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Preliminary Assessment of the East Coast Spanish Mackerel Fishery in Queensland

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Geoff R. McPherson and Neil A. Gribble
Agency for Food and Fibre Sciences
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Executive summary

The narrow-barred Spanish mackerel, *Scomberomorus commerson*, is an important target species of both commercial and recreational fishers across northern Australia. In Queensland distinct stocks have been identified from the Gulf of Carpentaria, Torres Strait, and the east coast. An assessment of the east coast stock is reported here.

Commercial catch and effort data have been collected since 1988 using compulsory logbooks (CFISH). Catch and effort have been variable, with no consistent trend in catch per unit effort (CPUE). A 26% increase in CPUE from 1996 to 1999 was followed by a similar reduction in the last two years. However, CPUE data are difficult to interpret in species such as Spanish mackerel due to hyperstability, caused by the behaviour of fishers, the commercial data collection procedures, and the fishes' schooling behaviour, particularly during spawning when they are heavily targeted. This behaviour also makes them vulnerable to over-exploitation.

Commercial catch data (Queensland Fish Board, CFISH, NSW Fisheries) and recreational catch data (RFISH, Qld charter boat logbooks, NSW Fisheries) for the east coast were collated back to 1950. These data, along with age data from 1977/78, 1978/79 and 2001, were put into a dynamic age-structured model to estimate fishing mortality rates, F, and trends in stock size. The stock assessment model suggested that the exploitable biomass had declined by approximately 56% below the estimated unfished biomass, and that any increase in fishing effort would be likely to result in a further decline in stock biomass. A high degree of uncertainty around parameter estimates and data used as input to the model was identified and assessed using analyses of the sensitivity of the model to changes in these estimates. Based on the analyses it was concluded that fishing effort should not be increased above current levels and a precautionary approach would suggest that effort be reduced.

Yield-per-recruit analyses were carried out to assess the current minimum legal size of 75cm TL (68cm FL) for Spanish mackerel. For sexes combined the optimum length is less than 70cm TL based on yield alone. The most recent estimate of size at maturity for male and female Spanish mackerel is approximately 89cm TL. The major rationale behind setting a minimum legal size, apart from optimising yield, is to maintain spawning biomass by ensuring that females of the population are not vulnerable to the fishery for at least one spawning season. Although the current minimum legal size does not ensure this, the commercial fishery currently targets fish much larger than the minimum legal size. Given the high mortality rate of released mackerel, and the dangers associated with releasing large active fish, there may be little benefit in increasing the minimum legal size. However, the results of YPR analyses and current estimates of size at maturity suggest that the current legal minimum size should be re-evaluated when better information on recreational catch size distributions and release mortality rates become available.

Recommendations for future work are made that would reduce the uncertainty in future assessments of Spanish mackerel stocks.

Acknowledgments

We would like to acknowledge the contributions that enabled the compilation of this report. Lew Williams, Jim Higgs and Clare Bullock (Queensland Fisheries Service) assisted in providing the CFISH catch and effort data, recreational catch data (RFISH and charter logbook) and Long Term Monitoring Program (LTMP) data. Julie Robins and the Reef CRC provided an electronic database containing the Queensland Fish Board data from 1936 to 1981. Dennis Reid of NSW Fisheries provided us with commercial and recreational catch figures for NSW. Rik Buckworth (NT Fisheries) and Carl Walters (University of British Columbia/MOTE) developed the age-structured model used here and Rik also reviewed the report and application of the model. His comments along the way have proved to be extremely useful. Andrew Tobin and Amos Mapleston (FRDC Project) kindly provided preliminary but helpful age data for 2001. Clare Bullock, Sue Helmke and Darren Rose of the LTMP also kindly provided preliminary but helpful age data for 2001. Michael O'Neill (DPI, Southern Fisheries Centre) also assisted in the application of the model and was particularly helpful with the yield-per-recruit analyses. Feedback and comments from participants at an east coast Spanish mackerel workshop held in Townsville on Monday July 15, 2002, were also very helpful and greatly appreciated.

CONTENTS

1. Introduction

The narrow-barred Spanish mackerel, *Scomberomorus commerson*, is widespread throughout tropical and sub-tropical areas of the Indo-Pacific. In Australia the species range extends throughout continental shelf waters to approximately 30°S on both the east and west coasts (McPherson, 1981; McPherson, 1992). They are a highly mobile pelagic fish commonly associated with reef edges and headlands. Commercial catches are reported from Western Australia, Northern Territory, Torres Strait, Queensland and New South Wales. Within Queensland waters catch is reported from the Gulf of Carpentaria (GOC) and the east coast, of which the east coast comprises approximately 80% of the total combined catch. Catch is also reported from the Torres Strait, which is managed as a Commonwealth fishery.

Preliminary stock structure research has indicated that Spanish mackerel in Queensland waters are made up of at least three genetic stocks. Fish of the GOC appear to be distinct from those in the Torres Strait, while fish on the east coast of Queensland and NSW are part of an east coast stock (Shaklee *et al*, 1990; Jenny Ovenden personal communication). There is uncertainty about further subdivision within the East Coast stock, though tagging data suggest that migration occurs over considerable distances (McPherson, 1992). At a Spanish mackerel stock assessment workshop conducted by Dr Carl Walters (University of British Columbia, Canada) in Darwin in 1997, the Queensland east coast stocks were considered to be heavily exploited. While the data used were sparse, conclusions were that spawning stock levels were low. These concerns about the Queensland east coast resource persist.

2. Biology and Ecology

Growth of juvenile Spanish mackerel is typically rapid, reaching approximately 65cm fork length (FL) in the first year. They reach the current minimum legal size early in their second year of growth and attain approximately 80 cm FL by 2 years of age. Differential growth between sexes occurs with the females showing faster growth and higher longevity (McPherson, 1992). Sexual maturity for males and females occurs around 2 years of age from about 79 cm FL (McPherson, 1993).

Spanish mackerel are known to aggregate in large numbers to spawn. During the 1970’s aggregations of spawning fish on the east coast were reported to occur between Lizard Island and Townsville. In recent years the only aggregation of spawning fish has occurred over a much smaller area on several reefs east of Ingham, north of Townsville. Fish gather on these reefs in large numbers during October and November each year. Spawning is determined by a combination of environmental factors, but can be observed over much of the two month period. Females in pre-spawning condition are common in troll catches during the morning hours of the day of spawning. Spawning appears to take place during late afternoon and early evening during which time the fish cease feeding. Feeding behaviour resumes immediately after spawning (McPherson, 1981; McPherson, 1993).

An unknown proportion of fish older than two years of age undertake post-spawning migrations into southern Queensland and northern NSW waters (McPherson, 1981). Smaller fish remain in Great Barrier Reef waters. Migratory fish return northwards near to the coast and inshore islands where small localised fisheries have developed for these larger fish. . Patterns in water temperature and baitfish distribution are likely to affect adult distributions throughout the year. Water temperature may also influence spawning behaviour and juvenile recruitment. Juveniles are highly dependent on estuaries and foreshores as nursery and feeding areas (McPherson, 1981).

3. Fishery

The recovery rate used by QFS to convert fillet weight recorded in logbooks to fish whole weight, was changed during 2001 from 2 to 1.25. The commercial catch data used in this assessment come from the CFISH database and were derived using the newer, more realistic recovery rate. All catches recorded as Spanish mackerel were included. Total estimated commercial catch from the Queensland east coast fishery for 2001 was 525 tonne. Estimates for the Queensland east coast recreational fishery are 17 tonne from the charter boat sector (charter boat logs) and 315 tonne from the private boat sector (RFISH data). The indigenous catch is unknown. The method of capture is line fishing by trolling or drifting baits.

3.1 Management

The management restrictions enforced for the east coast Spanish mackerel fishery are:

- Minimum size limit of 75 cm TL (approx. 68 cm FL and 2.2 kg total weight)
- Maximum of three troll lines and six hooks per commercial boat
- Recreational bag limit of 10 fish in possession
- Ban on target gill netting east of Cape York
- Trolling restrictions around some zoned reefs in the Great Barrier Reef
- Closures around areas with high reported incidence of ciguatera

3.2 Commercial fishing

The east coast fishery operates as a line fishery throughout Queensland waters from the NSW border to the Torres Strait Protected Zone. Line fisheries exist within NSW and the Torres Strait Commonwealth fishery managed waters. Boats that catch Spanish mackerel on the east coast usually have multiple licence endorsements and so not all boats target Spanish mackerel all year.

Total commercial catch for the Queensland east coast from 1988 to 2001 has ranged from between 326t and 651t. The number of boats reporting Spanish mackerel catch in 2001 was 534. The main production area on the east coast of Queensland is the single degree latitude band between Tully, and midway between Townsville and Ingham (18°S - 19°S). An average 35% of the commercial catch has come from reefs within this band between 1988 and 2001. Commercial landings from NSW between 1984 and 1998 was highly variable with a minimum of 8t (1994) and a maximum of 51t (1988). The average for 1993-98 was approximately 14t (Dennis Reid, NSW Fisheries).

Most of the commercial catch of Spanish mackerel is sold within Queensland, with the dominant product form being frozen fillets in the northern part of the state and cutlets being sold mainly in southern Queensland. Recently a new fishery has developed in southern Queensland based on whole fish packaged individually on ice and exported. The price of Spanish mackerel in 2001 ranged from $8 to $10 per kg, although new overseas markets are beginning to offer higher prices. The main competition for Queensland product comes from Northern Territory Spanish mackerel and from Queensland shark. There is some buyer resistance to gill net caught fish (GOC only) when line caught fish is available. The annual GVP for the fishery has ranged between $3m to $7m, with recent years (1997-2001) being between $5m and $7m (Williams, 2002).

