-	1778.0	0.992	24
1991/92	1358.8	-	1690.0	1.199	55
1992/93	1102.7	-	1371.5	1.030	85
1993/94	1846.9	1.4	2195.4	0.898	61
1994/95	2195.2	1.6	2615.4	0.937	79
1995/96	2368.2	9.2	3058.1	1.111	97
1996/97	2447.4	1.1	2900.3	1.051	165
1997/98	2130.4	8.4	2726.9	1.043	169
1998/99	2133.2	19.1	3089.8	0.990	66
1999/00	2438.6	3.1	2951.9	1.041	76
2000/01	3385.6	2.0	4052.1	1.000	4.9

* for the base case model missing discard rate data are replaced by the average of the years for which data are available

The SEF1 record is used to give annual landings of spotted warehou because of the problem of confusion between blue and spotted warehou in the SEF2, and because the model requires estimates of landings made in each of four depth classes. The average ratio of the SEF1 to SEF2 mass was calculated and used to scale up all SEF1 catches. This ratio (= 1.1725) was remarkably consistent over the period for which records are available, having a c.v. of 0.02.

During the early 1990s fishers in NSW are known to have recorded that some catches of their catches in coastal, state waters, when in fact these were made in Commonwealth waters. The absence of an OCS agreement between the NSW and Commonwealth governments meant that these catches were not deducted from their Commonwealth quota. This has lead to an obvious increase in the reported landings by the trawl fleet in the shallowest depth class during the early 1990s (Figure 37). This has been accounted for by replacing the proportion of the catch taken in the shallowest

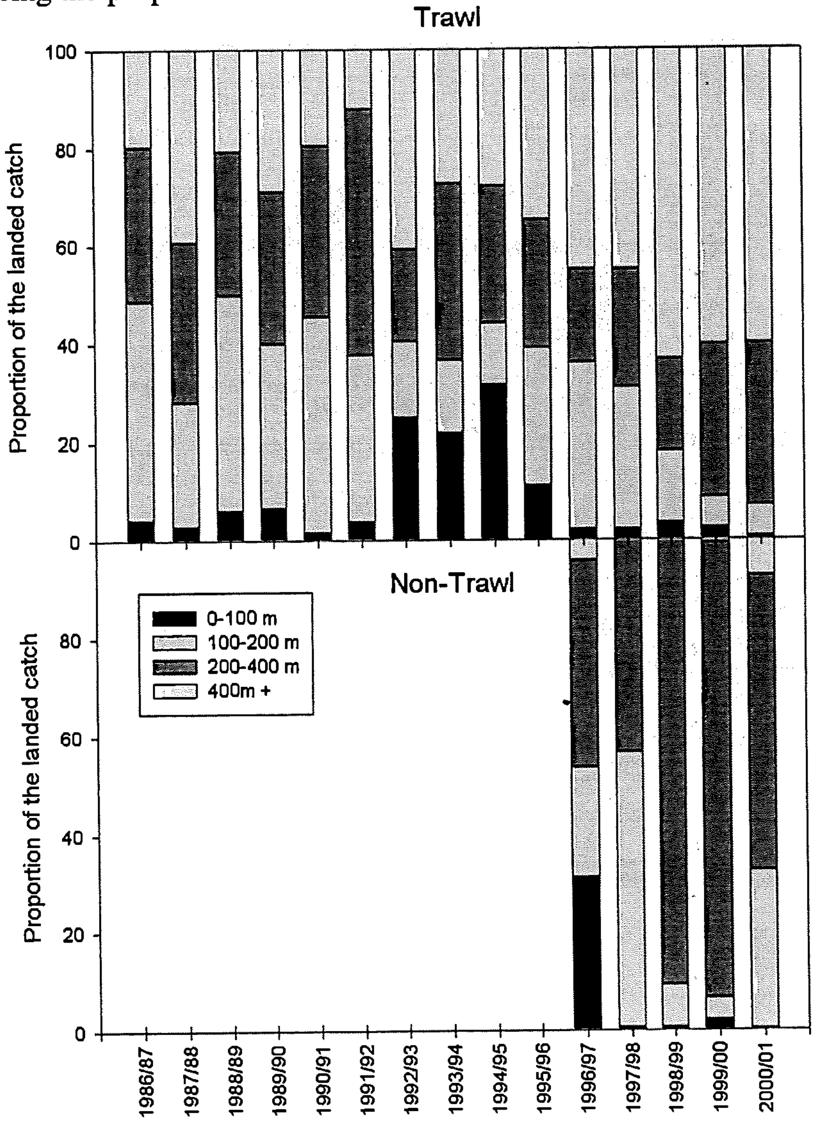


Figure 37. The proportion of the annual landed catch of spotted warehou that was taken by the trawl and non-trawl fleets in each of four depth classes.

depth class (0-100m) during the years 1992/93-1995/96 by the average proportion taken during other years. The proportion taken in the second shallowest depth class (100-200m) was adjusted upwards so that the proportions for all depth classes would sum to one. Thus, effectively, the fish that were over-reported from the 0-100m depth class were allocated to the 100-200m depth class. This was done, instead of allocating the over-reported fish across all depth classes, because the data show that the proportion of fish reported from the 100-200m depth class is unusually low during 1992-1995 whereas the deeper depth classes show no clear pattern during these years (Figure 1). It is possible that most of the mis-reported catches were in fact made close the state boundary.

The proportion of the landed catch that has been taken in deeper water is increasing, at least for the trawl fleet (Figure 37).

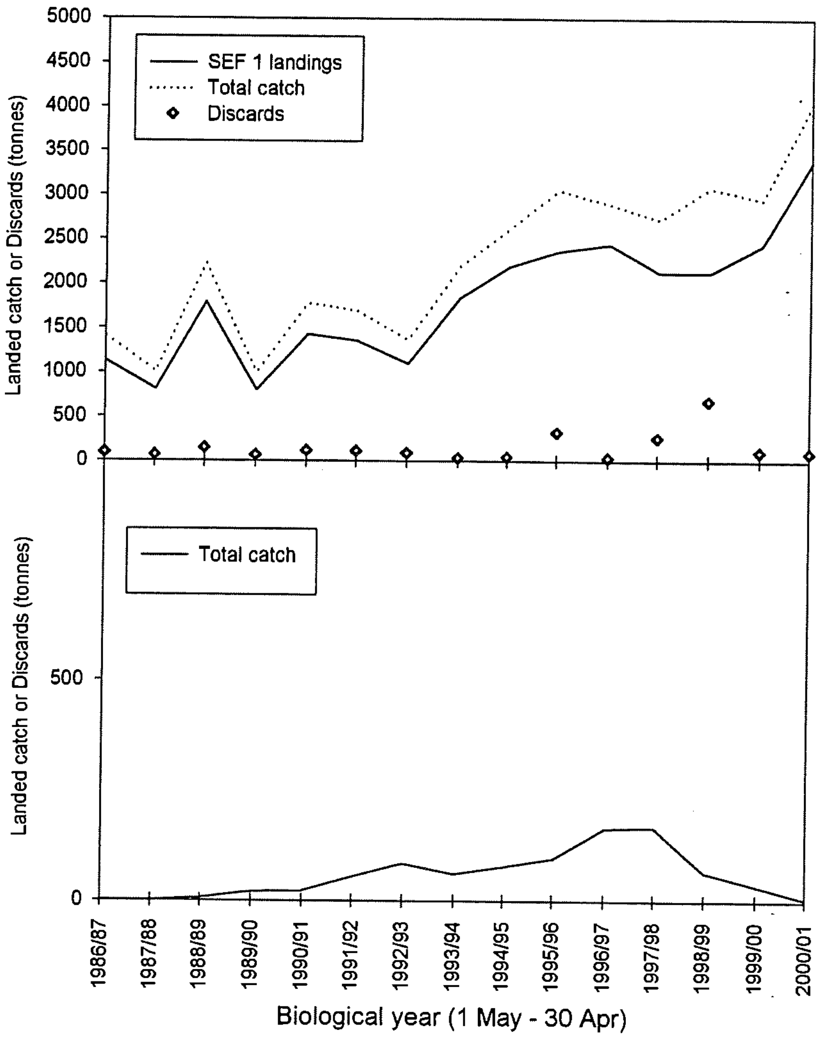


Figure 38. Annual landed catches for the trawl and non-trawl fleets and disardeds. The recorded landings for trawl ('SEF1 landings') are adjusted upwards by 1.1726 and by the addition of the estimated discards, the result is the 'Total catch' line in the upper plot.

7.3.2 Discards

Members of the fishing industry indicated that discarding of spotted warehou occurs when market prices are low and is therefore not related to the size of the fish caught. however, close examination of the ISMP data on the length frequency of catches and discards shows that while this is often true, there are times when discarding of spotted warehou is size-based. There is no clear pattern indicating when discarding will be market- and when size-related. Consequently, for the base case model the mass of fish that were estimated to have been discarded by the trawl fleet were added to the landed catch and not treated as a separate data source by the model. A sensitivity test is done in which all discards are considered to be size-based. The non-trawl fleet is assumed to have negligible discarding (Knuckey and Gason, 2001).

Years for which trawl discard rates were unknown were assumed to have the average level of discarding (this was done in order to prevent underestimation of the total catch for these years).

Large, New Zealand owned, factory vessels that have been operating in the blue grenadier spawning fishery since the winter of 1997 are known to take large catches of spotted warehou as a by-catch. These vessels have fishmeal processing plants onboard and consequently have almost no discarding. The ISMP-monitored discards were made available as estimated proportion discarded by zone and year and these did not include sampling aboard factory vessels. Therefore the estimates for Western Tasmania (zone 40, where spawning grenadier aggregate in winter) were overestimates. This was overcome by dividing the SEF1 catch data for Western Tasmania into 'factory vessels' and 'non-factory vessels', assigning the ISMP estimate for discarding in that zone to the 'non-factory vessels' component of the catch and assigning zero discards to the 'factory vessels' component. It has subsequently been found that an additional, Australian-owned, factory vessel also operates in the SEF; catches by this vessel will have to be taken into account in future analyses of discarding for this and other SEF species.

7.3.3 CPUE

CPUE data from SEF1 logbooks were standardised using a GLM analysis (Haddon, 2001b). The number of shots included in the analysis for each biological year were recorded (Table 23) and used in the model to weight the standardized CPUE figure for each year.

Table 23. Sample sizes for catch-at-length data for the retained component of the catch, ALK and CPUE data. The sample sizes for the ALKs were used to weight the catch-at-age for the corresponding year.

Year	Trawl Port lf	Trawl Onboard length frequency 0-100m	100-200m	200-400m	400m+	Non-trawl Port lf	ALK	CPUE
1986/87	-	-	-	-	-	-	-	1307
1987/88	1194	-	-	-	-	-	454	1034
1988/89	854	-	-	-	-	-	117	1707
1989/90	110	-	-	-	-	-	-	1209
1990/91	-	-	-	-	-	-	-	1409
1991/92	97	-	-	-	-	-	-	1424
1992/93	3764	-	-	-	-	261	109	1887
1993/94	3900	-	-	-	-	1845	370	2852
1994/95	2117	-	-	-	-	-	330	2873
1995/96	4720	-	-	-	-	120	680	3592
1996/97	8471	-	209	206	100	184	458	3764
1997/98	12553	-	1109	2059	1881	1069	374	3485
1998/99	16268	28	1206	1827	2912	152	660	3162
1999/00	13965	-	1142	1643	1889	411	839	3219
2000/01	14850	-	335	2436	2649	56	445	2916

The CPUE standardisation was applied in two ways: the method was applied to data from all depth classes combined (Figure 39); and to data from each of four depth classes separately (Figure 40).

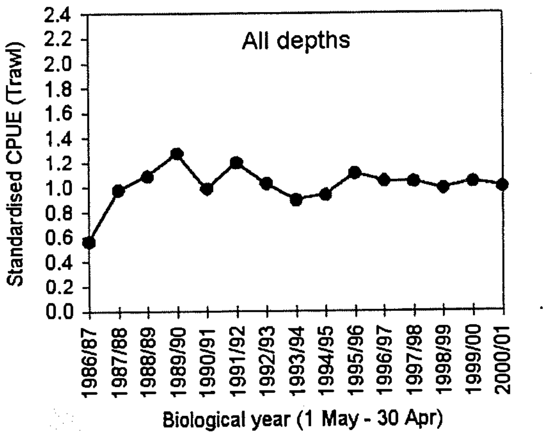


Figure 39. Standardised CPUE for spotted warehou for data from all depths combined.

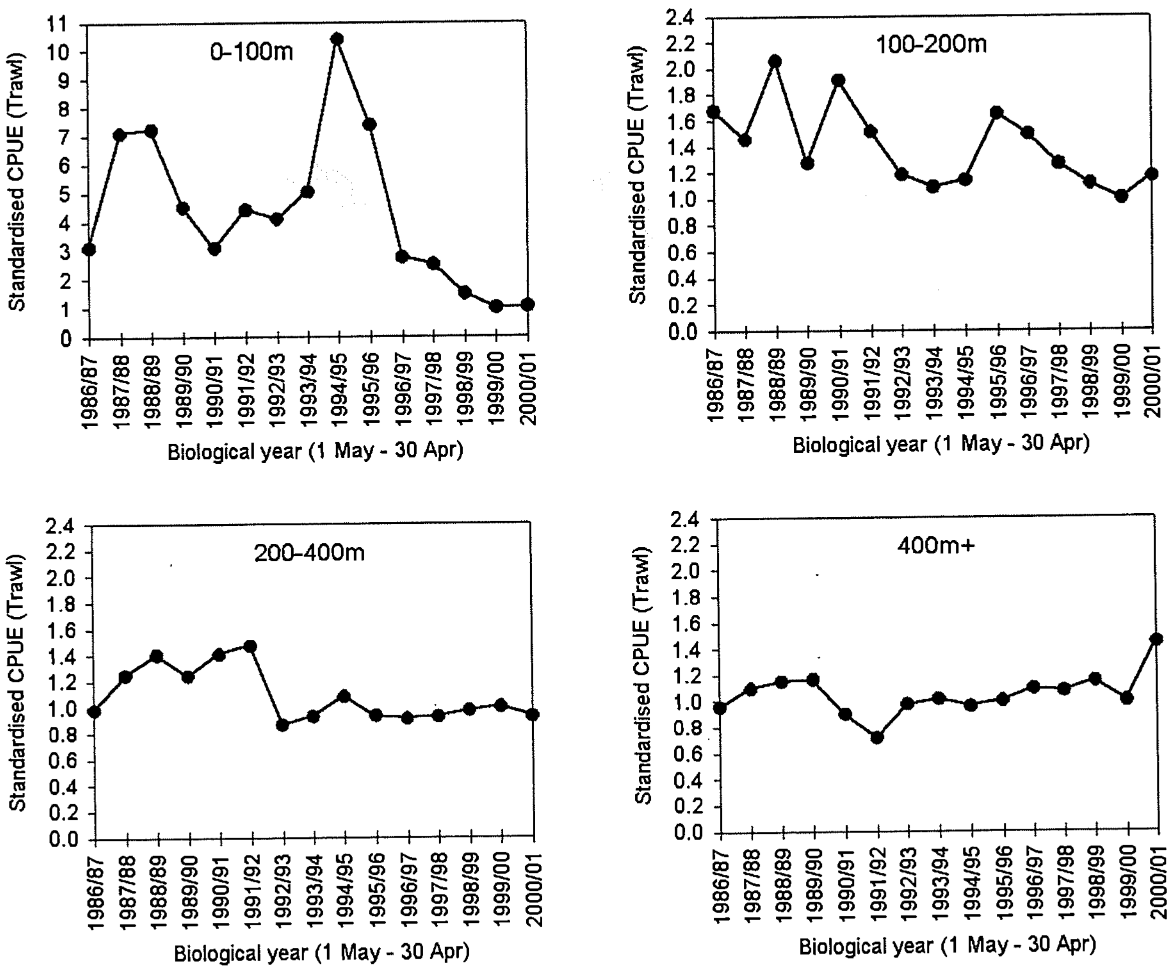


Figure 40. Standardised CPUE for spotted warehou for data from four separate depth classes.

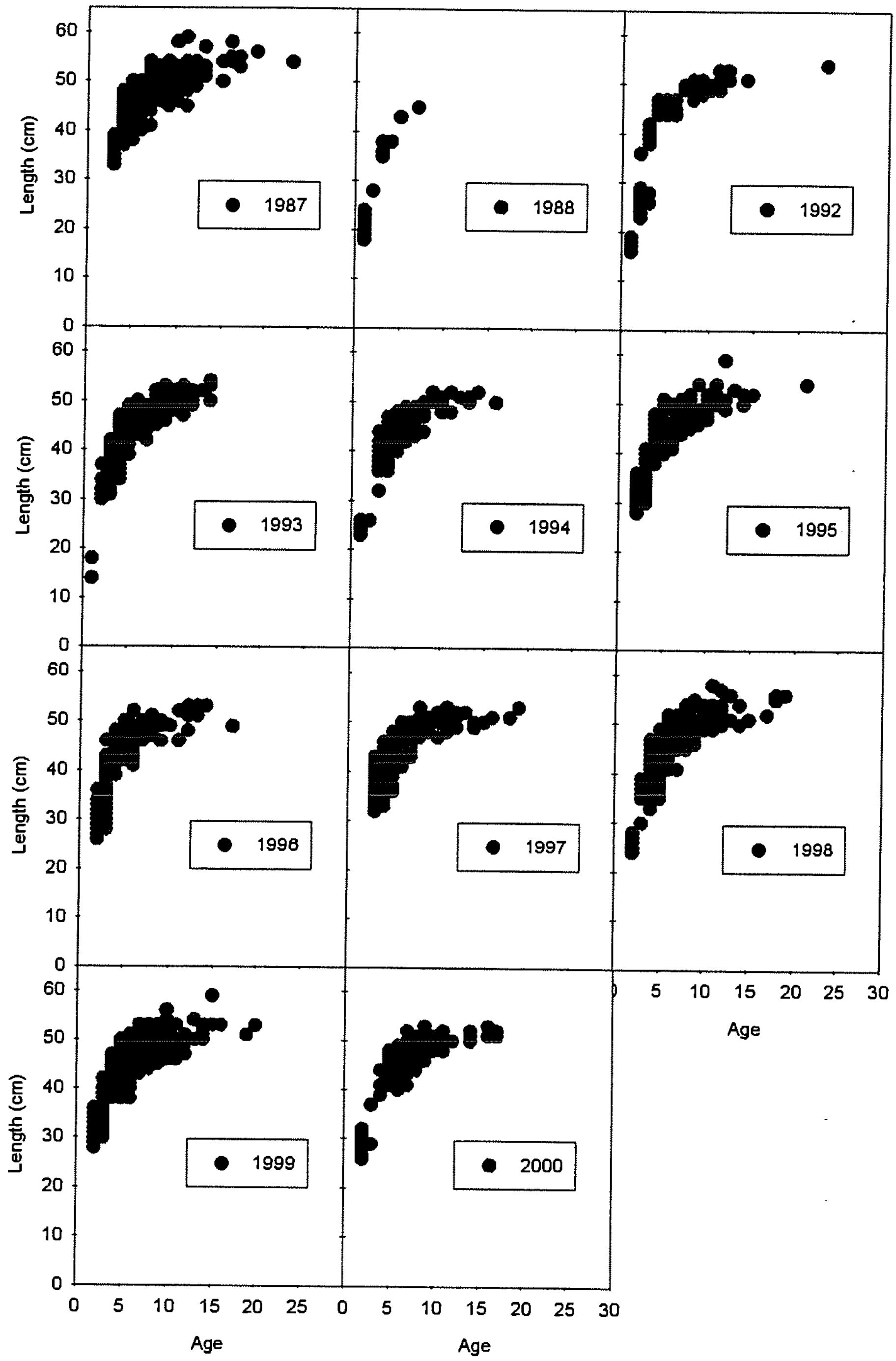


Figure 41. Age-length keys (ALKs) for spotted warehou for biological years e.g. 1987 indicates 1 May 1986 - 30 April 1987.

Table 24. Estimated mean length-at-age, calculated using age-length keys (ALKs) and length frequency data. Cells for which mean length could not be calculated are given the average value for that age.

Year	Age (years)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1986/87	23.49	31.11	36.75	40.93	44.04	46.33	48.04	49.30	50.24	50.93	51.45	51.83	52.11	52.32	52.48
1987/88	23.49	31.11	37.43	44.63	45.67	46.59	48.26	49.49	49.92	50.60	50.94	52.29	52.99	52.32	51.94
1988/89	23.49	31.00	36.20	40.91	43.60	46.00	46.40	49.00	50.00	50.93	51.00	51.83	52.11	52.32	52.00
1989/90	23.49	31.11	36.75	40.93	44.04	46.33	48.04	49.30	50.24	50.93	51.45	51.83	52.11	52.32	52.48
1990/91	23.49	31.11	36.75	40.93	44.04	46.33	48.04	49.30	50.24	50.93	51.45	51.83	52.11	52.32	52.48
1991/92	23.49	31.11	36.75	40.93	44.04	46.33	48.04	49.30	50.24	50.93	51.45	51.83	52.11	52.32	52.48
1992/93	23.49	33.34	38.60	45.71	45.16	46.12	49.63	49.01	49.06	49.46	50.87	52.14	52.11	51.00	52.00
1993/94	26.64	31.22	36.43	41.63	44.80	46.21	47.17	49.60	50.21	50.25	50.91	50.85	52.00	53.22	52.48
1994/95	27.00	31.75	34.80	42.84	45.61	47.55	48.03	48.32	50.82	50.31	50.12	51.00	50.56	52.00	52.48
1995/96	26.97	31.63	38.13	42.28	44.06	45.79	48.34	48.46	48.03	49.84	50.75	50.26	53.00	50.59	52.00
1996/97	24.75	32.17	35.72	44.32	46.41	46.91	48.92	49.19	49.18	49.00	50.79	50.75	51.41	53.00	52.48
1997/98	19.43	30.86	37.46	39.20	44.34	45.42	47.27	49.50	49.09	49.75	50.26	50.69	52.00	49.49	50.00
1998/99	23.49	30.75	33.81	41.97	43.17	46.80	48.43	48.43	48.99	50.69	50.30	52.27	51.00	50.32	51.00
1999/00	26.81	32.93	35.26	42.20	44.44	45.49	48.27	48.54	48.93	50.38	48.11	49.86	51.85	51.51	53.32
2000/01	23.81	30.31	36.73	41.72	44.43	45.19	45.82	46.13	47.21	49.08	47.80	50.00	52.11	50.78	52.48

7.3.4 Catch-at-length

Port-based measurements of the length frequency of the catch did not include information on the depths at which catches were made. However those measured onboard did include depth information. Both are included in the model. The sample sizes for each length frequency are used as weights in the model (Table 23). The length frequencies are shown in Appendix D.

7.3.5 Catch-at-age

Age-length keys (ALKs) were available for most of the years included in the model (Figure 41) The sample sizes for each ALK are used, together with the length frequency sample sizes, to weight the contribution of each year's age frequency data to the maximum likelihood (Table 23). The age frequencies, and the length frequencies that were used to derive them, are shown in Appendix D.

Mean length- and weight-at-age were calculated using Method 2 of Punt and Smith (in press) (Table 24). This method uses ALK and length composition data to calculate the actual mean length or weight of each age class for each year for which there are data, instead of assuming that all cohorts follow the von Bertalanffy curve. For years or age classes for which these data are not available the average length-at-age for years for which data were available, is used.

7.3.6 Discard-at-age

Discard-at-age data are available from the ISMP for the trawl fleet but are not used in the base case model although they are used in a sensitivity test that assumes that discarding is size-based. The available data are shown in Appendix D and the sample sizes in Table 25.

Table 25. Sample sizes for catch-at-length data for the discarded component of the catch.

Year	Trawl Onboard length frequency 0-100m	100-200m	200-400m	400m+
1986/87	-	-	-	-
1987/88	-	-	-	-
1988/89	-	-	-	-
1989/90	-	-	-	-
1990/91	-	-	-	-
1991/92	-	-	-	-
1992/93	-	134	-	250
1993/94	13	86	186	309
1994/95	23	268	1115	1583
1995/96	-	854	2206	2101
1996/97	-	115	2238	648
1997/98	-	-	200	-
1998/99	-	79	486	1418
1999/00	-	-	223	264
2000/01	13	118	550	62

7.4 Modelling Methods

7.4.1 Base case model

The model includes a function that takes account of the population's length-at-depth structure. Earlier versions of this model showed (Thomson, 2000d) that the selectivity parameters were confounded with the depth-at-length parameters. A wide range of choices for these parameters lead to similar fits to the data however not all of these parameter choices were realistic. In order to address this problem gear selectivity parameters which had been calculated from covered cod-end experiments (Knuckey *pers comm* and Bax *pers comm*) were included in the objective function for the base case model (see Appendix C). This is not an entirely satisfactory solution because the modelled "selectivity" is a function of gear selectivity and availability of fish to the gear whereas the figures added to the objective function pertain purely to gear selectivity. "Availability" is a function of fishing practices and fish behaviour e.g. vessels may catch different sized or aged fish depending on the grounds on which they operate and the time of day. However, an important source of variation due to availability is the depth at which the fishery operates and this has been separated from selectivity in this model.

This model is a variant of the model described in Appendix C (Table 26). The base case model estimates recruitment residuals for the first age (one year-olds) for each year of the model but does not attempt to fit residuals for each of the older ages in the first year.

This is due to lack of data and in the interests of model parsimony. The model does estimate a fishing mortality rate for the trawl fishery in the first year (and this rate is assumed to have applied to previous years as well). The sensitivity of the model to the weightings chosen for various data sources (Table 27) is explored. The effect of modelling the length-structure by depth is also investigated, along with several other sensitivity tests.

Table 26. Some of the choices made for the base case Integrated Analysis model applied to spotted warehou.

Aspect of model	Choice	Details
Stocks	1	
Fleets	2	Trawl and non-trawl
Selectivity pattern	Trawl	Logistic
	Non-trawl	Logistic
Observed trawl gear selectivity	31.0, 38.22 cm	$l_f^{S\,50}$, $l_f^{S\,95}$
Sexes	2	but they have the same parameters
Depth classes	4	0-100m; 100-200m; 200-400m, 400m+
Years	1986/87 - 2000/01	Not pristine in 1986/87
Ages	1-15	15 is a plus group
Lengths	20-60cm	20 and 60 are 'plus groups'
Initial conditions	Trawl but no non-trawl catches prior to 1986/87	Trawl F estimated
Egg data	No	
Stock-recruit relationship	Yes	Beverton-Holt
Method for fitting age frequencies	Log-normal	

Table 27 Weighting factors used in the base case model.

Parameter	Description	Value
N^{ca} and N^{cl}	weight given to catch composition data (multinomial)	50
σ_r	c.v. for the recruitment residuals	0.7
σ_q	c.v. for the CPUE data	0.3
σ^{ca} and σ^{cl}	c.v. for port catch-at-age and –length (log-normal)	0.12
$\sigma^{ca'}$ and $\sigma^{cl'}$	c.v. for onboard catch-at-age and -length (log-normal)	0.15

The model has 23 parameters: 1 average recruitment at unfished level R_0; recruitment residuals for the 15 years in the model; 4 selectivity parameters; and 3 parameters for the length-depth function (Table 28). The catchability co-efficients for the four depth classes are not estimated but are calculated from the maximum likelihood solution (see Appendix C). This means that risk assessment using this model will be slightly optimistic because uncertainty in the values of these parameters will be ignored.

Table 28. Parameters of the base case model for spotted warehou.

Parameter	Description	Number
R_0	Average recruitment at the unfished level	1
ε_y	Annual recruitment (age 1) residuals	15
S_a^f	Selectivity parameters	4
$m^\Psi, c^\Psi, \sigma^\Psi$	Parameters of depth-at-length relationship	3
		23

7.4.2 Risk analysis / Projections

Because of the depth structuring in the model, projections of the spotted warehou stock into the future have to assume some distribution of future catches among depth classes. The assumption was made that the proportion of the total catch taken from each depth class in the future would be the same as that observed in 2000/01. This is unlikely to be an accurate assumption as the fishery might move in response to the size structure of the stock and possibly even to changes in other fish stocks (such as blue grenadier). The fleet dynamics model that would be needed to investigate this problem further is unfortunately beyond the scope of this investigation. Alternatively, future work should ignore depth structure when projecting the population into the future. The current assumption is likely to be optimistic at high catch levels because increased fishing pressure means that the stock will be younger, on average, than is the case today, and will be clustered in the shallower depth classes where currently only a small portion of the catch is taken. In this case the model will deplete the deeper depth classes but may be unable to achieve the TAC because it cannot redirect effort to the shallower depth classes.

One thousand draws were made from the posterior distribution of the parameters of this model and these were used, together with random future recruitment residuals, to project the population forwards.

7.5 Results / Discussion

7.5.1 Base case model

The model is forced to fit the catch data (and the discard data because the base case model simply adds those to the landed catch) exactly because the catch data are used to calculate an exploitation rate.

Despite the OCS problem regarding the shallowest depth-class it seems preferable to fit the model to CPUE by depth class, rather than to the CPUE for all depths combined. The 'combined' CPUE contains less information about trends in different age classes than the depth class CPUE data. The model that uses the combined CPUE shows a trend that is almost the opposite of that in the standardized CPUE in early years but fits the trend in recent years (Figure 42).

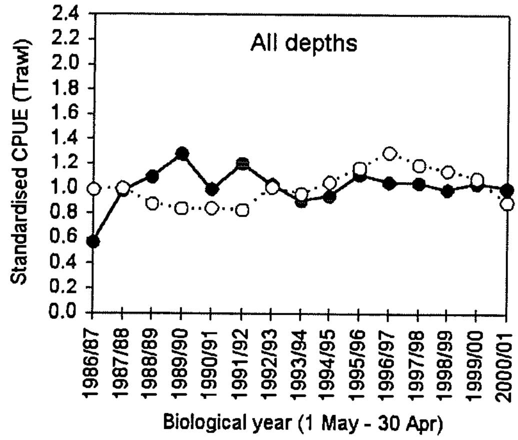


Figure 42. Standardised (observed) and estimated CPUE for the sensitivity test that uses the CPUE from data from all depth classes.

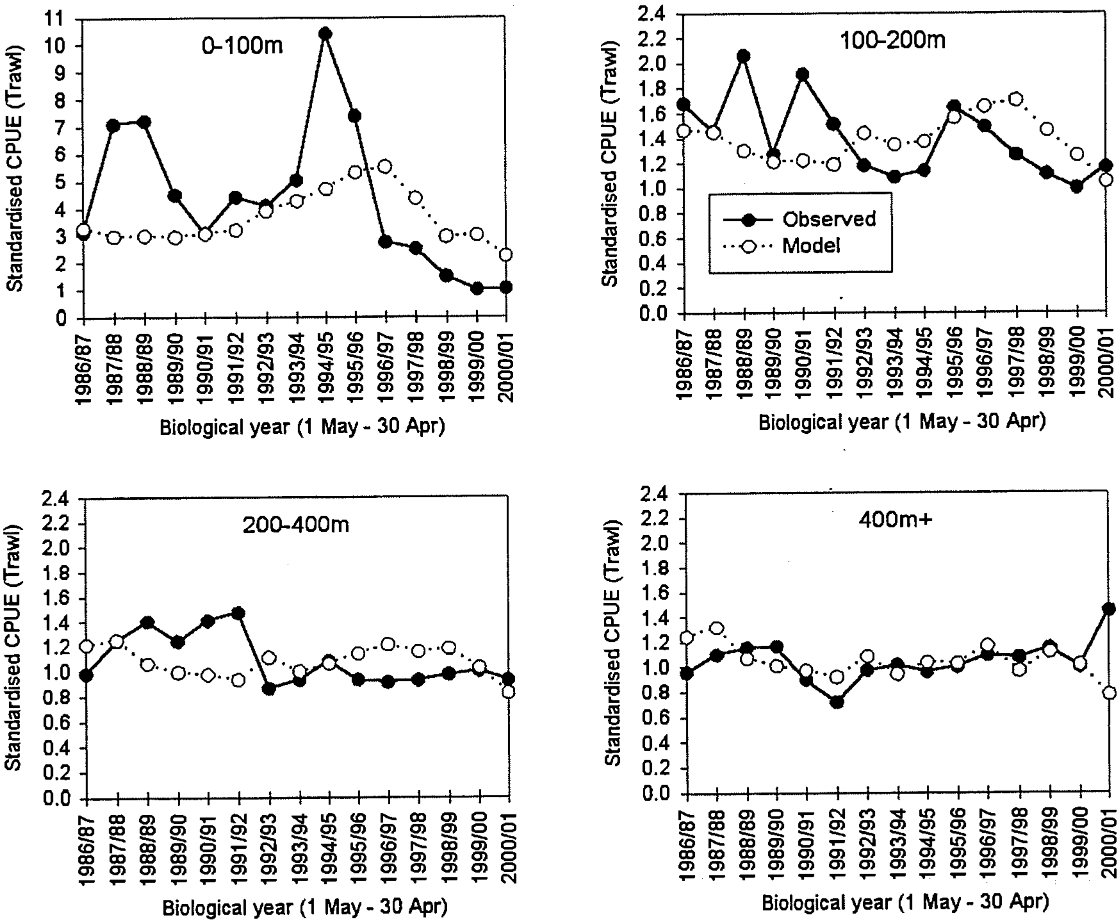


Figure 43. Standardised (observed) and estimated CPUE for the base case model for spotted warehou.

The base case model is able to achieve a reasonably good fit to the CPUE data by depth class (Figure 43). Not surprisingly the fit is less good for the shallowest depth class where sample size is smallest and consequently weighting lowest. The OCS loophole problem is likely to have contributed to the sharp rise and subsequent decline in the CPUE in this depth class during the early 1990s so it is not surprising that the model is unable to achieve a similarly sharp pattern. The corresponding dip in the CPUE for the 100-200m depth class is also likely to be due to the OCS problem.

Fits to the two catch-at-length samples for which ALKs do not exist (the others have been converted into catch-at-age samples and included in the model in that form) are shown in Figure 44. The sample size for 1991/92 is smaller than that for 1989/90 therefore it is accorded lower weight.

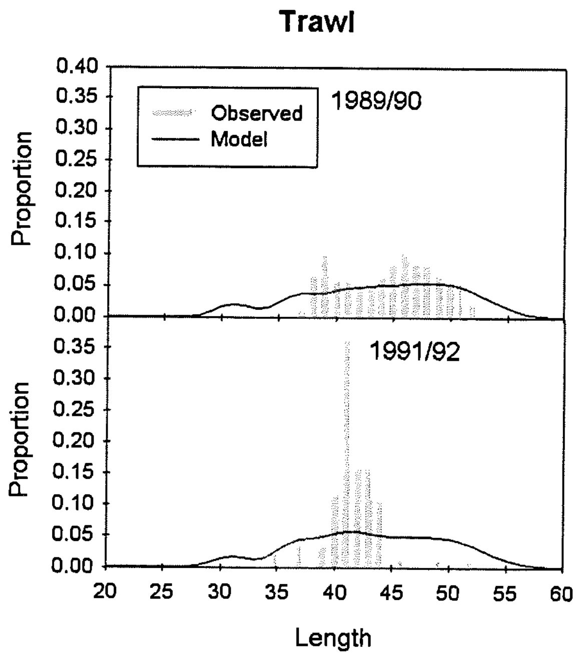


Figure 44. Annual proportion caught-at-length by the trawl fleet for the years for which length data are available but age data are not. The lines indicate the model estimated and the bars the observed values.

The model fit to the onboard catch-at-age data (i.e. the data for which depth class information is available) is reasonably good (Figure 45) except for the 100-200m depth class in the two most recent years. This might reflect a change in the behaviour of the fish, or perhaps the fishery, in recent years. The fit to the single sample obtained from the shallowest depth class (0-100m) is poor however the sample size is low.

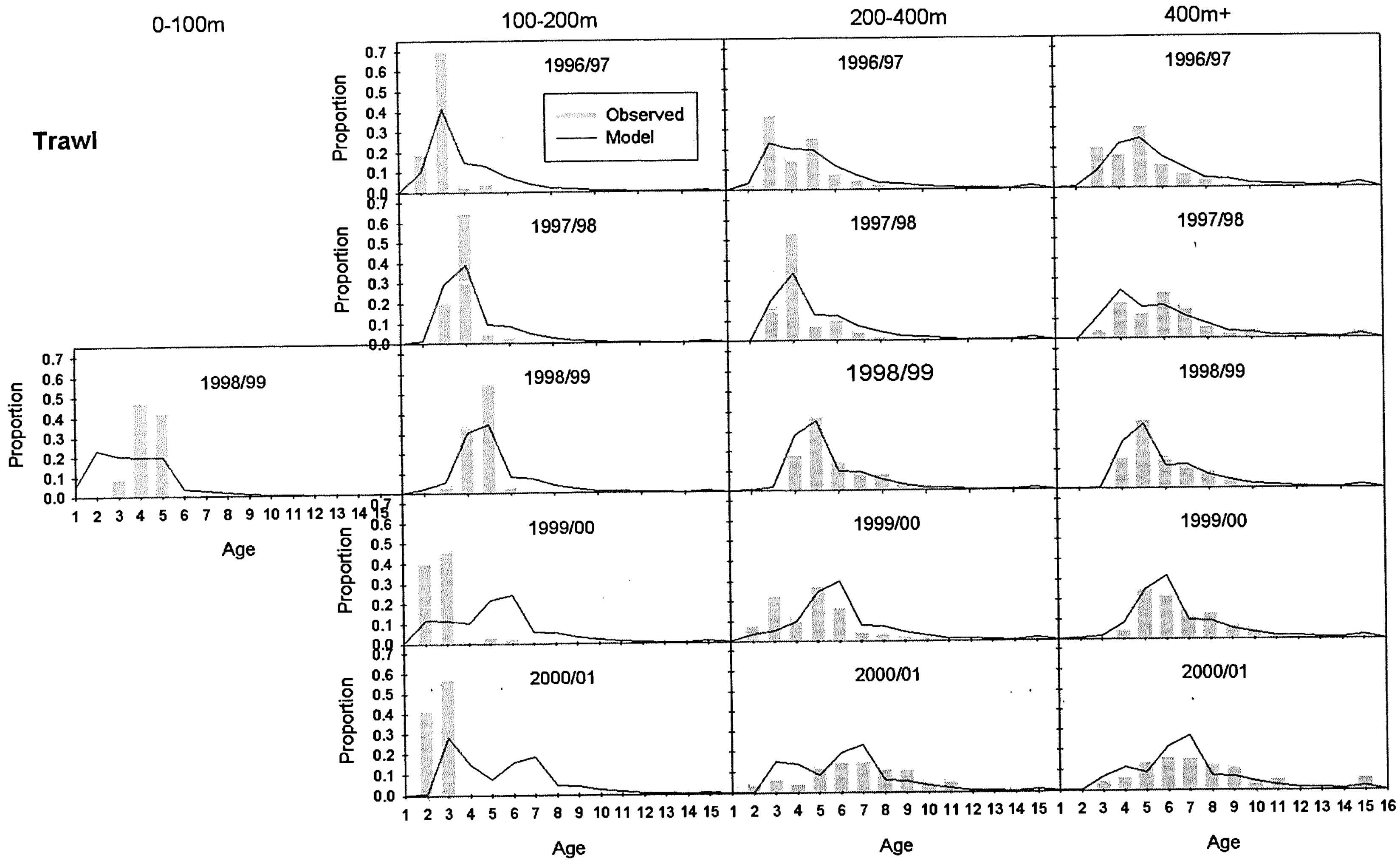


Figure 45. Annual proportion-caught-at-age by the trawl fleet for the years and depth classes for which data are available. Data were collected onboard the fishing vessels. The lines indicate the model estimated and the bars the observed values

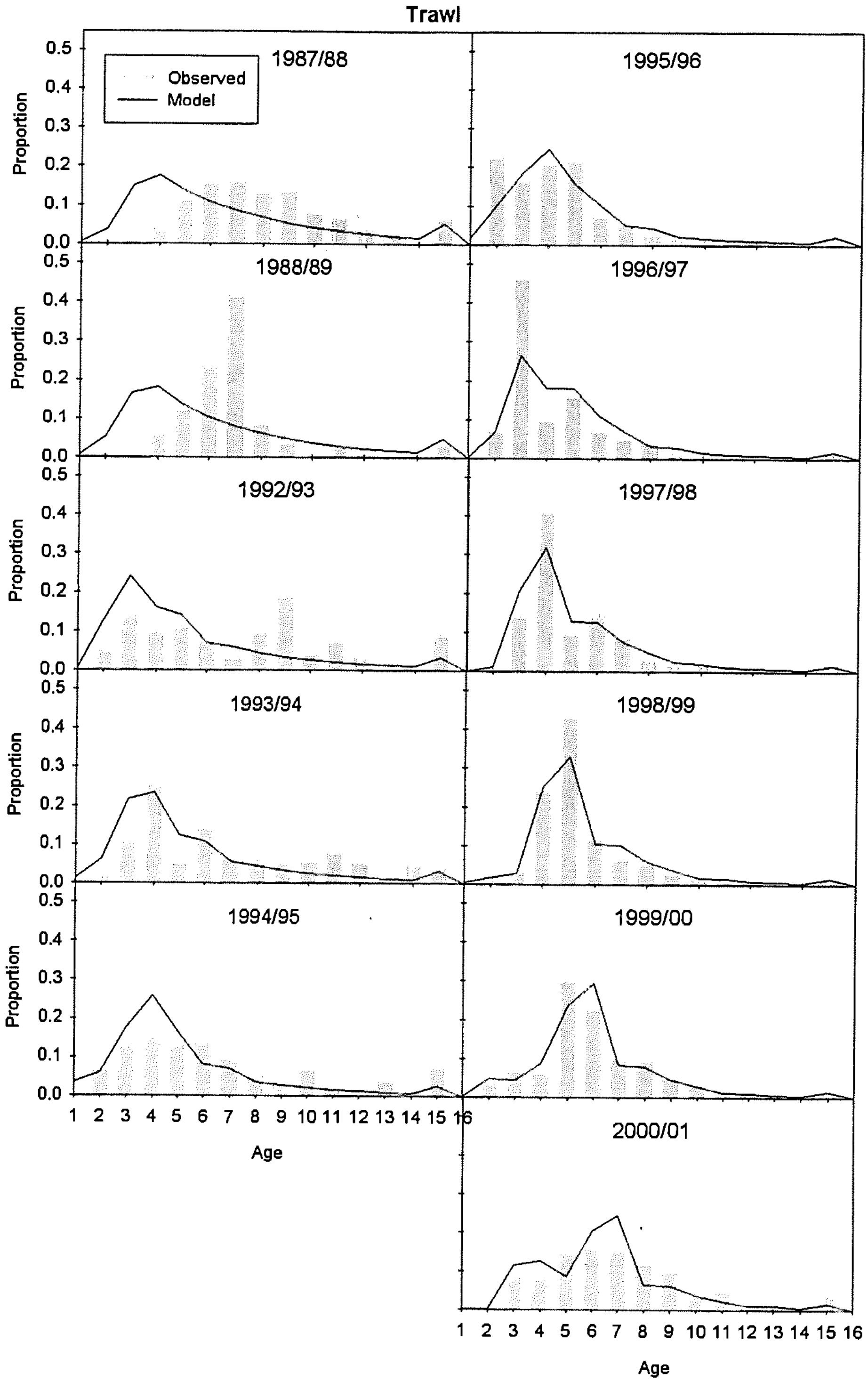


Figure 46a. Annual proportion-caught-at-age by the trawl fleet for the years for which data are available. Data were collected by port sampling. The lines indicate the model estimated and the bars the observed values.

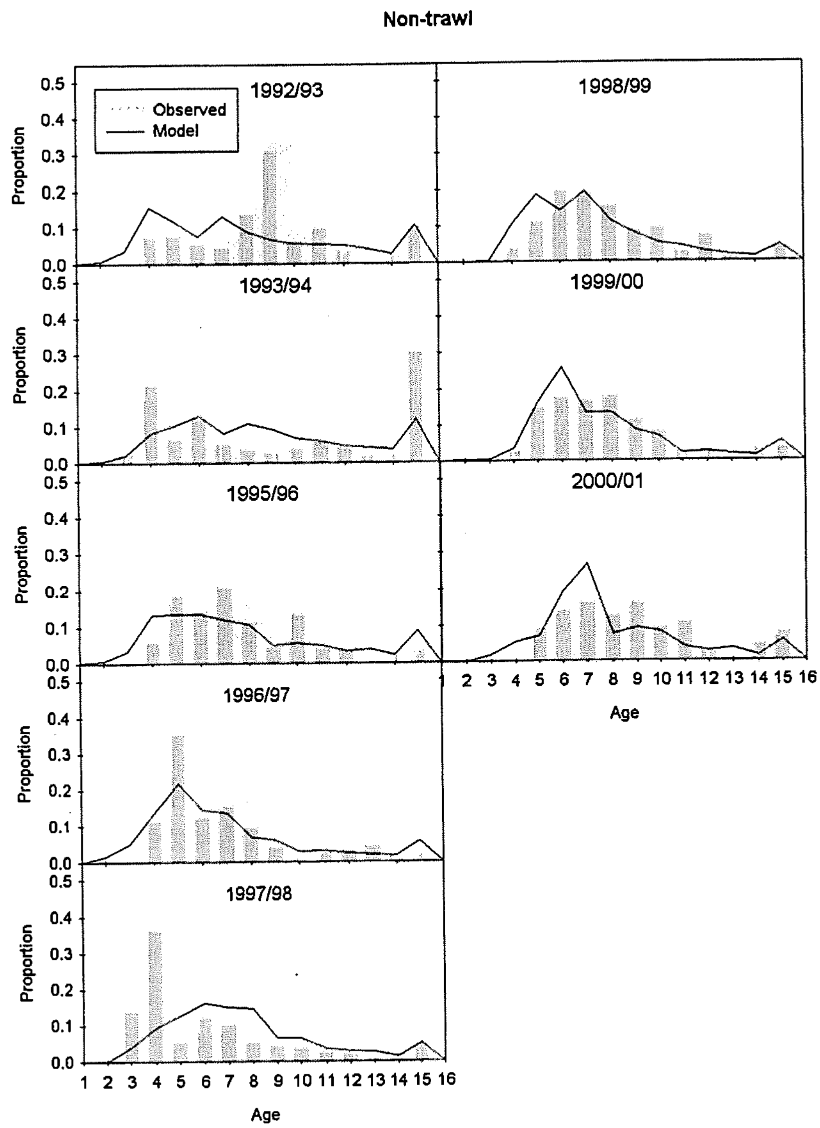


Figure 46b. Annual proportion-caught-at-age by the non-trawl fleet for the years for which data are available. Data were collected by port sampling. The lines indicate the model estimated and the bars the observed values.

