Stock Assessment of the Queensland–New South Wales Tailor Fishery (*Pomatomus saltatrix*)

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QI04065

Queensland Government
Department of Primary Industries and Fisheries

QI04065
ISSN 0727-6273

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This publication provides an assessment of the state of the population of Tailor, one of Queensland's premier sport angling fishes, together with options for managing the fishery and recommendations for future research and data collection.

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Executive summary

Data on catch sizes, catch rates, length-frequency and age composition from the Australian east coast tailor fishery are analysed by three different population dynamic models: a surplus production model, an age-structured model, and a model in which the population is structured by both age and length.

The population is found to be very heavily exploited, with its ability to reproduce dependent on the fishery's incomplete selectivity of one-year-old fish. Estimates of recent harvest rates (proportion of fish available to the fishery that are actually caught in a single year) are over 80%. It is estimated that only 30–50% of one-year-old fish are available to the fishery. Results from the age-length-structured model indicate that both exploitable biomass (total mass of fish selected by the fishery) and egg production have fallen to about half the levels that prevailed in the 1970s, and about 40% of virgin levels.

Two-year-old fish appear to have become smaller over the history of the fishery. This is assumed to be due to increased fishing pressure combined with non-selectivity of small one-year-old fish, whereby the one-year-old fish that survive fishing are small and grow into small two-year-old fish the following year. An alternative hypothesis is that the stock has undergone a genetic change towards smaller fish; the true explanation is unknown.

The instantaneous natural mortality rate of tailor is hypothesised to be higher than previously thought, with values between 0.8 and 1.3 yr^{-1} consistent with the models. These values apply only to tailor up to about three years of age, and it is possible that a lower value applies to fish older than three.

The analysis finds no evidence that fishing pressure has yet affected recruitment. If a recruitment downturn were to occur, however, under current management and fishing pressure there is a strong chance that the fishery would need a complete closure for several years to recover, and even then recovery would be uncertain. Therefore it is highly desirable to better protect the spawning stock.

The major recommendations are

- an increase in the minimum size limit from 30cm to 40cm in order to allow most one-year-old fish to spawn, and
- an experiment on discard mortality to gauge the proportion of fish between 30cm and 40cm that are likely to survive being caught and released by recreational line fishers (the dominant component of the fishery, currently harvesting roughly 1000t p.a. versus about 200t p.a. from the commercial fishery).

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1. Introduction

Tailor (*Pomatomus saltatrix*) occurs in subtropical and temperate waters of Australia, Africa (where it is known as Elf, Shad or Tassergal), Europe, North America (known as Bluefish) and South America (Enchova). Australia has two distinct fisheries, one on the east coast concentrated in New South Wales and southern Queensland, and one in Western Australia. Further details of the species are provided by, for example, van der Elst (1976), Bade (1977), Dichmont et al. (1999, pp. 97–117), Hoyle et al. (2000), Williams (2002, pp. 162–165) and Brown et al. (2003).

Pomatomus saltatrix

Tailor fishing is a popular sport in Queensland and NSW, and the recreational line fishery has come to dominate the commercial fishery. The number of anglers present on beaches has increased dramatically over the last few decades. Claydon (1996) comments (p. 37), “The picnic is over. … There are ten times more anglers chasing tailor in 1995 than there were in ’75.”

Recreational line fishing on Fraser Island

Many industries such as ferry and tourism operators and tackle merchants rely on the recreational tailor fishery, and its popularity and economic value necessitate this stock assessment.

Tailor generally school by size, and the schooling allows commercial fishers to catch them efficiently by beach seine netting. The Queensland–NSW fishery consists of

- recreational line fishing, mainly from beaches, headlands and estuaries
- commercial beach seine netting
- commercial gill netting and tunnel netting, and
- incidental catch from other commercial fishing methods such as line fishing.

The geographical spread of Australia's east-coast fishery is shown in Figure 1.

Commercial beach seine fishers sorting a catch of tailor

Tailor mature in their second year of life, when many enter the fishery (Williams, 2002, p. 164), and are highly fecund. Spawning generally takes places over an extended period, possibly from winter right through to autumn. Fecundity increases with size and age (Conand, 1975; van der Elst, 1976; Bade, 1977). Tailor are present all year round at most locations, but there is a substantial spawning-related movement of fish from NSW to Fraser Island between autumn and the following spring.

A wide range of values of growth parameters for this species has been reported in the literature, and estimates appear not to be transferable between regions. Barger (1990) found substantial differences in growth even between the Gulf of Mexico and the US southern Atlantic coast. Other growth information can be found in Richards (1976), van der Elst (1976), Bade (1977), Krug and Haimovici (1989, 1991), Terceiro and Ross (1993), and Govender (1999).

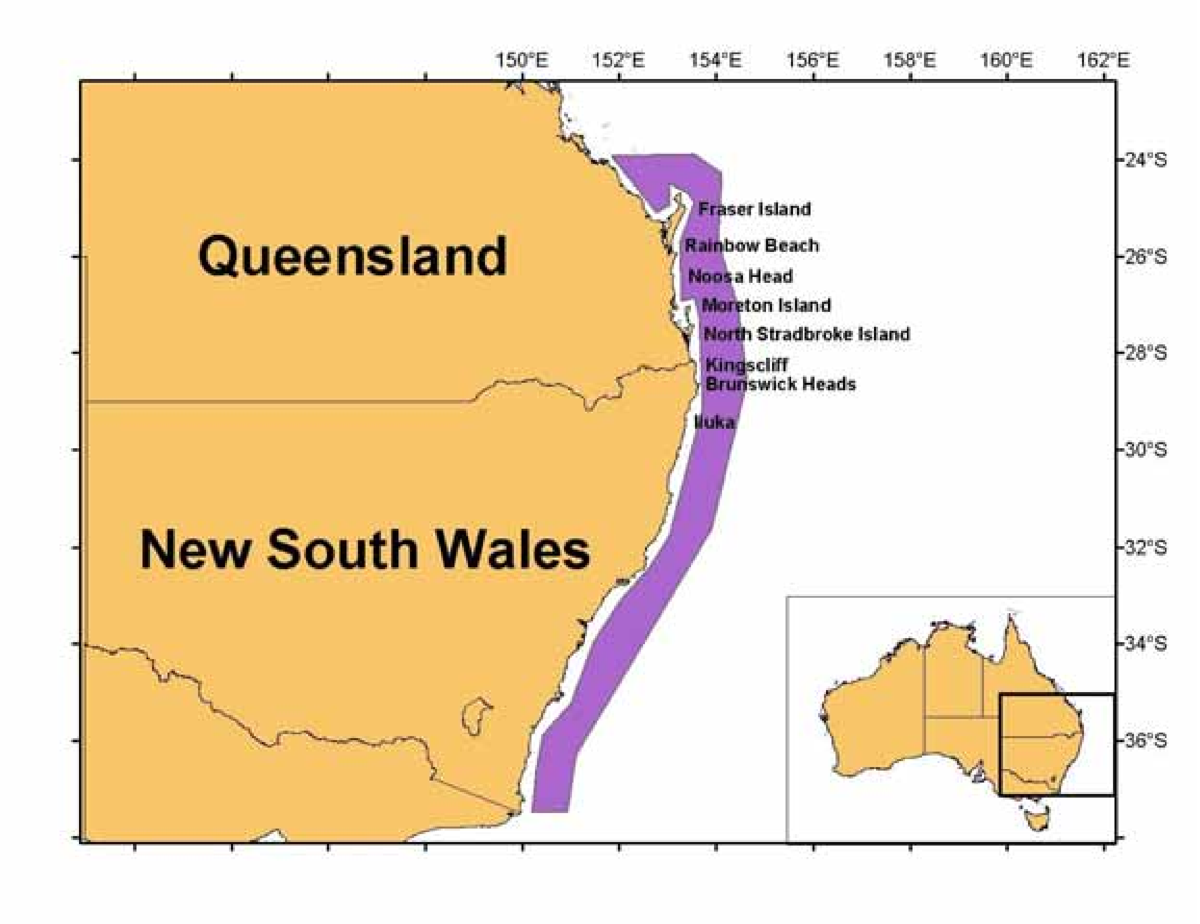


Figure 1: Geographical spread of the Queensland–NSW tailor fishery, with some major tailor fishing locations marked.

The following management measures have been applied to the eastern Australian fishery:

- minimum size limit 30cm total length (26.8cm fork length), introduced Queensland 1990, NSW 1993
- seasonal closure of Fraser Island to fishing, between 400m North of Waddy Point and 400m South of Indian Head, during September, introduced 1990, extended to the months of August and September in 2002
- bag limit 20 fish (30 for fishers staying on Fraser Island for 72 hours or more), introduced NSW 1993, Queensland 1 May 2002
- commercial net fishing ban in NSW (except for allowed “bycatch” of less than 100kg per fisher per day), introduced 1 September 2001
- Total Allowable Catch 120t for the Queensland commercial fishery (except for allowed “incidental catch” of less than 100kg per fisher per day), introduced 1 May 2002
- commercial net fishing ban on Fraser Island between Tooloora Creek and the northern end of North Ngkala Rocks, from 1 April to 1 September, introduced 20 September 2003.

2. Data sources and preliminary comments

The following data were obtained for analysis:

- Commercial logbook records including catch and effort from Queensland (1988–2003) and New South Wales (1984–2003) (from Queensland DPI&F database and NSW Fisheries)
- Historical reports on commercial harvest sales, not including effort, recorded by the Queensland Fish Board (1944–1981) (held on file at Southern Fisheries Centre) and NSW Fisheries (1940–1983) (kindly provided by NSW Fisheries).
- Recreational catch and effort data from Queensland (1997, 1999 and 2002) (DPI&F RFISH diary surveys)
- Recreational catch from Queensland and NSW in 2000 (National Recreational Survey, documented by Henry and Lyle, 2003)
- Fishing club records of catch and effort from Queensland (1954–2001) (DPI&F database)
- Charter fishing records of catch and effort from Queensland (1996–2003) (DPI&F database)
- Length frequency records and otolith ageing data from the Long Term Monitoring Program (1999–2003) (DPI&F database)
- Length frequency records and otolith ageing data from the FRDC Tailor Ageing Validation project (2000–2002) (held on file at SFC)
- Length frequency records and otolith ageing data from the FRDC Integrated Fish Stock Assessment and Monitoring Program (ISAMP) (1995–1997) (held on file at SFC)
- Length frequency records and tag return information from tagging studies conducted from 1987–1990 (led by Ian Halliday; held on file at SFC) and 1978–80 (conducted by Barry Pollock and David Bateman; held on file by DPI&F Long Term Monitoring Program)
- Length frequency records from a survey conducted by T. M. Bade for his 1977 Master's thesis (assumed to be from 1975) (manually entered from a copy of the thesis held at SFC).

In this report, lengths are expressed as fork length in centimetres. Regulated size limits are for total length. Bade (1977) gives the following equations relating fork length (L_f in cm) to total length (L_t in cm):

$$L_f = 0.896\, L_t - 0.1178$$

$$L_t = 1.114\, L_f + 0.1764.$$

The northern limit of the fishery is taken to be latitude 24° S, which is as far north as K- licensed (ocean beach) fishers have reported catches of tailor. In northern Queensland a fish generally known as "steelback" or "beach salmon" (*Leptobrama muelleri*) is locally known as tailor; catches north or 24° S recorded as "tailor" may actually be steelback.

A fishing year is defined in this report to be a calendar year. This puts the peak fishing seasons (approximately April in northern NSW through to September on Fraser Island) around the middle of the fishing year. It agrees with the fishing years over which Queensland recreational RFISH estimates are made, but contrasts with the May to April quota year used in Queensland, and the July to June year over which data are collected in NSW. Historical annual catches from 1944–81 (Queensland) or 1940–83 (NSW) were not converted to calendar years, because there are no effort data associated with them. The figures supplied from collection years are treated as if they come from calendar years. They are used only for inputting historical catch sizes to population dynamic models, whose use of such data does not rely on the timing of catches being exact.

Commercial fishing methods were difficult to distinguish in the Queensland CFISH database. The fishing method was generally not recorded in the early years (1988 to the mid 1990s). Dichmont et al. (1999, p. 87) described an algorithm for classifying catches by fishing method, using time of year and net length. A drawback of this algorithm is that it assigns catches to beach netting only between April and August (the K-licence season), even though there is much beach netting outside this season (when a K-licence is not required). For the analysis presented here, all catches by K-licensed fishers were assigned to beach netting. The algorithm of Dichmont et al. was used to distinguish tunnel netting from gill netting: net lengths greater than 800m in QFISH grid squares V34 and W37 were assigned to tunnel netting.

The tagging experiments from which data were available generally had low return rates (under 10%), short times at liberty (often only a few weeks), and were carried out with aims other than the estimation of mortality rates. Tagging data are used here only to provide length-frequency distributions. It is possible that future analysis may be able to use tag recovery records in the estimation of population parameters such as instantaneous fishing and natural mortality rates.

Length-frequency and ageing data were restricted to samples taken from the recreational fishery on Fraser Island over the period July to October. This was the only season-location combination for which many years of samples were available. Length-frequency data were available for 1975, 1978–80, 1987–90, 1995–97 and 1999–2003, and ageing data for 1995–97 and 1999–2003.

Ageing data were accepted as accurate from 1995 onwards. Ageing of Tailor was attempted prior to 1995, notably by Bade (1977) who examined scales, but the results were not considered reliable enough to use here. The technique of age determination from otoliths in tailor was validated by Brown et al. (2003, the Tailor Age Validation or TAV project), although they give the caveat (Appendix 5, p. 11) that "in the USA … the level of ageing error for this species is considered unacceptable and alternative stock assessment techniques are employed." The TAV project re-examined many of the otoliths examined by Hoyle et al. (2000, the ISAMP project): some otoliths were aged differently, but no biases were apparent, so the ISAMP ages were accepted as accurate for the work presented here.

The acceptance of ageing data as accurate produces unexpected relationships between age and length (see section 4), and hence has a big impact on the entire stock assessment, but we have been assured that the technique for age determination from otoliths is sound and that expert readers of otoliths can accurately discern the annual rings in an otolith.

3. Catch sizes and catch rates

3.1 Recorded catch sizes

The term "catch" is used here synonymously with "harvest", to mean the total weight of fish that were retained by fishers. Some fish were discarded by recreational fishers for various reasons (e.g., undersize, over bag limit), and these were assumed to have survived. Brown et al. (2003, Appendix 6, pp. 7–8) comment on an experiment on discard mortality of bluefish in the USA, in which 25% of fish died within 24 hours, and 54% within 86 days, many from fungal infections on the skin caused by handling. Undersize fish caught commercially by beach seine are almost always dead, and are usually buried on the beach. Commercial fishers may, however, have the opportunity to assess whether a school is composed of undersized fish before they decide to net it.

Commercial data from 1944–2003 are plotted in Figure 2(a, b). NSW data were actually provided starting from 1940–41, but there are no records for 1942–43 or 1943–44, so 1944 was considered a reasonable starting year for analysis. Queensland data were recorded in pounds until 1973, and in kg from 1974; all measurements have been converted to metric tonnes in Figure 2(a). The Queensland data have a gap between 1981, when the Queensland Fish Board data ended, and 1988 when the CFISH logbook records began.

The commercial catch fell in both States in the mid 1970s due to a lack of demand, especially the loss of a contract to supply tailor as the fish used in Queensland hospitals and institutions (Dichmont et al., 1999, p. 105). The rise of a variety of takeaway food shops in opposition to traditional fish-and-chip shops may have also played a part.

Commercial catch size by fishing method, for the periods for which logbook recording systems have been in operation, is shown in Figure 3(a, b). Much of the NSW catch is shown as having been made by an “ambiguous” fishing method, meaning that the method was not recorded properly. Attempts were made during this analysis to resolve this ambiguity, but they were not successful, and the ambiguous data were not analysed further.

The Queensland recreational catch by year is plotted in Figure 4. Data come from the 1997, 1999 and 2002 RFISH diary surveys (Higgs, 2001), and the 2000 National Recreational Survey (Henry and Lyle, 2003).

For this report, statistics of fish caught in the recreational fishery are based on an average weight of 558g per fish. This weight was calculated from fishing club data from the late 1990s, and converts to a fork length of approximately 35.5cm which appears to correspond to a reasonable average weight of fish in the ocean beach recreational fishery (see Figure 13). In contrast, the National Recreational Survey assumed an average weight of 250g, which converts to a fork length of 27.2cm and corresponds to a fish of approximately the minimum legal size of 26.8cm fork length (30cm total length). The 250g weight is not believed to be accurate for the Qld-NSW fishery, because it is unrealistic to assume that all retained fish are right on the legal limit. There may be a case to use a lesser weight than 558g in recognition of the fact that tailor are also caught in estuaries where they may be smaller. However, the average size of estuarine fish is an unknown quantity because no reliable, repeatable length-frequency data are available for the recreational estuarine fishery. The data from Aldo Steffe from NSW in 1993–95 give an average fork length of 28cm for tailor caught from break walls, and convert to an average weight of 312g, but only 45 fish were measured, 15 of which were undersize; the average weight of the legal-sized fish comes to 395g.

Recreational tailor fishing at Waddy Point, Fraser Island

The 1997 estimate of catch size is approximately double the 1999 catch, and it was believed that it may be an overestimate, possibly because it was the first year of the RFISH study and the Australian Bureau of Statistics may have refined its weighting procedures in later surveys. We did not use the 1997 catch size in further analysis (although we used the catch rates, which showed no anomalies). Analyses of RFISH data for other species (e.g., the spotted Mackerel analysis by M. O'Neill and G. Begg, in preparation) have faced the same dilemma, that the 1997 catch size estimate is much greater than the 1999 and 2002 estimates, but with no great variation in catch rate. We have been assured (J. Higgs, personal communication) that the ABS used the same weighting procedures for all RFISH surveys. The matter of whether to include the 1997 catch size estimate is one that can be reopened in future analyses.

The 2000 estimate in Figure 4 is from the National Recreational Survey, which is also the only year in which the NSW recreational catch was estimated. J. Higgs (personal communication) has suggested that the 2000 estimate may be an underestimate because the National Recreational Survey gives considerably lower estimates than the 1999 RFISH survey for most species other than tailor.

There are no data on the total size of the Queensland or the NSW recreational tailor fishery prior to 1997.

Figure 5 shows the combined commercial and recreational catches, emphasising that the recreational fishery is much bigger than the commercial fishery. For presentation purposes, the single estimate from 2000 for the NSW recreational fishery has been applied to all years.

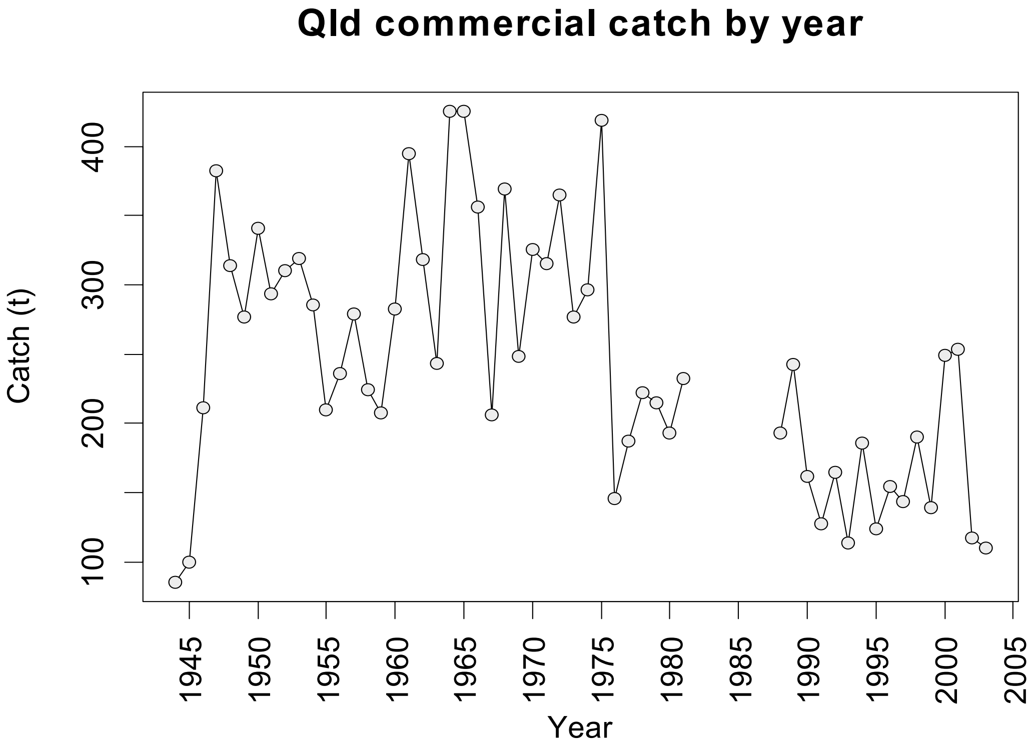


Figure 2(a): Queensland commercial tailor catch by year.

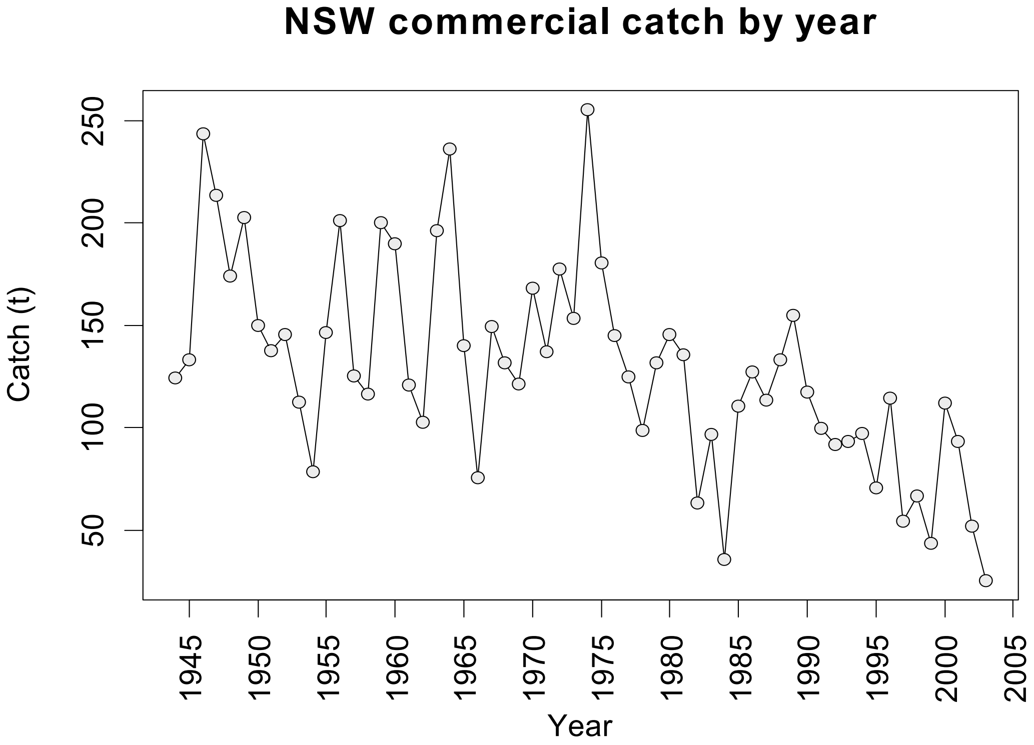


Figure 2(b): NSW commercial tailor catch by year.

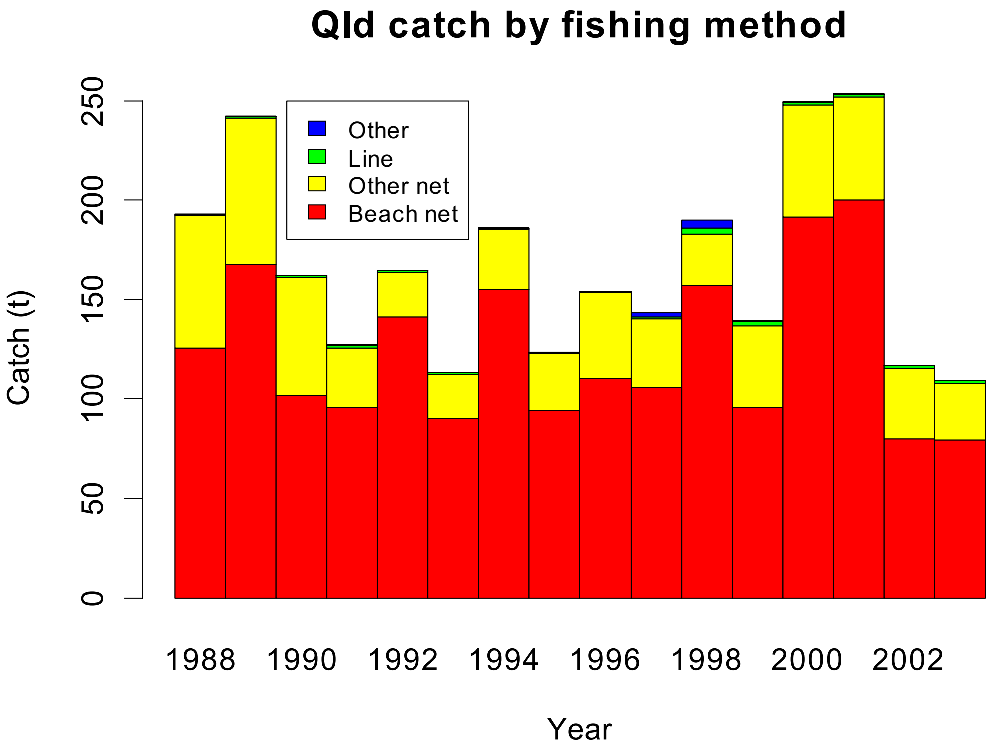


Figure 3(a): Queensland commercial catch by fishing method.

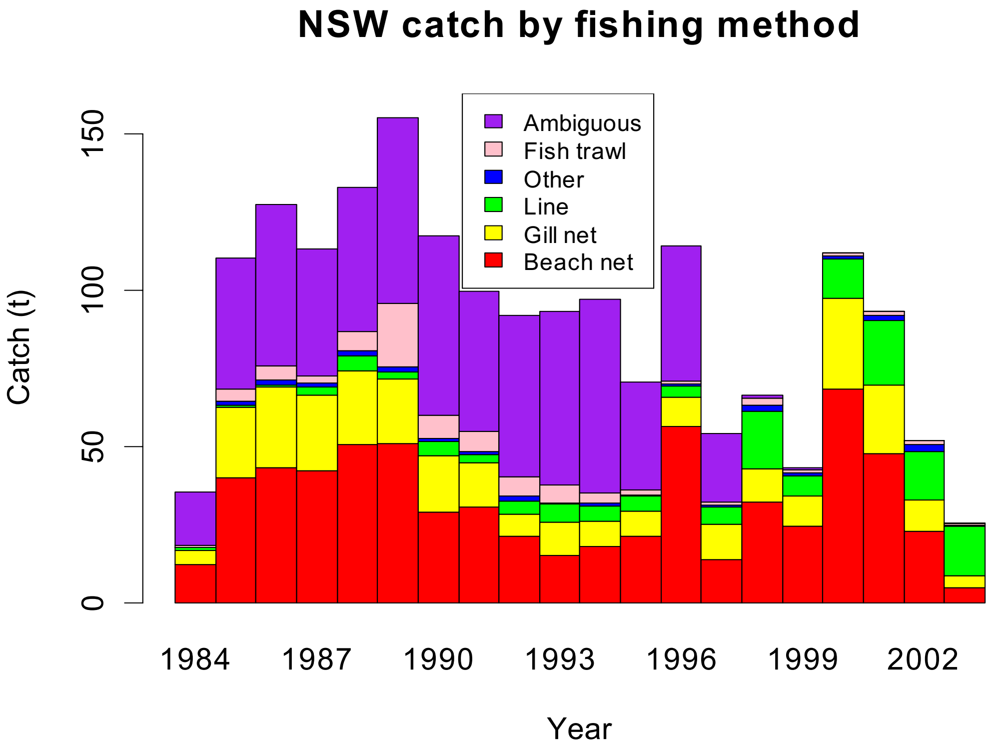


Figure 3(b): NSW commercial catch by fishing method.

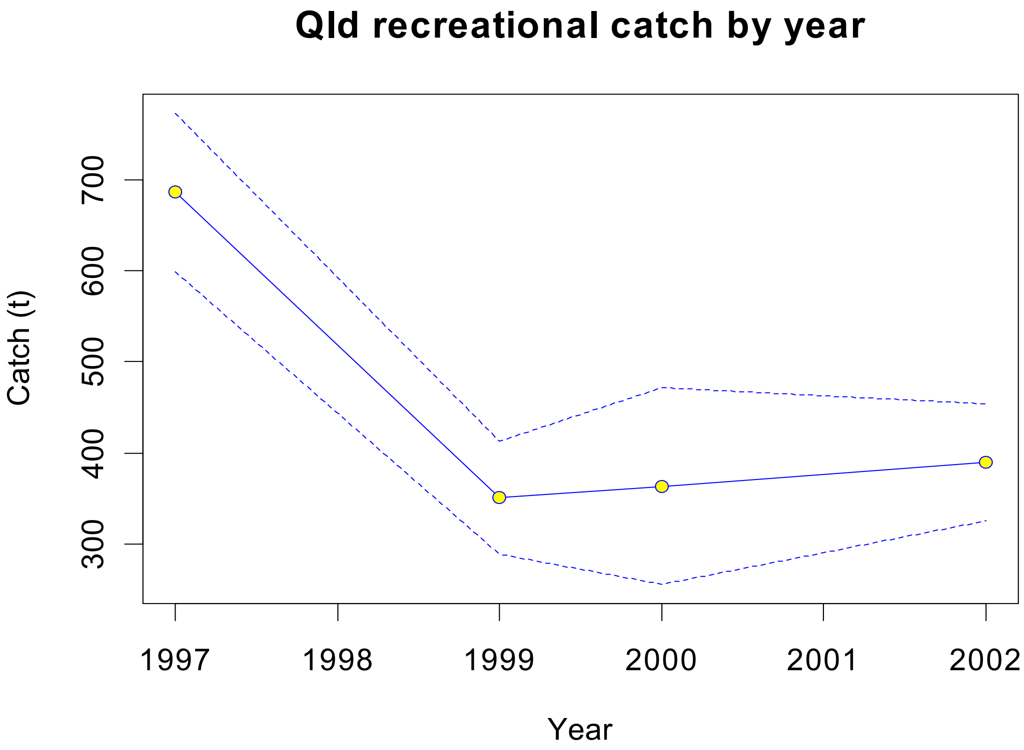

Qld recreational catch by year

Figure 4 (See caption over page.)

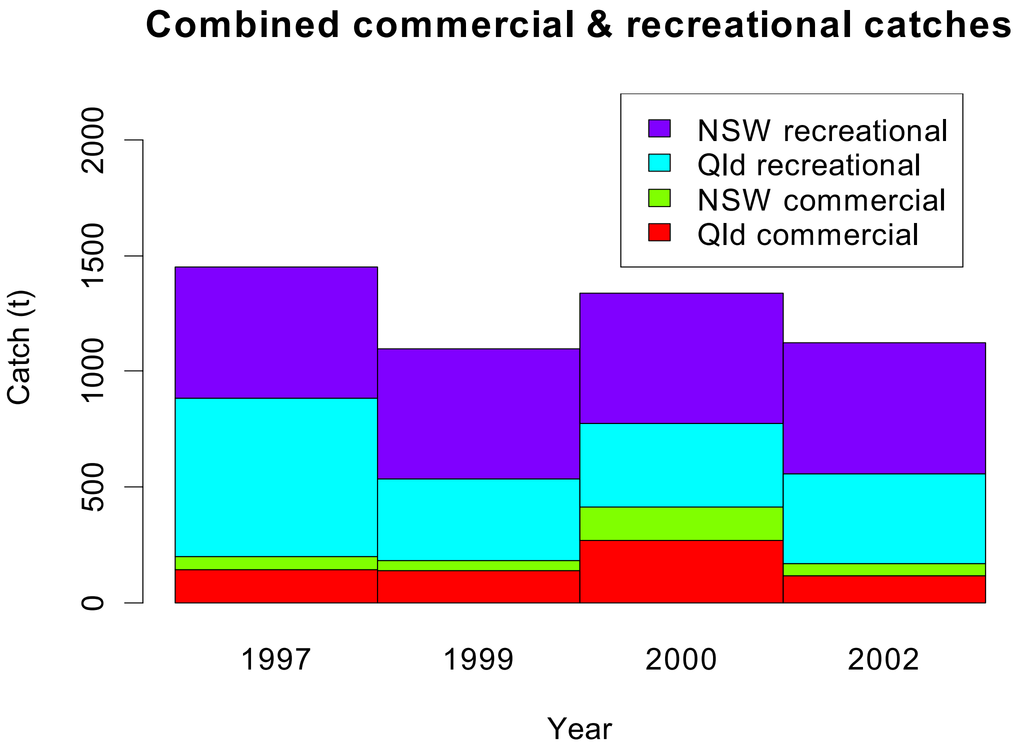

Combined commercial & recreational catches

Figure 5 (See caption over page.)

Figure 4: Queensland recreational harvest by year, with 95% confidence limits (± 1.96 standard errors). The 1997 estimate is believed to be an overestimate, possibly due to a different weighting procedure used by the Australian Bureau of Statistics. The 2000 estimate comes from the National Recreational Survey.

Figure 5: Total catches by different fishery components, showing that the recreational fishery made up the majority of the catch. Recreational estimates for 2000 come from the National Recreational Survey. The NSW catch in 1997, 1999 and 2002 has been assumed equal to the 2000 measurement which is the only measurement made on the total size of the NSW recreational fishery.

3.2 Catch rate analysis

3.2.1 General comments

The use of the term "catch rate" in this report is synonymous with "catch per unit effort", and refers to the average weight of fish caught by one fisher in one day. A day of effort has different meanings for different fishing methods and different data sets (Queensland and NSW commercial data, plus recreational and fishing club records).

In the Queensland commercial fishery, one record usually corresponds to a single day of effort. On some occasions many days were lumped together; the longest recorded duration was 153 days. To cope with these cases, the number of days of extra effort, beyond the first day, was included as an additional explanatory variable in catch-rate analysis. The result was that each additional day's duration counted for approximately 0.28 days of effective effort, which indicates that not all of the extra days recorded were active fishing days. Queensland data also included a field for recording number of operations carried out in a day, which was sometimes greater than 1, but this variable was not found to have a significant effect on catch.

NSW commercial records were provided as monthly summaries in which the number of days of effort was one of the fields. These effort records were accepted as given, but were not assumed to be equivalent to the same number of days of effort in the Queensland database (it is expected that NSW fishers would record days of effort even when they caught no tailor).

Smith and Deguara (2002) discuss some irregularities in the effort data which stem from changes in crew numbers, tendency of skippers to report catch of the entire crew rather than their personal share, and changes in fishery management and reporting requirements. They state (p. 31), "Access to the Ocean Haul fishery was restricted after 1995, and the format of monthly fisher returns was altered in 1997–98. These changes are likely to have affected catch and effort statistics, although the nature of the effects is unclear." Inspection of the data shows that some large changes in both the reported catch and effort took place in July 1997. In general, reported effort increased, but catches also increased, especially in the beach net fishery. Possibly the overall effect of the changes is to decrease the apparent catch rate, but modelling of this effect was not attempted.

A major problem with the analysis of catch rates, especially of schooling fish, is that no data are recorded when no fish are caught, even though substantial effort may have been expended in searching for fish or attempting to catch them. This limits the interpretation of catch-rate results, and can lead to a phenomenon known as hyper-stability, whereby no decrease in catch rate is apparent even though the population may be heavily fished down.

The catch rate analysis was still carried out because fishery-independent data were not available, but limitations in its use need to be borne in mind.

3.2.2 Method of analysis: log-linear and generalised linear models

Catch data were analysed by log-linear and generalised linear models to account for effects of year, month and location. For all the models the effects of year, month and location were assumed to be multiplicative. Multiplicative effects embody the assumption that the *ratios* of catch rates achieved at different times of year and locations tend to be constant over all years. For example, a day's catch in June may average triple the catch in December, producing 150kg and 50kg in a good year, and 75kg and 25kg in a bad year. An "additive" model, on the other hand, might assume that the average catch in June is 100kg more than December, in which case values of 150kg and 50kg in a good year might correspond to 101kg and 1kg in a bad year. The ratio of more than 100:1 in a bad year would be difficult to justify over the multiplicative model.

Technically, the function that transforms the mean catch so it depends linearly on the explanatory variables is called the *link function*. The assumption of multiplicative effects is equivalent to using a *log link*.

The above model description includes only what are called *main effects*, whereby, for example, the ratio between the June and December catch rates is the same in all years and locations. Deviations from this formulation are called *interactions*, and including them in the model allows the ratio of monthly catch rates to vary from year to year and from location to location, and the ratio of yearly catch rates to also vary with location. Inclusion of interactions typically adds a large number of parameters to the model, and the analyst has to decide how many parameters can be justified.

The other part of the model specification is the *error distribution*, the main purpose of which is to specify how the amount of random variation in catches depends on the mean. A *log-linear* model assumes that catches follow a lognormal distribution with standard deviations proportional to the means, so that the amount of random variation increases at the same rate as the size of the catch; in the notation of McCullagh and Nelder (1989, p. 326), the variance function is $V(\mu) = \mu^2$. A *gamma* error distribution also has $V(\mu) = \mu^2$, but with a gamma distribution for catch size.

A *negative binomial* error distribution, which can be used when catches are in numbers of fish rather than weight, has $V(\mu) = \mu + \mu^2 / k$ where k is the so-called "over-dispersion" parameter. When $k = \infty$, there is no over-dispersion and catches may follow a Poisson distribution (equivalent to assuming that fish arrive individually at random points in time). Smaller values of k give more rapid increases in variance as the mean increases, which is applicable to situations where fish school or fish behaviour is influenced by factors outside the model such as weather or time of day.

A model with a non-identity link function or a non-normal error is known as a *generalised linear model* (GLM). Generalised linear models are discussed in depth by McCullagh and Nelder (1989). A log-linear model is not generally counted as a

GLM because it is equivalent to taking logs of the data and applying an ordinary least-squares regression.

The distribution to use is often taken to be the one for which the data best follow the assumptions, the most important of which is how the variance changes with the mean. Statistical packages provide fitted values and standardised residuals, and a plot of standardised residuals against fitted values should show no trend and a uniform spread of residuals over all fitted values. The plot should also show no "outliers" (residuals of very high magnitude). Outliers can unduly influence the model's parameter estimates. The analyst has to choose whether outliers are mistakes in the data (in which case they should be corrected or excluded), or should be included uncorrected in the analysis.

An index of overall abundance of fish in each year is generated by the effect of year. Only the main effect is used, and interactions with year are ignored (although the interaction of month with location is allowed). Professor John Hoenig in his review (see Appendix 1) commented on the need to examine interactions with year in order to ensure the validity of this style of analysis.

3.2.3 Application of the models to tailor data

Log-linear models were used for commercial, charter and RFISH data, while negative binomial models were used for fishing club. A separate analysis was performed for each sector because the data were recorded differently. In the case of commercial data, each State–fishing method combination was analysed separately, both for convenience and because data were recorded differently in Queensland and NSW (see section 3.2.1 above).

In the analysis of fishing club data, club was included as an explanatory variable because it obviously explained much of the variation. Skill of recreational fishers appears to be possibly the most important factor in explaining fishing club catch rates, and skill levels appear to vary greatly from club to club. To some degree, the effect of fishing club is confounded with the effect of year, as new clubs form and later disband. The generalised linear model fitted effects for both year and club, but the resulting catch rates are subject to a good deal of variability, as can be seen in Figure 10(a). The values of the scale parameter k (see section 3.2.2) were determined by maximum likelihood, and came out to 3.4843 for the combined catch of all species, and 0.6949 for tailor. No adjustment was made for the non-recording of zero catches, but future analyses could use a method similar to that employed by O'Neill and Faddy (2003) to account for zero catches.

As remarked in section 3.2.2 above, the use of these models to generate annual abundance measures requires that interaction terms involving year be ignored. The most significant interactions, which were mainly between year and location, were examined, and it was concluded that the main effects provided sensible averages of the catch rate over different locations. Residual plots were also examined (although not shown here because they do not really form part of the results), and the quality of the fits was judged adequate.

Catch rate indices (denoted I) were standardised to a value of 1 in 1997 (a year chosen arbitrarily), and the standardised effort (E) was defined as $E = C / I$ where C denotes catch size. To combine different components of the fishery, catch and effort were summed and a combined index $\bar{I}$ was defined as $\bar{I} = \left(\sum_i C_i\right) / \left(\sum_i E_i\right)$ where i

denotes the i^{th} component of the fishery (accounting for different States and fishing methods).

Charter boat fishing data were excluded from the results used as input to the population dynamic models, because

- total charter catches were quite small (less than 10t per year)
- catches were already counted in the RFISH recreational surveys and the National Survey by Henry and Lyle (2003)
- catch rates showed an increase over time where other methods showed a decrease, giving rise to major concerns that the targeting behaviour of charter operators had changed.

It was thought better to comment on the charter results separately.

A future analysis may include weather and climatic factors as additional explanatory variables in the catch rates. These data are held at SFC but have not been put into exactly the format required for input to the analysis (e.g. some readings are made weekly rather than daily; and only a few weather stations are exposed to winds direct from the ocean, from which one would have to choose the most appropriate for each catch location).

3.2.4 Commercial and charter catch rate results

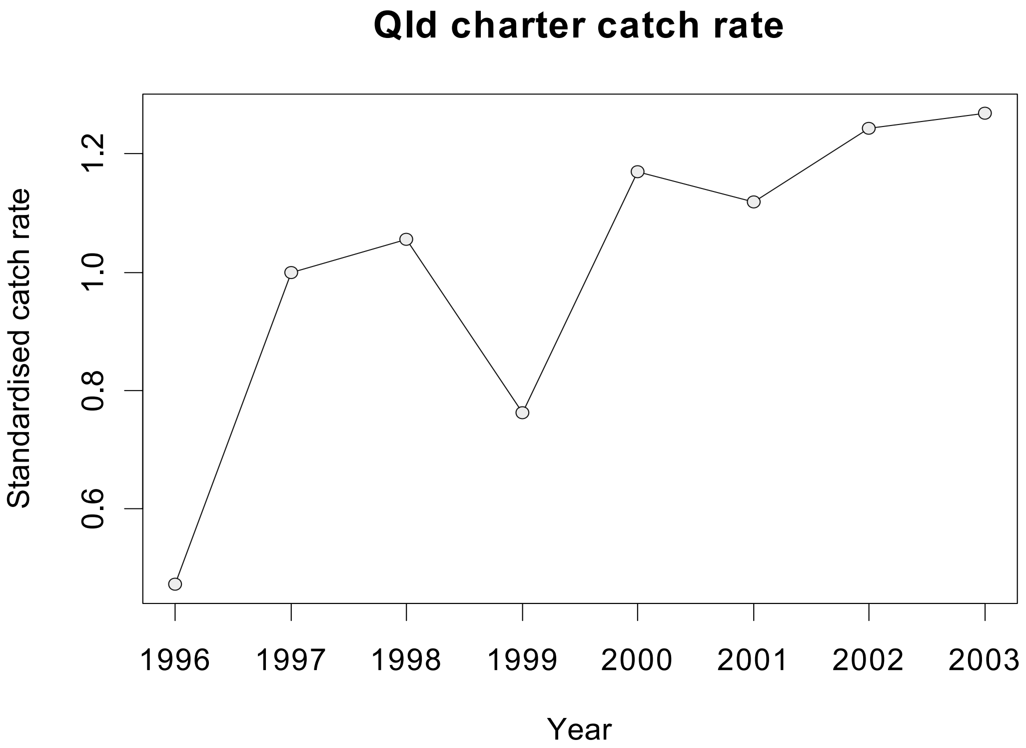


Figure 6: Catch rates for the Queensland charter fishery.