3.3 Recreational fishing

A significant private and charter vessel fishery that targets Spanish mackerel operates on the east coast of Queensland. Predominantly the fishing methods employed are trolling or drifting baits. Historical information on catch and effort for the recreational fishery is very limited. Since 1996 bi-annual recreational catch and effort data has been collected using surveys and a voluntary logbook system. Charter boat fishery logbooks have been voluntary since 1993 and compulsory since 1996. Catch estimates for the QLD charter vessel sector between 1996 and 2000 ranged from 12.3 – 19.7 tonnes, and estimates for the QLD private vessel sector for 1997 and 1999 were 365 and 390 tonnes respectively. Estimates of NSW recreational catch from 1993-1995 were between 4.8t and 6.7t (Steffe et al, 1996).

3.4 Research and monitoring

- A collaborative FRDC funded study by northern Australian fisheries organisations (NT, QLD, WA, and The University of Queensland) to determine the stock identity of Spanish mackerel throughout northern Australia.
- QDPI Long Term Monitoring Program in the Gulf, Torres Strait and Qld east coast.
- Reef CRC study aiming to document the characteristics of catch and effort of the different sectors of the east coast Spanish mackerel fishery.
- FRDC funded study investigating priorities for future research into mackerel fisheries (SARDI).

4. Fishery assessment

4.1 Historical Catch and Effort

Since the introduction of compulsory logbooks in 1988, catch and effort reported from the east coast commercial fishery have been variable (Figure 1). There has been no consistent trend in CPUE, with a 50% increase from 1996 to 1999, followed by a reduction to 1996 levels in the last two years (Figure 1). CPUE should interpreted cautiously, as CFISH records effort in terms of the total fishing operation and not the individual fishing units (dories).

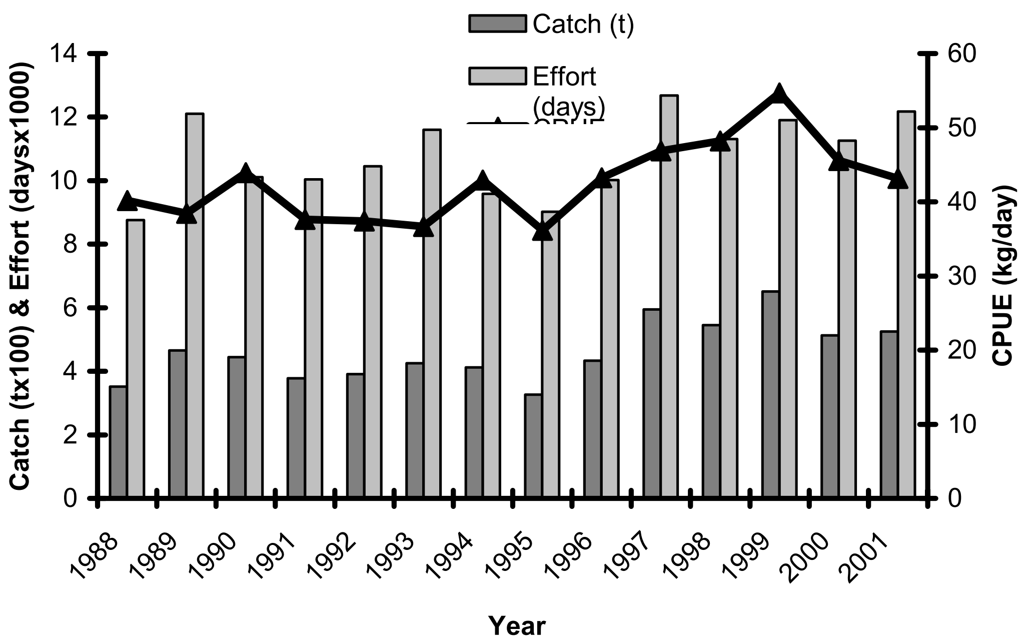

Figure 1. Catch, effort and CPUE for the east coast commercial fishery from 1988 to 2001.

4.2 Targeting of spawning stock

The east coast stock of Spanish mackerel is most heavily targeted during October/November over a relatively small area of reefs off Ingham. This corresponds to the period when the fish aggregate to spawn. Immediately after the spawning period fish disperse from the grounds, with a proportion of the spawning stock (predominantly larger, older fish) making a southerly migration during summer/autumn months as far south as the northern NSW north coast. These fish return north during the winter months and are thought to pass by the inshore headlands and islands between Townsville and Cardwell during August/September before moving offshore to adjacent reefs for spawning. The behaviour of targeting of spawning aggregations by the fishing fleet is demonstrated by comparing average monthly catch and effort data from the area where aggregating is known (Figure 2a), with a broader area between Cairns and Bowen that excludes the aggregation area (Figure 2b).

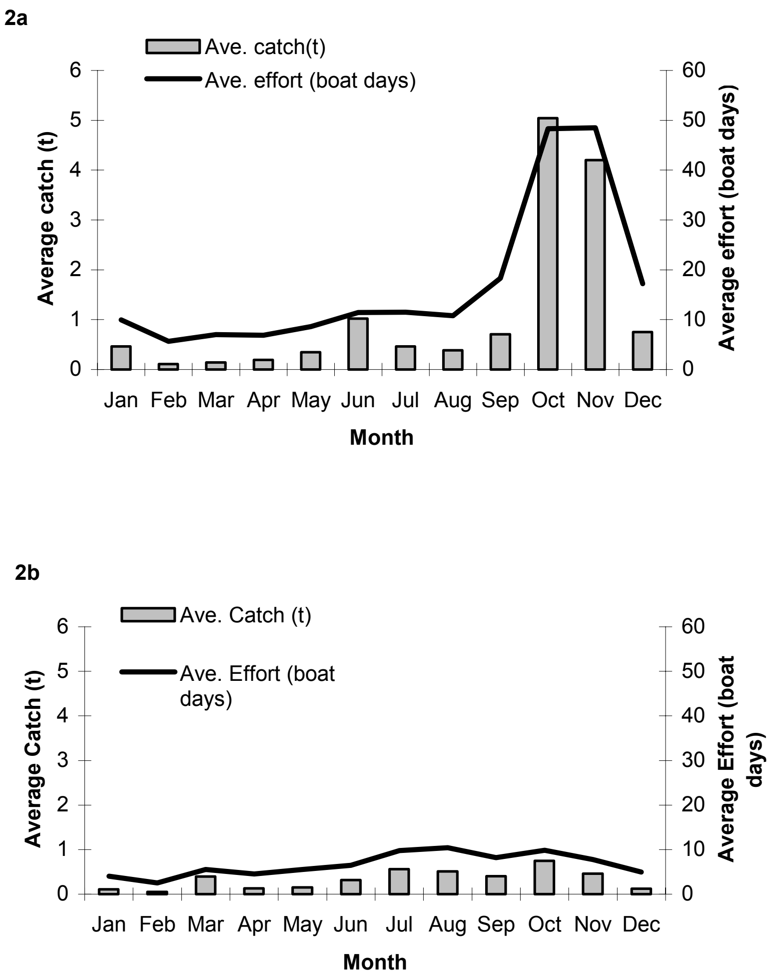

Figure 2. **a.** Average monthly commercial catch and effort between 1988 and 2001 for the area where Spanish mackerel are known to aggregate to spawn on the east coast. **b.** Average monthly commercial catch and effort between 1988 and 2001 from Cairns to Bowen, excluding the spawning area.

The nature of the fishery is that a relatively large proportion of the catch is taken from a particular area and during a time when Spanish mackerel are known to aggregate for spawning. This pattern of fishing is not uncommon in tuna fisheries. Targeting aggregations increases the efficiency of the fleet, but can result in declining stock size without any apparent change in CPUE. This is a potentially dangerous scenario for a fishery and is known as hyperstability. Other factors contributing to hyperstability include the recording of commercial effort in logbooks only when some fish are caught, and information-sharing and non-random search behaviour of fishers. Further, CPUE is unstandardised and technological advances such as the introduction of differential GPS have probably increased the fishing efficiency of the fleet in the last 10 years. Such advances could also have increased the efficiency of the recreational sector.

5. Stock assessment modelling

5.1 Yield per Recruit

Yield per recruit (YPR) analyses are used to estimate levels of fishing effort that maximise the yield from a fishery. In conjunction with reproductive characteristics they are also useful for assessing minimum legal sizes (Hilborn and Walters, 1992). The current minimum legal size (MLS) of Spanish mackerel was established by REEFMAC in 1991. The 75cm TL was introduced to offer juvenile fish protection from targeting in nearshore waters. At the time it was considered that post-release mortality would be a significant factor for fish between the 75cm TL MLS and a larger size that approximated the optimum biological MLS. We used a YPR model to assess the current minimum legal size of 75cm for Spanish mackerel, with other sizes. Spanish mackerel exhibit differential growth between sexes (McPherson, 1992). For the yield-per-recruit analysis we used growth parameters that represented both sexes combined. The inputs to the model are given in Table 1. The results of the analysis are shown in Figure 3 using a yield isopleth diagram.