The fit to the port-measured data captures most of the main features (Figure 46); the 1987/88 and 1988/89 samples for the trawl fishery are not well estimated and this is because the residuals for the ages in the first year are not estimated. It did not seem justified to include these 14 parameters, particularly given that the earliest data (the 1987/88 and 1988/89 trawl samples) were collected during a research survey and therefore may not be wholly comparable with the more recent (commercial) data. The large year class spawned in 1993/94 is under-estimated in early and over-estimated in later years. This implies that the mortality rate of that cohort is greater than expected. However, when the model is allowed to estimated the value of *M* is chooses a value which is similar to but slightly lower than the base case value (Table 29). It is well-known phenomenon for large cohorts to 'disappear' faster than expected.

A penalty was added to the negative log-likelihood if the parameters of the selectivity curve for the trawl fleet varied from those that had been observed (Table 26). Those for the non-trawl fleet were freely estimated by the model. The non-trawl fleet is found to select much larger fish than the trawl fleet (Figure 47). The mean depth preferred by the largest fish is estimated to be only roughly 350 m so that the deepest depth class (400+m) is populated only because the estimated c.v. for this relationship is quite large ($\sigma_\psi = 0.85$). However, note that alternative values for the selectivity parameters will alter these estimates.

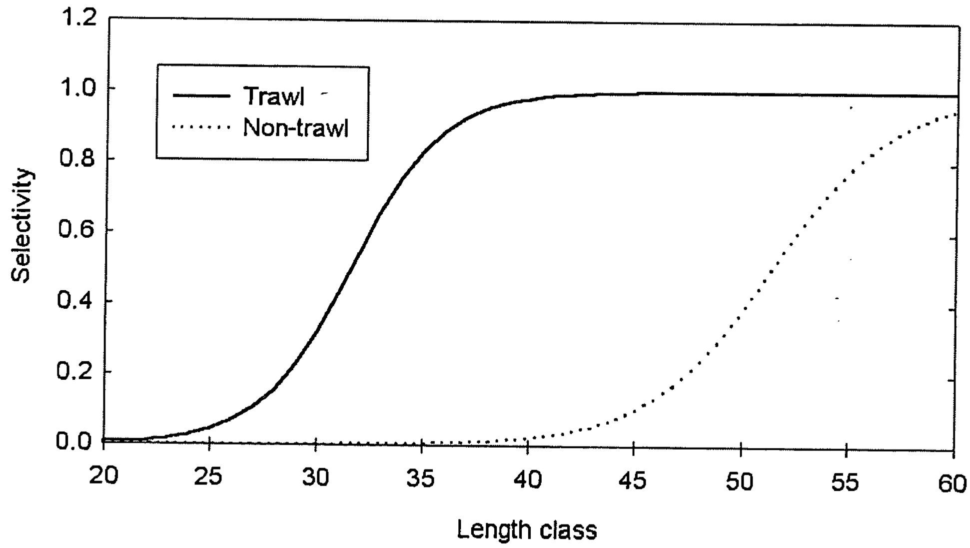


Figure 47. Selectivity for the trawl and non-trawl fleets for the base case model for spotted warehou.

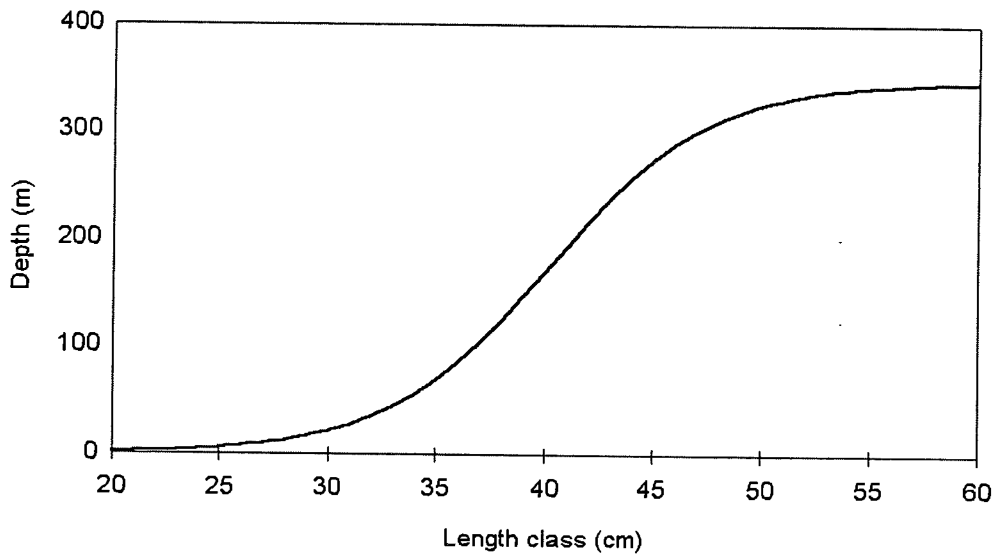


Figure 48. Mean of the length-depth relationship for the base case model for spotted warehou.

The annual exploitation rates, by fleet and depth class, appear reasonable (Figure 49). That for trawl fishery in the deepest depth class seems rather high, perhaps reflecting that the right-hand side of the length-depth relationship (Figure 48) ought to be higher. This exploitation rate is close to 0.7 when the observed selectivity parameters are not included in the model. This means that 70% of all available fish in that depth class was taken by the fishery, surely an unrealistic result. The peak in the exploitation rate for the non-trawl fleet in 0-100m for 1996/97 and in 100-200m for 1997/98 may be related to the presence of the large cohort spawned in 1993/94 in these depth classes. It may be an attempt by the model to reduce the under-representation of this cohort in the catches.

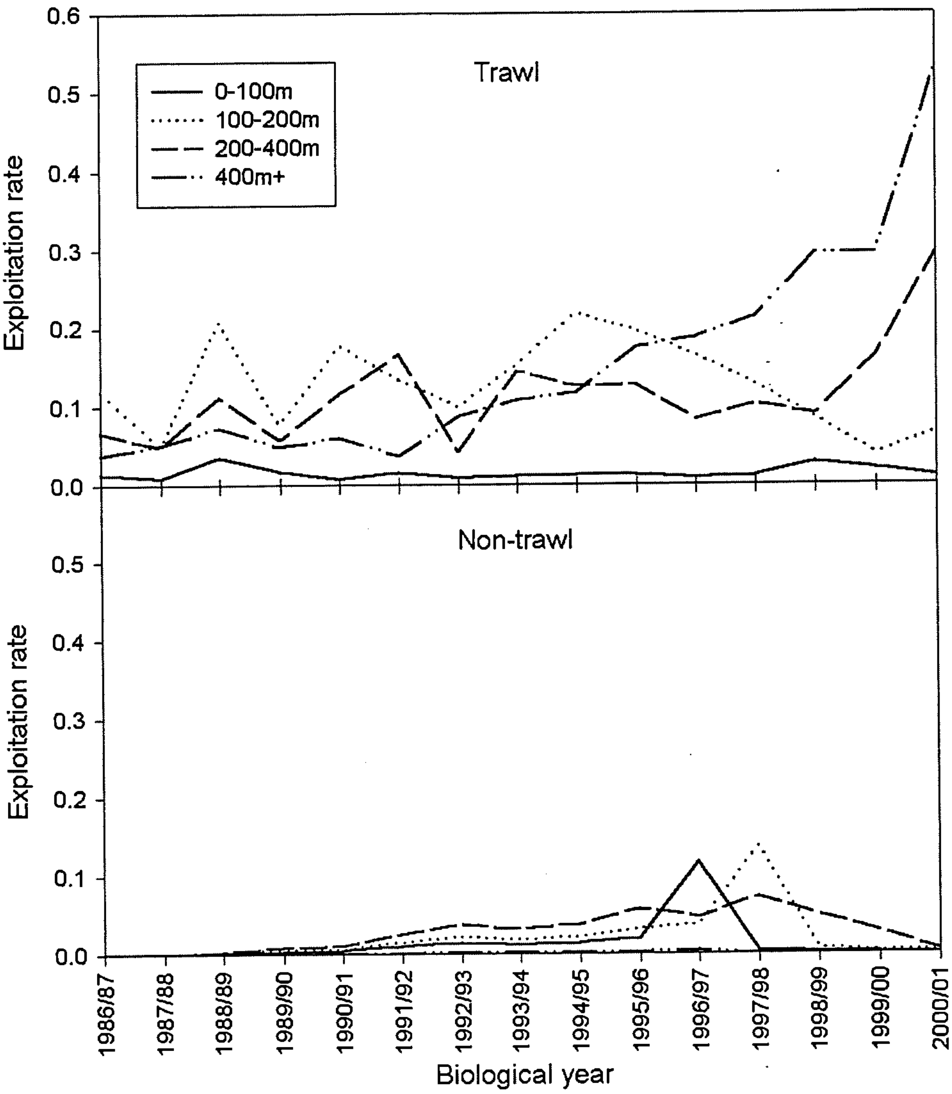


Figure 49. Exploitation rates by depth class for the trawl (upper plot) and non-trawl (lower plot) fleets.

The historic biomass trajectory shows little trend indicating that past catches have had little impact on the stock (Figure 50) although there is a downturn in the most recent years. The female spawning biomass in 1999/00 is 90% of the reference biomass (B_{ref}) and in 2000/01 is 75%.

The estimated number of recruits (one-year olds) shows a peak in 1994/95, reflecting the large recruitment in 1993/94. Reasonably good recruitment is also estimated for the following year but it is poor thereafter.

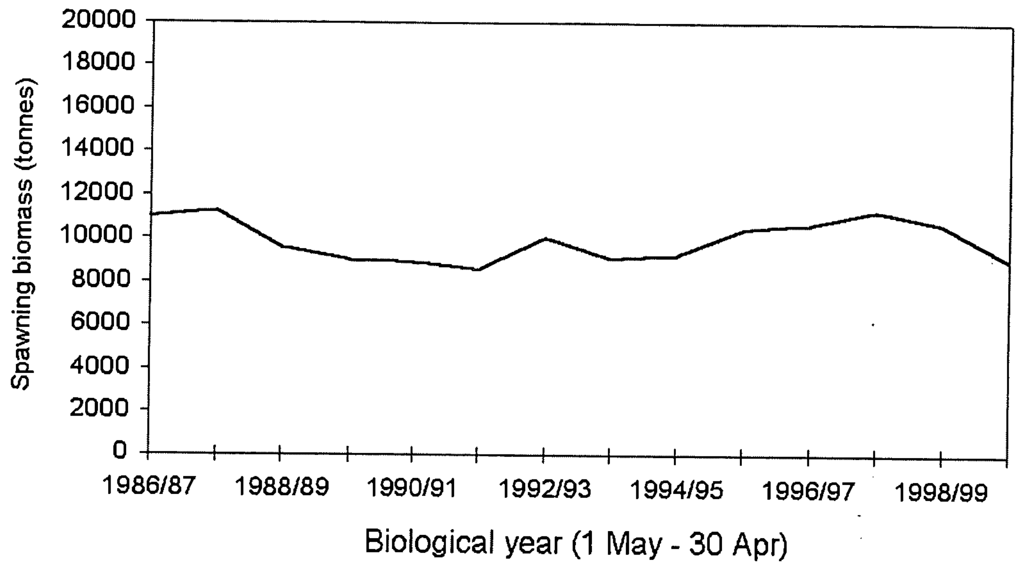


Figure 50. Estimated spawning biomass for the base case model for spotted warehou.

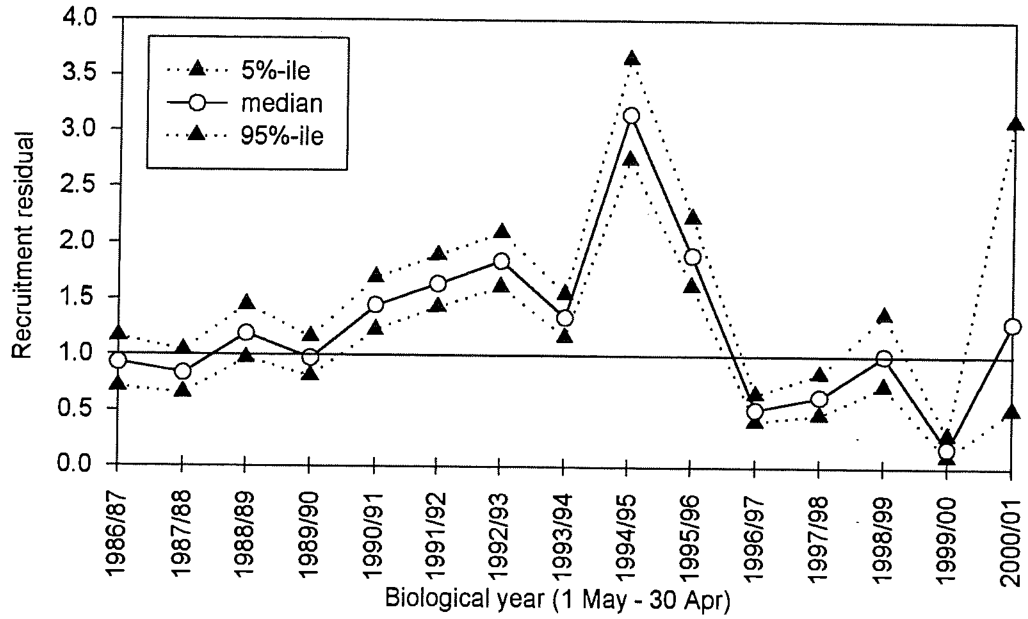


Figure 51. Median estimated recruitment residual for the spotted warehou population and 90% probability interval. These were calculated using 1000 draws made from the posterior distribution using the Marcov Chain method.

7.5.2 Sensitivity tests

The inclusion of the three parameters of the length-at-depth relationship, into the model, is clearly justified. When it is assumed that fish of all lengths are equally likely to be found in each of the four depth classes the negative log-likelihood increases by 107.75. The inclusion of these three parameters would be statistically justified if the negative log likelihood increased by only 3.9 ($\chi_3^2/2$, Schnute and Groot, 1991). Ignoring the depth structure altogether (i.e. assuming a single depth class and excluding the onboard observed data) allows the model to improve the fit to the CPUE data but has little effect on the results except to reduce the size of the population in 2000/01 relative to the reference biomass, by a small amount. The exploitation rate for the trawl fleet in 2000/01 is 0.291, which seems a more reasonable value that the high values estimated in the deepest depth class for all the other tests, which assume depth structuring.

Alternative functional forms for the mean depth-at-length were tried (Figure 52, Table 29). The "free" form allowed the model to select separate mean depths for nine different length groups which were defined according to length-at-age. These groups were: all lengths up to length-at-age 1; age 1 to 2; 3-4; 4-5; 5-6; 6-8; 8-11; 11 and greater. No restrictions were emplaced other than that depth could not be less than zero or greater than 2000m. This model places one-year olds in the 100-200m depth class but 2-6 year-olds in the 0-100m class. Animals aged 12+ are placed in shallower waters than 7-11 year-olds. The results of the linear and logistic forms do not differ much (Table 26) nor does the model that assumes a logistic function but estimates the third parameter of this function (which governs maximum depth attained). However, the linear model does lead to an unrealistically high exploitation rate in the deepest depth class for the trawl fishery. The 'free' form has a larger estimate for the size of the 1993/94 cohort, presumably because it is better able to fit its 'disappearance' through its greater flexibility in allocating age groups to depth classes.

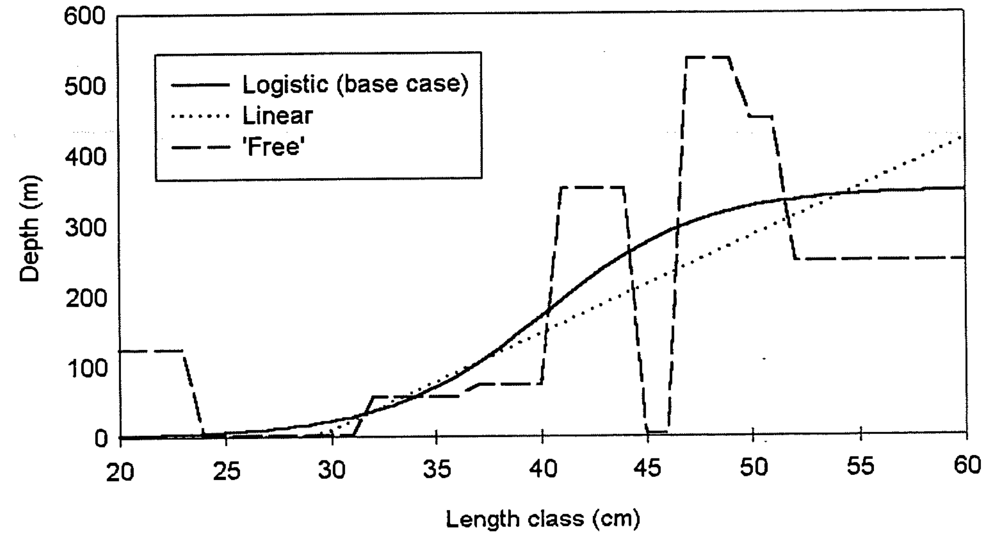


Figure 52. Alternative functional forms for the mean depth-at-length.

When the model is allowed to estimate the trawl selectivity pattern without restriction (i.e. without using the observed gear selectivity) the estimated trawl selectivity is much sharper than that of the base case. The non-trawl pattern is little changed (Figure 53). The only quantity of interest that changes substantially is the estimated trawl exploitation rate in the deepest depth class (Table 29). This illustrates that the model is able to fit the observed data equally well given quite different combinations of selectivity and depth-at-length parameter values. When dome-shaped selectivity patterns are assumed for both the trawl and non-trawl fleets the model fits the data a little less well but, again, results are similar to those of the base case.

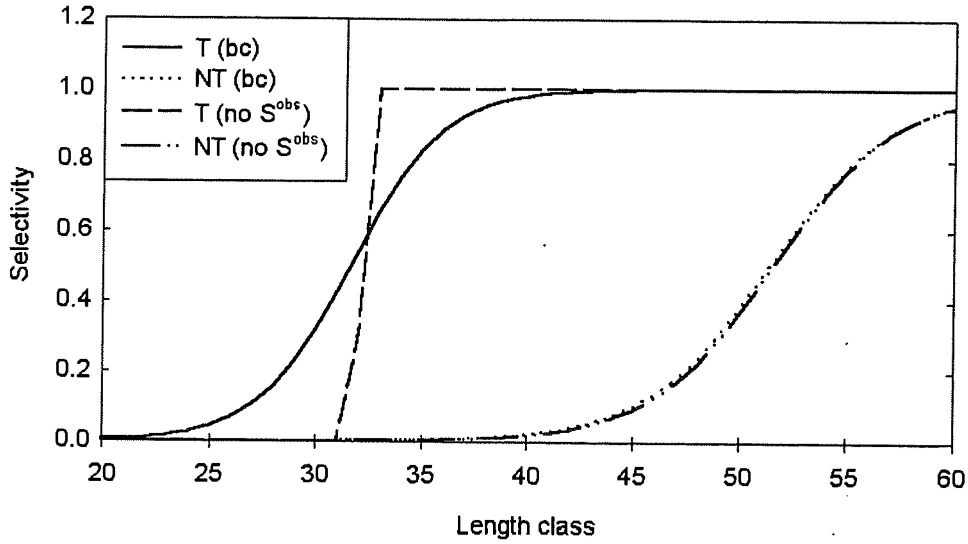


Figure 53. Selectivity for the base case mode for the trawl "T (bc)" and non-trawl fleets "NT (bc)". The sensitivity test which does not restrict the trawl selectivity curve "T (no S^{obs}) and "NT (no S^{obs})" is also shown.

The model is remarkably resilient, even when all discarding is assumed to be size-based the results are similar to the base case. Estimated natural mortality rate (M) is similar to the 0.25 assumed for the base case. However setting the base case value of natural mortality to 0.20 or 0.30 changes the negative log-likelihood value by a relatively small amount, indicating that the data are not very informative about the value of M. The estimate of depletion in 2000/01 surprisingly does not differ much from the base case although the estimates of B_0 are very different.

Similar results to those of the base case are obtained for the test that does not attempt to correct for the "OCS loophole"; that which estimates recruitment residuals for all ages in the first year; that which does not use a stock-recruit relationship; and that which does not estimate a trawl fishing mortality rate prior to the start of the model. The only test that produces a marked change in the results is the one that uses the CPUE data for all depths combined instead of those for each depth class individually. This model estimates that the stock is at 100% of the reference level during 2000/01. This is because the CPUE data showed no trend over time when all depth classes were combined. This seems a less realistic result that that for the base case. The test that includes recruitment residuals for all ages in the first year improves the negative log-likelihood by only 9.0, short of the 11.9 that is required to justify the addition of 14 extra parameters (Schnute and Groot, 1991).

Surprisingly, the model fits the data better when Method 1 is used to estimate length-at-of instead of Method 2. Method 1 assumes that all cohorts grow at the same rate. This sensitivity test estimates a smaller size for the 1993/94 cohort.

A test that assumes a multinomial error structure for the catch-at-age and -length data was not able to converge.

Table 29. Quantities of interest, the negative log-likelihood (-lnL) and some of its components, for the base case model for spotted warehou and for a range of sensitivity tests. B_0 is the pristine spawning biomass, B_{ref} is the reference biomass (average spawning biomass for the first 5 years, B_y^{sp} is spawning biomass in year y, $E_{1,00,max}$ is the exploitation rate for the trawl fleet during 2000/01 in the deepest depth class (usually 400m+), σ_ψ is the c.v. of the length-depth relationship, ε_{93} is the recruitment residual in 1993/94, M is the natural mortality rate, L_4 is the contribution to the negative log-likelihood (-ln L) of the port-measured age data, L_5 the onboard and L_8 the CPUE data.

Model specification	B_0	B_{ref}	$\tilde{B}_{00}$	$\tilde{B}_{86}/B_{ref}$	$\tilde{B}_{00}/B_{ref}$	$E_{1,00,max}$ (trawl)	ε_{93}	M	L_4	L_5	L_8	-ln L
Base-case	11006	9942	7471	110.7%	75.1%	0.529	3.096	0.25	195.01	177.89	10.19	410.99
No size-depth relationship	11266	10215	6246	110.3%	61.1%	0.319	3.081	0.25	193.38	232.26	12.76	518.74
Depth structure ignored	11178	10062	6849	111.1%	68.1%	0.291	3.311	0.25	192.16	0	7.55	277.29
Linear mean depth-at-length	10747	9676	7402	111.1%	76.5%	0.689	3.215	0.25	192.69	181.24	10.99	412.45
'Free' mean depth-at-length	10646	9601	7750	110.9%	80.7%	0.491	3.394	0.25	189.24	155.29	10.76	384.65
Estimate l^{ψ}_{max}	10984	9920	7479	110.7%	75.4%	0.592	3.104	0.25	194.44	178.16	10.16	410.92
No observed S parameters	10941	9850	7263	111.1%	73.7%	0.657	3.119	0.25	192.61	166.66	11.28	393.97
Dome-shaped selectivity	11337	10244	7732	110.7%	75.5%	0.505	3.071	0.25	207.46	177.67	10.13	423.26
Size-based discarding	10360	9357	6977	110.7%	74.6%	0.56	3.042	0.25	194.74	177.78	10.02	410.35
Estimate M	10549	9501	7113	111.0%	74.9%	0.55	3.185	0.243	194.24	178.25	10.21	410.92
$M = 0.2$	8329	7345	5376	113.4%	73.2%	0.687	3.948	0.20	190.81	180.98	10.46	414.17
$M = 0.3$	16377	15104	11705	108.4%	77.5%	0.361	2.591	0.30	201.97	175.74	10.21	414.73
Don't correct 'OCS loophole'	10174	9132	6431	111.4%	70.4%	1	3.18	0.25	202.06	197.09	11.8	663.2
Estimate ε_a												
No stock-recruit relationship	11015	9951	7523	110.7%	75.6%	0.525	3.053	0.25	194.93	177.91	10.25	410.82
No F in first year	11006	9942	7471	110.7%	75.2%	0.529	3.096	0.25	195.01	177.90	10.193	410.99
Use CPUE for all depths	11794	10754	10789	109.7%	100.3%	0.377	3.647	0.25	193.61	177.51	3.1	402.33
Method 1	10579	9405	7202	112.5%	76.6%	0.682	2.921	0.25	164.54	181.98	10.93	380.45

7.5.3 Risk analysis / Projections

The model predicts that catches of 4000t (similar to the adjusted catch in 2000/01) would cause the spawning biomass to decline steadily over a 20-year period (Figure 54). However note the concerns expressed below regarding the depth structuring of future catches.

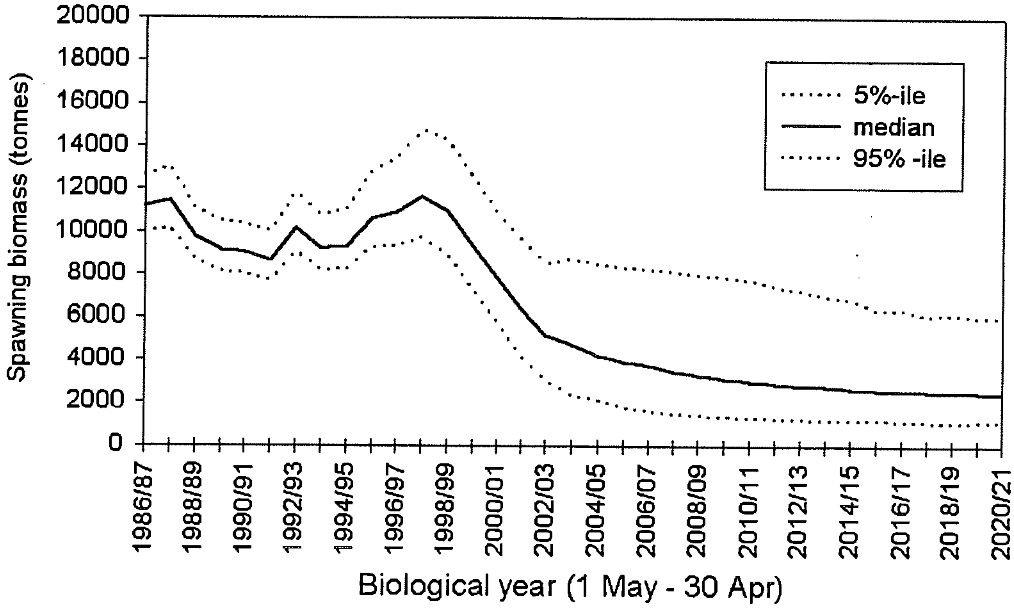
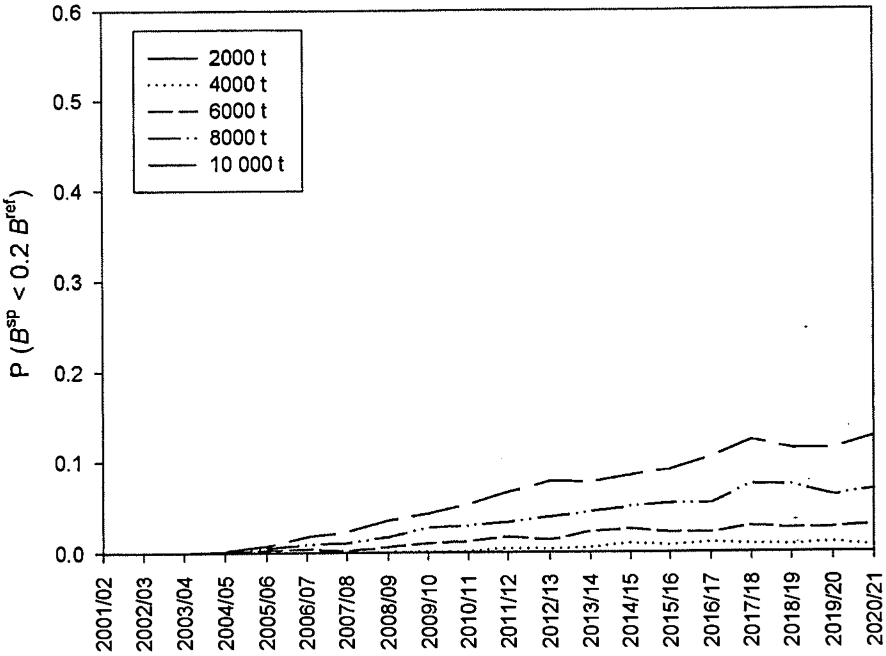


Figure 54. Median and 90%-ile for spotted warehou spawning biomass. After 2000/01 annual catches of 4000t are assumed, 96% taken by the trawl and 4% by the non-trawl fleet. The distribution of catches across depth classes is assumed to be the same as that observed during 2000/01.

The probability that the spawning biomass will fall below 20% or 40% of the reference biomass is relatively low, even for very high annual target catches (Figure 55 and Figure 56). This is because the actual annual catch is often much lower than the target level (Figure 57) due to the problem that the proportion of the catch to be taken from each depth class has been fixed at that observed during 2000/01. This pattern would be realistic for a species that is entirely a by-catch of fishing operations that target other species but not for one that is targetted. Spotted warehou are a both a targeted and a bycatch species (of the blue grenadier spawning fishery). Future work will need to incorporate some flexibility in the allocation of catches to depth classes.



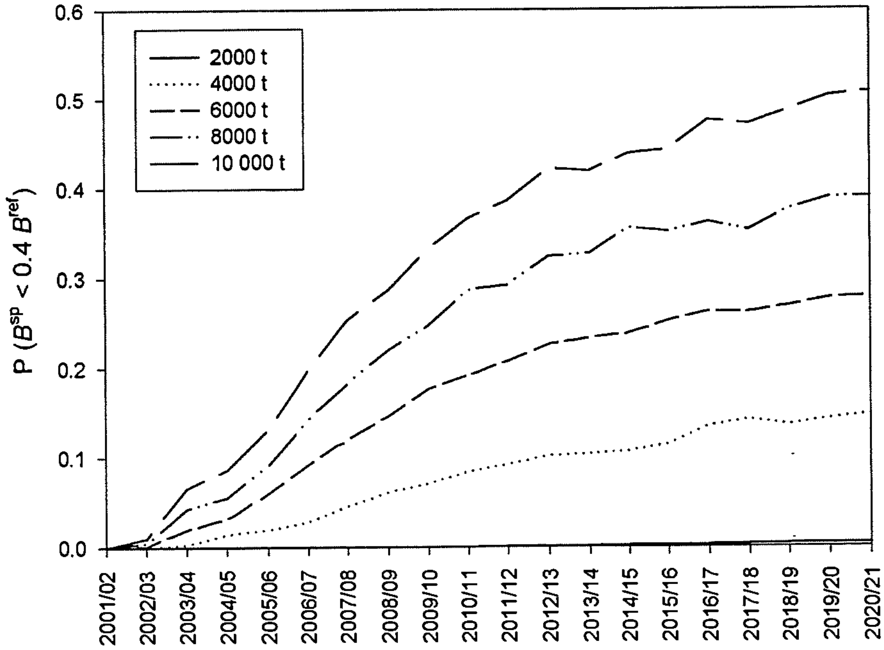


Figure 55. Probability that spawning biomass will fall below 20% (top plot) or 40% (bottom plot) of the reference biomass (B^{ref}) over a 20 year period for a range of annual target catches.

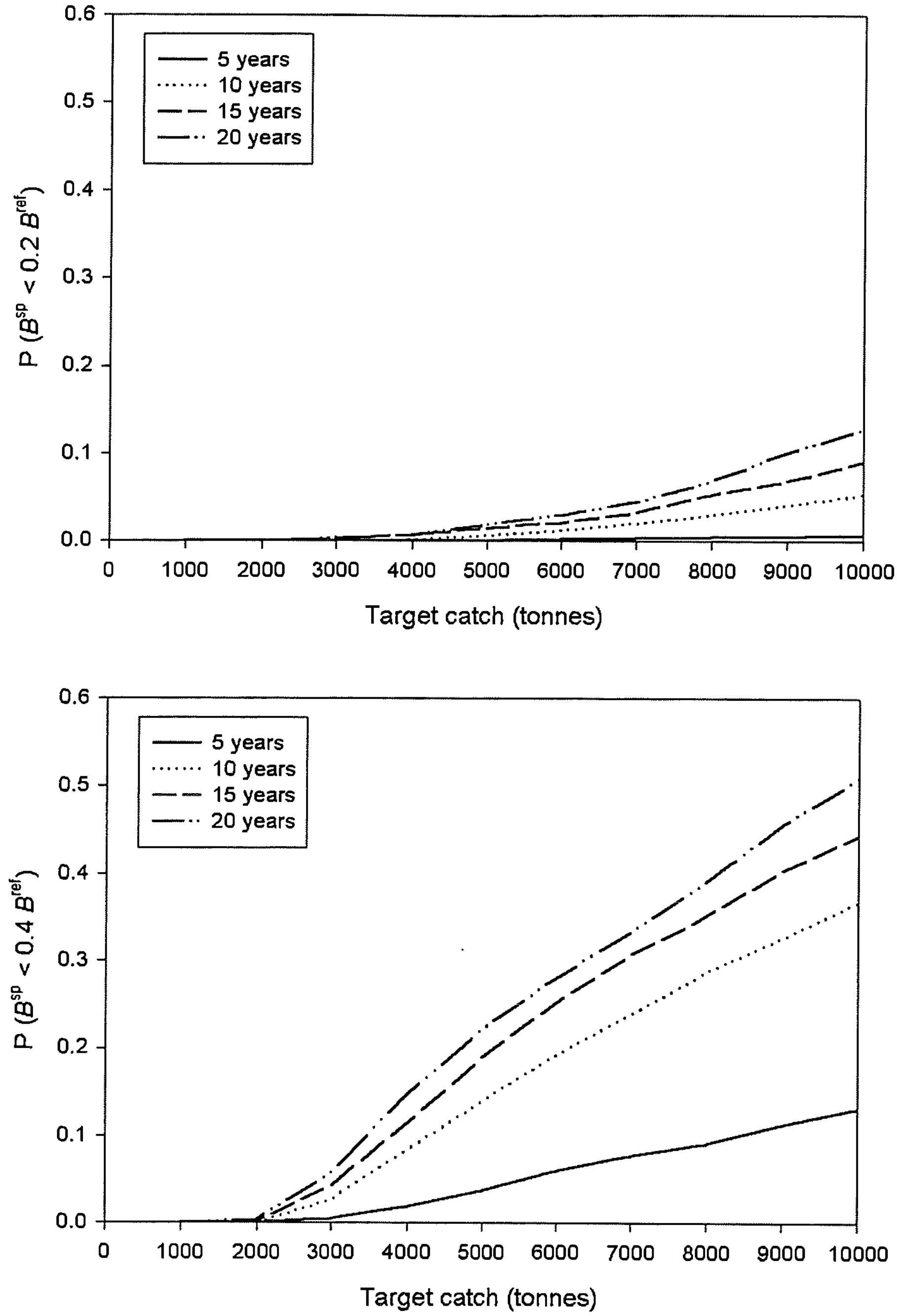


Figure 56. Probability that spawning biomass will fall below 20% (top plot) or 40% (bottom plot) of the reference biomass (B^{ref}) for a range of target catch levels.

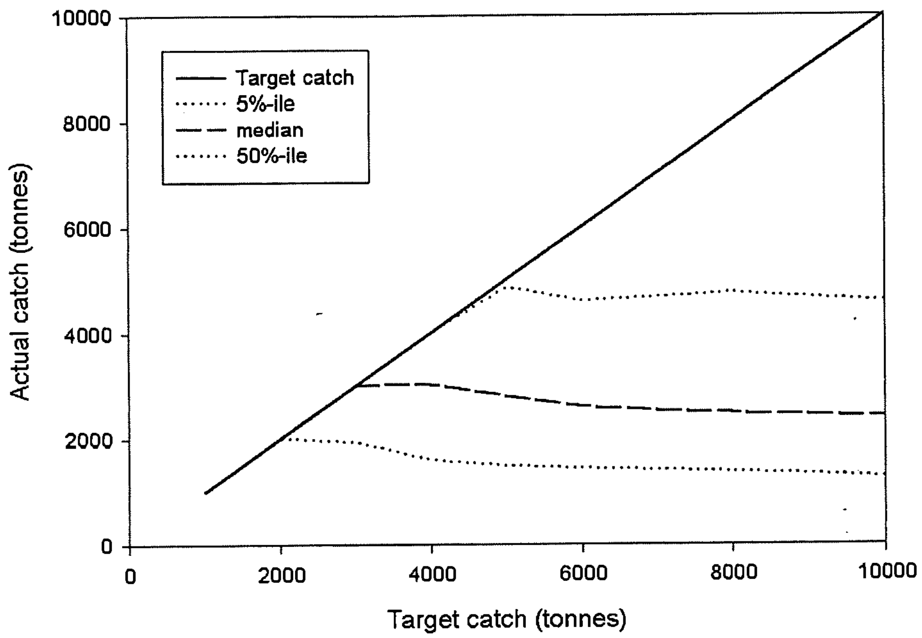


Figure 57. Median and 90%-iles for the actual catches taken, as a function of target catch, after 10 years of forward projection for spotted warehou.

Spotted warehou have not been fished down to a low level therefore the model is unlikely to be in a position to estimate the size of the stock with great accuracy. The results of the risk analysis should therefore be treated with caution.

8 BENEFITS

This project will directly benefit the operators in the South East Fishery that hold quota in blue grenadier, pink ling and spotted warehou. Providing high quality assessment advice on species determined by industry and management directly benefits the fishing industry by providing the best scientific advice on which the optimum sustainable TACs can be set.

At the same time, a high quality stock assessment based on an underlying simulation model of the stock provides a clear indication to research managers of the potential value (or lack of value) of specific research proposals for work on that species.

Ecologically sustainable development of Australian fisheries, is a management objective of AFMA and one that provides Australian society as a whole the ongoing benefits of a sustainable fishery and a protected marine environment. High quality stock assessment is a prerequisite for sustainable fishery management.

9 FURTHER DEVELOPMENT

Stock assessment is an ongoing process. At the end of every year the data that were collected during that year (even if this is just an estimate of the mass of the catch) need to be added to the model. For the three fish stocks discussed here a great deal of information is collected annually and this all needs to be included in the assessment, the GLM work on the CPUE updated, and the growth curve recalculated with the addition of the new age-length data. Furthermore, additional knowledge regarding the behaviour of the fish, the fishery, or the stock structure of the population may become available necessitating updates of the assessment. New and better assessment methods may become known and it is desirable to modify the assessment to include these. Even during the three year process of developing the assessments described here improved methods were developed and the last assessment to be completed (spotted warehou) includes more of these than the first (pink ling). The Blue Grenadier Assessment Group (BGAG) and the Blue Warehou Assessment Group (BWAG) will be directing future updates of the assessments for blue grenadier and spotted warehou. Any future work on pink ling will be overseen by the SEFAG.

The next step that will turn these assessments into good management advice is to incorporate them into a Management Strategy Evaluation. MSE work for blue grenadier has also begun as part of the work of the BGAG. Ongoing updates of assessments and some MSE work is underway as part of FRDC project 2000/101.

10 CONCLUSIONS

The Integrated Analysis stock assessment method was applied to three species in the South East Fishery. These are blue grenadier, pink ling, and spotted warehou. Integrated Analysis is a very flexible method that allows for gaps in the data and that can be adapted to fit to a variety of data sources.

The stock assessment for blue grenadier indicates that the cohort that hatched in 1994 is very large and that the one hatched in 1995 is also larger than expected. These cohorts, particularly the 1994 one, are growing more slowly than average and consequently may mature later (if it is assumed that maturity is a function of length and not age). These fish have grown large enough to be available to vessels fishing in the South East Fishery and now dominate the catches. It is predicted that catch rates will peak during 2001 and thereafter will decline as the large cohort moves out of the fishery and as subsequent poor recruitments enter the fishery. According to the base case model, an annual catch of 10 000t is likely to be sustainable over a period of up to 20 years but if recruitment continues to be poor then 10 000t will be too high. The absolute size of the stock is not well estimated and is reliant on two estimates of absolute spawning biomass from two surveys of egg abundance. If these surveys are biased then the estimated population size will, similarly, be biased.

The assessment for pink ling was unable to reconcile the flat or slightly increasing CPUE with the decline in the average age and length-at-capture. The stock could have been at any level (relative to the pristine biomass) between 20 and 70% of pristine. Forward projections using the base case assessment indicate that current levels of catch are not sustainable however this result must be viewed in the uncertain light of the assessment itself. Projections using the base case model also indicate that if a larger proportion of the annual catch is taken by the non-trawl fleet then the stock will be more depleted than if less of the catch were taken by non-trawl. However, again, this result is sensitive to changes in many of the assumptions made in the base case model and to the data. An earlier version of this assessment, that used a slightly different base case model and one year less data showed that the proportion of the catch taken by the non-trawl fleet had no impact of the stock's ability to sustain catches (Thomson, 2000c).

Spotted warehou show a clear length-depth relationship that can be taken account of as part of an Integrated Analysis assessment. Unfortunately, this means that some sort of fleet dynamics process is required when forward projections are performed. In this assessment the proportion of the landed catch that was taken in each of four depth classes during 2000/01 (the most recent year included in the assessment) was applied to every future year. This meant that the whole future target catch could not always be taken and that younger fish in the shallower depth classes were 'protected' from large catches. Therefore the risk of depleting the stock was underestimated. Future work should look into more sophisticated fleet dynamics models, or alternatively should ignore depth structure. The model indicates that although the stock is currently not severely depleted, future catches at the current high level may cause the stock to decline to undesirably low levels.

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APPENDIX A. INTELLECTUAL PROPERTY

No intellectual property has been produced.

APPENDIX B. STAFF / ACKNOWLEDGEMENTS

Name:	
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Andre Punt wrote the initial assessment model for blue grenadier and advised on aspects of all the models presented here. Contributions were also made to this project by a number of other people. Malcolm Haddon and Katherine Hodgson (Tasmanian Aquaculture and Fisheries Institute, TAFI) performed GLM analysis of the CPUE data for all three species covered by this project. Tony Smith (CSIRO) made valuable suggestions concerning the assessment models. The chair (David Smith, Marine and Freshwater Resources Institute, MAFRI, Victoria) and members of the Blue Grenadier Assessment Group, the Blue Warehou Assessment Group, and the attendees of the Workshop on Pink Ling contributed to hypothesis generation and to selecting the best framework for these models (such as identifying fleets). Ian Knuckey and the staff of the Integrated Monitoring Program (ISMP) and the Central Ageing Facility (CAF) collected most of the data used here and made it available. The members of the South East Fishery Assessment Group (SEFAG) also briefly reviewed these models and made helpful comments. This work has been funded by the Fisheries Research and Development Corporation (FRDC) and supported by the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

APPENDIX C. SPECIFICATION OF THE ASSESSMENT MODEL

The stock assessment model described here is age-based however several of the model processes can be either age- or length-based i.e. selectivity, discard probability, preferred depth-at-size, and weight. Only mortality is modelled as age (and time) -based. All implementations of this model have treated all processes as length-based (except mortality) or as age-based. The size-depth relationship is modelled as a length-based process only, therefore when this is used all the other model processes are also modelled as length-based.

The "year" used by the model is not necessarily a calendar year although it does consists of 12 calendar months. The start of the year can be defined in order to coincide with the likely hatching period for the fish in question. In the three stock assessments presented here growth rates for male and female fish were considered to be the same. The only parameter that has been considered to differ for male and female fish is the natural mortality rate (for blue grenadier). Therefore the equations considered below consider sex independent natural mortality only.

C1.1 Initial conditions

The number of fish of sex s and age a at the start of the first year modelled (y=1) is given by:

$$N_{s,1,a} = \begin{cases} 0.5R_0\, e^{\varepsilon_1} & \text{if } a=1 \\ 0.5R_0\, e^{-(a-1)Z_{s,0,a-1}}\, \varepsilon_a & \text{if } 1<a<x \\ 0.5R_0 \dfrac{e^{-(x-1)Z_{s,0,x-1}}}{\left(1-Z_{s,0,x}\right)}\, \varepsilon_a & \text{if } a=x \end{cases} \qquad \text{(C.1)}$$

where R_0 is the expected number of 1-year old fish when spawning biomass is at its deterministic pristine level (B_0), it is estimated by the model,

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

ε_1. is the recruitment residual for one-year olds in the first year of the model (see the definition of ε_y below), and

ε_a is the residual for each age in the first year (due to recruitment variability in the year that that cohort recruited to the population) and is assumed to follow a log-normal distribution with mean 1 and c.v. σ_r, and

$Z_{s,0,a}$ is the total mortality on fish of sex s and age a prior to the start of the modelled period:

$$Z_{s,0,a} = M_s + \sum_f S_{f,0,a}\, F_{f,0} \qquad \text{(C.2)}$$

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

$S_{f,0,a}$ is the selectivity by fleet f on fish of age a prior to the start of the model (see below for further details),

$F_{f,0}$ is the fully-selected fishing mortality by fishery f prior to year 1.

$F_{f,0}$ may be estimated by the model or, if it is believed that the stock was in an unfished state at the start of the first year (y = 1), then $F_{f,0}$ can be set equal to zero for all fleets (f). Alternatively, $F_{f,0}$ maybe set to zero for some fleets but not for others. $F_{f,0}$ may not be applied to the plus group.

C1.2 Numbers-at-age

The number of fish present in the population at the start of each year (other than the first year which is given by C.1) can be calculated in either of two ways - using Pope's approximation (Pope, 1972) or using continuous equations.

Using Pope's approximation reduces the number of parameters that have to be estimated but forces the model to treat the annual landed catch in mass by each fleet ($\tilde{C}_y$) as known exactly:

$$N_{s,y+1,a} = \begin{cases} N_{s,y+1,1} & \text{if} \quad a=1 \\ \left(N_{s,y,a-1}\, e^{-M_s/2} - C_{s,y,a-1}\right)e^{-M_s/2} & \text{if} \quad 1<a<x \\ \left(N_{s,y,x-1}\, e^{-M_s/2} - C_{s,y,x-1}\right)e^{-M_s/2} + \left(N_{s,y,x}\, e^{-M_s/2} - C_{s,y,x}\right)e^{-M_s/2} & \text{if} \quad a=x \end{cases} \qquad \text{(C.3)}$$

where $C_{s,y,a}$ is the total number of fish of sex s and age a caught during year y.

