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STOCK ASSESSMENT OF THE AUSTRALIAN EAST COAST SPOTTED MACKEREL FISHERY

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Non-Technical Summary

Stock assessment of the Australian east coast spotted mackerel fishery

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Objectives:

1. To collate available biological, historical fisheries, and commercial and recreational catch and effort data on the Australian east coast spotted mackerel fishery.
2. To review the extent and quality of all available data to determine the potential for a formalised assessment of the Australian east coast spotted mackerel fishery.
3. To optimise use of all available data to describe current trends in the fishery, and if data permits, undertake a formalised assessment of the status of the Australian east coast spotted mackerel fishery.
4. To advise on monitoring, reporting and/or further research required to improve or enable future assessments of the Australian east coast spotted mackerel fishery.

Summary:

This assessment arose in response to the growing concerns of all stakeholders in 2002 for the sustainability of the Australian east coast spotted mackerel (*Scomberomorus munroi*) fishery, and the necessary requirements of the Commonwealth EPBC Act. The fishery is comprised of a single unit stock that undertakes seasonal spawning and feeding movements along the Queensland and New South Wales coasts. The highly aggregated, near surface schooling behaviour of the stock coupled with its predictable seasonal movements along the east coast allows ease of targeting by both the commercial and recreational sectors; thereby making the stock susceptible to over-fishing. In 1999-2000, commercial catches of spotted mackerel increased significantly in response to the development of valuable overseas export markets, where subject to management intervention in 2002, an increase in effort was likely to continue while attractive prices were being offered and overseas markets continued to expand. Concurrently, anecdote suggested that recreational catches decreased significantly, leading to major concerns about the ecological sustainability of the fishery. In this assessment, therefore, we evaluate the Australian east coast spotted mackerel fishery from northern Queensland to northern New South Wales waters, incorporating all available biological data, and commercial and recreational catches for the fishing (*i.e.*, financial) years 1960-2002.

Spotted mackerel spawn between August and October in northern Queensland waters. Peak spawning occurs in September. Following spawning, the majority of the stock appears to undertake a summer feeding movement to southern Queensland and northern New South Wales waters, returning in autumn and early winter. The timing and extent of these movements are most likely related to water temperature and clarity, and baitfish distributions.

Spotted mackerel grow quickly for the first three years of life, and demonstrate sex-specific growth rates, with females tending to grow faster and to larger sizes. Considerable variation in length is found for any given age of spotted mackerel, where they have been aged up to 7 years and observed to 105 cm total length (TL) and 7.4 kg. Female and male spotted mackerel reach maturity at about 60 cm and 52 cm TL, respectively, within 1-2 years of age. Because of the significant differential growth between the sexes, sex-specific age length

distribution keys (ALK) were derived for spotted mackerel and used to estimate age structures from length distributions collected in 1991-1996, 1999 and 2002. Sex-specific age structures derived from the respective ALK were combined to form a single age structure for each year's catch in which there was fish length data and used as input into the assessment. Overall, the spotted mackerel population was highly dependent on young fish, with 1-3 year olds being the dominant age groups.

Although the Australian east coast spotted mackerel fishery extends into northern New South Wales waters, the majority of the fishery occurs in Queensland waters. Spotted mackerel are caught by both commercial and recreational fishers mainly around Bowen and Innisfail during winter and early spring (July-September), and from Hervey Bay and Moreton Bay during late spring and summer (November-February). Few by-product or by-catch species are caught when targeting spotted mackerel, although this will vary depending on method of fishing, and may include Spanish, school, grey and shark mackerel, long-tail and mackerel tuna, bonito, shark and trevally. In addition, relatively few sub-legal or undersize fish are discarded when targeting spotted mackerel, although potential numbers will most likely increase for line caught spotted mackerel with the introduction in 2002 of a 60 cm TL minimum legal size. Furthermore, little is known about the post release mortality of line caught and subsequent release of spotted mackerel, although anecdote suggests this to be significant.

Mackerel have been commercially caught from Queensland waters since at least 1945, with reported landings up to 855 t in 1974. Anecdote suggests that most of these historic landings were Spanish mackerel, with targeted commercial fishing for spotted mackerel commencing in about 1960. Commercial catches of spotted mackerel in Queensland waters have increased over the years, reaching a peak of 410 t in 2000. Prior to management intervention and the banning of targeted netting of spotted mackerel in 2002, the use of ring nets was the main method of capture by the commercial sector. Significant quantities of unspecified mackerel have also been reported in the compulsory commercial logbooks each year, ranging from 10-131 t. In contrast, spotted mackerel comprise a relatively small component of the total mackerel catch in northern New South Wales waters, with a peak catch of about 55 t in 1999.