Parameter	Sexes combined
Linf (asymptotic length)	141.25
K (growth rate)	0.21
t0 (theoretical length at age 0)	-1.97
a (parameter of length wt relationship)	0.00001155
b (parameter of length wt relationship)	2.92
Natural mortality (M)	0.34
Length at maturity (FL)	79
Minimum legal size (FL)	68
Standard deviation on LS	5

Table 1. Parameters used as inputs to the yield per recruit model. Data was sourced from McPherson (1992), O'Neill and McPherson (2000). Parameter estimates for sexes combined were calculated at a 1997 stock assessment workshop in Darwin by Rik Buckworth, Dr Carl Walters, Dr Malcolm Haddon and Geoff McPherson.

The maximum yield is achieved at a length of about 77cm TL but at a high fishing mortality rate of approximately 0.8 (Figure 3). At F=0.17, the estimated current F, the optimal MLS is less than 70cm (Figure 4). The most recent estimate of size at maturity for Spanish mackerel is about 88.5cm TL (79cm FL) (McPherson, 1993). The major rationale behind setting a minimum legal size, apart from optimising yield, is to maintain spawning biomass by ensuring that females of the population are not vulnerable to the fishery for at least one spawning season (Hilborn and Walters, 1992). The current minimum legal size of 75cm TL (68cm FL) does not ensure this. The optimum biological minimum legal size should take into account both optimum yield and size at maturity. Figure 4 suggests that, although an increase in MLS results in a loss in yield per recruit, this loss is small relative to the increased benefits likely to be derived if the increase ensures protection of the spawning biomass. The results of YPR analyses and current estimates of size at maturity suggests that the current legal minimum size of 75cm TL for Spanish mackerel should be re-evaluated.

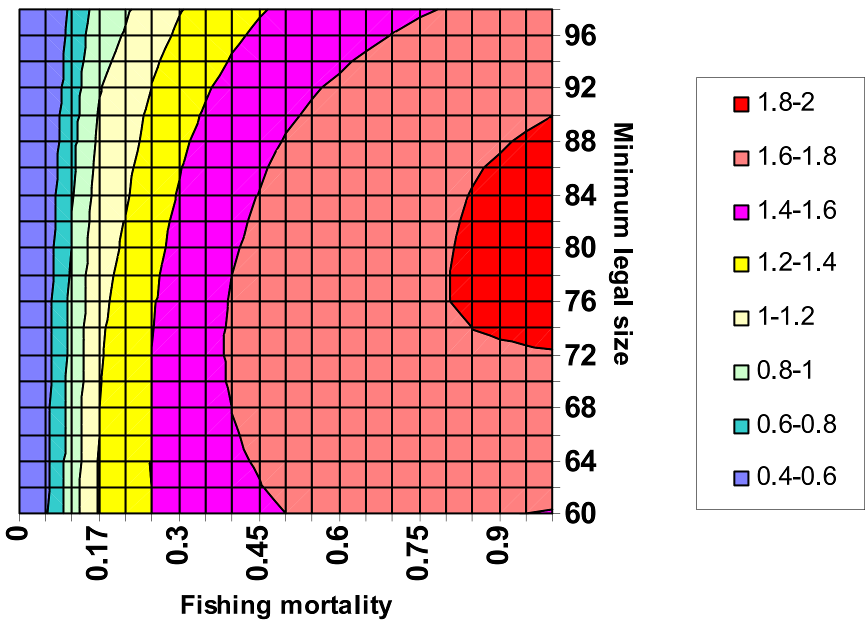

Figure 3. Yield per recruit plotted over a range of fish length (TL) and fishing mortality (F) for sexes combined. Different colours show the values of yield per recruit (grams) as indicated by the legend.

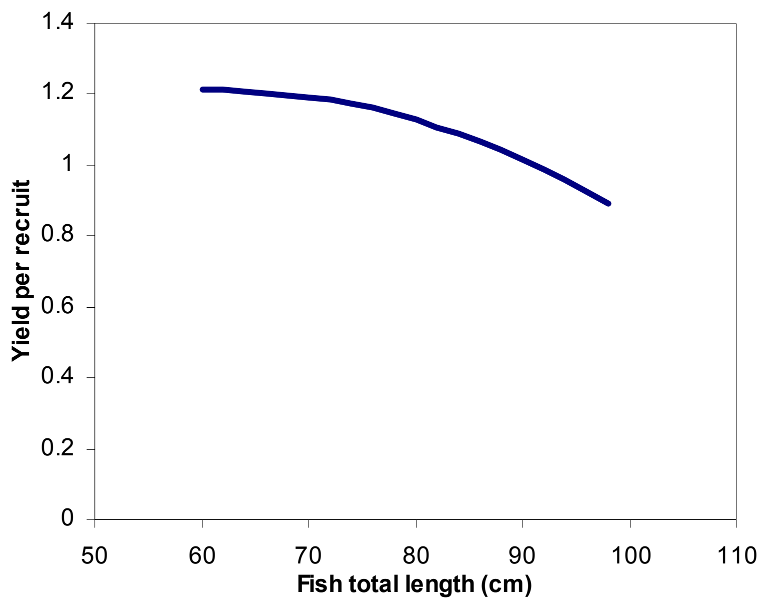

Figure 4. Yield per recruit (grams) plotted over a range of fish length (TL) for sexes combined at the estimated current F of 0.17.

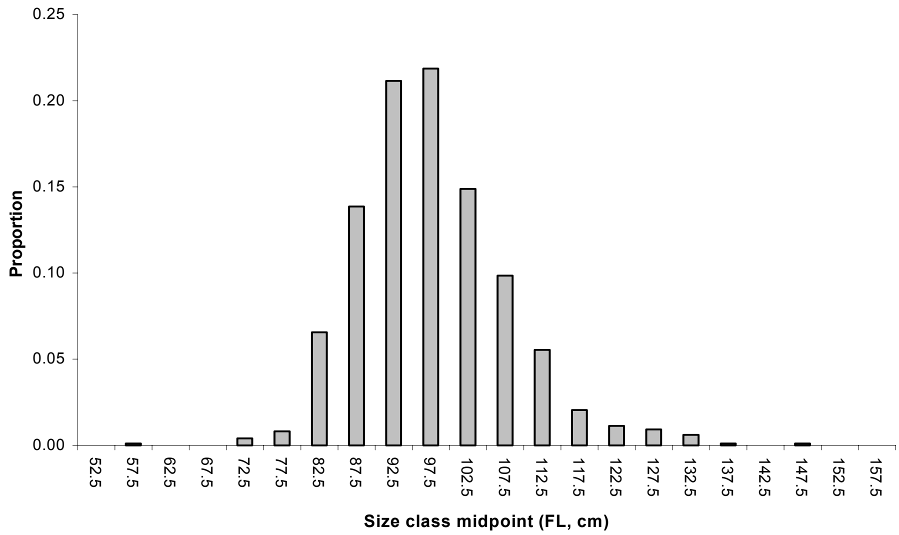

Figure 5. Size frequency sampled from the Queensland east coast commercial catch for 2000 and 2001 combined. (Source: DPI Long Term Monitoring Program).

A concern within the fishery that may impact upon the consideration of minimum size is that the post-release survivorship of mackerel above the legal minimum size is considered to be very low (McPherson, pers. com.). However the nature of the commercial fishery and the fishing gear are that larger fish are targeted. Figure 5 shows the size frequency of a sample taken from the commercial catch.

The mean size of fish taken was 97.2cm FL (111.9cm TL) and fish less than 90cm FL (102.6cm TL) comprised only 22% of the sample. Commercial fishers are known to move away from concentrations of small fish. This would suggest that post-release mortality of under-size fish is not a major impact within the commercial fishery due the low numbers of small fish released. The RFISH program estimates that approximately 18% of fish released by recreational fishers are due to being under the minimum legal size. Also, other recent size frequency data suggests that the Queensland recreational sector catch a much larger proportion of smaller fish compared to the commercial sector (A. Tobin, unpublished data, FRDC Project 2001/019). Therefore, the relative impacts of any change in the MLS on the recreational and commercial fishery sectors would need to be assessed. Post-release mortality, however, could significantly affect the whole stock, as large numbers of 'legal' fish are released as 'surplus' to the fisher's desired catch in the recreational sector (Jim Higgs, pers. com.).

Given the high mortality rate of released mackerel, and the dangers associated with releasing large active fish, there may be little benefit in increasing the minimum legal size. However, the results of YPR analyses and current estimates of size at maturity suggest that the current legal minimum size should be re-evaluated when better information on recreational catch size distributions and release mortality rates become available.

5.2 Age-structured model

A dynamic age-structured model developed by Mr Rik Buckworth (NT Fisheries) and Dr Carl Walters was applied to the east coast Spanish mackerel fishery. The model uses catch-at-age data and although it does not require age data for all years, it performs much better the more age data is used. Outputs from the model are estimates of the age structure of the fishery, and trends in past and future stock sizes as a function of fishing mortality (F). The model assumed equal rates of exploitation on all age classes. This model has been used in recent years in assessments of northern Australian Spanish mackerel stocks, and was adapted for east coast Spanish mackerel data at a stock assessment workshop held in Darwin in August, 2000 (see

O'Neill and McPherson, 2000). The model has been further adapted here following a workshop with REEFMAC members held in July in Townsville.

5.2.1 Model input parameters

Data were combined for both sexes to calculate the von Bertalanffy growth parameters and length-weight parameters using data from the stock assessment workshop held in Darwin in 1997, and from G McPherson (unpublished data). These were the parameters used by O'Neill and McPherson (2000). The parameters used in the model are given in Table 2.