If continuous equations are used then the number of animals at the start of each year is given by:

$$N_{s,y+1,a} = \begin{cases} N_{s,y+1,1} & \text{if } a=1 \\ N_{s,y,a-1} e^{-Z_{s,y,a-1}} & \text{if } 1<a<x \\ N_{s,y,x-1}\, e^{-Z_{s,y,x-1}} + N_{s,y,x}\, e^{-Z_{s,y,x}} & \text{if } a=x \end{cases} \qquad \text{(C.4)}$$

C1.3 Recruitment

The number of 1-year olds present in the population at the start of each year ($N_{s,y,1}$) can be calculated in two ways. Either annual recruitments are assumed to vary around a mean level of recruitment ($\overline{R}$):

$$N_{s,y,1} = \overline{R}\, \varepsilon_y \qquad \text{(C.5)}$$

where $\overline{R}$ is the average level of recruitment to the population, and
ε_y is the recruitment residual in year y; it is assumed to follow a log-normal distribution with mean 1 and c.v. σ_r.

or around a stock-recruit relationship:

$$N_{s,y,1} = \left[0.5\tilde{B}_{y-1}/(\alpha + \beta\, \tilde{B}_{y-1})\right]\varepsilon_{y-1} \qquad \text{(C.6)}$$

where $\tilde{B}_y$ is the female spawning biomass in the middle of year y, α and β are parameters of the Beverton-Holt stock recruit relationship and are defined by a single parameter (steepness, h) using the method developed by Francis (1992b):

$$\alpha = \varphi\,(1-h)/4h \qquad \text{(C.7)}$$

and

$$\beta = 5h - 1/(4hR_0) \qquad \text{(C.8)}$$

where φ is the deterministic female spawning biomass in the unfished state (i.e. female spawning biomass in the first year of the model if ε_1 and all ε_a's are set to zero and the result is divided by R_0).

C1.4 Spawning biomass

The female spawning biomass during year y is given by:

$$\tilde{B}_y = \mu \sum_a \eta_{y,a} w_{y+0.5,a} N_{1,y+0.5,a} \qquad \text{(C.9)}$$

where μ is the proportion of mature females that spawn each year (usually assumed to be 1),

$w_{y+0.5,a}$ is the weight of a fish of age a in the middle of year y, and

$N_{s,y+0.5,a}$ is the number of fish of age a and sex s present in the population in the middle of year y; depending on the method used to calculate numbers-at-age this will be given by:

$$N_{s,y+0.5,a} = N_{s,y,a}\, e^{-M_s/2} \qquad \text{(C.10)}$$

or:

$$N_{s,y+0.5,a} = N_{s,y,a} e^{-0.5Z_{s,y,a}} \qquad \text{(C.11)}$$

$\eta_{y,a}$ is the proportion of females of age a that are mature during year y, it is given by a knife-edged function:

$$\eta_{y,a} = \begin{cases} 0 & \text{if } L_{y,a} < l^{mat} \\ 1 & \text{otherwise} \end{cases} \qquad \text{(C.12)}$$

where l^{mat} is the length at maturity, and

$L_{y,a}$ is the mean length of a fish of age a during year y (see below)

C1.5 Available biomass

The biomass that is available to fleet f during year y is given by:

$$B^{av}_{f,y} = \sum_a w_{y+0.5,a}\, S_{f,y,a} (1 - d_{f,y,a}) \sum_s N_{s,y+0.5,a} \qquad \text{(C.13)}$$

where $B^{av}_{f,y}$ is the biomass available to fleet f during year y,

$w_{y+0.5,a}$ is the weight of fish in the middle of year y,

$S_{f,y,a}$ is the selectivity for fish aged a by fleet f during year y, and

$d_{f,y,a}$ is the probability that a fish of age a caught by fleet f during year y will be discarded.

If depth classes are used (which means that several model functions will be length-based) the available biomass for fleet f during year y in depth class ψ is given by:

$$B^{av}_{f,y,\psi} = e^{-M/2}\sum_s \left[N_{s,y,a} \sum_l w_l \left(1-d_{f,l}\right) S_{f,l}\ A_{y,l,a}\ P_{\psi,l} \right] \tag{C.14}$$

where $A_{y,l,a}$ is the proportion of fish of length class l in year y that were found to be aged a (i.e. the age-length key), and

$P_{\psi,l}$ is the probability of a fish of length class l being in depth class ψ.

Both $A_{y,l,a}$ and $P_{\psi,l}$ are explained in greater detail below.

C1.6 Mean length-at-age

The mean length-at-age can be calculated in a number of ways (Punt and Smith, *in press*). It can be assumed to be fixed for all cohorts (Method 1) or can be calculated for each age class in each year (Method 2). If Method 1 is used then the mean length-at-age can be given by the von Bertalanffy growth equation:

$$L_{y,a} = l_\infty \left(1 - e^{-\kappa(a-t_0)}\right) \tag{C.15}$$

where l_∞, κ, and t_0 are the parameters of the von Bertalanffy equation;

or by the mean of the empirical data:

$$L_{y,a} = \frac{1}{n}\sum_{y'} \tilde{L}_{y',a} \tag{C.16}$$

where $\tilde{L}_{y,a}$ is the mean length-at-age for fish aged a in year y according to Method 2, and

n is the number of years for which data are available to calculate $\tilde{L}_{y,a}$ values.

If Method 2 is used then the length frequency and ALK data are used to calculate mean length-at-age empirically:

$$L_{y,a} = \tilde{L}_{y,a} = \sum_l A_{y,l,a}\ \tilde{\rho}_{y,l}\ \bar{l} / \rho_{y,a} \tag{C.17}$$

where $A_{y,l,a}$ is the proportion of fish of length class l in year y that were found to be aged a (i.e. the age-length key),

$\tilde{\rho}_{y,l}$ is the proportion of fish in year y that were found to be in length class l (i.e. the length frequency),

$\bar{l}$ is the mean length of length class l, and

$\rho_{y,a}$ is the proportion of fish in year y that were found to be age a (i.e. the age frequency).

$L_{y,a}$ cannot be calculated by Method 2 for years in which ALK or length frequency data have not been collected or for age classes which are not caught by the fishery. Method 1 must be used to fill in any such gaps in the length-age matrix of $L_{y,a}$ values.

C1.7 Weight

The mean weight of a fish in length class l can be modelled as an age- or a length-based process:

$$w_{y,a} = a\left(L_{y,a}\right)^b \qquad \text{if age-based} \tag{C.18}$$

$$w_l = a\left(\bar{l}\right)^b \qquad \text{if length-based} \tag{C.19}$$

where $\bar{l}$, as mentioned above, is the mean length of a fish assigned to length class l.

If the length-based process is used then mean weight-at-age is given by:

$$w_{y,a} = \sum_l w_l \, P_{y,l,a}$$

where $P_{y,l,a}$ is given below.

C1.8 Length-at-age

The proportion of fish that are in length-class l in year y, given that they are of age a is described by:

$$P_{y,l,a} = \int_{\bar{l}-0.5\Delta l}^{\bar{l}+0.5\Delta l} \ln \mathrm{N}\left(L_{y,a}, \sigma_a^2\right) \; d\tilde{l} \tag{C.20}$$

where: Δl is the width of length class l (measurers assign animals to length class l if their length is $\subset [l, l+\Delta l)$), and

$\ln \mathrm{N}\left(L_{y,a}, \sigma_a^2\right)$ is a log-normal distribution with age-dependant variance σ_a^2, and median $L_{y,a}$.

The c.v. σ_a^2 is calculated using the ALK data or can be made a model parameter.

C1.9 Selectivity

The selectivity for fleet f ($S_{f,y,l}$ or $S_{f,y,a}$) includes gear selectivity and aspects of availability. It can be described by a logistic or a dome-shaped function. It can be a function of length class (l):

$$S_{f,y,l} = \begin{cases} \left(1 + e^{-\ell n 19 (\bar{l} - l_f^{S50}) / (l_f^{S95} - l_f^{S50})}\right)^{-1} & \text{for } \textit{logistic} \\ e^{-\ell n 20 (\bar{l} - l^{Smid})^2 / (l_f^{S95} - l^{Smid})^2} & \text{for } \textit{dome-shaped} \end{cases} \tag{C.21}$$

or, of age and mean length-at-age:

$$S_{f,y,a} = \begin{cases} (1+e^{-\ell n19(L_{y,a}-a_f^{S50})/(a_f^{S95}-a_f^{S50})})^{-1} & \text{for } logistic \\ e^{-\ell n20(L_{y,a}-a_f^{Smid})^2/(a_f^{S50}-a_f^{Smid})^2} & \text{for } dome\text{-}shaped \end{cases} \quad (C.22)$$

where a_f^{Smid} is the length-class at which a fish is most vulnerable to being caught by fleet f,
a_f^{Sp} is the length-at-p% vulnerability for fleet f.

In the case of the blue grenadier non-spawning fishery a third form is used – a logistic curve with a decreasing right-hand side:

$$S_{f,y,a} = \begin{cases} (1+e^{-\ell n19(L_{y,a}-a_f^{S50})/(a_f^{S95}-a_f^{S50})})^{-1} & \text{if } L_{y,a} \le a_f^{S95} \\ (1+e^{-\ell n19(L_{y,a}-a_f^{S50})/(a_f^{S95}-a_f^{S50})})^{-1} e^{-\lambda_f(L_{y,a}-a_f^{S95})} & \text{otherwise} \end{cases} \quad (C.23)$$

λ_y is a model-estimated parameter that controls the steepness of the decline on the right-hand size of the curve.

If selectivity is modelled as a function of length (i.e. equation C.21) then the selectivity-at-age is given by:

$$S_{f,y,a} = \sum_l S_{f,y,l} P_{y,l,a}$$

The selectivity prior to the first year modelled ($S_{f,0,a}$) is given by the above equations but with $L_{y,a}$ calculated using Method 1 i.e. set using either the von Bertalanffy or the mean of the $L_{y,a}$ estimated for years for which data exist.

C1.10 Discard probability

The probability of discarding a fish of age a or of length class l that was caught during year y is similarly given by:

$$\begin{aligned} d_{f,l} &= d^{d\max} \Big/ (1+e^{\ell n19(\bar{l}-l_f^{d50})/(l_f^{d95}-l_f^{d50})}) && \text{for } length-based \\ d_{f,y,a} &= d^{d\max} \Big/ (1+e^{\ell n19(L_{y,a}-a_f^{d50})/(a_f^{d95}-a_f^{d50})}) && \text{for } age-based \end{aligned} \quad (C.24)$$

where $d^{d\max}$ is the maximum proportion discarded (bounded above by 1 and below by 0), and
l_f^{dp}, a_f^{dp} are the length-at-p% vulnerability to being discarded by fleet f.

If discarding is modelled as a function of length then the discarding-at-age is given by:

$$d_{f,y,a} = \sum_l d_{f,l} P_{y,l,a}$$

The blue grenadier model allows for density dependant discarding. This is achieved by multiplying the parameter $d^{d\max}$ in equation C.24 by a factor, γ, which lies between 0 and 1:

$$\gamma = (\sum_{s'} N_{s',y,1}/R_0)^{\phi} / \max_{y'}(\sum_{s'} N_{s',y',1}/R_0)^{\phi} \quad (C.25)$$

where R_0 is the deterministic median recruitment in the absence of fishing (usually a model-estimated parameter), and

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

C1.11 Depth structure

A size-depth relationship has been found for a number of SEF species (Bax and Williams, 2001). This can be modelled by assuming that fish choose to occupy a particular depth range as a function of their length class. The preferred depth for fish of length class l can be described by a straight line or a logistic function:

$$\overline{\psi}_l = \begin{cases} m^{\psi}\bar{l} + c^{\psi} \\ l^{\psi}_{\max} \Big/ \left(1 + e^{-\ell n 19(\bar{l} - l^{\psi 50})^2 /(l^{\psi 95} - l^{\psi 50})}\right) \end{cases} \tag{C.26}$$

where $\overline{\psi}_l$ is the preferred depth of fish of length class l (note that this is depth, not depth class),

m^{ψ} and c^{ψ} are parameters of the straight line, and

$l^{\psi}_{\max}$ is the maximum depth preferred by any fish, and

$l^{\psi p}$ is the length at p%-preferred-depth.

Each length class is assumed to be distributed at depth according to a log-normal distribution with mean $\overline{\psi}_l$ and c.v. σ_{ψ}. Therefore the probability of a fish of length l being in depth class ψ ($P_{\psi,l}$) is given by the integral under this log-normal distribution across the depth range represented by depth class ψ:

$$P_{\psi,l} = \int_{\psi 1}^{\psi 2} \ln \mathrm{N}\left(\psi_l, \sigma_{\psi}^2\right) \; d\psi' \tag{C.27}$$

where $\psi 1$ and $\psi 2$ are the lower and upper depth limits of depth class ψ.

The c.v. of this distribution (σ_{ψ}) could be given by some function of length or depth (such as a straight line or a logistic) but attempts to estimate the parameters of such a function were unsuccessful and a constant was chosen instead.

The probability of a fish of age a being in depth class ψ during year y ($P_{y,\psi,a}$) is a function of the probability of a fish in length class l being at that depth, and the probability of a fish being in length class l if it is aged a:

$$P_{y,\psi,a} = \sum_{l} \left(P_{y,l,a} \; P_{\psi,l}\right) \tag{C.28}$$

where $P_{y,l,a}$ is given above.

C1.12 Catches and exploitation rate

The formula used to calculate the number of fish of age a caught by fleet f during year y ($C_{f,y,a}$) differs depending on whether or not Pope's approximation is being used:

If Pope's is not being used and the size-depth relationship is ignored, $C_{f,y,a}$ is given by:

$$C_{f,y,a} = \left(1-d_{f,y,a}\right)\sum_{s}\frac{F_{f,y,a}}{Z_{s,y,a}} N_{s,y,a}\left(1-e^{-Z_{s,y,a}}\right) \qquad \text{(C.29)}$$

where $Z_{s,y,a} = M_s + \sum_{f'} F_{f',y,a}$,

$F_{f,y,a} = F_{f,y}\, S_{f,y,a}$, and

$F_{f,y}$ is the fully-selected fishing mortality for fleet f during year y.

If the size-depth relationship is modelled then selectivity and discarding are modelled as functions of length, not age, for greater accuracy. If Pope's is being used and the size-depth relationship is modelled, the number of fish of age a caught by fleet f during year y in depth class ψ ($C_{f,y,a,\psi}$) is:

$$C_{f,y,a,\psi} = E_{f,y,\psi} \sum_{s} N_{s,y,a}\, e^{-M_s/2} \sum_{l}\left(\left(1-d_{f,l}\right)S_{f,l}\, P_{\psi,l}\, P_{y,l,a}\right) \qquad \text{(C.30)}$$

where $E_{f,y,\psi}$ is the exploitation rate for fleet f during year y in depth ψ and is given by:

$$E_{f,y,\psi} = \tilde{C}_{f,y}\, \rho'_{f,y,\psi} \Big/ \left[\sum_{s}\sum_{a} N_{s,y,a}\, e^{-M_s/2} \sum_{l}\left(\left(1-d_{f,l}\right)S_{f,l}\, P_{y,\psi,l}\, P_{y,l,a}\, w_l\right)\right] \qquad \text{(C.31)}$$

where $\tilde{C}_{f,y}$ is the observed catch in mass by fleet f during year y, and

$\rho'_{f,y,\psi}$ is the proportion of the catch by fleet f taken during year y in depth class ψ.

The total number of fish of age a caught during year y by fleet f ($C_{f,y,a}$) is given by:

$$C_{f,y,a} = \sum_{\psi} C_{f,y,a,\psi} \qquad \text{(C.32)}$$

The number of fish of length class l caught in depth class ψ during year y by fleet f ($C_{f,y,l,\psi}$) is given by:

$$C_{f,y,l,\psi} = \sum_{a} C_{f,y,a,\psi}\, P_{y,l,a} \qquad \text{(C.33)}$$

The weight of the catch is:

$$\tilde{C}_{f,y} = \sum_{a} C_{f,y,a}\, w_{y,a} \qquad \text{(C.34)}$$

and $w_{y,a} = \sum_{l}\left(\left(1-d_{f,l}\right)S_{f,l}\, P_{y,\psi,l}\, P_{y,l,a}\, w_l\right)$

C1.13 CPUE

The expected catch-per-unit effort for fleet f in depth class ψ during year y ($CP\hat{U}E_{f,y,\psi}$) is assumed to be proportional to the biomass that is available to that fleet:

$$CP\hat{U}E_{f,y,\psi} = q_{f,\psi}\, B^{av}_{f,y,\psi} \tag{C.35}$$

where: $q_{f,\psi}$ is a constant of proportionality for fleet f in depth class ψ. It can either be estimated as a parameter of the model or can be given by the maximum likelihood solution (e.g. Smith and Punt, 1998; Punt and Butterworth, 1996):

$$q_{f,\psi} = \exp\left[n^{-1} \sum_y \left(\ln CPUE^{obs}_{f,y,\psi} - \ln B^{av}_{f,y,\psi} \right) \right] \tag{C.36}$$

where n is the number of CPUE observations for fleet f in depth class ψ, and
$CPUE^{obs}_{f,y,\psi}$ is the observed CPUE for fleet f during year y in depth class ψ.

If CPUE is calculated for all depth classes combined then $q_{f,\psi}$ and $B^{av}_{f,y,\psi}$ are replaced by q_f and $B^{av}_{f,y}$.

C1.14 The likelihood function

The negative of the logarithm of the likelihood (-ln L) is given by:

$$-\ln L = \sum_i L_i \tag{C.37}$$

where the L_i are described below. In all cases, summations over years include only those years for which data are available.

C1.14.1 Recruitment residuals

The recruitment residuals ε_a and ε_y, are assumed to be log-normally distributed with mean zero and c.v. σ_r^2. They are assumed to be independent of one another (no serial correlation):

$$L_1 = (2\sigma_r^2)^{-1} \left(\sum_y \ln(\varepsilon_y)^2 + \sum_a \ln(\varepsilon_a)^2 \right) \tag{C.38}$$

the following constraints can placed on the residuals (this is not done for spotted warehou):

$$\sum_y \varepsilon_y = 0 \tag{C.39}$$

$$\sum_a \varepsilon_a = 0 \tag{C.40}$$

C1.14.2 Landings/ Discards

If Pope's approximation is not used then the landed catch is included in the log-likelihood. Errors in the measurement of landings are assumed to be log-normally distributed with a CV of σ_c:

$$L_2 = \frac{1}{2\sigma_{all}\sigma_c^2}\sum_f\sum_y(\ell n\tilde{C}^{obs}_{f,y} - \ell n\tilde{C}_{f,y})^2 \quad (C.41)$$

where $\tilde{C}^{obs}_{f,y}$ is the observed catch (in mass) by fleet f during year y.

σ_{all} is a parameter which is used to scale the overall weighting given the data, it is usually set equal to 1.

The contribution of the observed mass of discards to the negative of the log-likelihood (L_3) follows Equation (C.12) except that total landings are replaced by total discards.

If Pope's approximation is used then the observed landed catch is used to calculate the exploitation rate (equation C.31) and cannot therefore be treated as a data source. However, during the estimation process it is possible for parameter values to be chosen that result in some negative $N_{s,y,a}$ values. When this happens $N_{s,y,a}$ is reset to a small value and the estimated landed catch will not be equal to that observed. To prevent the estimation procedure choosing such parameter values a penalty function is added to the negative log likelihood:

$$P_1 = 1000 * \sum_f\sum_y(\ell n\tilde{C}^{obs}_{f,y} - \ell n\tilde{C}_{f,y})^2 \quad (C.42)$$

C1.14.3 Port measured catch-at-age

The errors in the proportion caught-at-age for the landed catch are assumed to be either multinomially or log-normally distributed:

$$L_4 = -N^{ca}\sum_f\sum_y w^{ca}_{f,y}\sum_{a=1}^{x}\rho^{obs}_{f,y,a}\,\ell n(\hat{\rho}_{f,y,a}/\rho^{obs}_{f,y,a}) \qquad \textit{for multinomial errors} \quad (C.43)$$

where: $\rho^{obs}_{f,y,a}$ is the observed proportion that fish of age a made up of the catch by fleet f during year y (calculated by normalising the observed catch-at-age for year y and fleet f so that they sum to 1 across ages),

$\hat{\rho}_{f,y,a}$ is the model estimated proportion that fish of age a made up of the catch by fleet f during year y, calculated by normalising $C_{f,y,a}$:

$$\hat{\rho}_{f,y,a} = C_{f,y,a}/\sum_{a'}C_{f,y,a'} \quad (C.44)$$

$w^{ca}_{f,y}$ is the relative weight given to the catch-at-age sample for fleet f for year y, and

N^{ca} is the weight given to the catch-at-age data relative to the other data sources.

$w^{ca}_{f,y}$ can be chosen to be 1 for all samples; it can be given by the sample size for the ALK for year y divided by the average sample size for all ALKs; or it can be given by the sample size of the ALK multiplied by that of the length frequency that was used to derive this age-composition that is being weighted, divided by the average of this product for all samples.

For log-normal errors:

$$L_4 = \sum_f\sum_y\sum_{a=1}^{x}\left[\ln(\varphi_{f,y,a}) + (2\varphi^2_{f,y,a})^{-1}(\ell n\,\rho^{obs}_{f,y,a} - \ell n\,\hat{\rho}_{f,y,a})^2\right] \quad \textit{for log-normal errors} \quad (C.45)$$

where: $\varphi_{f,y,a} = \sigma^{ca}\sigma_{all} \Big/ \sqrt{w^{ca}_{f,y}\ \hat{\rho}_{f,y,a}}$, and

σ^{ca} is the weight given to the catch-at-age data relative to the other data sources.

C1.14.4 Port measured catches-at-length

The contribution to the negative log-likelihood of the proportion caught-at-length (L_5) is calculated similarly (to L_4) except that $C_{f,y,a}$ is replaced by $C_{f,y,l}$. The weights are replaced by N^{cl} for the log-normal and σ^{cl} for the multinomial case. The weighting for the annual catch compositions are replaced by $w^{cl}_{f,y}$ which is the sample size for the length frequency for fleet f in year y divided by the average sample size for the length frequencies.

C1.14.5 Onboard measured catch-at-age

Unlike port-measured data, catch-at-length data collected onboard vessels includes information on the depth at which catches were made. However, the port-based length frequency samples typically have much greater sample sizes than those measured onboard and are therefore used in preference to the onboard data to give the estimated length-frequency of the catch for the year. But if the size-depth relationship is modelled then both the port- and onboard-based samples can be used; the former to give the annual catch-at-length or –at-age for the fishery for the year and the latter to give the catch-at-length or –at-age for each depth-class.

The errors in the proportion caught-at-age for the retained (landed) catch are assumed to be either multinomially or log-normally distributed:

$$L_6 = -N^{ca'} \sum_f \sum_y \sum_\psi w^{ca'}_{f,y,\psi} \sum_{a=1}^{x} \rho^{obs}_{f,y,a,\psi}\ \ell n(\hat{\rho}_{f,y,a,\psi} / \rho^{obs}_{f,y,a,\psi}) \quad \textit{for multinomial errors} \tag{C.46}$$

where: $\rho^{obs}_{f,y,a,\psi}$ is the observed proportion that fish of age a made up of the catch by fleet f during year y in depth class ψ,

$\hat{\rho}_{f,y,a,\psi}$ is the model estimated proportion that fish of age a made up of the catch by fleet f during year y, calculated by normalising $C_{f,y,a,\psi}$:

$$\hat{\rho}_{f,y,a,\psi} = C_{f,y,a,\psi} / \sum_{a'} C_{f,y,a',\psi} \tag{C.47}$$

$w^{ca'}_{f,y}$ is the relative weight given to the onboard catch-at-age sample for fleet f during year y, and

$N^{ca'}$ is the weight given to the onboard catch-at-age data relative to the other data sources.

$w^{ca'}_{f,y}$ can be given in the same ways as $w^{ca}_{f,y}$.

For log-normal errors:

$$L_6 = \sum_f \sum_y \sum_{a=1}^{x} \left[\ell n\,(\varphi'_{f,y,a,\psi}) + (2\varphi'^{2}_{f,y,a,\psi})^{-1} (\ell n\ \rho^{obs}_{f,y,a,\psi} / \ell n\ \hat{\rho}_{f,y,a,\psi})^2\right] \tag{C.48}$$

where: $\varphi'_{f,y,a,\psi} = \sigma^{ca'}\sigma_{all} \Big/ \sqrt{w^{ca'}_{f,y,dc}\ \hat{\rho}_{f,y,a,\psi}}$, and

$\sigma^{ca'}$ is the weight given to the onboard catch-at-age data relative to the other data sources.

C1.14.6 Onboard measured catches-at-length

The contribution to the negative log-likelihood of the proportion caught-at-length (L_7) is calculated similarly except that $C_{f,y,a,\psi}$ is replaced by $C_{f,y,l,\psi}$. The weights are replaced by $N^{cl'}$ for the log-normal and $\sigma^{cl'}$ for the multinomial case. The weighting for the annual catch compositions are replaced by $w^{cl'}_{f,y}$ which is the sample size for the onboard measured length frequency for fleet *f* in year *y* divided by the average sample size for the length frequencies.

C1.14.7 CPUE

Errors in the *CPUE* data are assumed to be log-normally distributed with mean generated by the model and c.v. σ_q.

$$L_8 = \sum_f \sum_y \left[\sigma'_q + \left(2\sigma'^2_q\right)^{-1} \ln\left(CPUE_{f,y} / C\hat{P}UE_{f,y}\right)^2 \right] \qquad \text{(C.49a)}$$

where $\sigma'_q = \sigma_{all}\sigma_q \Big/ \sqrt{w^{CPUE}_{f,y}}$

$CPUE_{f,y}$ is the observed catch-per-unit-effort for fleet *f* during year *y*, and

$w^{CPUE}_{f,y}$ is the weighting applied to the observed (standardised) CPUE for fleet *f* for year *y*, it is the number of observations for this figure, divided by the average number of observations for all CPUE figures.

Or, if CPUE is being modelled by depth class then:

$$L_8 = \sum_{dc} \sum_f \sum_y \left[\sigma'_{q,\psi} + \left(2\sigma'^2_{q,\psi}\right)^{-1} \ln\left(CPUE_{f,y,\psi} / C\hat{P}UE_{f,y,\psi}\right)^2 \right] \qquad \text{(C.49b)}$$

where $\sigma'_{q,\psi} = \sigma_{all}\sigma_{q,\psi} \Big/ \sqrt{w^{CPUE}_{f,y,\psi}}$

$CPUE_{f,y,\psi}$ is the observed catch-per-unit-effort for fleet *f* during year *y* in depth class ψ, and

$w^{CPUE}_{f,y,\psi}$ is the weighting applied to the observed (standardised) CPUE for fleet *f* for year *y* in depth class ψ, it is the number of observations for this figure, divided by the average number of observations for all CPUE figures.

C1.14.8 Egg estimates of biomass

The contribution of the egg-production estimate (or of any other absolute estimate of biomass) to the negative of the logarithm of the likelihood function is given by:

$$L_9 = \sum_y (\tilde{B}_y - B^{obs}_y)^2 / (2\sigma^2_y) \qquad \text{(C.50)}$$

where B^{obs}_y is the estimate of female spawning biomass for year *y* based on the egg-production method, and

σ_y is the standard error of B^{obs}_y.

C1.14.9 Penalty function

If Pope's approximation is used to calculate an exploitation rate, instead of estimating fishing mortality rates, then a penalty is added to the maximum likelihood, as explained above (equation C.42).

The spotted warehou model incorporates observed values for the parameters of the selectivity function. These are incorporated using a sum of squares equation like equation C.42.

Similar penalties are added to ensure that, e.g. the logistic selectivity is an increasing not a decreasing function (i.e. that the value of the parameter that gives the height of the curve at 75% of the maximum value is not lower than the 50% parameter). These penalties are all added to the negative log-likelihood value in order to ensure that the estimator searches the correct region of parameter space. The resulting maximum likelihood value ought not to be altered i.e. the penalty functions should all be zero at the maximum likelihood.

APPENDIX D. LENGTH AND AGE FREQUENCIES USED IN THE ASSESSMENT MODELS

All available length and age frequency data are shown here, normalised and shown as percentages. Not all of these data are included in the assessment models, in some cases data have been excluded because of low sample sizes (this will be indicated in the chapter discussing that species). Most of the length frequency data shown were used, in conjunction with ALK data, to generate the age frequencies and are included in the assessment model as age and not as length frequencies.

D1.1 Blue Grenadier

D1.1.1 Length frequency data (retained catches)

The stock assessment model for blue grenadier does not model length frequencies; rather these are all converted to age frequencies using ALK data. The length frequencies used are shown in Tables D1-2. Two fleets are distinguished in the assessment model – the spawning (zone 40 during June, July and Aug) and non-spawning fleets (all other times and places).

Table D1. Length frequencies for retained catches of blue grenadier for the spawning trawl fleet.

Length (cm)	1984	1985	1988	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
45													
46													
47						0.002							
48											0.015		
49													
50			0.004			0.004							
51			0.004		0.035		0.007			0.165	0.417		
52			0.033			0.021	0.015			0.041			
53			0.038			0.003	0.015				0.278		
54			0.125			0.002	0.038			0.041	1.194		0.031
55			0.190			0.002	0.061				1.259		
56	0.006		0.190				0.093			0.138	2.236	0.050	
57			0.161				0.085		0.015		2.301	0.172	
58	0.029	0.016	0.369				0.111		0.015		2.664	0.586	
59		0.016	0.473			0.002	0.178		0.022		1.774	0.682	0.031
60	0.059	0.016	0.403			0.115	0.210		0.022	0.041	1.765	1.521	0.031
61			0.809			0.001	0.265		0.051		1.687	1.766	0.031
62			1.340			0.016	0.265	0.008	0.056	0.084	1.028	2.593	0.062
63			1.562	0.199		0.006	0.371	0.053	0.071	0.052	0.711	2.874	0.155
64	0.118	0.031	1.990	0.598	0.035	0.075	0.601	0.070	0.086	0.041	0.665	2.461	0.093
65	0.059	0.063	1.990	0.598	0.144	0.002	0.562	0.072	0.322	0.201	0.712	2.651	0.403
66			2.166	1.935		0.082	0.527	0.132	0.314		0.575	1.544	0.683
67	0.312	0.330	2.379	2.703	0.133	0.191	0.527	0.278	0.322	0.222	0.162	1.374	1.365
68	0.195	0.016	2.885	2.305	0.173	0.176	0.676	0.519	0.151	0.166	0.273	1.045	3.506
69		0.377	2.266	1.736	0.543	0.313	0.796	0.649	0.129	0.234		0.855	4.592
70	0.047	0.063	3.173	3.842	0.935	0.636	0.878	1.065	0.216	0.052	0.195	0.968	7.291

71	0.371	0.393	3.321	3.842	1.710	0.746	0.853	1.515	1.003	0.181	0.047	0.573	7.012
72	0.312	0.079	3.518	2.163	2.721	1.160	1.286	1.995	0.625	0.277	0.015	0.335	7.695
73	1.657	0.330	2.965	2.732	2.469	2.272	1.915	2.216	0.916	0.505	0.014	0.174	7.478
74	2.447	0.974	2.965	2.134	2.844	2.848	2.711	2.361	0.681	0.758	0.008	0.327	6.205
75	4.599	1.131	2.694	1.736	3.780	4.973	3.135	2.559	1.564	1.038	0.007	0.185	4.530
76	3.225	1.382	2.511	2.305	2.417	5.090	3.421	3.067	2.247	1.479	0.170	0.273	4.065
77	5.736	4.901	2.183	3.643	3.355	6.069	4.476	3.269	2.531	1.550	0.218	0.307	2.668
78	5.188	4.870	2.435	2.533	4.502	6.810	5.314	3.862	2.787	2.165	0.350	0.239	2.637
79	3.755	7.430	2.435	1.935	1.114	5.566	4.477	4.187	4.834	3.024	0.473	0.735	2.017
80	4.587	7.022	2.592	3.671	2.925	5.593	4.620	5.013	5.176	3.344	1.059	1.213	1.396
81	4.599	5.561	2.596	2.476	2.198	4.063	5.031	4.690	5.132	4.745	1.131	1.509	0.993
82	3.732	7.760	2.529	2.903	4.146	3.387	3.962	5.064	3.997	5.347	1.158	2.074	0.993
83	3.260	6.205	1.891	3.870	1.975	4.364	3.632	4.444	5.806	4.691	1.763	2.114	0.590
84	3.926	5.199	2.347	3.671	2.586	3.893	2.889	4.917	5.234	4.483	1.981	3.106	0.869
85	2.447	2.121	1.919	4.468	2.707	2.967	3.059	4.023	5.196	5.460	2.331	2.523	0.869
86	2.771	2.325	1.690	2.903	1.686	2.720	3.291	4.155	3.063	4.068	2.417	3.216	0.962
87	2.240	3.927	1.542	3.301	2.300	2.737	2.946	4.229	3.470	4.917	2.127	3.641	1.117
88	1.975	2.121	1.542	2.903	3.534	1.744	3.044	4.003	5.116	4.185	2.193	3.456	0.838
89	0.890	2.026	1.372	2.163	3.773	2.697	3.014	3.469	2.613	3.379	2.973	2.731	1.086
90	1.627	2.309	1.326	2.362	3.268	2.751	2.857	3.362	3.338	3.392	2.680	3.035	1.334
91	2.287	1.382	1.430	2.305	2.459	2.278	2.886	3.156	3.576	3.257	3.783	3.069	1.210
92	2.223	2.278	1.033	1.764	3.316	1.960	2.715	2.020	3.525	3.353	2.335	3.180	1.241
93	1.503	2.576	1.472	2.732	2.437	2.095	2.836	2.303	2.724	2.717	3.406	4.141	1.117
94	4.392	2.545	1.615	3.472	1.942	2.130	2.282	2.142	3.118	3.424	4.230	2.354	1.489
95	3.036	2.576	1.601	2.533	1.853	2.060	1.859	2.081	2.814	2.752	4.163	4.238	1.334
96	3.007	1.005	1.477	0.996	2.739	1.611	2.282	1.666	2.865	2.564	4.497	3.121	1.241
97	3.402	1.948	1.477	1.736	1.862	1.758	1.615	1.858	2.344	2.447	4.740	2.933	1.520
98	3.042	2.560	1.332	1.764	3.045	1.173	1.570	1.564	1.802	2.234	4.199	3.933	1.272
99	2.417	1.979	1.318	0.398	2.177	0.928	1.881	1.315	1.644	2.481	3.951	3.746	1.489
100	2.659	2.576	1.301	1.167	1.626	1.469	0.768	1.124	2.641	2.614	3.745	3.011	1.551
101	2.541	1.964	0.997	1.736	2.411	1.458	1.030	1.031	0.825	2.774	3.858	2.886	1.117
102	2.317	1.068	1.523	0.598	2.407	1.028	0.809	0.864	1.260	2.940	2.939	2.969	1.117
103	1.415	0.675	1.625	0.598	1.488	0.956	0.806	0.648	1.366	1.787	2.319	2.057	0.993
104	0.749	0.958	1.600	2.106	2.047	0.773	0.764	0.596	0.612	1.334	2.482	2.087	0.807
105	0.867	1.681	1.624	1.366	1.580	1.091	0.482	0.448	0.604	1.087	1.933	0.619	1.520
106	0.873	0.974	1.624	0.768	1.666	0.740	0.991	0.401	0.050	0.499	1.079	1.018	1.148
107	0.861	0.943	1.457	0.768	1.309	0.636	0.692	0.293	0.055	0.454	1.053	0.713	1.179
108	1.297	0.016	1.278	0.768	2.343	0.656	0.308	0.323	0.389	0.315	0.554	0.228	0.993
109	0.312	0.958	1.026	0.199	0.754	0.159	0.435	0.274	0.020	0.137	0.592	0.333	0.714
110	0.271	0.314	0.889		0.752	0.176	0.416	0.238	0.255		0.403	0.130	1.024
111	0.165		0.889		0.674	0.196	0.358	0.185	0.204	0.173	0.191	0.099	0.434
112			0.600	0.398	0.105	0.209		0.120	0.184	0.108	0.233	0.037	0.279
113	0.195		0.400	0.199	0.417	0.041		0.062			0.086	0.037	0.248
114		0.031	0.348		0.266	0.123		0.017			0.001	0.153	0.124
115			0.174		0.037	0.060		0.015			0.091		0.621
116			0.208		0.206	0.057		0.003			0.063		0.217
117			0.173		0.076	0.075		0.003		0.086	0.015		0.093
118			0.156					0.003					0.093
119			0.086					0.003			0.017		
120			0.086								0.015		0.155
121			0.069										
122			0.034										
123			0.034										
124			0.017										
125			0.034										
126			0.017										

127	0.017	
128	0.017	
129	0.017	0.031

Table D2. Length frequencies for retained catches of blue grenadier for the non-spawning trawl fleet.

Length (cm)	1984	1985	1987	1988	1989	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
22										0.011					
23										0.035					
24										0.035					
25						0.009				0.091					
26						0.014				0.099					
27						0.028				0.091					
28						0.074				0.067					
29						0.119				0.067					
30						0.119				0.008					
31						0.131									
32						0.136			0.001						
33						0.108			0.002						
34				0.004		0.074			0.002	0.007	0.002				0.000
35				0.004		0.074			0.002	0.007	0.002			0.000	0.002
36				0.004		0.073			0.002	0.007	0.002			0.001	0.006
37				0.004		0.090		0.004	0.001	0.007	0.002			0.003	0.006
38				0.005		0.102		0.006	0.001	0.007	0.009	0.003	0.010	0.009	0.009
39	0.052	0.055		0.002		0.085		0.006	0.001		0.028	0.003	0.010	0.012	0.012
40	0.052	0.055		0.002		0.119		0.014	0.006		0.032	0.004	0.019	0.025	0.013
41			0.003	0.020	0.002	0.130		0.032	0.012		0.069	0.094	0.022	0.036	0.011
42	0.103		0.003	0.020	0.002	0.117		0.077	0.022		0.079	0.094	0.026	0.055	0.011
43	0.103		0.009	0.087	0.004	0.089		0.138	0.039		0.067	0.248	0.051	0.079	0.012
44	0.362	0.055	0.025	0.248	0.018	0.089		0.138	0.039		0.062	0.580	0.110	0.083	0.017
45	0.207	0.109	0.062	0.441	0.047	0.057		0.254	0.067	0.014	0.028	1.224	0.272	0.106	0.021
46	0.207		0.141	0.586	0.091	0.045		0.446	0.137	0.027	0.035	2.327	0.623	0.139	0.037
47	0.362	0.055	0.141	0.586	0.091	0.120		0.685	0.234	0.038	0.032	2.327	0.628	0.188	0.037
48	0.620	0.109	0.230	0.747	0.157	0.120		0.623	0.217	0.052	0.061	3.745	1.196	0.167	0.068
49	1.240	0.055	0.388	0.840	0.203	0.166		0.911	0.336	0.089	0.088	5.143	2.068	0.320	0.101
50	0.724	0.328	0.476	0.916	0.258	0.244	0.001	1.135	0.476	0.118	0.145	6.149	3.415	0.649	0.166
51	0.930	0.164	0.394	0.753	0.213	0.568	0.007	1.228	0.609	0.084	0.136	4.957	3.063	1.450	0.149
52	1.499		0.551	1.007	0.361	0.788	0.021	1.128	0.763	0.201	0.200	6.259	5.277	2.570	0.250
53	1.085	0.273	0.760	1.043	0.366	0.788	0.021	1.128	0.763	0.207	0.229	5.543	7.138	2.560	0.365
54	0.517	0.437	0.959	1.089	0.416	1.231	0.028	1.060	0.908	0.310	0.281	4.270	8.869	4.172	0.666
55	0.310	0.219	1.222	1.209	0.540	1.803	0.045	0.857	1.063	0.336	0.278	2.940	9.673	6.024	1.241
56	0.413	0.601	1.222	1.209	0.540	2.337	0.129	0.615	1.199	0.357	0.371	2.940	9.670	7.556	1.243
57	0.413	0.328	1.419	1.441	0.581	2.015	0.114	0.426	0.939	0.390	0.274	1.797	9.040	6.366	2.144
58	0.258	0.547	1.561	1.875	0.752	2.765	0.185	0.497	1.306	0.491	0.252	1.053	7.862	8.786	3.544
59	0.517	0.383	1.679	2.581	0.976	3.305	0.311	0.358	1.421	0.609	0.193	0.705	5.857	9.166	5.405
60	0.362	0.601	1.291	2.192	0.767	3.631	0.502	0.249	1.465	0.488	0.237	0.384	3.535	8.586	4.779
61	0.568	0.656	1.709	3.148	1.089	3.798	0.819	0.264	1.500	0.881	0.197	0.472	4.028	7.484	7.542
62	0.672	0.875	1.785	3.762	1.322	3.798	0.819	0.264	1.500	1.152	0.286	0.370	2.700	7.484	9.345
63	0.568	0.656	1.740	4.342	2.135	4.014	1.495	0.418	1.425	1.528	0.338	0.322	1.546	5.941	10.07
64	0.568	1.476	1.571	4.846	2.726	3.954	2.205	0.514	1.304	2.049	0.436	0.262	0.967	4.279	9.687
65	0.517	1.422	1.571	4.846	2.726	4.169	3.488	0.816	1.267	2.018	0.420	0.262	0.967	3.064	9.696
66	0.362	1.531	1.437	5.030	3.446	4.125	4.779	1.253	1.356	2.510	0.560	0.281	0.552	1.978	8.176
67	0.568	1.531	1.280	5.020	4.752	4.125	4.779	1.253	1.356	3.183	0.850	0.288	0.356	1.977	6.324
68	0.465	1.531	1.233	4.954	5.758	4.340	5.883	1.699	1.659	3.718	1.287	0.275	0.275	1.257	4.616

69	0.517	1.422	0.910	3.443	4.835	4.305	7.272	2.588	2.144	3.054	1.120	0.226	0.196	0.889	2.806
70	1.499	2.023	1.268	4.457	6.490	3.943	7.885	3.647	2.931	4.156	1.721	0.331	0.237	0.543	3.090
71	2.067	2.952	1.267	3.944	7.081	2.947	6.188	3.135	2.461	4.446	2.474	0.414	0.198	0.353	2.050
72	3.152	2.570	1.481	3.263	6.842	3.902	7.818	4.598	3.988	4.744	3.427	0.620	0.170	0.425	1.217
73	3.876	3.171	1.803	2.482	5.845	3.484	7.324	5.350	5.052	5.001	4.624	0.889	0.200	0.327	0.759
74	4.858	4.046	1.803	2.482	5.845	3.287	6.108	5.967	6.028	5.022	4.640	0.889	0.200	0.295	0.746
75	6.563	5.686	2.423	1.849	5.000	3.106	4.835	5.865	6.307	5.368	5.735	1.181	0.241	0.287	0.514
76	7.907	6.670	3.127	1.620	4.199	3.106	4.835	5.865	6.307	5.540	6.437	1.569	0.323	0.287	0.364
77	8.889	7.053	4.202	1.738	3.265	2.758	3.829	5.572	6.006	5.427	7.136	1.837	0.405	0.313	0.305
78	7.028	7.709	5.081	1.791	2.861	2.440	2.996	5.034	5.266	5.052	6.920	2.217	0.472	0.332	0.242
79	7.183	6.889	5.081	1.791	2.861	2.042	2.307	3.957	4.407	5.052	6.920	2.217	0.472	0.325	0.243
80	4.755	5.358	5.646	1.915	2.406	1.391	1.475	2.662	3.005	4.356	6.804	2.625	0.550	0.258	0.209
81	5.375	5.303	6.062	1.953	1.961	1.733	1.852	3.184	3.582	3.749	6.256	2.726	0.544	0.325	0.200
82	2.842	3.609	5.502	1.784	1.745	1.361	1.527	2.522	2.754	3.046	5.196	2.869	0.565	0.309	0.175
83	2.997	4.101	3.947	1.299	1.082	1.112	1.190	2.104	2.204	2.029	3.648	2.164	0.417	0.294	0.131
84	2.636	2.187	4.871	1.662	1.291	0.910	1.060	1.896	1.618	2.413	4.335	2.810	0.523	0.260	0.155
85	2.016	2.406	3.941	1.441	1.113	0.910	1.060	1.896	1.618	1.968	3.228	2.514	0.467	0.260	0.142
86	2.016	2.624	3.043	1.216	0.772	0.670	0.821	1.659	1.286	1.452	2.406	2.314	0.416	0.238	0.122
87	2.016	2.078	2.364	0.967	0.491	0.469	0.644	1.442	1.134	1.037	1.739	1.982	0.370	0.179	0.109
88	1.395	1.476	2.364	0.967	0.491	0.316	0.558	1.182	0.953	1.037	1.739	1.982	0.370	0.141	0.109
89	1.292	1.367	1.717	0.656	0.326	0.180	0.361	0.785	0.679	0.811	1.183	1.629	0.335	0.094	0.094
90	1.189	1.640	1.315	0.466	0.254	0.230	0.452	1.044	0.860	0.642	0.891	1.402	0.292	0.114	0.076
91	0.775	0.711	1.000	0.288	0.265	0.132	0.364	0.948	0.777	0.482	0.690	1.114	0.295	0.084	0.060
92	0.672	0.601	0.678	0.179	0.205	0.121	0.286	0.832	0.664	0.340	0.419	0.767	0.198	0.071	0.035
93	0.155	0.547	0.776	0.220	0.281	0.100	0.226	0.699	0.599	0.418	0.514	0.950	0.254	0.062	0.046
94	0.310	0.273	0.639	0.221	0.259	0.100	0.226	0.699	0.599	0.309	0.429	0.807	0.223	0.062	0.039
95	0.310	0.219	0.500	0.162	0.229	0.065	0.158	0.619	0.576	0.243	0.317	0.650	0.201	0.048	0.027
96	0.258	0.164	0.401	0.169	0.197	0.068	0.121	0.618	0.475	0.242	0.247	0.530	0.163	0.043	0.022
97	0.258	0.219	0.401	0.169	0.197	0.054	0.090	0.506	0.380	0.242	0.247	0.530	0.163	0.037	0.022
98	0.207	0.383	0.344	0.164	0.169	0.046	0.067	0.595	0.323	0.218	0.184	0.421	0.136	0.026	0.019
99	0.207	0.109	0.259	0.121	0.167	0.046	0.067	0.595	0.323	0.183	0.167	0.317	0.118	0.026	0.018
100		0.164	0.223	0.106	0.100	0.082	0.050	0.564	0.214	0.156	0.122	0.224	0.104	0.025	0.015
101		0.109	0.133	0.066	0.075	0.079	0.044	0.491	0.207	0.092	0.086	0.151	0.076	0.019	0.012
102	0.052	0.055	0.156	0.088	0.086	0.089	0.036	0.555	0.190	0.095	0.103	0.192	0.084	0.019	0.013
103			0.141		0.061	0.075	0.019	0.391	0.123	0.048	0.083	0.137	0.063	0.013	0.006
104		0.055	0.093		0.042	0.091	0.019	0.425	0.149	0.046	0.061	0.103	0.045	0.015	0.006
105	0.103		0.056		0.055	0.045	0.019	0.334	0.120	0.022	0.046	0.077	0.026	0.010	0.004
106			0.056		0.055	0.042	0.012	0.240	0.082	0.022	0.046	0.077	0.026	0.007	0.004
107			0.032		0.045	0.025	0.019	0.119	0.066	0.020	0.034	0.047	0.018	0.003	0.005
108			0.006		0.022	0.025	0.019	0.119	0.066	0.014	0.023	0.036	0.011	0.003	0.005
109			0.014		0.033	0.012	0.019	0.092	0.041	0.002	0.018	0.031	0.005	0.002	0.004
110			0.014		0.010	0.007	0.019	0.036	0.021		0.007	0.024	0.001	0.002	0.003
111					0.010	0.005	0.019	0.024	0.004		0.007	0.024	0.001	0.000	0.003
112					0.019	0.002	0.006	0.016	0.001	0.004	0.002	0.018	0.001	0.000	0.002
113					0.019	0.002	0.006	0.016	0.004	0.004	0.001	0.012	0.000	0.000	0.001
114							0.013	0.009	0.002	0.004	0.000	0.009	0.000		0.000
115							0.006	0.009	0.002	0.004		0.008			0.000
116							0.006		0.002	0.004		0.008			0.000
117							0.006		0.002			0.005			0.000
118							0.006					0.002			
119															
120															
121															
122															
123															
124															

125	
126	0.027
127	0.002
128	
129	

D1.1.2 Length frequency data (discarded catches)

Information on the discards by the non-spawning fishery are available from ISMP and SMP sampling (Table D3).