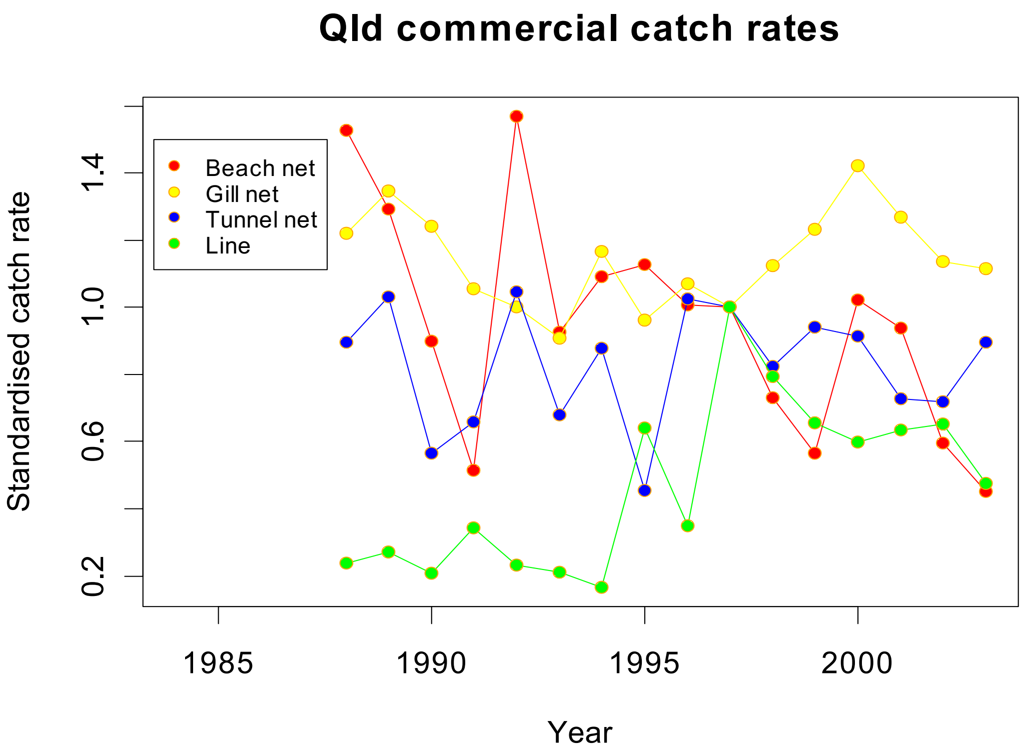


Figure 7(a): Catch rates for different components of the Queensland commercial fishery.

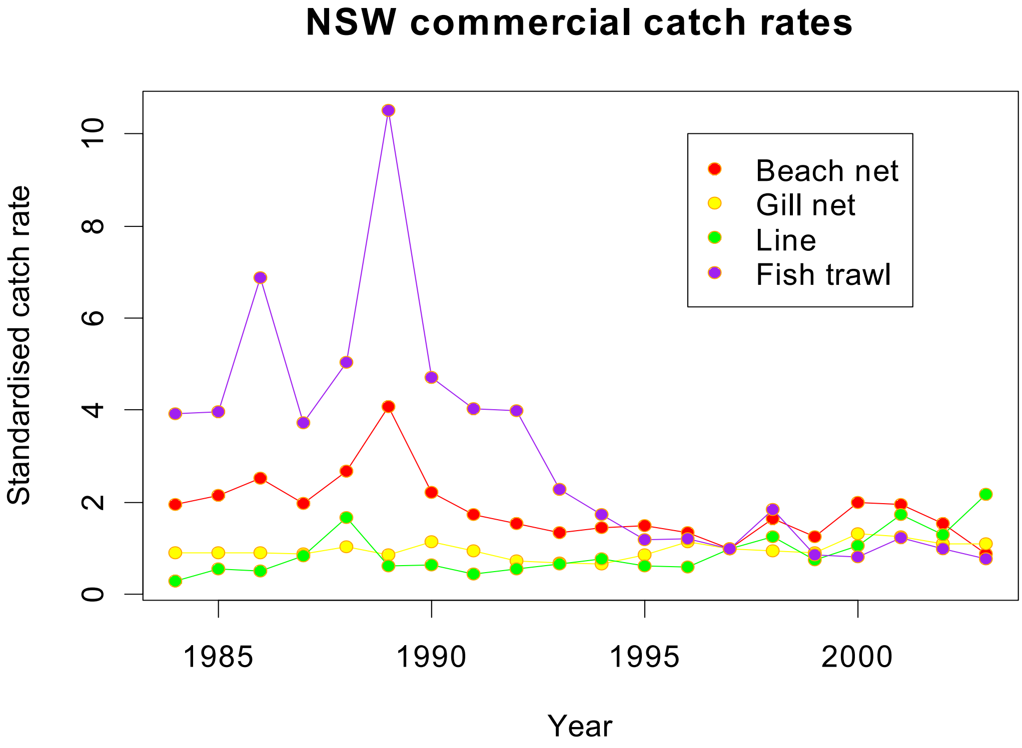


Figure 7(b): Catch rates for different components of the NSW commercial fishery.

The Queensland charter catch rate is shown in Figure 6, and Queensland and NSW commercial catch rates for different fishing methods are shown in Figure 7(a, b). All of these catch rates were found by fitting log-linear models, assuming that catch was lognormally distributed, and exponentiating the year coefficient.

As mentioned above, the charter catch rate shows an increase over time, in contrast to many of the commercial catch rates. This trend is also seen in both the Queensland and NSW catch rates by commercial line fishing, and may indicate changes in the targeting behaviour of fishers rather than any trend in abundance of tailor offshore.

A surprising result from the catch rates is that beach netting shows a decreasing trend in both Queensland and NSW whereas gill netting and tunnel netting show no trend. If hyperstability were present, one would expect it to be most marked in beach netting because that is the fishing method that relies most heavily on the schooling behaviour of tailor. It is possible that economic factors enter into this trend, whereby buyers may favour small quantities of gill-netted and tunnel-netted tailor over large quantities of lower-quality beach-netted tailor.

3.2.5 Recreational catch rate results

The recreational catch rate from Queensland RFISH surveys is plotted in Figure 8. This analysis uses the raw diary data which is not believed to be related to any problem in the estimation of total catch size referred to in section 3. The 2002 RFISH survey included information on species targeted by recreational fishers. This information was not used here because it was available for only one year, but it is considered a beneficial addition to the RFISH survey and is expected to be useful for future analyses when repeated over several surveys. A log-linear model as in section 3.2.4 was used to obtain the catch rates in Figure 8.

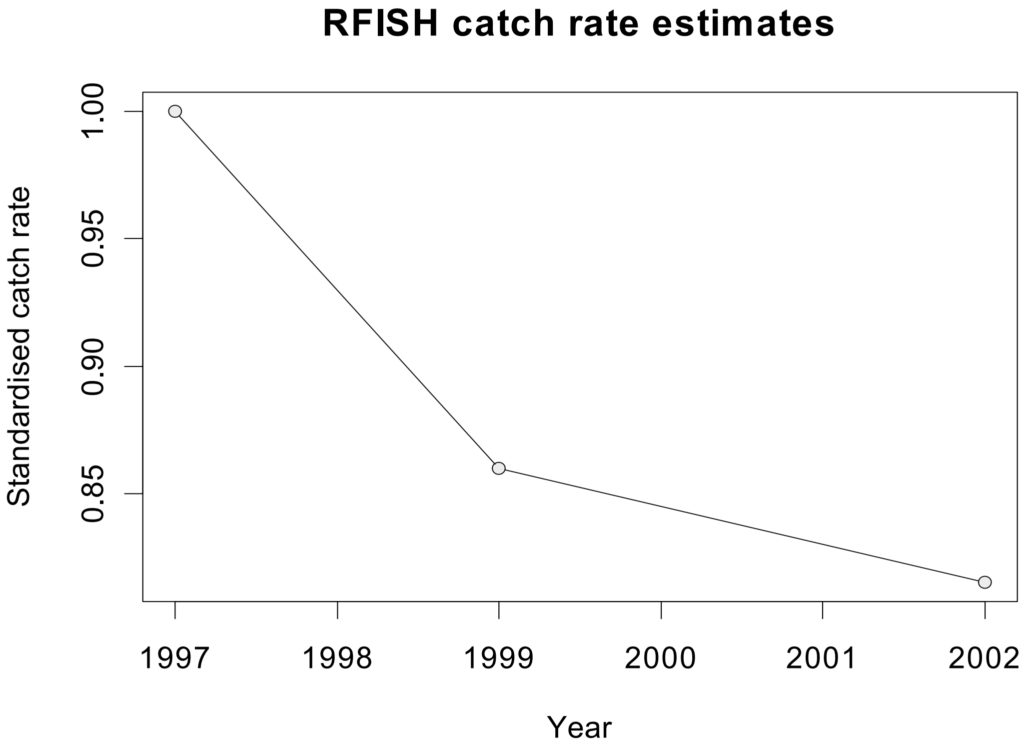


Figure 8: Queensland recreational catch rate, from RFISH diary data.

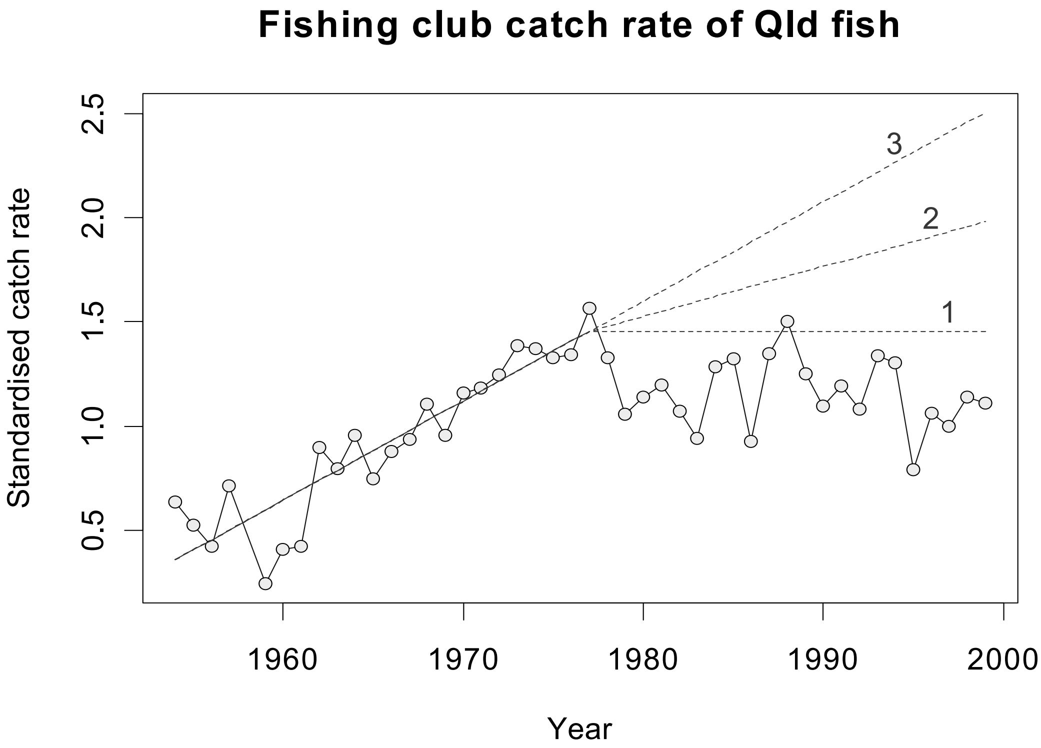


Figure 9: Catch rate of all species of fish combined, for Queensland club fishing trips in which any tailor were caught. Anglers' knowledge, skill and technology are assumed to increase to 1977 (solid line), after which different scenarios may apply (dotted lines 1–3).

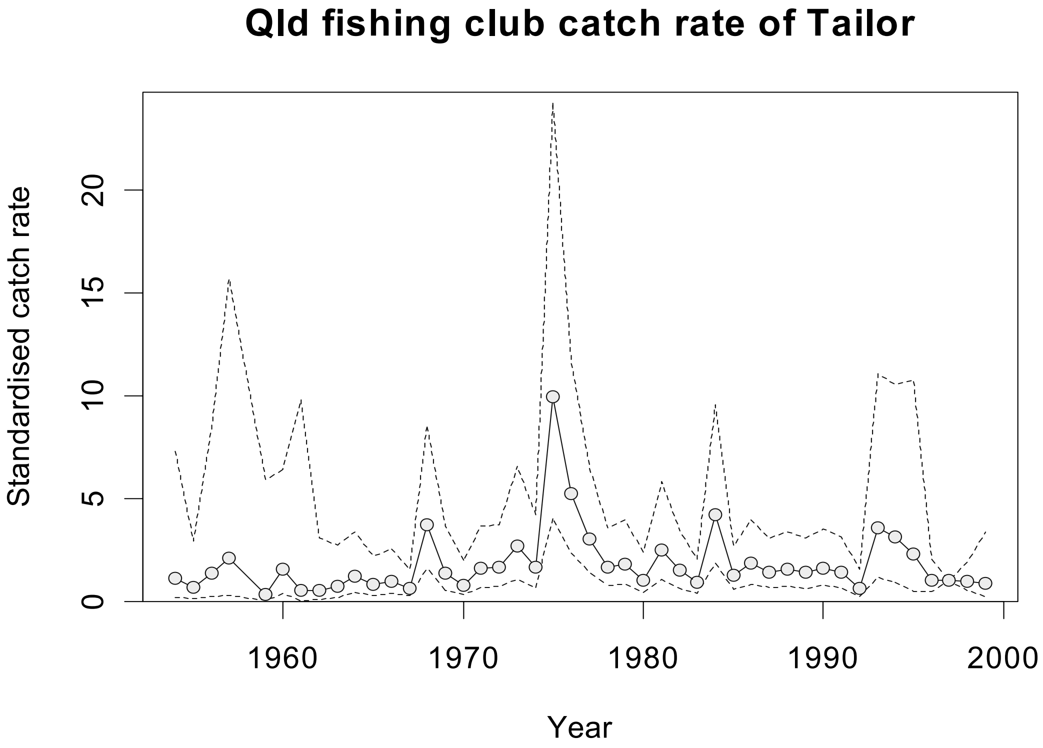


Figure 10(a): Club catch rate of tailor, assuming no increase in fishing power, with 95% confidence limits.

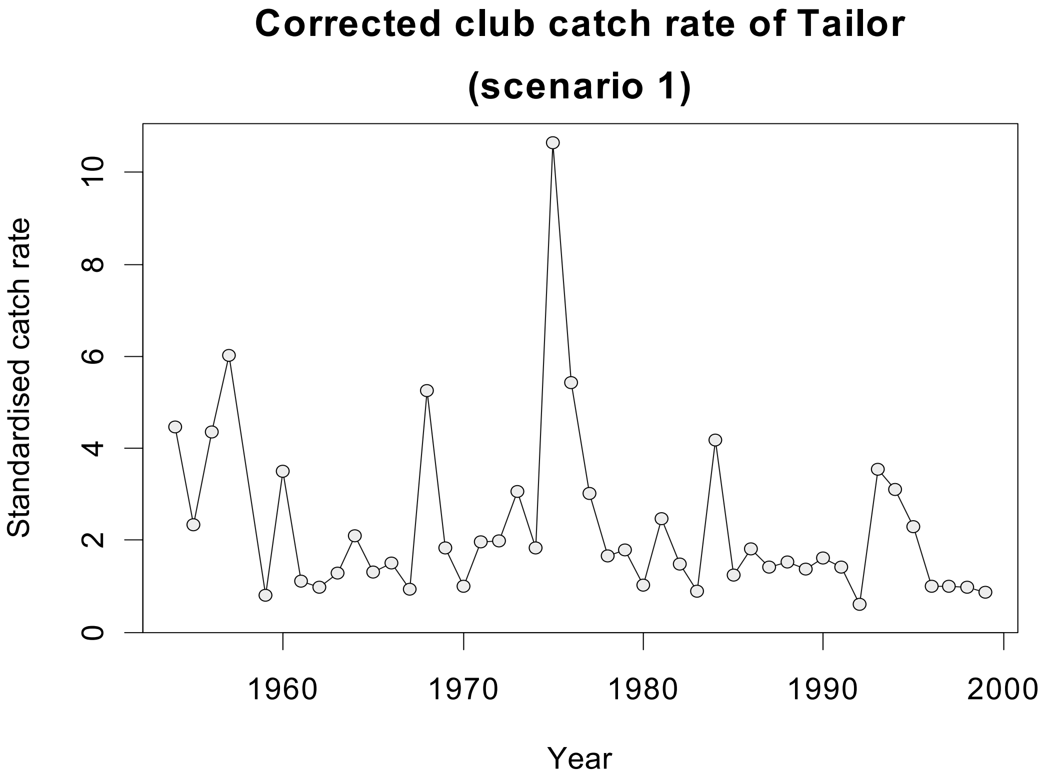


Figure 10(b): Club catch rate of tailor after correction for fishing power, assuming no increase in fishing power after 1977 (scenario 1).

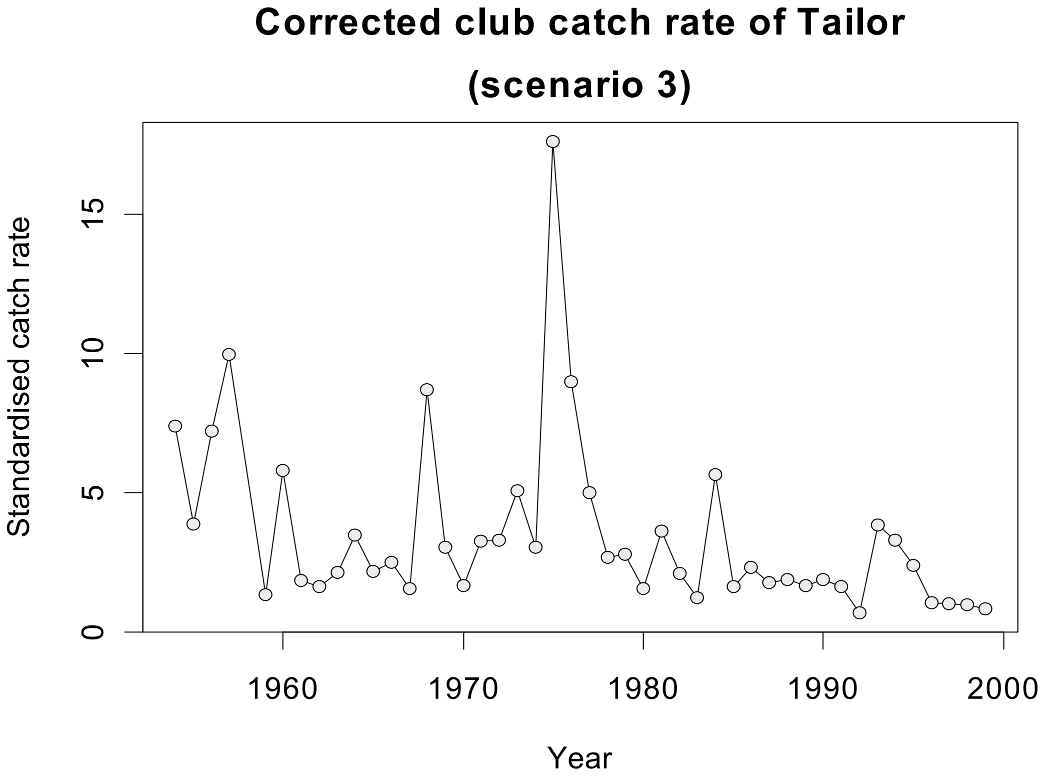


Figure 10(c): Club catch rate of tailor after correction for fishing power, assuming continued linear increase in fishing power after 1977 (scenario 3).

Analysis of fishing club data was complicated by what appears to be a steep rise in anglers' levels of skill and technology in the 1960s and 1970s. Figure 9 shows the club catch rate of all species of fish combined, for fishing trips on which any tailor were caught. A steady increase is apparent to 1977, followed by a moderate decrease since that year. The fish making the biggest contribution to Figure 9 were bream and whiting.

The increase in catch rate is assumed to be due to a rise in anglers' knowledge, skill and technology ("fishing power"), while the decrease is assumed to reflect a real decline in the abundance of fish in Queensland waters, due to fishing pressure. It is probable that fishing power continued to increase after 1977, but the rate of increase is unknown. Fishing power has not been measured and has to be inferred from the catch rate data. Three scenarios were considered (also shown in Figure 9):

Scenario 1: no increase in fishing power since 1977
Scenario 2: increase at half the annual rate that applied before 1977
Scenario 3: continued increase at the same rate that applied before 1977.

John Hoenig in his review of this work (see Appendix 1) pointed out that long-term natural fluctuations in abundance of fish do occur in fisheries around the world, and that at least some of the rise in catch rate evident in Figure 9 may be due to increasing abundance. The truth is unknown, but by including all species caught by anglers we have tried to minimise the probability of long-term fluctuations in abundance.

Club catch rates of tailor are shown in Figure 10(a–c). Part (a) is the raw catch rate, with no correction for increase in fishing power. The plot also shows 95% confidence limits on catch rates (the width of the confidence interval in 1997 is zero because catch rates are defined using a rate of 1 in 1997 as a base). Parts (b) and (c) show corrections under Scenarios 1 and 3 respectively (the two extremes in assumptions): the catch rates have been divided by the fitted fishing power curves. A straight line was fitted to the catch rates up to 1977 in Figure 9, after which the scenario-specific assumptions apply.

The peak in the tailor catch rate in the mid-1970s is almost certainly due to a few years of very high recruitment. It correlates well with length-frequency data from 1978–80, which show a comparatively very high number of fish aged 2 or more (see section 4 below).

3.3 Interpolation and extrapolation of catch sizes and catch rates

Catch sizes and catch rates from the following data sets had to be interpolated or extrapolated:

(a) Queensland commercial catch size 1982–1987
(b) Queensland recreational catch size 1944–1996, 1998, 2001 and 2003
(c) NSW recreational catch size for all years except 2000
(d) Queensland commercial catch rate 1944–87
(e) NSW commercial catch rate 1944–83
(f) Queensland recreational catch rate 1944–53, 1958, 2000–01 and 2003 (there were not enough fishing club data to be usable in 2000 or 2001)
(g) NSW recreational catch rate 1944–2003.

In addition, as mentioned above, the 1997 RFISH estimate of Queensland recreational catch was believed to be an overestimate, and it was thought best to extrapolate it from other years.

(a) There was little difference in the Queensland commercial catch sizes before and after the 1982–87 gap. The catch in each of the intervening years was set equal to the average catch over the five years before (1977–81) and the five years after (1988–92).

(b) Queensland recreational catch weight was assumed to increase exponentially at a constant rate from 1944 to 1993, and to show no trend from 1993 to 2003. Because the actual rate of increase was unknown, three different exponential rates were tried:

Scenario A: 5% per year
Scenario B: 8% per year
Scenario C: 11% per year.

A linear regression, with a fixed coefficient of 0.05, 0.08 or 0.11, was fitted to log of catch weight as a function of `min(year, 1993)`, and the fitted values were used to estimate catch sizes for the missing years. Data for 2001 and 2003 were set equal to 2002, which was thought to be a marginally better approximation than using the fitted values from the regression.

(c) The NSW catch size in all years was assumed proportional to the Queensland catch size, the ratio being given by the National Recreational Survey estimate (Henry and Lyle, 2003).

(d, e) The Queensland commercial catch rate from 1984 to 1987 was assumed equal to the NSW commercial catch rate. Both commercial catch rates were assumed equal to the Queensland recreational catch rate before 1984.

(f) The Queensland recreational catch rate in 2001 and 2003 was set equal to the rate in 2002, and the rate in 2000 was set equal to the average of the rates for 1999 and 2002. The catch rate for 1944–53 and 1958 was set equal to the geometric mean of the first ten years for which a catch rate is available, 1954–57 and 1959–64. A geometric mean was thought better in this case because there was a great deal of variability in the catch rates derived from fishing club data (Figure 10). The rates for 1944–53 are included only for completeness, and are not actually used in tuning the population dynamic models in sections 6–8.

(g) The NSW recreational catch rate was assumed equal to the Queensland recreational catch rate.

The three exponential rates of 5%, 8% and 11% per year produce Queensland recreational catches of 182t, 120t and 79t in 1979 (the Queensland commercial catch in 1979 was 215t). These catch sizes are at odds with the estimate by Pollock (1980) that 180t were caught on Fraser Island alone. Pollock's estimate is thought to be an overestimate for the following reasons:

(i) Tailor appear to have been plentiful in the late 1970s (see section 3.2.5 and section 4), due to high recruitment, a relatively small recreational fishery (compared to 1990s levels), and a demand-driven fall in the size of the commercial fishery. The population could not have "bounced" in this way if the recreational catch were much larger than the commercial catch, or if the recreational effort were anywhere near current levels (which length-frequency data indicate are very heavy).

(ii) Pollock used an average fish weight of 1kg, which is approximately double the average weight that is believed to apply over most of the history of the fishery (558g is used in this assessment; see section 3). The population bounce noted in

(a) corresponded to a time at which there was an exceptionally high number of large fish in the population. The figure of 1kg may well be correct in 1979, but is not representative of the mid 1970s or the late 1980s, judging from length-frequency data (see section 4). The population dynamic models used in sections 6–8 are unable to cope with this variation in mean weight of fish because they model recruitment deterministically. (Future models may include random variation in recruitment.) Therefore an average weight that is representative of most years of the fishery is more appropriate to use as input to these models.

(iii) Pollock assumed that every day in the fishing season is suitable for angling.

(iv) Pollock assumed an average catch of 12 fish per angler per day, which appears to overstate an average fishing day for a typical angler.

Catch sizes from these assumptions are plotted in Figure 11, and catch rates (combined by the procedure described in section 3.2.3) are plotted in Figure 12. Catch rates prior to 1984 are calculated from fishing club data alone because no commercial effort statistics were available. The different scenarios input to the population dynamic models are listed in Table 1.

Table 1: Scenarios input to the population dynamic models, to cope with unknown trend in recreational fishing power 1954–2003, and unknown recreational catch sizes 1944–97. The steep increase in fishing power to 1977 has been inferred from catch rates of all species combined (Figure 9).

Scenario no.	Assumed trend in recreational fishing power	Assumed trend in size of recreational catch
1A	Steep increase to 1977, no further increase	5% p. a. increase to 1993, no trend thereafter
1B	Steep increase to 1977, no further increase	8% p. a. increase to 1993, no trend thereafter
1C	Steep increase to 1977, no further increase	11% p. a. increase to 1993, no trend thereafter
2A	Steep increase to 1977, rate of increase halved after 1977	5% p. a. increase to 1993, no trend thereafter
2B	Steep increase to 1977, rate of increase halved after 1977	8% p. a. increase to 1993, no trend thereafter
2C	Steep increase to 1977, rate of increase halved after 1977	11% p. a. increase to 1993, no trend thereafter
3A	Unabated steep increase 1954–2003	5% p. a. increase to 1993, no trend thereafter
3B	Unabated steep increase 1954–2003	8% p. a. increase to 1993, no trend thereafter
3C	Unabated steep increase 1954–2003	11% p. a. increase to 1993, no trend thereafter

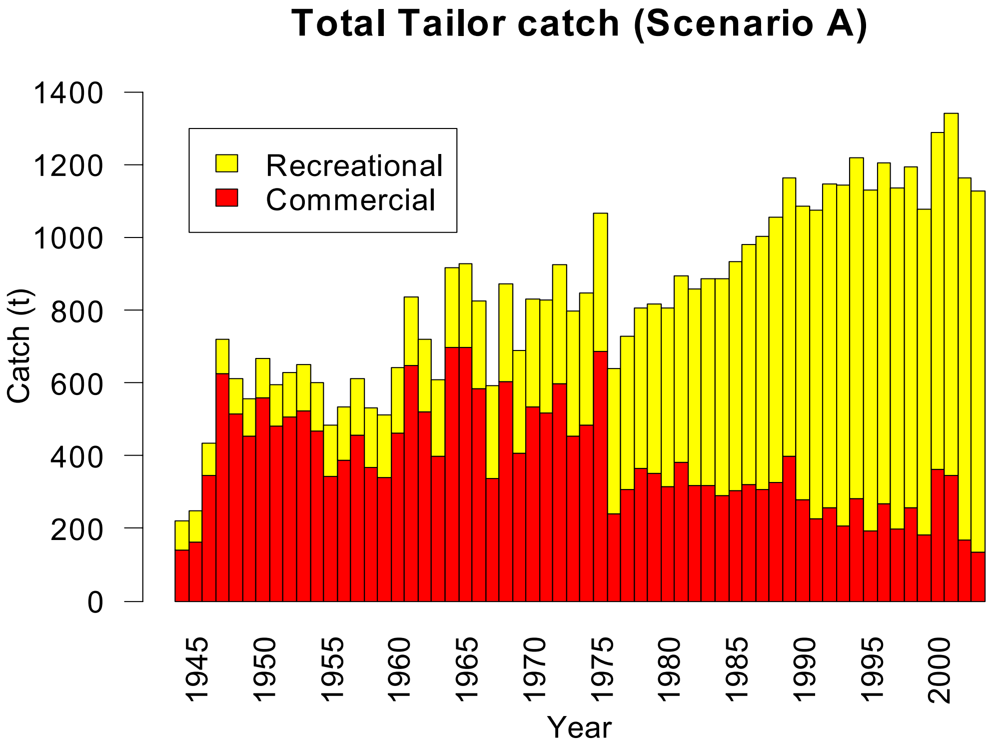


Figure 11(a): Catch sizes of tailor under Scenario A (5% p.a. increase in recreational catch to 1993).

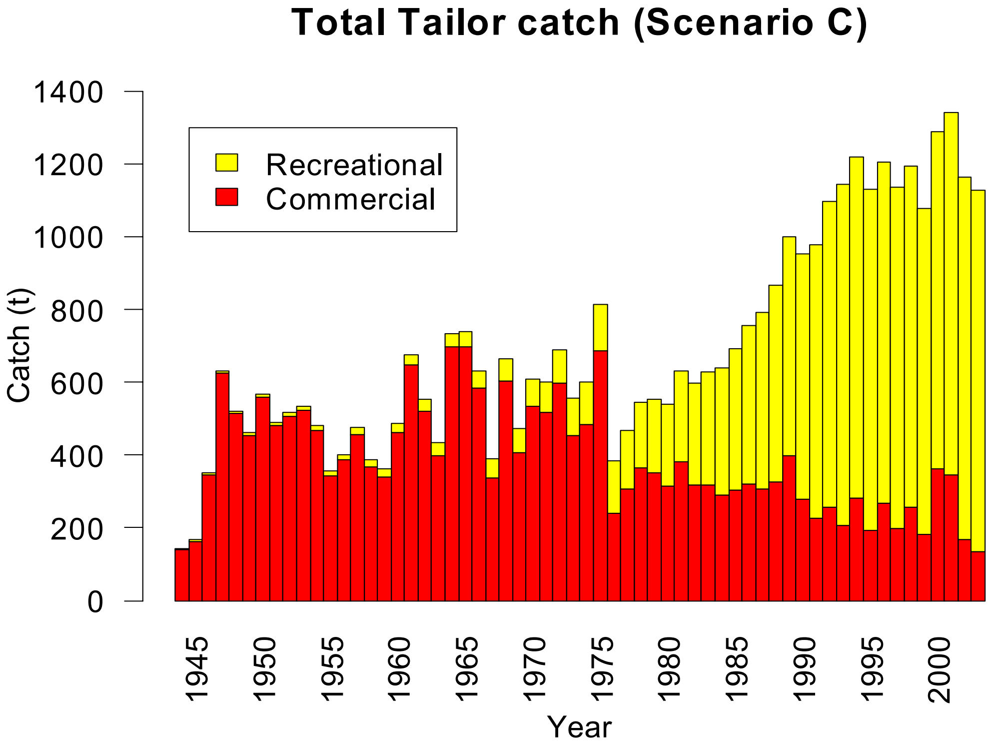


Figure 11(b): Catch sizes of tailor under Scenario C (11% p.a. increase in recreational catch to 1993).

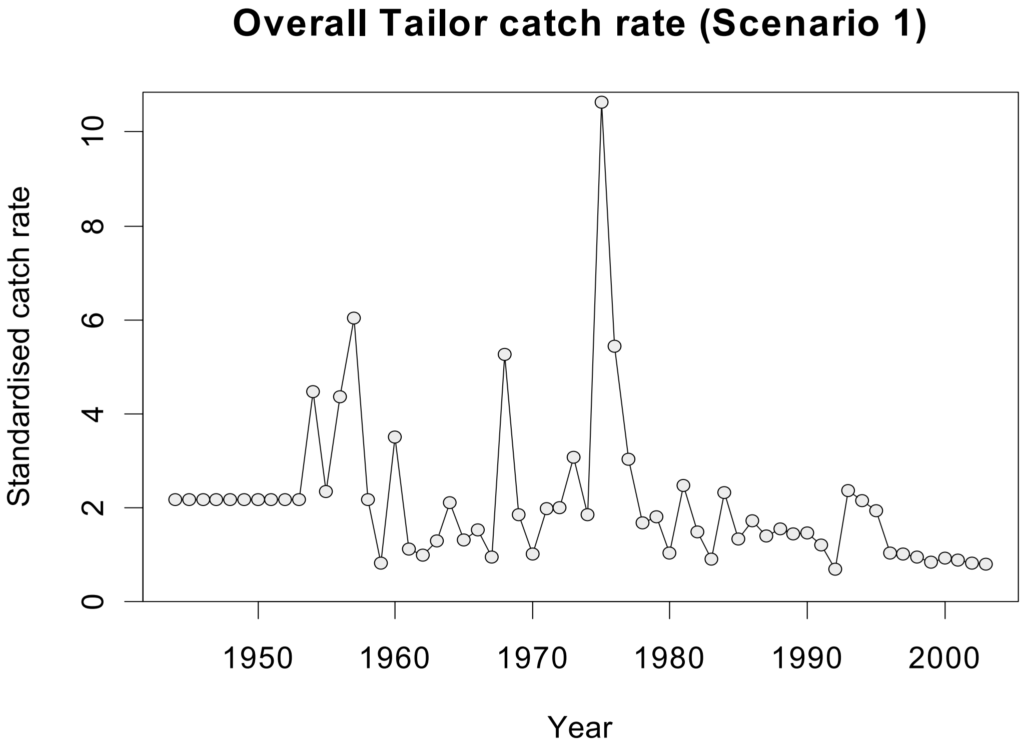


Figure 12(a): Catch rate of tailor under Scenario 1 (no increase in recreational fishing power since 1977).

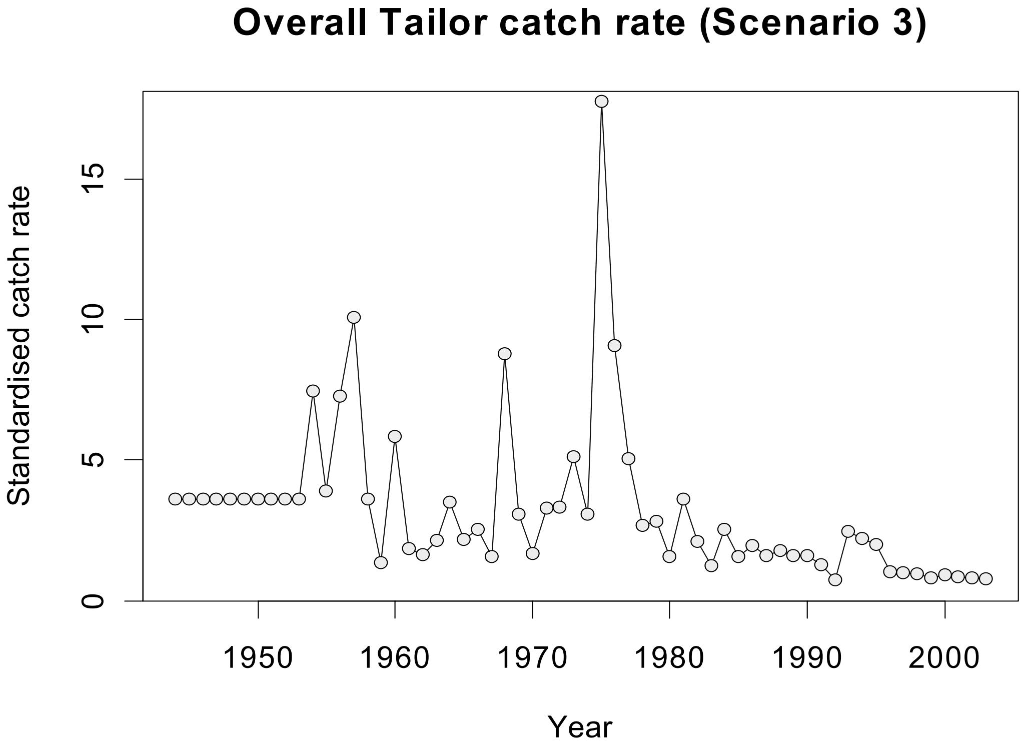


Figure 12(b): Catch rate of tailor under Scenario 3 (continued steep increase in recreational fishing power since 1977).

4. Age composition and length-frequencies

Length-frequency data came from a bewildering variety of sources, including those listed in section 2; the Sydney Fish Market, 1971–90; and a survey of the NSW recreational fishery from beaches, rocks and boats conducted by Aldo Steffe, 1993–95. Many of these data sets (including the two mentioned) could not be used for year-to-year comparisons because factors relating to targeting and location were highly inconsistent between years.

DPI&F fisheries scientist Michael O'Neill with a large line-caught tailor

As mentioned in section 2, data were restricted to samples from the recreational fishery on Fraser Island during the peak fishing period from July to October. Such samples were available over many years, and allowed year-to-year comparisons of length and age distributions. Problems remained in that different sampling strategies were employed in different years. For example, even though the 1978–80 tagging experiments sampled mainly large fish, it is known that in one of the years a boat was used in an attempt to target relatively small tailor. Also, in some years, only a few schools of tailor would have been sampled.

The following remarks can be made on the sampling methodologies employed:

- 1975 sample, probably taken from beach anglers other than the scientist fishing an ocean beach, probably a small number of schools
- 1978–80: tagging experiments, fish caught on Fraser Island by scientists who were expert anglers, mainly by beach angling; the experiments ran for approximately one week (end August–early September) in each of the three years; would have sampled plenty of schools but only for one week in each year
- 1987–90: tagging experiments, fish caught on Fraser Island by scientists who were probably expert anglers, probably by beach angling; Fraser Island

experiments ran on 14–18 September 1987, 13–20 August 1988, 12–18 August and 7–13 October 1989, and 11–18 August, 5–7 September and 29 September–6 October 1990; sampling properties probably similar to 1978–80 experiments

- 1995–97: fish obtained from beach anglers on Fraser Island, 24–29 August and 2–6 October 1995, 14–15 and 28–29 August and 1–2 October 1996, and 13–16 and 24 August, 16–19 and 28 September and 7–9 and 27–28 October 1997
- 1999–2003: fish obtained from beach anglers on Fraser Island over approximately three periods of a week each between August and October each year; samples collected by DPI&F Long Term Monitoring Program according to a scientific design aimed at sampling the catch from the fishery.

One major comment that can be made is that expert anglers are better at landing big fish than less skilled anglers. Therefore the length frequencies from tagging experiments (1978–80 and 1987–90) may include a greater proportion of larger fish than would have been the case for the overall recreational fishery at those times.

Given the short duration of the sampling period (July to October), no allowance was made for growth of fish during this period; such growth would have been dominated by random school-to-school variation in the size of fish, or variation due to weather conditions (see Discussion, section 9). The sampling methodology has been constant only since 1999 when the DPI&F Long Term Monitoring Program began.

Two samples were removed from the remaining data; one came from a school of small one-year-old fish tagged on 12–13 October 1989, the other from a school of zero-year-old fish whose length frequency was collected from Fraser Island Main Beach on 26 August 1999 (Sample Group ID 108; range 18–27cm fork length, mean 23cm).

The length-frequency samples are reproduced in full in Figure 13(a–p), because the stock assessment relies critically on them. Where ageing data are available, the age composition is also shown. Age composition was calculated using a separate age-length key for each year of sampling, and applying the key to the length-frequency sample from that year. For each length, the age-length key provided the age distribution of fish of that length.

Figure 14(a–c) shows the distribution of length of one-, two- and three-year-old fish from a composite sample of all the length-frequencies for years in which reliable ageing data are available (1995, 1997, 1999–2003).

Figure 15 shows the proportion of fish of length 40cm or more for every year in which length-frequency data are available.