Parameter	Estimate
Maximum weight	22.3 kg
Linf (asymptotic length)	141.25 cm
K (growth rate)	0.2
a (length-wt relationship parameter)	0.000013
b (length-wt relationship parameter)	2.9
M (natural mortality)	0.34
Age at 50% maturity	2 years
Age at full recruitment	2 years
Fecundity	76539 eggs/kg
Beverton-Holt-a	0.00000327
Beverton-Holt-b	5.333×10^{-9}
r_{max} (max reproductive rate at low pop size)	5.00

Table 2. Input parameters for the age-structured model. Data was sourced from McPherson (1992), McPherson (1993), and O'Neill and McPherson (2000). The M estimated using Hoenig's estimator (Hoenig, 1983) by O'Neill and McPherson (2000) was retained. Stock-recruitment parameter estimates Beverton and Holt a and b are redundant parameters fully constrained by rmax, which was based on estimates from similar species as described in the meta-analysis of Myers et al. 1999.

5.2.1.1 Data sources and assumptions

5.2.1.1.1 Catch data

The most reliable long-term source of catch data has been the Queensland commercial catch, recorded in compulsory logbooks since 1988 and entered into the CFISH database. Estimates of recreational catch for any species on the Queensland east coast have been very limited until the recent RFISH program. Using logbooks and telephone surveys, RFISH has estimated recreational catch of Spanish mackerel for the years 1997 and 1999. Queensland Fish Board data were recorded for the period 1936-1981 for financial years. CFISH data were therefore adjusted to financial years. This corresponded well with the assumed biological year classes for east coast Spanish mackerel as annual otolith checks are believed to become visible in approximately August. This also allowed the fitting of the model through extra years of age data, further improving the reliability in the model. The total catch data used in the model are given in Figure 6 below.

Queensland commercial catch

- The Reef CRC collated all catch data from 1936 to 1981 from the Queensland Fish Board records. In the model we included records from 1950, as these included all the years of greatest catch and the catch prior to 1950 was relatively low, and would have little effect on the results. These data are assumed to represent the commercial and part of the recreational catch. It is also assumed that recreational fishers kept a portion of their total catch. These records are in fact likely to underestimate total catch.
- Catch data for the years 1988 – 2001 were extracted from the CFISH database by Lew Williams (QFS, Condition and Trend).
- No catch records exist for the years 1982 – 1987. Also, catch records for the first two years of compulsory logbooks (1988-89) are reported to be inaccurate (Mark Elmer, QFS,

Resource manager). These records were therefore omitted. Commercial catch for the period 1982 – 1989 was assumed to be stable and taken as the average of catch from the 5 years either side of that period.

Queensland recreational catch

- Jim Higgs (QFS) provided charter boat catch records from the compulsory QLD charter boat logbook for 1996 – 2000, which has been compulsory since 1996. 2001 was incomplete and so was given the average catch of the previous five years.
- Estimates of private sector recreational catch were derived using total catch estimates for 1997 and 1999 from the RFISH program, and were provided by Jim Higgs (QFS). These estimates contain considerable uncertainty, although reliable confidence intervals are not provided. We assumed that recreational catch was constant relative to commercial catch (ie. recreational catch = 0.6 * commercial catch, based on RFISH estimates) for the years 1996 – 2001 inclusive. The proportion of the catch taken by recreational fishers was also assumed to decrease back through the entire time series at 4% per annum – an arbitrarily selected value.

NSW catch

- Dennis Reid (NSW Fisheries) provided NSW commercial catch data from 1984 to 1998 (Table 3). An average of the last five years of the data was used to estimate catch for 1999 - 2001. Catch prior to 1984 was assumed to change in proportion to the QLD commercial catch, since no information was available. Estimates of recreational catch for two years between 1993 and 1995 were obtained from Steffe *et al* (1996) (4.8t – 6.7t), and are reported to be increasing (Dennis Reid, NSW, pers com.). NSW recreational catch was assumed to be constant at 5t for the period 1996 – 2001. Prior to 1996 NSW recreational catch was assumed to decrease back through the entire time series at 4% per annum.

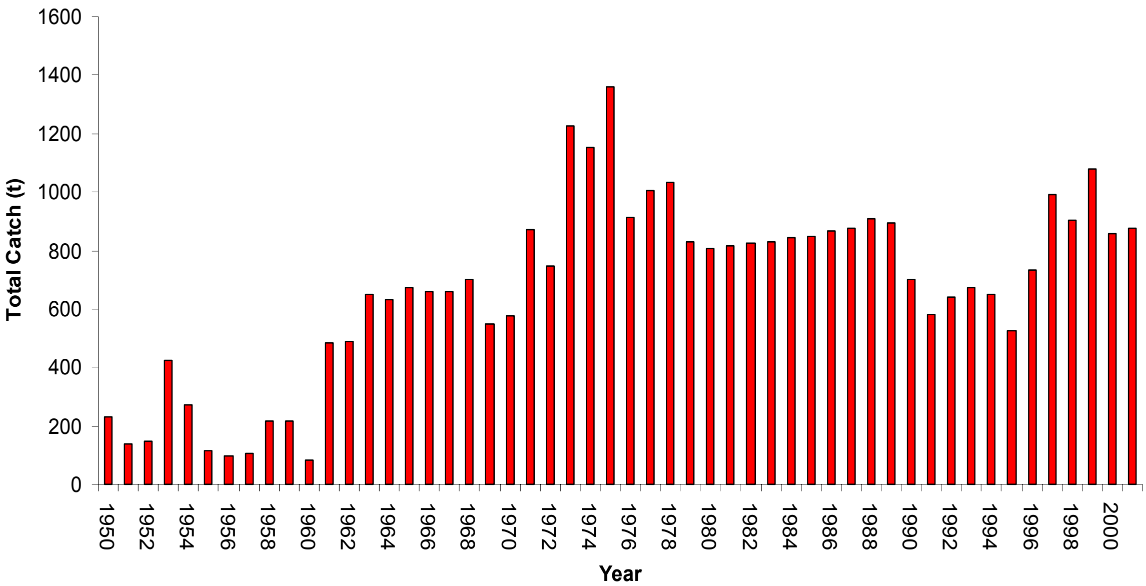

Figure 6. Total catch (tonnes) by all sectors in the east coast Spanish mackerel fishery for input to the model.

Year	Catch (t)
1984	29
1985	21
1986	31
1987	33
1988	51
1989	28

1990	45
1991	15
1992	48
1993	17
1994	8
1995	9
1996	23
1997	14
1998	14

Table 3. Catch estimates (tonnes) for the NSW commercial fishery from 1984 – 98. (Source: Dennis Reid, NSW Fisheries).

5.2.1.1.2 Age data

The model was fitted through three years of age structure data. The first two years, 1977/78 and 1978/79, were collected by Geoff McPherson. The final year of age data, 2001/02, was supplied by Andrew Tobin (FRDC Project 2001/019) and the QFS Long Term Monitoring Program (LTMP). The FRDC 2001/02 age data were collected from both the commercial and recreational sectors of the fishery and from northern and southern regions. The LTMP data were collected from the commercial sector and from spawning grounds during the spawning season. Age data from FRDC and the LTMP were still preliminary at the time of writing. Readings from all years may be biased low in the older age classes, since they are based on whole otolith readings. Readings of sections currently under way by both the LTMP and Reef CRC will either validate the whole ages or allow correction for bias.

The 1977/78 age data show high numbers of 1-3 year old fish with a mode at 1 year olds resulting in a negatively sloping curve (Figure 7). It is unlikely that 1 year olds are fully recruited to the fishery and the mode in this year class may represent a strong pulse in recruitment. The age data from 1978/79 are consistent with this theory with a very strong mode in 2 year old fish (Figure 8). Similarly, there appears to be a smaller pulse of 3 year old fish in 1977/78, becoming 4 years old in 1978/79. Examining spatial subgroups within the data shows a similar trend in different groups of data. Notably there are fewer old fish in the 1978/79 sample with no fish older than 7 years. The differences between the consecutive years of age data are striking and may be partly an artefact of the sampling regimes between years.

The 1977–1979 and 2001 datasets show quite different selectivity, with full recruitment apparently occurring at age 3 in 2001 compared with 1 and 2 in 1977/79. However, this difference may partly be explained by a strong 3 year old year class in 2001. It may also be a result of differences in the sampling regimes, and their spatial scale (given that there may be subdivision in the stock). This question will only be answered by obtaining data from several more years, as the LTMP and FRDC project are now doing.