Recreational fishing for spotted mackerel is similar to the commercial sector in being highly localised and seasonal, reflecting the spatial and temporal availability of the species. Recreational fishing for spotted mackerel is particularly important south of Townsville, and also for visiting interstate recreational anglers who target the winter run of spotted mackerel in northern Queensland waters. Recreational catches of spotted mackerel were estimated to be about 31,000, 210,000, 86,000, 129,000 and 53,000 fish in 1995, 1997, 1999, 2000 and 2002. As with the commercial sector, significant quantities of unspecified mackerel catches were also reported in the State and National recreational fishing surveys, of which a proportion of these were estimated to be spotted mackerel. The average length and weight of a recreationally caught spotted mackerel was about 65 cm TL and 1.64 kg, in contrast to the commercial sector which typically caught a 70 cm TL and 1.92 kg spotted mackerel.

The reported commercial and recreational spotted mackerel catches were used as the basis for this assessment because it was assumed that these were a function of fishing effort and abundance of the population, where the level of total catch over time may reflect changes in the proportion of the population caught, changes in the abundance of spotted mackerel, or both. However, significant quantities of unspecified mackerel were reported in the commercial logbooks and recreational fishing diaries each year, where it was assumed a proportion of these were spotted mackerel, which in turn needed to be estimated to determine total catches. Binary regression models, therefore, were used to allocate reported unspecified mackerel catches to spotted mackerel catches.

The binary regression models identified significant changes in the probability of commercial and recreational catches of mackerel being spotted mackerel between fishing regions, gears, months, years, number and weight of mackerel caught, time spent fishing, etc. The probability of a Queensland commercial catch of mackerel being reported as spotted mackerel was significantly greater when caught using ring nets, and from the traditional spotted mackerel fishing regions of Moreton Bay and Hervey Bay during summer, and Bowen during winter. As well, the probability of a recreational catch of mackerel being spotted mackerel was lower for longer times spent fishing, and higher when large numbers of mackerel were caught. The proportion of unspecified mackerel allocated as spotted mackerel varied from 1-42 t in any given year for the Queensland commercial sector, less than 1 t for the New South Wales commercial and Queensland charter sectors, and up to 94 t for the recreational sector.

Standardised annual catch rates (*i.e.*, catch per unit effort; CPUE) of spotted mackerel were used in the assessment as a relative index of population abundance. The standardisation analysis considered a number of different climate variables thought to affect the catchability (and subsequent catch rate) of spotted mackerel including the Southern Oscillation Index (SOI), wind speed and direction, sea surface temperature and lunar phase. The analysis also used Queensland and New South Wales spotted mackerel commercial and recreational catches from 1988 to 2002. The analysis examined only those spotted mackerel catches where fish were caught and retained (*i.e.*, catches > 0). No data were available on searching effort to find spotted mackerel or on fishing effort where no spotted mackerel were caught. The final model considered the reported spotted mackerel catch associated with the number of units and type of fishing effort (*e.g.*, days fished by commercial line operations or the number of fishers in a recreational fishing group), fishing year, month, region, lunar phase and climate/weather conditions. A range of weighting values were also examined to reduce the hyperstability effect of certain fishing effort types or target/non-target fishing for spotted mackerel.

Spotted mackerel catch rates varied according to fishing years, regions, months, strength of north-south winds, lunar cycle, SOI and the amount and type of fishing effort. Catch rates appeared to decline from 1990 to 1995, increasing slightly thereafter, before remaining relatively stable. As expected and supporting the anecdote, catch rates of spotted mackerel increased with favourable weather conditions such as light northerly winds (*i.e.*, <20 km/hr). Favourable weather and sea conditions would both increase the targeting efficiency of fishers and maintain the integrity of near surface feeding schooling mackerel; thereby leading to greater catch rates. Estimated average relative fishing power was also considerably higher for ring net fishing than the other line fishing effort types, suggesting potential hyperstability issues with net based catch rates. The pseudo target/non-target weightings had little influence on the analysis. Commercial line fishing catch rates, therefore, were considered best to reflect the underlying population abundance of spotted mackerel due to the elevated hyperstability of net fishing, and was used in the assessment as an annual relative index of abundance.