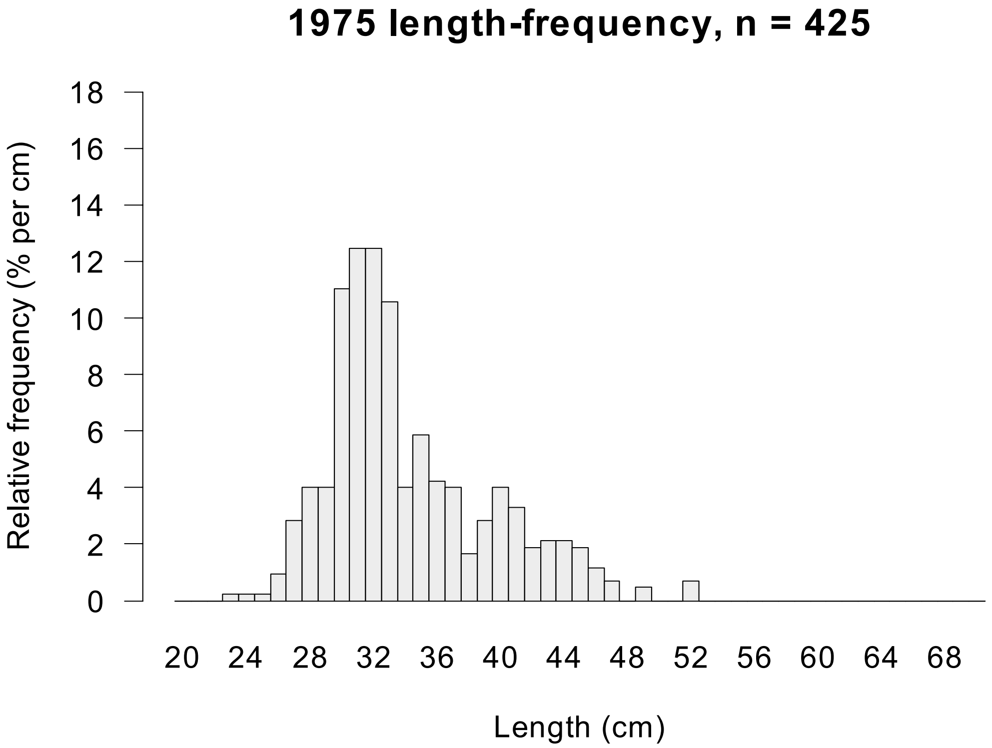


Figure 13(a): Length frequency from Bade (1977), assumed to have been collected in 1975.

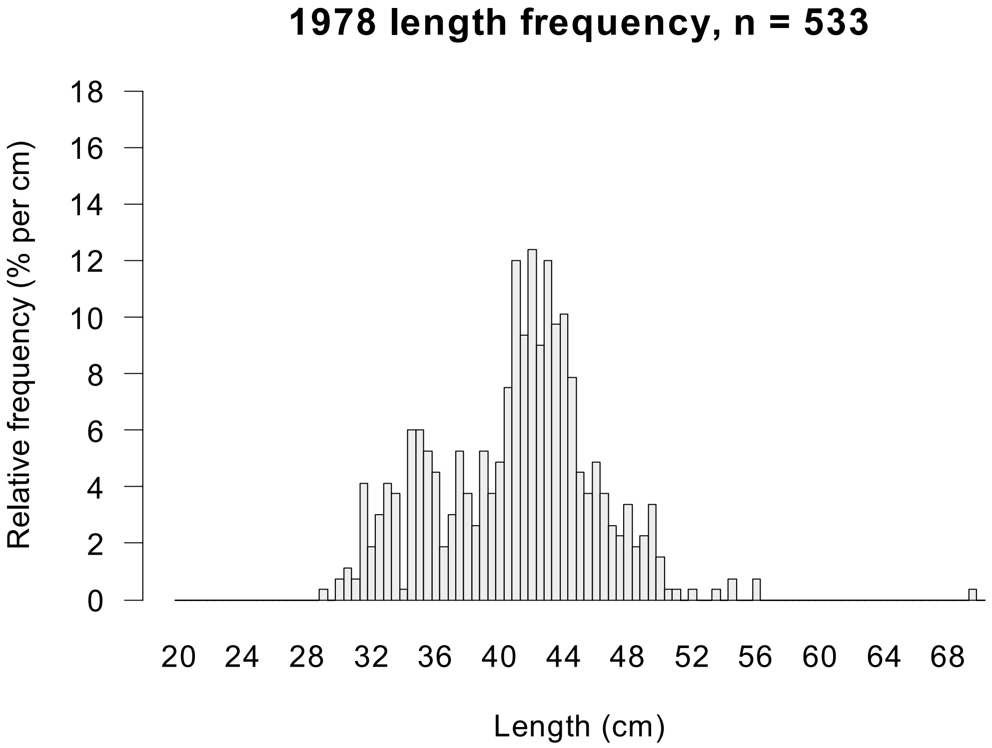


Figure 13(b): Length frequency from 1978, tagging experiment conducted by Barry Pollock and David Bateman.

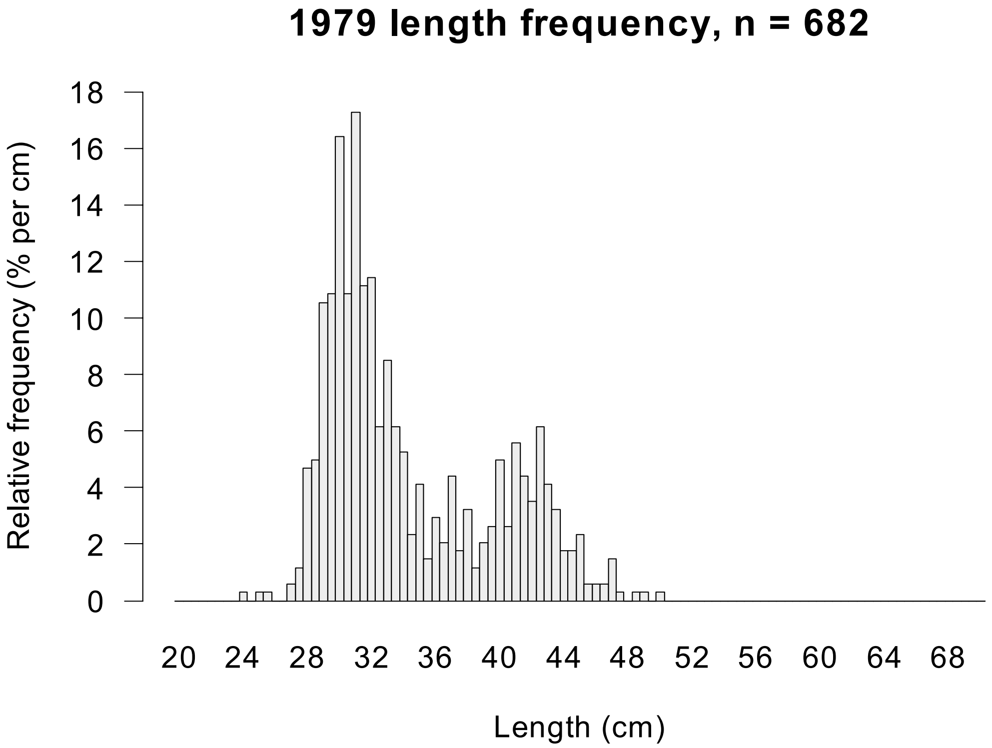


Figure 13(c): Length frequency from 1979, tagging experiment conducted by Barry Pollock and David Bateman.

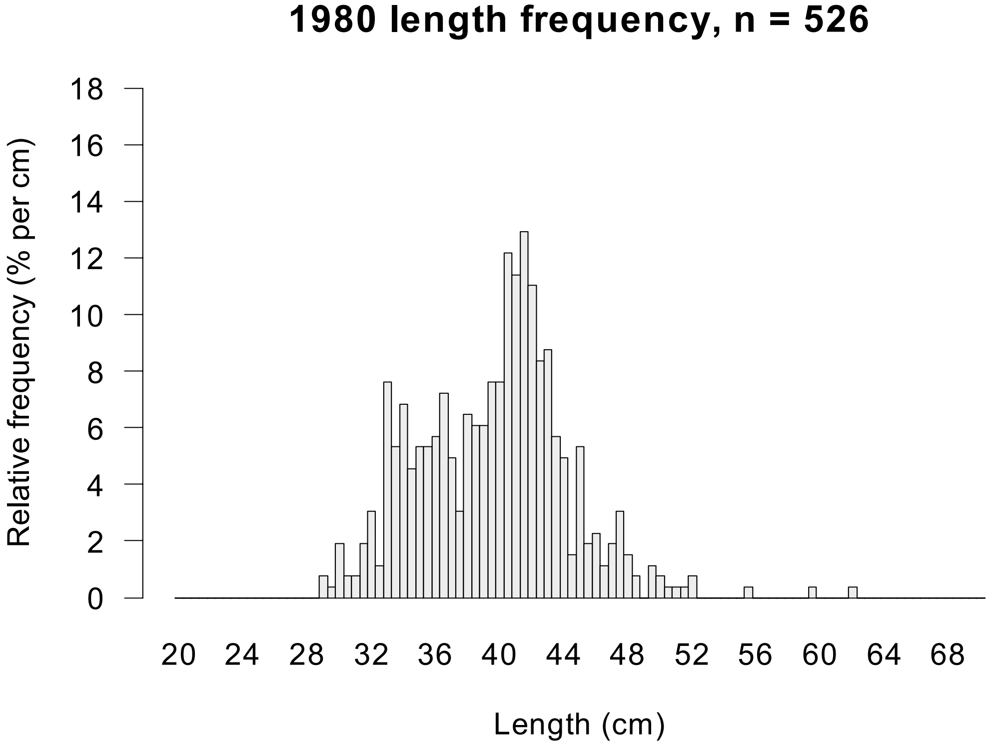


Figure 13(d): Length frequency from 1980, tagging experiment conducted by Barry Pollock and David Bateman.

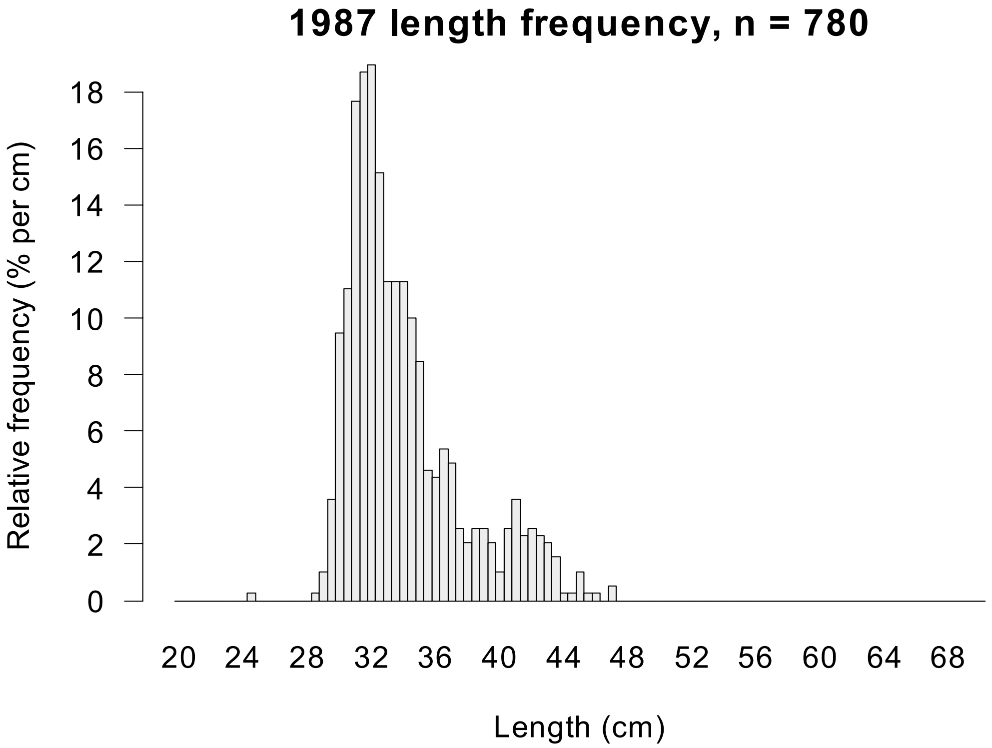


Figure 13(e): Length frequency from 1987, tagging experiment led by Ian Halliday.

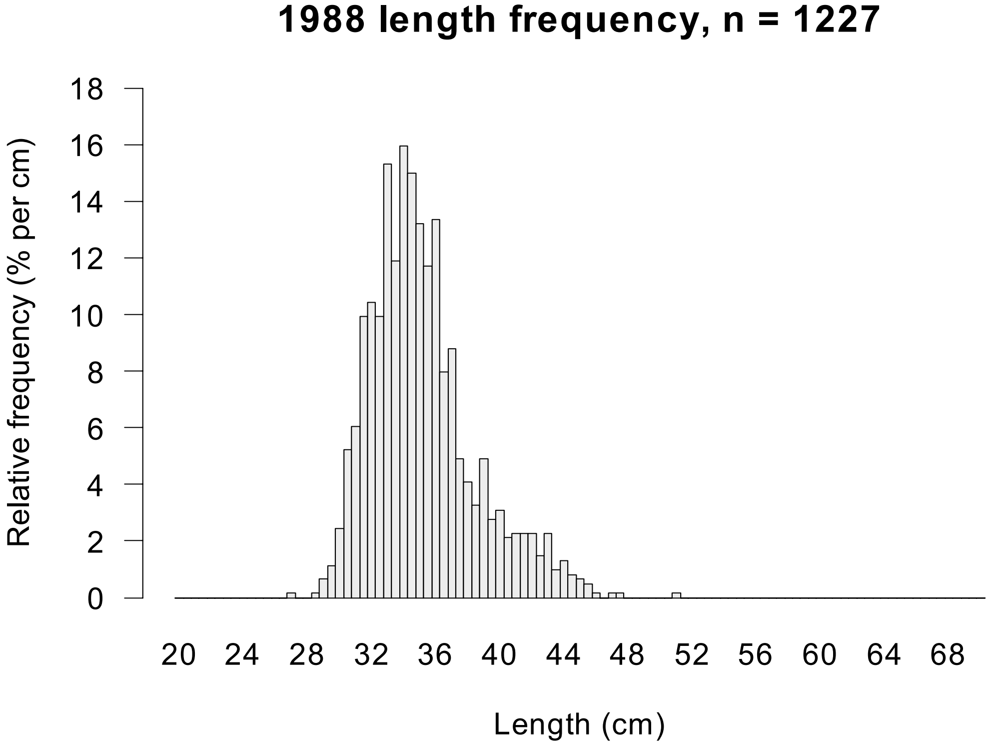


Figure 13(f): Length frequency from 1988, tagging experiment led by Ian Halliday.

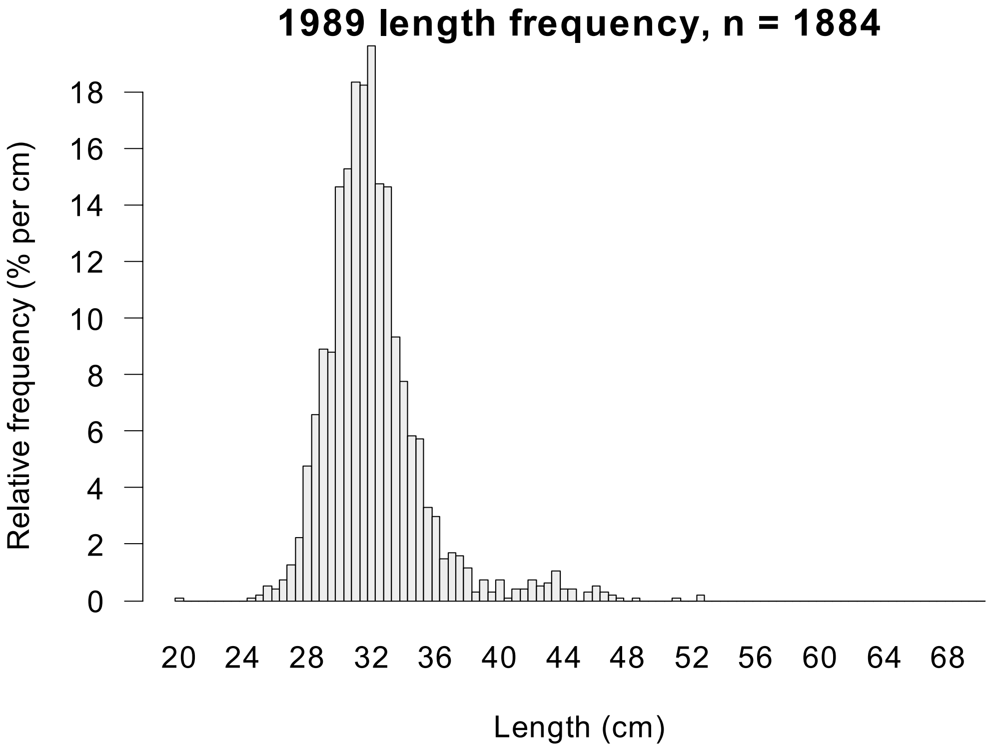


Figure 13(g): Length frequency from 1989, tagging experiment led by Ian Halliday.

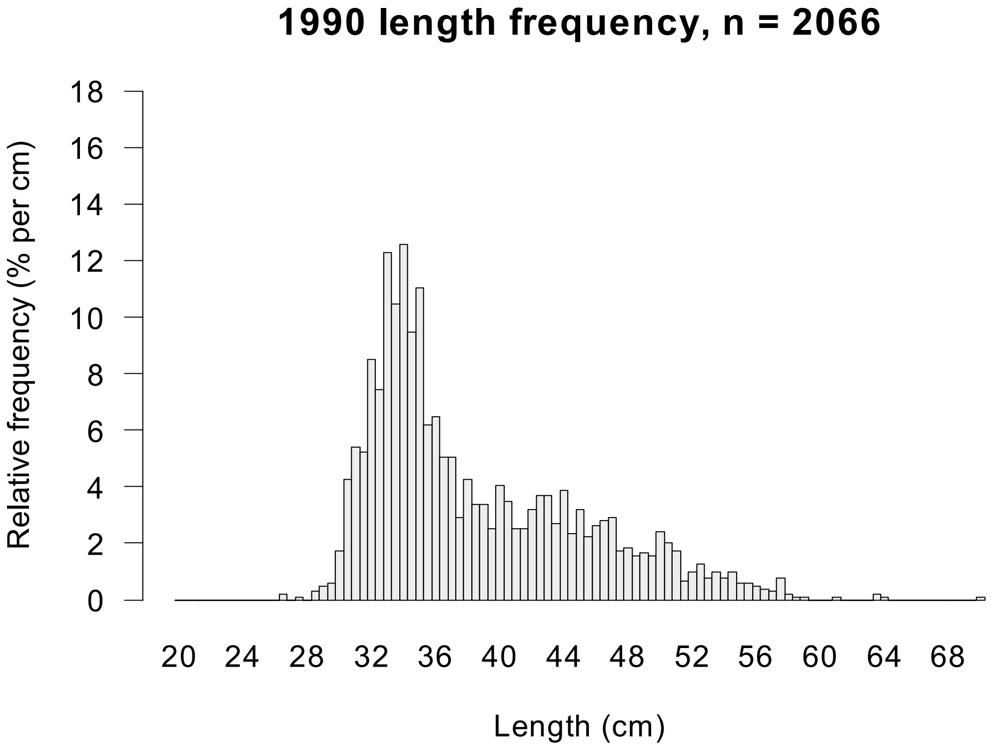


Figure 13(h): Length frequency from 1990, tagging experiment led by Ian Halliday.

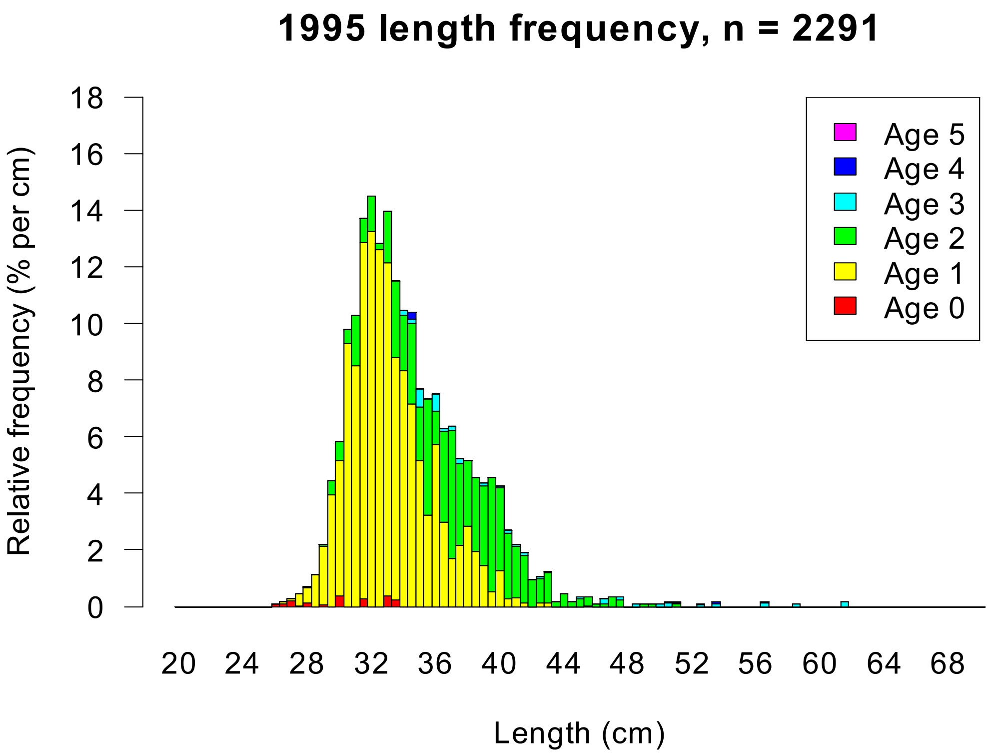


Figure 13(i): Length frequency with ageing from 1995, ISAMP project (Hoyle et al., 2000).

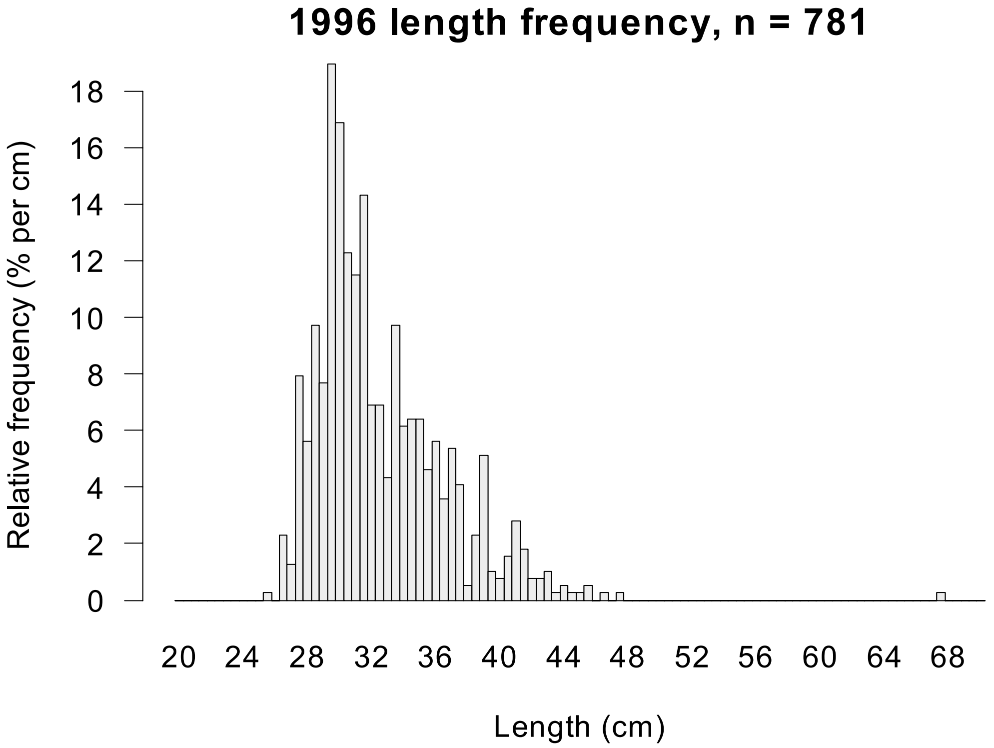


Figure 13(j): Length frequency from 1996, ISAMP project.

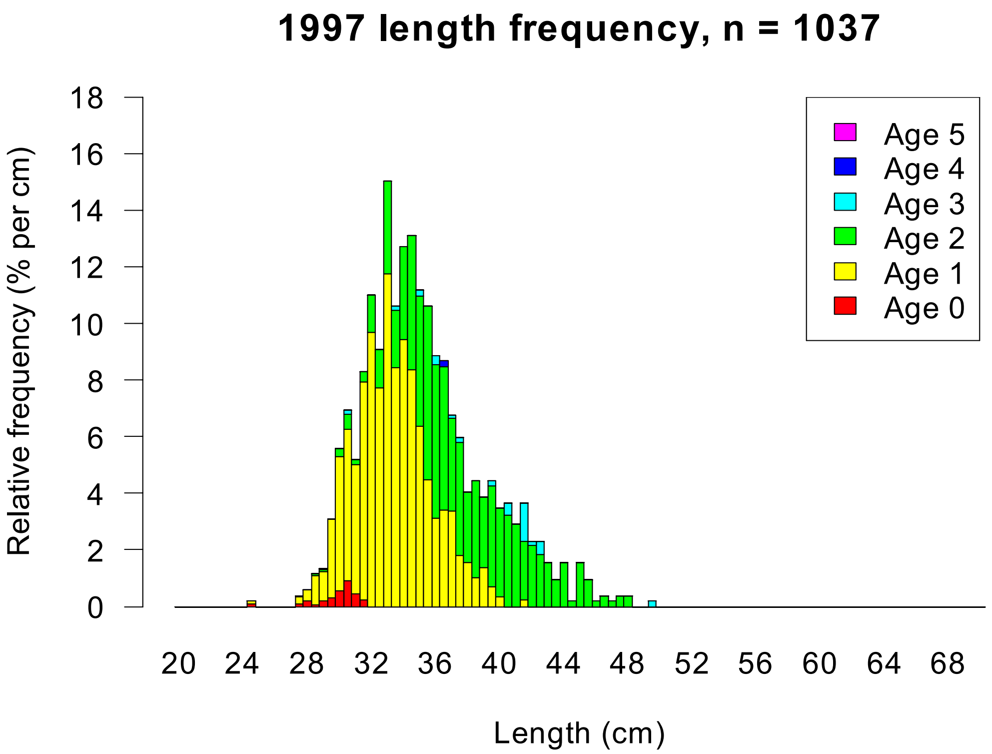


Figure 13(k): Length frequency with ageing from 1997, ISAMP project.

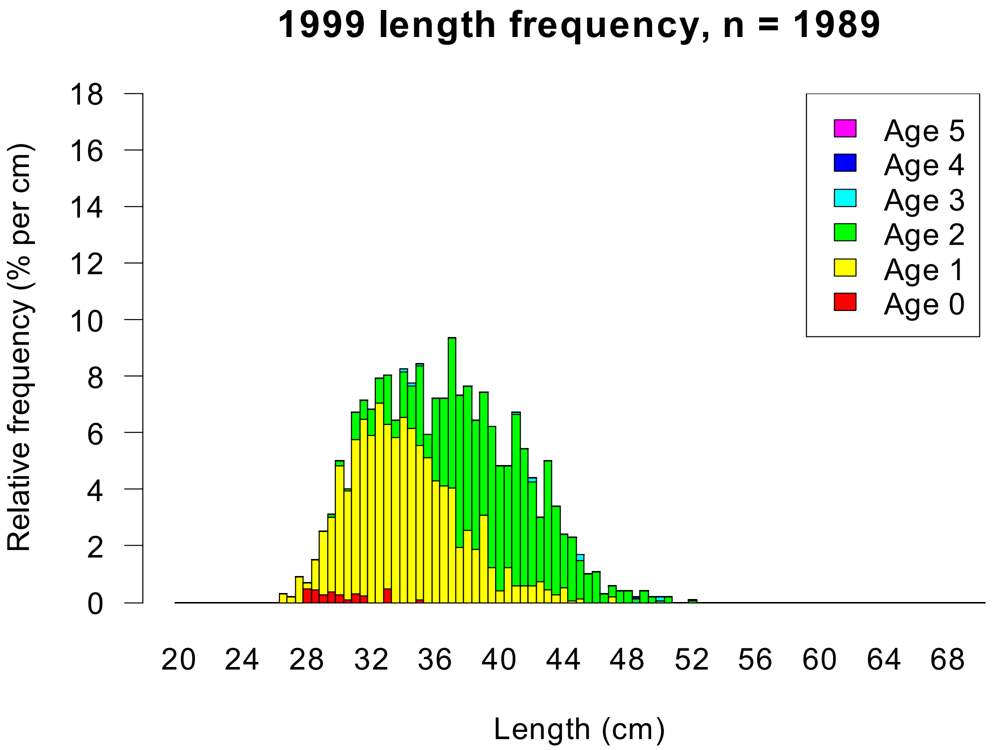


Figure 13(l): Length frequency with ageing from 1999, Queensland DPI&F Long Term Monitoring Program.

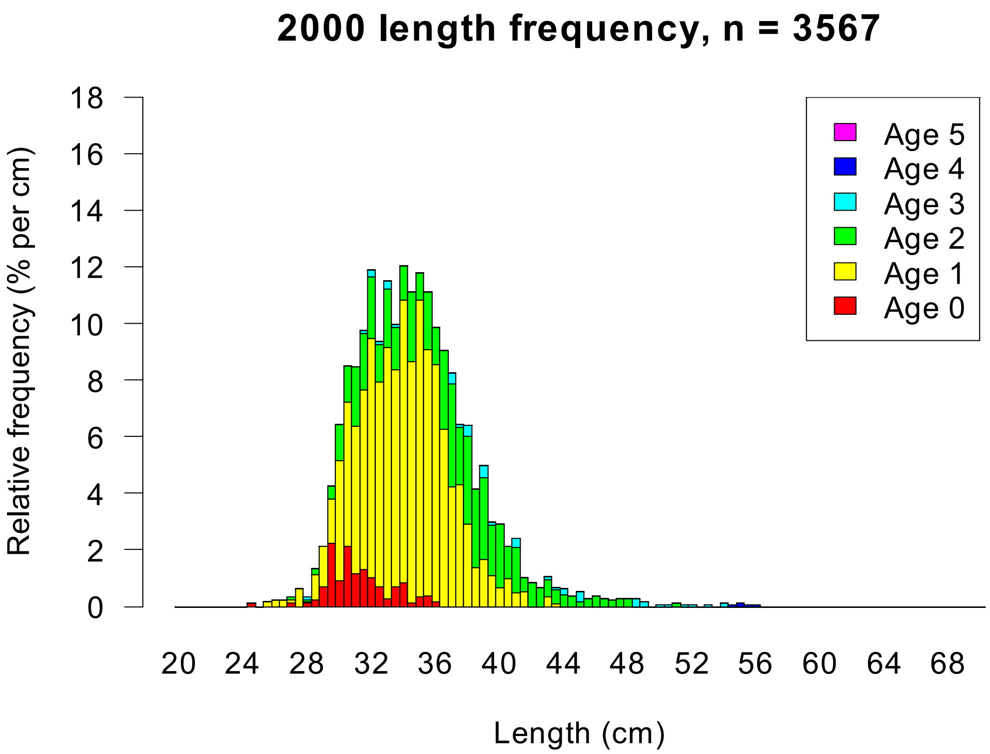


Figure 13(m): Length frequency with ageing from 2000, Long Term Monitoring Program combined with the Tailor Age Validation project (Brown et al., 2003).

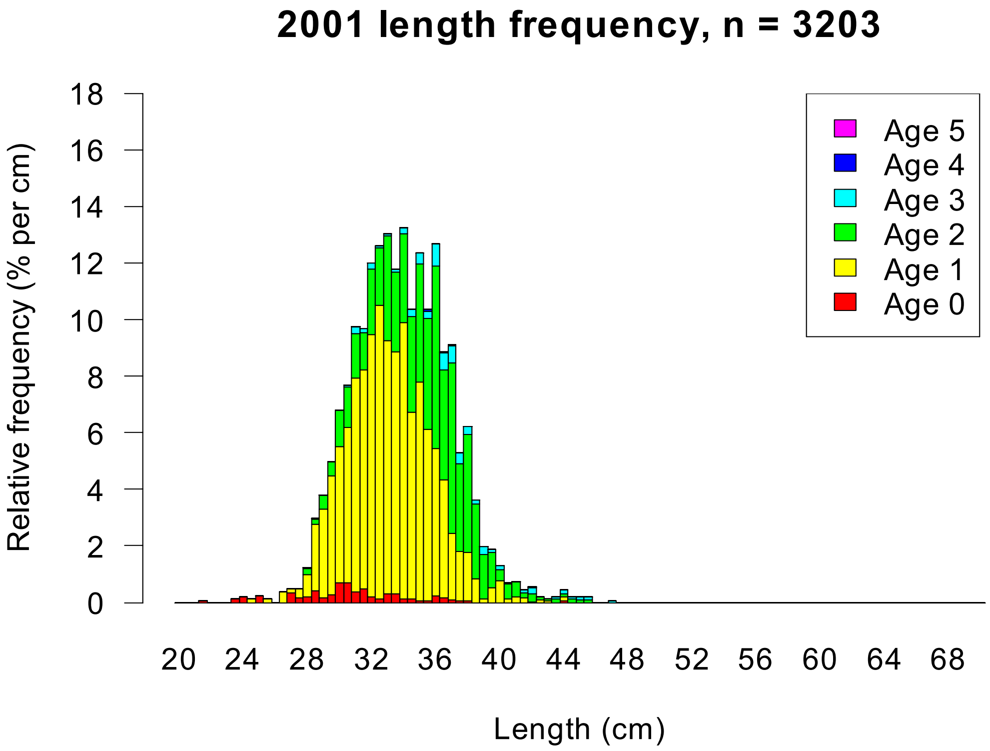


Figure 13(n): Length frequency with ageing from 2001, Long Term Monitoring Program.

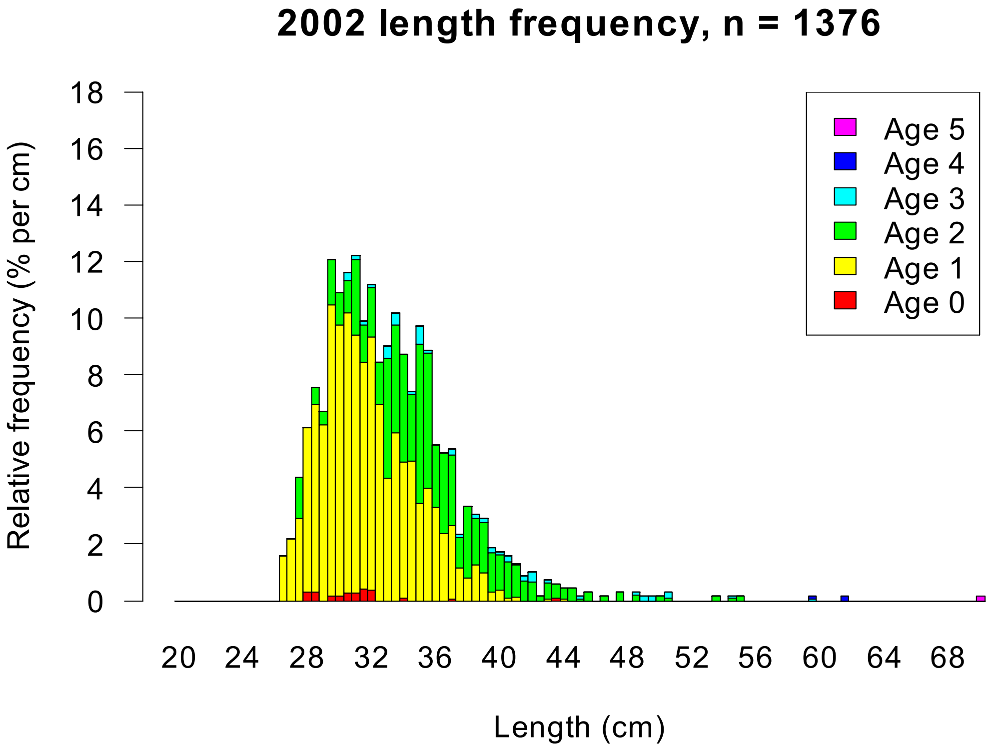


Figure 13(o): Length frequency with ageing from 2002, Long Term Monitoring Program.

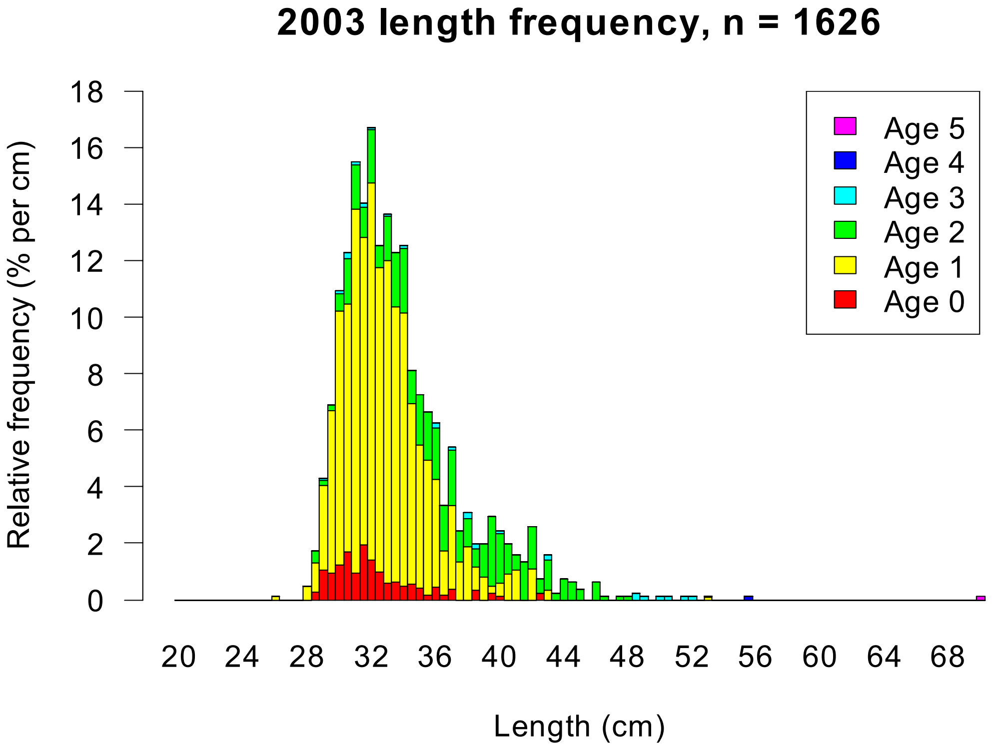


Figure 13(p): Length frequency with ageing from 2003, Long Term Monitoring Program.

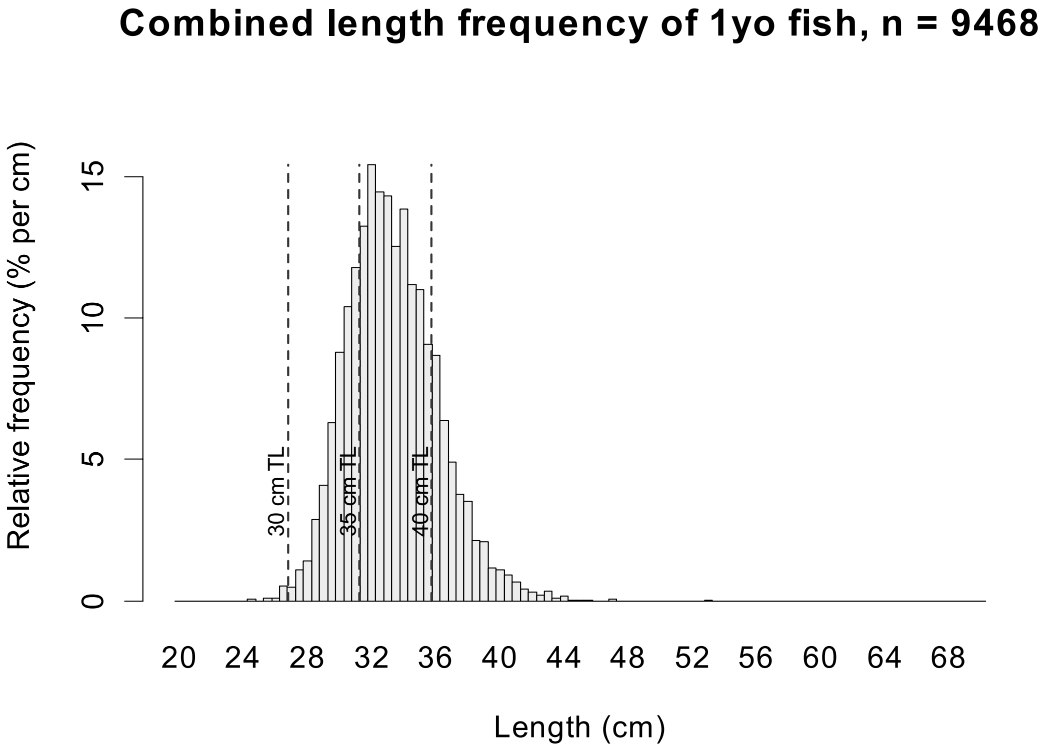

Combined length frequency of 1yo fish, n = 9468

Figure 14(a): Combined length frequency of one-year-old fish from all years in which ageing data are available (1995, 1997, 1999–2003).

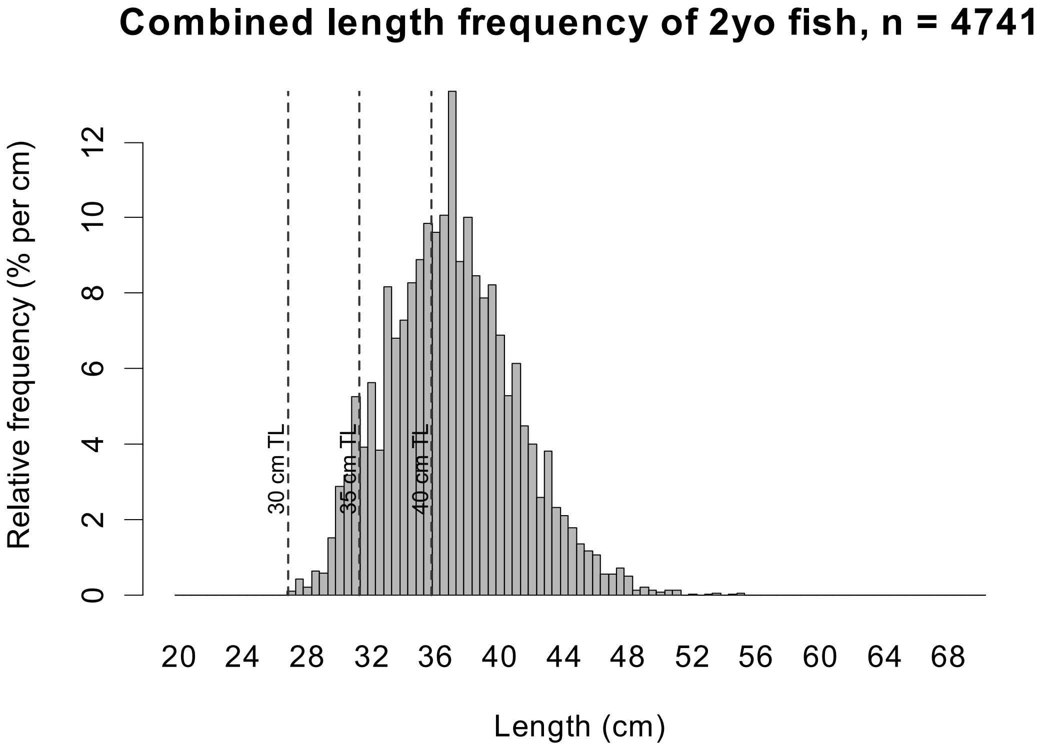

Combined length frequency of 2yo fish, n = 4741

Figure 14(b): Combined length frequency of two-year-old fish from all years in which ageing data are available (1995, 1997, 1999–2003).