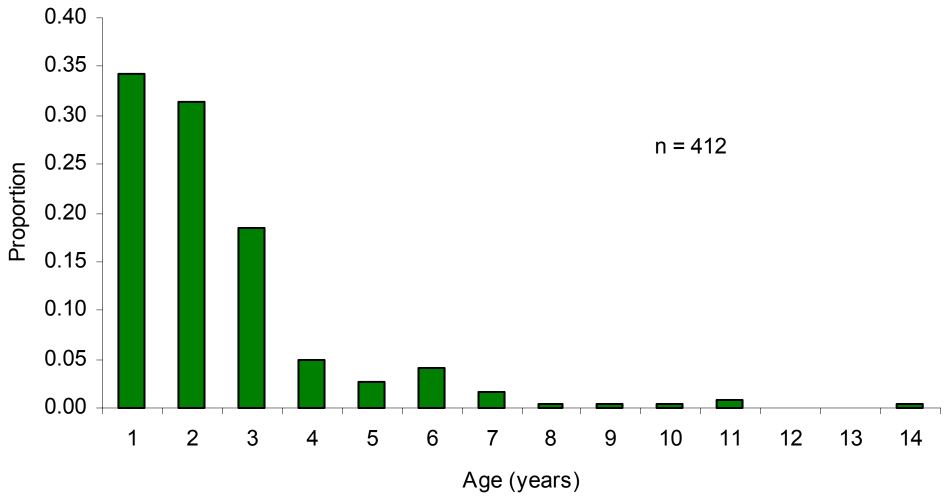

Figure 7. Input age structure data from 1977/78. (Data source: G. McPherson)

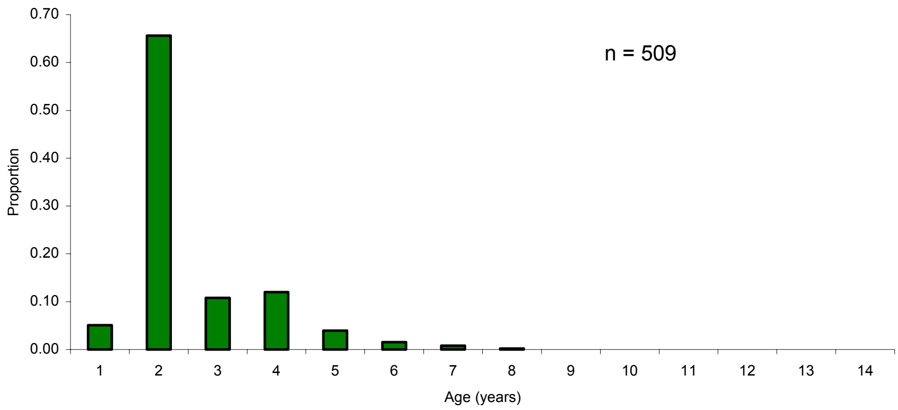

Figure 8. Input age structure data from 1978/79. (Data source: G. McPherson)

The age structure data from 2001/02 show a good spread of age classes with reasonable numbers in most ages and a mode at 3 years (Figure 9). The sampling regime for this year included sample collection over most of the year and from a wider geographical range than in previous years. Also relative selectivities across ages may have altered through time. Despite these potential factors affecting the age data between years, the 2001/02 age data does not indicate overfishing due to the presence of and gradual decline in numbers of older fish.

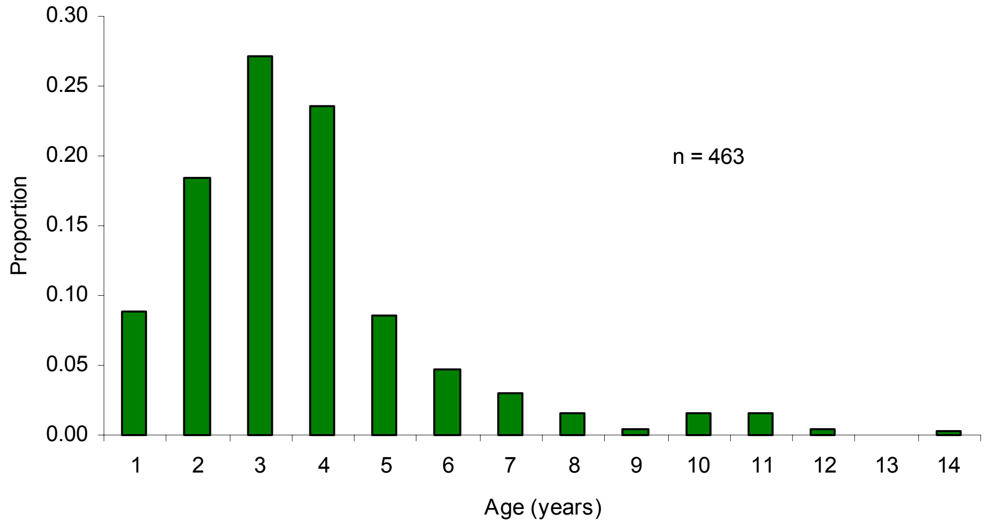

Figure 9. Input age structure data from 2001/02. (Data sources: QFS LTMP; Tobin, FRDC Project 2001/019).

5.2.2 Model estimates

The stock assessment model suggested that the exploitable biomass had declined substantially since fishing began but has been relatively stable for the last 20 years (Figure 10). The model estimates current exploitable stock at 44% of the unfished stock size, and current F imposed on the fishery of 0.17. The level of F recently proposed by the U.S. National Marine Fisheries Service as sustainable for pelagic fish stocks such as Spanish mackerel is equal to 0.5*M, where M = natural mortality (Rik Buckworth, pers. comm.). This target reference point was adopted for Northern Territory Spanish mackerel at the stock assessment workshop held in Darwin in 2000. Applying this reference point for F to the east coast Spanish mackerel stock, the model does not suggest that the fishery is currently being fished at unsustainable levels.

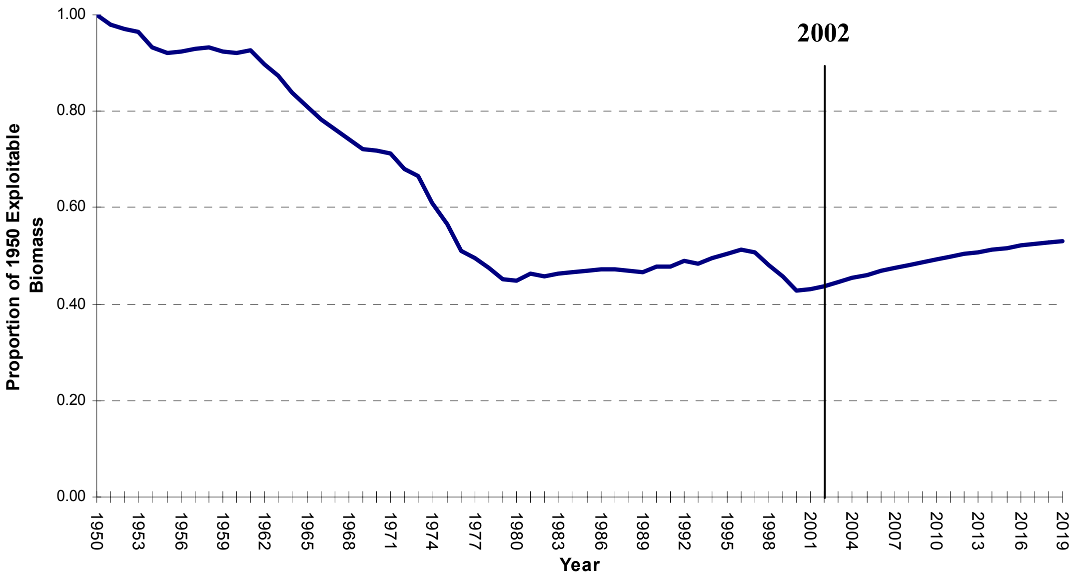

Figure 10. Trend in the exploitable biomass expressed as a proportion of unfished levels. The model estimates that the current biomass is 44% of the unfished biomass and F is at an assumed sustainable reference point for the fishery.

5.2.3 Model sensitivity

The base model presented above is predicated on the best available parameter estimates for Spanish mackerel and the best available data from the fishery. Nevertheless there is a high degree of uncertainty in the parameter estimates and in some data assumptions. To test the sensitivity of the model to these uncertainties we investigated the effect on the outputs of the base model of plausible changes in parameter estimates. We tested only one parameter at a time and ignored interaction effects of the various parameters on the model. This would require more complex and time-consuming analyses. We tested the sensitivity of F and 'current biomass as a proportion of unfished' to natural mortality (M), the stock-recruitment (S-R) relationship, growth, initial biomass estimate (B_0), catch data assumptions and age data.

5.2.3.1 Natural mortality uncertainty

Estimates of natural mortality are notoriously unreliable, particularly for fished stocks (Hilborn and Walters, 1992). The point estimate of 0.34 for M was derived using an approximation method that is a function of the longevity of the species (Hoenig, 1983) at the 2000 Darwin workshop, based on a maximum observed age of 13. Subsequent ageing has found several 14 year old fish, suggesting M of 0.31, yet Pauly's method (Pauly 1980) based on growth rate and water temperature gives an estimate of 0.40. To estimate a plausible range of M we obtained estimates for similar mackerel species from the literature (Table 3).

Species	Est.	Location	Author	Method
S. cavalla	0.4	Gulf of Mexico	(Arreguin-Sanchez *et al.* 1995)	?
S. commerson	0.13	Kenya	(Nzioka 1991)	?
S. commerson	0.36	Arabian Gulf	(Kedidi *et al.* 1994)	?
S. commerson	0.5	South Africa	(Govender 1995)	Catch curve & Pauly
S. commerson	0.35	Oman	(Al-Hosni and Siddeek 1999)	"life history parameters"
S. commerson	0.64	Oman	(Al-Hosni and Siddeek 1999)	"life history parameters"
S. commerson	0.77	Oman	(Al-Hosni and Siddeek 1999)	"life history parameters"
S. maculatus	~0.3	Gulf of Mexico	(Ehrhardt and Legault 1997)	Guess
S. niphonius	0.31	Eastern Set Inland Sea	(Nagai *et al.* 1996)	"life span" – Hoenig?
S. plurilieatus	0.27	Western Indian Ocean	(Chale-Matsau *et al.* 1999)	Pauly, length-based
S. plurilieatus	0.4	Western Indian Ocean	(Chale-Matsau *et al.* 1999)	Pauly, age-based

Table 3.