Table D3. Length frequencies for discarded catches of blue grenadier for the non-spawning trawl fleet.

Length (cm)	1995	1996	1997	1998	1999	2000
20	0.006					
21	0.006					
22	0.014					
23	0.017					
24	0.017					
25	0.029					
26	0.072					
27	0.142					
28	0.180					
29	0.301					
30	0.534					
31	0.745	0.017				
32	0.893	0.057				
33	0.893	0.057	0.010			
34	0.870	0.114	0.236			
35	0.715	0.327	1.155			
36	0.490	0.477	1.802			
37	0.354	0.582	1.885			
38	0.270	1.668	1.542			
39	0.130	3.040	1.321			
40	0.044	4.842	1.325		0.156	
41	0.019	6.932	1.659		0.156	
42	0.019	6.932	2.533		0.821	
43	0.025	10.566	4.864		0.977	
44	0.034	10.856	5.154		2.384	1.930
45	0.043	10.289	7.966		5.139	3.860
46	0.053	10.163	7.805	0.268	7.933	5.801
47	0.053	10.163	8.517	0.671	8.617	7.731
48	0.058	6.126	7.848	0.653	11.176	9.981
49	0.069	4.967	7.326	1.755	11.196	10.311
50	0.071	3.852	7.369	2.631	9.340	5.471
51	0.072	2.295	5.968	3.711	8.382	7.571
52	0.069	2.025	5.143	6.038	8.538	12.081
53	0.070	1.253	4.271	7.488	8.226	14.011
54	0.085	0.779	3.849	7.892	5.725	11.111
55	0.082	0.502	2.967	10.405	3.165	4.350
56	0.083	0.502	2.286	11.560	2.052	
57	0.098	0.198	1.456	12.193	2.032	
58	0.122	0.183	0.884	11.904	1.250	1.930

59	0.136	0.098	0.580	7.623	1.055	3.860
60	0.156	0.057	0.360	4.607	0.762	
61	0.218	0.042	0.342	4.540	0.352	
62	0.282	0.042	0.090	2.397	0.254	
63	0.475		0.167	1.176	0.156	
64	0.777		0.145	0.916	0.156	
65	0.776		0.143	0.391		
66	1.196		0.185			
67	1.765		0.003	0.248		
68	2.267		0.146	0.234		
69	2.528		0.098			
70	2.760		0.098	0.234		
71	3.109					
72	3.356		0.122	0.234		
73	3.551		0.098	0.117		
74	3.551		0.073	0.117		
75	3.780		0.073			
76	3.991					
77	4.085		0.061			
78	4.200		0.037			
79	4.200		0.012			
80	4.132		0.012			
81	4.012					
82	3.858		0.012			
83	3.728					
84	3.556					
85	3.235					
86	2.903					
87	2.553					
88	2.553					
89	2.182					
90	1.823					
91	1.513					
92	1.348					
93	1.237					
94	0.996					
95	0.790					
96	0.585					
97	0.585					
98	0.484					
99	0.429					
100	0.381					
101	0.360					
102	0.327					
103	0.247					
104	0.202					
105	0.160					
106	0.160					
107	0.118					
108	0.093					
109	0.077					
110	0.065					
111	0.065					
112	0.058					
113	0.044					
114	0.034					

115	0.023
116	0.020
117	0.015
118	0.014
119	0.011
120	0.011
121	0.007

D1.1.3 Age frequency data (retained catches)

Where possible length frequency data have been converted to age frequency data by multiplying the length frequency by the age-length key (ALK) for the corresponding year (Tables D4-5). All samples were aged at the Central Ageing Facility (CAF) in Victoria.

Table D4. Age frequencies for retained catches of blue grenadier for the spawning trawl fleet.

Age	1984	1985	1988	1992	1993	1994	1995	1996	1997	1998	1999	2000
1												
2			3.11	0.04	0.03		0.58	0.13	0.09	0.14		
3	0.04	0.03	18.60	0.27	0.13	1.52	8.15	1.54	1.22	5.13	0.31	0.04
4	0.24	0.11	17.62	1.84	0.12	3.81	7.88	3.05	1.31	11.72	5.16	1.51
5	3.56	4.15	4.53	3.64	0.59	0.75	3.45	6.39	4.24	2.92	14.22	17.69
6	26.28	27.43	5.77	9.67	5.81	3.56	1.81	3.71	4.65	0.96	4.32	38.06
7	11.59	15.13	4.00	9.84	12.80	20.59	11.35	1.84	3.02	1.93	0.56	11.03
8	9.15	10.24	3.42	10.70	14.43	24.58	26.32	9.01	3.46	2.45	3.51	1.56
9	5.14	4.21	8.34	6.21	12.51	12.50	15.20	21.94	10.61	3.97	2.24	1.46
10	2.83	2.78	6.74	4.91	7.82	7.91	6.85	19.72	17.22	10.59	3.66	1.61
11	2.47	2.78	2.56	4.86	6.08	3.53	3.79	10.23	13.35	19.01	6.34	1.15
12	6.77	5.78	2.34	4.53	5.54	2.15	2.43	7.10	9.84	16.22	13.79	2.83
13	7.84	6.55	3.26	6.09	5.27	3.71	2.10	3.64	9.63	9.88	21.32	5.87
14	7.29	6.44	0.50	9.79	6.09	2.92	1.53	1.68	4.56	6.35	13.14	6.85
15	6.09	5.62	0.93	8.91	6.68	4.79	1.52	1.79	3.70	2.49	6.40	4.38
16	2.90	2.85	1.21	7.61	7.81	4.35	2.05	1.91	3.45	1.76	2.37	3.07
17	1.16	0.63	1.82	5.02	4.00	1.51	3.27	3.05	2.91	0.95	0.82	1.37
18	1.16	1.18		2.46	1.47	0.65	1.02	2.08	3.34	0.98	0.83	0.36
19	2.28	1.88	0.76	0.95	0.71	0.75	0.25	0.49	1.68	0.82	0.45	0.61
20	1.18	0.88		0.97	0.49	0.34		0.21	1.14	1.02	0.24	0.24

Table D5. Age frequencies for retained catches of blue grenadier for the non-spawning trawl fleet.

Age	1984	1985	1987	1988	1989	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	0.88	0.27	0.95	1.98	0.25		0.67	0.19	0.03	0.43	0.44	0.25	0.30	0.10
2	5.58	0.71	11.20	16.86	8.22	0.07	4.93	0.92	3.50	2.28	16.32	0.75	3.00	0.26
3	3.51	2.79	5.26	35.04	28.99	2.25	4.77	9.26	27.17	5.29	37.15	28.19	4.56	6.49
4	3.26	5.69	17.30	22.45	34.56	11.20	2.85	14.47	23.07	11.66	2.97	51.70	25.98	16.58
5	6.86	11.23	13.87	4.68	12.08	11.21	2.27	2.29	5.11	14.62	3.48	9.53	52.10	37.66
6	40.39	39.09	8.66	4.16	2.17	23.26	8.35	4.20	1.97	10.38	3.53	1.04	10.17	31.92
7	14.10	14.09	3.90	2.84	4.60	18.29	19.54	20.91	7.08	2.73	1.62	1.11	0.42	5.76
8	10.00	10.23	10.41	1.99	2.80	15.08	17.89	27.68	16.63	6.87	1.68	0.24	0.33	0.27
9	6.42	5.96	14.45	3.38	1.44	5.57	11.59	9.12	8.98	19.21	4.72	0.30	0.07	0.11
10	1.00	1.17	4.93	3.84	1.81	5.12	4.92	3.76	2.72	14.77	8.80	1.25	0.15	0.06

11	0.76	1.04	1.38	1.51	0.73	2.18	3.75	1.67	1.14	5.88	6.15	1.96	0.21	0.04
12	1.73	1.65	0.78	0.25	0.66	1.10	3.23	0.67	0.50	2.61	4.29	1.92	0.40	0.08
13	1.47	1.77	0.70	0.39		1.01	2.84	1.00	0.31	1.26	3.41	0.86	1.29	0.22
14	2.19	2.18	1.84	0.03	0.25	0.99	3.04	1.01	0.23	0.52	1.83	0.35	0.71	0.25
15	1.14	1.27	1.83	0.17	0.35	1.17	3.04	1.11	0.16	0.42	1.07	0.16	0.21	0.13
16	0.57	0.69	1.43	0.24	0.16	0.48	3.31	1.00	0.28	0.29	1.05	0.27	0.06	0.07
17	0.01	0.03	0.31	0.15	0.17	0.58	1.57	0.35	0.45	0.38	0.43	0.04	0.01	0.02
18	0.06	0.01	0.27		0.28	0.15	0.47	0.16	0.12	0.23	0.52	0.02	0.01	0.00
19	0.06	0.05	0.17	0.04		0.16	0.23	0.11	0.03	0.07	0.29	0.02	0.01	0.01
20	0.01	0.02	0.20		0.20	0.04	0.17	0.07		0.06	0.13	0.03	0.00	0.00

D1.1.4 Age frequency data (discarded catches)

The discards-at-age for the non-spawning fishery are shown in Table D6. All samples were aged at the Central Ageing Facility (CAF) in Victoria.

Table D6. Age frequencies for discarded catches of blue grenadier for the spawning trawl fleet.

Age	1995	1996	1997	1998	1999	2000
1	0.94	36.89	4.66		7.22	5.79
2	2.26	62.40	52.67	0.62	58.26	10.82
3	17.14	0.61	40.12	30.95	9.33	28.03
4	14.13	0.04	1.72	57.70	6.66	47.27
5	4.17		0.11	10.36	17.85	8.08
6	1.84		0.06	0.38	0.68	
7	8.91		0.03		0.00	
8	20.32		0.01			
9	11.38		0.03			
10	4.33		0.06			
11	2.11		0.06			
12	1.17		0.19			
13	0.98		0.02			
14	0.67		0.02			
15	0.62		0.00			
16	0.87		0.00			
17	1.47					
18	0.40		0.00			
19	0.11					
20						

D1.2 Pink Ling

D1.2.1 Length frequency data (retained catch)

The stock assessment model for pink ling distinguishes between four fleets: east trawl (zones 10-30), west trawl (zones 40-60), non-trawl (all non-trawl gears lumped) and research (two research cruises conducted using the vessel *Kapala*). Length frequency for these fleets was collected by the SMP and the ISMP (trawl and non-trawl fleets from 1992 onwards, Ian Knuckey *unpublished data*), and by NSW fisheries (the *Kapala* data, Andrew *et al*, 1997). Where age-length keys (ALKs) exist these data have been converted to age data and included in the model in that form. Tables D7-10 show all available length frequency data, including those that were not used in the model directly but were converted to age frequencies instead. The length frequencies have been normalized and are presented as percentages.

Table D.7. Length frequencies for retained commercial catches of pink ling for the trawl fleet in the east (zones 10-30) from the SMP and ISMP (Knuckey, unpublished data).

Length (cm)	1992	1995	1996	1997	1998	1999
30						
31						
32			0.010			
33			0.003			
34				0.003		
35			0.019			0.015
36			0.024	0.003		0.033
37			0.019	0.003		
38			0.045	0.009	0.098	0.044
39			0.010	0.012	0.158	0.262
40			0.092	0.098	0.218	0.164
41			0.112	0.127	0.654	0.642
42			0.157	0.070	1.167	0.500
43			0.256	0.245	1.195	1.523
44			0.552	0.396	1.541	1.302
45			0.482	1.032	2.356	1.685
46		2.101	1.005	1.247	2.677	2.741
47		0.151	0.995	1.664	2.598	3.463
48		2.855	2.260	3.028	3.299	3.533
49		1.401	2.095	3.752	3.184	3.676
50		6.304	3.612	5.024	3.334	5.322
51		4.504	3.604	5.757	3.302	4.159
52		1.552	3.897	6.572	2.780	5.823
53	3.704	4.105	4.950	6.622	4.244	5.960
54	3.704	3.103	5.375	6.271	4.572	5.079
55	3.704	1.702	5.301	7.450	5.172	4.107
56	1.852	2.855	5.045	5.661	5.256	4.040
57	1.852	6.206	4.746	4.782	4.052	4.298
58		2.952	4.931	3.998	5.149	3.693
59	9.259	4.105	5.829	3.800	4.568	2.852
60	5.556	2.553	4.413	3.779	3.584	3.048
61	7.407	2.987	4.439	2.230	2.591	2.461
62	3.704	8.040	2.966	1.917	3.366	1.980
63	3.704	5.383	3.394	1.638	1.885	3.465
64	1.852	6.036	2.850	1.750	2.311	2.061
65	5.556	5.386	2.877	2.471	2.463	1.142
66		1.723	1.965	1.257	1.507	1.176
67	1.852	2.358	2.616	1.664	1.656	0.861
68	5.556	3.159	1.678	2.031	1.314	1.188
69	1.852	4.549	1.959	0.993	1.322	1.526
70	7.407	2.104	1.388	0.978	0.716	0.900
71		0.531	1.461	1.355	1.371	1.039
72		2.906	1.489	1.286	0.693	0.713
73	3.704	0.365	1.201	0.986	1.011	0.886

74		1.108	0.996	0.952	1.423	1.179
75	1.852	0.394	0.956	0.742	0.711	1.279
76		0.926	0.710	0.607	0.475	0.499
77	3.704	0.394	0.548	0.494	0.954	0.647
78	3.704	0.531	0.908	0.615	0.930	0.884
79		0.394	0.390	0.433	0.743	0.910
80	1.852	0.046	0.473	0.317	0.693	0.835
81	1.852	0.394	0.335	0.592	1.132	0.285
82	1.852	0.183	0.396	0.265	1.149	0.322
83		0.880	0.256	0.429	1.067	0.635
84	1.852	0.834	0.518	0.102	0.566	0.143
85	1.852		0.351	0.098	0.381	0.439
86	1.852		0.244	0.191	0.551	0.386
87		0.531	0.428	0.221	0.162	0.384
88	1.852	0.046	0.383	0.161	0.265	0.290
89	1.852		0.107	0.245	0.185	0.524
90	1.852	0.591	0.119	0.171	0.159	0.112
91			0.159	0.224		0.248
92		0.394	0.221	0.125	0.130	0.272
93			0.131	0.039		0.112
94		0.046	0.192	0.119		0.252
95			0.064	0.141	0.171	0.112
96			0.119	0.176	0.063	0.163
97			0.116	0.005	0.067	0.112
98		0.046	0.089	0.099		
99		0.151	0.058	0.021	0.099	0.224
100			0.036	0.091		0.146
101		0.046	0.086	0.026	0.108	0.136
102			0.091	0.025		0.282
103	1.852	0.046	0.048	0.055	0.229	0.136
104			0.041	0.075		0.112
105			0.071	0.054		0.136
106			0.037	0.005		0.224
107				0.032		0.112
108					0.063	
109			0.014		0.099	
110			0.024	0.034		
111		0.046	0.015			
112			0.014			
113			0.017	0.016		
114						0.051
115						
116				0.016		
117			0.071	0.010		0.051
118					0.063	
119						
120			0.025			
121						
122						
123						
124						
125						
126						
127						

128						
129			0.021			
130				0.014		
131						
132				0.005		
133						

Table D.8. Length frequencies for retained commercial catches of pink ling for the trawl fleet in the west (zones 40-60) from the SMP and ISMP (Knuckey, *unpublished data*).

Length (cm)	1992	1995	1996	1997	1998	1999
30						
31						
32			0.010			
33			0.003			
34				0.003		
35			0.019			0.015
36			0.024	0.003		0.033
37			0.019	0.003		
38			0.045	0.009	0.098	0.044
39			0.010	0.012	0.158	0.262
40			0.092	0.098	0.218	0.164
41			0.112	0.127	0.654	0.642
42			0.157	0.070	1.167	0.500
43			0.256	0.245	1.195	1.523
44			0.552	0.396	1.542	1.302
45			0.482	1.032	2.356	1.685
46		2.101	1.005	1.247	2.677	2.741
47		0.151	0.996	1.664	2.598	3.463
48		2.855	2.260	3.028	3.299	3.533
49		1.401	2.095	3.752	3.184	3.676
50		6.304	3.612	5.024	3.334	5.322
51		4.504	3.604	5.757	3.302	4.159
52		1.552	3.897	6.572	2.781	5.823
53	3.704	4.105	4.950	6.622	4.244	5.960
54	3.704	3.103	5.375	6.271	4.572	5.079
55	3.704	1.702	5.301	7.450	5.172	4.107
56	1.852	2.855	5.045	5.662	5.256	4.040
57	1.852	6.206	4.747	4.782	4.052	4.298
58		2.952	4.931	3.998	5.150	3.693
59	9.259	4.105	5.829	3.800	4.568	2.852
60	5.556	2.553	4.413	3.779	3.584	3.049
61	7.407	2.987	4.439	2.230	2.591	2.461
62	3.704	8.040	2.966	1.917	3.366	1.980
63	3.704	5.383	3.394	1.638	1.885	3.465
64	1.852	6.036	2.850	1.750	2.311	2.061
65	5.556	5.386	2.877	2.471	2.463	1.142
66		1.723	1.965	1.257	1.507	1.176
67	1.852	2.358	2.616	1.664	1.656	0.861
68	5.556	3.159	1.678	2.031	1.314	1.188
69	1.852	4.549	1.959	0.993	1.322	1.526
70	7.407	2.104	1.388	0.978	0.716	0.900
71		0.531	1.461	1.355	1.371	1.039

72		2.906	1.489	1.286	0.693	0.713
73	3.704	0.365	1.201	0.986	1.011	0.886
74		1.108	0.996	0.952	1.423	1.179
75	1.852	0.394	0.956	0.743	0.711	1.279
76		0.926	0.710	0.607	0.475	0.499
77	3.704	0.394	0.549	0.494	0.954	0.647
78	3.704	0.531	0.908	0.615	0.930	0.884
79		0.394	0.390	0.433	0.743	0.910
80	1.852	0.046	0.473	0.317	0.693	0.835
81	1.852	0.394	0.335	0.592	1.132	0.285
82	1.852	0.183	0.396	0.265	1.149	0.322
83		0.880	0.256	0.429	1.067	0.635
84	1.852	0.834	0.518	0.103	0.566	0.144
85	1.852		0.351	0.098	0.381	0.439
86	1.852		0.244	0.191	0.551	0.386
87		0.531	0.428	0.221	0.162	0.384
88	1.852	0.046	0.383	0.161	0.265	0.290
89	1.852		0.107	0.245	0.185	0.524
90	1.852	0.591	0.119	0.171	0.159	0.112
91			0.159	0.224		0.248
92		0.394	0.222	0.125	0.130	0.272
93			0.131	0.039		0.112
94		0.046	0.192	0.119		0.252
95			0.064	0.141	0.171	0.112
96			0.119	0.176	0.063	0.163
97			0.116	0.005	0.067	0.112
98		0.046	0.089	0.099		
99		0.151	0.058	0.021	0.099	0.225
100			0.036	0.091		0.146
101		0.046	0.086	0.026	0.108	0.136
102			0.091	0.025		0.282
103	1.852	0.046	0.048	0.055	0.229	0.136
104			0.041	0.075		0.112
105			0.071	0.054		0.136
106			0.037	0.005		0.225
107				0.032		0.112
108					0.063	
109			0.014		0.099	
110			0.024	0.034		
111		0.046	0.015			
112			0.014			
113			0.017	0.016		
114						0.051
115						
116				0.016		
117			0.071	0.010		0.051
118					0.063	
119						
120			0.025			
121						
122						
123						
124						
125						

126						
127						
128						
129			0.021			
130				0.014		
131						
132				0.005		
133						

Table D.9. Length frequencies pink ling for retained commercial catches of the non-trawl fleet (net, trawl and line gears combined) from the SMP and ISMP (Knuckey, *unpublished data*).

Length (cm)	1995	1996	1997	1998
50				
51		0.464		
52				0.398
53				0.398
54		0.232		1.195
55		0.232		1.992
56		0.928		1.195
57		0.232		1.992
58				3.187
59		0.232		3.586
60		0.696	0.655	3.586
61		0.464		1.195
62		0.232		2.789
63		0.928	0.655	1.992
64		0.464		2.789
65		0.928		3.984
66	2.305	0.464	0.655	4.382
67		0.696		4.781
68		1.624	1.964	3.187
69		1.856		2.390
70		3.260	1.983	3.586
71	0.758	1.856	1.964	1.195
72	4.611	10.599	3.274	1.992
73	3.327	5.321	3.292	4.781
74	4.085	4.354	3.274	2.789
75		4.945	1.328	2.390
76	1.780	4.605	3.274	2.390
77	1.517	3.934	3.274	1.195
78	8.696	2.184	0.655	1.195
79	4.611	4.801	3.947	2.390
80	7.674	9.504	2.037	1.195
81	2.044	4.110	3.274	1.195
82	3.560	3.352	5.238	1.992
83	2.275	1.567	5.948	1.594
84	6.362	0.928	3.947	
85	1.517	1.405	3.347	1.195
86	3.033	1.947	3.310	2.789
87	5.866	2.792	4.602	2.390
88	9.455	4.166	3.274	2.789
89	4.844	0.477	2.674	1.992

90	2.275	2.508	3.947	0.398
91	1.780	1.637	0.673	1.195
92	1.022	1.493	1.964	1.195
93	3.822	0.477	3.929	0.797
94	4.085	0.232	3.929	1.594
95	0.758	0.871	0.673	0.398
96	1.022		0.655	0.398
97	2.305	1.135	0.655	0.797
98		1.160	0.655	
99		0.232		
100		0.232	1.964	0.398
101	2.305	0.232	0.655	
102		0.232	2.619	0.797
103		0.464	0.655	
104			1.310	0.398
105		0.464	0.018	0.398
106		0.232	0.655	0.797
107			1.310	0.398
108		0.696		0.797
109			1.964	
110		0.232		0.398
111			1.310	0.797
112	2.305			0.797
113		0.232	1.310	
114		0.232		0.398
115			0.655	
116				
117				
118		0.232	0.655	
119				
120				
121				
122				
123				
124				
125				
126				
127				
128				0.398
129				
130				0.398
131				
132				
133				

Table D.10. Length frequencies for catches of pink ling for the research fleet (two *Kapala* research cruises and other NSW data) from the NSW fisheries (Andrew *et al*, 1997).

Length (cm)	1977	1979	1997
25	0.108		
26			
27			
28			
29			
30	0.108		

31			0.038
32			0.038
33	0.054		
34			
35		0.039	
36	0.162		0.075
37	0.108		
38	0.108	0.117	0.113
39		0.039	0.038
40	0.108	0.234	0.113
41	0.216	0.117	0.414
42		0.234	0.452
43	0.216	0.234	0.904
44	0.108	0.312	0.753
45	0.216	0.896	1.394
46	0.540	0.779	1.318
47	0.432	0.818	1.657
48	0.432	1.090	2.109
49	0.594	1.402	3.239
50	0.863	1.947	4.143
51	0.809	2.570	3.503
52	1.187	2.765	4.369
53	1.511	2.765	4.105
54	1.997	2.882	5.273
55	1.349	4.089	6.026
56	2.428	3.583	5.574
57	1.835	4.089	5.461
58	1.781	3.076	4.934
59	1.997	3.271	4.520
60	2.267	2.687	4.407
61	2.644	2.843	3.540
62	2.321	1.908	4.143
63	1.997	2.336	2.486
64	2.428	1.986	2.712
65	0.863	1.480	2.486
66	2.536	2.336	2.185
67	2.428	1.480	1.657
68	2.213	1.791	1.846
69	1.835	1.558	1.770
70	2.321	1.519	1.507
71	1.727	0.857	1.055
72	1.673	1.713	1.281
73	2.159	1.713	0.904
74	1.835	1.012	0.678
75	2.051	1.480	0.753
76	1.565	1.558	0.490
77	1.673	1.051	0.452
78	1.781	1.402	0.527
79	1.403	1.402	0.264
80	0.971	1.012	0.678
81	1.403	1.168	0.188
82	1.241	1.597	0.113
83	1.187	1.129	0.339
84	1.025	1.012	0.226
85	1.133	0.896	0.151
86	1.133	1.207	0.226

87	0.971	1.324	0.151
88	1.349	1.012	0.113
89	0.756	0.779	0.113
90	1.349	0.818	0.151
91	1.835	0.818	0.075
92	1.457	0.974	0.038
93	1.673	1.285	0.075
94	1.349	0.701	0.264
95	1.079	1.012	0.226
96	1.673	1.207	0.075
97	1.133	1.168	0.075
98	1.349	0.896	0.075
99	0.809	0.428	0.038
100	1.511	0.896	0.188
101	1.349	0.779	0.038
102	1.079	0.584	0.038
103	0.809	0.584	0.075
104	0.756	0.779	0.113
105	0.809	0.312	0.038
106	0.756	0.623	0.038
107	0.648	0.312	
108	1.025	0.312	
109	0.648	0.389	0.038
110	0.756	0.312	0.113
111	0.863	0.312	0.038
112	0.809	0.234	
113	0.594	0.234	0.038
114	0.486	0.312	
115	0.378	0.234	
116	0.594	0.117	
117	0.162	0.117	
118	0.432	0.195	0.038
119	0.270	0.117	0.038
120	0.270	0.117	0.075
121		0.039	
122	0.216	0.039	
123	0.216	0.117	
124	0.054	0.039	
125	0.108		
126	0.216		
127			
128	0.054		
129	0.054		
130	0.054		
131	0.054		
132	0.108		
133			

D1.2.2 Length frequency data (discarded catch)

Only the east and west trawl fleets are considered to discard catches (Tables D11-12), the non-trawl and *Kapala* research fleets retain the entire catch.

Table D.11. Length frequencies for discarded commercial catches of pink ling for the trawl fleet in the east (zones 10-30) from the SMP and ISMP (Knuckey, unpublished data).

Length (cm)	1994	1995	1996	1997	1998
16					
17				1.766	
18					
19					
20					
21	0.601				
22				0.119	
23					
24					
25	0.203				
26	1.972		2.052		3.080
27	0.406				
28	0.406		1.383		0.448
29	2.086		8.305	1.571	
30	1.096	10.538	3.017	0.059	
31	26.597				1.791
32	0.203		5.242	3.215	
33	3.760	10.538	1.148	0.311	
34	0.605		0.618	1.075	0.895
35	0.305		4.627	5.073	1.343
36	0.406	6.090		6.763	4.707
37	1.156	3.831	1.204	5.140	2.238
38	2.441	1.014	1.890	5.779	4.423
39	0.684	1.418	7.616	4.713	3.418
40	3.518	0.345	3.547	5.436	2.970
41	0.406	14.600		8.713	6.160
42	4.099	1.035	5.714	6.984	1.911
43	3.619	10.913	0.712	1.652	
44	0.164	3.105	3.746	2.040	0.448
45	0.066	1.035	0.557	0.364	
46	0.332	1.380	0.973	5.298	0.732
47	0.094	2.070	2.388	2.730	2.091
48	0.457	2.070	4.705	1.184	2.927
49	0.771	3.105	2.294	4.126	5.018
50	1.328	2.415	2.075	2.440	7.108
51	3.286	2.415	2.604	2.691	5.122
52	1.107	0.690	1.240	3.737	7.735
53	1.728	1.380	2.860	3.831	7.213
54	2.118	0.690	1.854	6.251	12.126
55	2.236	0.690	2.160	2.037	4.390
56	1.134	1.035	2.221	2.673	4.390
57	1.235		2.445	0.465	2.927
58	1.261	1.380	1.650	0.465	2.927
59	1.472	1.035	2.588	0.573	
60	1.836	1.035	2.934	0.217	1.464
61	1.405	1.380	2.303	0.093	
62	1.833	1.035	0.938	0.372	
63	1.797	0.345	1.854	0.047	
64	2.170	1.035	0.938		
65	1.366	1.725	0.570		

66	1.812	0.690	0.713
67	1.041	1.035	0.592
68	0.744	1.035	0.285
69	0.918	1.035	0.570
70	1.169		0.795
71	0.806	0.690	0.652
72	1.350		0.428
73	0.807	0.690	0.856
74	0.474		0.428
75	0.543		
76	0.482	0.690	
77	0.781		0.285
78	0.552	0.690	0.285
79	0.343	0.690	0.143
80	0.514	0.345	
81	0.301	0.345	
82	0.504		
83	0.269		0.143
84	0.199	0.345	0.143
85	0.210		
86	0.165		
87	0.230		
88	0.234	0.345	
89	0.129		0.143
90	0.164		0.143
91	0.169		0.143
92	0.170		
93	0.066		
94	0.066		
95	0.066		0.143
96	0.097		
97	0.015		
98			
99	0.108		
100	0.066		
101	0.071		
102	0.133		
103	0.066		
104			
105	0.066		
106	0.066		
107	0.066		
108			
109			0.143
110	0.066		
111			
112	0.005		
113			
114	0.066		
115	0.066		
116			
117			
118			
119			

Table D.12. Length frequencies for retained commercial catches of pink ling for the trawl fleet in the west (zones 40-60) from the SMP and ISMP (Knuckey, *unpublished data*).

length (cm)	1992	1993	1994	1995	1996	1997	1998	1999
20								
21								
22			0.006					
23			0.006					
24								
25								
26			0.006					
27								
28			0.001					
29			0.012					
30			0.006					
31			0.012	0.001				
32			0.016					
33			0.006	0.000				
34			0.017					0.016
35			0.006					
36			0.007		0.000			
37			0.015	0.001				0.016
38			0.012	0.001				
39			0.011	0.001	0.000			
40			0.023	0.007				0.016
41		0.018	0.008	0.013	0.000			0.016
42		0.018	0.019	0.003				0.016
43			0.023	0.007	0.060	0.004		
44		0.054	0.081	0.040	0.030		0.130	
45		0.072	0.079	0.039	0.030	0.004		
46		0.018	0.298	0.140	0.132	0.020		
47		0.215	0.842	0.220	0.251		2.385	
48		0.036	0.753	0.567	0.544	0.004		0.032
49		0.179	1.184	0.892	0.726	0.378		
50		0.097	1.771	1.146	0.929	0.892	2.515	7.492
51		0.018	2.148	1.550	1.276	1.271	4.640	9.989
52		0.161	2.539	1.776	1.839	2.522	9.150	7.492
53			2.458	2.383	2.714	5.021	4.510	7.492
54		0.322	2.801	2.354	2.719	5.774	2.255	9.989
55		0.484	2.589	2.837	3.758	6.261	9.020	7.492
56		0.484	3.697	3.209	3.439	7.479	15.785	4.995
57	0.709	0.319	3.079	3.009	4.296	7.605	2.255	4.995
58		1.116	3.409	3.486	4.032	5.603	15.785	4.995
59		0.161	3.204	3.596	4.078	6.967	4.510	4.995
60		0.724	4.065	3.614	4.004	7.222	6.765	2.497
61	0.709	0.645	3.959	3.440	3.834	5.971	9.020	2.497
62	0.709	0.322	3.320	3.061	3.966	7.229	4.510	
63		1.116	2.680	3.429	4.243	6.225	2.255	
64	1.418	0.484	2.490	3.040	4.745	3.981		
65	0.709	1.368	2.731	2.945	4.219	4.988	2.255	
66		1.121	2.819	3.456	3.668	5.105	2.255	4.995
67		0.484	2.791	3.159	3.388	5.234		
68	2.837	1.530	2.382	3.439	3.258	2.742		

69	2.837	1.675	2.768	3.286	3.534	0.999	
70	2.837	1.848	2.686	2.874	3.002	0.499	2.497
71	2.837	1.757	3.057	3.014	2.545		
72	2.128	2.880	2.050	2.345	2.132		
73	2.837	2.021	3.364	2.259	1.765		
74	4.965	4.413	2.974	2.491	1.849		
75	2.128	3.128	2.235	2.060	1.585		
76	3.546	3.368	1.917	1.912	1.232		
77	2.837	5.047	2.362	1.758	1.248		
78	1.418	6.750	1.612	1.793	1.136		
79	4.965	3.442	1.016	1.419	0.667		
80	2.837	3.366	0.786	1.845	0.891		
81	2.837	3.859	0.707	1.714	1.222		2.497
82	2.837	4.645	0.871	1.379	0.936		
83	7.092	5.069	0.959	0.860	1.061		
84	4.255	2.888	0.624	1.031	0.585		
85	5.674	2.491	0.779	0.791	1.150		
86	4.255	2.398	0.680	1.112	0.776		2.497
87	3.546	2.168	1.333	0.775	0.345		
88	4.255	1.770	0.827	0.713	0.550		
89	3.546	1.441	0.317	0.457	0.326		
90	2.128	3.047	0.534	0.628	0.126		
91	0.709	1.848	0.357	0.552	0.598		
92	2.128	1.608	0.415	0.383	0.360		2.497
93	3.546	0.562	0.471	0.686	0.439		4.995
94		0.964	1.456	0.483	0.239		
95	1.418	0.964	0.317	0.281	0.098		
96	1.418	0.799	1.031	0.468	0.186		
97	0.709	1.691	0.069	0.450	0.439		
98	0.709	1.286	0.580	0.285	0.258		2.497
99	0.709	1.046	0.610	0.423	0.296		
100	0.709	0.484	0.515	0.280	0.113		2.497
101	0.709	1.122		0.173	0.126		
102	0.709	1.204	0.248	0.265	0.135		
103		0.161	0.332	0.299	0.234		
104	2.128	0.645	0.210	0.265	0.281		
105		0.802	0.109	0.251	0.126		
106		0.401		0.163	0.106		
107		0.322	0.029	0.154	0.154		
108		0.158	0.069	0.097	0.053		
109		0.724		0.077	0.053		
110		0.161	0.069	0.161	0.271		
111			0.069	0.057	0.106		
112			0.069	0.087	0.106		
113		0.240		0.130			
114		0.484	0.069	0.060	0.053		
115					0.053		
116		0.161		0.033	0.053		
117		0.322					
118					0.126		
119		0.161	0.069	0.024	0.053		
120		0.161					
121		0.161					
122		0.161		0.040			

123						
124		0.161				
125						
126					0.047	
127						
128						
129	0.709					
130						

D1.2.3 Age frequency data (retained catch)

Where possible, length frequency data have been converted to age frequency data by multiplying the length frequency by an age-length key (ALK). When this has been done the age frequency is included in the assessment model and the corresponding length frequency excluded. The available age frequency data for the four pink ling fleets are shown in Tables D13-16. The data have been normalized and are shown as percentages. All ALK data were collected by the SMP and ISMP (Ian Knuckey, *unpublished data*) except for the 1979 sample which was collected by NSW fisheries (Andrew *et al*, 1997). All samples were aged at the Central Ageing Facility (CAF) in Victoria.

Table D.13. Age frequencies for retained commercial catches of pink ling for the trawl fleet in the east (zones 10-30).

Age	1994	1995	1996	1997	1998	1999
1	2.063	2.252	6.186	10.237	12.624	25.852
2	32.163	21.894	42.150	64.389	32.077	39.198
3	42.295	24.917	30.860	13.781	28.921	22.830
4	14.397	28.769	13.242	6.803	16.653	2.104
5	3.249	13.289	3.860	1.999	3.478	1.455
6	2.835	3.374	1.497	0.923	1.858	2.223
7	1.007	2.404	0.468	0.321	0.594	0.850
8	0.062	0.388	0.631	0.460	1.779	2.517
9	0.108	1.120	0.127	0.034	0.713	0.502
10	1.171	0.382	0.126	0.318	0.159	0.614
11		0.491	0.170		0.315	0.205
12		0.238	0.045	0.051		0.046
13			0.088		0.171	0.263
14	0.202			0.176		0.249
15			0.015			0.046
16		0.197	0.020	0.099		
17			0.027			
18		0.151		0.021	0.099	0.092
19	0.062					0.076
20						

Table D.14. Age frequencies for retained commercial catches of pink ling for the trawl fleet in the west (zones 40-60).

Age	1995	1996	1997	1998	1999
1		0.127	1.288	0.146	0.358
2	2.965	13.017	8.227	5.324	6.685
3	14.686	30.062	26.646	30.264	16.410
4	36.860	19.882	27.226	24.800	25.486
5	25.096	14.330	15.689	13.889	18.305

6	8.025	2.933	5.134	6.061	14.390
7	2.077	2.495	5.431	4.618	8.684
8	2.727	2.431	1.542	2.786	3.300
9	0.393	2.613	2.417	0.700	0.329
10	1.192	2.471	0.111	2.348	2.005
11	1.961	1.449	1.044	1.666	0.945
12	0.831	1.034	1.094		0.648
13	0.889	0.999	0.613	1.164	0.055
14		0.970	0.890	0.698	0.294
15		0.597	0.162	1.045	
16	0.268	0.246	1.029	0.340	0.292
17			0.054		0.244
18		0.494		0.556	0.090
19	0.472	0.711		0.352	0.212
20					0.171

Table D.15. Age frequencies for commercial catches of pink ling for the non-trawl fleet (net, trawl and line gears combined).

Age	1995	1996	1997	1998	1999
1		0.141		0.389	
2		3.345	1.038	9.577	0.325
3	1.108	13.166	9.463	27.201	8.489
4	8.420	30.855	23.971	26.751	11.196
5	10.198	25.832	17.079	12.329	20.495
6	15.039	12.161	8.483	6.685	18.376
7	11.379	4.022	7.066	3.628	16.656
8	8.550	4.287	3.928	2.219	7.307
9	8.809	0.510	5.702	0.598	0.595
10	6.848	0.239	1.326	1.461	7.358
11	7.395	1.400	6.348	1.992	1.168
12	9.179	0.387	4.533		
13	6.074	1.103	0.655		
14			1.202		1.786
15			1.310	0.398	
16	1.329	0.387	1.200		
17		0.077	0.655		
18					
19	1.060			0.398	
20					2.679

Table D.16. Age frequencies for catches of pink in NSW (Andrew *et al*, 1997).

Age	1979
1	0.35
2	2.72
3	27.92
4	23.96
5	14.03
6	9.95
7	6.8
8	2.76
9	1.87
10	2.25
11	1.44

12	0.65
13	0.5
14	0.44
15	0.27
16	0.79
17	0.83
18	0.04
19	0.02
20	0.16
21	0.02
22	
23	
24	
25	
26	
27	
28	2.22

D1.2.4 Age frequency data (discarded catch)

The age frequencies for the discards for the east and west trawl fleets are shown in Tables D17-18.

Table D.17. Age frequencies for discarded commercial catches of pink ling for the trawl fleet in the east (zones 10-30).

Age	1994	1995	1996	1997	1998
1	25.77	36.92	30.58	53.85	20.30
2	38.28	8.87	29.33	40.39	45.38
3	13.97	6.54	13.10	0.83	18.02
4	9.85	9.98	4.75	0.04	3.94
5	4.61	2.87	0.86		0.10
6	2.36	1.17	0.30		
7	1.68	1.15	0.10		
8	0.68	0.26	0.06		
9	0.63	0.62	0.05		
10	0.29	0.12			
11	0.34	0.17	0.05		
12	0.07	0.35			
13	0.13		0.14		
14	0.10				
15					
16					
17					
18	0.11				
19	0.07				
20					

Table D.18. Age frequencies for discarded commercial catches of pink ling for the trawl fleet in the west (zones 40-60).

Age	1995	1996	1997	1998	1999
1		0.13	1.29	0.15	0.36
2	2.96	13.02	8.23	5.32	6.69

3	14.69	30.06	26.65	30.26	16.41
4	36.86	19.88	27.23	24.80	25.49
5	25.10	14.33	15.69	13.89	18.30
6	8.02	2.93	5.13	6.06	14.39
7	2.08	2.49	5.43	4.62	8.68
8	2.73	2.43	1.54	2.79	3.30
9	0.39	2.61	2.42	0.70	0.33
10	1.19	2.47	0.11	2.35	2.01
11	1.96	1.45	1.04	1.67	0.94
12	0.83	1.03	1.09		0.65
13	0.89	1.00	0.61	1.16	0.06
14		0.97	0.89	0.70	0.29
15		0.60	0.16	1.05	
16	0.27	0.25	1.03	0.34	0.29
17			0.05		0.24
18		0.49		0.56	0.09
19	0.47	0.71		0.35	0.21
20					0.17

D1.3 Spotted warehou

D1.3.1 Length frequency data

The stock assessment model for spotted warehou distinguishes between two fleets: trawl and non-trawl. Both port-measured and onboard-measured data are used in the model and the onboard data is divided into four depth classes. Length frequency for these fleets was collected by the SMP and the ISMP (trawl and non-trawl fleets from 1992 onwards, Ian Knuckey *unpublished data*), and by a research project conducted during 1987-89 (Smith *et al*, 1995). Where age-length keys (ALKs) exist these data have been converted to age data and included in the model in that form. Tables D19-21 show all available length frequency data, including those that were not used in the model directly but were converted to age frequencies instead. The length frequencies have been normalized and are presented as percentages. There are no onboard measured data for the non-trawl fleet.

Table D19. Length frequencies for catches of spotted warehou for the trawl fleet from port-based measures.

Length (cm)	1987	1988	1989	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
10													
11													
12													
13													
14									0.15				
15													
16													
17													
18													
19										0.89			
20													
21													0.00

22													0.00
23													0.01
24									0.02				0.08
25									0.05	0.02			0.15
26						0.01		0.01	0.00	0.04	0.04	0.00	0.29
27						0.01	0.07	0.32	0.05		0.05	0.01	0.21
28					0.06	0.09	0.29	0.88	0.00		0.11	0.01	0.33
29					0.08	0.14	0.29	2.28	0.52		0.25	0.10	0.33
30					0.46	0.37	0.66	4.43	1.20	0.05	0.81	0.15	0.34
31		0.02			0.68	0.70	1.88	4.84	2.53	0.29	0.93	0.52	0.43
32					0.65	0.67	3.28	3.32	4.43	0.26	0.70	1.34	0.46
33					1.00	1.33	3.54	2.97	6.26	1.05	0.61	2.18	0.80
34	0.05				1.33	1.39	3.06	2.16	8.41	2.00	0.96	1.37	1.04
35				2.06	1.44	1.41	2.69	1.88	8.69	4.78	1.29	0.91	1.89
36		0.65	0.91		1.87	1.57	1.88	2.09	6.03	6.14	1.73	1.38	0.90
37	0.42		0.91	3.09	1.95	2.07	1.19	2.95	5.00	7.52	2.07	0.78	1.45
38	0.02	0.14	6.36		1.49	1.87	0.32	4.68	1.55	7.54	1.87	1.15	1.40
39	0.32	0.02	10.00	3.09	1.30	3.34	0.86	3.97	1.74	6.08	2.14	1.39	1.41
40	0.12	2.28	5.45	11.34	1.93	3.85	2.74	4.75	1.65	3.95	3.91	1.81	1.09
41	0.22	1.25	5.45	36.08	2.15	5.00	1.14	6.65	4.11	5.54	5.15	2.15	2.60
42	0.20	2.02	4.55	15.46	2.05	4.97	1.62	8.14	3.64	5.74	9.07	3.36	4.43
43	1.07	4.85	4.55	15.46	2.64	5.73	3.12	8.16	2.75	5.25	12.41	7.73	7.79
44	4.41	7.39	6.36	10.31	2.78	4.99	3.98	7.84	2.72	5.17	10.92	12.33	11.51
45	5.98	16.58	8.18		6.08	5.37	6.73	7.30	3.96	5.04	11.20	12.19	14.48
46	10.14	23.23	10.00	1.03	7.14	4.96	6.69	4.48	5.77	6.73	8.40	11.10	13.18
47	11.46	16.29	8.18		10.50	5.93	6.97	3.57	7.51	7.14	6.58	9.12	9.78
48	11.38	8.52	8.18		8.87	7.05	12.12	3.17	6.12	5.97	5.84	9.01	7.17
49	12.62	8.16	6.36	1.03	10.71	6.71	9.32	3.02	5.02	4.49	4.50	6.24	5.47
50	11.93	3.43	5.45		12.86	7.69	8.23	3.78	4.25	3.30	4.53	5.21	3.46
51	8.41	2.33	5.45		8.07	6.93	8.23	1.46	3.27	1.45	2.15	3.24	2.80
52	8.09	0.94	1.82	1.03	5.99	5.40	3.40	0.47	1.16	1.28	0.75	2.66	1.85
53	4.74	1.34	0.91		3.18	4.18	2.89	0.35	0.58	1.35	0.54	0.99	1.46
54	3.52	0.38	0.91		1.55	2.53	1.17	0.02	0.34	0.56	0.32	0.82	0.74
55	2.50				0.93	1.40	0.63	0.06	0.20	0.24	0.13	0.38	0.22
56	1.71	0.17			0.23	0.67	0.22	0.00	0.21	0.02		0.10	0.09
57	0.45				0.04	0.43	0.22				0.04	0.03	0.05
58	0.22					0.35			0.11	0.05		0.20	0.06
59						0.38						0.01	0.09
60						0.22						0.01	0.04
61						0.07				0.07		0.01	0.06
62						0.15						0.01	0.02
63						0.07							0.01
64													0.00
65							0.11						0.01
66							0.22						
67													
68							0.11						
69													
70													
71													
72													
73													
74													
75													
76													
77							0.11						

Table D20. Length frequencies for catches of spotted warehou for the non-trawl fleet from port-based measures.