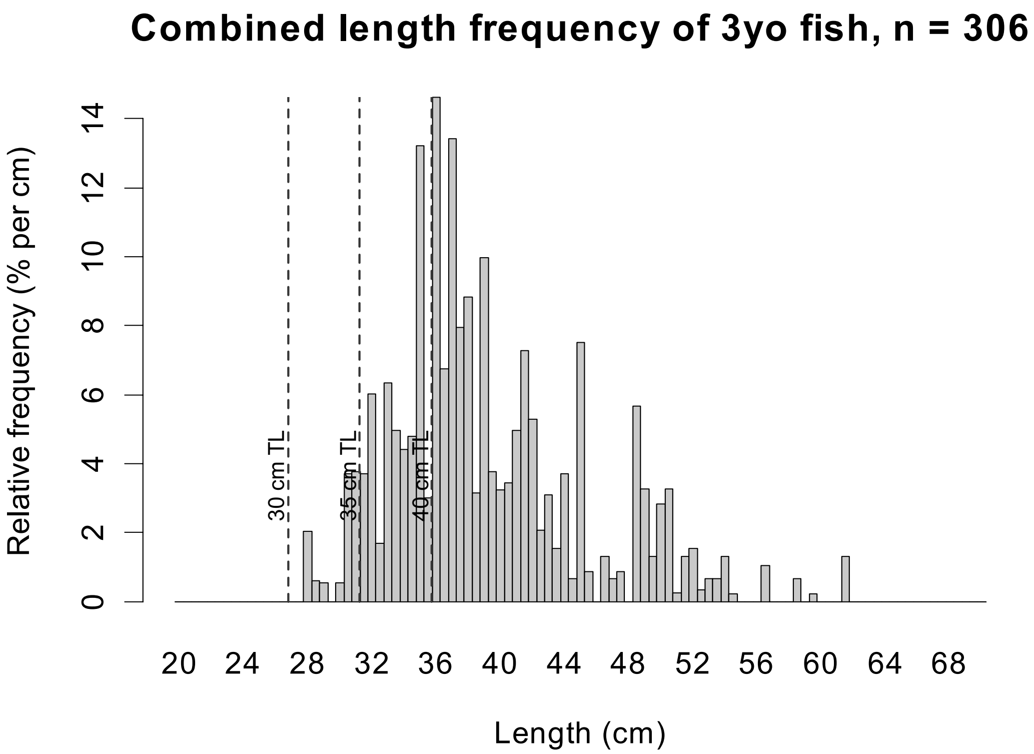


Figure 14(c): Combined length frequency of three-year-old fish from all years in which ageing data are available (1995, 1997, 1999–2003).

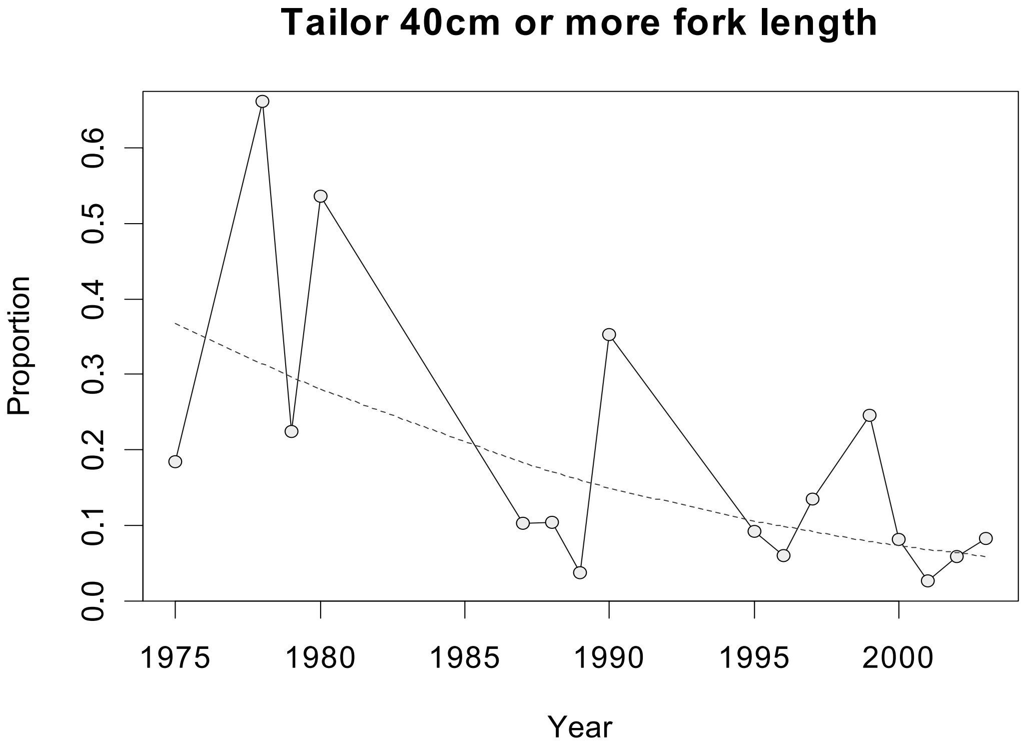


*Figure 15: Proportion of fish in length-frequency samples with fork length 40cm or more, including a curve calculated by fitting a straight line to the logit of the proportion (*p*),* $\log\{p / (1 - p)\}$.

Figures 14(a, b, c) show an unexpected result, that since 1995 the mean lengths for fish aged 1, 2 and 3 have been very close together (33.3cm, 37.0cm and 39.2cm respectively). Judging from length-frequency data, this was not the case before the 1990s, when modes of presumably two-year-old fish were approximately 42cm in 1978–80 and 1987 (Figure 13). There are two possible explanations for this phenomenon:

(a) The majority of fish are present only because they were not selected by the fishery in the previous year.
(b) The population has responded to fishing pressure by undergoing a genetic change towards smaller fish.

Both of these explanations imply a high degree of size-selectivity and an extremely high level of fishing pressure on fish that have been selected. We believe that explanation (a) is more likely because

- the standard deviation of lengths increases markedly with age at a much greater rate than the mean length does (see Figure 14; standard deviations are 2.8cm, 4.0cm and 6.2cm), and
- there are very few fish aged three or more in the population (Figures 13 and 14).

The size-selectivity of the fishery makes it impracticable to fit a growth curve to ageing data, which is why the estimation of a definitive set of growth parameters is not pursued in this report.

As mentioned in section 3.3, Figures 13(b–d) and 15 show that tailor were plentiful in the late 1970s, with a high number of large fish present. This period lines up well with the high recruitments observed in the mid-1970s, reflected in high catch rates (Figure 12). The cause of these high recruitments and consequent high numbers of larger fish is unknown, but possibly related to the 1974 Brisbane floods which would have substantially increased the amount of nutrients flowing into bays and inlets. Whatever the case, the population was certainly aided by the relatively small size of the recreational fishery at that time, and the demand-driven fall in the commercial fishery. It is unlikely that tailor could flourish to that degree under current levels of fishing effort, whatever the level of recruitment.

The partial selectivity of one-year-old fish appears to be unrelated to the size limit, because it was present well before the size limit was introduced.

The ageing data show very few fish three years old or more (Figures 13 and 14). The obvious explanation for this is that they are caught by fishers before reaching this age. The increasing catch rates by charter boats and commercial line fishers (Figures 6 and 7) could lead one to speculate that tailor are beginning to respond to fishing pressure by departing from their schooling behaviour and moving offshore. This is not believed to be the case because no great numbers of large tailor have been found offshore. It is likely that charter boat operators are increasingly targeting tailor in response to lack of availability of more popular species.

Figures 13 and 15 show a large amount of year-to-year variation in the number of large fish present, but little evidence of strong year-classes continuing from one year to the next (e.g., very few two-year-old fish were sampled in 2003, but a scarcity of one-year-old fish in 2002 is not evident). Therefore we believe that the year-to-year variation is largely due to variation in the selectivity of the Fraser Island recreational fishery during the sampling periods (e.g., weather factors; see Discussion, section 9), rather than changes in the population structure. We note that this variation has continued to take place since 1999 when the sampling methodology was standardised scientifically: for example, many large fish were sampled in 1999, and very few in 2001. As discussed above, the high number of large fish present in 1978–80 is a real effect.

5. Maturity and fecundity

Data on maturity and fecundity are scarce for Australian tailor. Bade (1977) found that they mature at 26–30cm fork length. In this report it is assumed that all tailor are immature at age zero, and that all are mature by age one.

Bade measured fecundity on nine fish, which appear to be the only results available from Australia. Other measurements have been made by van der Elst (1976) who measured 12 South African Elf, and Conand (1975) who measured 117 Tassergal from Senegal.

The following curve was fitted to Bade's data:

$$\log(\text{fecundity}) = 4.723 + 0.04120 \times \text{fork length},$$

which is equivalent to

$$\text{fecundity} = 113.96 \times \exp(0.04120 \times \text{fork length})$$

(a small bias correction has been used here, which is why the 113.96 coefficient differs slightly from exp(4.723)). In these formulae, fork length is measured in cm and logs are natural logs (base *e*).

Bade's data and the fitted curve are plotted in Figure 16, together with curves provided by van der Elst (1976) and Conand (1975). The Australian data show a smaller rate of change of fecundity with length than the overseas data. Only the *relative* fecundity is considered in this report, i.e. the way fecundity changes with length. Absolute magnitudes of fecundity measurements are not considered. The curves from van der Elst and Conand have been scaled to fit Bade's measurements.

It should be noted that van der Elst and Conand both examined larger fish than Bade did (and indeed larger fish than are generally present in the Australian fishery); therefore their results are not really applicable to the Australian fishery. Van der Elst's fish ranged from 29cm to 69cm fork length, and Conand's from 38cm to 92cm fork length (both authors expressed their results in total length rather than fork length).

The curve fitted to Bade's data is used for the analyses presented here, but further experimental work on fecundity of Australian tailor is desirable.

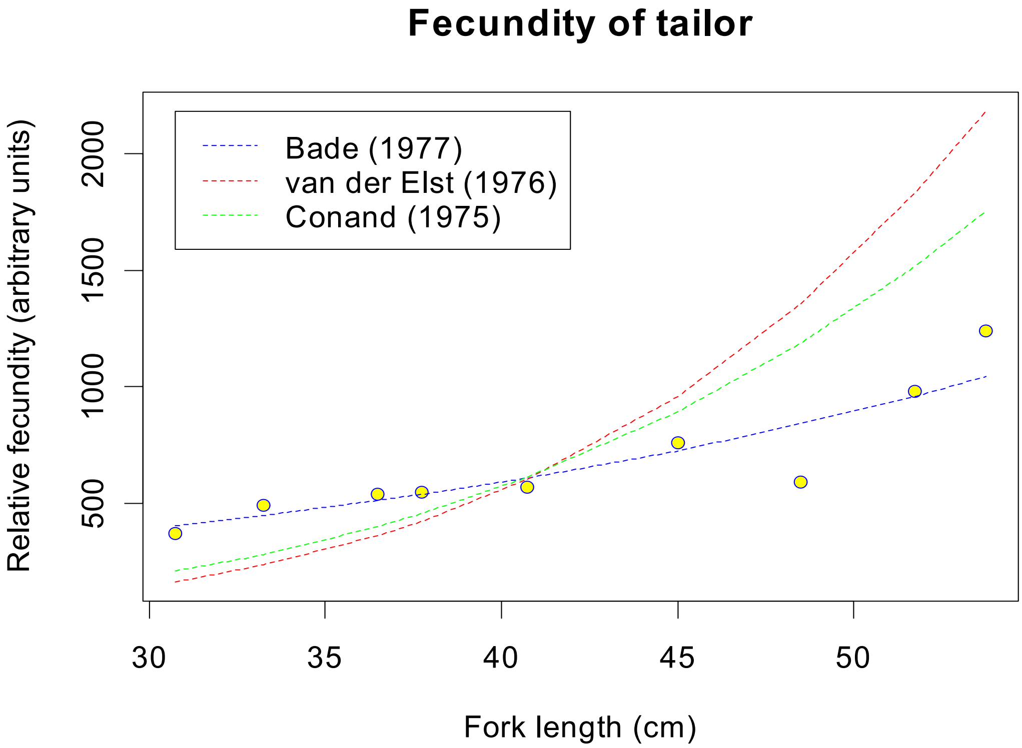


Figure 16: Fecundity of tailor with points measured by Bade (1977), curve fitted to Bade's data, and curves from van der Elst (1976) and Conand (1975). Conand presented two curves which are very close together; the two exponents have been averaged here to produce a single curve.

6. Surplus production model

Surplus production models use catch and catch-rate data only, without considering age structure of the catch (Haddon, 2001, ch. 10). The Schaefer form is used here (Haddon, 2001, pp. 288–9):

$$B_{t+1} = B_t + rB_t\,(1 - B_t / K) - C_t,$$

where B_t is the biomass at the beginning of year t, C_t is the catch in year t, and r (the population replenishment rate) and K (the maximum population size) are parameters that are estimated. The catch rate I_t is assumed indicative of the exploitable biomass, and the trend in I_t is matched to the trend in B_t.

To fit the model, B_t was taken to be deterministic (i.e. subject to no random error), and I_t was assumed to be subject to lognormal errors. The model was fitted by minimising the sum of squares

$$\sum_t [\log I_t - \log\{q(B_t + B_{t+1})/2\}]^2 ,$$

where q is the catchability, estimated by

$$q = \prod_t I_t \Big/ \prod_t \frac{B_t + B_{t+1}}{2} .$$

The quantity $(B_t + B_{t+1}) / 2$ is an approximation to the midyear biomass which is recommended by Haddon (2001, p. 293). The initial biomass B_1 was generated by running the model for a "warm-up" period of 20 years, beginning at the virgin state K, with a constant catch equal to the average of the first two years' data (1944 and 1945, assuming that catches were low in line with these years for the whole of the World War II period).

The sum of squares had dual minima for the majority of the scenarios, with the global minimum given by a zero value of r and a high value of K. This fit was not sensible because it explains falling catch rates by postulating that the population is fished down indefinitely with no ability to replenish itself. This is certainly not the case for tailor.

For Scenarios 1A–C, 2C and 3C, it was possible to get the model to converge to a local minimum that was higher than the global one but provided sensible answers. The parameter values were very similar for Scenarios 1A–C. Results from Scenarios 1B, 2C and 3C are shown in Figure 17(a–l). For these scenarios, values of *r* were 1.00, 0.88 and 0.64 respectively, and values of *K* were 4300t, 4800t and 6100t.

All scenarios in Figure 17 show extremely high recent harvest rates, with more than 80% of exploitable biomass being harvested in 2003.

The surplus production model shows a population that would be in a dire state if all mature fish were selected by the fishery. The surplus production method is incapable of modelling partial selectivity of mature fish, as can be seen by the difference between the observed and predicted catches at the right-hand side of Figure 17(d, h and l); therefore it predicts a population collapse. The model highlights the reliance of the tailor fishery on the partial selectivity of one-year-old fish.

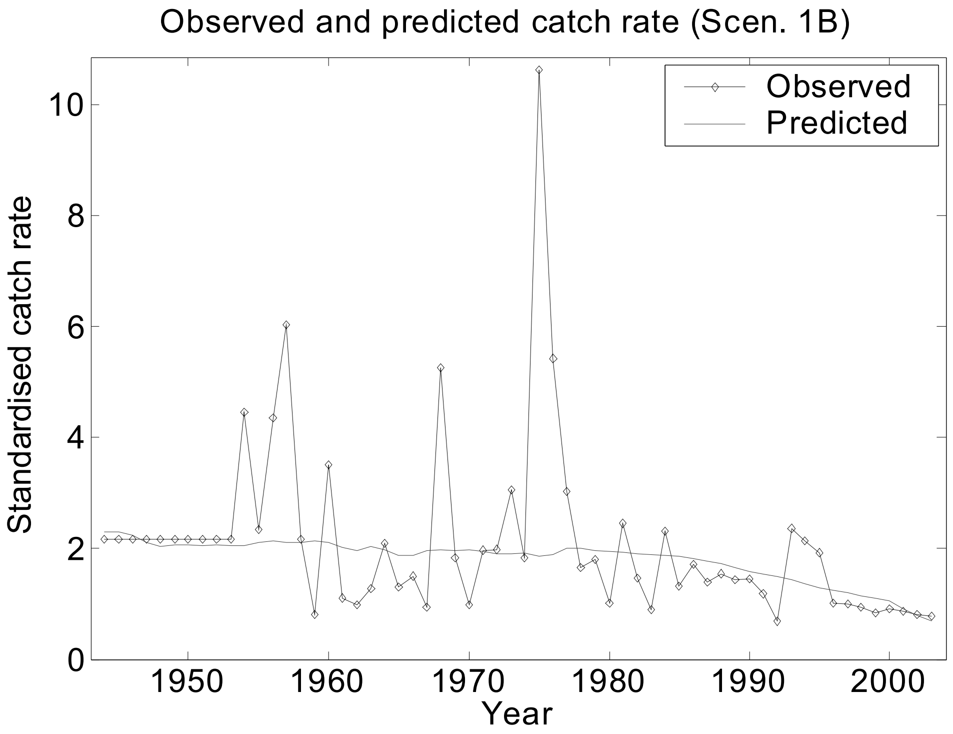


Figure 17(a): Surplus production catch rates (observed points and line, predicted line only) for scenario 1B (no increase in recreational fishing power since 1977, 8% p.a. increase in recreational catch size to 1993).

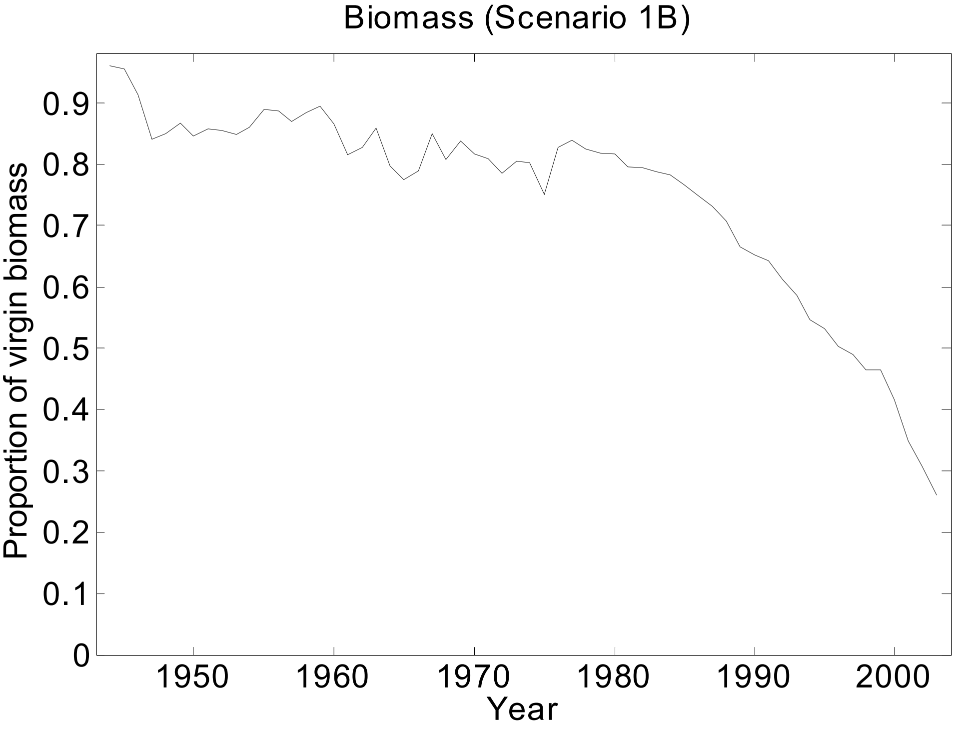


Figure 17(b): Surplus production biomass trend for scenario 1B (no increase in recreational fishing power since 1977, 8% p.a. increase in recreational catch size to 1993).

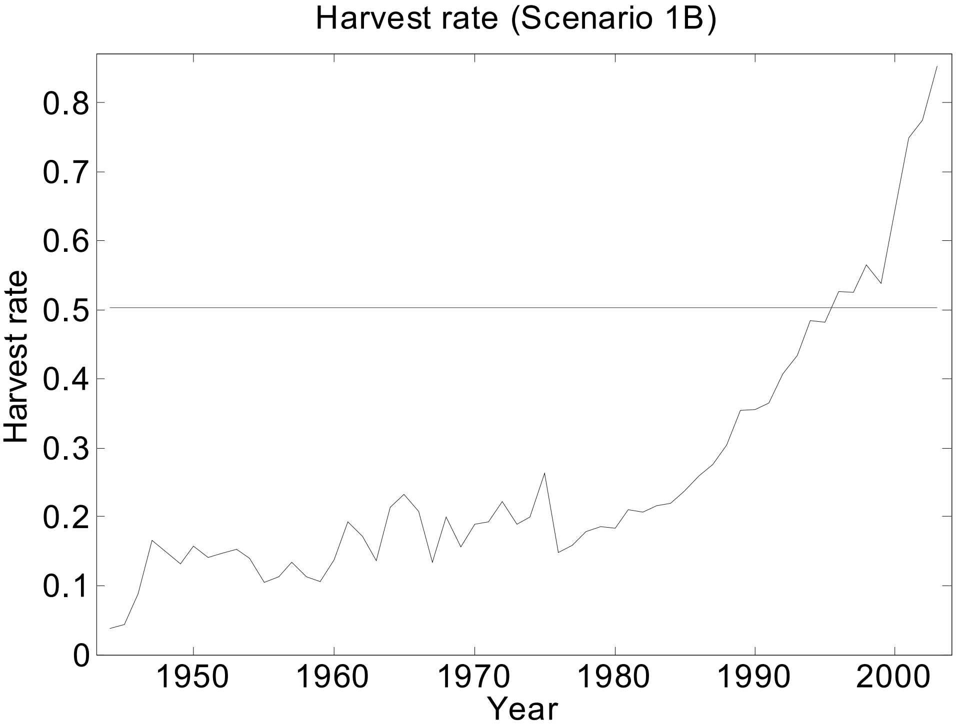


Figure 17(c): Surplus production harvest rate (proportion of exploitable biomass that is caught in each year) for scenario 1B (no increase in recreational fishing power since 1977, 8% p.a. increase in recreational catch size to 1993). The line is at r */ 2, the harvest rate giving maximum sustainable yield.*

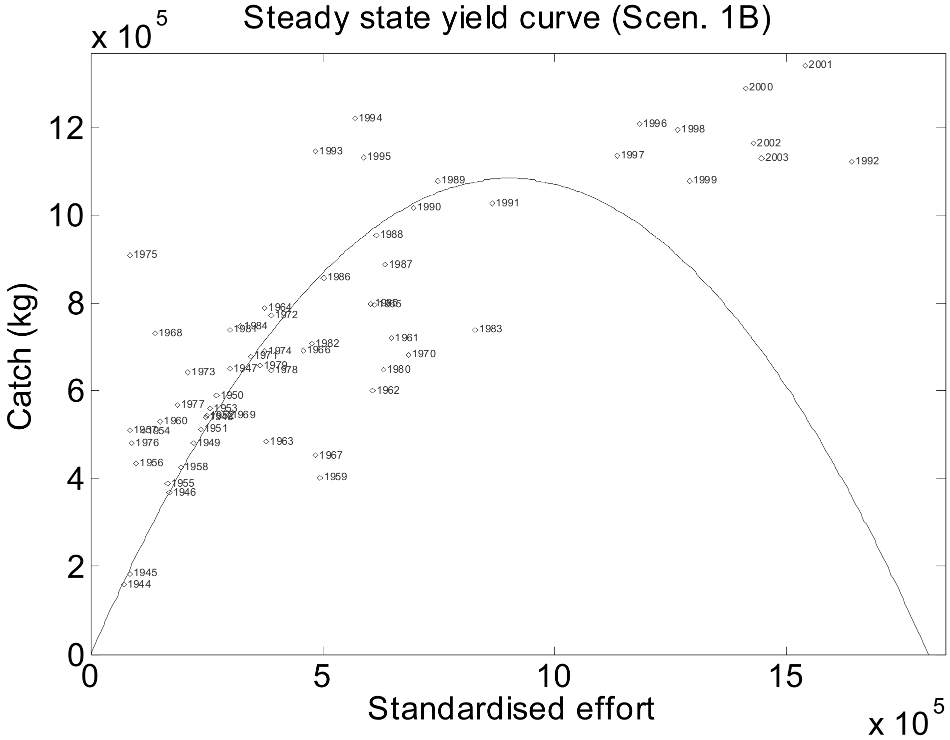


Figure 17(d): Surplus production yield curve, with observed annual catch and effort, for scenario 1B (no increase in recreational fishing power since 1977, 8% p.a. increase in recreational catch size to 1993). The points in the top right corner show the inability of the surplus production method to model non-selectivity of some mature fish.

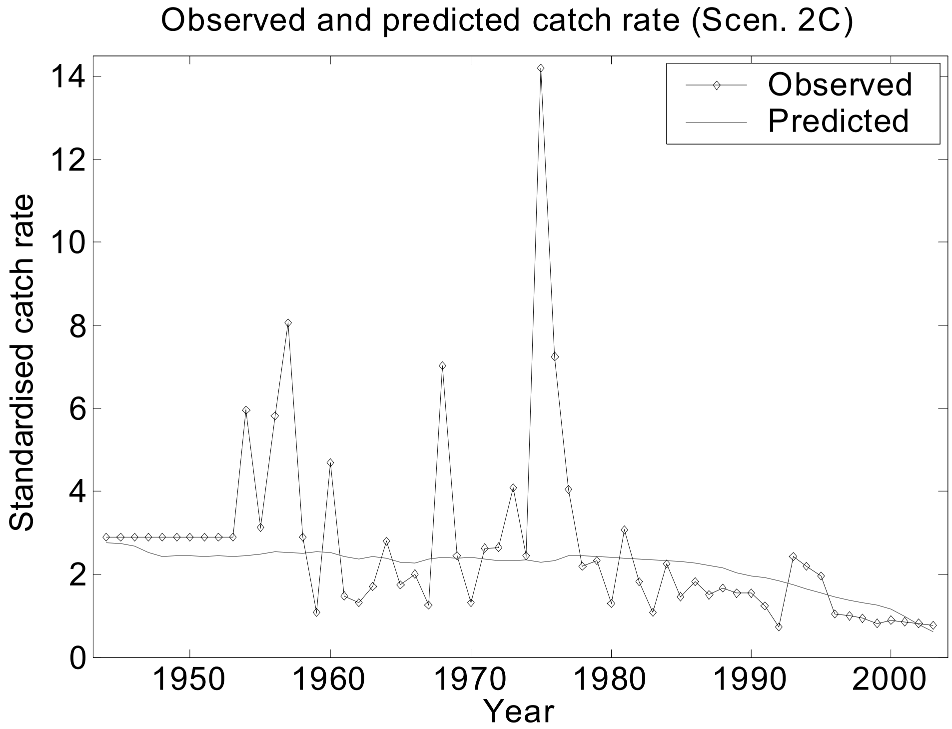


Figure 17(e): Surplus production catch rate for scenario 2C (moderate increase in recreational fishing power since 1977, 11% p.a. increase in recreational catch size to 1993).

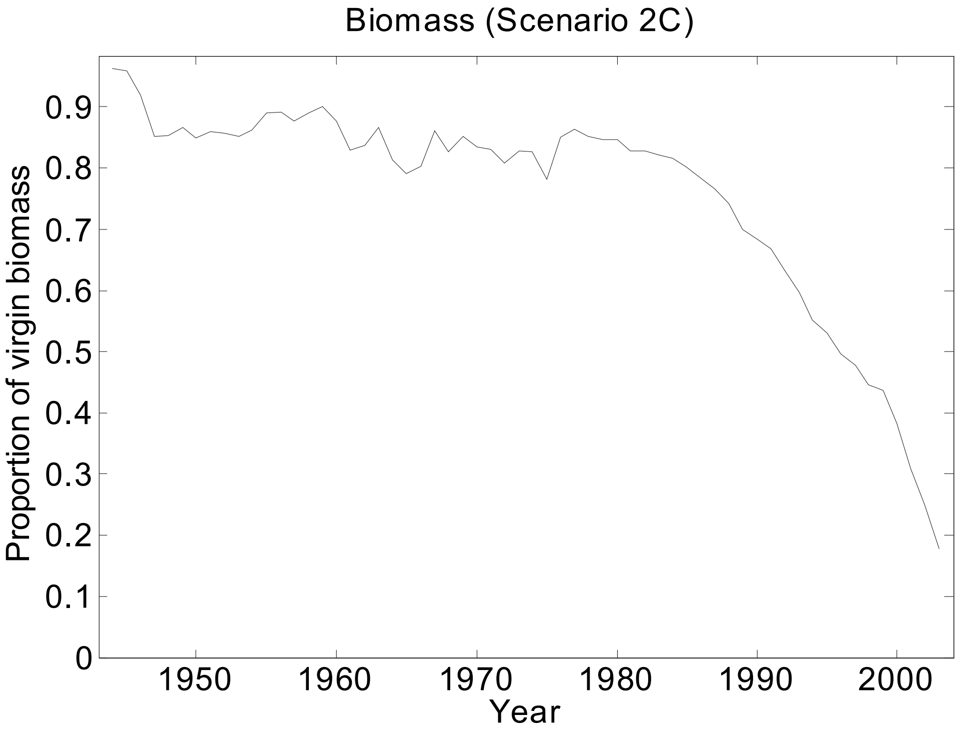


Figure 17(f): Surplus production biomass trend for scenario 2C (moderate increase in recreational fishing power since 1977, 11% p.a. increase in recreational catch size to 1993).

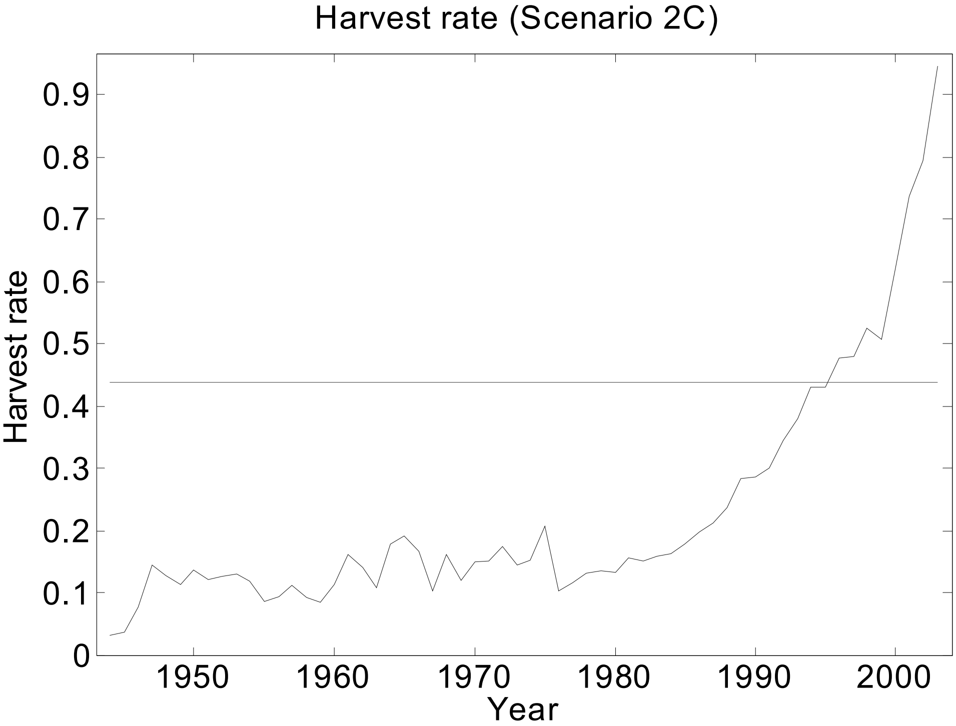


Figure 17(g): Surplus production harvest rate (proportion of exploitable biomass that is caught in each year) for scenario 2C (moderate increase in recreational fishing power since 1977, 11% p.a. increase in recreational catch size to 1993). The line is at r */ 2, the harvest rate giving maximum sustainable yield.*

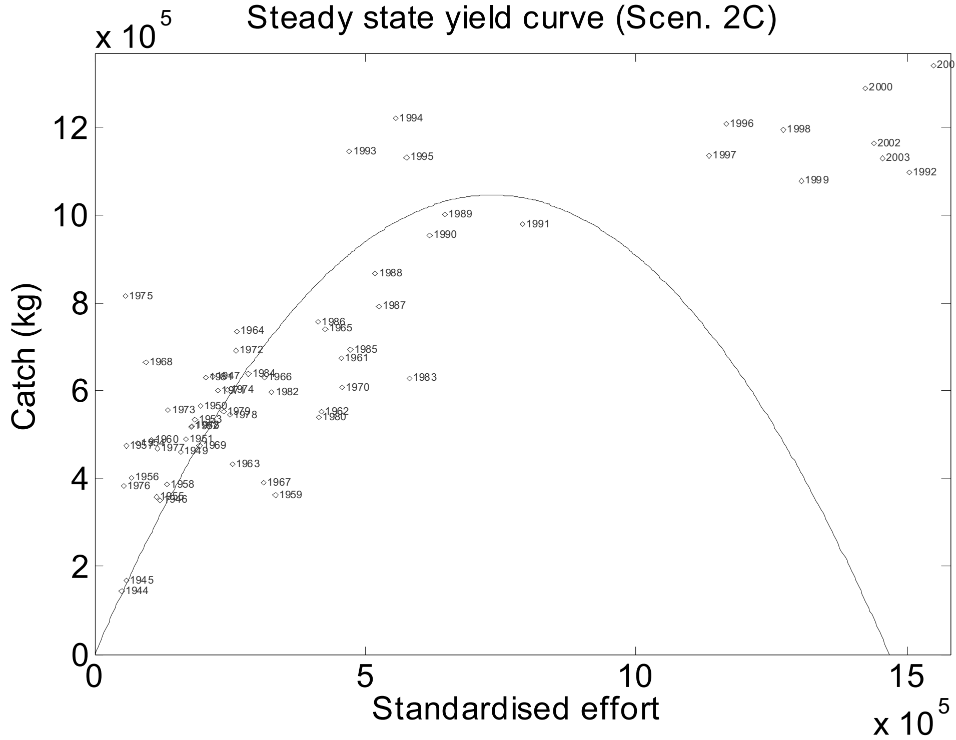


Figure 17(h): Surplus production yield curve, with observed annual catch and effort, for scenario 2C (moderate increase in recreational fishing power since 1977, 11% p.a. increase in recreational catch size to 1993). The points in the top right corner show the inability of the surplus production method to model non-selectivity of some mature fish.

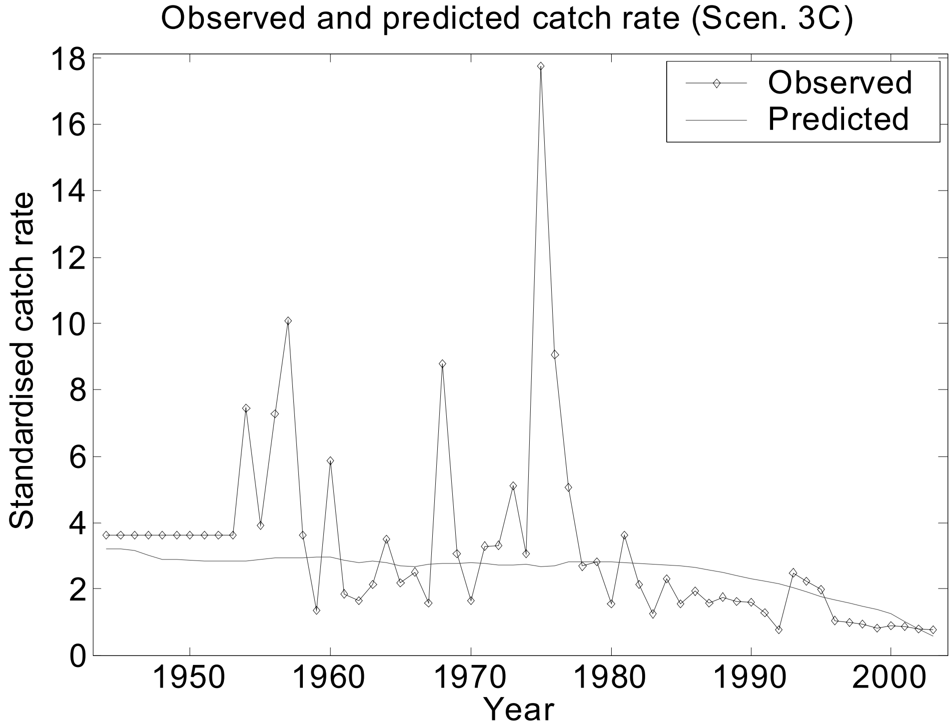


Figure 17(i): Surplus production catch rate for scenario 3C (continued steep increase in recreational fishing power since 1977, 11% p.a. increase in recreational catch size to 1993).

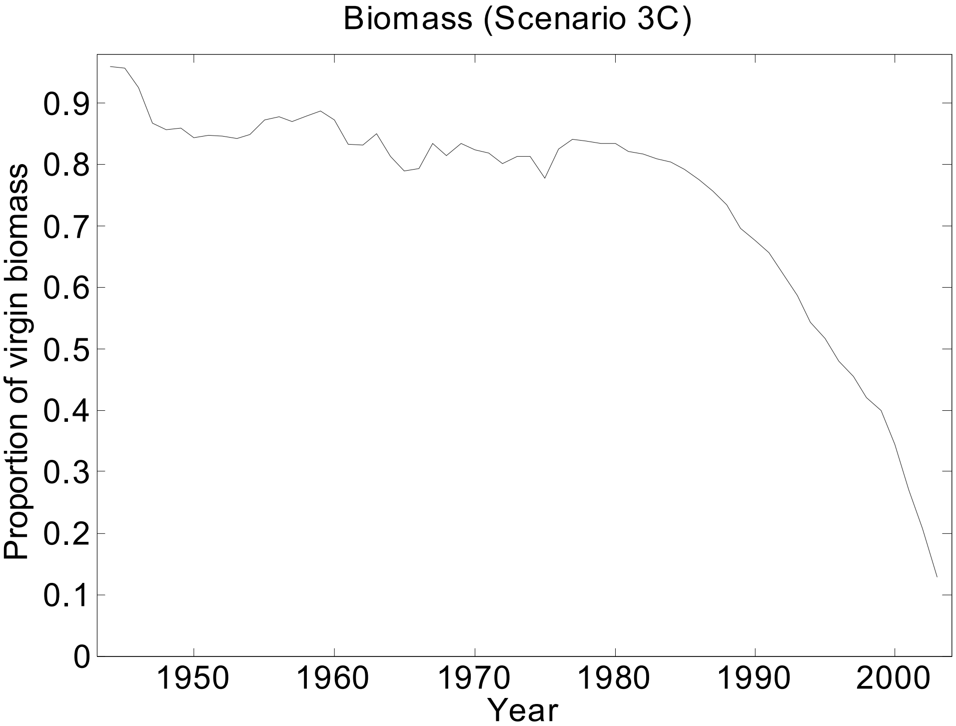


Figure 17(j): Surplus production biomass trend for scenario 3C (continued steep increase in recreational fishing power since 1977, 11% p.a. increase in recreational catch size to 1993).

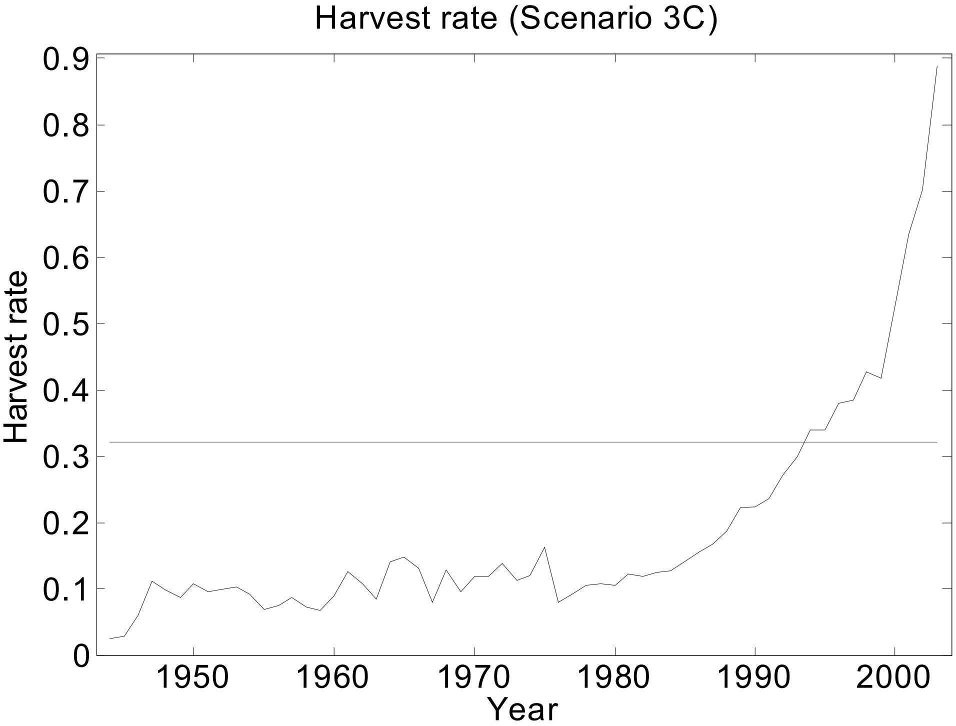


Figure 17(k): Surplus production harvest rate (proportion of exploitable biomass that is caught in each year) for scenario 3C (continued steep increase in recreational fishing power since 1977, 11% p.a. increase in recreational catch size to 1993). The line is at r */ 2, the harvest rate giving maximum sustainable yield.*

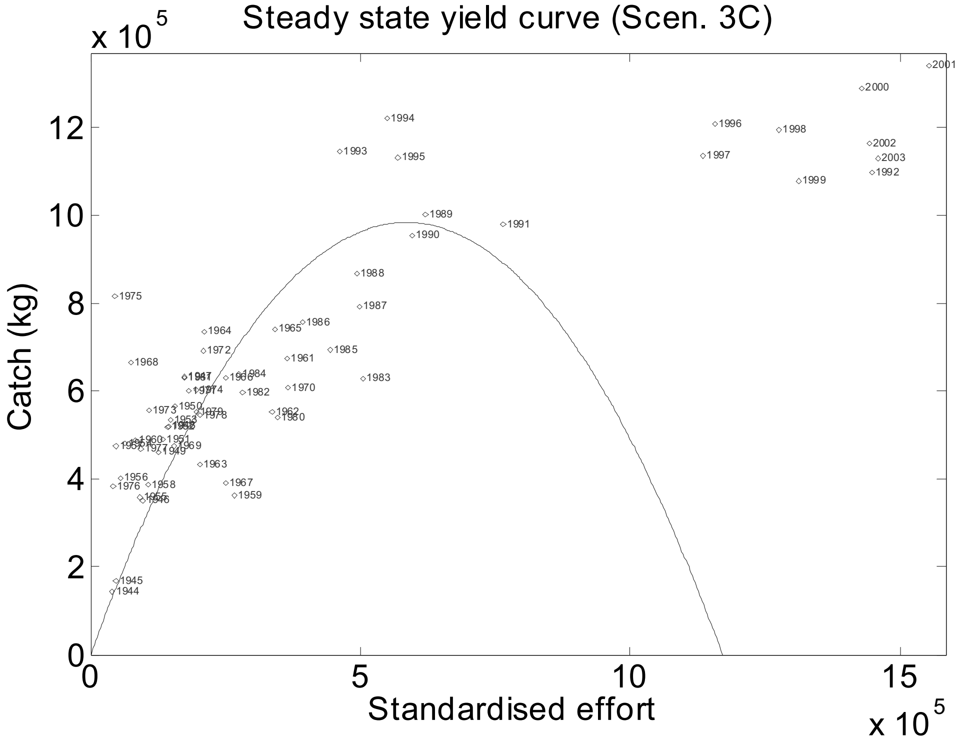


Figure 17(l): Surplus production yield curve, with observed annual catch and effort, for scenario 3C (continued steep increase in recreational fishing power since 1977, 11% p.a. increase in recreational catch size to 1993). The points in the top right corner show the inability of the surplus production method to model non-selectivity of some mature fish.