To test the sensitivity of the model to estimates of M we ran the model using upper and lower limits of +/- 30% of the point estimate (0.44 – 0.24). Note that the sustainable reference points for F become 0.22 and 0.12 respectively for the two scenarios presented.

The results indicate that the model is extremely sensitive to the estimate of natural mortality. A higher estimate of M implies a more productive stock, with the model estimating that the stock is currently at 61% of unfished biomass levels and that F is 0.12, well below the sustainable reference point of 0.22. At the lower estimate of M the model estimates that the stock is approaching dangerous levels at 22% of the unfished biomass and that F is nearly three times the reference point at 0.35 (Figure 11).

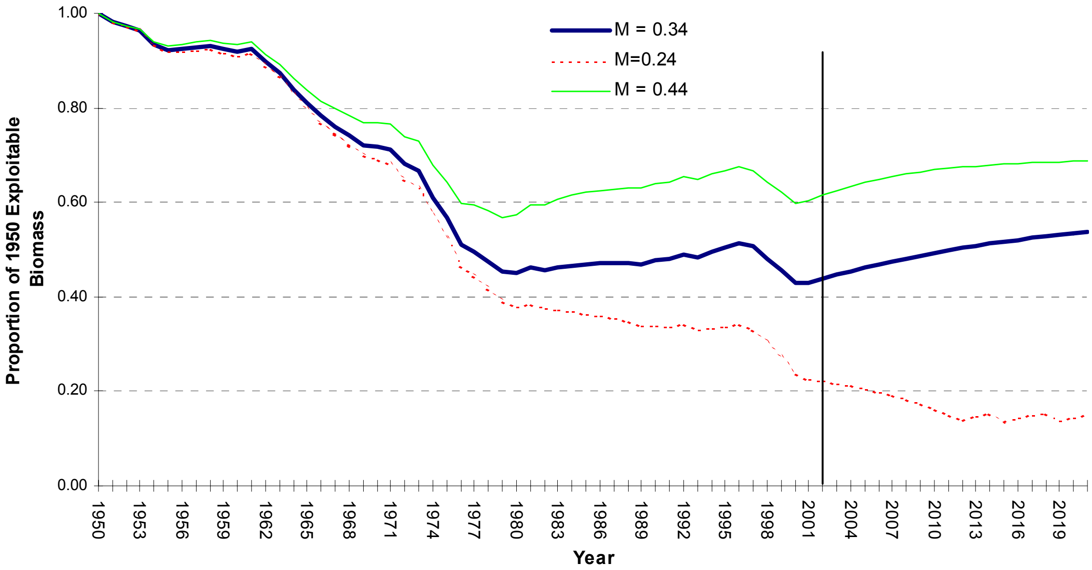

Figure 11. Sensitivity of the model to estimates of M using plausible upper and lower estimates as indicated. The bold line indicates the base model.

5.2.3.2 Stock-recruitment uncertainty

There is no information available with which to estimate the parameters that describe the S-R relationship for *S. commerson*. We used the Beverton-Holt model to describe the S-R relationship, with parameters, based on existing knowledge and assumptions for similar species, the same as those adopted at the stock assessment held in Darwin in 2000 (R. Buckworth, pers. comm.). To assess the sensitivity of the model to the S-R parameters we trialed a plausible upper and lower range of values for r_{max} of 7.0 and 3.0 respectively (base model r_{max} = 5.0). The parameter r_{max} is indicative of the productivity of the stock at low levels of biomass and effectively describes the S-R relationship.

The upper estimate of r_{max} used here resulted in little or no change in the estimates of current relative biomass or in estimated F. The lower estimate of r_{max} however, led to an estimate that the stock was at 33% of the unfished biomass, and that the current F was 0.22 (Figure 12).

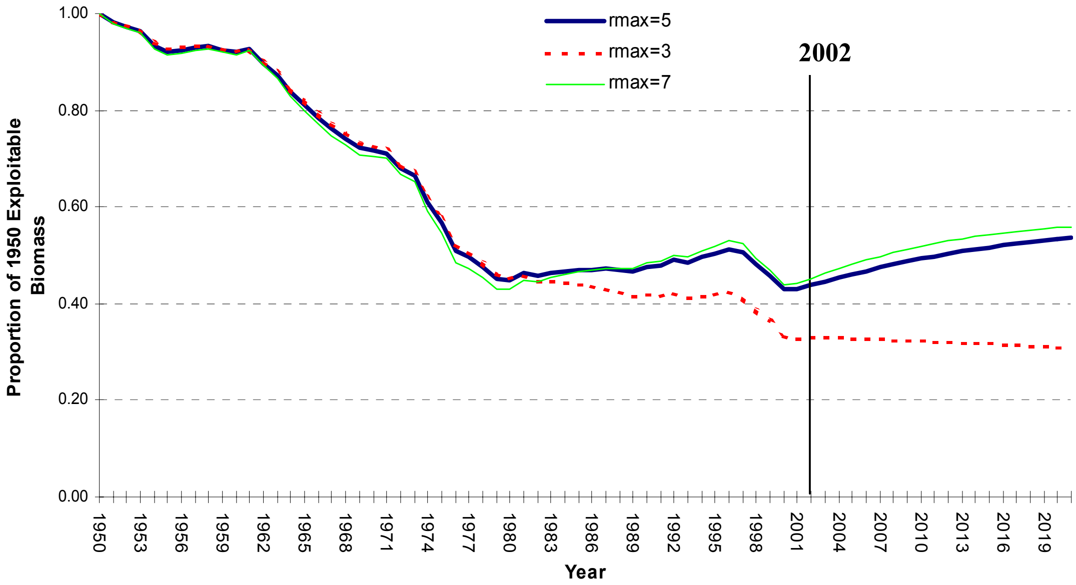

Figure 12. Sensitivity of the model to parameter estimates of the Beverton-Holt stock-recruitment relationship. This was assessed using plausible upper and lower estimates of the r_{max} parameter. The bold line indicates the base model.

5.2.3.3 Growth uncertainty

Growth parameters for east coast *S. commerson* have been estimated using the von Bertalanffy growth function by G. McPherson (1992)(see Table 2). Upper and lower ranges for the parameters L_{inf} and K were selected based on other estimates for the species (see www.fishbase.org). The range of estimates used for L_{inf} were 170.0 – 110.0cm FL and for K were 0.3 – 0.1. Although a strong relationship exists between the two parameters, we assessed the sensitivity of the model to each parameter in isolation.

The model was relatively insensitive to changes in the estimates of L_{inf} and the results presented are for the K parameter only. The higher estimate of 0.3 for K estimates only a slightly better scenario for the stock with the current exploitable biomass estimated to be 47% of unfished levels. The current estimated F was slightly higher than that estimated by the base model at 0.18 (Figure 13). The lower estimate of K had a more dramatic effect with the model estimating that the current biomass is 0.32 of unfished levels and that F is approximately 1.4X the sustainable reference point at 0.24 (Figure 13).

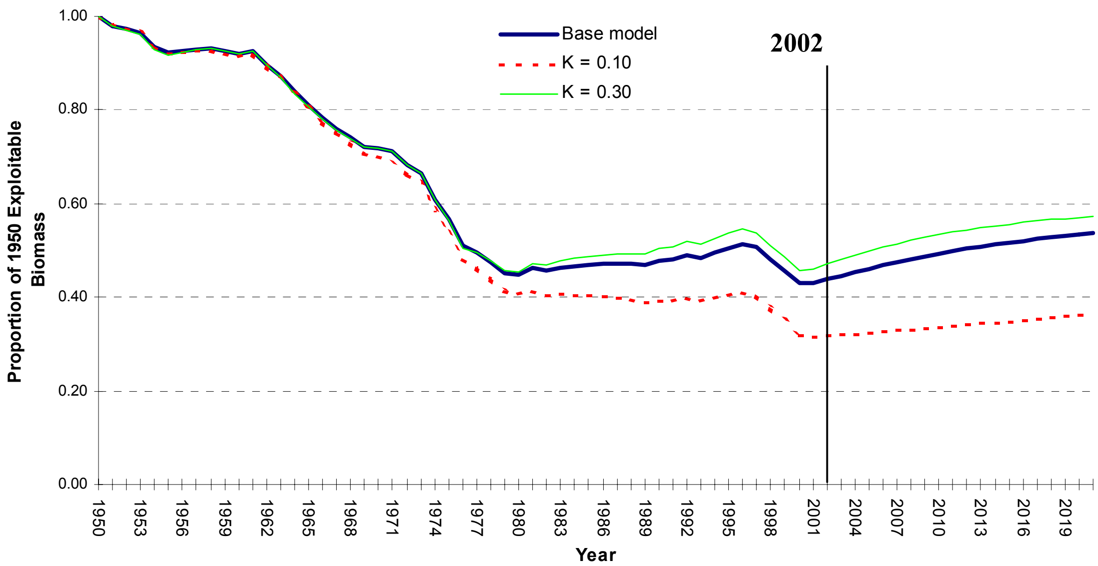

Figure 13. Sensitivity of the model to the von Bertalanffy growth parameter K.