Length (cm)	1992	1993	1995	1996	1997	1998	1999	2000
30								
31								
32					0.58			
33		0.18			1.74			
34					5.23			
35					4.27			
36					6.08			
37					12.89			
38	0.25				10.81		0.25	
39		1.54			0.50	0.98		
40		2.70			0.56	0.98	1.11	
41	0.49	3.30			6.01	0.98	0.88	
42	0.25	5.75			1.55	0.99	1.44	
43	0.99	4.58				0.50	3.20	
44	3.33	10.16	1.95	0.93	1.21	0.99	1.70	
45	3.82	5.68	4.97	20.90	3.01	0.99	4.40	5.36
46	5.42	5.88	11.43	5.43	3.66	0.99	7.04	10.71
47	8.13	8.10	14.15	13.52	2.81	8.38	9.71	12.50
48	16.13	0.89	13.99	10.00	8.08	7.41	10.29	23.21
49	18.23	1.82	10.22	16.00	12.05	15.74	16.56	14.29
50	16.26	1.02	19.39	19.02	9.59	18.29	14.49	12.50
51	13.79	3.27	14.43	6.30	5.90	20.19	7.52	7.14
52	7.02	11.27	7.67	4.39	0.63	9.83	10.76	8.93
53	2.83	2.92		2.66	0.63	10.31	8.42	5.36
54	1.11	0.69			0.13	0.50	2.22	
55	1.97	9.27	0.60	0.86	0.50	1.96		
56		10.01			0.42			
57		6.29			1.15			
58		2.17						
59		1.29						
60		0.71						
61		0.53						
62								
63								
64								
65								
66			0.60					
67			0.60					

Table D21a. Length frequencies for catches of spotted warehou for the trawl fleet from onboard measures. Depth classes 1 and 2 are shown (0-100m; 100-200m).

Length (cm)	0-100m	100-200m				
	1998	1996	1997	1998	1999	2000
19						
20					0.05	
21					0.51	
22					1.17	

23					0.61	
24					0.61	
25					0.73	
26					0.26	0.19
27						
28		2.50				
29		1.25			0.60	
30		1.25			4.33	3.52
31		7.50	0.97		10.46	12.21
32		17.50	2.50		22.30	22.88
33		28.75	4.67		27.66	27.77
34		12.50	3.96	0.51	12.83	21.81
35	7.14	5.00	7.54	3.82	5.53	10.27
36	25.00	2.50	10.28	1.85	1.50	0.96
37	25.00	1.25	16.26	7.02	1.07	0.19
38	3.57	3.75	20.53	11.48	0.68	0.19
39	25.00	2.50	13.44	12.96	0.53	
40	7.14	2.50	5.04	20.33	0.53	
41	7.14	1.25	2.38	14.87	0.31	
42			1.02	10.04	0.56	
43		2.50	1.27	6.71	0.88	
44		2.50	1.91	4.24	1.10	
45		1.25	2.59	1.45	0.82	
46		2.50	2.81	0.84	0.35	
47		1.25	1.28	1.22	1.41	
48			0.63	0.86	1.48	
49			0.30	0.77	0.44	
50			0.30	0.76	0.35	
51			0.30	0.13	0.38	
52						
53						
54				0.13		

Table D21b. Length frequencies for catches of spotted warehou for the trawl fleet from onboard measures. Depth classes 3 and 4 are shown (200-400m; 400m +).

Length (cm)	200-400m					400m +				
	1996	1997	1998	1999	2000	1996	1997	1998	1999	2000
19					0.13					
20					0.65					
21					0.79					
22					0.84					
23					0.59					
24					0.24					
25					0.63					
26					0.86					
27					0.98					
28					0.26					
29					0.09					
30	0.29	0.30	0.01	0.56	0.05					
31	0.29	0.00	0.04	0.88	0.14					
32	1.43	0.31	0.08	2.69	0.63					0.10
33	4.28	2.61	0.09	3.69	0.93			0.10		0.33
34	7.13	2.16	0.05	5.06	0.88					0.52
35	6.84	5.10	0.24	5.19	1.37	2.00	0.28			0.59

36	7.13	6.47	0.09	4.58	1.40	4.00	0.11	0.10		0.74
37	4.85	10.89	0.59	4.18	0.79	2.00	0.20	0.08		1.13
38	1.43	10.15	1.48	3.67	1.05	1.00	0.20	0.41		1.16
39	1.63	10.85	2.61	4.21	1.12	4.00	0.74	0.48	0.34	1.02
40	2.61	10.18	3.42	5.17	2.08	4.00	3.26	2.04	1.02	1.62
41	3.11	8.88	6.88	7.75	2.36	2.00	4.78	2.39	2.35	2.26
42	0.78	5.03	5.70	6.67	2.33	3.00	7.00	4.76	3.65	3.33
43	2.33	1.94	7.46	8.14	2.10	2.00	5.36	7.40	5.55	5.55
44	8.54	2.94	5.49	9.44	4.44	9.00	5.68	10.16	7.30	6.63
45	12.42	3.29	11.34	6.23	9.42	11.00	8.29	11.34	8.87	10.85
46	14.75	3.84	10.74	5.79	11.72	11.00	9.45	9.83	11.40	11.09
47	5.43	3.14	8.68	5.42	14.78	14.00	11.95	11.04	12.77	16.14
48	6.99	3.28	10.28	3.70	13.80	12.00	12.94	11.13	13.73	9.36
49	3.88	3.17	7.15	1.85	11.24	6.00	11.75	9.19	10.71	10.68
50	3.11	2.63	7.55	2.45	6.24	5.00	8.17	7.29	7.01	5.20
51	0.78	0.92	3.79	0.68	2.16	4.00	5.37	4.67	6.68	3.10
52		0.76	2.73	0.79	1.48	2.00	2.45	3.24	4.46	3.88
53		0.60	2.59	0.13	0.77	1.00	0.87	1.85	2.08	2.08
54		0.18	0.87	0.63	0.65	1.00	0.45	1.16	1.24	2.08
55		0.34	0.04	0.36			0.45	0.59	0.56	0.13
56		0.03						0.28	0.15	0.10
57		0.02					0.25	0.28	0.04	0.23
58				0.09			0.01	0.09	0.06	0.13
59								0.09	0.04	

APPENDIX E. STANDARDIZATION OF CATCH/EFFORT DATA FROM THE SOUTH-EAST PINK LING FISHERY

Malcolm Haddon and Katheryn Hodgson

This report describes the methods used and the results obtained using data up to 1998. This work was later updated by including the 1999 data and those updated results are used in the model (see the chapter on pink ling), however the paper was not updated. The methods and general conclusions are the same.

Additional CPUE Standardization Analyses for the South-East Pink Ling (*Genypterus blacodes*) Fishery.

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Summary

Previous examination of the Pink Ling fishery and the derivation of standardized indices of relative abundance as reported in Haddon (1999) provided impetus for further investigation. Two fisheries were recognized, a western fishery made up of the catches from zones 40, 50 and 60, plus an eastern fishery made up of the catches from zones 10, 20, and 30. Catch-effort data was initially standardised for these two fisheries by Haddon (1999) with data restrictions; only vessels with more than two years of data and records with reported catches of greater than 30 kg were included in the analyses.

For this report, all catch records were analysed, including small catches, and the results compared to the analyses using records of large catches (>30 kg) only. This was done firstly for all trawl vessels in the fishery and then for a sub-set of vessels; those deemed to be major or dominant players in the fishery. More complex models including interaction terms such as Zone*Depth were investigated in these analyses.

When all records were analysed, the statistically optimal model used for the eastern fishery was: Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone x Vessel, describing 43 % of the catch-effort variation. The inclusion of the interaction term significantly changed the standardized catch rates between 1986 and 1992. This suggests a re-organisation of vessels among zones at this point, most likely a result of the introduction of ITQ's in 1992.

In the western fishery the best fitting model was: Ln(CE) = Constant + Year + Month + Zone + Depth + Vessel + Month x Depth, which successfully described 32 % of the catch-effort variation.

The main effect of the standardizations were to reduce the severity of the apparent fluctuations in real catch-rates through time. In the Western fishery there appears to have been a steady increase in catch rates since 1992. In the eastern fishery there appears to have been a slow and steady increase in catch rates since the fishery started recording data, with two significant highs in 1990 and 1995. Whether this slight rise is enough to be biologically significant is debatable. For both fisheries the analysis of CPUE provides no negative impressions concerning the status of the fishery.

The standardised catch rate profiles for the western fishery using all records showed very little difference to that with data restrictions (>30 kg catches). In the eastern fishery the differences were more marked with catch rates considerably and consistently lower where all records were analysed; this is not surprising as only smaller catches were added to the analyses. The two eastern fishery analyses showed similar patterns overall, except between 1996 and 1998 where the two profiles estimated opposing directions of change. This may be related to a significant peak in the number of records reported with catches greater than 30 kg in 1997.

Excluding more minor boats in the fishery had the effect of removing statistically random noise from the data. As expected this had a negligible effect on the standardization of catch rates in both the eastern and western fisheries.

Examination of the distribution of Ling catches (Haddon 1999) suggested that in the eastern fishery there is a relatively shallow water fishery plus a more typical deeper water fishery. These two sub-fisheries, delineated at 200 m depth of catch, were analysed separately and standardised catch rates derived.

In the shallow fishery the best fitting model was: Ln(CE) = Constant + Year + Month + Vessel + Zone x Vessel, which described 25 % of the catch-effort variation when all records were used. There appears to be an overall steady decline in shallow water Ling biomass over time, except for a peak in the period between 1992 and 1995 which had relatively high standardized catch rates. The majority of shallow catches are small (<30 kg) and so when the data is restricted, N becomes very small (5,714 records) and the profile changes markedly. The peak between 1992 and 1995 is still outstanding for large catches only, but in contrast to that with all records, the overall the profile suggests a slight increase in catch rates over time.

The optimal statistical model for the standardisation of the deep fishery is: Ln(CE) = Constant + Year + Month + Zone + Vessel + Zone x Vessel, describing 23 % of the catch-effort variation when all records were used. The restriction of records to large catches made very little difference to the catch-effort profile, both displaying a slight increase over time.

The validity of these standardizations are questionable as the two depth zones may not reflect any real natural sub-division of the fish stock.

Introduction

Further analyses of the pink ling (*Genypterus blacodes*) commercial catch effort data were required to complement the new stock assessment analyses being carried out by CSIRO researchers. The objectives of this document are to provide catch-effort standardizations for pre-defined sub-sets of the data as required by particular questions being asked during the modelling process.

The particular analyses conducted were:

1. Repeat the standardization of catch rates for the eastern and western fisheries but including records where catches were less than 30kg.

2. Repeat standardization of catch rates as in 1. but only for those vessels which contributed appreciably to the fishery. Vessels were excluded from the analysis if they had been in the fishery (*i.e.* reporting Ling catch) for less than three years, caught an average of less than one tonne a year, had a median annual catch of less than 500 kg, or showed an obvious and radical change in fishing behaviour through time.

3. Conduct a standardization of catch rates for the eastern fishery separately for two depth ranges: less than 200m and greater than 200m. Catch rates less than 30 kg were included.

General Methods

The eastern fishery was defined as being zones 10, 20, and 30, while the western fishery was defined as being zones 40 and 50 (see Fig. 1, from Haddon, 1999). Zone 60 was excluded as less than 0.6% of the fishery catch comes from this region (Haddon 1999).

Analyses were conducted using records in the AFMA database which recorded pink ling catch. Only records from method 27 (single trawl) were used, and only where both catch and effort data were present. In previous analyses (Haddon 1999) observations were not restricted to single trawl, but were restricted to boats which had been in the fishery for more than 2 years and to catches greater than 30 kg (Haddon 1999).The absolute number of observations in these earlier analyses thus vary from those given here.

Ling Catch Effort Standardization.

Various statistical models were fitted to the available data with various combinations of factors. Because catch-effort data is typically considered to be at least log-normally distributed a General Linear Model was fitted to the natural logarithm of the catch-effort for each record (see Fig. 12 in Haddon, 1999). The models were built in a number of steps so as to monitor the increase in the amount of the variation in the catch-effort data described. The general log-linear model used was:

$$Ln(CE) = Const + a.Year + b.Month + c.Zone + d.DepthCat + e.VesselNo$$

or

$$\frac{C}{E} = e^{Const} e^{aYear} e^{bMonth} e^{cZone} e^{dDepthCat} e^{eVesselNo}$$

or subsets of this, or with the addition of interaction terms between depth and month, zone and month, or zone and vessel. The variables Year, Month, Zone, Vessel Number, and Capture Depth were all put into the analysis as dummy variables. The average depth of capture was restructured as a set of capture depth categories in the MS-Access database (Cat_Dep = Int(([Avg_Dep]/50)*50+25)). This was to avoid having to include some non-linear equation into the model when trying to account for the modal form of catch rates with depth (*cf.* Fig. 11, Haddon, 1999).

In all cases examined, Model 1 was limited to the factor Year (*Ln(CE) = Const + Year*). This is equivalent to and produces the same result as the analysis of geometric means.

All analyses were run using the GLM package inside Systat version 8, and this requires post-hoc hypothesis testing which was completed after the initial analysis to determine whether each term plays a significant part in determining the observed variation in catch-effort. By including Year as a dummy variable into the statistical model the parameter estimates for Year constitute the indices of relative abundance which are used in subsequent stock assessment modelling.

It should be noted that the output from a GLM does not guarantee that a relation exists between stock size and standardized catch per unit effort. It is possible that factors not included in the GLM model (through no information being available) may be obscuring any effects of changes in stock biomass. In this case, however, there are no other data available to be included in the statistical models so this analysis constitutes the most that can be done at present.

The Statistical Models

It is possible to define the so-called 'full model' for the set of factors being considered. This would include all of the factors and the entire set of interaction terms possible between them. Some of the interaction terms possible would be difficult to give a real interpretation and their value in describing the data is marginal. However, there is no doubt that the more parameters used in a statistical model the more likely we are to describe a larger proportion of the variation in the available data. But just adding more and more parameters to a model is not necessarily an improvement when there can be such things as parameter correlation. What is required is a compromise between the variability of the data described by the statistical model and its complexity.

One way of selecting such a compromise, which is becoming more and more accepted as such a criterion, is the use of the Akaike's Information Criterion (AIC). This is usually based around a maximum likelihood framework but, in the special case of a least squares estimation with normally distributed additive errors the AIC can be expressed as:

$$AIC1 = nLn\left(\hat{\sigma}^2\right) + 2K$$

where $$\hat{\sigma}^2 = \frac{\sum \varepsilon^2}{n}$$

(Burnham & Anderson, 1998)

Or analogously as,

$$AIC2 = Ln\left(\sum \varepsilon^2\right) + 2\left(\frac{K}{n}\right)$$

(Hilborn & Mangel, 1997)

where $\hat{\sigma}^2$ is the maximum likelihood estimator of σ^2, ε^2 is the estimated residual for the candidate model, K is the total number of estimated parameters, including the intercept and σ^2, and n is the total number of observations. The criterion is selected which gives rise to the smallest AIC (this includes negative numbers, thus -23001 is smaller than -23000).

Results:

1. Analysis of Eastern and Western single trawl fisheries, including all vessels and catches less than 30 kg.

Previously, catches of less than 30kg were excluded from the analyses in an attempt to focus on targeted fishing and major fishers, and away from small incidental catches or by-catch (Haddon 1999).

Inspection of the data revealed a significant number of small catch records in both the Eastern and Western fisheries (Table 1). Analyses were compared with and without the 30kg limit to investigate the importance of these small catches to the standardisation of catch rates.

Table 1. Number of records (N) for the Eastern and Western fisheries where Pink Ling catch is less than or equal to 30 kg and where catch is greater than 30 kg. %T is the percentage of the total no. of records in each of these categories.

	Eastern fishery		Western fishery		Both	
Catch	N	%T	N	%T	N	%T
≤30 KG	31,914	41.6	8,558	28.9	40,472	38.1
>30 KG	44,841	58.4	21,059	71.1	65,900	61.9
TOTAL	76,755	100.0	29,617	100.0	106,372	100.0

In the eastern fishery Model 7 (Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Zone*Vessel) described the greatest proportion of variability in the data- 43.6% (Table 2). It had the lowest AIC value of all models tested and thus accounted for the most variability in the data without becoming overly complex.

The standardized catch effort data (Model 7) and the simple geometric means (Model 1) showed different patterns of change through time (Figure 1). While the geometric means are variable, they suggest an overall decline in catch rate through time, and by inference a decline in stock biomass. Model 7 suggests a variable but slight overall increase in the relative catch rate (approx. 10%) over the 12 years of data, with two significant peaks around 1990 and 1995.

Model 5 (Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone) is Model 7 without the interaction term Zone*Vessel (Table 2). The two models show similar standardised catch rates except for the period 1986- 1991 (Figure 1). This period is prior to the quota system (introduced in 1992) and the proportion of vessels returning information is reported to be lower (Tilzey 1994). The difference in standardised catch rates may have been brought about by a re-distribution of vessels around the zones on the introduction of quotas.

In the western fishery the statistically optimal model was Model 8 (Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Month*Depth) (Table 3), accounting for the 31.7% of the variability in the data (Table 3). The main effect of the standardization was to reduce the severity of the change in catch rate that appeared to have occurred through time (compare Model 1, Figure 2). Model 5, which does not include the interaction term Month*Depth, had very similar standardized catch rates to Model 8. The inclusion of the interaction term explained a further 3% only of the data variability, above the 28.7% explained by Model 5.

Western fishery annual standardized catch rates declined from 1986 reaching an overall low in 1992. After 1992 catch rates improved steadily to a maximum in 1997, almost double that of 1992 and 15% greater than that in 1986. In both fisheries, eastern & western, the standardized catch rates have declined slightly between 1997 and 1998 (Figures 1 & 2).

Table 2. GLM results for the Eastern Pink Ling fishery (Zones 10, 20 and 30) for all records. Depth is a set of 50m depth categories, Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 7.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Depth
Model 4	Ln(CE) = Const + Year + Month + Depth + Vessel
Model 5	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone
Model 6	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Month
Model 7	**Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Vessel**
Model 8	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Month*Depth

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
F	47.50	89.29	670.78	233.50	232.70	217.22	**166.77**	133.92
Resid SS	147589.9	144810.3	105520.5	86436.0	86246.5	85495.9	**83523.8**	84457.4
df Params	12	23	46	233	235	257	**353**	428
DF Resids	76742	76731	76412	76225	76223	76201	**76105**	76030
N	76755	76755	76459	76459	76459	76459	**76459**	76549
Var%	0.7	2.6	28.8	41.6	41.8	42.3	**43.6**	43.0
# Param	14	25	48	235	237	259	**355**	430
AIC	50211.874	48774.541	24727.313	9847.666	9683.856	9059.523	**7467.215**	8386.007
AIC2	11.903	11.884	11.568	11.373	11.371	11.363	**11.342**	11.355
DVAR%	0.0	1.9	26.2	12.8	0.2	0.5	**1.8**	1.2

YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
1986	1.1936	1.1549	0.9493	0.9268	0.9296	0.9361	**0.8976**	0.9503
1987	1.2411	1.1960	0.9666	1.0161	1.0192	1.0408	**0.9734**	1.0534
1988	1.2486	1.1747	0.9900	1.0171	1.0131	1.0243	**0.9589**	1.0460
1989	1.2399	1.1889	0.9637	0.9352	0.9296	0.9361	**0.8590**	0.9493
1990	1.5023	1.4888	1.3034	1.2995	1.2892	1.3008	**1.1770**	1.3100
1991	1.3979	1.3593	1.1841	1.2105	1.2044	1.2349	**1.0887**	1.2238
1992	1.2662	1.2337	1.1549	1.0151	1.0171	1.0253	**1.0010**	1.0151
1993	1.3840	1.3512	1.2436	1.0274	1.0305	1.0336	**1.0141**	1.0367
1994	1.2789	1.2548	1.2032	1.0182	1.0274	1.0284	**1.0294**	1.0192
1995	1.2776	1.2624	1.3205	1.1653	1.1735	1.1818	**1.1924**	1.1759
1996	1.0523	1.0693	1.0909	0.9950	0.9970	1.0020	**0.9940**	1.0171
1997	1.0243	1.0222	1.0876	1.0450	1.0481	1.0492	**1.0263**	1.0629
1998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**	1.0000

Table 3. GLM results for the Western Pink Ling fishery (Zones 40 and 50) for all records. Depth is a set of 50m depth categories, Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 8.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Depth
Model 4	Ln(CE) = Const + Year + Month + Depth + Vessel
Model 5	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone
Model 6	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Month
Model 7	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Vessel
Model 8	**Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Month*Depth**

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
F	47.99	81.48	184.44	92.78	92.99	93.17	68.42	**42.23**
Resid SS	31731.6	30422.4	25053.9	22970.0	22902.7	22331.6	22650.7	**21924.3**
df Params	12	23	45	126	127	138	179	**321**
DF Resids	29604	29593	29423	29342	29341	29330	29289	**29147**
N	29617	29617	29469	29469	29469	29469	29469	**29469**
Var%	1.9	6.0	22.0	28.5	28.7	30.5	29.5	**31.7**
# Param	14	25	47	128	129	140	181	**323**
AIC	2070.52	844.64	-4689.09	-7086.19	-7170.66	-7892.81	-7392.71	**-8069.26**
AIC2	10.366	10.325	10.132	10.051	10.048	10.023	10.040	**10.017**
DVAR%	0.0	4.1	16.0	6.5	0.2	1.8	0.8	**3.0**

YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
1986	0.8187	0.8746	0.8049	0.8547	0.8624	0.8212	0.8573	**0.8462**
1987	1.2190	1.1877	1.0202	0.9773	0.9831	0.9231	0.9646	**0.9704**
1988	0.8878	0.9389	0.7906	0.7550	0.7596	0.7327	0.7535	**0.7423**
1989	1.1152	1.1377	0.8994	0.7866	0.7835	0.7423	0.7641	**0.7780**
1990	0.8344	0.8179	0.6551	0.7005	0.6942	0.6610	0.6771	**0.6880**
1991	0.8278	0.8538	0.7453	0.7364	0.7416	0.7161	0.7276	**0.7423**
1992	0.6096	0.6213	0.5051	0.5455	0.5406	0.5247	0.5423	**0.5406**
1993	0.8711	0.8878	0.6977	0.7305	0.7189	0.7096	0.7225	**0.7261**
1994	1.0419	1.0243	0.8420	0.8737	0.8702	0.8504	0.8720	**0.8694**
1995	0.9646	0.9666	0.8914	0.9185	0.9158	0.9213	0.9194	**0.9389**
1996	0.9940	1.0080	0.9522	0.9570	0.9695	0.9512	0.9753	**0.9550**
1997	1.0294	1.0377	1.0182	1.0325	1.0450	1.0419	1.0408	**1.0597**
1998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**

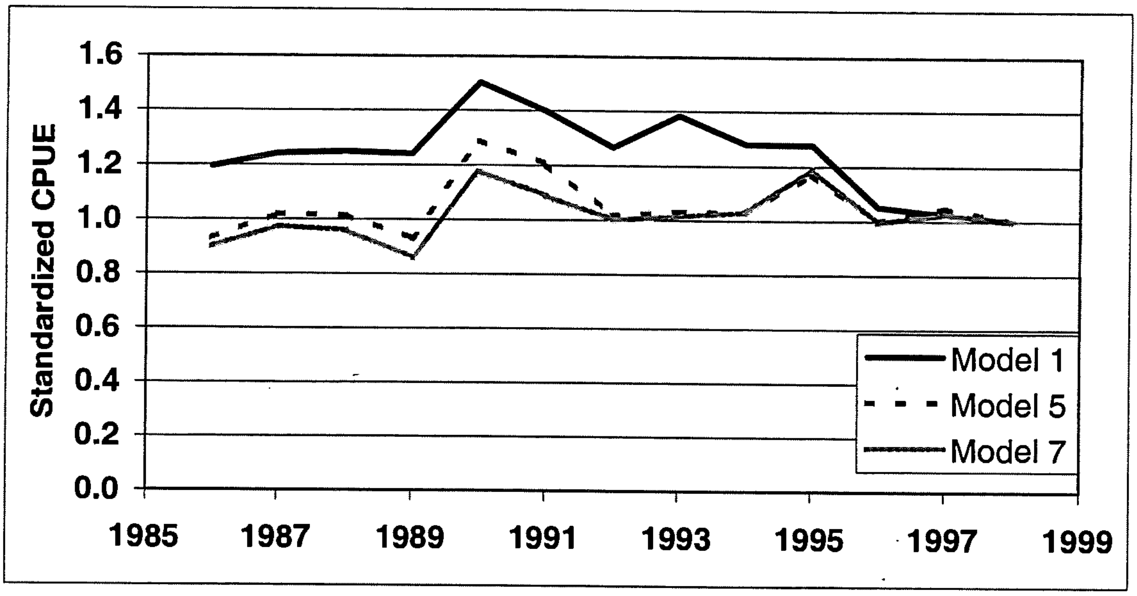


Figure 1. Standardized CPUE for the eastern fishery (zones 10, 20, and 30) for all records. Model 1 is simply the geometric mean CPUE for each year. Model 5 was: Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone. Model 7 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Zone*Vessel (Table 1).

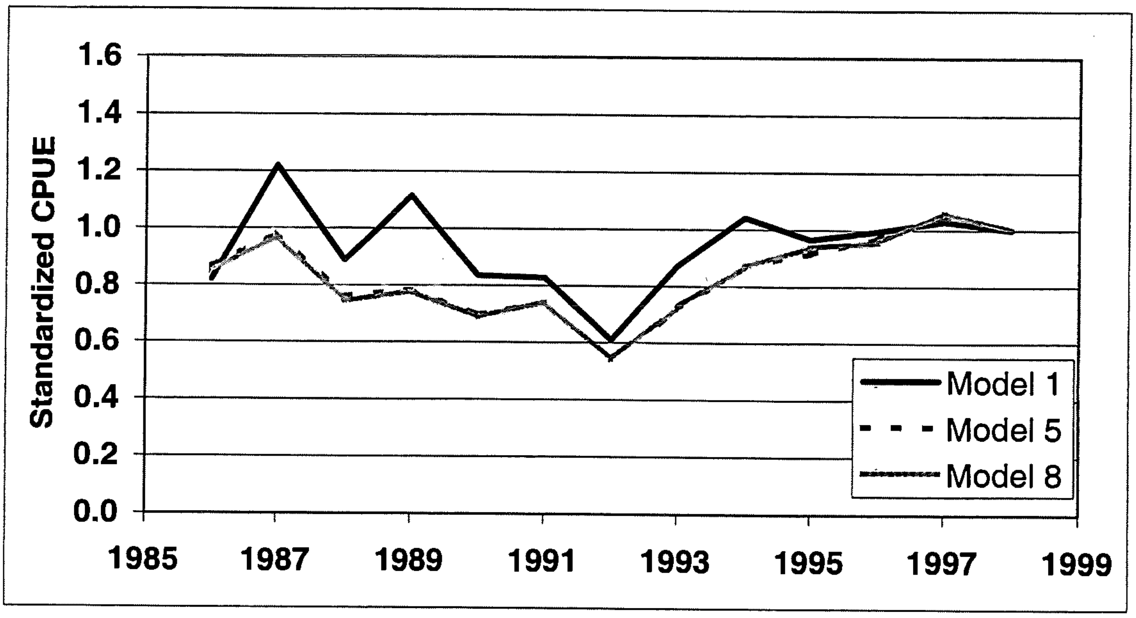


Figure 2. Standardized CPUE for the western fishery (zones 40 and 50) for all records. Model 1 is simply the geometric mean CPUE for each year. Model 5 was: Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone. Model 8 was the optimal statistical model : Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Month*Depth (Table 2).

Comparison with analyses using records of Pink Ling catches greater than 30 kg only.

In the eastern fishery catch rate profiles for analyses conducted on all records ('All') and on records of catches greater than 30 kg only ('>30 kg') displayed similar patterns through time (Table 4, Figure 3). However, standardized catch rates for '>30 kg' were consistently lower than those for 'All' and were rather less severe in the apparent changes in CPUE (Figure 3). While the 'All' profile shows standardized CPUE above that of 1998 for almost 60% of the years analyzed, the '>30 kg' standardized CPUE are greater than 1998 in one instance only, 1995 (Figure 3). The two profiles change in different directions between 1996 and 1998; 'All' shows an increase between 1996 and 1997 when '>30 kg' shows a decrease, and vice versa between 1997 and 1998 (Figure 3).

In the western fishery the two profiles displayed a similar and consistent pattern (Table 4, Figure 4). The most obvious difference being the apparent 'smoothing' of the profile where catches less than or equal to 30 kg were excluded (Figure 4).

Table 4. GLM results for the Pink Ling fishery (Eastern & Western) for records where catch is greater than 30 kg. Results of the analyses are shown only for those models which were deemed statistically optimal in analyses presented in Tables 2 & 3.

	Eastern Fishery	**Western Fishery**
	Model 7	**Model 8**
F	40.82	25.62
Resid SS	22696.1	9650.8
df Params	307	281
DF Resids	44384	20656
N	44692	20938
Var%	22.0	25.8
# Param	309	283
YEAR		
1986	0.8538	0.7945
1987	0.8834	0.9222
1988	0.8179	0.7498
1989	0.7804	0.7914
1990	0.9512	0.7453
1991	0.8923	0.7019
1992	0.8386	0.5758
1993	0.8958	0.7953
1994	0.8843	0.8772
1995	1.0481	0.9531
1996	0.9841	0.9685
1997	0.9465	1.0502
1998	1.0000	1.0000

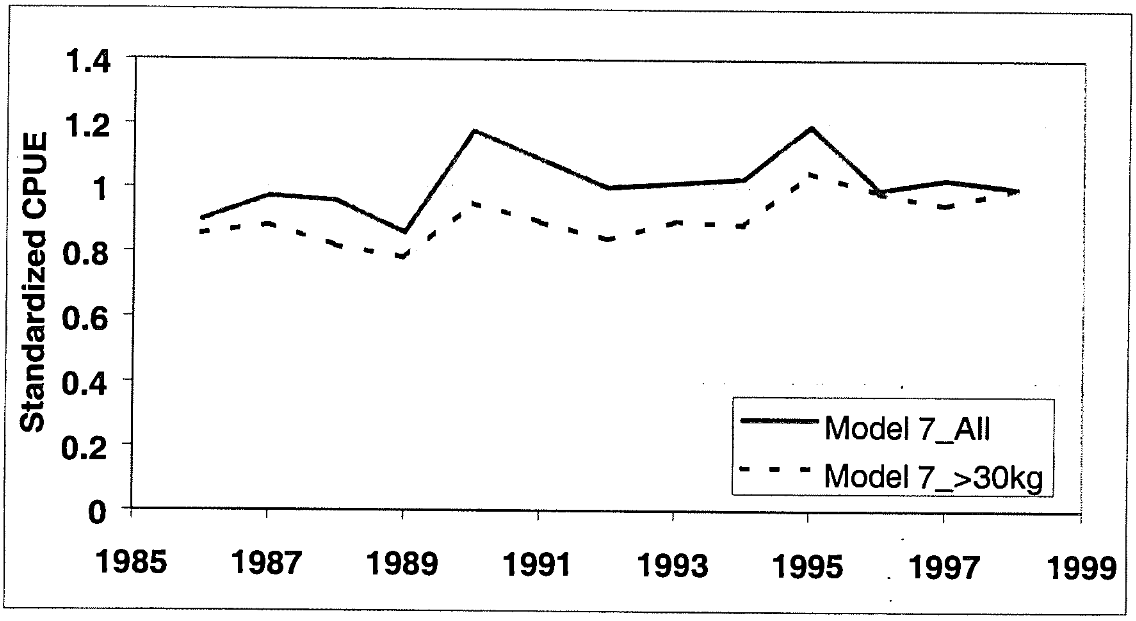


Figure 3. Standardized CPUE for the Eastern fishery (zones 10, 20 and 30) for all records (Model 7_All) and for records where catches were greater than 30 kg (Model 7_>30kg). Model 7 is the statistically optimal model: Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Zone*Vessel (Tables 2 & 4).

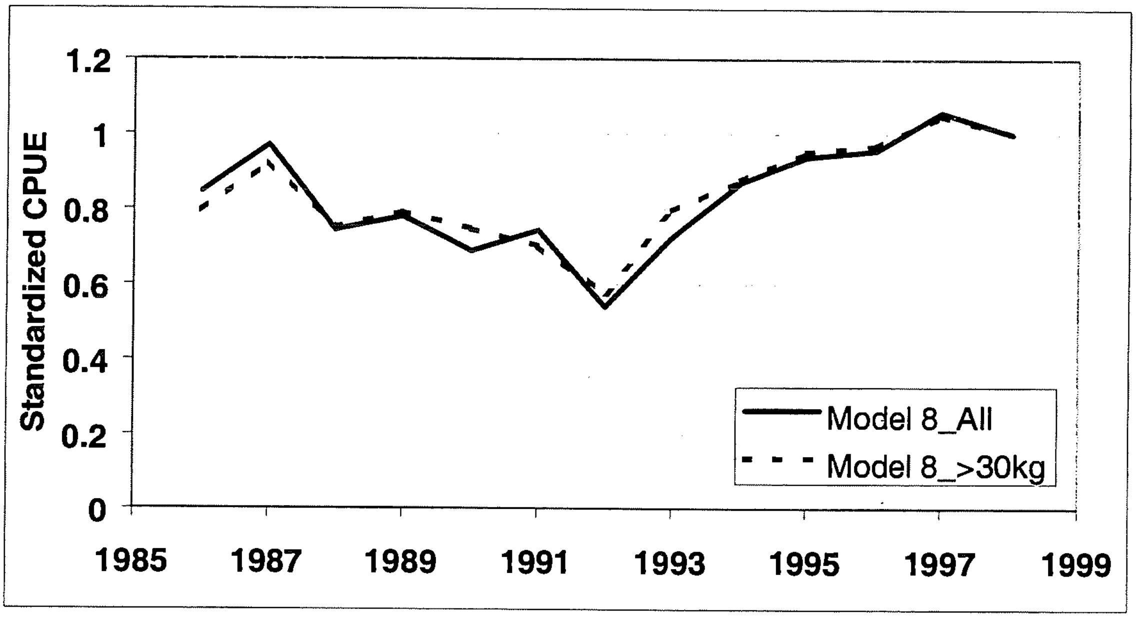


Figure 4. Standardized CPUE for the Western fishery (zones 40 and 50) for all records (Model 8_All) and for records where catches were greater than 30 kg (Model 8_>30kg). Model 8 is the statistically optimal model: Ln(CE) = Constant + Year + Month + Zone + Depth + Vessel + Month*Depth (Tables 3 & 4).

2. Analysis of Eastern and Western single trawl fisheries for major vessels.

The analyses in 1. were repeated using a sub-set of the data: records of catches by the major vessels contributing to the fishery only. Vessels were excluded from the analyses if they had been in the fishery (*i.e.* reporting Ling catch) for less than three years, caught an average of less than one tonne a year, had a median annual catch of less than 500 kg, or showed an obvious and radical change in fishing behaviour through time. This reduced the number of boats in the Eastern fishery analyses from 188 to 102, and from 82 to 47 in the Western fishery. The number of records in the analyses were reduced by approx. 7% in both the Eastern and Western fisheries (Table 5).

Table 5. The number of records (N) for major vessels and for all vessels of the Eastern and Western Pink Ling fisheries. % All refers to the percentage of the fishery vessels which are deemed major vessels.

Catch Records	Eastern fishery	Western fishery	Both fisheries
	N	N	N
Major Vessels	71,645	27,656	99,031
All Vessels	76,755	29,617	106,372
%All	93.3	93.4	93.1

In the eastern region, Model 7 (Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Zone*Vessel) described the greatest proportion of the available variability in the data- 41.7% (Table 6, Figure 5). Model 7 was also the optimal statistical model (Var% of 43.6), when records for all vessels were included (Table 2).

In the western area 30.8% of the catch-effort data was explained by Model 8 (Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Month*Depth) (Table 7). This model had the lowest AIC and described the greatest proportion of variability in the data when fitted to the full data-set (Table 3), as well as to the reduced data-set for dominant vessels only (Table 7).

The overall patterns of catch-effort for the eastern and western fisheries when dominant vessels only were included are the same as those where records for all vessels were included (Figure 7). Exclusion of the more minor vessel catch records from the data-set does not seem to have altered the fit of the models.

Table 6. GLM results for the Eastern Pink Ling fishery (Zones 10, 20 and 30) for records of catches by dominant boats in the fishery. Depth is a set of 50m depth categories, Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 7.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Depth
Model 4	Ln(CE) = Const + Year + Month + Depth + Vessel
Model 5	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone
Model 6	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Month
Model 7	**Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Vessel**
Model 8	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Month*Depth

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
F	34.11	79.24	600.58	317.22	314.76	280.75	**206.43**	144.32
Resid SS	134593.2	132003.1	97251.1	81538.4	81352.2	80585.1	**78719.0**	79605.5
df Params	12	23	46	147	149	171	**246**	342
DF Resids	71632	71621	71335	71234	71232	71210	**71135**	71039
N	71645	71645	71382	71382	71382	71382	**71382**	71382
Var%	0.6	2.5	27.9	39.6	39.7	40.3	**41.7**	41.0
# Param	14	25	48	149	151	173	**248**	344
AIC	45202.556	43832.399	22170.936	9793.816	9634.658	9002.341	**7479.946**	8471.267
AIC2	11.810	11.791	11.486	11.313	11.311	11.302	**11.281**	11.294
DVAR%	0.0	1.9	25.4	11.7	0.1	0.6	**2.0**	1.3

YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
1986	1.1320	1.0964	0.9076	0.9213	0.9240	0.9333	**0.8905**	0.9455
1987	1.1877	1.1445	0.9484	1.0192	1.0222	1.0450	**0.9734**	1.0576
1988	1.1723	1.1052	0.9570	1.0131	1.0090	1.0202	**0.9512**	1.0450
1989	1.1491	1.1019	0.9231	0.9259	0.9194	0.9250	**0.8470**	0.9399
1990	1.4106	1.4007	1.2763	1.3192	1.3073	1.3192	**1.1901**	1.3298
1991	1.3192	1.2815	1.1503	1.2226	1.2177	1.2548	**1.1041**	1.2374
1992	1.1889	1.1618	1.1152	1.0161	1.0192	1.0284	**1.0020**	1.0182
1993	1.3087	1.2763	1.2008	1.0263	1.0294	1.0336	**1.0121**	1.0346
1994	1.1865	1.1642	1.1468	1.0171	1.0263	1.0274	**1.0274**	1.0182
1995	1.1782	1.1665	1.2649	1.1700	1.1770	1.1865	**1.1960**	1.1818
1996	0.9920	1.0111	1.0704	1.0030	1.0060	1.0101	**1.0010**	1.0274
1997	1.0020	1.0000	1.0757	1.0523	1.0544	1.0555	**1.0305**	1.0714
1998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**	1.0000

Table 7. GLM results for the Western Pink Ling fishery (Zones 40 and 50) for records of catches by the dominant boats in the fishery. Depth is a set of 50m depth categories, Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 8.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Depth
Model 4	Ln(CE) = Const + Year + Month + Depth + Vessel
Model 5	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone
Model 6	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Month
Model 7	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Vessel
Model 8	**Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Month*Depth**

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
F	52.13	78.99	168.90	113.19	113.17	110.49	84.43	**43.69**
Resid SS	29021.8	27847.7	23069.1	21410.2	21346.9	20811.5	21118.7	**20391.7**
df Params	12	23	45	91	92	103	128	**277**
DF Resids	27643	27632	27465	27419	27418	27407	27382	**27233**
N	27656	27656	27511	27511	27511	27511	27511	**27511**
Var%	2.2	6.2	21.7	27.3	27.5	29.3	28.3	**30.8**
# Param	14	25	47	93	94	105	130	**279**
AIC	1361.135	241.015	-4750.424	-6711.568	-6790.992	-7467.819	-7014.706	**-7680.342**
AIC2	10.277	10.236	10.050	9.978	9.975	9.951	9.967	**9.943**
DVAR%	0.00	4.00	15.50	5.60	0.20	1.80	0.80	**3.30**

YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
1986	0.8914	0.9352	0.8598	0.8122	0.8228	0.7780	0.8155	**0.7985**
1987	1.4106	1.3553	1.1331	0.9891	0.9950	0.9389	0.9782	**0.9891**
1988	0.9085	0.9589	0.7985	0.7483	0.7535	0.7276	0.7535	**0.7393**
1989	1.1491	1.1607	0.9130	0.7874	0.7843	0.7438	0.7680	**0.7804**
1990	0.8616	0.8403	0.6690	0.6984	0.6921	0.6597	0.6777	**0.6866**
1991	0.8311	0.8538	0.7445	0.7276	0.7334	0.7103	0.7204	**0.7349**
1992	0.6188	0.6256	0.5066	0.5417	0.5369	0.5210	0.5396	**0.5369**
1993	0.8834	0.8940	0.7012	0.7247	0.7132	0.7047	0.7182	**0.7204**
1994	1.0523	1.0356	0.8487	0.8676	0.8642	0.8462	0.8685	**0.8624**
1995	0.9851	0.9822	0.8923	0.9085	0.9057	0.9112	0.9112	**0.9296**
1996	0.9589	0.9656	0.9103	0.9427	0.9560	0.9399	0.9627	**0.9408**
1997	1.0336	1.0387	1.0161	1.0367	1.0492	1.0429	1.0460	**1.0618**
1998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**

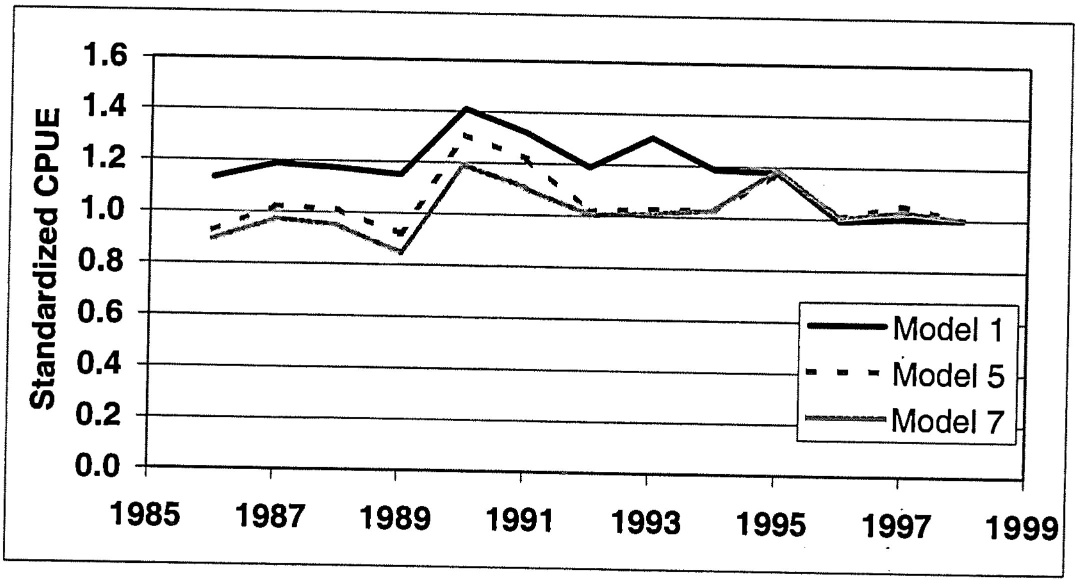


Figure 5. Standardized CPUE for the eastern fishery (zones 10, 20, and 30) for records of catches by the dominant boats in the fishery. Model 1 is simply the geometric mean CPUE for each year. Model 5 was: Ln(CE) = Constant + Year + Month + Zone + Depth + Vessel. Model 7 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Zone + Depth + Vessel + Zone*Vessel (Table 6).

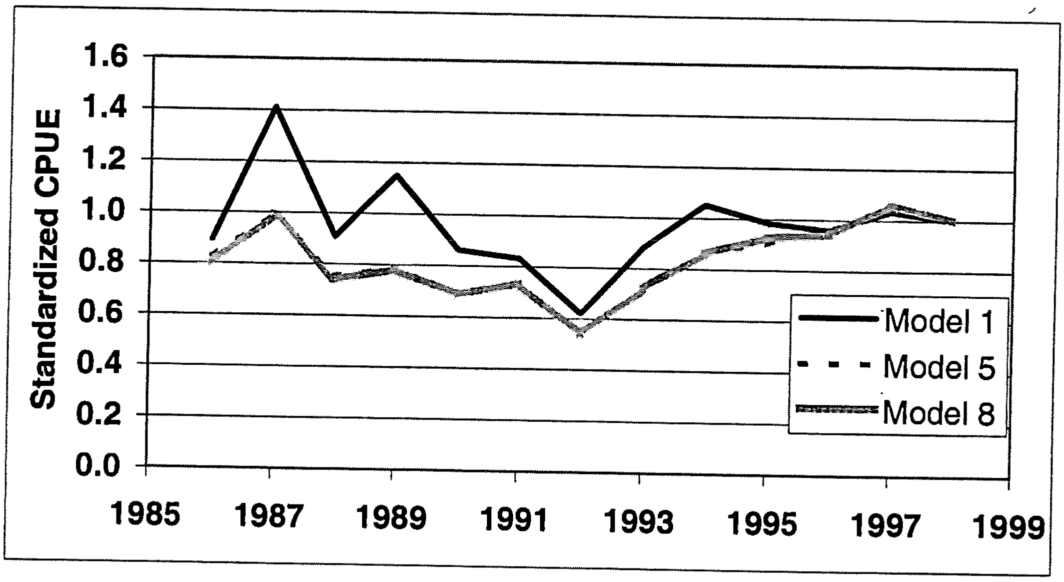


Figure 6. Standardized CPUE for the Western fishery (zones 40 and 50) for records of catches by the dominant boats in the fishery. Model 1 is simply the geometric mean CPUE for each year. Model 5 was: Ln(CE) = Constant + Year + Month + Depth + Vessel. Model 8 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Depth + Vessel + Month*Depth (Table 7).