7. Age-structured model

7.1 Formulation of model

This was the model reviewed by John Hoenig.

The age-structured model included the number of fish in each age class (0–5 which was the oldest age recorded in the ageing data) present in the population in each year. It also included selectivity whereby not all fish in the population were subject to exploitation.

The model and notation are similar but not identical to those of Haddon (2001, ch. 11): $N_{a\,y}$ is the number of fish of age a in the population in year y (actually at the beginning of year y). In the next year, $y + 1$, for $a \geq 1$, the number of fish of age a is given by

$$N_{a\,y+1} = N_{a-1\,y}\,(1 - S_{a-1}\,U_y)\,e^{-M},$$

where S_a is the proportion of fish of age a that are selected by the fishery, U_y is the harvest rate in year y (probability that a selected fish is caught), and M is the instantaneous rate of natural mortality, assumed constant and measured in yr^{-1}. The final age group is in fact the “plus group” of all fish aged 5 or more. In this formulation, the model is strictly that of a “pulse fishery” whereby the catch is taken just after the start of the year, before any of the year’s natural mortality has taken place. This formulation is convenient because the harvest rate can be expressed simply as the catch divided by the exploitable biomass at the start of a year. The model could be reformulated to have fishing effort applied uniformly throughout the year, but for the tailor fishery it is unclear whether that would be any better approximation than the pulse fishery assumption.

Selectivity follows a logistic curve:

$$S_a = 1 / [1 + \exp\{-\log(19)\,(a - a_{50}) / (a_{95} - a_{50})\}],$$

where a_{50} is the age at which 50% of fish in the population are recruited to the fishery, and a_{95} is the age at which 95% of fish are recruited.

Recruitment of zero-year-old fish is assumed to be deterministic and is related to the previous year’s stock size by a Beverton-Holt stock-recruitment relationship (Haddon, 2001, pp. 251–254), adapted to use the number of eggs produced:

$$N_{0\,y+1} = \alpha\,e_y / (1 + \beta\,e_y),$$

where e_y is the relative number of eggs produced in year y ($= \Sigma_a\,N_{a\,y}\,\text{mat}_a f_a$ where mat_a is the proportion of fish mature by age a and f_a is relative fecundity at age) and α and β are given by

$$\alpha = r_{\max}\,N_0 / e_0$$

and

$$\beta = (r_{\max} - 1) / e_0\,,$$

N_0 being the virgin recruitment and e_0 the virgin relative number of eggs produced. The parameters N_0 and $r_{\max}$ have to be estimated. The parameter $r_{\max}$, in the absence of fishing, is identical to the parameter denoted $\hat{\alpha}$ by Myers, Bowen and Barrowman (1999), described by them as “the number of spawners produced by each spawner over its lifetime at very low spawner abundance”. Myers et al. centre their discussion on the parameter $\tilde{\alpha}$, “the number of spawners produced by each spawner per year”, which is related to $r_{\max}$ by $\tilde{\alpha} = r_{\max}\,(1 - e^{-M})$. The parameter $r_{\max}$ is related to the more widely-used “steepness” parameter h by $h = r_{\max} / (4 + r_{\max})$; steepness is defined as the proportion of virgin recruitment that takes place when the spawning population size (or egg production) is reduced to 20% of its virgin level.

Myers et al. find that $\tilde{\alpha}$ usually ranges between 1 and 7.

It is convenient to state at this point that neither the age-structured model nor the age-length-structured model in the next section found any evidence that recruitment depended on stock size, i.e. they both estimated $r_{\max} = \infty$. Therefore $r_{\max}$ was not estimated by the models but was set to the maximum value recommended by Myers et al., i.e. $r_{\max} = 7 / (1 - e^{-M})$.

It is usual in running models to set M to a value found by other sources. For tailor, Dichmont et al. (1999, pp. 101–102) listed values of 0.40, 0.49, 0.59 and 1.16 yr^{-1}.

In this application it was found that many values of M provided poor fits to the age composition data (they produced too may fish aged three or more); hence it appeared possible to allow the model to estimate M.

As noted in section 4, because of size-selectivity in the fishery and variation in mean length-at-age over the years, it was not considered worthwhile to fit a growth curve to the length-at-age data. The model used direct length-at-age and length-frequency measurements to infer weight-at-age (see section 7.3).

7.2 Model parameters

The following parameters were estimated by the model:

1. N_0, the number of recruits to the virgin population (millions of fish)
2. a_{50}, the age at which 50% of fish are selected by the fishery (yr)
3. a_{95}, the age at which 95% of fish are selected by the fishery (yr)
4. M, the instantaneous natural mortality rate (yr^{-1}).

Values of the selectivity parameters match length-frequency and ageing data from the Fraser Island recreational fishery, and are assumed to apply to the commercial fishery and to other locations; the model is not greatly sensitive to this assumption. The 1990 introduction of a minimum size limit had little effect (Figure 13). In addition to the above parameters,

- $r_{\max}$, the stock-recruitment parameter, as mentioned above, was set to $7 / (1 - e^{-M})$
- N_{a1}, the initial numbers-at-age, were generated as in section 6 by running the model for a “warm-up” period of 20 years, beginning from the virgin state (determined by N_0 and M), with a constant catch equal to the average of the first two years (1944 and 1945) and weight-at-age calculated from the 1975 length-frequency data
- q, the catchability parameter, was set to $(\Pi_y \text{cpue}_y) / (\Pi_y B_y)$, where cpue_y is the catch rate or catch per unit effort in year y, and B_y is the midyear biomass in year y.

7.3 Input data and model fitting

The model was fitted by matching the expected to the observed catch rate and age composition. Catch rates from 1954 to 2003 were used, and age compositions from 1975, 1978–80, 1987–90, and 1995–97 and 1999–2003.

Catch rate was assumed to follow a lognormal distribution, giving rise to the log-likelihood

$$L_{\mathrm{cpue}} = -n_{\mathrm{cpue}} \log \sigma_{\mathrm{cpue}} - \Sigma_y (\log \mathrm{cpue}_y - \log \mathrm{pred.cpue}_y)^2 / (2\sigma_{\mathrm{cpue}}^2),$$

where n_{cpue} is the number of years of catch-rate data, cpue_y is the observed catch rate for year y, $\mathrm{pred.cpue}_y$ is the catch rate predicted by the model, and σ_{cpue} is the standard deviation of the lognormal distribution. Age composition in year y was measured by the cumulative distribution function, $\mathrm{cdf}_y(a)$, which is the proportion by weight of fish in the catch of age $\leq a$. The mean absolute difference between distribution functions was assumed to follow a half-normal distribution, giving the log-likelihood

$$L_{\mathrm{age}} = -n_{\mathrm{age}} \log \sigma_{\mathrm{age}} - \Sigma_y (\Sigma_a |\mathrm{cdf}_y(a) - \mathrm{pred.cdf}_y(a)| / A)^2 / (2\sigma_{\mathrm{age}}^2),$$

where n_{age} is the number of years for which length-frequency or ageing data are available (the sum over y is over those years), A is the number of age-classes (the sum over a is over these age-classes), $\mathrm{pred.cdf}_y$ is the age composition in year y predicted by the model, and σ_{age} is the standard deviation of the half-normal distribution. Some constant terms have been omitted from these log-likelihoods. The negative sum of the two log-likelihoods was minimised by the Matlab polytope (or simplex) routine `fminsearch`.

All ageing data from 1995, 1997 and 1999–2003 were combined into a single age-length key, which was used to determine age composition of the population in all the years for which length-frequency data were available (1975, 1978–80, 1987–90, and 1995–97, 1999–2003).

Weight-at-age obviously varied between years, and it would have been inaccurate to treat it as invariant through the years. The model did not attempt to estimate this variation; it simply accepted the observed weight-at-age in each year. For years in which length-frequency data were available, the weight-at-age was estimated from the observed length-frequency using Bade's (1977, p. 78) length-weight relationship:

$$W = 1.203 \text{ x } 10^{-5}\, L_f^{3.01},$$

where W is weight in kg and L_f is fork length in cm (Bade used g and mm which is why the value of the coefficient differs). The 1975 values for weight-at-age were used prior to 1975. For years after 1975 in which length-frequency data were unavailable, the weight-at-age was estimated by a linear interpolation from the years in which data were available.

Fecundity data f_a were taken from the curve fitted to Bade's (1977) data (see section 5).

The data input to the model were

1. annual catch weight (1944–2003)
2. annual catch rate (1954–2003), used as an index of abundance and assumed to be proportional to exploitable biomass
3. relative numbers-at-age sampled from the catch (1975, 1978–80, 1987–90, 1995–97, 1999–2003)
4. mean weight-at-age of fish (1944–2003).

7.4 Results

The model provided sensible results for all scenarios, and all gave similar stories of the population. Results are shown in Figure 18(a–n) for Scenarios 2B (middle-of-the-road assumptions), 1C and 3A (most extreme results).

It was difficult to estimate both N_0 and M with much precision, and the maximum likelihood estimates of M were larger than would be acceptable to many biologists. For this reason, the model was also run with M set equal to the lower limit of its 95% confidence interval, as determined by the likelihood profile method (Haddon, 2001, pp. 104–108). The likelihood profile method seeks parameter values for which the log-likelihood differs from its maximum value by $\frac{1}{2} \times \chi^2_{1\ 0.95} = 1.92$. Because these estimates of M were more biologically reasonable, they are the ones presented in Figure 18 for Scenarios 1C and 3A; results for both values of M are given for Scenario 2B.

Parameter estimates and maximised log-likelihood values are listed in Table 2.

Table 2: Parameter estimates from the age-structured model for Scenarios 2B (middle-of-the-road assumptions), 1C and 3A (most extreme scenarios). The parameters are N_0, the virgin number of recruits at age 0; a_{50}, the age at which 50% of fish are selected by the fishery; a_{95}, the age at which 95% of fish are selected; and M, the instantaneous natural mortality rate. "Min. M" refers to the results of setting M to the lower limit of its 95% confidence interval. The other rows include maximum likelihood estimates of M.

Scenario	N_0 (millions)	a_{50} (yr)	a_{95} (yr)	M (yr^{-1})	Log-lik
1C	52.5660	1.2076	1.7701	1.8211	82.5537
1C (min. M)	17.2832	0.9979	1.5745	1.26	80.6196
2B	32.5663	1.1737	1.7529	1.6166	80.5783
2B (min. M)	12.9154	0.9849	1.5998	1.12	78.6172
3A	17.0771	1.0873	1.6873	1.2743	77.5849
3A (min. M)	9.0874	0.9244	1.5435	0.92	75.6505

The parameter estimates, especially of N_0 and M, vary widely between scenarios, but the underlying story remains the same, that the population is very heavily exploited and its ability to reproduce is preserved only by the partial selectivity of one-year-old fish.

Estimates of M were very high. It must be emphasised that the model's estimates apply only to fish up to about three years of age, because there are hardly any fish older than this in the catches. It is possible that a substantially lower value of M applies to fish older than three.

The selectivity values for one-year-old fish in Scenario 2B were found to be 29.26% in the case of unconstrained estimation of M, and 51.81% when M was fixed to its lower confidence limit; these values were relatively constant between scenarios. The model is estimating a "hidden" population of one-year-old fish that amounts to around 71% or 48% respectively of the total population of one-year-old fish. The ability of these hidden fish to spawn is the main factor maintaining egg production.

Figure 18 shows the exploitable biomass exceeding the virgin level in some years. This is explained by high recruitment in the mid-1970s, which by chance was greater than the average virgin recruitment.

This model does not include year-to-year variation in recruitment, and so cannot fit the big spike in recruitment in the mid-1970s. The increase in biomass that the model has been able to fit at that time is due mainly to the presence of bigger two-year-old fish rather than a greater number of them.

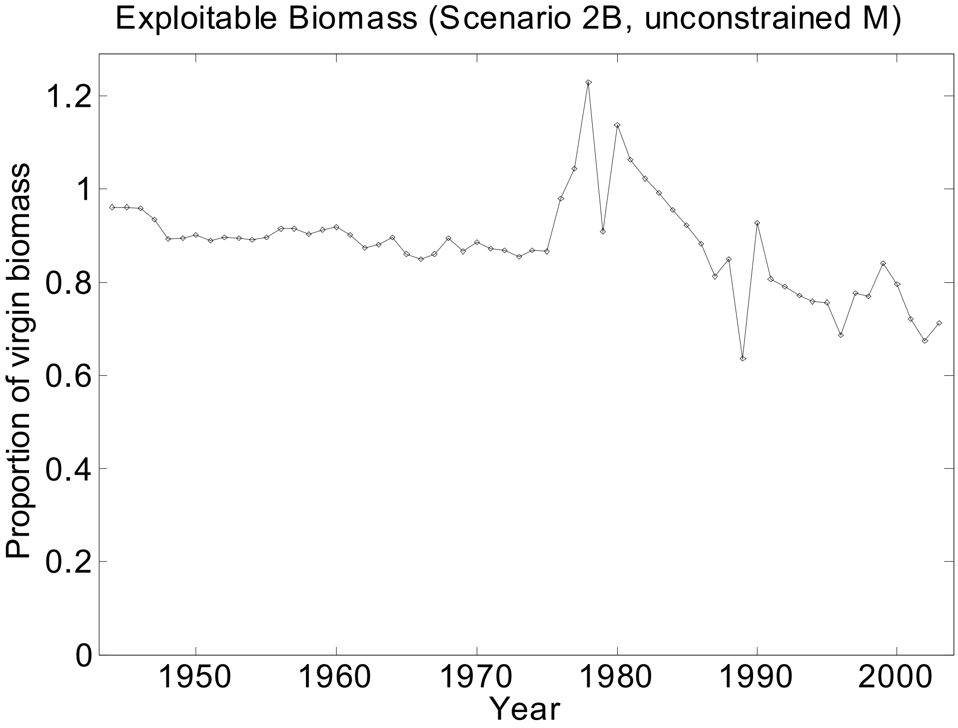


Figure 18(a): Exploitable biomass from the age-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), with unconstrained natural mortality parameter M *(1.62 yr^{-1}).*

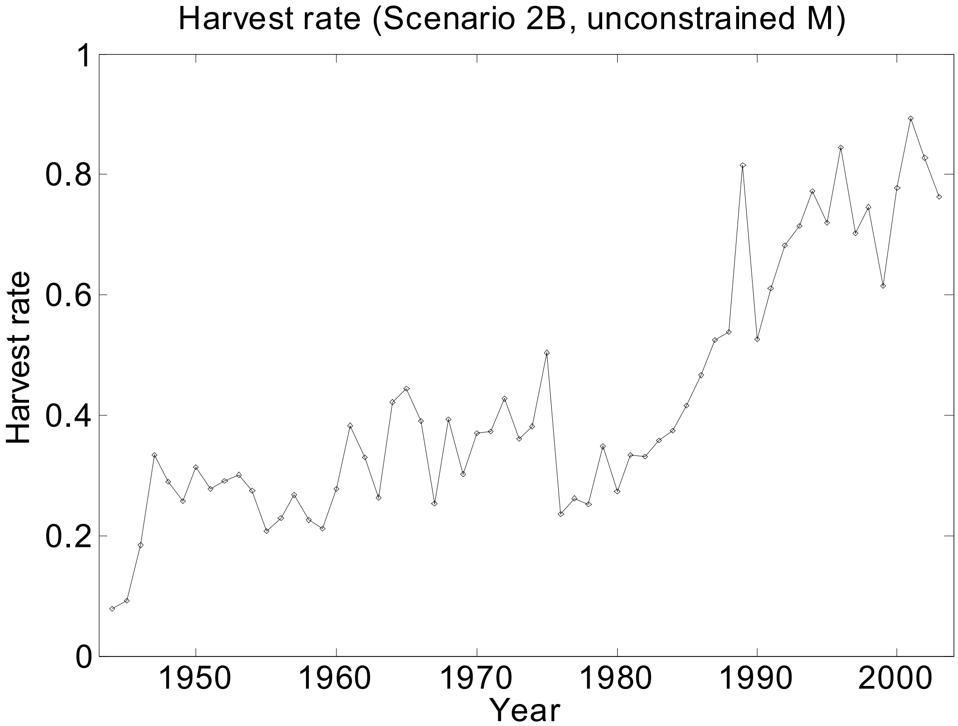


Figure 18(b): Harvest rate (proportion of exploitable biomass that is caught in each year) from the age-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), with unconstrained natural mortality parameter M *(1.62 yr^{-1}).*

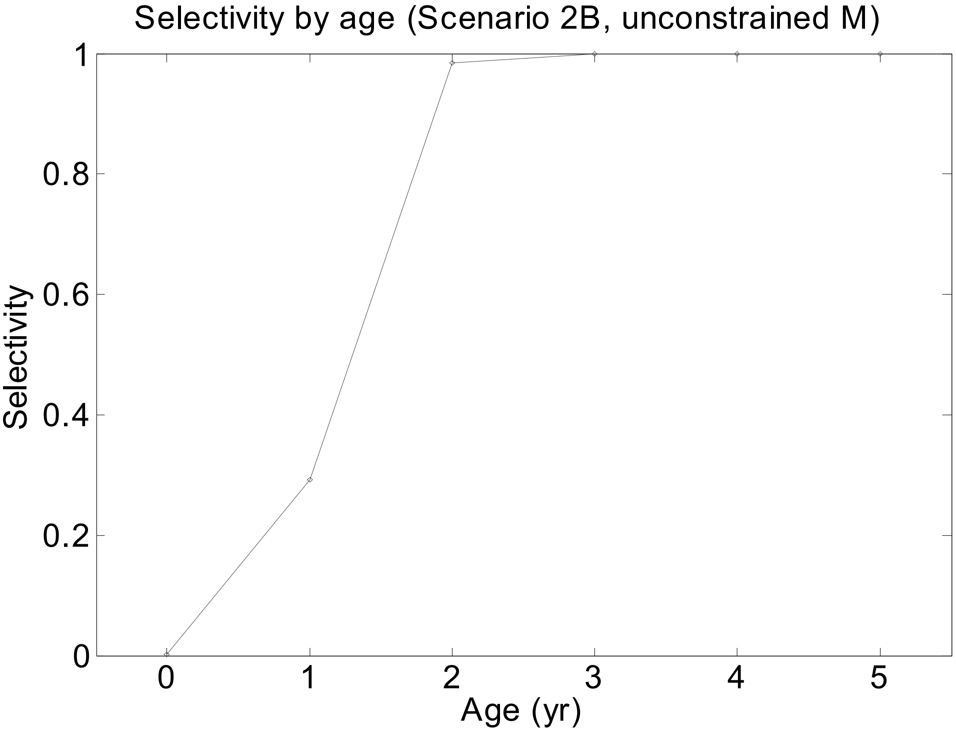


Figure 18(c): Age-selectivity from the age-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), with unconstrained natural mortality parameter M *(1.62 yr^{-1}).*

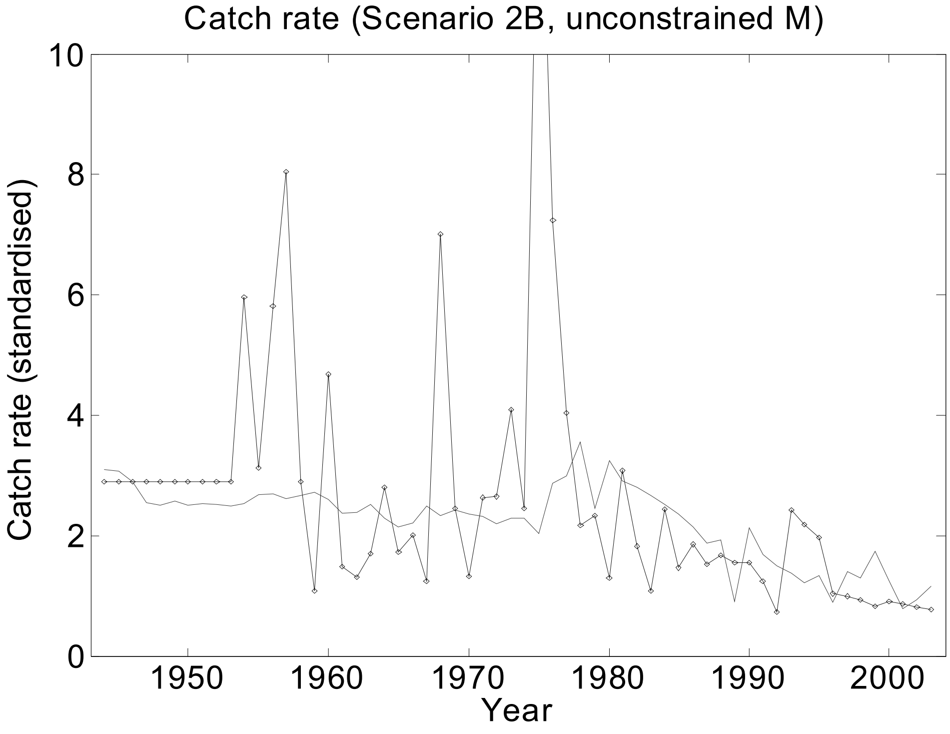


Figure 18(d): Catch rates from the age-structured model (observed points and line, predicted line only) under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), with unconstrained natural mortality parameter M *(1.62 yr^{-1}).*

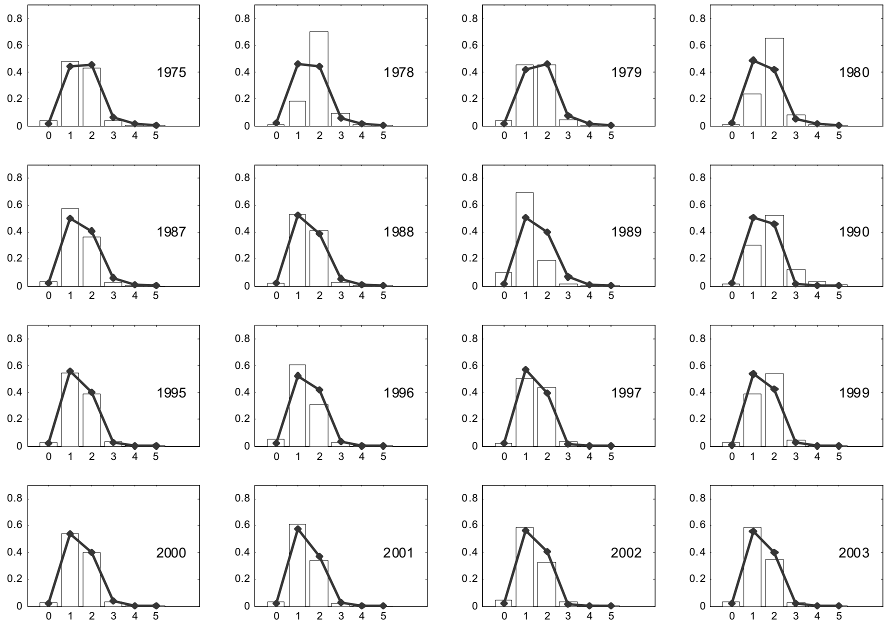


Figure 18(e): Matches to the age-composition by weight from the age-structured model (observed histogram, predicted line) under Scenario 2B (moderate increase in recreational fishing power from 1977; 8% p. a. increase in size of the recreational catch to 1993), with unconstrained natural mortality parameter M *(1.62 yr^{-1}).*

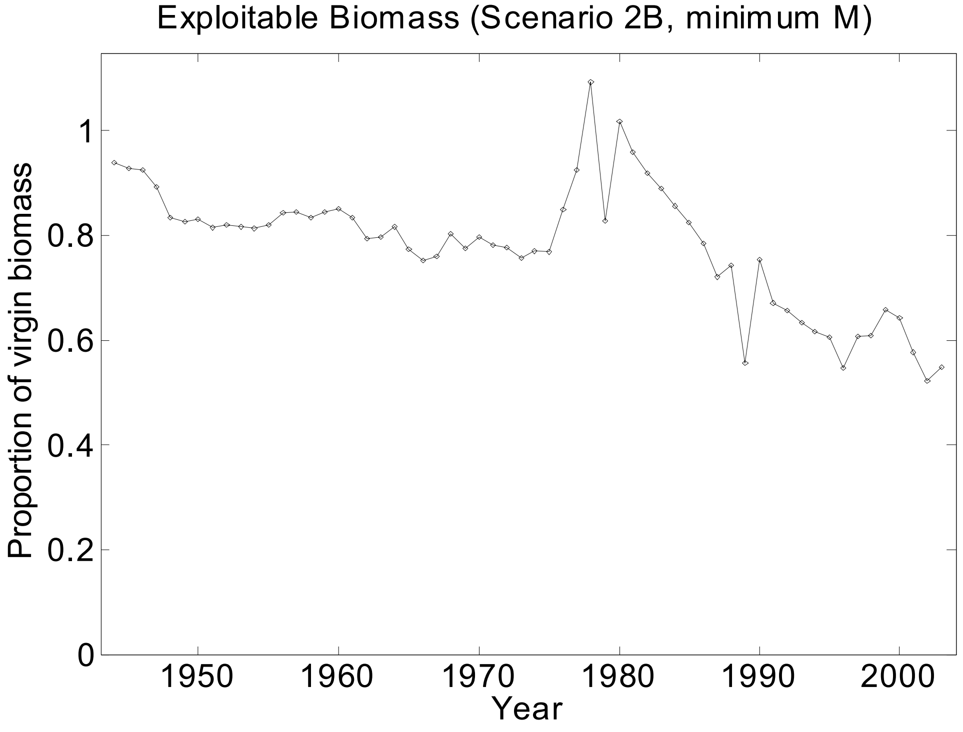


Figure 18(f): Exploitable biomass from the age-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), with natural mortality parameter M *set to its lower confidence limit (1.12 yr^{-1}).*

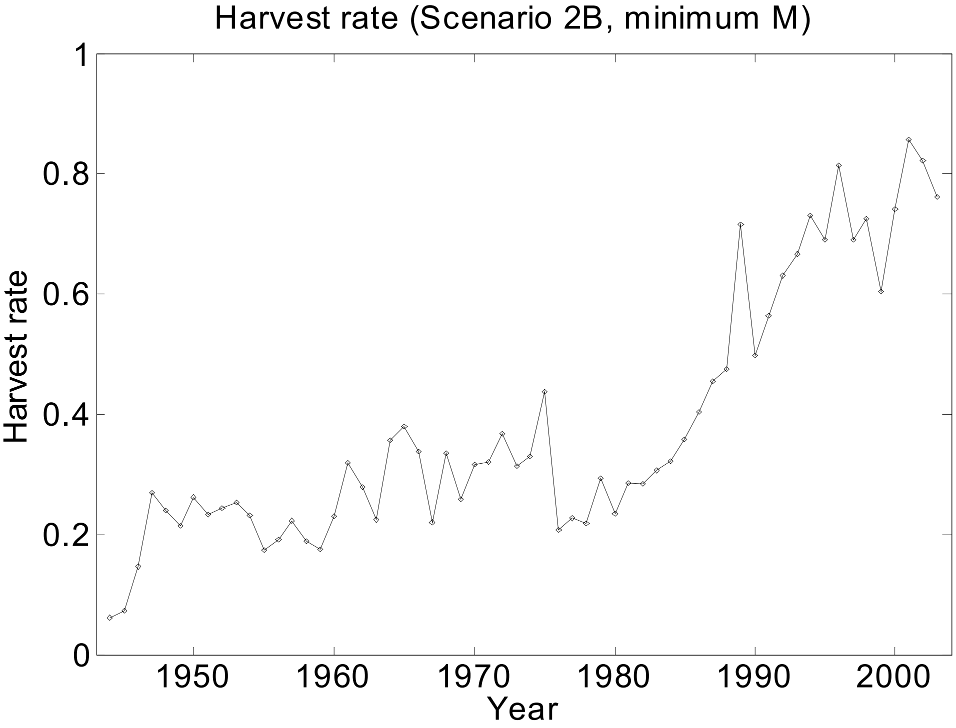


Figure 18(g): Harvest rate from the age-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), with natural mortality parameter M *set to its lower confidence limit (1.12 yr^{-1}).*

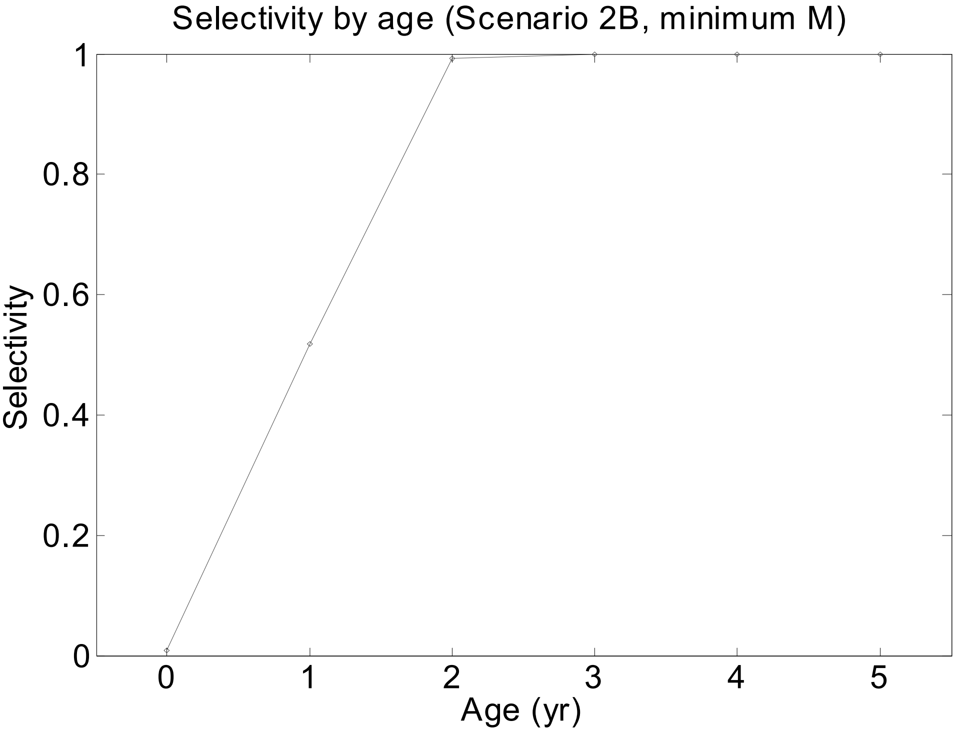


Figure 18(h): Age-selectivity from the age-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), with natural mortality parameter M *set to its lower confidence limit (1.12 yr^{-1}).*

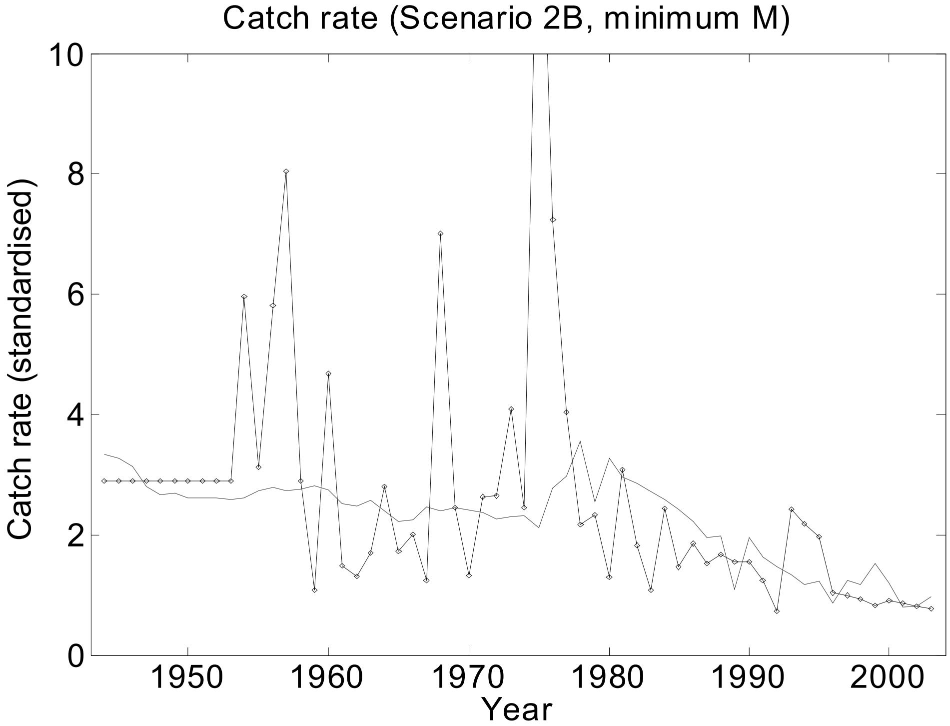


Figure 18(i): Catch rates from the age-structured model (observed points and line, predicted line only) under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), with natural mortality parameter M *set to its lower confidence limit (1.12 yr^{-1}).*

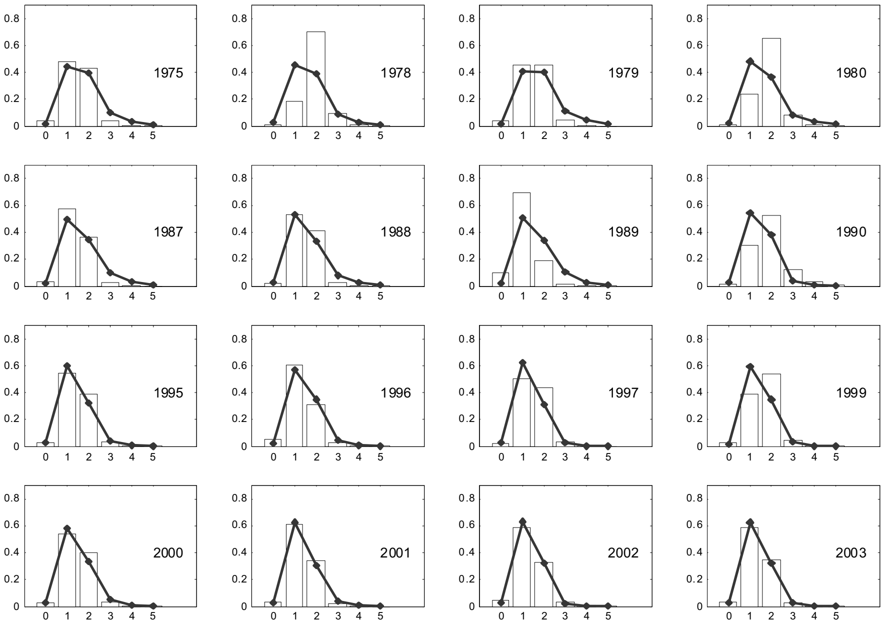


Figure 18(j): Matches to the age-composition by weight from the age-structured model (observed in black; predicted in red) under Scenario 2B (moderate increase in recreational fishing power from 1977; 8% p. a. increase in size of the recreational catch to 1993), with natural mortality parameter M *set to its lower confidence limit (1.12 yr^{-1}).*

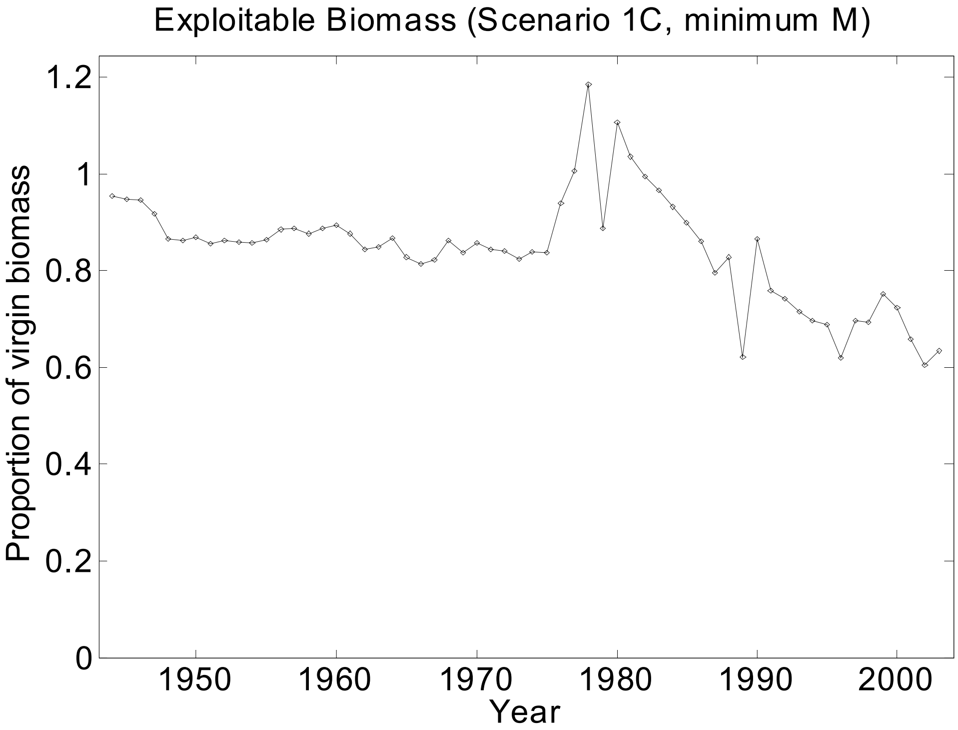


Figure 18(k): Exploitable biomass from the age-structured model under Scenario 1C (no increase in recreational fishing power since 1977; 11% p. a. increase in size of recreational catch to 1993), with natural mortality parameter M *set to its lower confidence limit (1.26 yr^{-1}).*

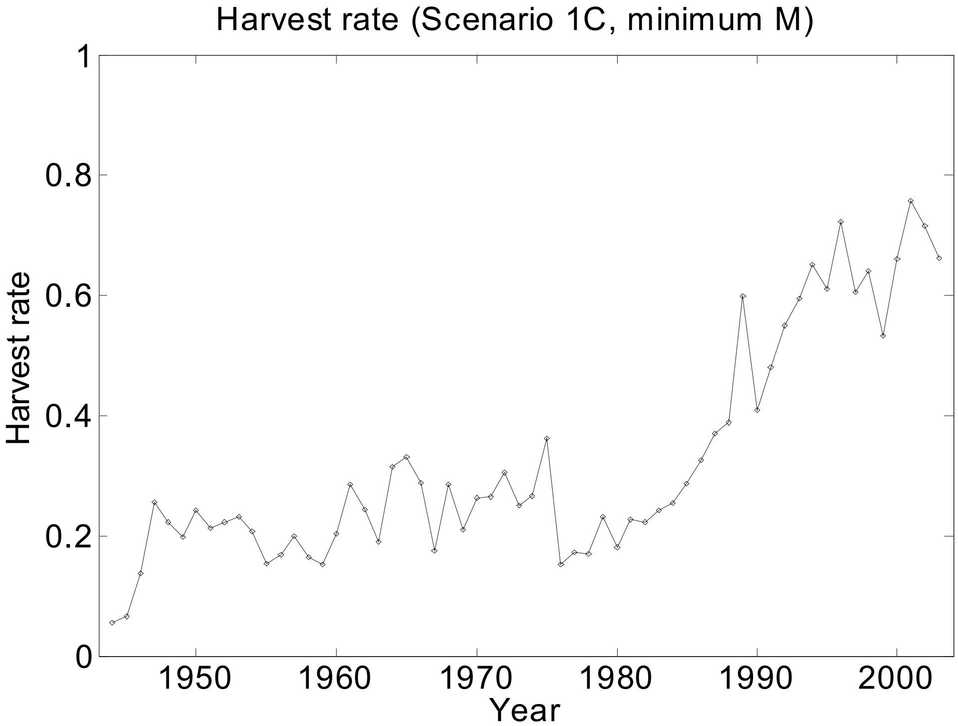


Figure 18(l): Harvest rate from the age-structured model under Scenario 1C (no increase in recreational fishing power since 1977; 11% p. a. increase in size of recreational catch to 1993), with natural mortality parameter M *set to its lower confidence limit (1.26 yr^{-1}).*

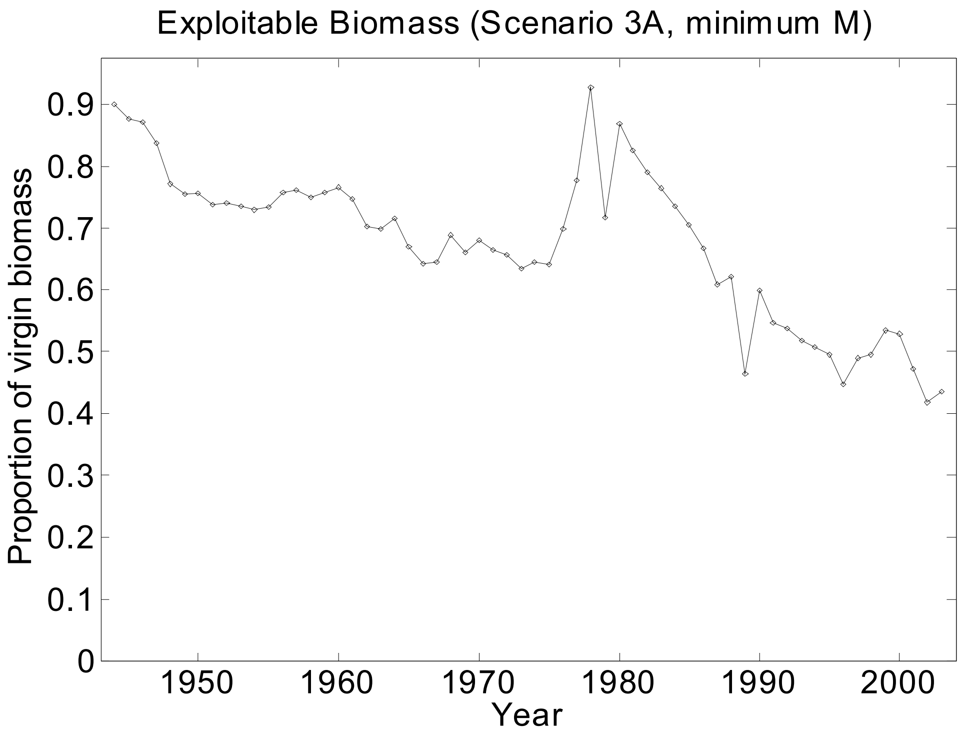


Figure 18(m): Exploitable biomass from the age-structured model under Scenario 3A (continued steep increase in recreational fishing power since 1977; 5% p. a. increase in size of recreational catch to 1993), with natural mortality parameter M *set to its lower confidence limit (0.92 yr^{-1}).*

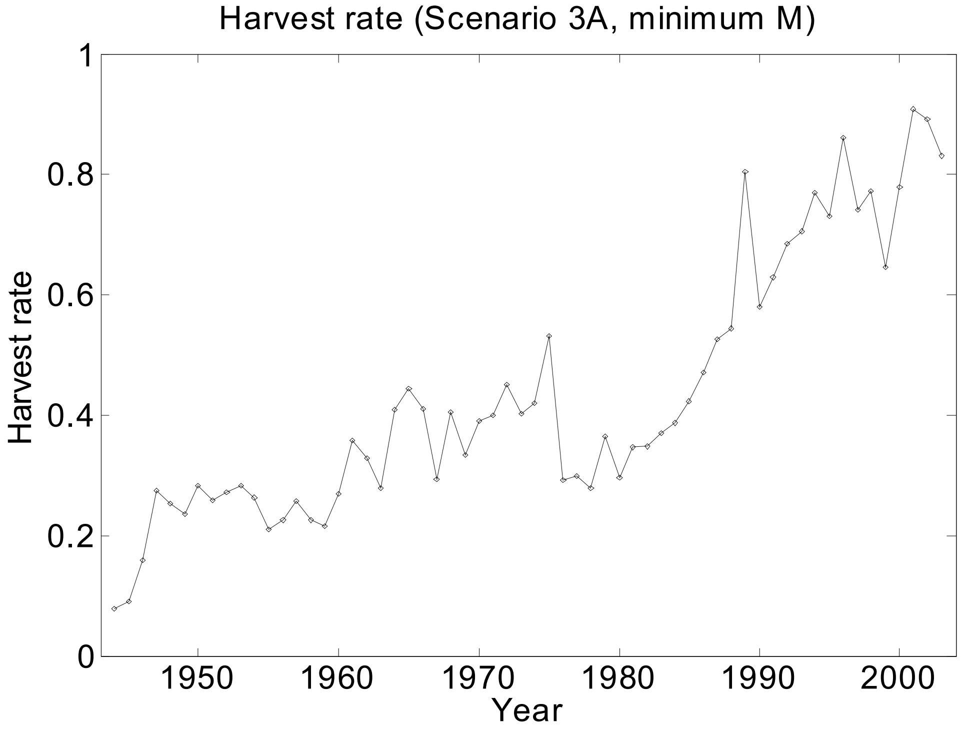


Figure 18(n): Harvest rate from the age-structured model under Scenario 3A (continued steep increase in recreational fishing power since 1977; 5% p. a. increase in size of recreational catch to 1993), with natural mortality parameter M *set to its lower confidence limit (0.92 yr^{-1}).*

8. Age- and length-structured model

8.1 Overview and need for a new model

A new population model was developed in response to the changes in length-at-age of the catch over the years, especially of two-year-old fish. The new model structured the population by both length and age. It generated population numbers as a three-way array, year × age × length, as opposed to just year × age for the age-structured model in section 7. The intention was to model the process by which fishing pressure gave rise to smaller two-year-old fish, rather than accepting size-at-age an input variable in each year. The model can then infer high fishing effort in years in which there are few large two-year-old fish in the catch, which the age-structured model cannot.