5.2.3.4 Age data uncertainty

The assessment model requires age data that is representative of the fishery. This is difficult to assess for the earlier years of data from 1977/78 – 1978/79, but we know that the age data for 2000/01 was collected from different sectors of the fishery. Uncertainty about the selectivity of the fishery through time, and the representativeness of the data, are therefore sources of uncertainty in the results. The inclusion of age data both in the earlier years and at the end of the time series greatly improves the performance of the model. In the base model the full data sets from both the LTMP and FRDC collected age data for 2001/02 were included. To assess the sensitivity of the model to the age data we weighted the two data sets differently for the final year of the time series in the following way:

- the full FRDC data set and 0.5X the LTMP data set (ie. 0.5 x age class frequency),
- the full FRDC data set only,
- the full LTMP data set and 0.5X the FRDC data set, and
- the full LTMP data set only.

We also examined the relative influence of the 1970's data and 2001 data by removing each in turn.

The former two options investigated had very little effect on the model estimates of exploitable biomass and fishing mortality rate. The model was most sensitive to the latter two options that include the full LTMP data set and so only the results of these analyses are presented. Inclusion of the full LTMP data set and 0.5X the FRDC data set resulted in an estimated exploitable biomass 39% of the starting biomass and F estimated to be 0.20. Excluding the FRDC data set completely had the most impact on the model and resulted in exploitable biomass estimated to be 33% of unfished and F estimated to be 0.26 (1.53X the estimated sustainable F) (Figure 14).

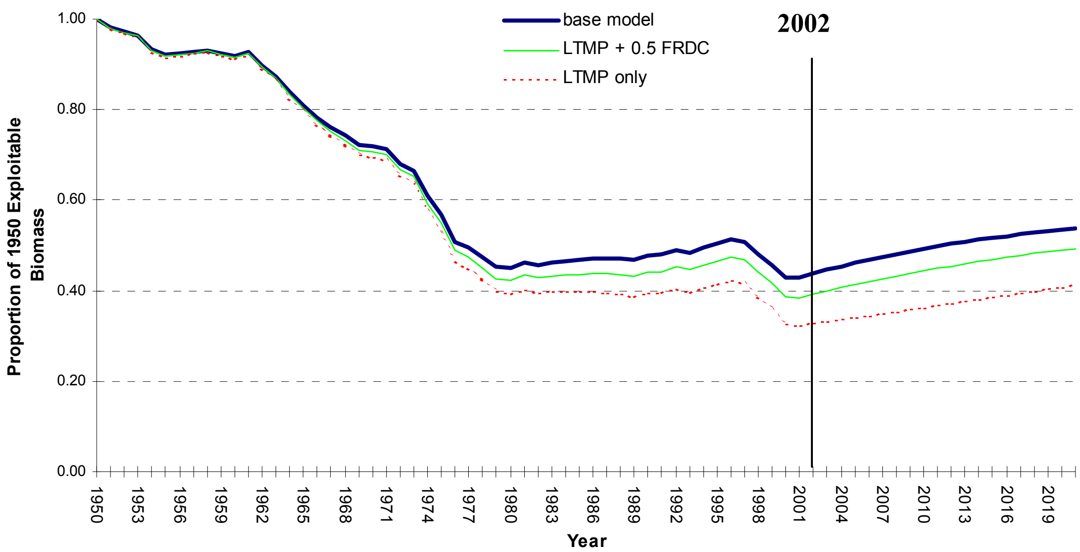

Figure 14. Sensitivity of the model to different weightings of the 2001/02 age data.

Excluding the 1970s data resulted in higher estimates of current biomass and lower estimates of current F. Excluding the 2001 data had the opposite effect, with the model estimating that the fishery should have collapsed in the early 1980's. This demonstrates that the 1970's age structure data is very influential, and exerts a downward influence on estimates of current biomass levels.

5.2.3.5 B_0 uncertainty

During the model fitting process the initial biomass for the time series, B_0, is estimated using maximum likelihood. This process provides relative probabilities for different values of B_0. The estimated starting exploitable biomass with the highest likelihood for the base model was approximately 10,300t with a relative probability of 0.51 (Figure 15). To assess the sensitivity of the model to other possible estimates of B_0 we used a lower starting biomass of 9,500t (rel. prob. = 0.08), and an upper starting biomass of 12,500t (rel. prob. = 0.17) (Figure 15).

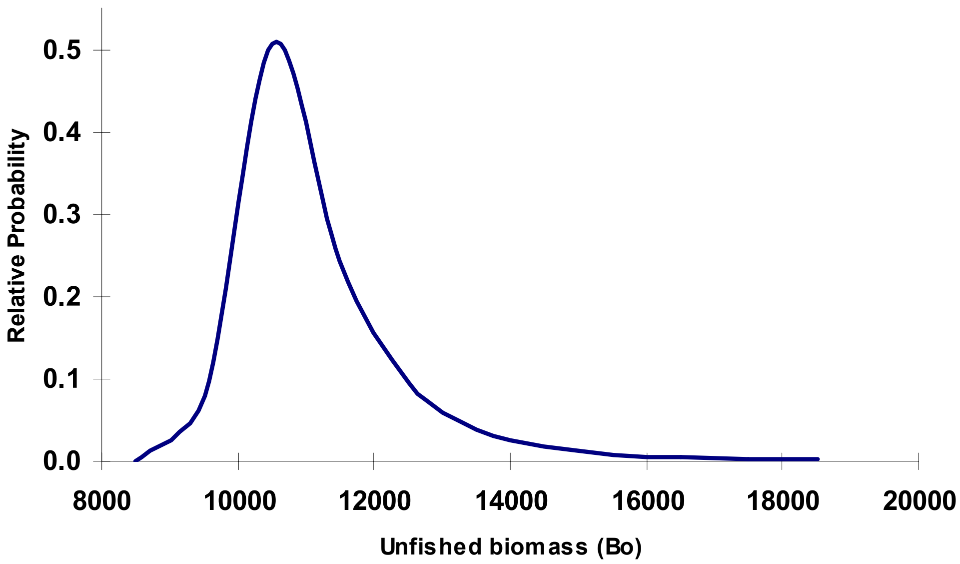

Figure 15. Relative probability curve for the initial unfished biomass (B_0) estimated by the model and based on the 1977/78, 1978/79 and 2001/02 age data. B_0 units of measurement are in tonnes.

The model was sensitive to the estimate of B_0 with the upper estimate of 12,500t resulting in a current exploitable biomass estimate of 58% of the unfished biomass and F estimated to be lower than the target reference point at 0.10. However, using the lower estimate of B_0 the model estimates that the current biomass is only 30% of the unfished biomass and F is estimated to be higher than the target reference point at 0.29 (1.7X the sustainable F) (Figure 16).

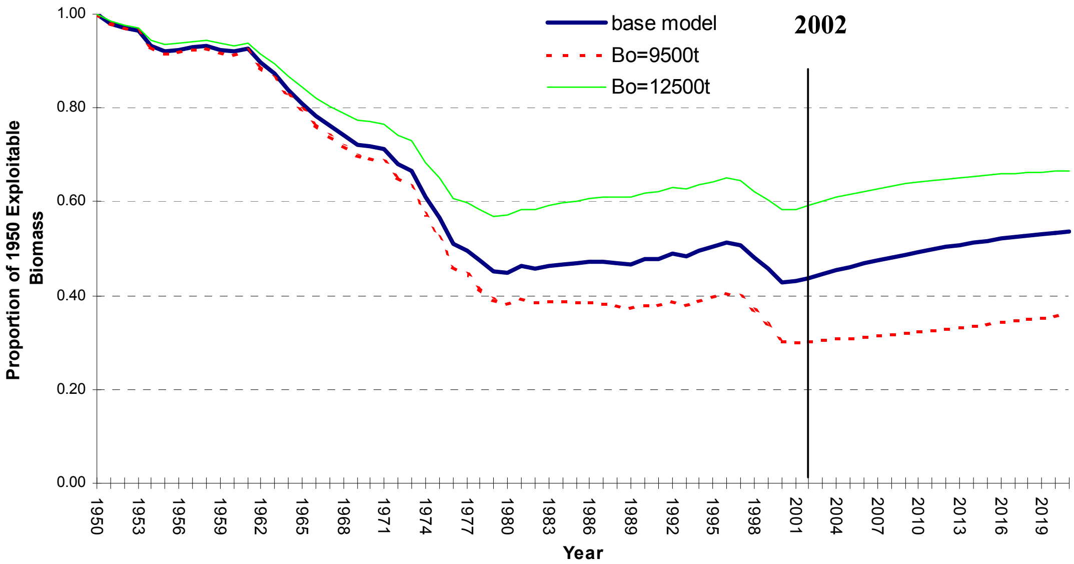

Figure 16. Sensitivity of the model to different estimates of the initial biomass, B_0.

5.2.3.6 Catch data uncertainty

Two major assumptions were necessarily made in the use of the catch data. The first was in the Queensland commercial catch where records were unavailable or known to be unreliable for the period 1982-88 and a constant average estimate was calculated. To assess the sensitivity of the model to this assumption we fitted the model using upper and lower estimates of catch for this period. These were 0.8X (-20%) the average used in the base model and 1.2X (+20%) the average used in the base model. The second assumption was based on the estimate of Queensland recreational catch relative to the commercial catch as derived by the QFS RFISH program. The recreational catch estimate was calculated to be 0.6X the commercial catch with a high degree of uncertainty associated with this estimate (J. Higgs, pers. comm.). To assess the sensitivity of the model to changes in the relative estimates of recreational catch we fitted the model using upper and lower estimates of 0.8X and 0.4X the commercial catch respectively.

The model was relatively insensitive to the changes made to the catch data. Alterations to the assumed catch for the period 1982-88 resulted in negligible change in the estimated exploitable biomass levels and in the estimate of F. Little change also resulted in the model using a decrease in the estimate of recreational catch. By increasing the estimate of recreational catch the model estimated that the current exploitable biomass is 39% of unfished biomass and F is above the target reference point at 0.22 (approx. 1.3X sustainable F) (Figure 17).