The annual total catches for the fishery that were used in the assessment included data from the Queensland and New South Wales commercial and recreational sectors. Total catches were estimated separately for two periods of the history of the fishery (1960-1987; 1988-2002) because of data availability issues. Total catches of spotted mackerel for each year of the historic period (1960-1987) included: 1) Queensland commercial catch from Queensland Fish Board data (1960-1980); 2) New South Wales commercial catch of 1 t based on the average catch of spotted mackerel for the initial years of the logbook data (1984-1988); and 3) average total catch for years in which no data were available. In those years where there were no data available (1981-1987) or only commercial data (1960-1980) a generalised linear model was used to estimate the average total catch; being fitted to the nominal total catches for 1988-2002 and projected back to 1960.

Total catches of spotted mackerel for each year of the more recent period (1988-2002) included: 1) actual reported catches for spotted mackerel from the Queensland and New South Wales commercial logbooks (plus binary model allocated unspecified mackerel catch); 2) Queensland recreational survey catch estimates for 1995 (52 t), 1999 (201 t), 2000 (265 t) and 2002 (180 t); 3) New South Wales recreational survey catch estimates for 1993 (5 t), 1994 (1 t) and 2000 (27 t); 4) estimated Queensland recreational catch for 1988-1994, 1996-1998 and 2001 when there was no actual survey conducted; and 5) estimated New South Wales recreational catch for 1988-1992, 1995-1999 and 2001-2002 when there was no actual survey conducted. In those years when there were no surveys conducted, recreational catch estimates were based on the average relative recreational effort for the years in which data were available. The estimated total catches for spotted mackerel increased significantly since the fishery was assumed to have commenced in 1960. Total catches reached a peak of about 755 t in 2000, just prior to the investment warning in 2002. Major uncertainties, however, exist in the total catches and relate mostly to the magnitude of the historical catches and those of the recreational sector.

The assessment used all available and relevant biological and fisheries data to provide an indication of the current level of exploitation and sustainability of the spotted mackerel fishery. A sex-specific age-structured population dynamics model was used to evaluate the status of the fishery. The main data sources for the model were the total catches, catch rates and age structures. Results from the model suggested that the stock is most likely being harvested near or exceeding maximum sustainable levels, and is at risk of being over-fished; albeit given the data and model assumptions and uncertainties. Biomass trends demonstrated significant declines in the stock over the past 10 years, particularly during the mid-1990s to early-2000s when catches were at their peak, with current levels estimated to be at 33-63% of unfished or virgin biomass (*i.e.*, B_0) levels. Sensitivity analyses demonstrated that the assessment model was quite robust with similar biomass ratios and management quantities estimated for a variety of model runs. This included testing a range of input parameters such as natural mortality and stock-recruitment steepness. The estimated catches (or yields) when fished at a level to attain maximum sustainable yield (*i.e.*, $Y(F_{MSY})$) varied from 296-570 t for the different model runs, although the preferred base models fitted to the age structure and CPUE data, and age structure data alone, estimated $Y(F_{MSY})$ to be about 366 t and 296 t, respectively. Only for the latter base model (*i.e.*, $Y(F_{MSY})$ = 296 t), was the spotted mackerel exploitable biomass in 2002 predicted to be below that which would sustain MSY (*i.e.*, $B_{2002} < B_{MSY}$). Furthermore, projections based on this model suggest that future catches of less than 350 t will likely increase biomass back to B_{MSY} and above. Management advice derived from the age structure only model was the preferred option because of uncertainties associated with the potentially hyperstable catch rates; a directive in accordance with the precautionary approach.

Several alternate assessment models (*e.g.*, surplus production (ASPIC), virtual population analysis (VPA/ADAPT), statistical catch-at-age (ASAP)) were also examined to evaluate the relative performance, robustness and uncertainty associated with the population trends derived from the age-structured population dynamics model. Results from the surplus production model (ASPIC) were in contrast to those expected for the life history of spotted mackerel. Biomass estimates from ASPIC were at extremely high and unrealistic levels as the model attempted to fit to the relatively flat catch rate time series. In contrast, results from the VPA/ADAPT and ASAP models were relatively similar to those from the population dynamics model tuned only to age structures. Overall, results from the alternate models showed the sensitivities associated with some of the key input data and assumptions. In particular, results from the models suggested that the relatively flat standardised catch rate data may still not be a good indicator of population abundance; undoubtedly being affected by hyperstability.