The age-length model is also able to match observed length frequencies rather than having to first convert them to age frequencies. It avoids having to use age-length keys in years in which ageing was not carried out.

The advantages of the age-length model over the age model from section 7 are:

- Estimation is more powerful because the model can directly relate the absence of large two-year-old fish to high fishing pressure.
- Extrapolation of age-length keys to years other than those in which they were collected is avoided.
- Inputting of separate weight-at-age estimates for each year is avoided.

8.2 Formulation of model

The model included the number of fish in each age class (0–5 which was the oldest age recorded in the ageing data) and of each length (1–70cm, in half-cm increments) present in the population in each year. Selectivity was length-based rather than age-based.

Model structure and notation are similar to the age-structured model of section 7. The number of fish of length l and age a in the population at the beginning of year y is denoted $N_{l\,a\,y}$. In the next year, $y + 1$, for $l > 1$cm and $a \geq 1$, the number of fish is given by

$$N_{l\,a\,y+1} = N_{l-\delta l\;a-1\;y}\,(1 - S_{l-\delta l}\,U_y)\,e^{-M},$$

where S_l is the proportion of fish of length l that are selected by the fishery, and δl is the amount by which fish grow in a year. Again the final age group is a “plus group” of all fish aged 5 or more.

The lengths of zero-year-old recruits are assumed to follow a normal distribution whose mean and standard deviation parameters are estimated by the model. The growth increment δl is assumed constant, which corresponds to a linear growth curve and no random variation in growth after age zero. Obviously linear growth would not be appropriate for old fish, and the practice of most fisheries scientists is to assume a von Bertalanffy growth curve which puts a limit on the maximum length attained. The linear curve was considered adequate for modelling the distribution of the young tailor that constitute most of the catch of the Australian east coast fishery.

In general δl is not an integer multiple of the 0.5 cm length increment in the length-frequency distributions, and the model sources fish of nominal length l in year $y + 1$ from two different length classes in year y.

Selectivity follows a logistic curve on length:

$$S_l = 1 / [1 + \exp\{-\log(19)\ (l - l_{50}) / (l_{95} - l_{50})\}],$$

where l_{50} is the length at which 50% of fish in the population are recruited, and l_{95} is the length at which 95% of fish are recruited.

The number of zero-year-old recruits that come into the fishery is modelled identically to the age-structured model (see section 7), except that fecundity is made a function of length rather than age. As mentioned there, the parameter $r_{\max}$ was set to $7 / (1 - e^{-M})$.

This model is similar to an age-length model used by Quinn, Turnbull and Fu (1998). They used a von Bertalanffy growth curve with random variation in the growth increment of an animal from one year to the next. The data analysed here did not support the estimation of an L_∞ parameter (the fish were too young), and in order to maximise the contrast in length distributions from lightly versus heavily fished populations, random variation in growth increments was also excluded.

8.3 Model parameters

The model estimated the following parameters:

1. N_0, the number of recruits to the virgin population (millions of fish)
2. l_{50}, the length at which 50% of fish are selected by the fishery (yr)
3. l_{95}, the length at which 95% of fish are selected by the fishery (yr) (actually the difference between l_{95} and l_{50} was estimated, in case it had to be set to a constant value)
4. μ_1, the mean length of one-year-old fish in population (cm) (from which μ_0 is derived as $\mu_0 = \mu_1 - \mu_{\text{inc}}$).
5. σ, the standard deviation of length of zero-year-old fish in the population (cm)
6. $\mu_{\text{inc}} = \delta l$, the amount by which a fish grows in a year (cm)
7. M, the instantaneous natural mortality rate (yr^{-1}).

As for the age-structured model, other parameters $r_{\max}$ and q were determined from these parameters and not estimated independently. The initial numbers-at-length-and-age, $N_{l\,a\,1}$, were generated in the same way as the initial numbers-at-age in the age-structured model, by running the model for a “warm-up” period of 20 years beginning from the virgin state.

8.4 Input data and model fitting

The model was fitted by matching the expected to the observed catch rates, length distributions (in years for which length-frequencies were available but ageing data were not) and age-length distributions (in years for which ageing data were available). Catch rates from 1954 to 2003 were used, together with length distributions from 1975, 1978–80, 1987–90 and 1996, and age-length distributions 1995, 1997 and 1999–2003.

Catch rate was assumed to follow a lognormal distribution, as for the age-structured model. Length distribution in year y was measured by the cumulative distribution function, in the same way that age composition was measured in the age-structured model. Distribution functions were measured by weight of fish in a category (as opposed to number of fish). Age-length distribution was measured by a two-dimensional cumulative distribution function which was the proportion by weight of fish in the catch with both age ≤ a and length ≤ l; for each age in each year, the mean absolute difference between distribution functions was assumed to follow a half-normal distribution. The negative sum of the three log-likelihoods for catch rate, length distribution and age-length distribution was minimised by again using the Matlab routine `fminsearch`.

A different age-length key was used for each year of ageing data (1995, 1997, 1999–2003), and age-length keys were not required for years in which ageing data were not available. Weight of fish and fecundity were again estimated from Bade's (1977) length-weight relationship and fecundity data.

The data input to the model were

1. annual catch weight (1944–2003)
2. annual catch rate (1954–2003), used as an index of abundance and assumed to be proportional to exploitable biomass
3. distribution of length (1975, 1978–80, 1987–90, 1996)
4. joint distribution of length and age (1995, 1997, 1999–2003).

8.5 Results

Results are shown in Figure 19(a–u) for Scenarios 2B (middle-of-the-road assumptions), and Figure 20(a–l) for Scenarios 1C and 3A (most extreme results).

Again the maximum likelihood estimates of the instantaneous natural mortality rate M were larger than would be acceptable to many biologists. These values were rejected both because they were unreasonably large and because lower values produced very little change in the log-likelihood (as noted in section 7, a difference of 1.92 in the log-likelihood is considered significant at the 5% level). Acceptable ranges of M were generated by running the model with M set equal to the value that gave 30% selectivity of one-year-old fish (selectivity of less than 30% was held to be unreasonable), and the value corresponding to the lower limit of the 95% likelihood profile confidence interval (as discussed and used in section 7).

For Scenarios 2B the model was also run without the catch rate data, in order to check for hyperstability in the catch rates. The resulting expected catch rate from this run is shown in Figure 19(u). It matches the observed catch rate very well, and therefore indicates that there is no evidence of hyperstability in this data set. It is emphasised that the commercial ocean beach fishery (the one thought most likely to produce hyperstability) constitutes only a small part of the data.

Parameter estimates and maximised log-likelihood values are listed in Table 3.

Again parameter estimates vary widely between scenarios, but the underlying story is consistent and the same as for the age-structured model: the population is very heavily fished, and its ability to reproduce is maintained only by the partial selectivity of one-year-old fish. Model results indicate that exploitable biomass (total mass of fish selected by the fishery) and egg production have fallen to approximately 40% of their virgin levels (50% for Scenario 1C, 30% egg production for Scenario 3A), and about half the levels that prevailed in the 1970s; and the harvest rate (proportion of selected fish that are actually caught by the fishery in a single year) is around 80% (70% for Scenario 1C), three times the harvest rate in the 1970s.

Estimates of M are similar to those obtained for the age-structured model, and the same comments apply. Values of M in the range 0.8–1.3 yr^{-1} are consistent with the model.

Table 3: Parameter estimates from the age-length-structured model for Scenarios 2B (middle-of-the-road assumptions), 1C and 3A (most extreme scenarios). The parameters are N_0, the virgin number of recruits at age 0; l_{50}, the length at which 50% of fish are selected by the fishery; l_{95}, the length at which 95% of fish are selected (expressed as the difference between l_{95} and l_{50}); μ_1, the mean length at age 1; σ, the standard deviation of lengths around the mean length-at-age; μ_{inc}, the amount by which fish grow in a year; and M, the instantaneous natural mortality rate. "Min. M" refers to the results of setting M to the lower limit of its 95% confidence interval; "1yo sel. 0.3" refers to setting M to the value that results in selectivity of one-year-old fish of 30%; "ex catch rate" refers to results excluding catch rate data from the estimation. The remaining rows include maximum likelihood estimates of M.

Scenario	N_0 (× 10^6)	l_{50} (cm)	$l_{95} - l_{50}$ (cm)	μ_1	σ	μ_{inc}	M (yr^{-1})	Log-lik
1C	87.8901	31.4487	2.3749	23.2108	6.6542	12.0364	1.9761	213.3927
1C (1yo sel. 0.3)	21.8145	31.9076	2.7331	29.5851	3.6096	8.5467	1.28	212.6231
1C (min. *M*)	14.2984	32.0906	2.8996	30.7860	2.9300	7.3001	1.05	211.4867
2B	33.7510	31.3205	2.4254	26.3101	5.6312	11.0412	1.5397	212.1730
2B (1yo sel. 0.3)	18.5845	31.6852	2.6927	29.1319	4.0760	9.0575	1.22	211.9221
2B (1yo sel. 0.3, ex catch rate)	18.6805	31.7801	2.7506	29.3856	3.8354	8.8686	1.22	211.8851
2B (min. *M*)	10.1393	32.2720	3.2586	31.3605	2.6268	6.7500	0.88	210.2541
3A	17.8311	31.3171	2.5325	28.1275	4.9705	9.9448	1.2055	210.6798
3A (1yo sel. 0.3)	16.0159	31.0841	2.5101	28.0729	5.1491	10.2500	1.15	210.4996
3A (min. *M*)	8.2683	32.4767	3.5390	31.7752	2.3932	6.3043	0.77	208.7917

The selectivity values for one-year-old fish in Scenario 2B were found to be 20.65% in the case of unconstrained estimation of *M* (values less than 30% were not considered reasonable) and 41.60% when *M* was fixed to its lower confidence limit; for Scenarios 1C and 3A with M set to its lower confidence limit they were 37.70% and 43.79% respectively. The model therefore estimates a hidden population of one-year-old fish that amounts to around 56–70% of the total population of one-year-old fish. The ability of these hidden fish to spawn is the main factor maintaining egg production.

Again this model does not include year-to-year variation in recruitment, and so cannot fit the big spike in recruitment in the mid-1970s.

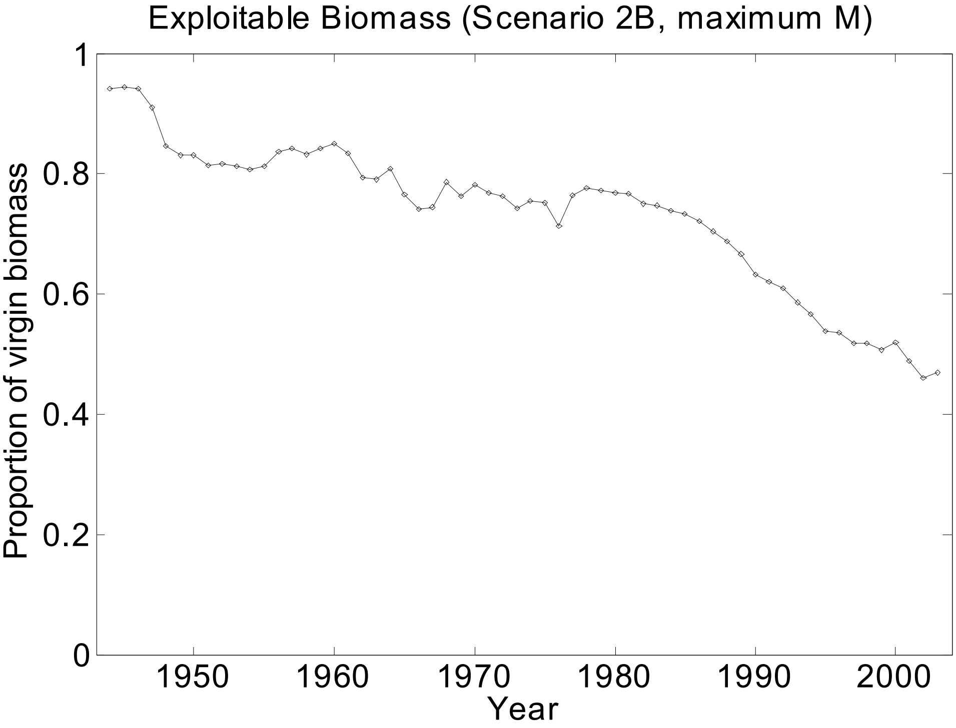


Figure 19(a): Exploitable biomass from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *1.22* yr^{-1} *set for 30% selectivity of one-year-old fish.*

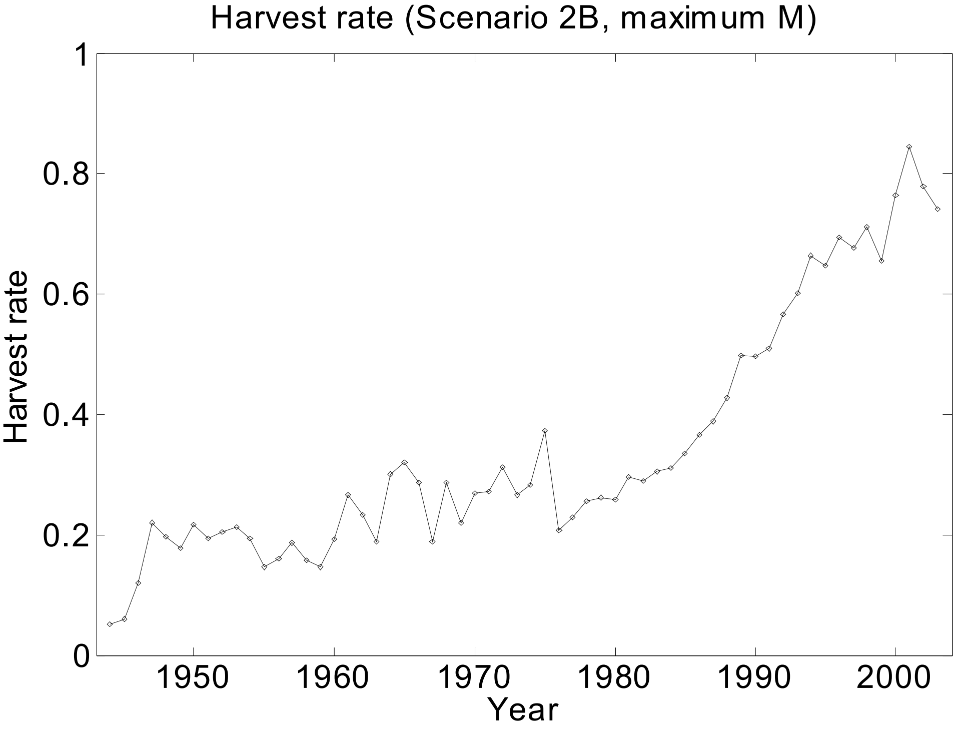


Figure 19(b): Harvest rate (proportion of exploitable biomass that is caught in each year) from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *1.22* yr^{-1} *set for 30% selectivity of one-year-old fish.*

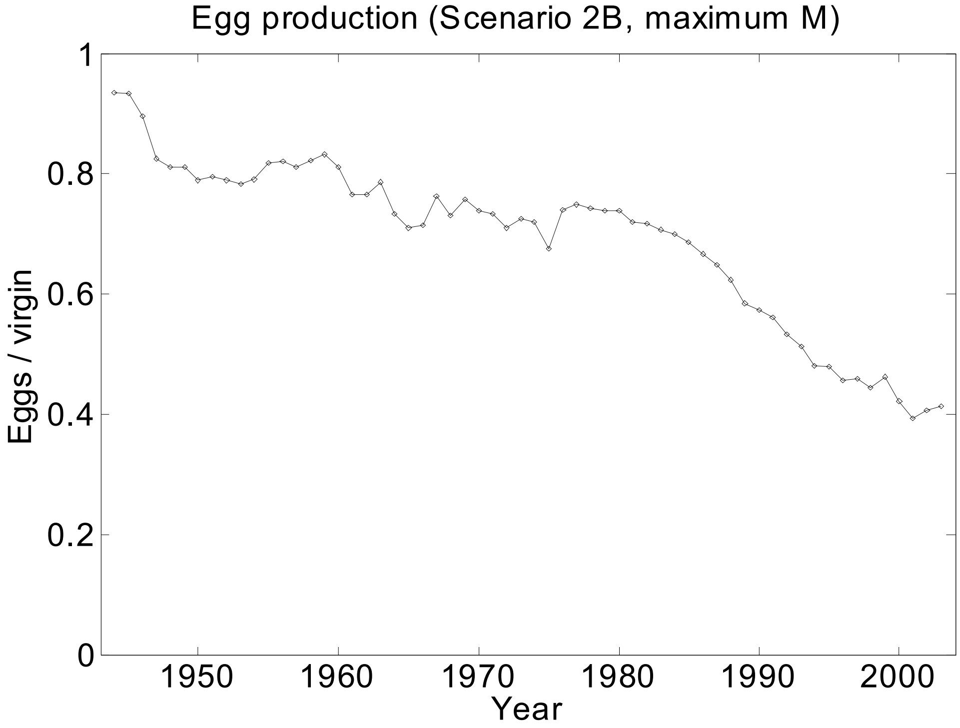


Figure 19(c): Egg production from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *1.22* yr^{-1} *set for 30% selectivity of one-year-old fish.*

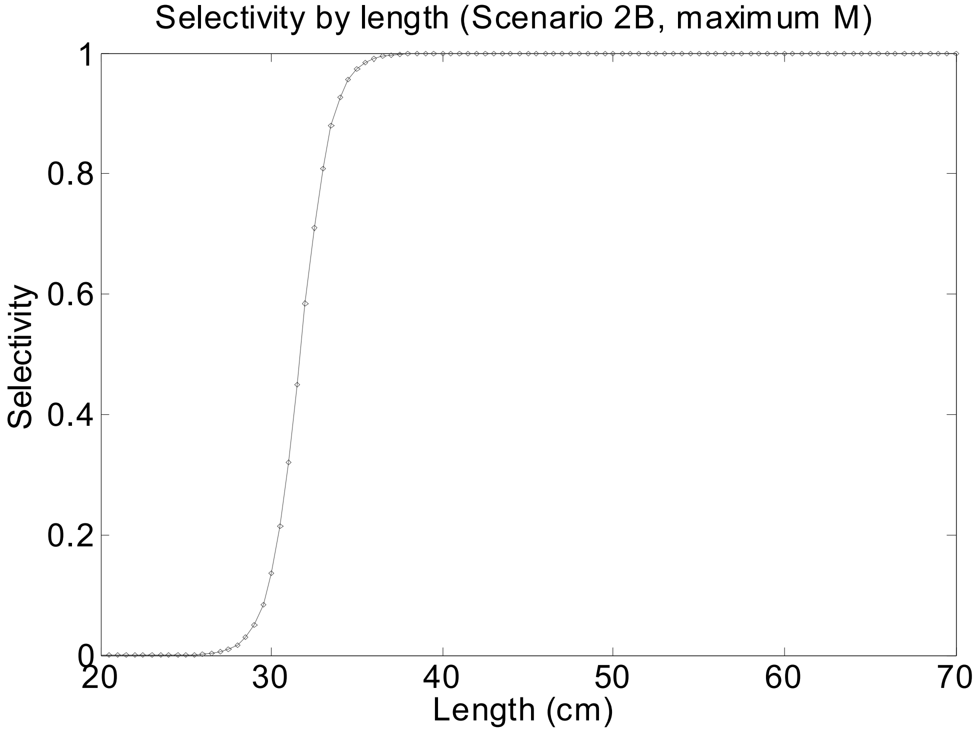


Figure 19(d): Selectivity of fish by length from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *1.22* yr^{-1} *set for 30% selectivity of one-year-old fish.*

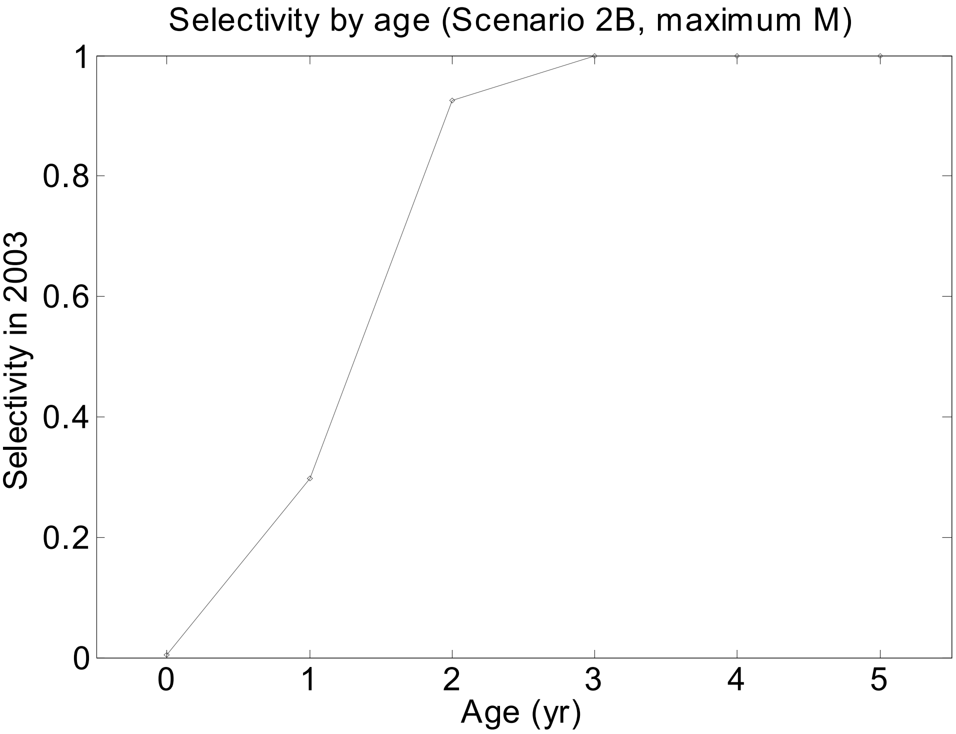


Figure 19(e): Selectivity of fish by age from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *1.22* yr^{-1} *set for 30% selectivity of one-year-old fish.*

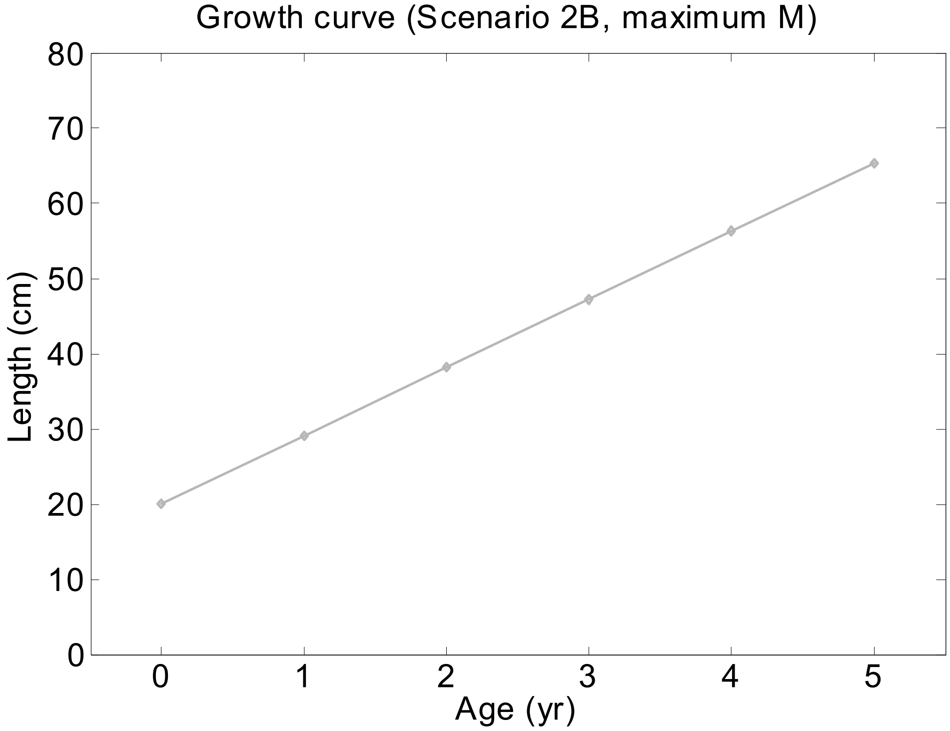


Figure 19(f): Linear growth curve from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *1.22* yr^{-1} *set for 30% selectivity of one-year-old fish.*

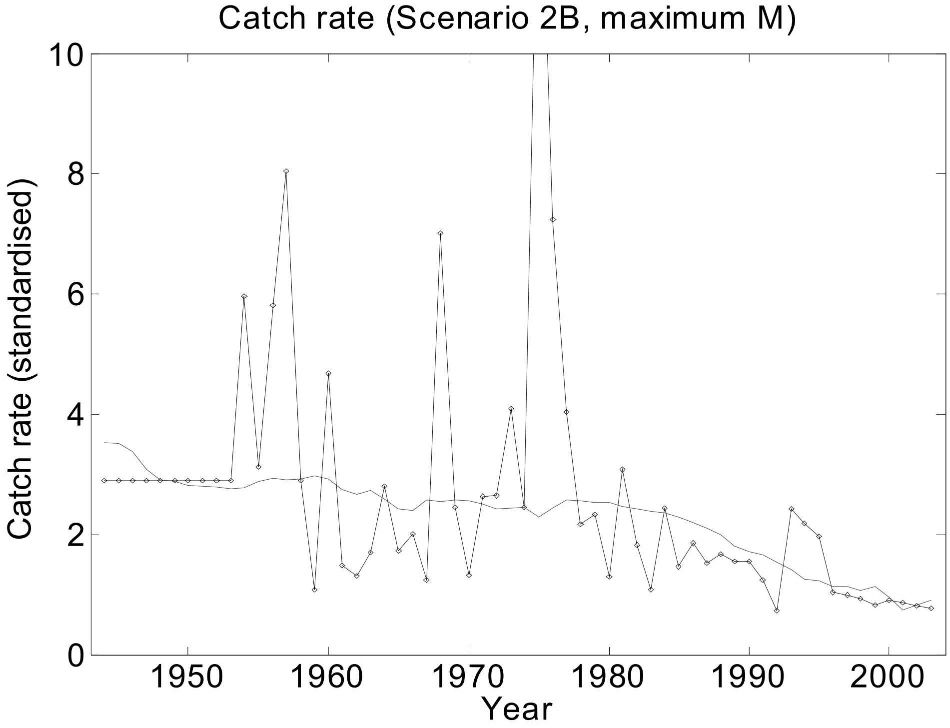


Figure 19(g): Catch rates from the age-length-structured model (observed points and line, predicted line only) under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *1.22* yr^{-1} *set for 30% selectivity of one-year-old fish.*

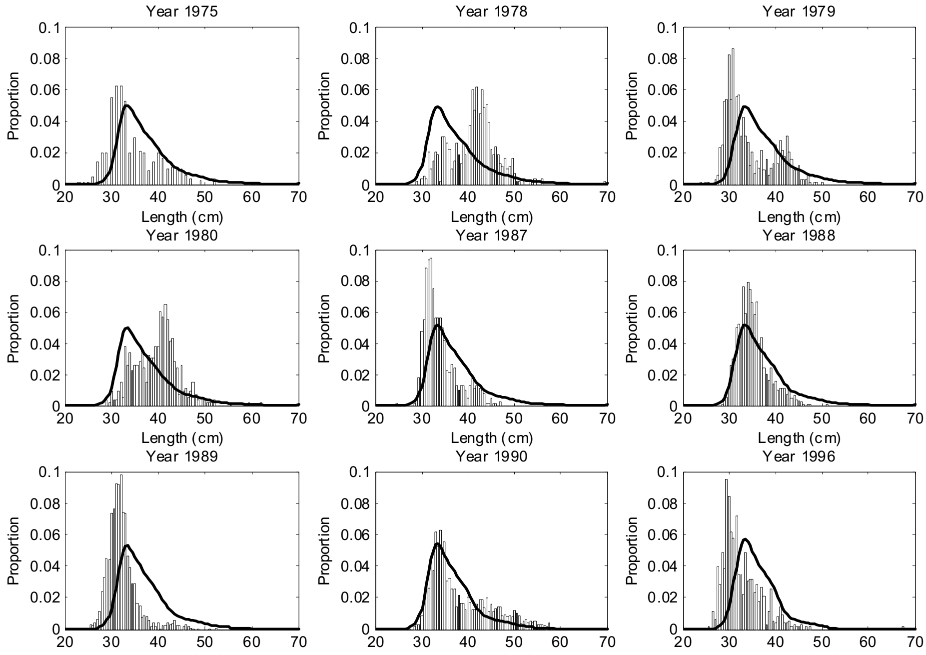


Figure 19(h): Weight-based length-frequencies for non-ageing years from the age-length-structured model (observed histogram, predicted solid line) under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *1.22* yr^{-1} *set for 30% selectivity of one-year-old fish.*

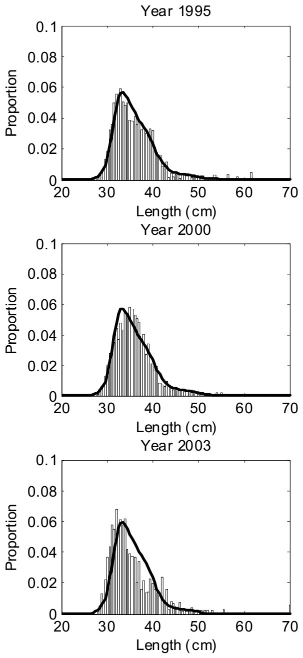


Figure 19(i): Weight-based length-frequencies for ageing years from the age-length-structured model (observed histogram, predicted solid line) under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *1.22* yr^{-1} *set for 30% selectivity of one-year-old fish.*

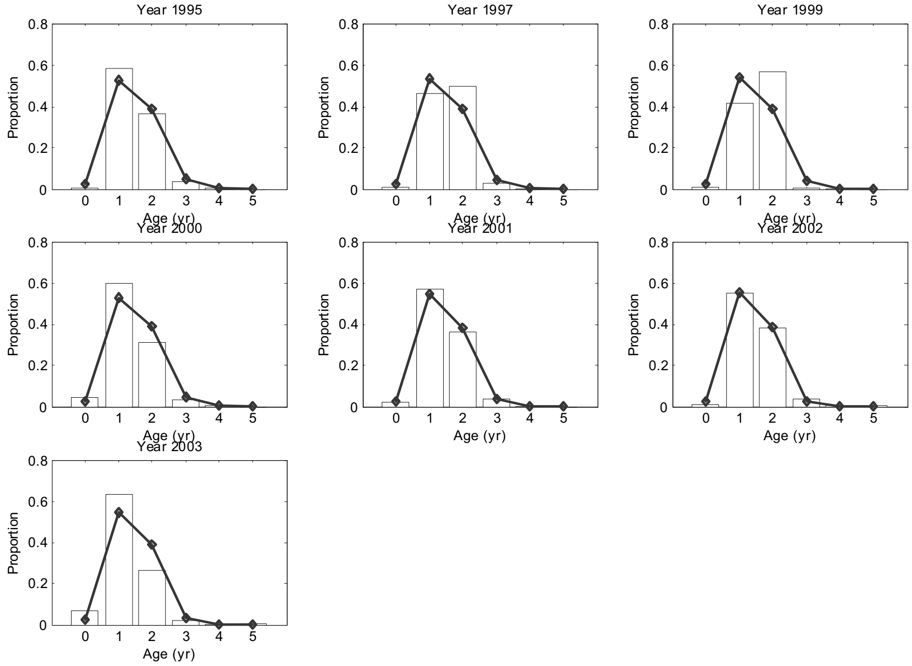


Figure 19(j): Weight-based age-frequencies for ageing years from the age-length-structured model (observed histogram, predicted line and points) under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *1.22* yr^{-1} *set for 30% selectivity of one-year-old fish.*

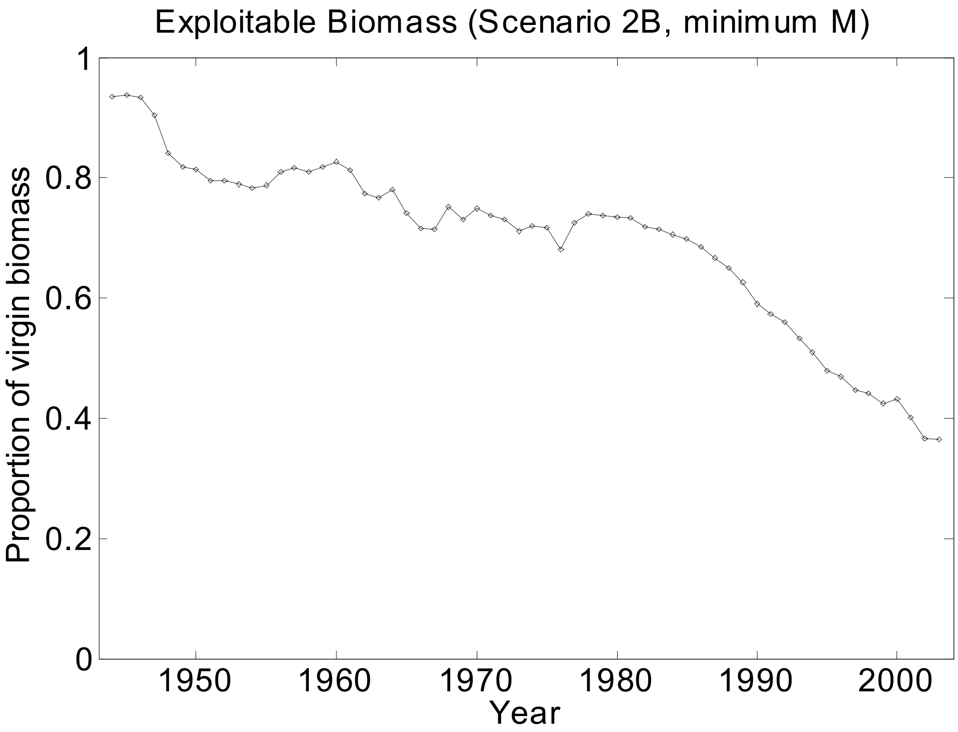


Figure 19(k): Exploitable biomass from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *0.88* yr^{-1} *set to its lower confidence limit.*

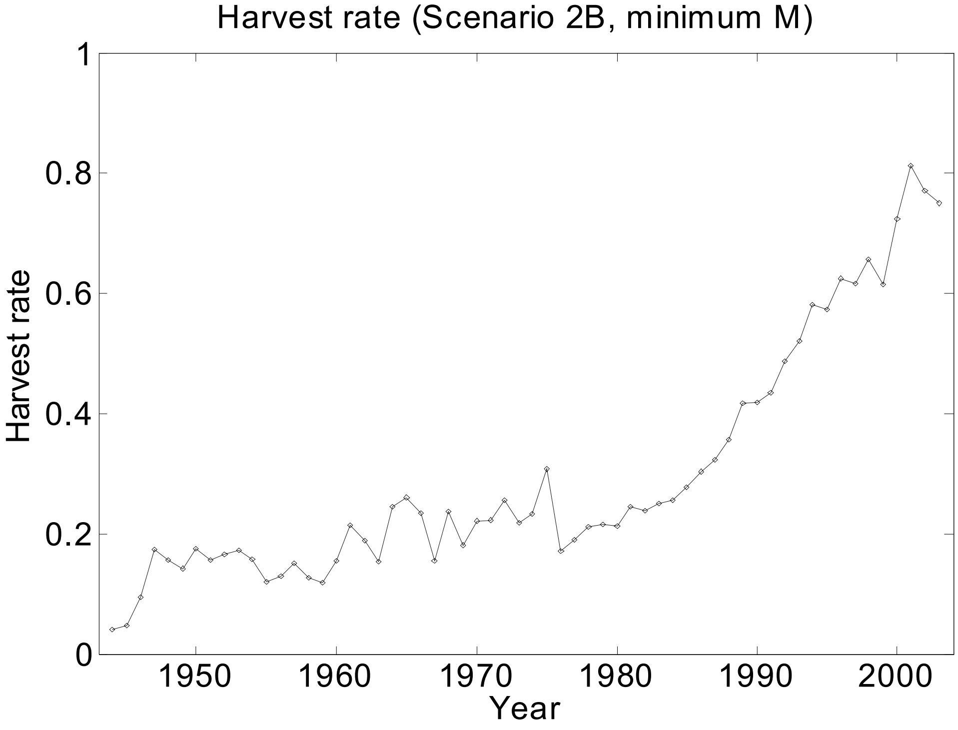


Figure 19(l): Harvest rate (proportion of exploitable biomass that is caught in each year) from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *0.88* yr^{-1} *set to its lower confidence limit.*

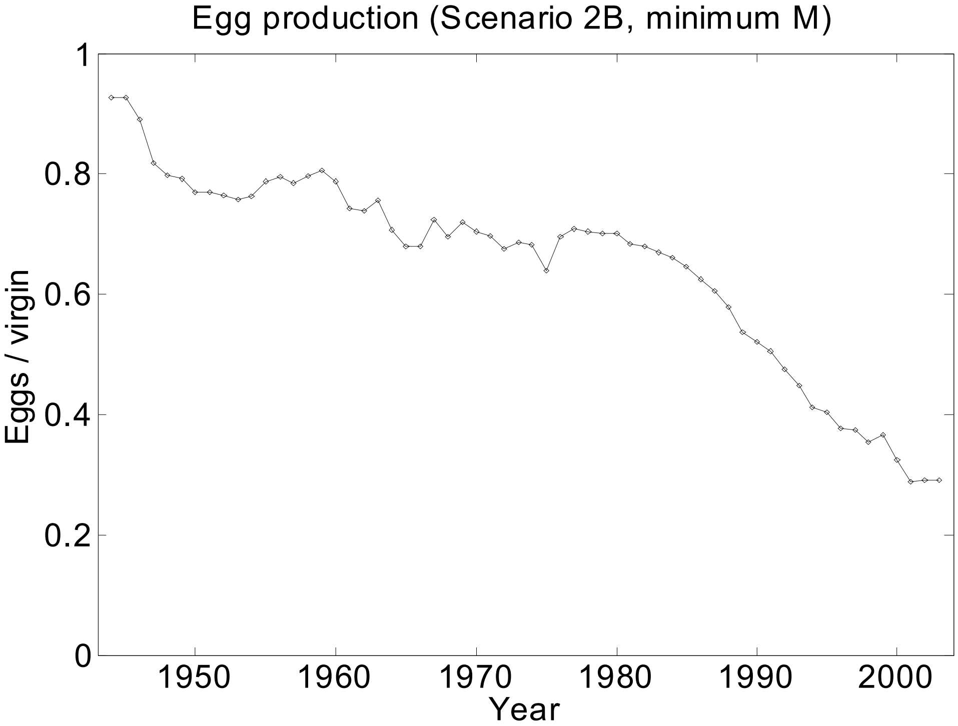


Figure 19(m): Egg production from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *0.88* yr^{-1} *set to its lower confidence limit.*