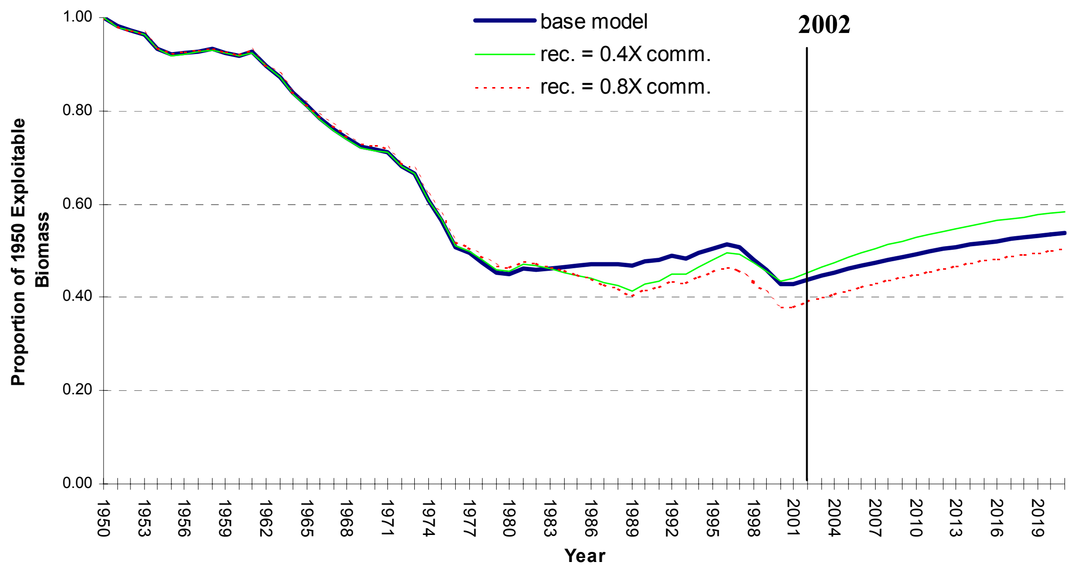

Figure 17. Sensitivity of the model to different estimates of the recreational catch used as input data.

5.3 Maximum Constant Yield

Faced with uncertainty in stock assessment the New Zealand Ministry of Fisheries have developed a method for determining an alternative to maximum sustainable yield using commercial catch and effort information. Maximum Constant Yield (MCY) is defined as "..the maximum constant catch that is estimated to be sustainable.." (New Zealand Ministry of Fisheries, 2002). MCY represents the average catch that can be taken from a stock taking into account the natural variability inherent in the particular stock. MCY therefore is effectively a method of estimating the Total Allowable Catch (TAC) for the fishery. In data-limited fisheries such as the east coast Spanish mackerel fishery, MCY represents a conservative strategy. MCY is calculated by the following equation:

$$MCY = cY_{av}$$

where *c* is the natural variability factor (related to natural mortality, M; see Table 4), and Y_{av} is the average catch across the appropriate time series (see Appendix 1; New Zealand Ministry of Fisheries, 2002). With the estimate of natural mortality used in the assessment model we can estimate *c* for *S. commerson* (*c* = 0.7; see Table 4).

M	*c*
< 0.05	1.0
0.05 – 0.15	0.9
0.16 – 0.25	0.8
0.26 – 0.35	0.7
> 0.35	0.6

Table 4. Guide to the relationship between natural mortality estimate, M, and the natural variability factor, *c*. The value of *c* is lower for fish stocks of greater variability. (Source: New Zealand Ministry of Fisheries, 2002).

The estimate of MCY was calculated here using the more reliable time series of CFISH commercial catch data from 1990-2001. This resulted in an estimate of MCY for the Queensland east coast Spanish mackerel fishery of 346t (see Appendix 1).

The use of MCY assumes that the stock biomass is at or above a size that enables MSY to be achieved (B_{msy}). A stock lower than B_{msy} would necessitate a lower estimate of MCY.

Therefore at low stock sizes, using the MCY strategy involves high risk as a larger proportion of the stock is being removed. The sensitivity analyses presented above indicate the possibility that the east coast Spanish mackerel stock is at a low size and therefore caution should be taken in using MCY here. Use of MCY as a TAC would represent a precautionary approach from the current situation but would also require continued careful monitoring of effort and CPUE from the fishery. Further, MCY is calculated based only on Queensland commercial catch and any catch reductions would necessitate commensurate reductions in all sectors of the east coast fishery. If MCY is considered as a management option, it is recommended that it not be used in isolation from the assessment model used here. We recommend further investigation of management strategies, using a formal management strategy evaluation approach.

5.4 Conclusions

The assessment model suggests that the level of exploitable biomass of east coast Spanish mackerel is currently at 44% of the unfished levels. The model also suggests that the current rate of fishing, F, is fully exploited and at the target reference point: considered to be a sustainable level. However, a high degree of uncertainty in the model input data and parameters are believed to exist. Analysis of the sensitivity of the model to these inputs provided estimates of stock between 22% and 61% of the initial biomass, and current F between 0.6 and 3.0 times the estimated sustainable F of 0.17. From the current assessment we conclude that fishing effort should not be permitted to increase above current levels.

The current legal minimum size of 75cm TL, although providing more yield per recruit than higher legal sizes, allows some females to be captured before first spawning. Higher legal size may therefore provide more security for the spawning stock. Also, CPUE is a poor indicator of abundance in schooling species such as Spanish mackerel.

6. Future work

This is a continuation of the initial modelling carried out at the Darwin workshop and should still be considered preliminary. A major limitation at this time is the lack of appropriate data. In particular, age data of the current stock should continue to be collected and incorporated into future assessments. One of the important outcomes of this assessment is the identification of the uncertainty in the current available parameters for *S. commerson* and in the data from the fishery. Also important is the assessment of how sensitive the model is to plausible changes in these parameters and data.

The parameter that the model proved most sensitive to was natural mortality and it should be a priority to obtain a better estimate for M. This parameter can also influence the estimates of YPR models used here. Much discussion revolved around this at the Darwin workshop in August, 2000 and the development of improved tagging techniques to determine exploitation rates for mackerel were discussed as a priority (see O'Neill and McPherson, 2000). Tagging studies were also seen as necessary to validate the model used here. A new GENEtag project on the northern Australian stock of *S. commerson* led by Rik Buckworth of the NT Fisheries will hopefully address this issue.

The model was also influenced to some extent by r_{max} (S-R relationship), the growth co-efficient K, the age data used and the estimate of the biomass at the beginning of the time series. A better understanding of the relationship between the spawning stock size and recruitment is required but to achieve this requires a long time series of estimates of the spawning stock size and the corresponding number of individuals recruiting to the fishery. The latter would occur 1-2 years later in the case of Spanish mackerel. Information necessary to estimate spawning stock size, such as relative numbers per age class and fecundity by age class, could be collected from the known spawning aggregations during spawning (Hilborn and Walters, 1992). Information necessary to estimate the relative numbers of recruits to the fishery can possibly be derived from annual representative sampling from the fishery (eg. LTMP).

The parameters that describe growth can change under exploitation and therefore it is necessary to obtain data to re-estimate the von Bertalanffy growth parameters on a regular basis. The acquisition of age and length samples taken annually from the fishery as is currently done by the LTMP should be continued. Collection of fishery-independent age and length data to ensure that smaller, younger fish are represented in the sample will provide more confidence in the estimation of growth parameters.

The age data used as input to the model determine both the estimate of total mortality and the selectivity schedule, both vitally informative about the status of the fishery. It is very important that the age data collected from the fishery for future assessments are representative of the catch. We strongly urge that sampling should continue annually, and that methods be adjusted to improve representativeness. We suggest that the LTMP consider, based on anticipated results from the FRDC project, sampling from the recreational catch either in addition to or instead of commercial sampling.

The sensitivity analyses carried out on this assessment used single parameters or assumptions, and included only upper and lower estimates of the uncertainty. A more complete sensitivity analysis would use bootstrapping and Monte Carlo methods to estimate the distribution of the results, as a function of the likely uncertainty distribution of the parameter/s. Further, the uncertain parameters and assumptions are not likely to be independent and further analysis of the interaction effects of the parameters on the model are suggested. This would require a more complex and time-consuming analysis. Use of Bayesian methods to integrate across the full range of uncertainty would result in more accurate estimates of model outputs, possibly with much narrower confidence intervals (Nielsen and Lewy 2002).

Collection of catch and effort data from all sectors of the fishery (including NSW) should also be continued. Suggested changes to the logbook that would improve the resolution of commercial data are that the numbers caught should be included and fishing operations should record the number of individual fishing units operating on each day. It is hoped that this model can be built on and improved in future years to enable more reliable estimates of relative stock size to be obtained for the entire east coast stock.

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Appendix 1.

Calculation of estimates of Maximum Constant Yield (MCY):

M = 0.34
c = 0.7 (see Table 4)

$MCY = c * Y_{av}$

Where *c* is the natural variability factor and Y_{av} is the average catch over a determined time frame.

The time frame over which the average catch is determined should,
1. show no systematic trends in catch or effort, and
2. be over a period that is longer than half the exploited life span of the species.

Y_{av} (1990-2001) = 494.605t

MCY = 494.605 * 0.7 = 346.224t