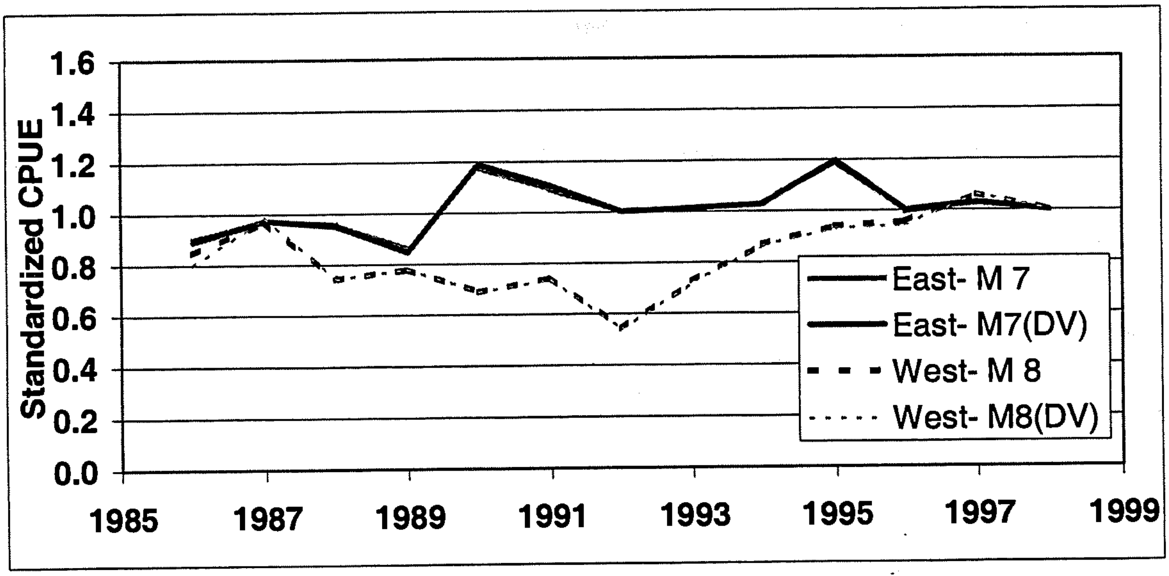


Figure 7. Standardized CPUE for the Eastern and Western fisheries for all records and for dominant vessel records only (DV). Model 7 was the optimal statistical model for the Eastern fishery: Ln(CE) = Covnstant + Year + Month + Depth + Vessel + Zone*Vessel (Tables 2 & 6). Model 8 was the optimal statistical model for the Western fishery: Ln(CE) = Constant + Year + Month + Zone + Depth + Vessel + Month*Depth (Tables 3 & 7).

2. Analysis of Eastern Fishery in Two Depth Zones.

Inspection of the spatial distribution of Ling catches suggest two distinct fisheries in the eastern region, an inshore shallow fishery and an offshore fishery (Haddon 1999). Catches in the eastern region were therefore divided into shallow (occurring in less than 200 m depth) and deep (greater than or equal to 200 m depth) sub-fisheries and catch rates standardised separately.

In the Eastern fishery 21,996 of the 76,459 records (29%) were catches taken in shallow water. 74% of shallow catches were less than 30 kg, compared to only 28% in the deep water sub-fishery (Table 8).

Table 8. No of records in the shallow and deep Eastern sub-fisheries where catches were greater than 30 kg (>30 kg) and for all records (All). Unknown refers to records where no depth of trawl has been recorded.

# Records	Shallow	Deep	Unknown	Total
>30 kg	5,714	38,978	149	44,841
All	21,996	54,463	296	76,755

In both depth categories Model 6 (Ln(CE) = Constant + Year + Month + Vessel + Zone + Zone*Vessel) provided the statistical best fit to the data, explaining 25.4% of the variability in the shallow fishery and 23.2% in the deep fishery (Table 9 & 10).

Catch rates in the shallow area were highly variable, increasing from 1991 to 1995 but then dropping rapidly between 1995 and 1996 to an overall low in 1998 (Figure 8). The standardised annual catch rate in 1998 was only 67% of that in 1985 and 54% of that in 1994 (Table 9, Figure 8).

In the deeper water catch rates were less variable (Figure 9).Generally, standardised catch rates have increased over the time period by about 20% since 1986 (Figure 9).

Table 9. GLM results for the Eastern Pink Ling fishery (Zones 10, 20 and 30) for records where catch was taken in less than 200 m depth. Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 6.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Vessel
Model 4	Ln(CE) = Const + Year + Month + Vessel + Zone
Model 5	Ln(CE) = Const + Year + Month + Zone + Vessel + Zone*Month
Model 6	**Ln(CE) = Const + Year + Month + Zone + Vessel + Zone*Vessel**

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
F	117.50	64.36	35.30	34.96	32.83	**27.16**
Resid SS	32989.1	32889.3	26913.6	26907.5	26605.0	**26172.5**
df Params	12	23	188	190	212	**273**
DF Resids	21983	21972	21807	21805	21783	**21722**
N	21996	21996	21996	21996	21996	**21996**
Var%	6.0	6.3	23.3	23.4	24.2	**25.4**
# Param	14	25	190	192	214	**275**
AIC	8943.344	8898.700	4818.157	4817.149	4612.471	**4373.932**
AIC2	10.405	10.403	10.218	10.218	10.208	**10.197**
DVAR%	0.0	0.3	17.0	0.1	0.8	**2.0**

YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
1986	1.6537	1.6636	1.4134	1.4162	1.4391	**1.5144**
1987	1.7023	1.7194	1.4681	1.4696	1.4993	**1.5342**
1988	2.0730	2.0689	1.6537	1.6570	1.6922	**1.6955**
1989	1.9387	1.9309	1.5936	1.5888	1.5936	**1.5574**
1990	1.9640	1.9877	1.6703	1.6603	1.6871	**1.6389**
1991	1.6339	1.6258	1.3840	1.3758	1.4176	**1.3744**
1992	1.7700	1.7736	1.4903	1.4948	1.5174	**1.4814**
1993	2.3893	2.3821	1.8776	1.8889	1.8965	**1.8571**
1994	2.5193	2.5143	1.8294	1.8441	1.8368	**1.8645**
1995	2.3233	2.3048	1.7612	1.7683	1.7437	**1.8076**
1996	1.2943	1.2982	1.1019	1.1041	1.1264	**1.1096**
1997	1.1984	1.2032	1.1434	1.1422	1.1491	**1.1400**
1998	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**

Table 10. GLM results for the Eastern Pink Ling fishery (Zones 10, 20 and 30) for records where catch was taken in greater than or equal to 200 m depth. Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 6.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Vessel
Model 4	Ln(CE) = Const + Year + Month + Vessel + Zone
Model 5	Ln(CE) = Const + Year + Month + Vessel + Zone + Zone*Month
Model 6	**Ln(CE) = Const + Year + Month + Vessel + Zone + Zone*Vessel**

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
F	35.95	74.04	77.06	77.79	72.44	**56.38**
Resid SS	78386.8	76611.2	62786.0	62520.5	61964.6	**60640.5**
df Params	12	23	182	184	206	**291**
DF Resids	54450	54439	54280	54278	54256	**54171**
N	54463	54463	54463	54463	54463	**54463**
Var%	0.8	3.0	20.5	20.9	21.6	**23.2**
# Param	14	25	184	186	208	**293**
AIC	19859.856	18633.979	8113.204	7886.428	7444.032	**6437.618**
AIC2	11.270	11.247	11.054	11.050	11.042	**11.023**
DVAR%	0.00	2.20	17.50	0.40	0.70	**2.30**

YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
1986	0.8378	0.8130	0.8369	0.8479	0.8547	**0.8122**
1987	0.8090	0.7858	0.8163	0.8261	0.8454	**0.7788**
1988	0.8237	0.7827	0.8270	0.8278	0.8328	**0.7765**
1989	0.8073	0.7827	0.7734	0.7695	0.7741	**0.7096**
1990	1.1208	1.1208	1.1298	1.1140	1.1309	**1.0212**
1991	1.0661	1.0325	1.0534	1.0408	1.0608	**0.9493**
1992	1.0111	1.0000	0.8633	0.8702	0.8772	**0.8547**
1993	1.0294	1.0060	0.8470	0.8513	0.8513	**0.8411**
1994	0.9194	0.9021	0.8017	0.8114	0.8098	**0.8114**
1995	1.0212	1.0202	0.9389	0.9455	0.9503	**0.9531**
1996	0.9891	1.0020	0.9484	0.9522	0.9503	**0.9531**
1997	1.0284	1.0284	0.9950	0.9980	1.0000	**0.9734**
1998	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**

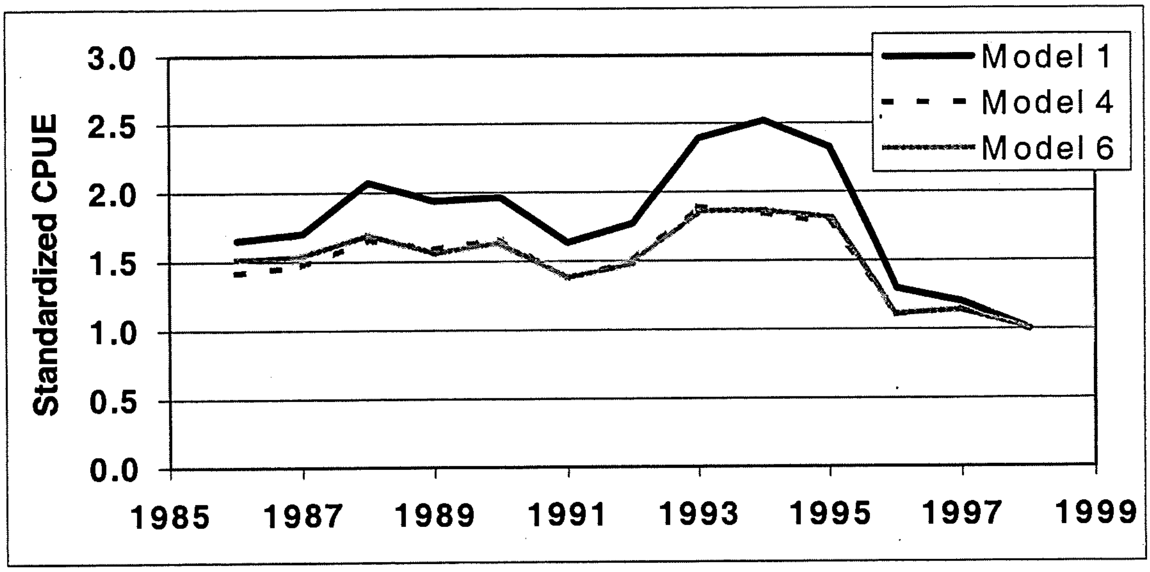
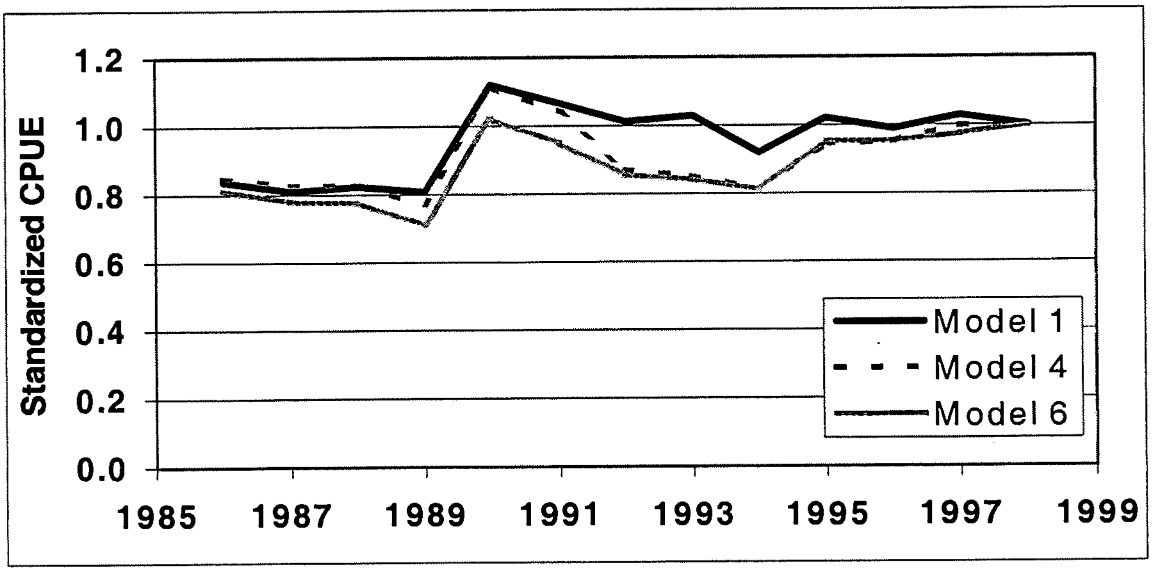


Figure 8. Standardized CPUE for the eastern fishery (zones 10, 20 and 30) for records where catch was taken in less than 200 m depth. Model 1 is simply the geometric mean CPUE for each year. Model 4 was: Ln(CE) = Constant + Year + Month + Vessel + Zone. Model 6 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Vessel + Zone + Zone*Vessel (Table 9).

Figure 9. Standardized CPUE for the Eastern fishery (zones 10, 20 and 30) for records where catch was taken in greater than or equal to 200 m depth. Model 1 is simply the



geometric average CPUE for each year. Model 4 was: Ln(CE) = Constant + Year + Month + Vessel + Zone. Model 6 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Vessel + Zone + Zone*Vessel (Table 10).

Comparison with analyses using records of Pink Ling catches greater than 30 kg only.

In the eastern shallow fishery catch rate profiles for analyses conducted on all records ('All') and on records of catches greater than 30 kg only ('>30 kg') showed a similar pattern, but large differences in the standardized catch rate values (Figure 10). The standardized catch rates for '>30 kg' were consistently and significantly lower than those for 'All'. Both analyses showed a significant jump in catch rates after 1992, decreasing again after 1995 (Figure 10). When the period between 1992-96 is ignored, the analysis of all records shows a decline in catch rates over time, while the analysis of large catches only suggests an increase in catch rates (Figure 10).

The large differences between the two analyses for the eastern shallow fishery are expected when such a large number (74% of the total, Table 8) are lost with the exclusion of catches less than 30 kg; only 5,714 records are left for analysis. In the deep fishery the exclusion of small catches had less of an impact on N, 38,978 records were still available for analysis, 72% of the total (Table 8). The two deep fishery the profiles were very similar and displayed a consistent pattern through time (Figure 11).

It is possible that the standardization of the data from the two depth zones does not reflect a natural sub-division of the fishery/fish stock. If this is the case the validity of the standardization is questionable.

Table 11. GLM results for the Eastern Pink Ling sub-fisheries (Shallow & Deep) for records where catch is greater than 30 kg. Results of the analyses are shown only for those models which were deemed statistically optimal in analyses presented in Tables 9 & 10.

	Shallow fishery	**Deep fishery**
	Model 6	**Model 6**
F	14.73	22.47
Resid SS	2683.7	20185.6
df Params	199	278
DF Resids	5514	38699
N	5714	38978
Var%	34.7	13.9
# Param		280
YEAR		
1986	0.7865	0.8772
1987	0.8115	0.8668
1988	0.8070	0.8187
1989	0.7707	0.7851
1990	0.8897	0.9773
1991	0.8564	0.8967
1992	0.9101	0.8564
1993	1.1173	0.9240
1994	1.4780	0.8479
1995	1.4836	0.9831
1996	0.9406	1.0253
1997	0.9297	0.9637
1998	1.0000	1.0000

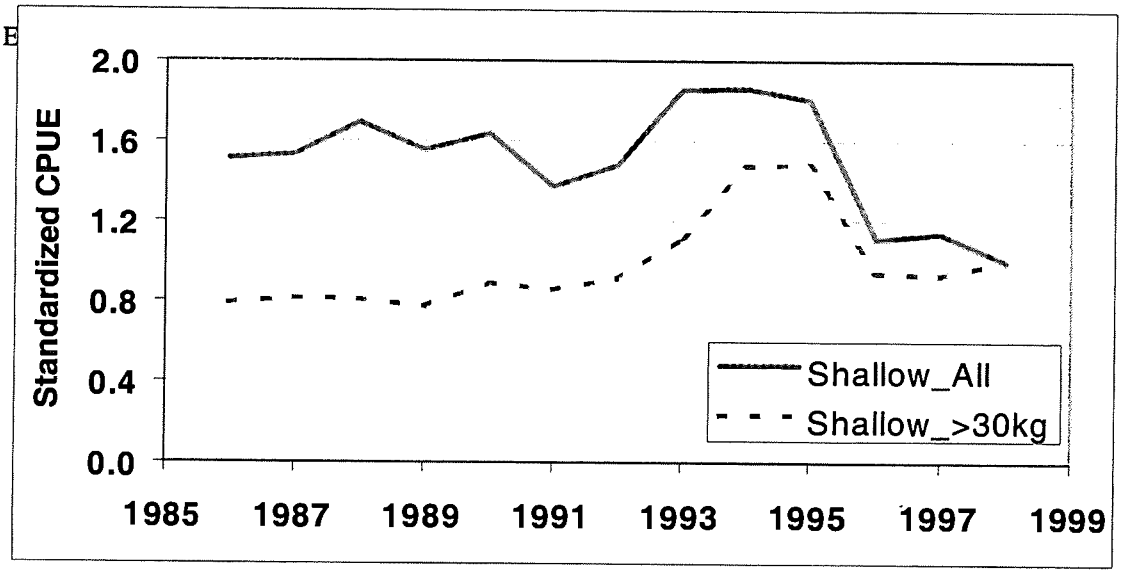


Figure 10. Standardized CPUE for the shallow eastern fishery (< 200 m depth) for all records (Shallow_All) and for records where Pink Ling catch was greater than 30 kg (Shallow_>30kg). Model 6 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Vessel + Zone*Vessel (Table 8).

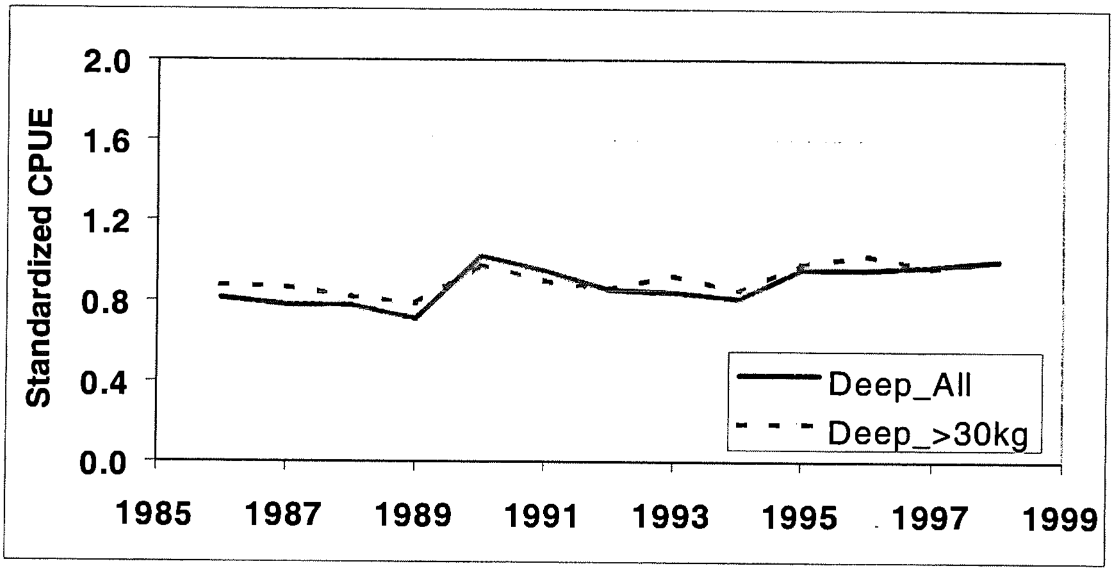


Figure 11. Standardized CPUE for the deep eastern fishery (≥ 200 m depth) for all records (Deep_All) and for records where Pink Ling catch was greater than 30 kg (Deep_>30kg). Model 6 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Zone + Vessel + Zone*Vessel (Table 9).

References

Burnham, K.P. & D.R. Anderson (1998) *Model Selection and Inference. A practical Information-Theoretic approach.* Springer-Verlag, New York Ltd. 353p.

Haddon, M. (1999) *Standardisation of Catch/Effort data from the South-East Pink Ling fishery.* SEFAG Working Group Paper: May 1999. 16 p.

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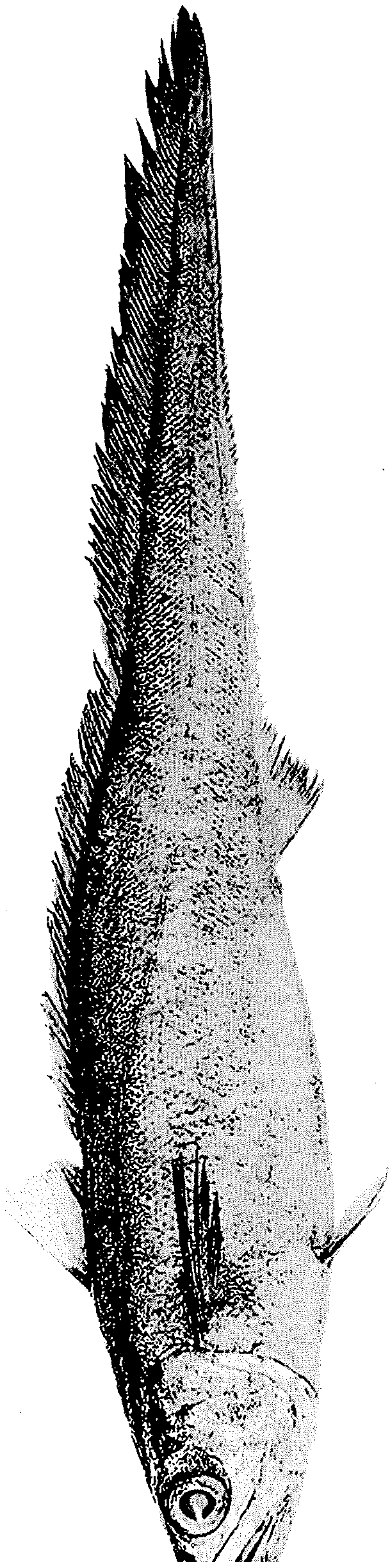
APPENDIX F. SYNOPSIS OF BIOLOGICAL DATA ON BLUE GRENADIER, *MACRURONUS NOVAEZELANDIAE* (HECTOR, 1871)



Synopsis of biological data on Blue Grenadier

***Macruronus novaezelandiae* (Hector, 1871)**

CSIRO
MARINE RESEARCH

December 2000

Kim Woolley and Xi He

CSIRO Marine Research, Hobart, Tasmania, Australia

Cover photo illustration used with permission from "Australian Seafood Handbook - an identification guide to domestic species" by Yearsley, Last & Ward, 1999

1 IDENTITY

1.1 Nomenclature

1.1.1 Valid Name

Macruronus novaezelandiae (Hector, 1871)

1.1.2 Synonymy

Originally *Coryphaenoides novae-zelandiae* (Hector, 1871); other scientific names – none; other common names – blue grenadier, blue hake, hoki, whiptail, New Zealand whiptail.

1.2 Taxonomy

1.2.1 Affinities

Phylum	Vertebrata
Superclass	Pisces
Class	Osteichthyes
Subclass	Actinopterygii
Order	Gadiformes
Family	Macruronidae

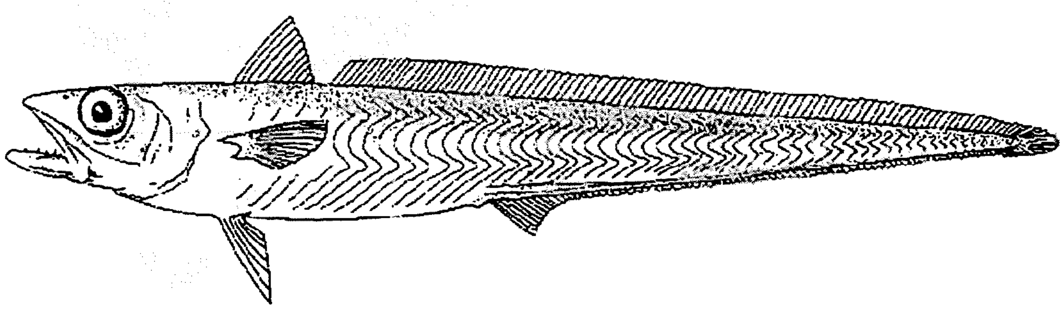


Figure 1 – Macruronus novaezelandiae (Hector, 1871).
(Source: FAO Website www.fao.org).

"Body shallow (13-17% SL), very elongate, compressed, tapering to a point posteriorly. Head of moderate size (16-20% SL), pointed, compressed, without longitudinal ridges; eyes large (25-32% HL); mouth large, reaching to below eyes, oblique; jaws with row of slender canines, upper with second, inner row of small teeth; chin without barbel. Scales minute, cycloid, weakly attached, covering body and top of head; lateral line nearly straight, near centre of sides. Two dorsal fins, first of moderate height, base short; second dorsal moderately low, base extremely elongate, continuous at tip of tail with caudal and anal fins, dorsals separated by very short space; caudal fin confluent with dorsal and anal; anal fin high anteriorly, rapidly tapering to a very low fin posteriorly, base very elongate. Pectoral fins small, no rays elongate. Ventral fins small, originating behind pectoral fin bases and below anterior third of first dorsal fin.

Silver with purple to bluish green sheen above, silver below; fins dark blue. Reaches a maximum length of 130cm, common from 60 to 100cm". (Gomon et al, 1994).

2 DISTRIBUTION

2.1 Total Area

Blue grenadier are distributed through southern Australian waters from mid New South Wales to southern Western Australia, including the coasts of Tasmania (Figure 2).

This species is also found off New Zealand, where they are most abundant around South Island, Chatham Rise and Campbell Plateau (Kuo and Tanaka, 1984a).

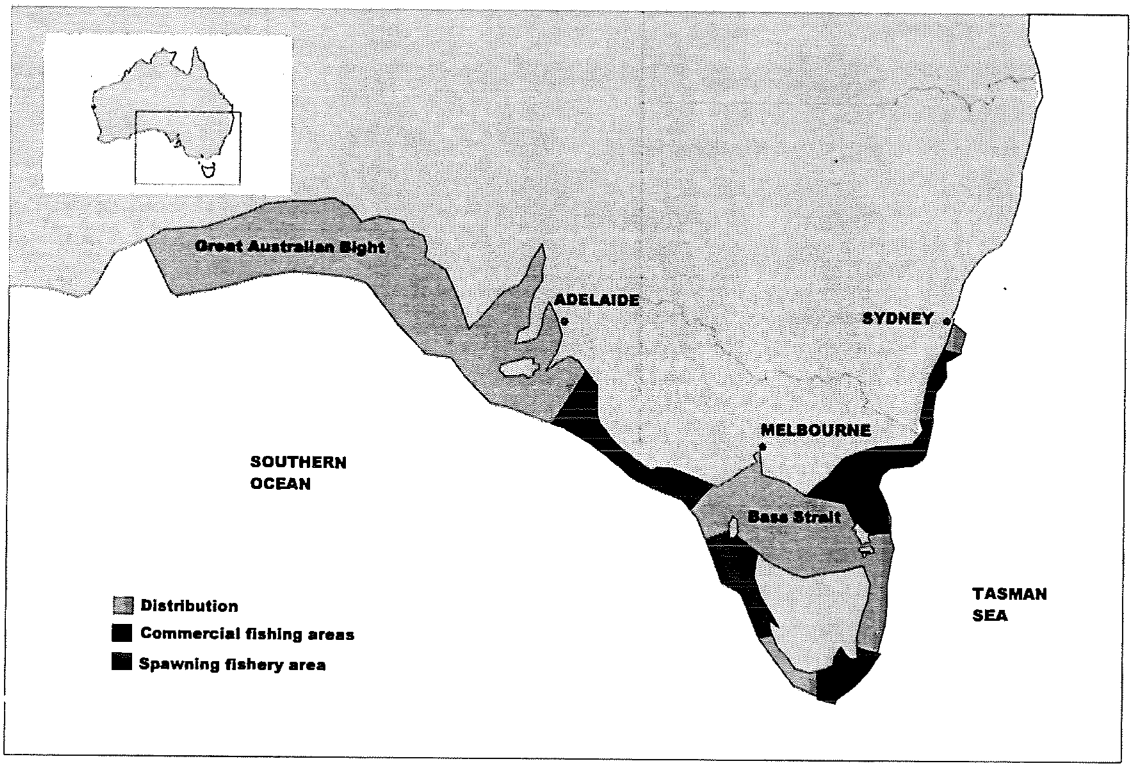


Figure 2 - Geographic distribution and major commercial fishing areas for blue grenadier in Australian waters.

2.2 Differential Distribution

2.2.1 Spawn, Larvae and Juveniles

Spawning in Australian waters takes place at a major spawning ground on the west coast of Tasmania that is used each year. There is no substantial evidence that blue grenadier regularly spawn elsewhere in the Australian Fishing Zone apart from a minor ground off the eastern Victorian coast (Kenchington and Augustine, 1987). All adults that are ready to spawn apparently migrate from throughout the broad distribution range to the Tasmanian spawning area in early winter, and disperse again in spring. The distribution of blue grenadier larvae indicates spawning takes place off the west coast of Tasmania between Sandy Cape and Cape Sorell, between 41°S and 43°30'S, from mid May to September (Gunn et al, 1989). Thresher et al (1989) found that larvae were collected in largest numbers at nearshore and midshelf depths (30-100m) and that larval abundance peaks in July and August.

After being spawned, larvae remain in the water column for approximately 40 days, during which time the larvae are subject to passive transportation by currents. In Australia, eggs and developing larvae are passively transported south and east from the spawning area by the Zeehan Current, along the west coast to the south eastern and eastern coasts of Tasmania (Chesson and Staples, 1995; Thresher et al, 1989). The Zeehan current is approximately 40km wide and restricted largely to the edge of the continental shelf; it moves southwards at a depth averaged flow in the order of about 20km/day (Thresher et al, 1989). Approximately a quarter of the larvae spawned remain on the west coast, while the remainder are transported to recruit into adult habitats on the east coast (Blaber, 1984).

Juveniles are common in estuaries and bays of southern Tasmania, sometimes in deep shelf waters (Kailola et al, 1993; Bruce, 1998a).

Blue grenadier spawning off New Zealand show a similar pattern to the Australian population, with the migration of the fish from feeding grounds off both the east and west coasts to spawning grounds off the west coast of South Island between 41°S and 44°S (Patchell, 1982), and in the Cook Strait in late June (Murdoch et al, 1990), with spawning occurring between late June and mid September (peaking in July and August).

In the Cook Strait Canyon area, blue grenadier eggs have been found to be most abundant along the shelf edge and slope (Murdoch et al, 1990; Zeldis et al, 1998). Newly hatched larvae (2.0-3.9 mm) were found in the greatest numbers between the Cook Strait Canyon and the shallow inshore region of Cape Campbell, whilst larger larvae (>10 mm) were most abundant at nearshore stations along the coasts of South and North Island (Murdoch et al, 1990), a similar pattern to what is seen in Tasmanian waters (Gunn et al, 1989; Thresher et al, 1989).

Length frequency data from trawl surveys suggest that Chatham Rise is a nursery ground for juveniles, whilst Campbell Plateau is primarily a feeding ground dominated by fish over 60cm in total length (Livingston and Schofield, 1996).

2.2.2 Adults

Blue grenadier as adults are a deepwater species and, in Australian waters, normally inhabit depths between 200 and 700m (Kailola et al, 1993), although they have also been recorded at depths of less than 10m (eg Storm Bay, Tasmania) to over 1000m (Smith, 1994).

In New Zealand, blue grenadier are usually found between 200-1000m, peaking within the 400-600m depth range. Kuo and Tanaka (1984a) observed that the range of length distribution of blue grenadier is wider at depths of 200-600m, while at depths between 600-800m the range of length distribution became narrow. At depths of 800-1000m only fish larger than about 70cm were found. These results indicate that larger fish inhabit deeper areas, possibly attributable to different size classes preferring different temperatures (Smith, 1994).

Adult blue grenadier form dense schools on the seabed during the day and disperse into the water column at dusk (Kailola et al, 1993)

There have been no direct studies on movement or migration of blue grenadier (Smith, 1994), however it is known that adult blue grenadier populations in both Australia and New Zealand annually migrate from throughout their normal distributions to spawning areas.

3 LIFE HISTORY

3.1 Reproduction

3.1.1 Sexuality

The sexes are separate (dioecious), with no external sexual characters. Both testes and ovaries are paired and undergo seasonal development simultaneously (Gunn et al, 1989).

3.1.2 Maturity

Most age determinations for blue grenadier are based on counts of assumed annuli in otoliths (Smith, 1994), as attempts to count annuli in spines and scales have been unsuccessful.

Estimates of the age and size at first maturity vary from 3 to 7 years and 60cm to 73cm (both male and female) for the Australian and New Zealand populations of blue grenadier (Table 1). Blue grenadier are thought to reach a maximum size of 130cm (with females reaching greater maximum lengths than males) and have been estimated to live for up to 25 years.

Table 1 – Length and age at first maturity estimates for blue grenadier (length in centimetres and age range in years).

Sex	Measure	Length	Age Range	Area	Source
Unsexed	TL	60.0	3.0 – 4.0	SE Australia	FishBase (2000)
Female	TL	73.0	4.0 – 7.0	SE Australia	
Female	TL	65.0 – 65.02		New Zealand	
Male	TL	60.0 – 60.02	4.0 – 5.0	New Zealand	

3.1.3 Fertilisation

External.

3.1.4 Gonads and Fecundity

Gunn et al (1989) found a seasonal pattern in the gonad-somatic indexes (GSIs) of blue grenadier, which they explain indicates total spawning in a relatively protracted season. It was found that individual fish collected from the west coast of Tasmania had high GSIs in June and August, coinciding with dates of spawning determined from patterns of larval abundance.

Gunn et al (1989) found for 5 females examined, estimated fecundity varied from 321,000 eggs in an 81cm, 2.0kg female to 1,592,000 eggs in a 92cm, 3.7kg female (with a mean of 994,000 eggs).

3.1.5 Spawning

Spawning activity follows a weak lunar cycle, with peak activity in the week following the full moon (Gunn et al, 1989). For Australian waters, there are no data regarding the behaviour of adults in the spawning area, or the rates of movement of adult fish in and out of it (Chesson and Staples, 1995).

In New Zealand waters, blue grenadier spawn at night, from close to the surface down to a maximum depth of about 300m, over bottom depths of about 400-700m (Patchell et al, 1987).

3.1.6 Spawn

Blue grenadier eggs are buoyant (pelagic), spherical in shape (1.01-1.14 mm in diameter) with a smooth chorion and homogenous yolk containing a single oil droplet (Patchell et al, 1987). Laboratory reared fertilised eggs will hatch at 2.2-2.3mm after 55 to 60 hours (at 14°-19°), releasing the pelagic larvae (Bruce, 1988b).

3.1.7 Larval Phase

Bruce (1988a; 1988b) describes and illustrates the development of blue grenadier from both reared specimens and larvae collected from Tasmanian waters (Figure 3). Larvae are 2.2-2.3mm at hatching, and can be distinguished .from other known gadiform larvae by characteristic pigmentation, a myomere count of 78-80, and by the sequence of fin development.

Patchell et al (1987) in their study of laboratory-reared larvae found that at 29mm larvae have the appearance of juveniles and all fins except the caudal fin have completed development.

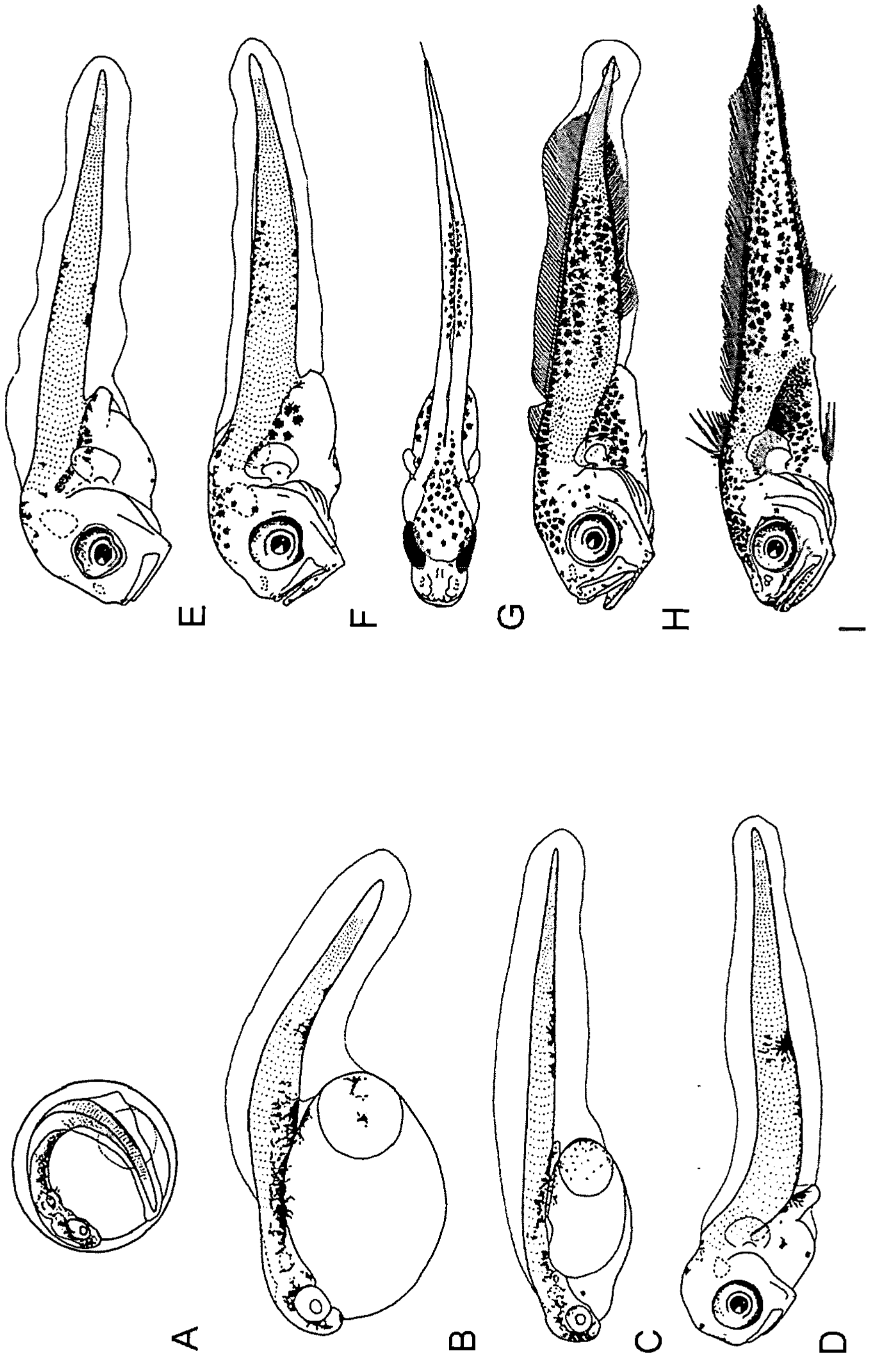


Figure 3 – Development of blue grenadier: **A**) late stage egg 1.08mm; **B**) 2.2mm; **C**) 3.5mm; **D**) 3.6mm; **E**) 5.3mm; **F**) 7.2mm; **G**) dorsal view of above; **H**) 12.0mm; **I**) 24.2mm [A-C reared specimens, D-I field collected]. Illustrated by BD Bruce.

(*Source*: Bruce, 1988b)

3.2 Feeding and Growth

3.2.1 Feeding

The mouth is sub-terminal, with the bottom jaw slightly protruding and the maxilla reaching to the mid-eye. Adult blue grenadier are diel vertical migrators, feeding on prey in the water column. Juveniles lead a pelagic existence.

Blue grenadier feed during the night and attain maximum stomach fullness by early morning (about 6am) after which feeding continues at a much reduced level during the benthic phase. Bulman and Blaber (1986) found that stomach fullness values for blue grenadier were significantly higher for pelagic fish caught during the period 2000-0400 h compared to demersal fish caught during the period 0800-1600 h, supporting the hypothesis of diel vertical migration for feeding purposes.

This can also be supported by the vertical migration patterns of the main prey species, *Lampanyctodes hectoris*, as well as other mesopelagic prey *Maurolicus muelleri* and *Diaphus danae*, which also have similar migration patterns (Young and Blaber, 1986; Kuo and Tanaka, 1984a).

3.2.2 Diet

Murdoch et al (1990) studied the diets of blue grenadier larvae from New Zealand waters by examining the gut contents of 228 larvae. Larvae were considered to be first-feeding at a length of 3.2-3.9mm, and in this study larvae from 3.2-17.15mm were examined. A total of 35 prey types were recorded, and the diet consisted primarily of the copepodite and adult stages of copepods.

Murdoch et al (1990) found that the maximum size of prey consumed by the larvae was similar for all the larval size classes, however the range in size of prey appeared to decrease with increasing larval length. Small larvae are possibly less selective feeders than older larvae, Murdoch et al (1990) explains, and this may account for the diverse number of small prey in the diets of small blue grenadier larvae (Table 2).

Table 2 - Summary of information on feeding habits of blue grenadier larvae collected from New Zealand waters for each size class of specified size range (values for prey items are percentage of the total volume of major prey types; volume is in μm^3).
(*Source*: Murdoch et al, 1990).

Prey Item	Larval Size Class (mm)						
	3.0-3.9	4.0-4.9	5.0-5.9	6.0-7.9	8.0-9.9	10.0-13.9	14.0-17.9
Phytoplantkton	0.07	<0.01					
Tintinnids	0.29	0.22					
Copepods							
Copepod eggs	0.01						
Calanoid nauplii	1.25	0.13	0.13	0.16	0.07	0.06	
Paracalanus indicus	2.41	12.53	12.53	6.86	3.18	3.87	4.83
Calocalanids	43.53	46.30	46.30	44.15	4.72	6.38	13.15
Clausocalanus spp	11.44	25.64	25.64	32.57	75.39	66.12	64.22
Oithona spp	2.5	2.00	2.00	9.50	12.10	17.42	10.88
Others	37.95	13.35	13.35	6.55	4.54	6.15	6.92
Unidentified eggs	0.36	0.04	0.04				
Total volume	6356.8	7942.2	3612.9	1116.2	2411.4	5938.9	3170.3
Number of larvae sampled	131	53	20	6	6	7	5

Bulman and Blaber (1986) studied the stomach contents of juvenile fish (15-29cm) and found that the diet of juvenile blue grenadier differs from that of the adults, with euphausiids making up almost 80% of the prey found in the juvenile stomachs.. While euphausiids had a high frequency of occurrence, it was found that as a food source they only contributed about 25% of the energy requirement of the fish. Bulman and Blaber (1986) found that the myctophid fish *Lampanyctodes hectoris* (Hector's lanternfish), occurred in about one-third of stomachs of juveniles, but contributed about two-thirds of the energy requirement.

Adult blue grenadier exhibit intraspecific predation, and will prey upon juveniles of the same species during periods of high juvenile abundance (Kailola et al, 1993), such as when juveniles from the winter spawning occur in the feeding zone of the adult fish during the summer (Bulman and Blaber, 1986).

The diet of adult blue grenadier include *Lampanyctodes hectoris*, *Maurolicus muelleri*, *Diaphus danae*, decapods, euphausiids and squid, with the fish making up the highest frequency in the diet. Bulman and Blaber (1986) found a slight regional variation in stomach contents between adult blue grenadier (30-120cm) from the west coast of Tasmania, Bass Strait and Maria Island (Table 3), but suggest that these differences are related to prey availability in the three areas.

Table 3 - Summary of information on feeding habits of blue grenadier from three areas around Tasmania (values for prey items are percentage frequency of occurrence).
(*Source*: Bulman and Blaber, 1986).

Prey Item	Area			
	Maria Island (juveniles)	**Maria Island (adults)**	**Bass Strait (adults)**	**Western Tasmania (adults)**
Lampanyctodes hectoris	34.1	65.4	28.9	31.1
Maurolicus muelleri	3.6	4.3		0.6
Diaphus danae	0.4	2.1	3.6	5.1
Macruronus novaezelandiae		1.9	0.4	
Unidentified fish	11.7	17.2	40.0	24.9
Euphausiidae	79.8	13.9	6.8	8.5
Copepoda	3.1	0.3		
Brachyuran megalops	0.9			
Unidentified crustacea	1.8	9.0	3.2	
Caridae		2.5	25.4	6.8
Squid		5.4	5.7	6.3
Other		8.8	15.2	14.9
Number of stomachs with food present	223	575	280	177
Number of stomachs sampled	243	841	406	303

3.2.3 Otoliths and Growth

Kenchington and Augustine (1987) studied blue grenadier otoliths and described the otoliths as:

> "somewhat elongated on the anterior-posterior axis, proximally-distally flattened, concave towards their distal faces and toothed on their dorsal and ventral margins. Their general shape and particularly their degree of toothing is quite variable".

Kenchington and Augustine (1987) found that early in life, blue grenadier otoliths seem to develop evenly and so retain their overall shape (Figure 4), however after the age of about 8 years further growth seems fastest on the proximal face of the otolith, on either side of the sulcus acousticus. This causes the otoliths to thicken without markedly increasing in length or width (Figure 5), hence making ageing difficult.

In Australian waters, blue grenadier have been estimated to live for up to 25 years (Figure 5) and, based on otolith studies, females appear to grow slightly faster, reach a larger maximum size and have a higher maximum age than males (Smith, 1994).