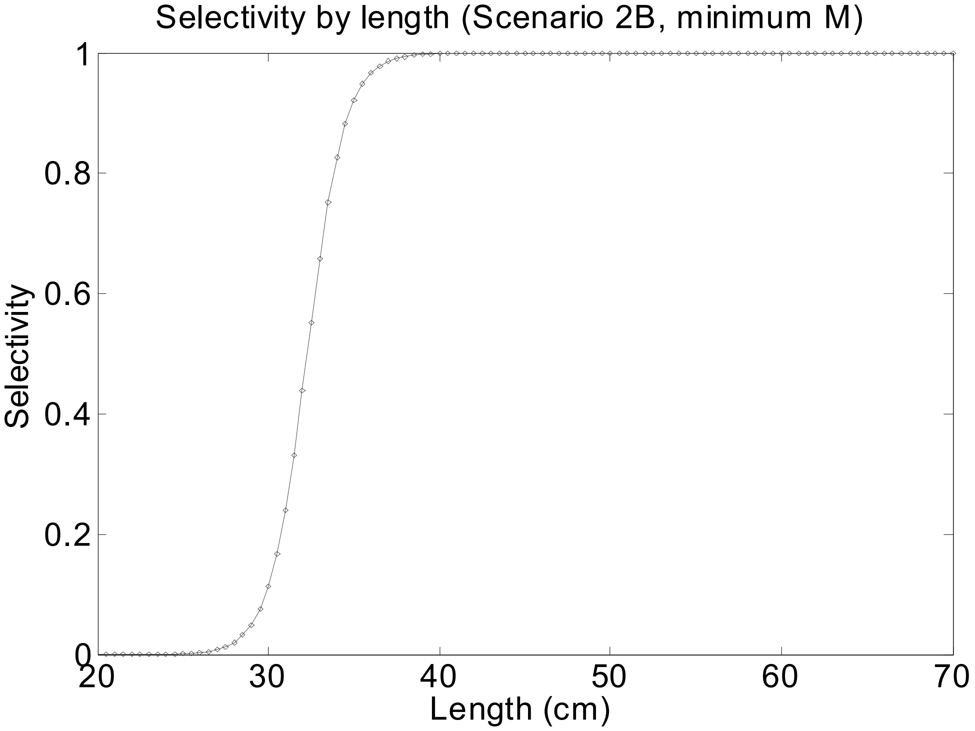


Figure 19(n): Selectivity of fish by length from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *0.88* yr^{-1} *set to its lower confidence limit.*

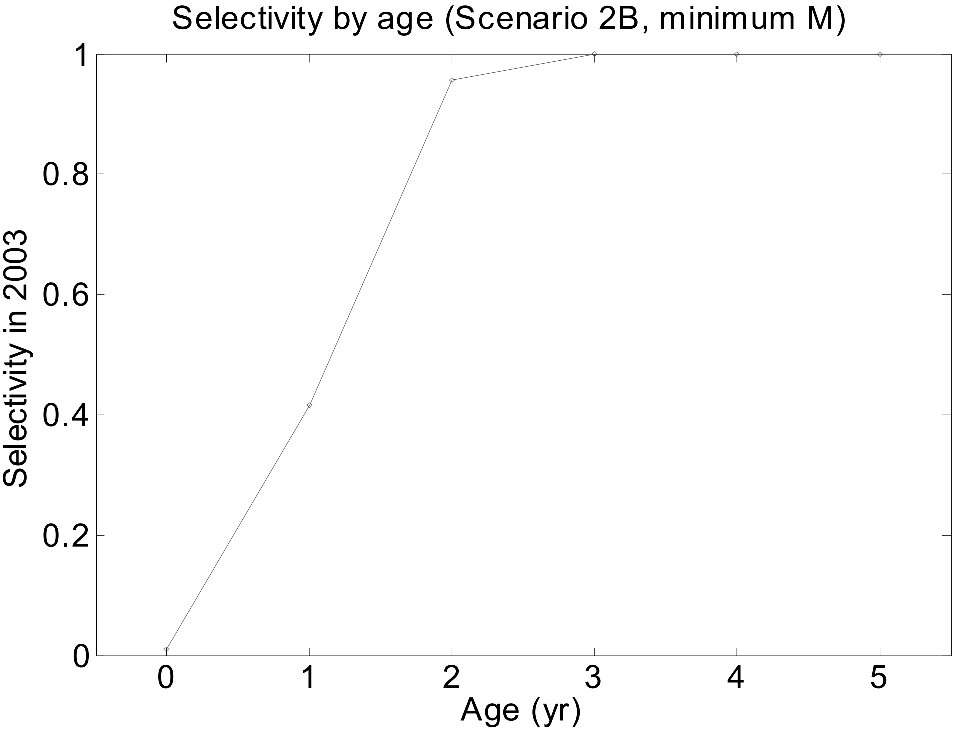


Figure 19(o): Selectivity of fish by age from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *0.88* yr^{-1} *set to its lower confidence limit.*

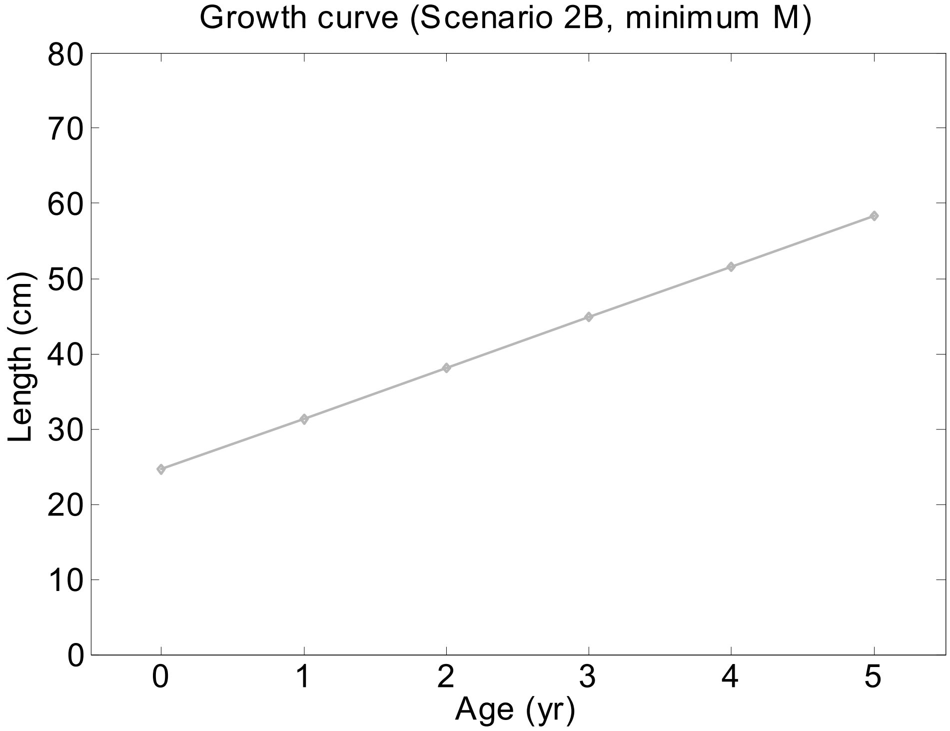


Figure 19(p): Linear growth curve from the age-length-structured model under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *0.88* yr^{-1} *set to its lower confidence limit.*

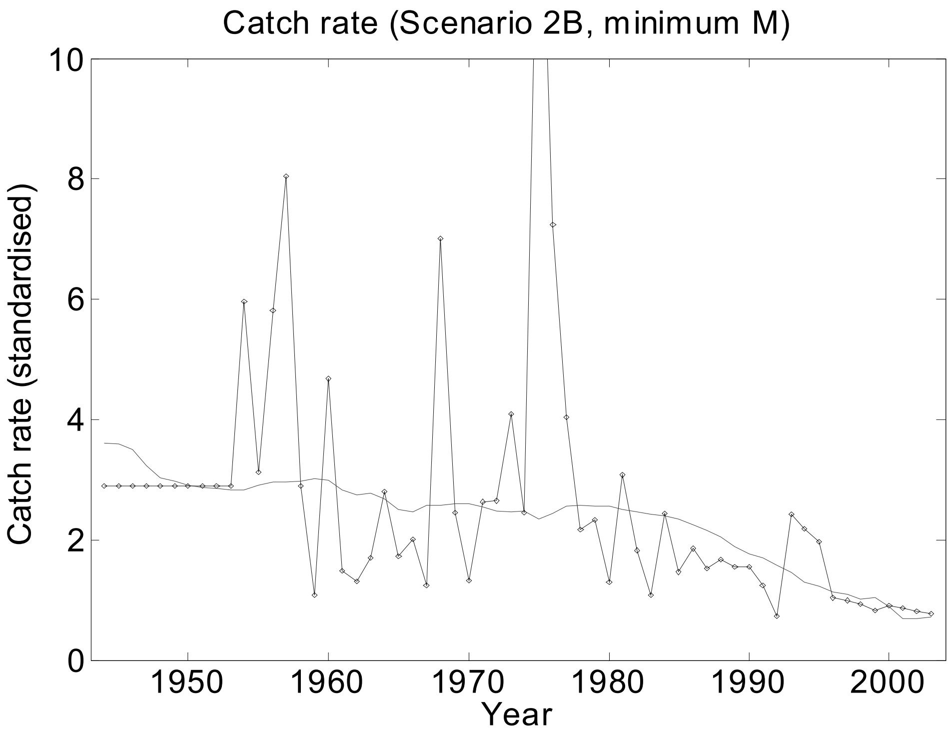


Figure 19(q): Catch rates from the age-length-structured model (observed points and line, predicted line only) under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *0.88* yr^{-1} *set to its lower confidence limit.*

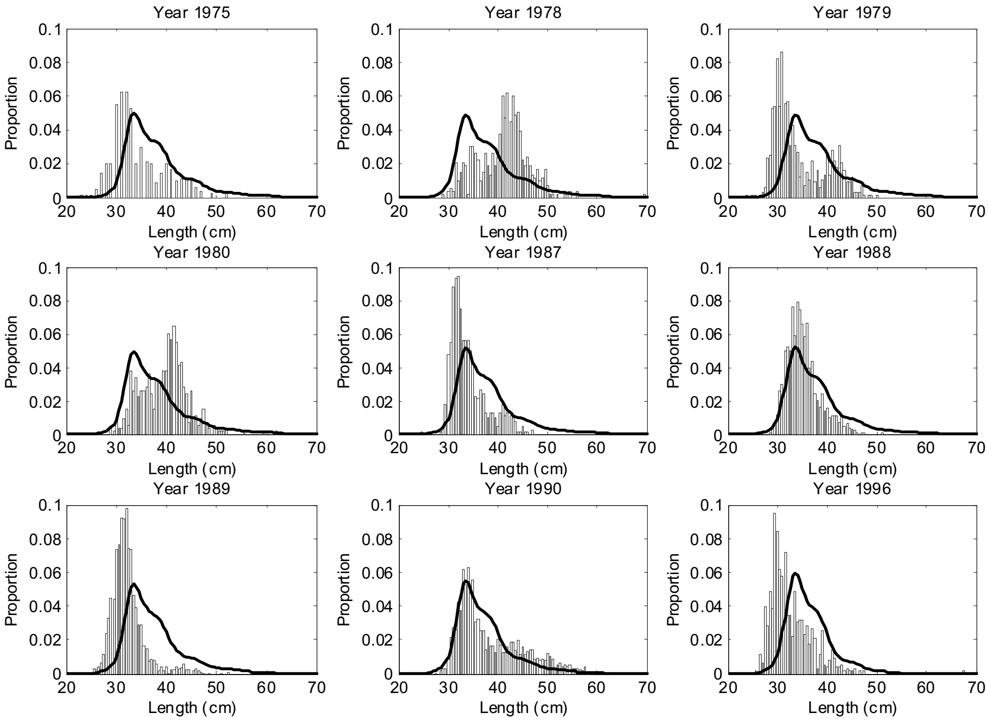


Figure 19(r): Weight-based length-frequencies for non-ageing years from the age-length-structured model (observed histogram, predicted solid line) under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *0.88* yr^{-1} *set to its lower confidence limit.*

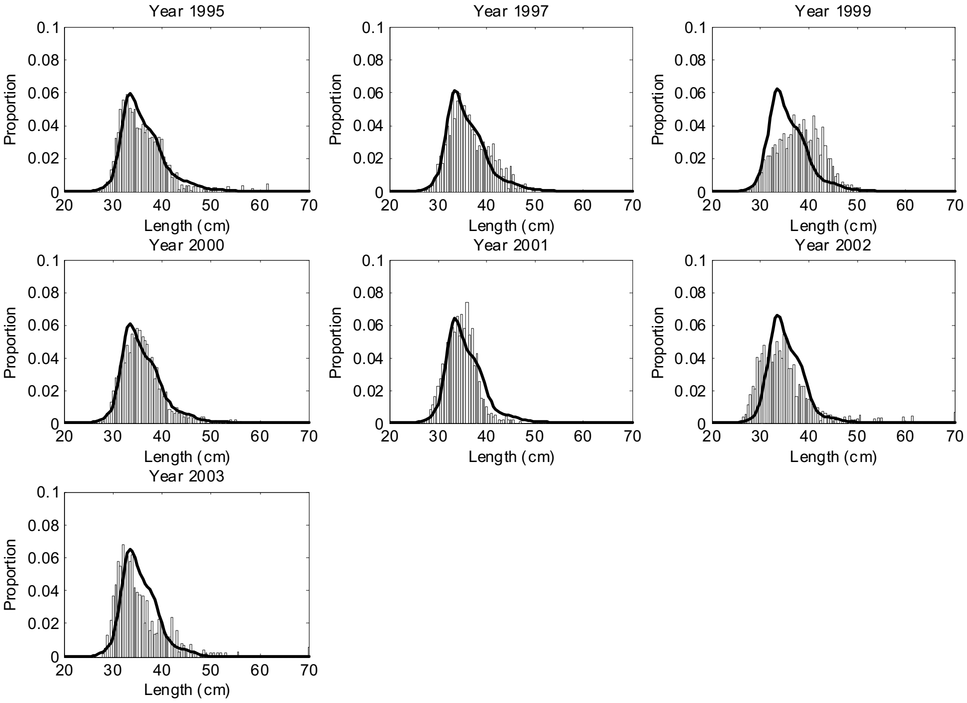


Figure 19(s): Weight-based length-frequencies for ageing years from the age-length-structured model (observed histogram, predicted solid line) under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *0.88 yr^{-1} set to its lower confidence limit.*

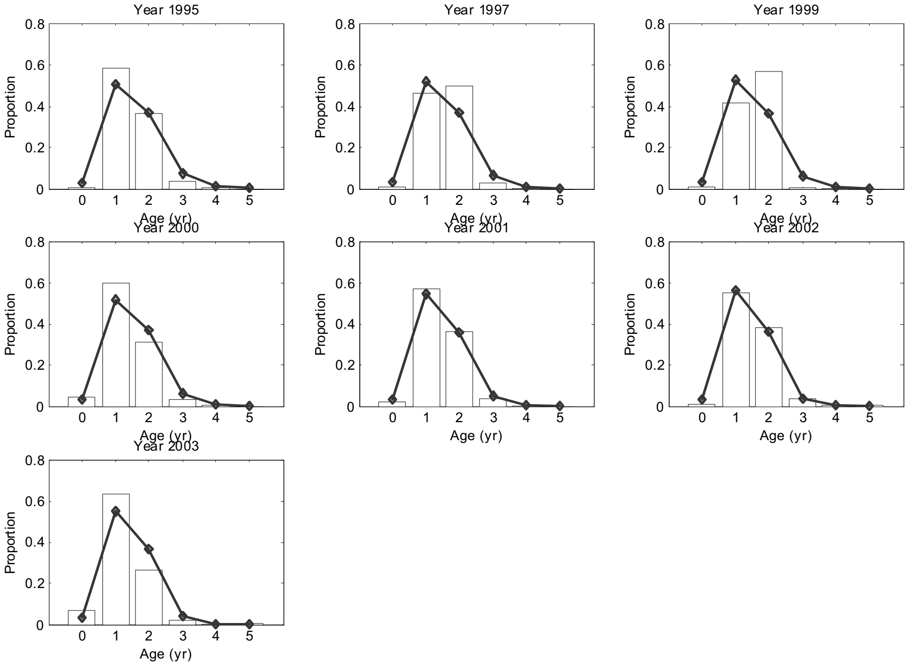


Figure 19(t): Weight-based age-frequencies for ageing years from the age-length-structured model (observed histogram, predicted points and line) under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *0.88 yr^{-1} set to its lower confidence limit.*

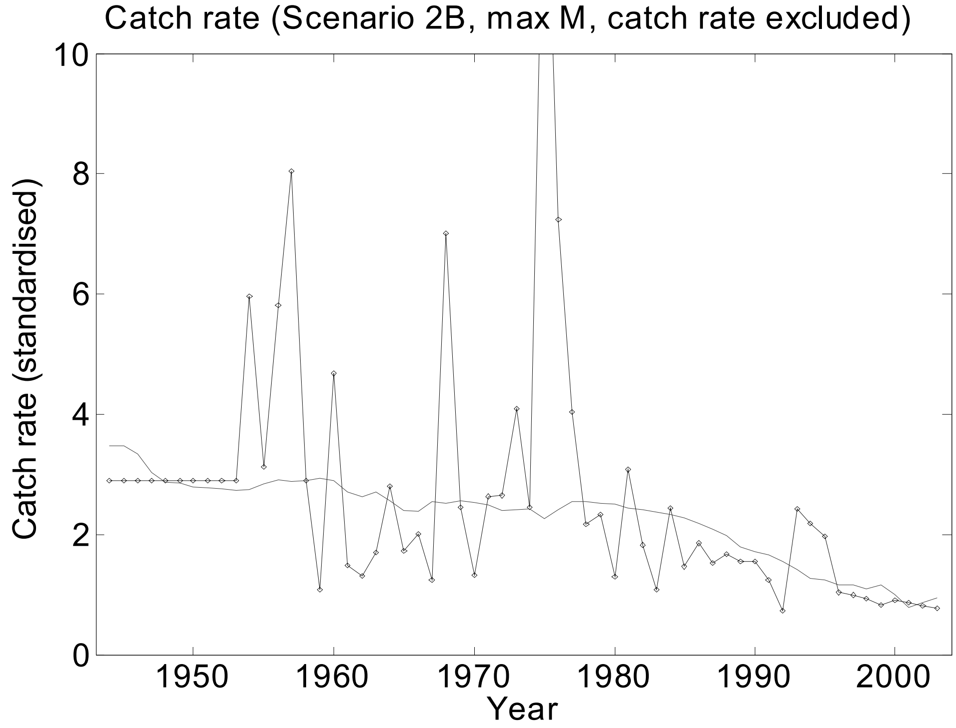


Figure 19(u): Catch rates from the age-length-structured model (observed points and line, predicted line only) under Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), M = *1.22 yr^{-1} set for 30% selectivity of one-year-old fish and catch rate data excluded from analysis.*

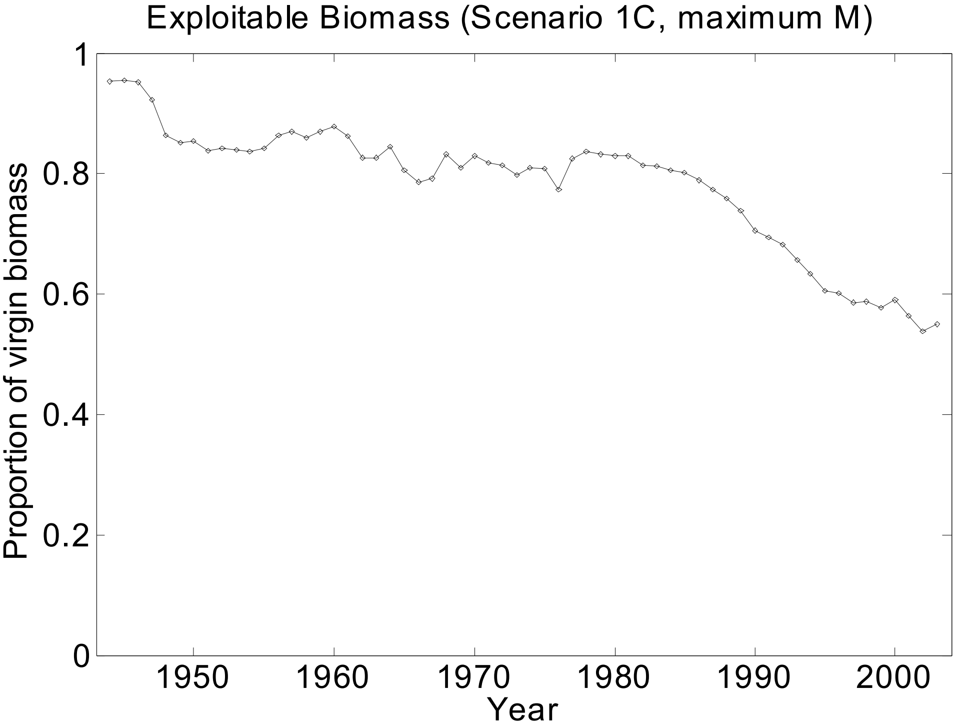


Figure 20(a): Exploitable biomass from the age-length-structured model under Scenario 1C (no increase in recreational fishing power since 1977; 11% p. a. increase in size of recreational catch to 1993), M = *1.28 yr^{-1} set for 30% selectivity of one-year-old fish.*

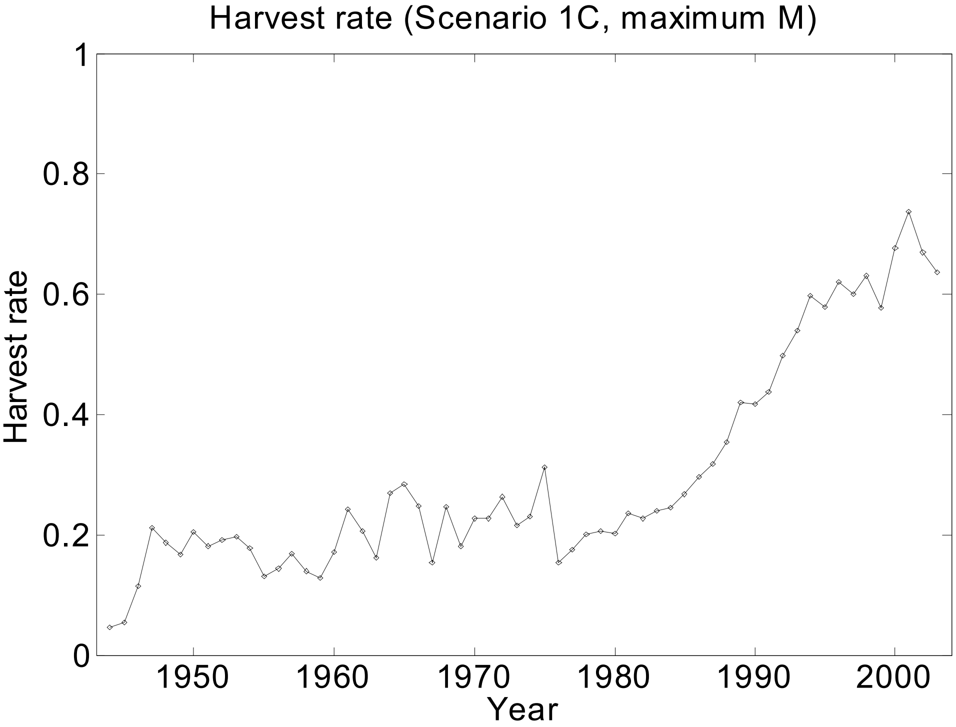


Figure 20(b): Harvest rate (proportion of exploitable biomass that is caught in each year) from the age-length-structured model under Scenario 1C (no increase in recreational fishing power since 1977; 11% p. a. increase in size of recreational catch to 1993), M = *1.28* yr^{-1} *set for 30% selectivity of one-year-old fish.*

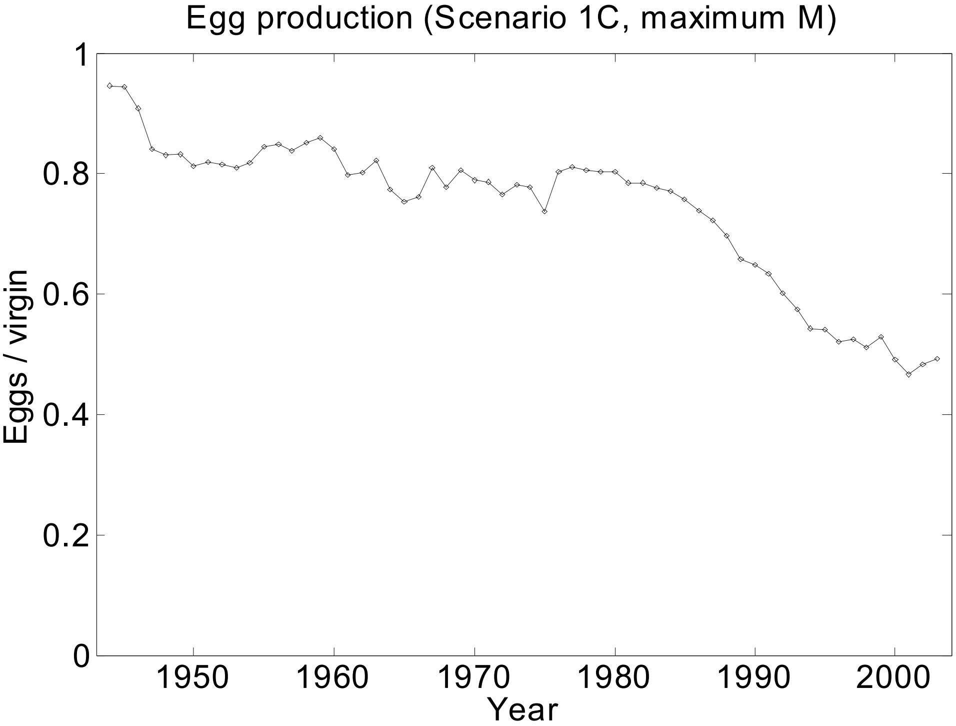


Figure 20(c): Egg production from the age-length-structured model under Scenario 1C (no increase in recreational fishing power since 1977; 11% p. a. increase in size of recreational catch to 1993), M = *1.28* yr^{-1} *set for 30% selectivity of one-year-old fish.*

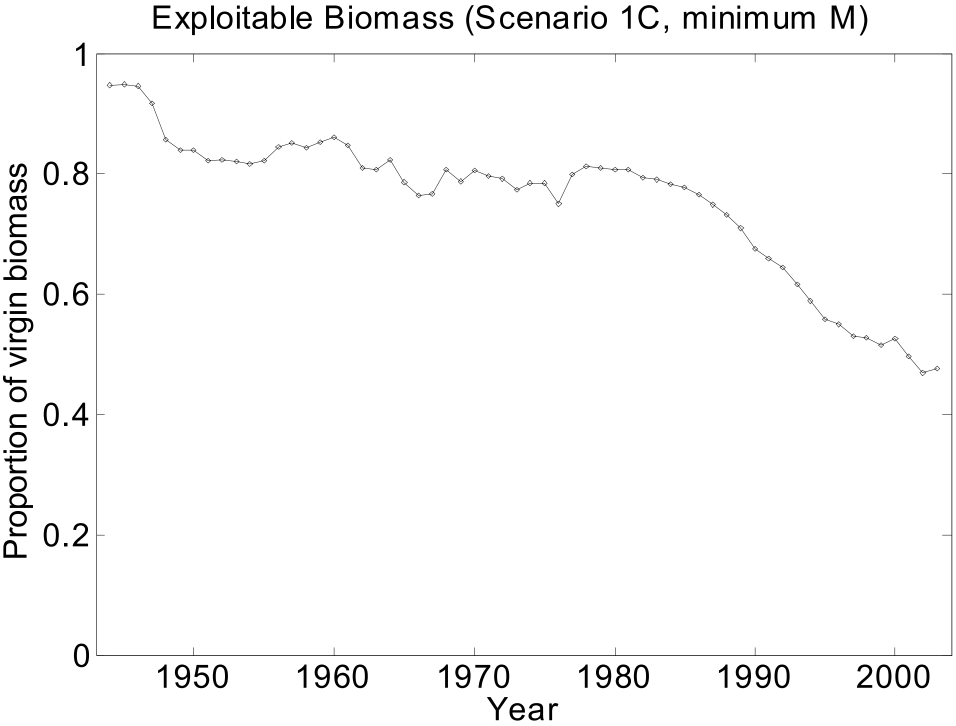


Figure 20(d): Exploitable biomass from the age-length-structured model under Scenario 1C (no increase in recreational fishing power since 1977; 11% p. a. increase in size of recreational catch to 1993), M *= 1.05* yr^{-1} *set to its lower confidence limit.*

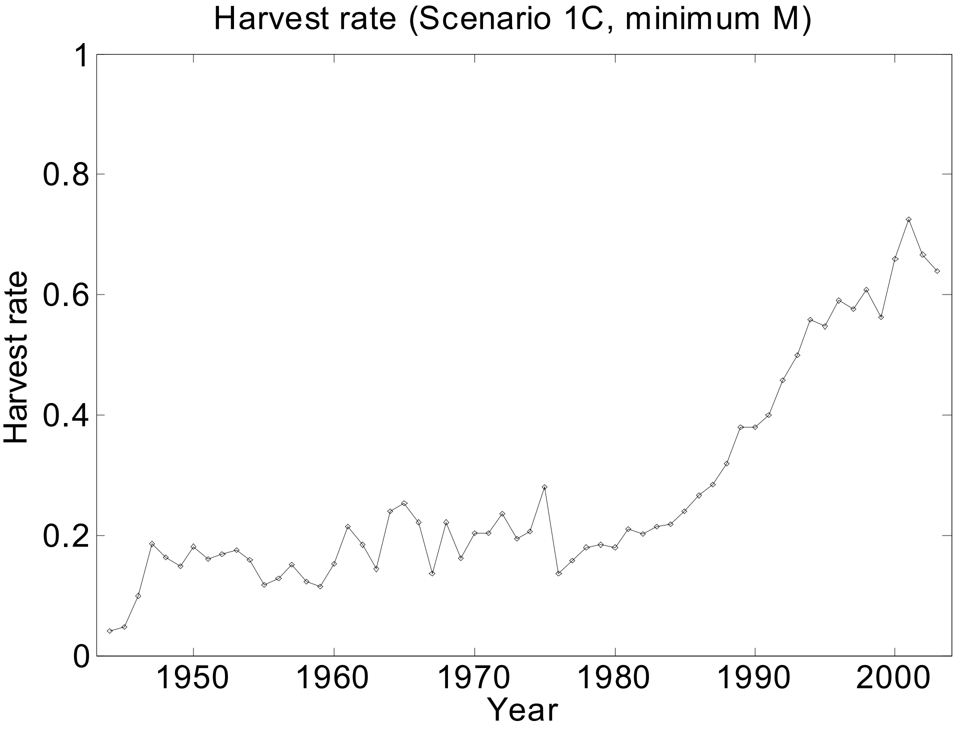
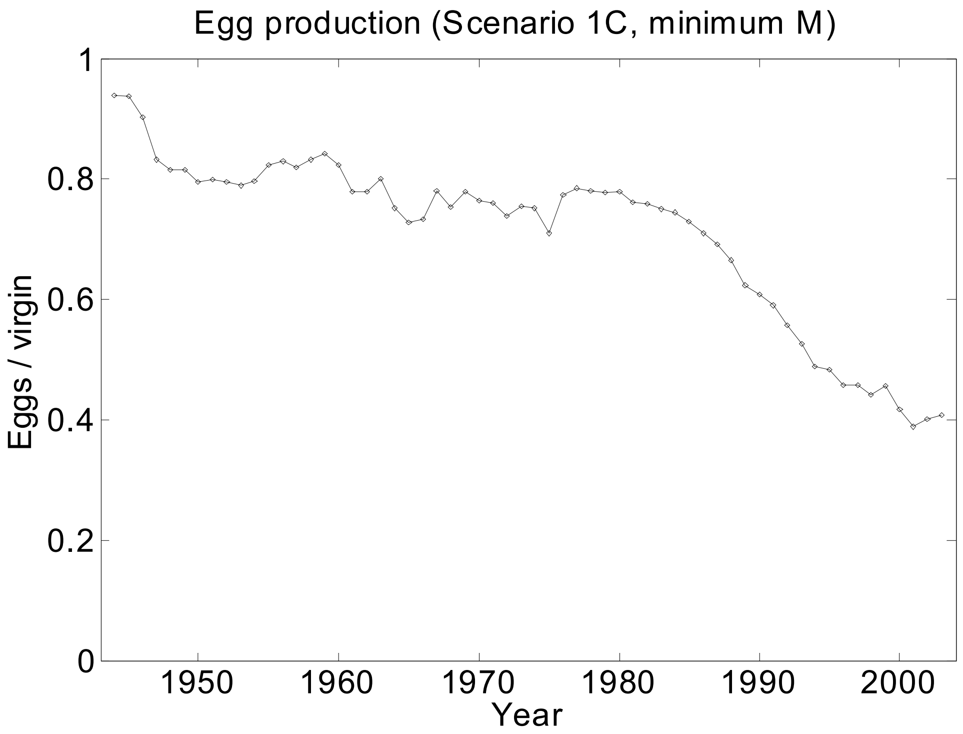
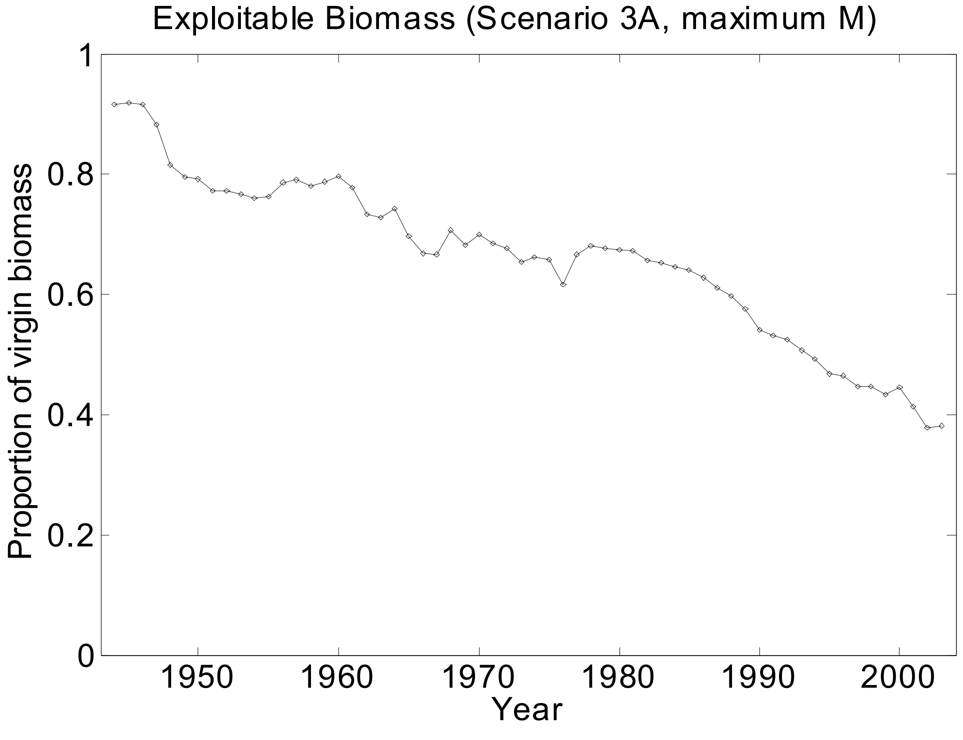


Figure 20(e): Harvest rate (proportion of exploitable biomass that is caught in each year) from the age-length-structured model under Scenario 1C (no increase in recreational fishing power since 1977; 11% p. a. increase in size of recreational catch to 1993), M *= 1.05* yr^{-1} *set to its lower confidence limit.*



Egg production (Scenario 1C, minimum M)

Figure 20(f): Egg production from the age-length-structured model under Scenario 1C (no increase in recreational fishing power since 1977; 11% p. a. increase in size of recreational catch to 1993), M = *$1.05\ yr^{-1}$ set to its lower confidence limit.*



Exploitable Biomass (Scenario 3A, maximum M)

Figure 20(g): Exploitable biomass from the age-length-structured model under Scenario 3A (continued steep increase in recreational fishing power since 1977; 5% p. a. increase in size of recreational catch to 1993), M = *$1.15\ yr^{-1}$ set for 30% selectivity of one-year-old fish.*

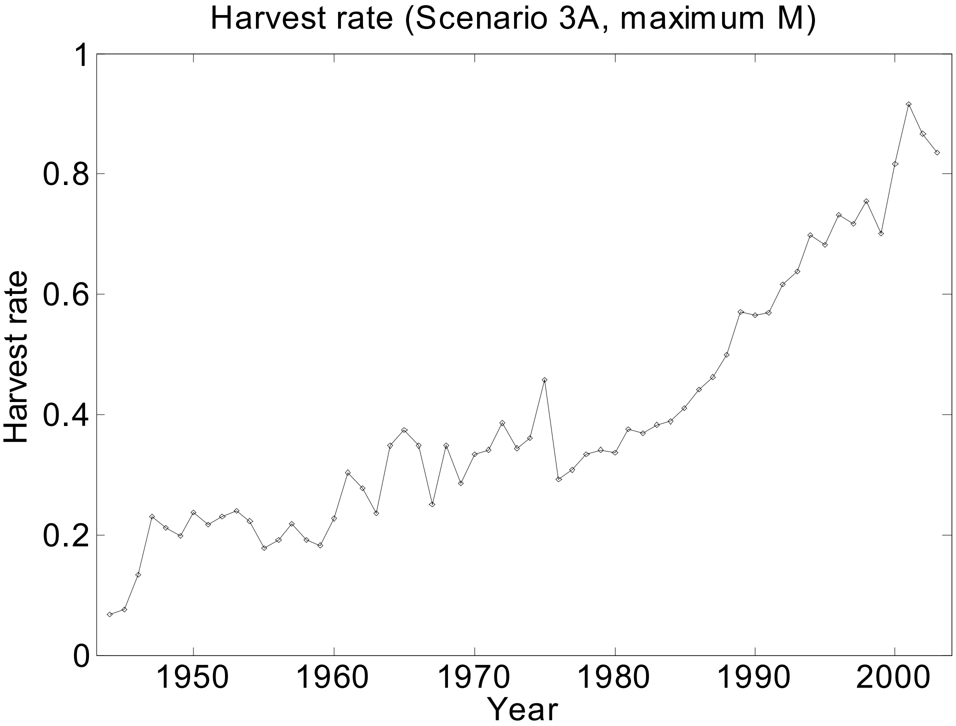


Figure 20(h): Harvest rate (proportion of exploitable biomass that is caught in each year) from the age-length-structured model under Scenario 3A (continued steep increase in recreational fishing power since 1977; 5% p. a. increase in size of recreational catch to 1993), M = *1.15* yr^{-1} *set for 30% selectivity of one-year-old fish.*

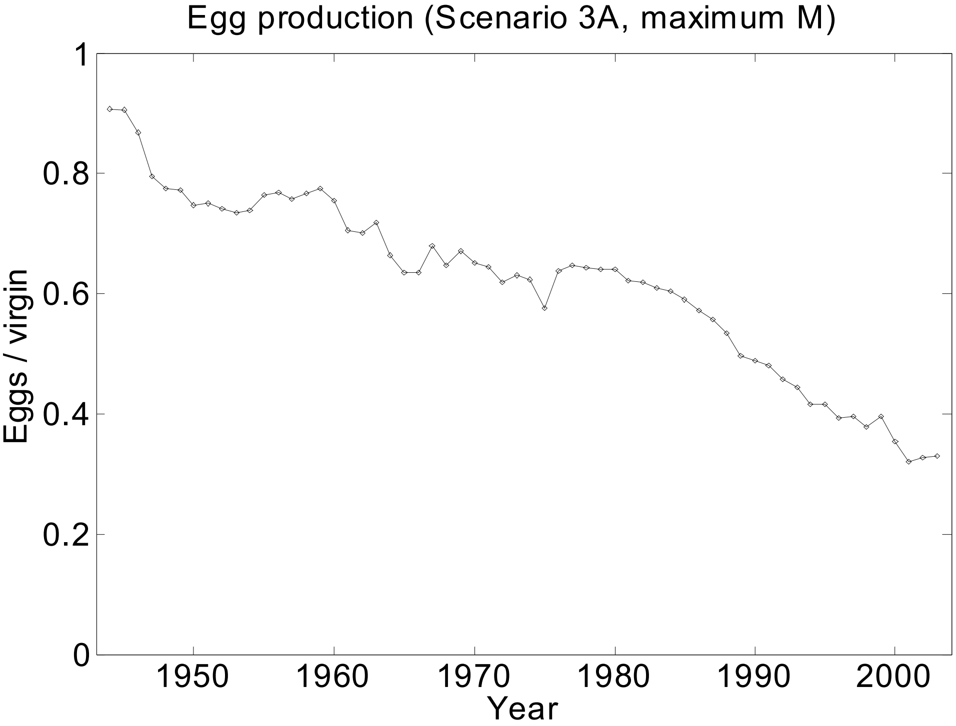


Figure 20(i): Egg production from the age-length-structured model under Scenario 3A (continued steep increase in recreational fishing power since 1977; 5% p. a. increase in size of recreational catch to 1993), M = *1.15* yr^{-1} *set for 30% selectivity of one-year-old fish.*