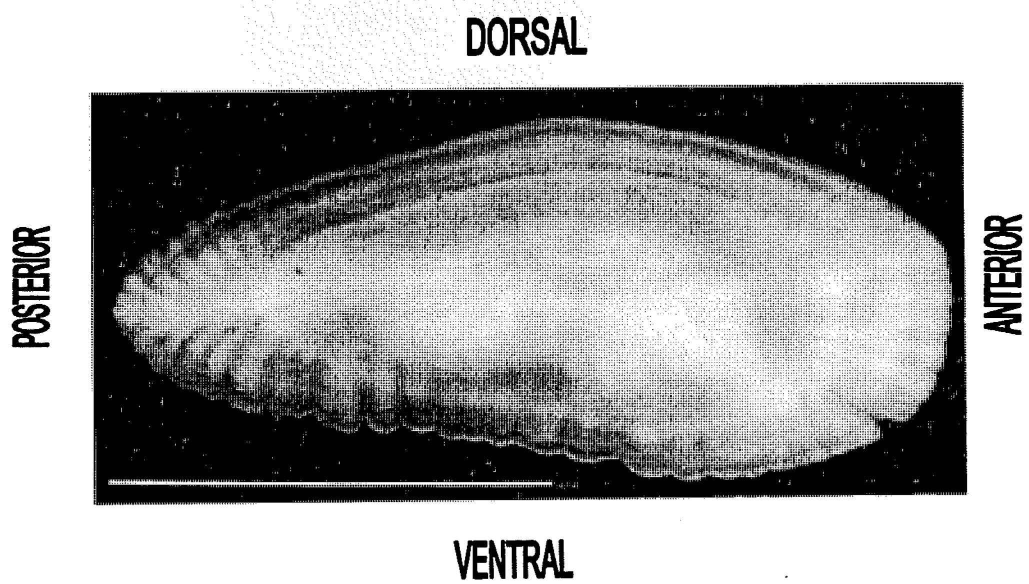


Figure 4 – Whole otolith of a 3 year old male blue grenadier (distal view). Scale bar = 1cm
(Source: Kenchington and Augustine, 1987).

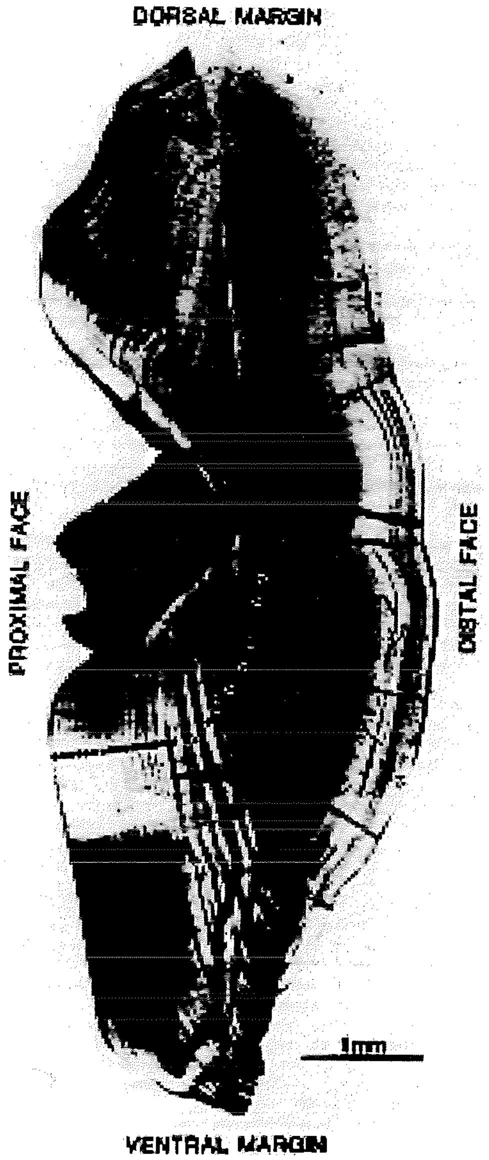


Figure 5 – Transverse thin section of otolith of a 25 year old blue grenadier. (Annuli indicated by black dots, ringed in white where necessary for clarity).
(*Source*: Kenchington and Augustine, 1987).

Estimated relative growth rates (K) of female blue grenadier tend to be lower than that for male blue grenadier (Table 4), however females grow towards larger asymptotic sizes (L_∞) than do the males. Kenchington and Augustine (1987) found the growth curves for length of the two sexes significantly different in both asymptotic length and growth rate. Length-weight relationships for blue grenadier are presented in Table 5.

Table 4 - Parameters of the von Bertalanffy growth equation for blue grenadier (lengths in centimetres; ages in years; ± confidence limits are standard errors; confidence ranges are 95% confidence intervals; L_∞ is the asymptotic length; K is a parameter describing how rapidly L_∞ is achieved; T_0 is the hypothetical age at length zero; N is the number of samples; N/A indicates data not available).

Area	Sex	L_∞	K	T_0	N	Author
West coast Tasmania	Males	93.0 ± 1.4	0.196 ± 0.023	-2.48 ± 0.65	206	Kenchington and Augustine (1987)
	Females	101.2 ± 1.2	0.181 ± 0.014	-1.71 ± 0.35	301	
East coast Tasmania	Males	89.5 ± 0.7	0.276 ± 0.028	-1.03 ± 0.11	403	
	Females	93.5 ± 0.7	0.268 ± 0.009	-0.93 ± 0.09	469	
Bass Strait	Males	95.5	0.20	-0.86	N/A	Smith (1994)
	Females	101.0	0.18	-0.58	"	
	Males +Females	100.1	0.17	-0.38	"	
West and East coasts of Tasmania	Males	90.7 ± 0.6	0.256 ± 0.009	-1.21 ± 0.11	"	Blaber (1984)
	Females	99.3 ± 0.7	0.203 ± 0.007	-1.48 ± 0.11	"	
South East Fishery	Males+ Females	105.0	0.148	-2.31	"	Thomson (2000)
New Zealand (East)	Males+ Females	124	0.39	-0.125	"	Kuo and Tanaka (1984c)
New Zealand (Northwest)	Males+ Females	132	0.39	-0.122	"	
New Zealand (South)	Males+ Females	133	0.21	-0.121	"	
West coast South Island (NZ)	Males	92.6 (91.7-93.6)	0.261 (0.249-0.274)	-0.50 (-0.63 to –0.38)	"	Horn and Sullivan (1996)
	Females	104.0 (102.9-105.1)	0.213 (0.202-0.224)	-0.60 (-0.78 to –0.42)	"	
Cook Strait (NZ)	Males	89.5 (88.2-90.8)	0.232 (0.211-0.252)	-1.23 (-1.58 to –0.88	"	
	Females	102.0 (100.0-104.0)	0.166 (0.149-0.184)	-2.00 (-2.48 to –1.52)	"	
South East Fishery	Males	90.7 ± 0.6	0.256 ± 0.009	-1.21 ± 0.11	"	
	Females	99.3 + 0.7	0.203 ± 0.007	-1.48 ± 0.11	"	

Table 5 – Length-weight relationships for blue grenadier in Australian waters (weight in kilograms; length in centimetres; N is number of samples; dashes indicate data not available).

Sex	Relationship	N	r^2	Author
Males+Females	$W = 0.743 \times 10^{-5} L^{2.852}$	2562	0.96	Kenchington and Augustine (1987)
Males	$W = 1.3402 \times 10^{-5} L^{2.712}$	-	-	
Females	$W = 0.7528 \times 10^{-5} L^{2.8498}$	-	-	
Males+Females	$W=0.375 \times 10^{-5} L^{3.013}$	-	-	CSIRO (1995)

3.3 Mortality

Estimates of total mortality rates of 0.31 for male, and 0.20 for female blue grenadier in Australian waters were produced by Evans (1986) based on 1984 commercial catch data (Table 6). Natural mortality rates assumed for stock assessment work by Punt et al (in press) are between 0.2 and 0.3 for females and 120% higher for males.

Table 6 – Total and natural mortality rates for blue grenadier in Australian waters (age in years; dashes indicate data not available).

Year	Type	Sex	Age Range	Mortality Estimate	S.E.	Author
1984	Total	Male	5 - 20	0.31	-	Evans (1986)
		Female	5 - 23	0.20	-	
2000	Natural	Male	-	-	-	Punt et al (in press)
		Female	-	0.2 – 0.3	-	

4 POPULATION STRUCTURE

Blaber (1984) found no evidence of more than one stock of blue grenadier in Australian waters. Through a genetic study of tissue samples of the heart, muscle and liver of fish collected from eastern, western and south eastern Australia, little genetic variation was detected between the three areas, and most of the variation found was within samples and between samples from the same region. In the same study, highly significant differences ($P<0.01$) were found between the Australian samples and a sample of New Zealand blue grenadier. This is strong evidence for the Australian and the New Zealand blue grenadier being separate stocks.

Livingston and Schofield (1996) found evidence for two different blue grenadier spawning stocks in New Zealand waters, with fish from the Cook Strait and Chatham Rise areas being morphometrically different from those from the West Coast and Campbell Plateau areas, based upon significant differences ($P>0.001$) in head shape. However, no evidence for a genetic difference between the two groups has been found (Horn and Sullivan, 1996).

A similarity index was created by Koopman et al (2000) which compares summaries of published information on maximum age, and uses an assigned habitat code, an assigned depth code, an assigned diet code, as well as a weighting factor for each of these pieces of information, for any two species. Koopman et al (2000) found the Australian and New Zealand populations of blue grenadier to be identical in terms of their similarity index.

4.1 Sex Ratio

Bulman et al (1999) found sex ratios (M:F) ranging from 1.68:1 to 2.09:1 from samples collected from spawning seasons during 1992 until 1995 (Table 7). It was suggested that these differences in ratios were due to factors such as differences in residence time on the spawning grounds between the sexes, or to the fishes availability to the sampling gear, as the sex ratio outside the spawning season is closer to 1:1 (Bulman et al, 1999).

Kuo and Tanaka (1984b) studied the catch records of a Japanese research trawler operating in New Zealand waters, and found that the male to female ratio was about 1:1 for fish under 62cm in total length, but that females became dominant in the size classes where total length exceeded about 92cm.

Table 7 – Summary of length frequency data used by Bulman et al (1999) in estimating sex ratio.

(*Source*: Bulman et al, 1999)

Sampling Month	Sex	Year				Total	Sex Ratio (M:F)
		1992	1993	1994	1995		
June	Male	15473	11800	21218	26604	75095	1.68:1
	Female	7332	5800	11204	20392	44728	
July	Male	638		21117	23721	25814	1.70:1
	Female	1478		17175	7872	13317	
August	Male		6900			6900	2.09:1
	Female		3300			3300	

5 FISHERIES

5.1 Fishing Gear

Blue grenadier are caught throughout the South East Fishery with demersal otter trawl gear (Kailola et al, 1993).

5.2 Fishing Areas and Seasons

5.2.1 Geographic Ranges

Within the South East Fishery of Australia, there are two distinct components to the blue grenadier fishery - the non-spawning fishery which concentrates on juveniles and sub-adults, and the winter spawning fishery which targets mature fish (Smith and Wayte, 2000). The highest catches of blue grenadier are taken off the west coast of Tasmania (Daley et al, 1997) where fisheries focus on the adult fish in the winter spawning aggregations.

5.2.2 Depth Range

In Australian waters, blue grenadier are commonly found between 200 and 700m, and are mainly caught in depths between 300m and 600m (Kailola et al, 1993).

5.2.3 Fishing Seasons

The highest Australian catches of blue grenadier are caught during winter (July to September), where the operations focus primarily on the spawning aggregations. At other times of the year when the adults are widely dispersed throughout the continental shelf of southern Australia, catches are relatively smaller (Thresher et al, 1988).

5.3 Fishing Operations and Catches

5.3.1 Effort and Intensity

Blue grenadier are fished widely in the South East Fishery, with operations based in Tasmania and Victoria, and smaller operations in South Australia and New South Wales (Figure 2).

5.3.2 Selectivity

The other species caught in abundance and retained by the blue grenadier fishery are pink ling (*Genypterus blacodes*), mirror dory (*Zenopsis nebulosus*) and blue eye (*Hyperoglyphe antarctica*), and most of the blue grenadier catch results from targeted fishing (Kailola et al, 1993).

Discard rates for blue grenadier dropped dramatically from 1998 to 1999, with the increase in retention due to the large 1994 year-class reaching a marketable length (Smith and Wayte, 2000).

5.3.3 Catches

Blue grenadier is one of the most important species in the South East Fishery according to both the quantity and the value of the catch, and the fishery is managed by the Australian Fisheries Management Authority (AFMA). The recorded 1999 retained catch of blue grenadier of 9326t (Figure 6) has been estimated to have had a gross value of $15.9 million (Smith and Wayte, 2000).

Since 1990 catches for blue grenadier have increased from 4% of the total retained catch from the South East Fishery to 34% in 1999; catches of blue grenadier between 1990 and 1999 have increased in weight by about 7000 tonnes (Smith and Wayte, 2000).

Blue grenadier are usually sold on the domestic fresh fish market, and the fish are mainly processed as fillets or cutlets (Kailola et al, 1993). Some of the catch is also exported as frozen fillets to the United States of America.

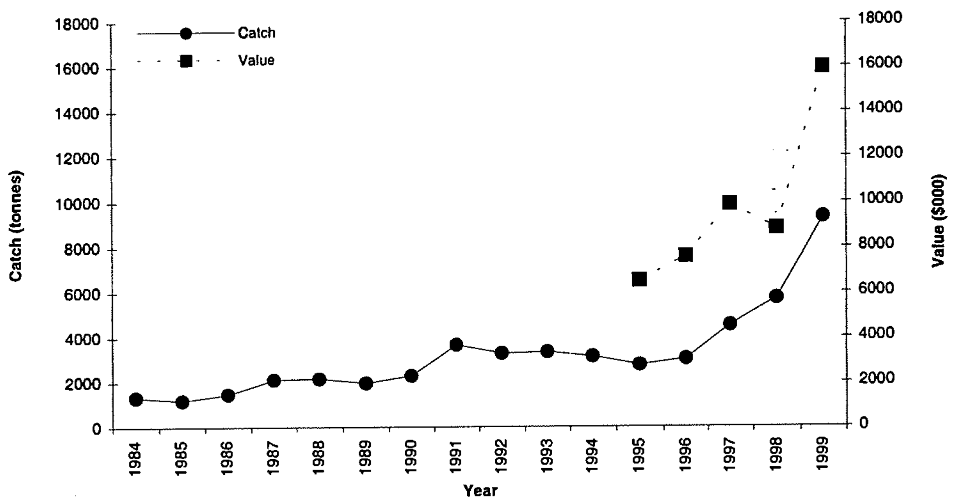


Figure 6 – Recorded catch (in tonnes) and estimated value (in $000's) for the blue grenadier fishery in the SEF 1984-1999 (Catches recorded by Commonwealth boats in Commonwealth and State waters).
(*Source*: 1984-1996 from Tilzey, 1999; and 1997-1999 from Smith and Wayte, 2000).

5.4 Fisheries in New Zealand

Blue grenadier are targeted throughout the year in various areas of the New Zealand EEZ, however the main blue grenadier fishery targets spawning aggregations off the West Coast of South Island and Cook Strait (Horn and Sullivan, 1996). A fishery based on the feeding aggregations of blue grenadier is present on the Chatham Rise and in sub-Antarctic waters.

In New Zealand, fishing for spawning aggregations concentrate in depths of around 300m to 700m, and feeding aggregations are targeted at depths between 400m and 800m (Ballara et al, 1998).

The main fishery for blue grenadier in New Zealand operates from late June to late August (continuing through into September in some years), concentrating on spawning aggregations. Catches of blue grenadier from feeding aggregations peak in May-June (Ballara et al, 1998).

Japanese trawlers began fishing in New Zealand waters in 1966, and blue grenadier were caught and retained since 1970; the highest catch was recorded in 1977 of 54,000 tons, and catches decreased after 1978 (Kuo and Tanaka, 1984a). The domestic blue grenadier fishery in New Zealand developed in the early 1970s, but remained relatively small up to 1985 (Horn and Sullivan, 1996). Today, blue grenadier are one of the most important species in New Zealand waters according to annual commercial landings (around 210,000 t annually).

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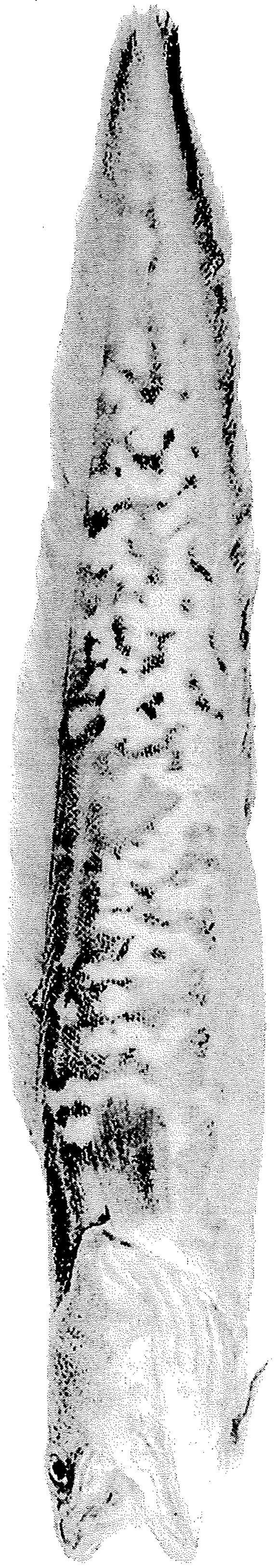
APPENDIX G. SYNOPSIS OF BIOLOGICAL DATA ON PINK LING, *GENYPTERUS BLACODES* (FORSTER, 1801)



Synopsis of biological data on Pink Ling

Genypterus blacodes (Forster, 1801)

CSIRO
MARINE RESEARCH

December 2000

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Cover photo illustration used with permission from "Australian Seafood Handbook - an identification guide to domestic species" by Yearsley, Last & Ward, 1999.

1 IDENTITY

1.1 Nomenclature

1.1.1 Valid Name

Genypterus blacodes (Forster, 1801).

1.1.2 Synonymy

Originally *Ophidium blacodes* (Bloch and Schneider, 1801); other.scientific names – *Genypterus microstomus* (Regan, 1903), *Genypterus australis* (Castelnau, 1872); other common names – pink ling, banded ling, common ling, rock ling, ling, Northern ling, hokarari.

1.2 Taxonomy

1.2.1 Affinities

Phylum	Vertebrata
Superclass	Pisces
Class	Osteichthyes
Subclass	Actinopterygii
Order	Ophidiiformes
Family	Ophidiidae

Figure 1 – Genypterus blacodes (Forster, 1801).

(*Source*: FishBase, 2000)

1.2.2 Species Description

"Body shallow (10-15% SL), very elongate, compressed, gradually tapering posteriorly. Head moderately small (22-25% SL); eyes moderately small (14-22% HL); mouth large (upper jaw length 42-45% HL), terminal, angled slightly obliquely, centre of posterior edge of each maxilla reaching below posterior margin of eye; teeth pointed, of moderate size, single row in each jaw, also single rows on vomer and palatines; opercula without spines; each anterior nostril a low tube, located above the upper lip near tip of snout; opercular membranes free from isthmus. Scales minute, cycloid, embedded, covering body and most of head, approximately 290-300 scales in horizontal series; lateral line nearly straight, not associated with scales. Dorsal and anal fins confluent with pointed caudal fin, of rather uniform height, dorsal arising above and just behind pectoral fin base. Pectoral fins small, reaching less than halfway to anus. Ventral fins of moderate length, arising below front of eyes, reaching short of posterior edge of opercula.

Pinkish, mottled with brown, wavy, vertical to oblique markings on sides, head uniformly brown above; dorsal, anal and caudal fins with broad black band posteriorly near base and whitish margin, dorsal with brown blotches anteriorly, pectoral fins with brown blotch near base. Large adults mainly pink. Reaches a maximum length of 200cm, common about 75cm". (Gomon et al, 1994).

1.2.3 Remarks on Taxonomy

Pink ling from south eastern Australian waters consists of two forms. A shallow water orange form can be found in shelf waters (out to 200m) and a pink form can be found in deeper slope waters (Kailola et al, 1993; Daley et al, 2000). It has been suggested that these two different forms of pink ling are two separate species (Gomon et al, 1994). Daley et al (2000) used genetic and morphometric analyses to determine if they were simply different forms of one species, or indeed two different species. No evidence suggesting that these two forms were different species was found; in fact, genetic identity between the two forms was found to be extremely high, no differences in allele frequencies, no evidence of any allozyme separation, nor any evidence for DNA microsatellite separation of fish from different depth strata. Daley et al (2000) therefore suggests that the orange and pink forms may safely be regarded as one species.

The rock ling (*Genypterus tigerinus*), from Australian waters, is commonly mistaken for pink ling as they are similar in appearance and inhabit shallow waters within the pink ling distribution, however the larvae of rock ling and pink ling are distinctively different (D Furlani, pers comm).

The South African kingklip (*Genypterus capensis*) is regarded by some as a synonym of the pink ling of the south west Pacific waters of New Zealand and temperate Australia (Morison et al, 1999), and is, like pink ling, a deepwater species. Daley et al (2000), through mitochondrial DNA analysis, found sequence divergence between samples of the kingklip and pink ling to range from 8.8-10.0%. Sequence divergence between samples of rock ling and pink ling ranged from 14-16%, whilst rock ling and kingklip sampled differed by 22-23%. The results of this study suggest that pink ling and kingklip are separate species, but are more closely related to each other than either species is to rock ling.

2 DISTRIBUTION

2.1 Total Area

Pink ling are found in the south west Pacific waters of New Zealand and temperate Australia, and are also recorded from South America (Kailola et al, 1993). Closely related species of *Genypterus* are also found in Australian waters (*G. tigerinus*) and waters surrounding South America (*G. chilensis*) and South Africa (*G. capensis*).

The Australian distribution of pink ling continues throughout the southern shelf and upper slope waters from southern Western Australia to New South Wales, including the waters around Tasmania (Tilzey, 1994; Kailola et al, 1993). Crowdy Head, New South Wales, is the northern limit of their east coast distribution (Kailola et al, 1993), and pink ling occur right through the Great Australian Bight (Newton and Klaer, 1991), to as far north as 33°06' in Western Australian slope waters (Williams, 1992).

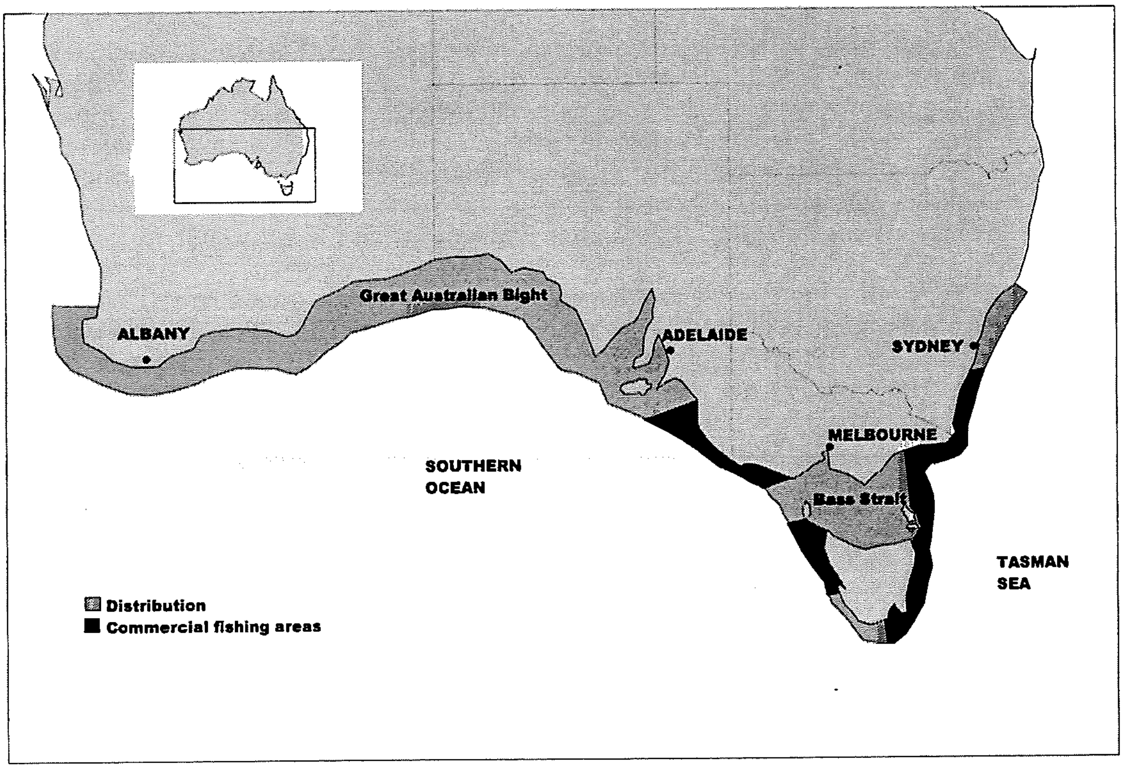

Figure 2 – Geographic distribution and major commercial fishing areas for pink ling in Australian waters.

2.2 Differential Distribution

2.2.1 Spawn, Larvae and Juveniles

It is thought that spawning by pink ling occurs to the west of Bass Strait during late winter and early spring, based on seasonal catch by depth data, which also suggest that the adults move into deeper water (450-550m) to spawn (Tilzey, 1994; Kailola et al, 1993, Smith and Tilzey, 1996). Pink ling in New Zealand are known to spawn between August and October (Paul, 1986).

Pink ling larvae have been caught in shelf and slope waters of New South Wales from July to September, and in coastal waters off Sydney from April to August (Furlani, 1998). The presence of the pelagic larvae in shelf waters suggests that the larvae are passively transported by ocean currents into coastal waters, if adults do indeed move into deeper water to spawn (Smith and Tilzey, 1996; Kailola et al, 1993).

Juvenile pink ling (<40cm TL) are present in the shallower shelf waters of the species distribution (Withell and Wankowski, 1989; Kailola et al, 1993).

2.2.2 Adults

Adult pink ling are demersal and inhabit depths between 20 and 900m (Furlani et al, 2000a), and are most abundant between 550 and 600m (Last et al, 1983; Tilzey, 1994). Pink ling live over a variety of bottom types including rocky ground and reefs, where they inhabit caves, to soft sand and mud (Tilzey, 1994), but appear to be most abundant over soft substrates, into which they burrow (Daley et al, 2000). Furlani et al (2000b) analysed the lengths of 123 pink ling and found that the species showed a distinctive progressive increase in size with increasing depth.

In New Zealand waters, adult pink ling are generally found to inhabit depths from 70 to 900m (McClatchie et al, 1997; Horn, 1993).

Although there are no records of regular migrations of pink ling, it is thought that pink ling move into deeper waters to spawn during winter and spring (Tilzey, 1994), and it is suggested that pink ling also move into deeper waters in summer (Smith and Tilzey, 1996). Anecdotal evidence from fishers suggest that adult pink ling move off reefs to trawlable ground during certain phases of the moon, and that adults and juveniles occasionally school in areas of the South East Fishery, particularly in the Horseshoe area of north-eastern Bass Strait (Smith and Tilzey, 1996).

Roberts (1987) reported a longline catch of pink ling from around North Cape, in New Zealand waters, of about 100 fish ranging in size from 60 to 180cm TL, the majority of which were <120cm TL. In this catch, Roberts (1987) estimated a sex ratio (F:M) of 1:2. The males in the catch were staged for maturity as resting or developing, in contrast to the females, which were staged as either maturing or ripe. Roberts (1987) suggests that the stages of development of the most mature gonads present in the sample indicates that the fish were not yet ready to spawn, and that breeding pink ling were not present (or not feeding from the baited hooks). Roberts (1987) suggests that this concentration of pink ling represented a prespawning aggregation.

3 LIFE HISTORY

3.1 Reproduction

3.1.1 Sexuality

The sexes are separate (dioecious), with no external sexual characters.

3.1.2 Maturity

Pink ling mature at an estimated 50cm or over (Daley et al, 2000), can reach 200cm in length, 20kg in weight (Daley et al, 1997; Yearsley et al, 1999), and can live to around 30 years of age. Lyle and Ford (1993) suggest that females mature at around 72cm; Smith and Tilzey (1996) suggest maturity at around 60cm.

3.1.3 Fertilisation

External.

3.1.4 Gonads and Fecundity

Gonad-somatic index (GSI) values for pink ling in Tasmanian and western Bass Strait are highest between August and November, with the highest mean value occurring in September (Lyle and Ford, 1993; Smith, 1992).

Little is known about the fecundity of pink ling, however it appears that fecundity is moderately low (Kailola et al, 1993; Tilzey, 1995).

3.1.5 Spawning

Little is known of the spawning behaviour of pink ling. Daley et al (2000) suggests that spawning may not be restricted to only certain seasons of the year, after observing a mixture of yolked and unyolked eggs in a dissected ovary from a female taken from Tasmanian waters. Horn (1996) states that a relatively long spawning season is indicated from gonad stage data collected from pink ling in New Zealand waters, and is also supported by a wide variation in the size of the first otolith ring.

3.1.6 Spawn

Pink ling eggs are undescribed. Eggs of the closely related kingklip (*Genypterus capensis*) are pelagic and spherical, 1.18 to 1.30mm in diameter, and have a single oil globule 0.09 to 0.11mm in diameter (Furlani, 1998).

3.1.7 Larval Phase

Furlani (1998) describes and illustrates the development of pink ling larvae collected from the coastal waters of northern and central New South Wales (Figure 3). Furlani (1998) examined 20 pink ling larvae ranging from 2.5 to 25.1mm in body length. Larvae are around (but less than) 2.5mm in length at hatching, and less than 24.1mm in length at settlement. The body is very elongate to elongate (body depth 9-12% of body length), and the head small (head length 14-20%). The snout length is typically less than the eye diameter, and the angle of the lower jaw is ventrally pronounced in preflexion larvae. Dorsal and anal fin rays develop from posterior to anterior, and larvae are lightly pigmented.

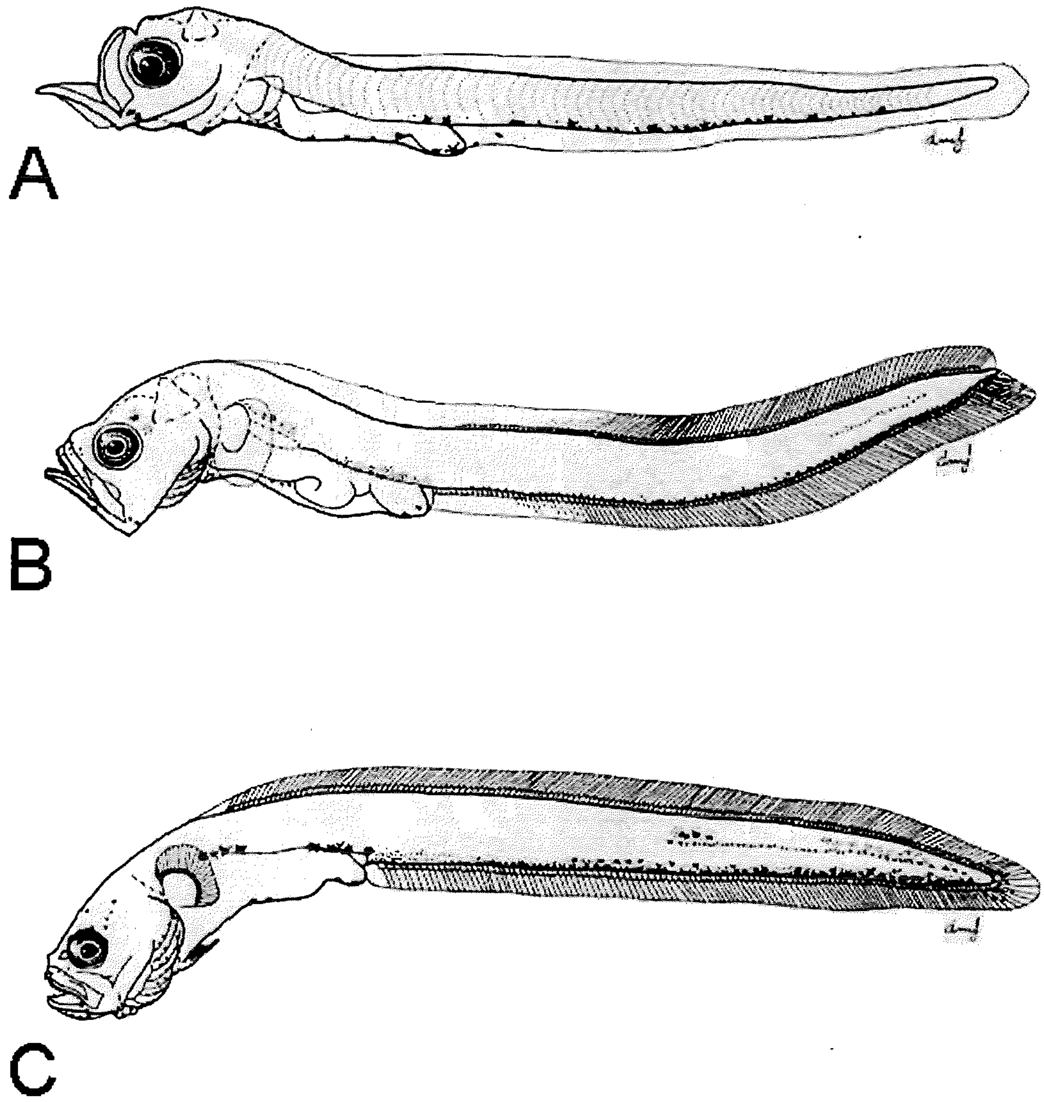

Figure 3 – Development of pink ling: **A**) 4.1mm, preflexion; **B**) 9.4mm, flexion (note pelvic-fin bud; myomeres omitted); **C**) 15.6mm, postflexion (myomeres omitted). A-C from NSW coastal waters. Illustrated by DM Furlani.

(*Source*: Furlani, 1998)

3.2 Feeding and Growth

3.2.1 Feeding

The mouth is large and terminal, on a slightly oblique angle, with moderately developed lips and the maxilla extending beyond the eye; the teeth are pointed and are of moderate size (Gomon et al, 1994). Pink ling are a benthic piscivorous species (Bulman et al, 2000).

Clark (1985b) suggests that pink ling, as benthic fish, feed to some extent during the day, and that dietary overlap with other benthic feeders studied from the Campbell Plateau, in New Zealand waters, is generally low, with differences in prey composition and relative prey size consumed.

3.2.2 Diet

Pink ling are active predators, feeding on crustaceans, molluscs and a variety of bony fish such as blue grenadier (*Macruronus novaezelandiae*) and *Lepidorhynchus denticulatus*. Studies of pink ling diet in New Zealand waters (Mitchell, 1984; Clark, 1985a) indicate an increase in the importance of fish in the diet with age, with a concurrent decrease in the importance of crustaceans. This pattern can also be supported in the contents of pink ling stomachs studied in Bulman et al (2000) of fish collected from the South East Fishery. Bulman et al (2000) found that the percentage occurrence of benthic fish in the diet of pink ling increased with increasing fish length (and therefore age), whereas the percentage occurrence of crustaceans decreased with increasing fish length.

Blaber and Bulman (1987) studied the stomach contents of 449 pink ling (ranging in size from 45 to 130cm SL) collected from the upper continental slope off Maria Island, in Tasmanian waters. In their study, Blaber and Bulman (1987) found that the macrourid *Lepidorhynchus denticulatus* is the most important prey item for pink ling (Table 1), with the highest percentage energy contribution (24.2%), while the highest percentage frequency of occurrence was for galatheid crustaceans (37.3%). They also noted marked changes in main prey species for pink ling from season to season, with blue grenadier predominating the diet in autumn, the galatheid crustacean *Munida haswelli* in winter and the macrourids *Coelorinchus spp.* and *Lepidorhynchus denticulatus* in summer.

Clark (1985a) sampled pink ling from the Campbell Plateau in New Zealand. Clark (1985a) found that natant decapods were the principal prey species of pink ling, and that macrourid fishes (particularly the striped rattail, *Coelorhinchus fasciatus*) were also important in the diet. Through the distribution of its prey species, Clark (1985a) suggests that pink ling feed near the bottom – the most abundant species of decopods in the diet of pink ling are benthic, and are found on muddy and sandy bottoms, and macrourids are generally considered to be benthopelagic.

Mitchell (1984), from a study in New Zealand waters, determined that pink ling were benthic feeders, with the dominant prey species being fishes, crustaceans and molluscs. Graham (1956) states that in general, pink ling in New Zealand waters feed on fishes, cephalopods and crustaceans.

Table 1 - Summary of information on the percentage energy contributions of prey categories to the overall diet of pink ling, collected from the upper continental slope off Maria Island, East Tasmania.

(*Source*: Blaber and Bulman, 1987).

Prey Item	% Energy Contribution	% Frequency of Occurrence
Pisces		
Lepidorhynchus denticulatus	24.2	5.0
Macruronus novaezelandiae	14.1	0.8
Helicolenus percoides	12.3	2.1
Unidentified fish	9.8	17.4
Coelorinchus sp. 4	5.9	3.7
Austrophycis marginata	4.8	5.8
Epigonus lenimen	3.0	0.8
Epigonus denticulatus	2.2	0.4
Muraenichthys sp.	0.7	0.8
Chlorophthalmus nigripinnis	0.5	0.4
Azygopus pinnifasciatus	0.5	0.4
Hoplostethus intermedius	0.4	0.8
Ventrifossa nigromaculata	0.2	0.8
Apogonops anomalus	0.2	0.4
Lampanyctodes hectoris	0.1	1.2
Coral	<0.1	0.8
Polychaeta	<0.1	1.2
Crustacea		
Galatheidae	7.1	37.3
Brachyura	1.3	7.1
Caridae	0.9	2.8
Isopoda	0.7	7.1
Ostracoda	0.2	0.4
Penaeidae	0.1	0.4
Euphausiacea	<0.1	2.1
Unidentified Crustacea	0.1	6.2
Mollusca (Gastropods, Squid)	10.5	3.3
Echinodermata (Ophiuroids)	<0.1	1.2
Others	<0.1	1.2
Number of stomachs sampled	449	
% Stomachs sampled empty	46	

3.2.3 Otoliths and Growth

Withell and Wankowski (1989) examined otoliths of pink ling collected from the continental slope of eastern Bass Strait in order to determine age and growth estimates. Whole otoliths or sections of otoliths were used in their study as opposed to scales due to the small size of the scales. Withell and Wankowski (1989) found that pink ling are a fairly long lived species, with fish from their samples reaching an estimated maximum age of 21 years, and an estimated maximum length of 128.2cm. No significant growth differences between males and females were observed by Withell and Wankowski (1989). Examples of the otolith samples used by Withell and Wankowski (1989) are presented in Figure 4.

Daley et al (2000) found that the shape of otoliths of pink ling varied considerably with growth, and that the otoliths of larger individuals were generally smoother and more rounded (Figure 5a). Daley et al (2000) also noted that there was considerable variation in the shape of otoliths from fish of the same sex and of similar size (Figure 5b), and suggests that this may be due to a possible difference in age of the fish sampled.

Horn (1993), in a study of pink ling from four areas around New Zealand, found that females grow faster and attain a greater size than males (Table 2), with calculated L_∞ values ranging from 125.7 to 160.1cm for females, compared to 95.1 to 146.1cm for males. Morison et al (1999) also found females to have a higher growth rate and a larger asymptotic size than the males in their study of an Australian sample of pink ling (Table 2)

In his study, Horn (1993) states that maximum age did not appear to vary between the sexes, with 1% of females sampled reaching 24-27 years, and 1% of males sampled reaching 23-26 years. The oldest recorded pink ling in this study was a 39 year old male, but only 7 out of 3133 otolith samples showed fish to be older than 30 years.

Furlani et al (2000b) found a maximum length of 118.0 cm, and a maximum individual weight of 7.4kg from 700 samples collected from the South East Fishery.

Length to weight relationships derived from studies of pink ling from Australian and New Zealand waters are presented in Table 3.

Table 2 - Parameters of the von Bertalanffy growth equation for pink ling (lengths in centimetres; ages in years; ± confidence limits are standard deviations; L_∞ is the asymptotic length; K is a parameter describing how rapidly L_∞ is achieved; T_0 is the hypothetical age at length zero; N/A indicates data not available).

Area	Sex	L_∞	K	T_0	N	Author
South East Fishery	Males + Females	99.9	0.186	-1.88	12181	Furlani et al (2000a)
Southern waters New South Wales (1970's)	Males	112.5	0.167	-0.769	142	Morison et al (1999)
	Females	126.0	0.151	-0.791	238	
South East Fishery (1994-97)	Males	96.2	0.198	-1.83	N/A	
	Females	117.8	0.14	-2.19	"	
East Bass Strait	Males + Females (1st Reader)	135.5 ± 3.3	0.095 ± 0.006	-1.410 ± 0.195	377	Withell & Wankowski (1989)
	Males + Females (2nd Reader)	134.9 ± 3.1	0.096 ± 0.006	-1.39 ± 0.185	377	
Chatham Rise (NZ)	Males	119.00	0.108	-1.24	1601	Horn (1993)
	Females	160.10	0.0760	-1.50		
Southern Plateau (NZ)	Males	95.10	0.1940	0.16	940	
	Females	125.70	0.1130	-0.67		
Bounty Platform (NZ)	Males	123.20	0.1280	0.28	221	
	Females	158.4	0.0790	-0.70		
West Coast South Island (NZ)	Males	146.10	0.0870	-0.13	371	
	Females	165.9	0.09	0.22		

Table 3 – Length-weight relationships for pink ling in Australian and New Zealand waters (weight in kilograms; length in centimetres; N is number of samples).

Area	Sex	Relationship	N	Author
South East Fishery (1979-87)	Males+Females	$W = 1.17 \times 10^{-6} L^{2.736}$	560	Lyle and Ford (1993)
	Males	$W = 5.23 \times 10^{-6} L^{3.004}$	259	
	Females	$W = 5.10 \times 10^{-6} L^{2.495}$	195	
South East Fishery (West of 147°E) (1987-89)	Males+Females	$W = 2.80 \times 10^{-6} L^{3.15}$	1167	Smith et al (1995)
	Males	$W = 2.80 \times 10^{-6} L^{3.15}$	500	
	Females	$W = 3.20 \times 10^{-6} L^{3.12}$	574	
South East Fishery (East of 147°E) (1982-96)	Males+Females	$W = 1.93 \times 10^{-6} L^{3.153}$	1397	Furlani et al (2000a)
South East Fishery (West of 147°E) (1982-1985)	Males+Females	$W = 2.78 \times 10^{-6} L^{3.157}$	371	
South East Fishery (1982-96)	Males+Females	$W= 2.93 \times 10^{-6} L^{3.139}$	1768	
Campbell Plateau, New Zealand	Males+Females	$W=3.388 \times 10^{-7} L^{3.56}$	90	Clark (1985b)

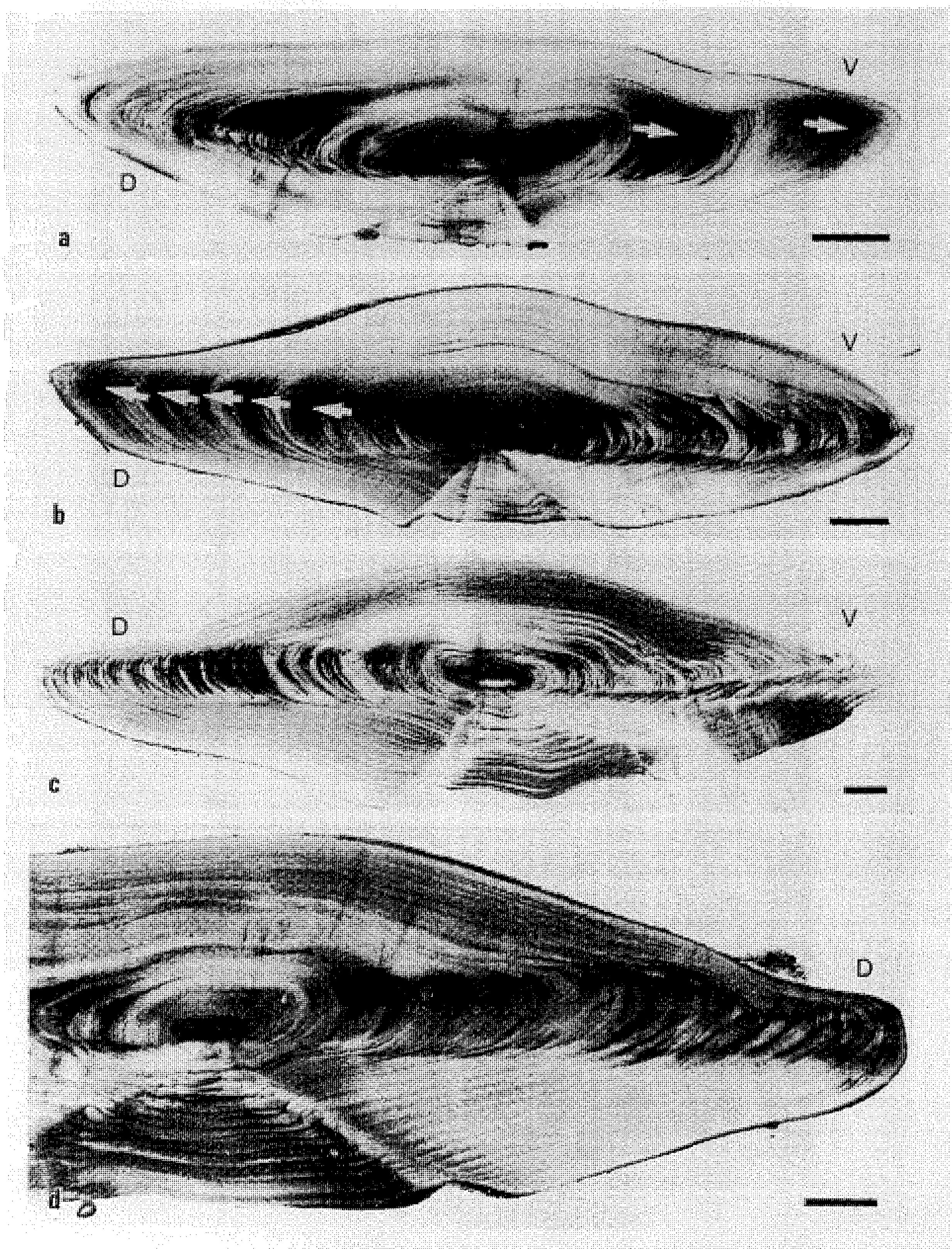

Figure 4 – Transverse sections of pink ling otoliths observed with reflected light: a) 2 year old; b) 5 year old; c) 14 year old; d) 18 year old (portion of otolith only). D=dorsal, V=ventral, arrows indicate annuli. Scale bars=0.5mm.

(*Source*: Withell and Wankowski, 1989).

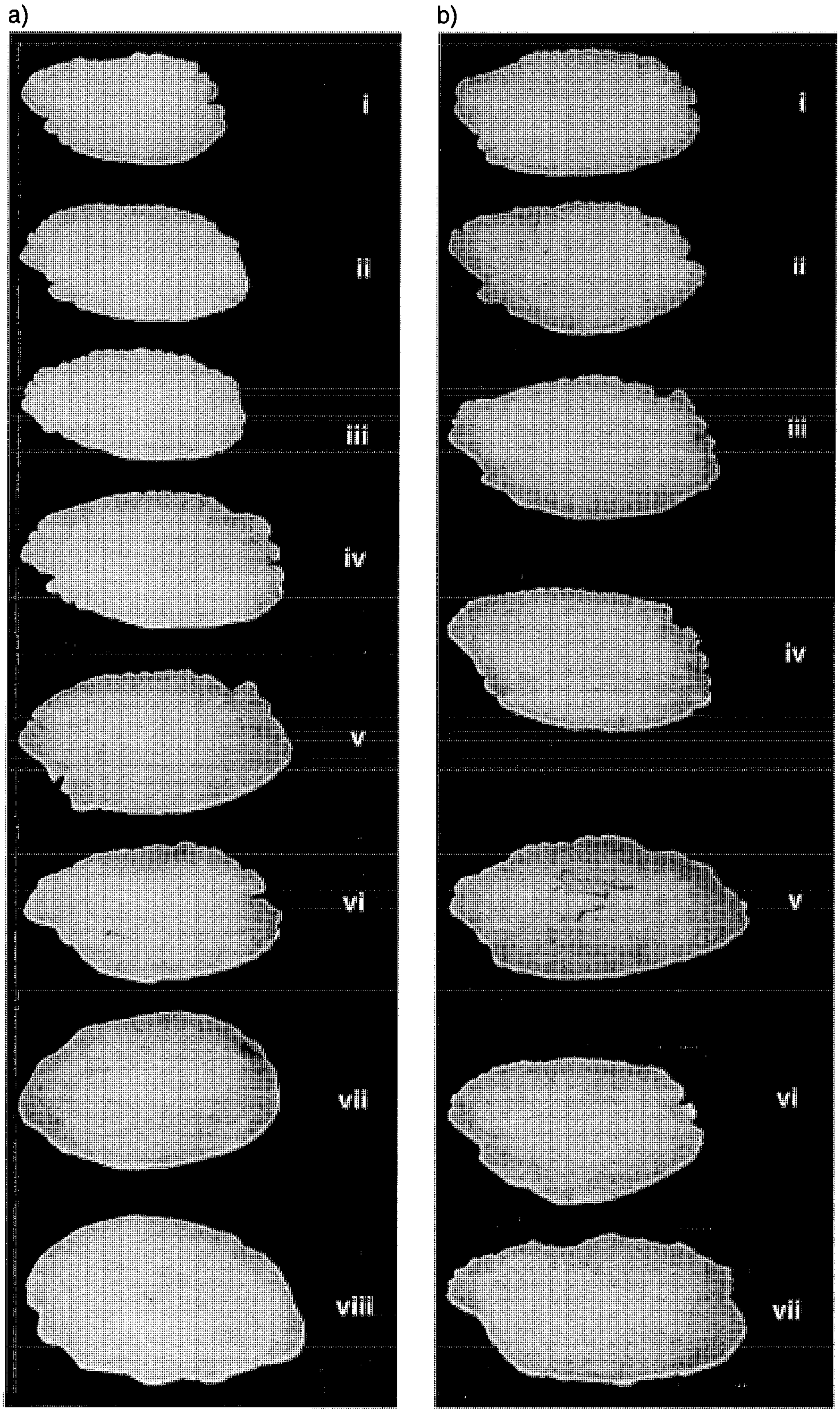

Figure 5 – Pink ling otoliths collected by Daley et al (2000).

a) Otolith samples showing the change in otolith shape with growth (males only shown here) i. 59cm TL; ii. 67cm TL; iii. 68cm TL; iv. 76cm TL; v. 84cm TL; vi. 83cm TL; vii. 88cm TL; viii. 98cm TL.

b) Otolith samples showing the variability in otolith shape between pink ling of a similar size (females only shown here) i. 85cm TL; ii. 88cm TL; iii. 88cm TL; iv. 90cm TL; v. 94cm TL; vi. 94cm TL; vii. 98cm TL.

(*Source*: Daley et al, 2000).

3.3 Mortality

Tilzey (1994) estimates from the size and age structure of the catch of pink ling sampled by Withell and Wankowski (1989) that the total annual mortality is around 20% for fish between 6 and 12 years old (assuming the sample from the survey was fully recruited and therefore equally vulnerable to the trawl from the age of six years onwards).

In New Zealand, Horn (1993) calculated a mean mortality estimate of 0.18 (range 0.17-0.20) from five samples of age data (Table 4). Thomson (2000) assumes a rate of 0.29 for fish 10 years old or less, and a rate of 0.14 for fish older than 10 years.

Table 4 – Estimates of mortality rates for samples of pink ling in Australian and New Zealand waters (age in years; 95% confidence intervals in brackets).

Area	Sex	Age Range	Mortality Rate (y^{-1})	Author
Chatham Rise (NZ)	Males+ Females	12-27	0.22 (0.17-0.27)	Horn (1993)
	Males+ Females	12-27	0.22 (0.20-0.25)	
Southern Plateau (NZ)	Males+ Females	8-27	0.20 (0.16-0.24)	
	Males+ Females	8-26	0.26 (0.23-0.29)	
West Coast South Island (NZ)	Males+ Females	11-30	0.21 (0.17-0.25)	
South East Fishery	Males+ Females	≤10	0.29	Thomson (2000)
	Males+ Females	>10	0.14	

4 POPULATION STRUCTURE

Through genetic and morphometric analyses conducted on both the orange and the pink forms of pink ling collected from different areas (from New South Wales, eastern and western waters of Tasmania, and eastern and western waters of Victoria), Daley et al (2000) found no evidence of more than one stock of pink ling in Australian waters.

Analysis of enzyme polymorphisms by Smith (1979) and Smith and Francis (1982) suggested that there are two main stocks of pink ling in New Zealand waters separated by the subtropical convergence. They also suggested that there could be another separate stock in the Campbell Island area. Colman (1995) analysed morphometric measurements of pink ling otoliths, and measurements of the head and pectoral fins of pink ling from New Zealand waters, and found evidence for at least three separate stocks in the New Zealand EEZ.

4.1 Sex Ratio

The female to male ratio found from Withell and Wankowski's (1989) study was 2:1, where immature individuals represented less than 1% of the total sampled. Morison et al (1999) found a sex ratio (F:M) of 1.68:1 (from a sample of 415 fish, with 20 fish of unknown sex).

5 FISHERIES

5.1 Fishing Gear

Pink ling are caught throughout the South East Fishery by demersal otter trawlers on the continental slope. Droplining, trapping and bottom set longlining methods are also used to catch pink ling in shelf and upper slope waters throughout the South East Non-Trawl Fishery (Kailola et al, 1993; Thomson, 2000).

5.2 Fishing Areas and Seasons

5.2.1 Geographic Ranges

Pink ling catches occur throughout shelf and slope waters, and a large component of the south east trawl catch is taken from waters between Cape Howe and Ulladulla in New South Wales (Tilzey, 1994).

5.2.2 Depth Range

In Australian waters, pink ling are commonly found between 20 and 900m (Furlani et al, 2000a), and the majority of large adults are caught from around 550 to 600m (Last et al, 1983; Tilzey, 1994).

5.2.3 Fishing Seasons

Pink ling are taken year round in the South East Fishery, however catch rates from demersal trawls are highest during spring and summer, rising to about 150kg per hour, in waters to the west and south east of Tasmania (Kailola et al, 1993).

5.3 Fishing Operations and Catches

5.3.1 Effort and Intensity

Pink ling support a profitable fishery off western Victoria and western Tasmania in the South East Fishery (Figure 2).

5.3.2 Selectivity

Most of the pink ling catch in the early 1990s was taken as bycatch by fishers targeting gemfish and blue grenadier with demersal trawls, and droplines targeting blue eye (Tilzey, 1994), but pink ling are now increasingly being targeted because of a good market price. Pink ling are also caught incidentally by the Southern Shark Fishery using bottom set longlines and gillnets in Victorian waters (Kailola et al, 1993; Tilzey, 1994)

5.3.3 Catches

Pink ling are an upper-slope species, and therefore were not caught in significant numbers during the early phase of the South East Fishery in Australian waters (Tilzey, 1995). Now, however, pink ling are among the most commercially important and profitable fishes of the South East Fishery, having rapidly grown in fishery size and significance in recent years. Pink ling commands a high price on the domestic market, prices significantly higher than many other quota species and, during 1999, was the fourth most valuable species caught in the South East Trawl Fishery (Smith and Wayte, 2000). Since 1992 recorded retained catches of pink ling from the south east have tripled, increasing from 567t to 1701t in 1999, with the 1999 catch being worth an estimated $5.6 million.

In Australian waters, capture of pink ling is controlled under limited entry regulations in the Great Australian Bight Trawl Fishery, and a catch quota system in the South East Fishery, both of which are managed by the Australian Fisheries Management Authority (AFMA). Within the south east, pink ling are managed as a single stock. Two species of ling are taken in the fishery, with rock ling (*Genypterus tigerinus*) rarely being caught in quantity by trawlers, but often mistaken for pink ling.

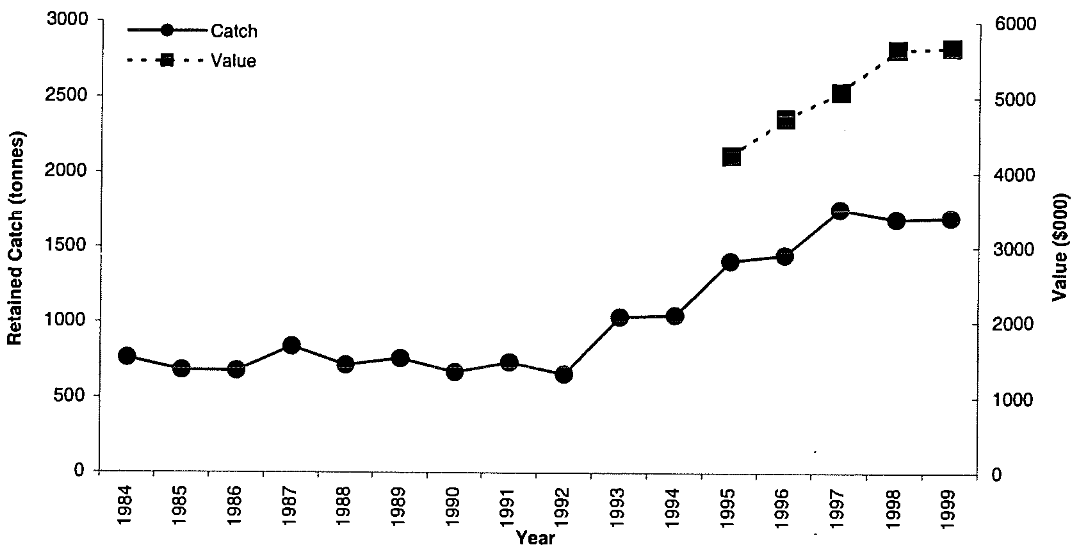

Figure 5 – Recorded catch (in tonnes) and estimated value (in $000's) for the pink ling fishery in the SEF 1984-1999 (Catches recorded by Commonwealth boats in Commonwealth and State waters).

(*Source*: 1984-1996 from Tilzey, 1999; and 1997-1999 from Smith and Wayte, 2000).

5.4 Fisheries in New Zealand

The fishery for ling in New Zealand waters is widespread, predominantly in areas around the South Island. In New Zealand EEZ waters, there are eight separate management areas for pink ling, in each of which pink ling are managed as a unit stock (Colman, 1995). New Zealand catches of pink ling have increased since the introduction of more efficient fishing techniques, with catches doubling from 1984 (7696t) to 1994 (15,961t).

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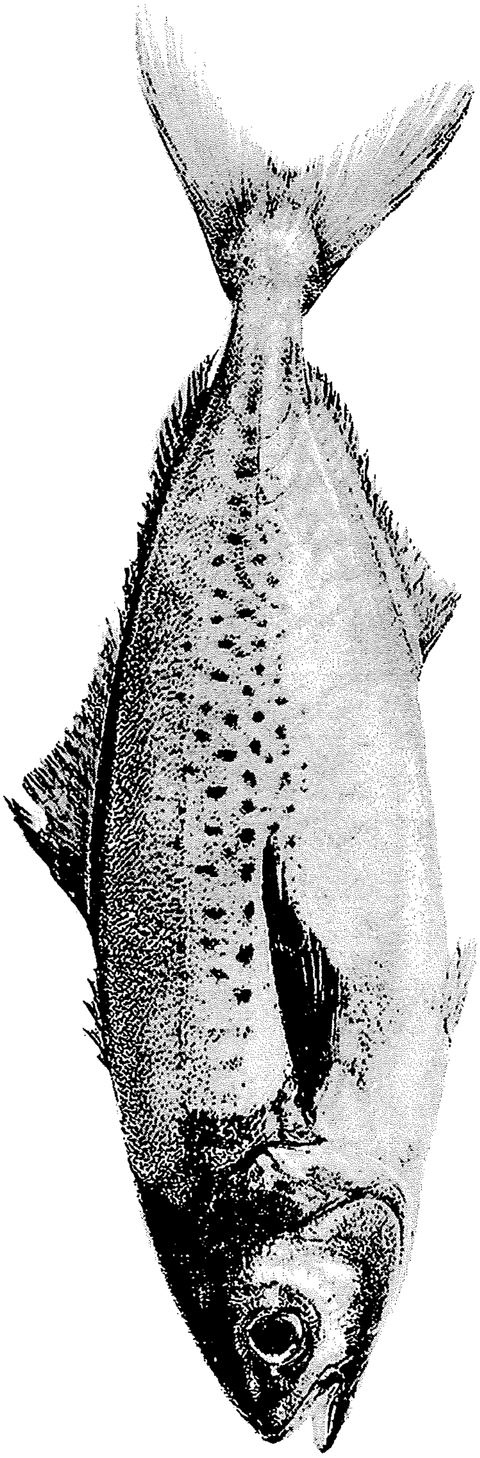
APPENDIX H. SYNOPSIS OF BIOLOGICAL DATA ON SPOTTED WAREHOU, *SERIOLELLA PUNCTATA* (FORSTER, 1801)

Synopsis of biological data on
Spotted Warehou

Seriolella punctata
(Forster, 1801)



CSIRO
MARINE RESEARCH

December 2000

Kim Woolley and Xi He

CSIRO Marine Research, Hobart, Tasmania

Cover photo illustration used with permission from "Australian Seafood Handbook - an identification guide to domestic species" by Yearsley, Last & Ward, 1999.

1 IDENTITY

1.1 Nomenclature

1.1.1 Valid Name

Seriolella punctata (Forster, 1801).

1.1.2 Synonymy

Other scientific names - *Seriolella bilineata* (Hutton, 1873), *Seriolella maculata* (Graham, 1953), *Neptomenus dobula* (Günther, 1869), *Neptomenus bilineatus* (Hutton, 1872); other common names – silver warehou, blue bass, mackerel trevalla, mackerel snotgall, spotted trevally, spotted trevalla, snotty nose trevally, trevally, silver-fish.

1.2 Taxonomy

1.2.1 Affinities

Phylum	Vertebrata
Superclass	Pisces
Class	Osteichthyes
Subclass	Actinopterygii
Order	Perciformes
Family	Centrolophidae

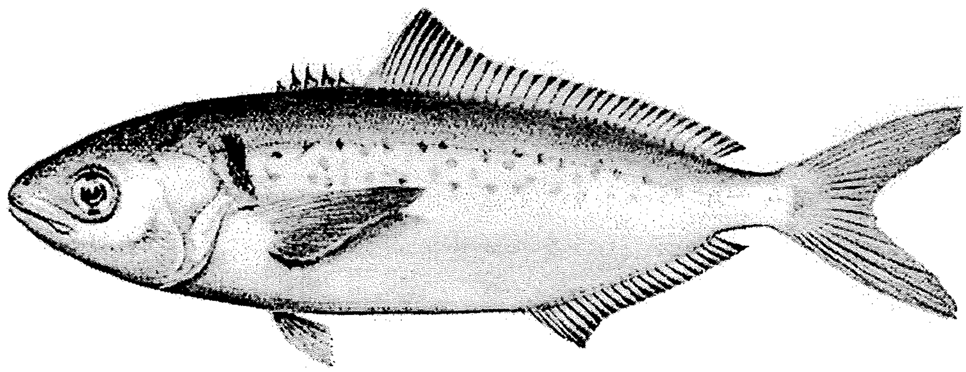


Figure 1 – Seriolella punctata (Forster, 1801).

(*Source*: FishBase, 2000)

1.2.2 Species Description

"Body streamlined, moderately shallow (27-33% SL), compressed; caudal peduncle slender, without lateral keels. Head of moderate size (26-31% SL); snout pointed; eyes small (14-23% HL); mouth small, maxillae reaching below front of eyes, slightly oblique; teeth fine, single row in each jaw. Scales very small and easily dislodged, anterior scale limits on nape with distinct fleshy margin forming pointed 'mask'; lateral line curved, about parallel to profile of back. Head and trunk covered with numerous small pores. Pyloric caeca few and finger-like. Two dorsal fins, first dorsal with origin above pectoral fin bases, having short stout spines, connected by membrane to base of second dorsal, second dorsal fin much higher, anterior fin rays longest, outer margin deeply concave; anal fin similar to and opposite second dorsal; caudal fin deeply forked. Pectoral fins of moderate size, not reaching to anus, moderately falcate. Ventral fins of moderate size, thoracic.

Silvery-blue to grey on back, almost metallic; paling somewhat on sides, silvery-white on belly; head darker grey-brown above, around snout and around eyes, creating a 'mask'; dark blotch above each pectoral fin base, followed in small examples by irregular lateral series of small dark spots which are lost in large individuals. Reaches a length of 66cm and a weight of 5.5kg". (Gomon et al, 1994).

1.2.3 Remarks on Taxonomy

The South American *Seiolella porosa* (Guichenot, 1848) is considered by some to be synonymous with *S. punctata* (Stehmann and Lenz, 1973 as cited in Cousseau et al, 1993; McDowall, 1982), however others believe it is a separate, valid species (Haedrich and Horn, 1969 and Nakamura, 1986 as cited in Cousseau et al, 1993; Haedrich, 1967).

Cousseau et al (1993) studied 188 South American *S. porosa* specimens and compared their description to the original description by Guichenot, and additional information given by McDowall (1982) and Nakamura (1986). They found that the most important differences between *S. porosa* and *S. punctata* were to do with the placement of the pelvic fins, presence of basibranchial teeth, the number of spines in the anal and the first and second dorsal fins, and the number of pyloric caecea.

Cousseau et al (1993) state that while *S. porosa* and *S. punctata* are very similar in morphology and colouration, they should not be considered to be synonymous, but that the hypothesis of a common "*punctata* type" ancestor for the two, as proposed by Stehmann and Lenz (1973), is possible.

Paul (1980) states that spotted warehou can be distinguished from the blue and white warehous by a distinctive colour pattern and skin texture, and also by a more slender body shape.

2 DISTRIBUTION

2.1 Total Area

Spotted warehou are found in waters surrounding temperate Australia, New Zealand and off both coasts of southern South America.

In Australia, the distribution limits are uncertain however spotted warehou have been recorded from waters of central New South Wales to South Australia, including waters around Tasmania (Kailola et al, 1993; Gomon et al, 1994).

In New Zealand, adult spotted warehou are found in the Subtropical Convergence region from the Chatham Islands to Banks Peninsula, and along both coasts of South Island (Grimes and Robertson, 1981).

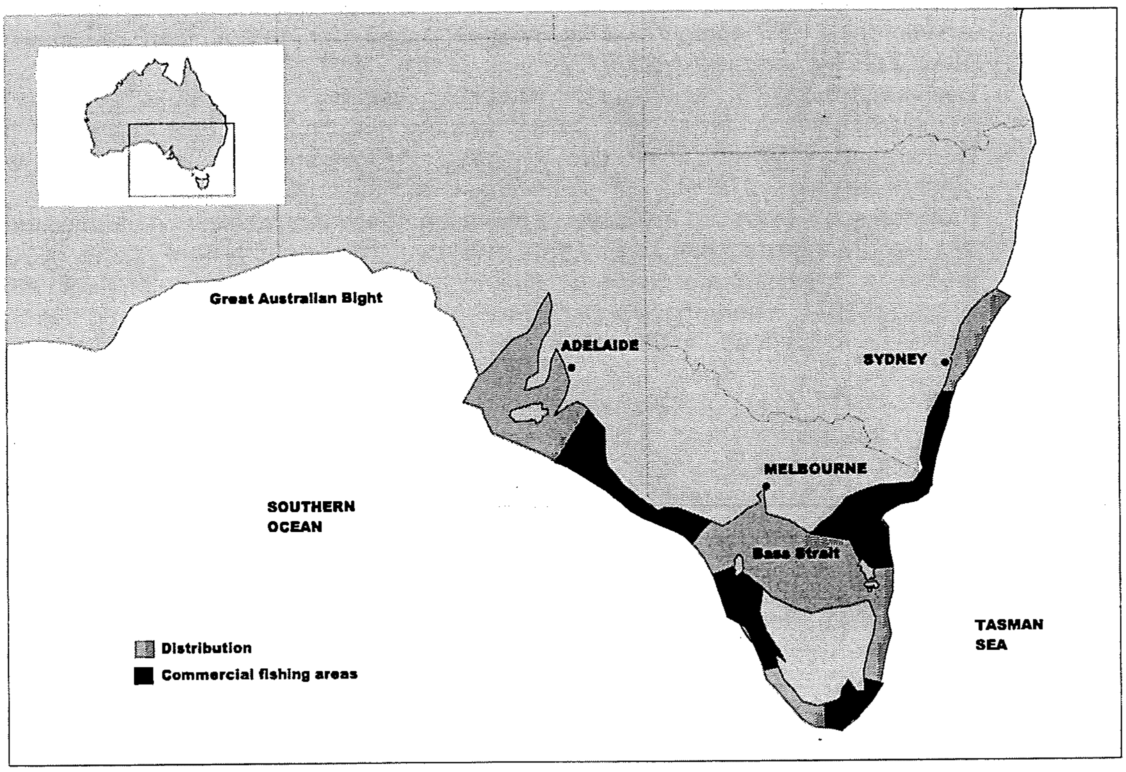


Figure 2 – Geographic distribution and major commercial fishing areas for spotted warehou in Australian waters.

2.2 Differential Distribution

2.2.1 Spawn, Larvae and Juveniles

Juvenile spotted warehou are pelagic, inhabit offshore areas to depths of 100m (May and Maxwell, 1986), and are often associated with floating objects such as jellyfish – juveniles have been observed living amongst the tentacles of the sea nettle, *Cyanea capillata* (Last et al, 1993). Juveniles are partly resistant to the jellyfish's toxin as they have a heavy mucous coating over the skin (Haedrich, 1967).

Subadult spotted warehou (less than 30cm long) are pelagic and move inshore in large numbers (May and Maxwell, 1986). Subadults are often found in bays and inlets during summer and autumn (Kailola et al, 1993; Smith, 1994).

2.2.2 Adults

Adult spotted warehou are usually demersal, inhabiting continental shelf and slope waters from a depth of 50m to up to 800m, but are more common in the 300-500m depth range (May and Maxwell, 1986; Grimes and Robertson, 1981). Furlani et al (2000) analysed the lengths of 1021 spotted warehou and found that the species showed a distinct progressive increase in size with increasing depth.

Spotted warehou are a schooling species, usually aggregating close to the seafloor, and there is some evidence that they move into the middle water column at night. Seasonal trends in catches of spotted warehou in south-east Australian waters indicate that some form of schooling behaviour may be associated with spawning (Kailola et al, 1993).

Annala et al (1999) state that spotted warehou aggregate to both feed and spawn. In New Zealand waters, both adult and juvenile fish migrate to feed along the continental slope off the south east and east coasts of South Island. Shuntov (1971) found that catches of members of the genus *Seriolella* in New Zealand waters tended to increase at Mernoo Bank (western area of Chatham Rise) at the times when catches decreased along the south coast of South Island, and vice versa. This provides some evidence for seasonal migration of warehou in New Zealand waters. It has been suggested that fish migrate in the summer months from places of winter spawning concentrations on the Chatham Rise to feed on the slope of South Island. Shuntov (1971) also suggests that some spotted warehou continue along the slope, ending up at the southern tip of South Island and in the Snares Island region.

Shuntov's (1971) suggestion of southward feeding migrations in New Zealand waters during the summer can also be supported by Gavrilov and Markina's (1979) observation of a maximum amount of macroplankton in the slope area of South Island during summer (95% of which is accounted for by tunicates, one of the main prey items for spotted warehou). Paul (1980) states that the eastern Stewart Island and the Snares Island waters of New Zealand are feeding grounds for adult spotted warehou during summer, when salps and other small jellyfish are concentrated in these areas by ocean currents

3 LIFE HISTORY

3.1 Reproduction

3.1.1 Sexuality

The sexes are separate (dioecious), and there is some evidence that the sexes may be slightly dimorphic, with respect to colour and/or relative proportions (Haedrich, 1967).

3.1.2 Maturity

Spotted warehou mature at an estimated 3-4 years of age, or a size of around 40cm FL, can reach an estimated maximum size of 66cm and have been estimated to live for up to 11 years (Caton and McLoughlin, 2000). Annala et al (2000) state that initial growth of spotted warehou is rapid, and that sexual maturity is reached at around 45cm FL, at around 4 years of age. Horn and Sutton (1995), in a study of otoliths of spotted warehou from New Zealand waters, found male fish in their sample to have a maximum age of 19 years (although less than 5% of fish were older than 14), and the females in their sample to have a maximum age of 23 years (with only 5% older than 15).

3.1.3 Fertilisation

External.

3.1.4 Gonads and Fecundity

Fecundity in spotted warehou is high, with the number of eggs ranging from 1.1 to 1.6 million per individual fish. Gonad somatic indexes (GSIs) are also high, with values of up to 40% reported (Smith, 1994).

3.1.5 Spawning

Spawning appears to occur from late winter through to spring in Australian waters (Smith, 1994), and there is no evidence for discrete spawning grounds, as spawning appears to occur throughout their Australian distribution. Larvae have been caught in coastal waters of eastern Victoria, Tasmania and southern New South Wales from July to October (Bruce et al, 1998).

In New Zealand, spawning occurs in late winter through to early summer, with spawning times varying with area (Grimes and Robertson, 1981). Annala (1989) and Livingston and Berben (1986) state that spawning occurs on Chatham Rise and west coast South Island in late winter and at the Chatham Islands in late spring-early summer. Gavrilov and Markina (1979) have suggested that spotted warehou undergo northward migrations from the Stewart/Snares Shelf to the Chatham Rise during winter to spawn in spring. Shuntov (1971) state that spawning of spotted warehou is generally completed by December, and that observed concentrations of fish in the Mernoo Bank area during winter and spring are initially pre-spawning and then spawning aggregations.

3.1.6 Spawn

Spotted warehou eggs are pelagic and spherical, range from 1.1mm to 1.2mm in diameter, and contain a single oil droplet 0.3mm to 0.35mm in diameter. Eggs have a homogeneous yolk and a smooth chorion. Laboratory reared fertilised eggs will hatch after 146 hours at 10-13°C (Grimes and Robertson, 1981; Bruce et al, 1998).

While the developmental features of spotted warehou are typical of planktonic teleosts, the melanophore pattern, egg size and oil droplet size are distinct enough to allow recognition of late stage eggs (Grimes and Robertson, 1981).

3.1.7 Larval Phase

Bruce et al (1998) describes and illustrates the development of spotted warehou from both reared specimens and larvae collected from Tasmanian waters (Figure 3). Bruce et al (1998) examined 25 larvae and found that at hatching, larvae are 2.3-2.8mm in length, and are >11.7mm at settlement. The body is elongate to moderate (body depth 11-34%), the head is small to moderate (head length 14-26%), and the larvae are moderately pigmented.

Grimes and Robertson (1981) describe the melanophore pattern in newly hatched larvae.

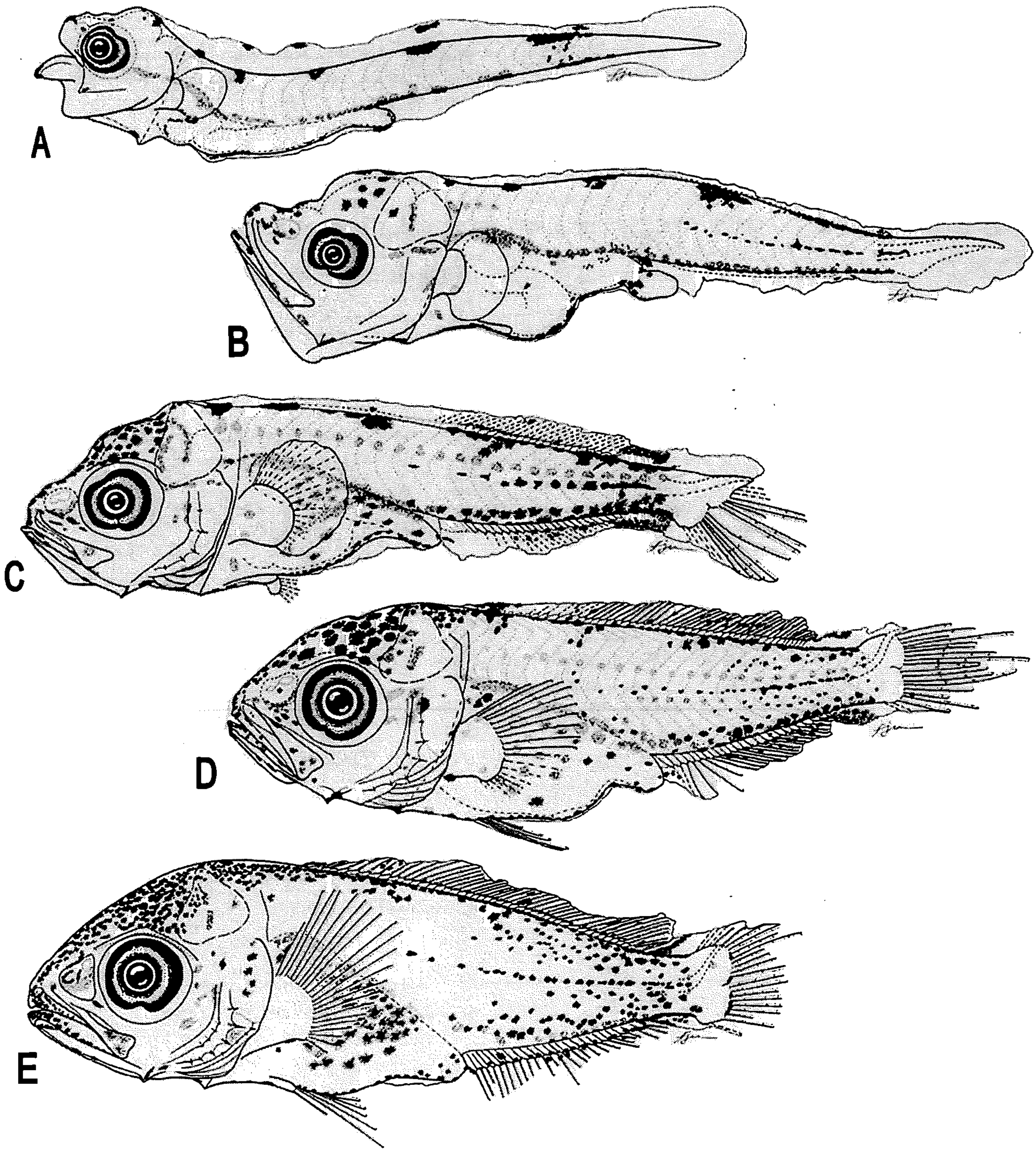


Figure 3 - Development of spotted warehou: **A**) preflexion, 3.8mm; **B**) early preflexion, 6.4mm (note pelvic-fin bud and developing dorsal and anal fins); **C**) late flexion, 8.3mm; **D**) early postflexion, 9.0mm; **E**) postflexion, 10.6mm.
[A-C, E from NSW coastal waters; D from Tasmanian coastal waters]. Illustrated by FJ Neira.
(Source: Bruce et al, 1988)

3.2 Feeding and Growth

3.2.1 Feeding

The small mouth is sub-terminal and slightly oblique, with fine teeth, and maxillae reaching below the front of the eyes (Gomon et al, 1994). Spotted warehou are pelagic invertebrate feeders (Bulman et al, 2000).

Heemstra (1977) describes the observation of a rich purple colouration of the posterior segment of the intestine in two spotted warehou samples collected in Australian waters. This purple segment of intestine was filled with a viscous purple fluid. In the absence of any published record of this modification, Heemstra (1977) suggests that the fish "may be able to void a cloud of bright purple faecal matter when frightened, and thus distract or (if the purple fluid is particularly distasteful) deter an attacking predator".

3.2.2 Diet

Bulman et al (2000) studied the stomach contents of 462 spotted warehou, and found over 80% of stomachs contained pelagic invertebrates (Table 1), and that nearly 50% (by weight) of the prey items were members of the class Thaliacea (pyrosomes and salps). Smith (1994) states that adult spotted warehou eat mainly planktonic tunicates. McDowall (1982) states that this species is a macroplankton eater, living on the tunicate *Pyrosoma*, amphipods, coelenterates and salps.

Gavrilov and Markina (1979) found that the range of diet of fish of the genus *Seriolella* in New Zealand waters includes a small number of zooplankton of different taxonomic groups. It was found that amphipods and chaetognathans were the most common food source of juvenile spotted warehou, having frequencies of occurrence of 75% and 60% respectively (Table 2). The stomach contents of the adult spotted warehou studied by Gavrilov and Markina (1979) show a large component of the diet to be made up of tunicates (Table 3), with two species, *Iasis zonaria* and *Pyrosoma atlanticus* combining to make up 98% (by weight) of the diet.

Table 1 – Summary of information on stomach contents of spotted warehou collected from south east Australian waters during six research cruises by the *FRV Southern Surveyor* from 1993 until 1996 (numbers in survey columns are percentage wet weight of prey items within each survey; numbers in final column are total percentages of wet weight of prey items over the six surveys).

(*Source*: Bulman et al, 2000).

Prey Items	SS9305	SS9402	SS9405	SS9503	SS9602	SS9606	% wet weight of prey
Thaliacea	63.33	6.03	99.34	62.89	64.78		49.397
Unidentified	31.69	93.48	0.01	32.18	20.84	42.66	36.812
Cnidria			0.16		12.59	14.51	4.544
Pisces	0.64		0.02	0.62	0.28	24.76	4.387
Ascidiacea		0.16	0.01		1.3	17.56	3.172
Cephalopoda	3.54		0.4	3.52			1.243
Unidentified crustacea	0.74	0.01	0.04	0.74	0.01		0.257
Amphipoda	0.02	0.22	0.01	0.02	0.09	0.51	0.145
Polychaeta	0.02	0.09		0.02	0.02		0.025
Ectoprocta (bryozoans)					0.04		0.007
Echinodermata	0.01			0.01	0.01		0.005
Copepoda			0.01		0.01		0.003
Foraminiferida					0.02		0.003

Table 2 – Summary of information on stomach contents of specimens of juvenile spotted warehou (12-18cm FL) from waters around New Zealand, collected in all seasons from 1968 to 1977 (values for prey items are percentage frequency of occurrence, and percentage by weight).

(*Source*: Gavrilov and Markina, 1979).

Prey Items	% frequency of occurrence	% by weight
Amphipoda (*Hiperia* sp., *Phronima* sp.)	75	36.7
Chaetognatha (general sp.)	60	40.0
Euphausiidae (*Nyctiphanes australis*)	38	20.0
Copepoda (*Copilla* sp., *Sapphirina* sp., *Oucaea* sp.)	23	3.0
Decapoda (larvae)	9	0.3

Table 3 – Summary of information on stomach contents of specimens of adult (sexually mature) spotted warehou (32-67cm FL) from waters around New Zealand, collected in all seasons from 1968 to 1977 (values for prey items are percentage by weight).

(*Source*: Gavrilov and Markina, 1979).

Prey Items	% by weight
Tunicata	
Iasis zonaria	59.0
Pyrosoma atlantica	39.0
Amphipoda general sp.	1.0
Euphausiidae (*Nyctiphanes australis*)	0.7
Coelenterata general sp.	0.3

3.2.3 Otoliths and Growth

Furlani et al (2000) found a maximum length of 58.0cm, and a maximum individual weight of 2370g from 2125 samples measured for length frequency. In the same study, the largest aged fish was 52.0cm in length, and the maximum aged sample was nine years old. McDowall (1982) studied 23 samples of spotted warehou from the south east coast of South Island, in New Zealand waters, from 10.25cm to 58.20cm in length.

Gavrilov (1974) determined growth rates and ages from scales of spotted warehou specimens from New Zealand waters. Gavrilov (1974) found variations in growth rate during the life cycle of spotted warehou, with the highest growth increase observed in four year old fish (ie after the first spawning). Horn and Sutton (1995) also state that growth is most rapid in spotted warehou up to the time of sexual maturity, and that growth slows markedly after the time of first spawning.

McDowall (1982) states that spotted warehou attain an approximate adult form at a small size, as specimens in his study of about 10.0cm FL were easily recognisable as spotted warehou. McDowall (1982) states that this indicates that no obvious changes in the body shape of the fish occur with growth.

Horn and Sutton (1995) state that female spotted warehou have a faster rate of growth than males and reach a larger maximum size (Table 4), although length at age is almost identical for the two sexes up to the age of five. Horn and Sutton (1995) also found that female spotted warehou appear to live longer than males.

Length to weight relationships for spotted warehou are presented in Table 5.

Table 4 - Parameters of the von Bertalanffy growth equation for spotted warehou (lengths in centimetres; ages in years; numbers in brackets are 95% confidence intervals; N/A indicates data not available; L_∞ is the asymptotic length; K is a parameter describing how rapidly L_∞ is achieved; T_0 is the hypothetical age at length zero).
**Calculated parameters from Gavrilov (1974) are referenced here as given in Horn and Sutton (1995).*

Area	Sex	L_∞	K	T_0	N	Author
South East Fishery	Males+ Females	54.97	0.36	-0.20	N/A	Smith (1991)
South East Fishery	Males+ Females	52.44	0.321	-0.76	N/A	Thomson (2000)
New Zealand	Males + Females	58.4	0.36	-0.20	N/A	Gavrilov (1974)*
SE Coast South Island (NZ)	Females	54.5 (54.0-55.0)	0.33 (0.31-0.35)	-1.04 (-1.19 to -0.89)	413	Horn & Sutton (1995)
	Males	51.8 (51.3-52.3)	0.41 (0.38-0.43)	-0.71 (-0.83 to -0.60)	383	
Southern Chile	Females	56.0 (54.7-57.4)	0.23 (0.21-0.24)	-0.52 (-0.59 to -0.44)	407	Aguayo & Chong (1991)
	Males	53.4 (50.5-56.3)	0.24 (0.21-0.28)	-0.48 (-0.66 to -0.30)	310	
	Males + Females	55.7	0.23	-0.49	717	

Table 5 – Length-weight relationships for spotted warehou (weights in grams; length in centimetres FL).

Area	Sex	Relationship	Author
South East Fishery	Males+Females	$W=0.004 \times L^{3.4}$	Smith (1991)
South East Fishery	Males+Females	$W=0.0065 \times L^{3.27}$	Thomson (2000)
Chatham Rise (NZ)	Males+Females	$W=0.00848 \times L^{3.214}$	Annala et al (2000)
Southland (NZ)	Males+Females	$W=0.00473 \times L^{3.380}$	
Southern Chile	Females	$W=0.00738 \times L^{3.20594}$	Aguayo & Chong (1991)
	Males	$W=0.00688 \times L^{3.24586}$	
	Males+Females	$W=0.00484 \times L^{3.31430}$	

3.3 Mortality

Horn and Sutton (1995) estimate an instantaneous natural mortality rate of 0.25 from a study of spotted warehou from New Zealand waters. Thomson (2000) assumes a natural mortality parameter of 0.25, with a range of 0.20 to 0.30.

4 POPULATION STRUCTURE

For assessment and management purposes, the south east Australian population of spotted warehou is considered to be a single stock. Although there have been no previous studies into the stock status of spotted warehou, Tilzey (1999) states that widespread catches and industry comment have indicated that this species are abundant in the South East Fishery (SEF).

5 FISHERIES

5.1 Fishing Gear

Spotted warehou are taken by bottom and coastal set gill nets, and also by trawlers in the South East Fishery with demersal otter trawl nets (Kailola et al, 1993).

5.2 Fishing Areas and Seasons

5.2.1 Geographic Ranges

Kailola et al (1993) states that the main trawling grounds for warehous (both spotted and blue) are off southern New South Wales, eastern and western Victoria, and north-western Tasmania within the South East Fishery (Figure 2). Juvenile and sub-adult spotted warehou are also taken by recreational fishers in large bays and estuaries throughout their distribution, however adults are rarely caught recreationally (Smith, 1994).

5.2.2 Depth Range

Spotted warehou catches are greatest from depths of 150 to 250m, with catch rates peaking in the 200 to 249m depth range, and to a lesser extent between 400m and 550m (Smith, 1994).

5.2.3 Fishing Seasons

The highest catches of spotted warehou are caught from late winter to early spring (Kailola et al, 1993). Smith (1994) states that 58% of the total spotted warehou catch in the waters of the South East Fishery is caught in winter.

5.3 Fishing Operations and Catches

5.3.1 Effort and Intensity

In Australian waters, spotted warehou were first landed domestically in marketable quantities in the mid to late 1970s (Smith, 1994). Catches were first taken from southern New South Wales and north-east Victoria, and rose rapidly due to an increase in market acceptance of the fish.

The highest catch rates for spotted warehou are from southern New South Wales and north-east Victoria, eastern and western Tasmania and western Victoria, corresponding to the areas of highest catch weights (Smith, 1994).

5.3.2 Selectivity

In 1994, just over half of the spotted warehou catch was estimated to have been targeted. The low targeting estimate is supported by the fact that effort peaks in the 100-149m depth range, whereas catch peaks in the 150-199m depth range and catch rate in the 200-249m (Smith, 1994).

Spotted warehou are also caught by fishers targeting blue warehou in the Southern Shark Fishery. Both blue and spotted warehou are caught and retained by gillnet fishing for school sharks (*Galeorhinus galeus*) and gummy sharks (*Mustelus antarcticus*) also in the Southern Shark Fishery, however the quantity of spotted warehou is relatively small (Smith, 1994).

5.3.3 Catches

The trawl fishery for spotted warehou is managed by the Australian Fisheries Management Authority (AFMA). In 1992 a total allowable catch (TAC) for spotted warehou was introduced which grouped the species with blue warehou, however separate catch limits were set for each species in 1993. Catches of blue and spotted warehou within the Southern Shark Fishery are also managed by AFMA. The Tasmanian State Government manages the gillnet fishery for warehou in coastal waters around the State.

Spotted warehou are generally sold on the domestic fresh fish market within Australia, and are often marketed with blue warehou, but when they are marketed separately, spotted warehou tend to gain lower prices (Kailola et al, 1993).

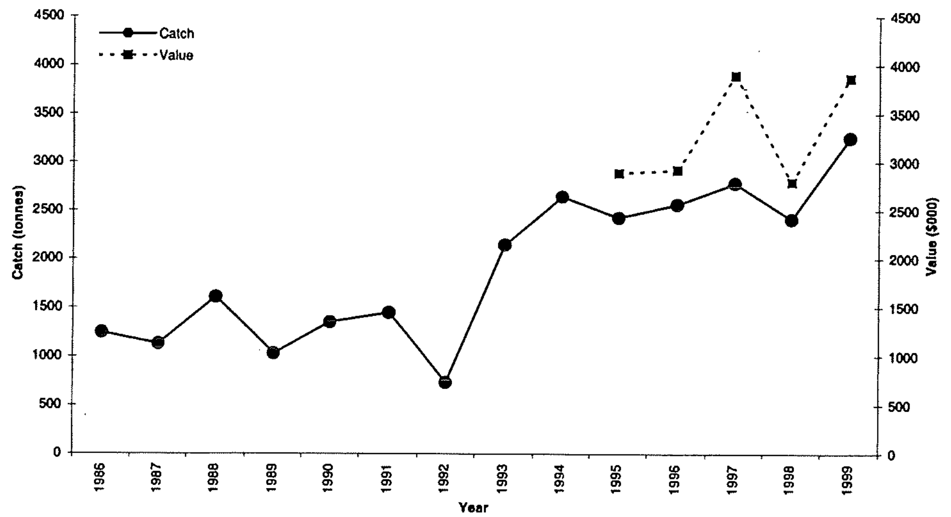


Figure 4 – Recorded catch (in tonnes) and estimated value (in $000's) for the spotted warehou fishery in the SEF 1984-1999 (Catches recorded by Commonwealth boats in Commonwealth and State waters).
(*Source*: 1984-1996 from Tilzey, 1999; and 1997-1999 from Smith and Wayte, 2000).

Annual spotted warehou trawl catches from the South East Fishery have increased over recent years due to catches on the west coast of Tasmania associated with the blue grenadier (*Macruronus novaezelandiae*) spawning fishery (Smith and Wayte, 2000). In 2000, catch rates of spotted warehou from the blue grenadier spawning fishery had doubled since the 1991/1992 season, with the availability of spotted warehou having increased markedly during the late 1990s due to a strong year class, spawned in 1993, passing through the fishery (Smith and Wayte, 2000).

5.4 Fisheries in New Zealand

Spotted warehou have been caught domestically in New Zealand since 1978 (when the New Zealand EEZ was declared) from the Chatham Rise and Stewart Shelf areas. Catches have since extended to the West Coast, Cook Strait, and south around the Auckland Islands, with fishers concentrating on winter spawning populations. Prior to the declaration of the EEZ, spotted warehou are thought to have made up a considerable proportion of the foreign fleet annual warehou catch (about 15,000 tons/year), which, at this time, included spotted warehou, common (blue) warehou and white warehou. A report of Japanese experimental fishing (Inoue et al, 1968) carried out in New Zealand waters using an otter trawl states that among the species caught, the meat of spotted warehou was "tasty".

Spotted warehou were a valuable export fish in New Zealand in 1985 with a value of about NZ$13.55 million, placing them behind orange roughy and blue grenadier in terms of dollars earned for New Zealand from deepwater fishing (Livingston and Berben, 1986).

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