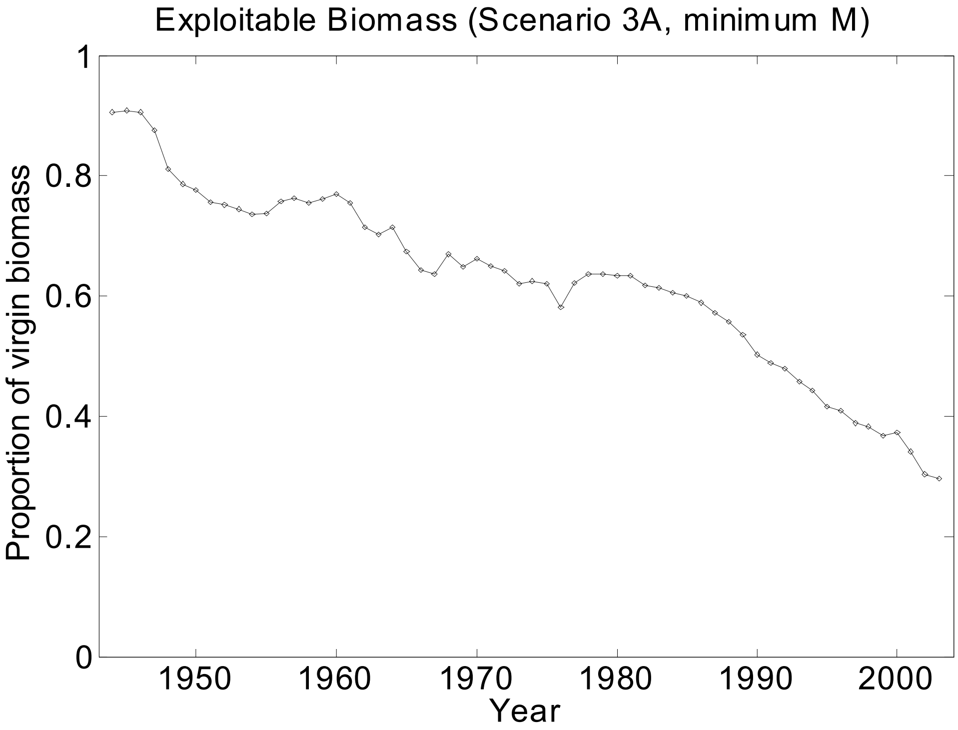


Figure 20(j): Exploitable biomass from the age-length-structured model under Scenario 3A (continued steep increase in recreational fishing power since 1977; 5% p. a. increase in size of recreational catch to 1993), M = *0.77* yr^{-1} *set to its lower confidence limit.*

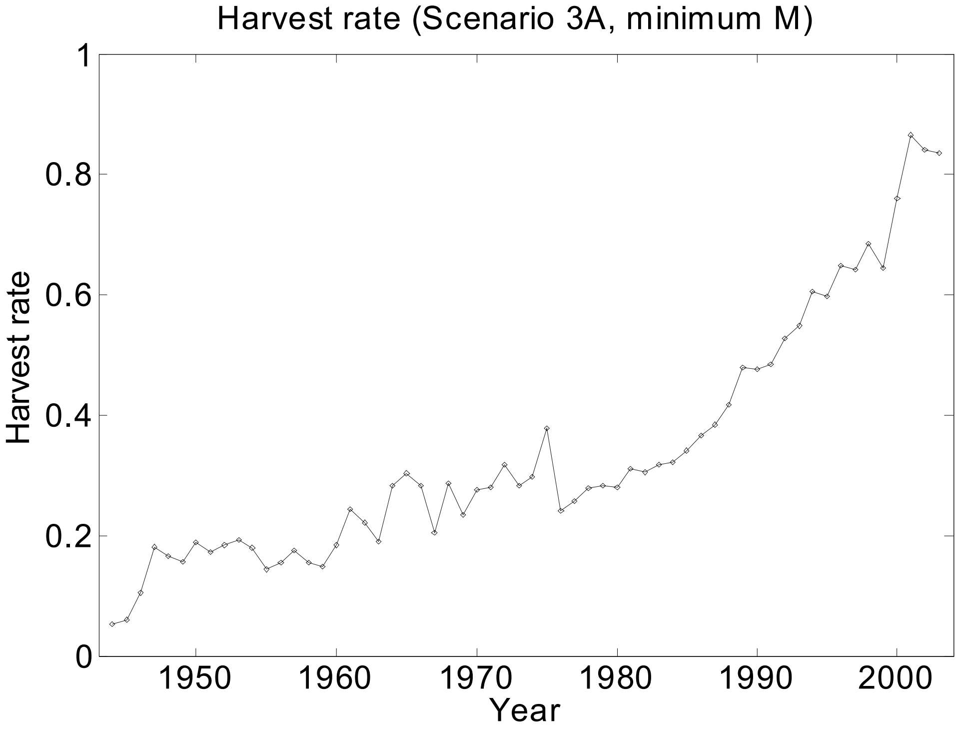


Figure 20(k): Harvest rate (proportion of exploitable biomass that is caught in each year) from the age-length-structured model under Scenario 3A (continued steep increase in recreational fishing power since 1977; 5% p. a. increase in size of recreational catch to 1993), M = *0.77* yr^{-1} *set to its lower confidence limit.*

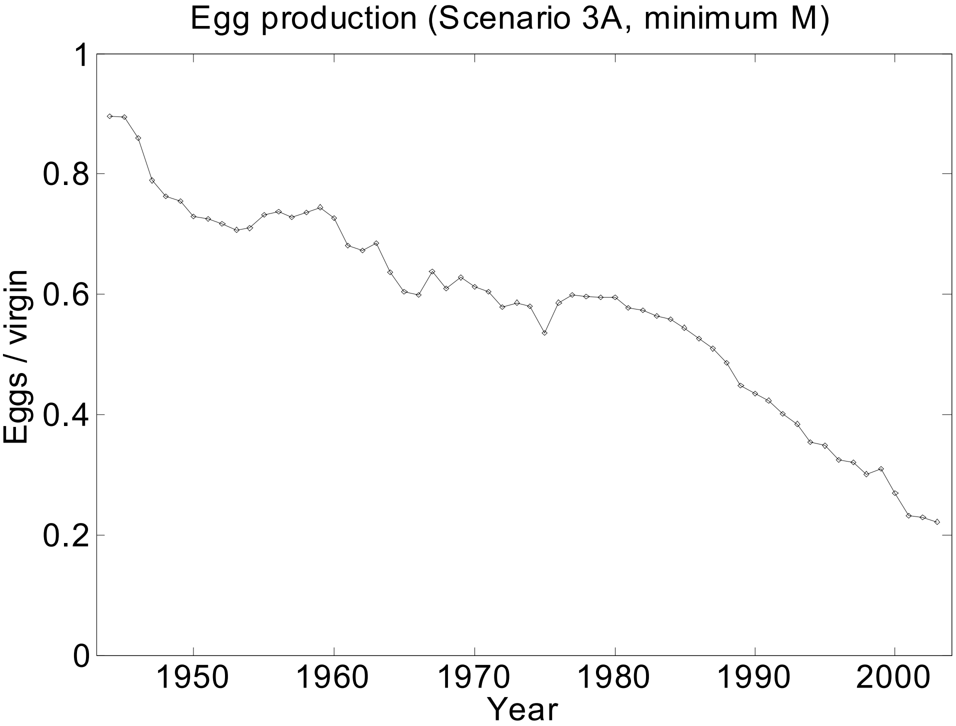


Figure 20(l): Egg production from the age-length-structured model under Scenario 3A (continued steep increase in recreational fishing power since 1977; 5% p. a. increase in size of recreational catch to 1993), M = *0.77* yr^{-1} *set to its lower confidence limit.*

8.6 Yield Per Recruit Analysis

The Yield Per Recruit (mass of fish harvested per fish recruited at age zero) is shown in Figure 21 as a function of the Minimum Legal Size. Results are shown for Scenario 2B, for both the reasonable values of M (0.88 and 1.22 yr^{-1}) shown in Table 2. They were calculated by running the age-length model for 20 years into the future with a constant harvest rate equal to the 2003 level.

Yield Per Recruit is evidently maximised when the Minimum Legal Size is low. This is due to the high level of natural mortality whereby so many fish die of natural causes each year that their biomass cannot be replaced by growth in those that survive.

The setting of Minimum Legal Size therefore has to be based on considerations other than Yield Per Recruit. The view taken in this report is that the capacity of the stock to reproduce must be protected.

Figure 21: Yield Per Recruit of age zero for Scenario 2B (moderate increase in recreational fishing power since 1977; 8% p. a. increase in size of the recreational catch to 1993), for the minimum and maximum instantaneous natural mortality rates that are held to be reasonable (0.88 and 1.22 yr^{-1}*).*

9. Discussion

The major result from this assessment is that the east-coast tailor population is very heavily exploited, and its ability to reproduce is maintained only by the fishery's partial selectivity of one-year-old fish.

The fishery contains very few fish aged three or more, which the population dynamic models ascribe to a combination of high natural mortality and high fishing mortality. The instantaneous natural mortality rate M appears to be between 0.8 and 1.3 yr^{-1}, and therefore higher than commonly believed (e.g., Dichmont et al., 1999 used $M = 0.66$). There is no confirmation of the value of M from, for example, tagging experiments. It is emphasised that values of M discussed here apply only to young fish (up to about three years old), and a lower value may apply for fish older than three.

In addition to the trend of the proportion of fish 40cm fork length or more in Figure 15, the size of the peaks also decreases with time, illustrating the effect that fishing has had on the population.

Migration of large tailor out of the fishery appears unlikely, because researchers have searched for them without success. Brown et al. (2003) found that the average size of tailor offshore did not differ greatly from the average size inshore.

Two-year-old fish appear to have become smaller since the 1970s, judging from the length-frequency data in Figure 13 and assuming that many of the larger fish observed in years prior to 1995 (the first year in which ageing data are available) are two years old. This effect has also been observed in the USA (Brown et al., 2003, Appendix 6, p. 6). It is assumed to be due to increased fishing pressure combined with non-selectivity of small one-year-old fish by the fishery, whereby the one-year-old fish that survive fishing are small and grow into small two-year-old fish the following year. The alternative hypothesis is that there has been a genetic change in the stock. The true explanation is unknown.

The length-frequency samples (Figures 13 and 15) show a large amount of year-to-year variation in the size distribution of fish, probably more variation than is actually present in the population. This variation has continued to take place even since 1999 when the sampling methodology was scientifically standardised by the Long Term Monitoring Program (see examples at the end of section 4). It appears that even though the number of schools sampled is large (E. Jebreen, personal communication), there are factors such as weather and surf conditions, and presence of seaweed in the water, that can influence the size distribution of fish taken by the fishery throughout a sampling period. Since 1999, the sampling period has generally been a week, and samples have been taken several times over the Fraser Island season. The sampling strategy is believed to accurately record the distribution of fish caught by the fishery during sampling periods.

The population dynamic models do not model year-to-year variation in recruitment. Recruitment was exceptionally high in the mid-1970s. Figure 15 shows relatively high numbers of two-year-old fish in 1978, 1980, 1990 and 1999, which implies high recruitment of zero-year-old fish in 1976, 1978, 1988 and 1997. It is possible that some of these are not real effects but reflect random variation in the size of fish that are selected by the fishery at the times of sampling. Judging from the catch rate in 1975, there must also have been an extremely high recruitment in 1974, which should have produced a large number of two-year-old fish in 1976 (a year in which it is believed that length-frequency data were not collected).

A model with random recruitment is an option to develop in the future. It would have to impose a probability distribution (such as lognormal) on the annual number of recruits. A method that estimates each year's recruitment by exactly matching catch rate data is not recommended because catch rates are subject to large random errors.

10. Recommendations

10.1 Minimum size limit

The major recommendation of this assessment is an increase in the minimum size limit, from 30cm total length to 40cm total length. It is highly desirable for New South Wales and Queensland to move in parallel in adopting the increased size limit.

The change is needed because fishing pressure is extremely heavy on many one-year-old fish and all fish aged two or more. If the population's ability to reproduce is not better protected, a single year of low recruitment could necessitate drastic management measures. This stock assessment has found no evidence that recruitment has been significantly affected to date. Recruitment downturns in fisheries can, however, occur for many reasons, mostly connected to reduced spawning stock and sometimes magnified by unfavourable environmental conditions. If a recruitment downturn were to happen in the tailor fishery, under current management and fishing pressure, there is a strong chance that the fishery would need a complete closure for several years to recover, and even then recovery would be uncertain.

This recommendation does not stem from a consideration of yield-per-recruit or maximum sustainable yield, but simply the survival of the fishery by allowing at least one full age-class to reproduce.

The recommended change will protect most one-year-old fish in the population, and allow them to spawn. It will also protect many two-year-old fish. If discard mortality is not excessive, the increased size limit is expected to offer protection for the stock in the face of current and future fishing pressure.

Our reason for favouring an increase in the size limit over other management strategies such as seasonal and spatial closures is that the fishing effort on tailor is so high that closures would still leave the population in danger. An increase in availability of tailor in the open seasons and areas would bring out extra anglers, and effective effort could quickly return to its former level. Also tailor are highly migratory, so spatial closures would not protect a significant proportion of the stock.

The following comments are relevant to the timing of an increase in size limit:

- The success of the strategy depends on the discard mortality being acceptably low. If the experiment on discard mortality can be run in the near future, its results (or even preliminary results) will ensure that managers are as well informed as possible in deciding on this action.
- A publicity campaign is desirable before the change, to inform recreational anglers of not only the change but also its benefits. The ideal outcome is that fishers cease fishing at times and locations where fish are below the new legal size.
- It is important that Queensland and NSW adopt a unified management strategy.
- Although the effects of a recruitment downturn under current arrangements would be very severe, recruitment appears not to have been strongly affected to date.

The following factors constitute the major risks to a management strategy of increasing the size limit:

- The discard mortality may be too high for the change to be effective.
- There may have been a genetic change towards smaller fish in the population, which will prevent many fish from growing over the size limit.
- Queensland and New South Wales may not move together in adopting the new size limit, which may result in one State continuing to catch fish between 30 and 40cm total length, and the other State still having few fish longer than 40cm total length.

It was noted in section 9 that two-year-old fish appear to have become smaller over the years. This effect has been ascribed to growth of small one-year-old fish, which are not selected by the fishery, into small two-year-old fish. If this interpretation is incorrect and the population has instead undergone a genetic change, increasing the size limit will not provide a resource of larger fish that can be caught by fishers.

If the full increase in size limit is implemented in one step, there will be a significant reduction for the first year in the number of fish of legal size available to be caught. It is assumed that anglers will still target undersized fish and discard them. An alternative is to stage the increase in size limit, e.g. to 35cm in the first year and 40cm in the second year.

10.2 Discard mortality

The strategy of managing the stock by a minimum size limit depends on a high survival rate of discarded undersized fish.

To assess discard mortality, an experiment is recommended that involves holding line-caught fish at sea in cages for 72 hours and analysing their condition and survival rate. It is also desirable to hold some fish for longer periods (possibly months) to examine whether they suffer longer-term mortality from skin damage while being handled.

A substantial increase to the size limit would have a much bigger effect on the fishery than was the case for the introduction of the current size limit (30cm total length, 26.8cm fork length, introduced in Queensland in 1990), because most fish caught in the fishery before 1990 were already above the size limit (see Figure 13(a–g) which graphs fork length). The proposed experiment on discard mortality would provide confidence in the management strategy given the magnitude of the change to a 40cm total length size limit.

Little work on discard mortality of tailor has been reported in the literature to date. Ayvazian, Wise and Young (2002) held 1155 Western Australian tailor in a holding pool for two hours, and recorded an overall mortality rate of 3%. They kept 22 of these fish under laboratory conditions for up to 433 days, 13 of which survived the full time. Work from the USA is summarised by Brown et al. (2003, Appendix 6, pp. 7–8). National Marine Fisheries Service staff held 67 fish for up to 100 days, 25% of which died in the first 24 hours, and another 15% died over the next 21 days. Total mortality over 86 days was 54%.

The need for a new experiment on discard mortality is highlighted by the short holding time of Western Australian fish (only two hours), and the small sample size from the USA (67 fish).

Large tailor fight hard when hooked (which is part of the experience of tailor fishing loved by many recreational fishers), and may exhaust themselves by the time they are reeled in. Also, researchers in the USA have found that tailor may suffer long-term fungal infections to the skin due to being handled (A. Butcher, personal communication). And, of course, hooked fish sustain direct injury to various parts of the body. It is well known that, for fish in general, gill efficiency is reduced when fish are large and when their ambient temperature is high, and this will affect their post-release survival. Tailor are not thought to suffer significant barotrauma (stress due to being pulled up from deep water), firstly because they are generally caught near the surface, and secondly because they do not have highly developed swim bladders.

An experiment on discard mortality should also study

- the likely change in anglers' behaviour in response to a change in size limit (especially, will anglers keep fishing a location where the tailor are undersized, or will they move somewhere else?)
- the effects of different types of hooks; if a big effect of hook type is found, it may be possible to ban ganged hooks (where typically four hooks are set in

line; see Claydon, 1996, pp. 12–13) and restrict anglers to single hooks and possibly even barbless hooks in some locations.

10.3 Commercial TAC

The commercial catch is only a small part of the total harvest of tailor, and any variation in the commercial Total Allowable Catch, within reasonable limits, will make no significant difference to the stock. No recommendation about the level of TAC is made here.

An important consideration in managing the commercial fishery must be the effect on undersized fish that are caught, especially if the size limit is increased. It is recognised that there is almost no chance of survival of fish discarded by the ocean beach fishery. The emphasis must therefore be on gauging the size of fish before deciding to catch them. The ocean beach fishery uses seine nets with small mesh, and no practical change to mesh size would allow undersized fish to escape.

The size of the commercial fishery is small enough that it could be allowed to continue to catch fish between 30 and 40cm. However, it is not thought that such a course would be politically acceptable, especially because New South Wales no longer permits net fishing of tailor and it is essential that New South Wales and Queensland move in parallel in managing the tailor stock.

10.4 Fishery-independent surveys

The review by John Hoenig highlighted the opportunity to undertake fishery-independent surveys of the abundance of both tailor and fishers. It is recommended that these be done by aerial means. An aerial survey of tailor stocks was conducted in 1991, and reported by Mann (1992), who found the technique very accurate in estimating the size of schools of tailor. He recommended that an aerial survey be conducted again in future years. It provides probably the most cost-effective means of fishery-independent survey.

Such a survey could be of great benefit in comparing current tailor stocks to their 1991 level, in terms of both the number of schools and the size of schools. It would help to resolve whether the schooling behaviour of tailor has changed in response to fishing.

The survey could also count the number of anglers on the beaches, producing a baseline measure of recreational fishing effort.

10.5 Data collection

10.5.1 Queensland commercial data

Appendix 2 discusses possible anomalies in the catch data in the CFISH database, which may concern not only catch rates but also the size of the total catch. It is recommended that the following data sources be made available to future analyses of CFISH data:

- records of telephone calls made by fishers to report their catches to DPI&F
- buyer returns from the processors who buy the catches.

10.5.2 Fishing club data

This assessment has relied on fishing club data to provide recreational catch rates of tailor prior to 1997. It is recommended that fishing club data, dating from as far back as possible to the present, continue to be collected and collated into the DPI&F database. It is important to collect data from as many different clubs as possible because there are big differences between the skill levels of anglers in different clubs, and the more clubs that can be included in the database, the more accurate the catch rates will become. Club angler gradings should also be recorded. Angler IDs are currently recorded but exist in multiple forms (e.g. Andrew Smith, A Smith, A. Smith, A.Smith), and to be usable they would have to be filtered into a unique ID for each angler.

Additional fishing club data that can be collected will aid future studies of many species of fish that are caught by fishing clubs, and future analysis of them could provide an overview of the state of many of Queensland's fish stocks.

The catch rates used in the population dynamic models in sections 6–8 relied heavily on fishing club data, and were not found to suffer significantly from hyperstability (see Figure 19(u)). Therefore the club data appear to be of great use; the main drawback of the club data used here is its noisiness (Figure 10(a)), which can be remedied by collecting more data.

10.5.3 New South Wales recreational data

Data from the NSW recreational fishery are sparse, and 2000 is the only year for which even an estimate of the total catch is available. It is desirable to add to this data set by encouraging further surveys of the NSW recreational fishery.

10.5.4 Sampling by the Long Term Monitoring Program

The Long Term Monitoring Program has concentrated its sampling on fish caught at Fraser Island. This concentration has the advantages that fish are readily available, a large number of schools can be sampled in a relatively short time, and the samples are comparable to historical samples.

The main restriction of the sampling appears to be that it consumes a week at a time, and only a few weeks can be sampled in a season. The data to hand indicate that samples taken within the same week are not truly independent. For example, factors such as weather conditions may stay the same for the whole week, which may bias that week's catch towards either big fish or small fish.

The best sampling strategy for the ocean beach fishery appears to be to maximise the number of truly independent samples taken, where samples are considered independent only if they are taken well apart in either time (e.g. more than a week) or space (e.g. further than 20km, but more discussion with LTMP members is needed to refine this number). The most cost-effective improvement that we can suggest is to maintain the focus on Fraser Island and take samples from as many widely spaced locations on the Island as possible. We note that substituting a week on Fraser Island for a week at some other ocean beach location (e.g., Moreton Island) may in fact lead to less representative sampling if there are fewer schools available to sample.

The most informative spatial extension of the sampling would be to sample fish that may not migrate as far as Fraser Island, for example from New South Wales (although this would fall outside the Queensland LTMP mandate) or North

Stradbroke Island. The degree to which this would make the sampling more representative of the population available to the fishery is unknown.

Since recreational angling dominates the fishery, it is appropriate that most of the sampling effort go towards this component, although there is an argument that the commercial fishery provides a more representative sample of the population at large and is less dependent on weather conditions.

10.5.5 Maturity and fecundity

There is a paucity of data on maturity and fecundity of tailor, with Bade's (1977) measurements on nine fish constituting the only available data set on fecundity from Australia. It is recommended that some data on maturity and fecundity of tailor, as functions of both age and length, be collected as a one-off study. The DPI&F Long Term Monitoring Program could handle this experiment, and redirect some resources resulting in a reduced number of otoliths being read one year.

New data on maturity might also help to resolve the question of whether tailor have undergone a genetic change and are maturing at smaller lengths than in the past.

10.6 Management strategies for recreational fisheries

It is recommended that possible strategies for managing Queensland's recreational fisheries be studied for the economic and social effects. At present the fishing effort on tailor is extremely high (models indicate that approximately 80% of fish available to the ocean beach recreational fishery are caught in a single year), and the most effective way the stock can be protected appears to be by a minimum size limit.

Direct effort control may be a more effective way of managing many of Queensland's recreational fisheries. Possible measures that could be considered include a recreational fishing licence and seasonal and spatial closures. These may have limited application to tailor because tailor are highly migratory and will be subject to very high fishing effort even if closures are introduced. The magnitude of closures required to protect tailor, as an alternative to increasing the size limit, would cause major disruption to the fishery.

Acknowledgements

This report takes account of comments from DPI&F staff Jim Higgs, Len Olyott (both of whom provided us with much of the data from the DPI&F databases), Eddie Jebreen, Adam Butcher and Tony Courtney, all of whom reviewed previous versions. We benefited from exchanging ideas with our co-worker in the Stock Assessment group, Paul Bell. NSW Fisheries staff, especially Dr James Scandol and Mr David Makin, assisted greatly in providing data.

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Appendix 1 Review by international expert John Hoenig

A1.1 Text of review

Review of Stock Assessment for Tailor (*Pomatomus saltatrix*) in Queensland

Report completed under contract to the Queensland Department of Primary Industries and Fisheries by John M. Hoenig, Ph.D. (contractee), Virginia Institute of Marine Science, Gloucester Point, Virginia, USA

May 7, 2004

Available information on the commercial and recreational fisheries for tailor (*Pomatomus saltatrix*) in Queensland and New South Wales was reviewed. There appears to be very little fishery-independent information. The model developed to synthesize available data and to provide estimates of abundance, harvest rates, and reproductive potential was then reviewed.

The modeling appears to have been done well, and I have few criticisms of this effort. However, because of the rather severe limitations of the data, it is not clear how reliable is the model. I believe extensive sensitivity analyses should be conducted to identify critical data components and to determine the range of results that can arise from alternative assumptions and inputs.

It seems clear to me that neither the model, nor any of the assessment results, can be used at this point to push the fishery to its limits. That is, we do not have enough information to determine annual quotas in relation to annual status determinations. Rather, I believe the proper use of the model is to: 1) try to gain a general impression of the level of exploitation to provide managers with a planning horizon (e.g., determine whether or not the current level of exploitation can be sustained, or determine when actions will be needed to limit the fishery given current rate of growth of the fishery), 2) identify which types of data are most critical for improving predictive capability, and 3) assess the fishery in terms of trends and benchmarks, especially biomass and spawning potential in relation to a reference state where conditions were known reasonably well. In other words, the model is likely to provide better information on relative state of the stock than on absolute values (of biomass or spawning biomass).

In terms of managing the fishery, it seems that the commercial fishery is stable and controlled by quota. The recreational fishery is poorly studied. It is managed by minimum size limit and bag limit. It is important to note that the bag limit does not provide a failsafe mechanism for protecting the fishery. In fact, the bag limit serves to work in the opposite way to what is desired. That is, when the stock is at record high levels, the bag limit of 20 serves to prevent anglers from obtaining the yield that they could legitimately have without harming the stock. If the stock falls to a low level, then few anglers are able to catch the bag limit so the bag limit is not limiting the harvest much. The lower the population size, the fewer people reach the bag limit so the bag limit does less. In contrast, a minimum size limit can provide a failsafe mechanism under certain circumstances. If fish begin to mature below the minimum size limit, then the minimum size limit can guarantee a certain amount of spawning, regardless of whether the stock assessment model and quotas have been computed well. However, in order for the minimum size limit to work well, it should be chosen on the basis of how much spawning will occur given a particular size limit. The assessment model may provide information on spawning potential relative to the virgin level. Another way to get at this question is to conduct an egg-per-recruit analysis. At the same time, one might as well conduct a yield-per-recruit analysis. It is possible that an increase in minimum size limit would result in a greater harvest in weight than that obtained under the current minimum size limit. Information on age- or size-specific maturation and fecundity is important for any of the methods of assessing degree of protection of spawning biomass. Another key factor is the fate of sublegal sized fish that are caught. Compliance with the minimum size limit and fate of discarded fish is required to judge the effectiveness of a minimum size limit.

Technical comments on the model

I believe the use of a "pooled" age-length key (using data from several years) was probably necessary to make any sense of the historical data. However, the practice tends to minimize the apparent differences among years, i.e., it erroneously tends to make all years look very similar. Thus, the apparent decline in older fish over time deduced from the length-frequency data and the pooled age-length key probably represents an underestimate of the actual decline. I suggest that the fraction of large fish (say, over 40 cm) in the catch be plotted versus year. I suspect that the decline will be more severe than the decline in older fish seen in the model.

The various indexes of stock size over time are not in strong agreement. An effort was made to use the "best" index. However, I think it would be worthwhile to look at the range of model outputs that would arise from using various alternative indices of abundance.

Recommendations for research

Short-term work

1) Focus attention on the spawning potential as an output of the assessment model.
2) Conduct a sensitivity analysis of model inputs and assumptions
3) Try a surplus production model as an alternative to the age-structured model
4) We held some discussions on whether samples should be collected and aged every year or whether this could be done every few years. I believe it would be helpful to do this every year. We want to know if there is consistency in year class strengths (e.g., an apparently strong year class this year should also appear as a strong year class next year), and we want to know if strong year classes are reflected in the length frequency data and in the model results.

Longer-term work

1) Obtain base-line information on recreational fishing effort, perhaps through an aerial survey. If possible, a roving creel survey or a "bus-route" study should be used to apportion effort to species and to determine catch-rates of tailor. The survey should also look at compliance levels for the minimum size limit.

My recommendation is that the survey should be conducted for at least 2 and preferably three years so that the consistency of the results can be observed. The survey should also be repeated at intervals to measure the growth of the recreational fishery.

2) Obtain an estimate of the abundance of spawning biomass of tailor by conducting an aerial survey off the beaches. Such a survey was conducted in 1991. Thus, an estimate of current abundance would show the change in stock abundance since 1991 and would be extremely valuable in validating the model outputs and could serve to anchor the assessment to the change in abundance determined from the aerial surveys. The aerial survey should ideally be conducted for several years to judge the consistency of the results.
3) Estimate the survival of discarded fish in the recreational fishery and, if possible, in the beach seine fishery. This is key for evaluating how well the minimum size limit protects the stock.
4) Consider implementing a tagging program in which anglers are trained to tag and release fish. This may provide estimates of total mortality rate which would be very useful as a benchmark.

A1.2 Other comments by John Hoenig while he was visiting

A1.2.1 Catch rates

It is informative to show catch rates by different fishery on the same chart.

Can we be sure that the increase to 1977 in the recreational catch rate aggregated over all species is due to increase in fishing power? Long-term natural increases in fish abundance do occur.

Using the log-linear/generalised linear model approach to modelling catch rates has problems when there are significant interactions between “year” and other factors. To find a single catch rate for each year, these interactions have to be ignored. It would help to examine the magnitude of interactions of month, location etc. with year. If they are small the approach can be regarded as valid. If large, it is unclear what we are measuring in calculating a single catch rate for a year. For the analysis presented here, there are no fishery-independent data, so there is not much alternative.

A1.2.2 Age composition

Age-length keys work best if we have a separate one for each year. For years in which there are no ageing data, an age-length key from other years can be used, but it must be borne in mind that this tends to make the population structure appear the same as when the age-length key was taken. The age composition used for the age-structured model shows a decrease in the numbers of older fish, but the real situation is probably even worse.

A plot of the percentage of fish of length > 40cm may show the true magnitude of the change in abundance of older fish.

It is desirable to examine age composition with respect to year-class strength. If a strong year-class can be tracked through age 1, 2 and 3, it would lend support to the ageing technique. Using different age-length keys would help in this (would show more contrast that using a common age-length key). Undertaking ageing every year will create confidence in the ageing techniques if year-class strength can be tracked.

A1.2.3 The population dynamic model

Confidence limits for model parameters will not be highly relevant. Sensitivity analyses will be much more important. Sensitivity analysis is likely to tell us that the true parameter values are between a millimetre and a mile. But we do the best we can with available data.

Look at status of population from the standpoint of egg production. What fraction of virgin egg production are we on? A figure of e.g. 25% protected is OK.

The main thing in an analysis with this uncertainty is to have a failsafe, make sure that some spawning is protected. The size limit seems to achieve this, but we need to know more about discards and discard mortality. We could run the model for different size limits, but would need an estimate of discard mortality.

The model can be used to set TAC etc., but it is not exact enough to respond year-to-year (e.g., if catch is up this year, can we increase the TAC next year?). Given the uncertainties present, it is best to stick to a constant TAC. If we don't know the total catch well enough, we need to protect reproduction.

A1.2.4 Suggestions for other work

Can we catch up with Bade? He might have some useful information. At least, he might tell us when his length-frequency sample was taken, and he might know whether any of his scales survived. We could contact the University of Queensland Zoology Dept. to see whether they still have Bade's scales.

Is there any information in the tag-return data? We have used them only for length-frequencies, and assumed that the returns contained little information because return rates were very low.

It is feasible to undertake a tagging experiment using anglers as taggers. They must first come to a training workshop, and we would need to reward them for participation. Posters may be part of the reward, and could double as advertising. T-shirts and caps can be used as rewards for recoveries, as can rulers giving age from length. We must stress the need release and recovery information (e.g., date, location, length) on each fish.

We need to measure the rate of increase of the recreational fishery, e.g. by aerial surveys of the number of anglers on beaches.

It is possible to manage effort by regulating the fishing season.

Appendix 2 Incidental commercial catch

The March 2004 meeting of the Inshore Finfish Management Advisory Committee expressed concern at the total amount of commercial tailor catch that was taken as incidental catch (i.e. individual catches less than 100kg), and therefore fell outside the Total Allowable Catch for the commercial fishery.

Incidental catch amounts to about 40t per year, compared to the Queensland TAC of 120t and the combine Queensland-NSW recreational fishery of about 1000t. The total weight in tonnes of catches under 100kg remained fairly steady through the change.

The significance and breakdown of incidental catch is summarised in Figures 22–24.

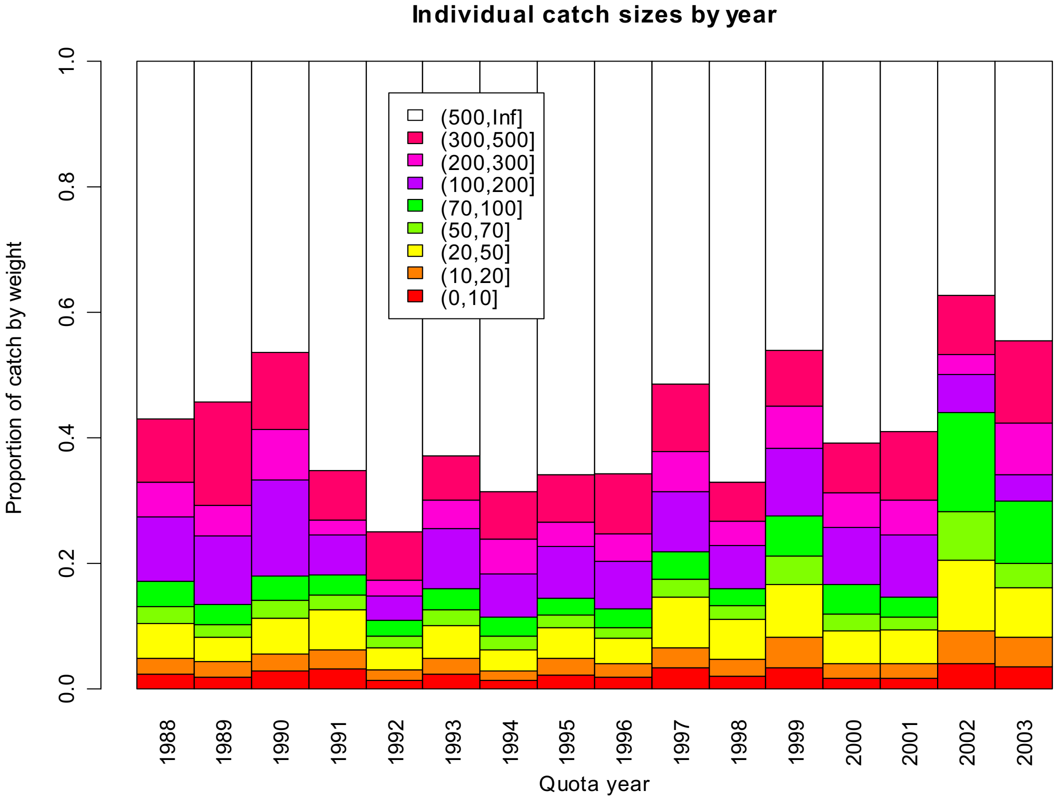

Figure 22: Queensland commercial catches, by size of individual catch, scaled to sum to 100% in each year. The white bars at the top represent all catches over 500kg. The chart clearly shows the change in the proportion of reported catches over 100kg that came about with the new reporting system in 2002, but it is important to note that because the reported total catch fell in 2002, the total amount of catch under 100kg has remained about the same.

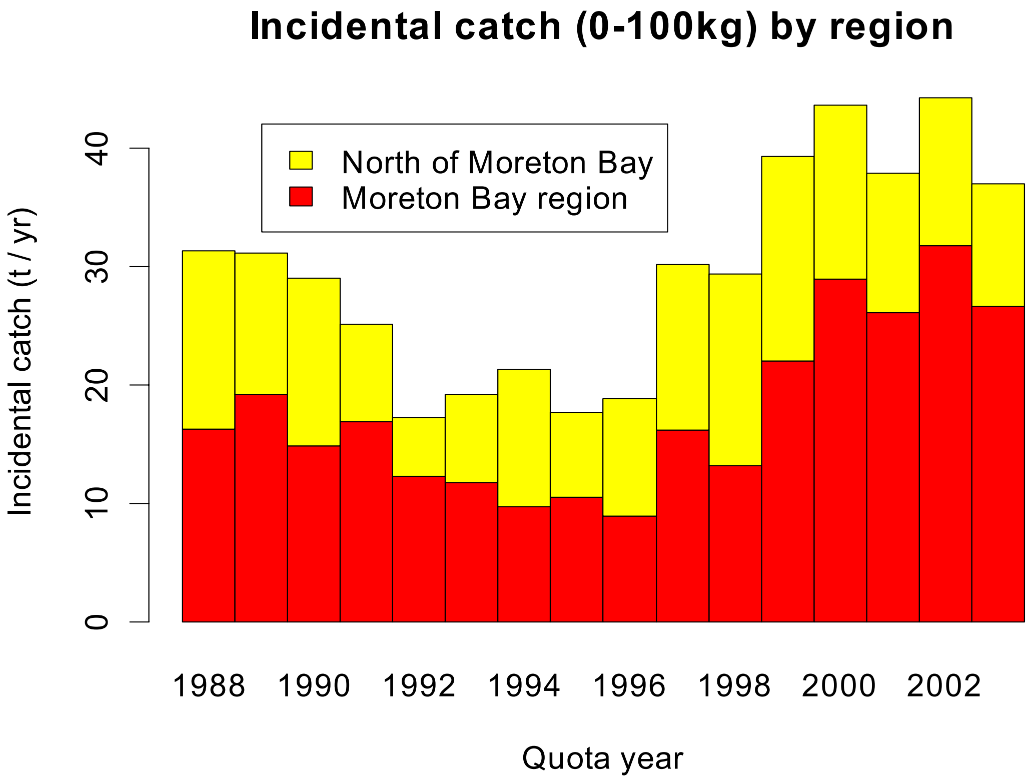

Figure 23: Breakdown of incidental catch by region (Moreton Bay region versus north).

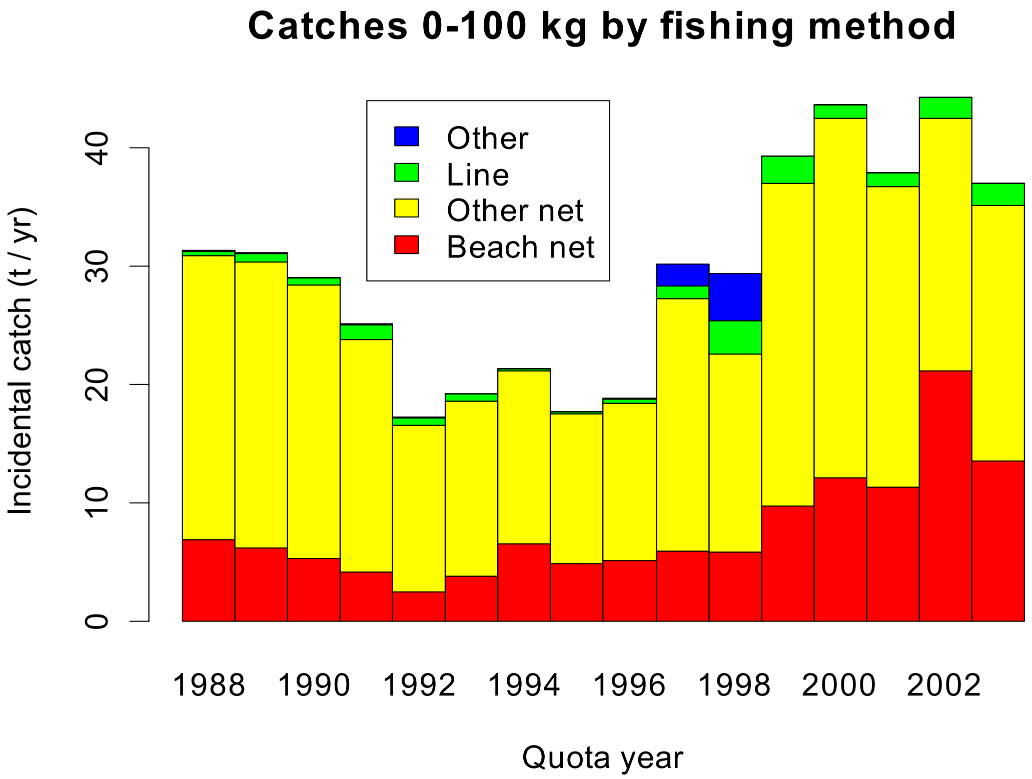

Figure 24: Breakdown of incidental catch by fishing method.

Figure 22 shows that the change to the new system of TAC with incidental catch, introduced in 2002, had a big effect on reporting. However, whether current reporting is more accurate or less accurate than before is unknown. The following suggestions come from industry participants and others:

- It is now in fishers' interests to split catches; for example, if a team of three fishers catches 270kg, they may now split it as three lots of 90kg each, whereas previously one person would have reported a catch of 270kg.
- The new system may be more accurate in that fishers report the catch as they catch it, whereas previously they may have lumped several days' catches together or several fishers' catches together.
- In the lead up to the change, fishers may have considered the new system likely to involve individual quotas, and that their quotas would be related to individuals' past catches. Hence they may have reported higher catches than they actually made. Figure 2(a) shows high catches in 2000 and 2001 that may have been artificially inflated.

Figures 23 and 24 show that incidental catches come from a variety of locations and fishing methods.

The above discussion highlights that not only individual catch sizes but also the total catch size itself may have been subject to systematic errors. This makes it important to include all possible data sources when estimating the total catch. In addition to fishers' logbook data, other sources include

- records of telephone calls that fishers are obliged to make to DPI&F when they take catches of over 100kg, and
- buyer returns from the processors who buy the catches.

There is a case for excluding the Queensland commercial catches for 2000 and 2001 from analysis because they are much greater than the catches for any other years between 1990 and 2003, and may have been artificially inflated. The reasons these data were included despite the decision to exclude the 1997 RFISH data were that

- The New South Wales commercial fishery also recorded relatively large catches in 2000 and 2001, providing some credibility to the recorded catches in Queensland, and
- the commercial fishery has been only a small component of the total fishery in recent years, and the exclusion would have made little difference.

The matter of whether to exclude the 2000 and 2001 Queensland commercial catch sizes is one that can be taken up again in future analyses.

Appendix 3 Computer files

All the files used in the analysis are contained in the directory `Stock Assessment\Tailor` on the DPI&F Deception Bay server. Raw data files are in the subdirectory `data`. The raw data actually used in the analysis were first converted into comma-separated-values (`csv`) files, which are in the subdirectory `analysis`. Preliminary analysis and catch-rate analysis were performed in the statistical package R (free software; see web-site `www.r-project.org`). The population dynamic models were programmed in the mathematical package Matlab (distributed by The MathWorks, `www.mathworks.com`). These models have their own subdirectories `analysis\Matlab\SurplusProduction`, `analysis\Matlab\AgeModel` and `analysis\Matlab\Age+LengthModel`. They read their data from files output by R in the `analysis` directory.

Code to group names of fishing locations into areas usable for analysis was written in R, and hopefully will not have to be substantially rewritten for future analyses. The file `RfishLocations.xls` in the data directory is an Excel spreadsheet giving the grouping for locations specified by Rfish diary holders.