A hierarchical approach to reference point estimation, which dictates that reference points be determined by the method that most reliably captures the salient population and fishery dynamics given the data available, was used to evaluate a range of reference points (including those derived from the age-structured population dynamics model) for determining sustainable catch strategies of spotted mackerel. Reference point estimation was assessed in terms of data type, quantity and quality to enable the associated uncertainty to be evaluated in a transparent, hierarchical framework. Uncertainty in the data types was a common problem and varied according to representativeness of data coverage, degree of extrapolation for years of missing data, use of proxies or species analogies when no data were available, etc. Most of the data types were considered to have moderate to high uncertainty. A suite of target (*i.e.*, desirable) and limit (*i.e.*, avoidable) candidate reference points were chosen that may be considered appropriate for the management of spotted mackerel. At the lower tier of the hierarchy, based on simple historical proxies for sustainable catch levels, a target total catch for the fishery was estimated to be about 200 t with a limit of 333 t. In contrast, the more complex age-based production model estimated a target total catch for the fishery of 277-282 t and a limit of 296 t. The nominal 2003 total catch of 350 t (if the TACC of 140 t was fully realised) for the fishery was above all the estimated candidate reference points, irrespective of the data and models used. Management of the spotted mackerel fishery, therefore, may need to consider more prudent actions in the future, in accordance with the precautionary approach to ensure the long-term sustainability of the fishery, even given the recent management intervention. Also, selection of candidate reference points should be informed by the use of alternate methods and their assumptions, which in turn should be used to identify critical assumptions in the estimation process and to direct future research and monitoring programs.

The uncertainty associated with this assessment and subsequent reference points and management advice derived from the related analysis and models was a function of the quality and extent of the input data. Future research and monitoring programs, therefore, should be directed towards providing the necessary data required for improved model parameters and reference point estimation. Various forms of monitoring and opportunistic or project oriented research provided the necessary data used in this assessment of spotted mackerel. The assessment data came from a range of sources, but relied heavily on Queensland's commercial and recreational fishing databases, as well as fishery-dependent spotted mackerel length and age data. The continuation of a monitoring program for spotted mackerel, therefore, is essential if further data- or model-based assessments are to be conducted for this fishery. Consequently, we used random effects modeling and power analysis to determine an effective and optimal monitoring strategy for spotted mackerel in the future.

Results from the analysis showed the importance of monitoring spotted mackerel lengths (and ages) every year, with samples ideally collected across fishing regions from all line fishing sectors. We recommend the minimum sampling of at least 600 fish from both the recreational and commercial line sectors across two broad regions: 1) northern Queensland (Townsville – Bowen); and 2) south east Queensland (Hervey Bay – Moreton Bay). This equates to a minimum sample each year of 600 fish distributed across the 2 fishing sectors and 2 regions (*i.e.*, sampling target of 150 fish per sector per region); all fish should be sexed and aged. Furthermore, based on the median daily catch by sector, a minimum of 20 catches should be sampled from the commercial sector and 150 from the recreational sector. Overall, the need for more age-structured data collected from both the commercial and recreational sectors is of greatest importance to improve this assessment in the future.

All indications from this assessment, besides the relatively flat CPUE time series, suggest that the spotted mackerel stock is most likely being harvested near or exceeding maximum sustainable levels, and is at risk of being over-fished. Although the best available data were used to determine the status of the stock and inform an appropriate level of risk, there was an inherent level of uncertainty associated with the data and model assumptions that need to be considered for management advice and future assessments. Major levels of uncertainty exist in the key biological parameters of natural mortality, stock-recruitment and reproductive output, as well as in the fisheries data of the historical and recreational catches. The transparent and comprehensive nature of this assessment should enable all stakeholders and managers involved in the spotted mackerel fishery to make more informed decisions concerning the management of the resource, with an understanding of the associated uncertainties and risks. The choice of management actions to implement in the future should be examined in a management strategy evaluation framework, similar to the approach used in this assessment, to determine the trade-offs between particular management actions and the management objectives to be met; coupled with the associated levels of risk.

In addition, to improve and develop this assessment in the future, we recommend the need for: 1) a more comprehensive and structured monitoring approach to the collection of appropriate age-structured data from both the commercial and recreational sectors; 2) the recording of a better measure of effort and species identification in the commercial logbooks and recreational diaries to provide a more reliable indicator of CPUE; 3) a review of the historical catch data to confirm the assumed commencement of the fishery and magnitude of the catches; 4) a robust evaluation of the selectivity functions for the different fishing gears; 5) an appraisal of the protocols used to age spotted mackerel; 6) a fishery-independent measure of changes in stock size; 7) investigations into the fecundity, spawning, recruitment processes and environmental-catch distributions of spotted mackerel; and 10) a periodic review and update of the data and models used in the assessment via a systematic and transparent stock assessment review process.

This stock assessment is the most comprehensive attempt to evaluate the status of the Australian east coast spotted mackerel fishery. The assessment used all available biological and fisheries data to provide an indication of the current level of exploitation and sustainability of the Australian east coast spotted mackerel fishery. The results, however, need to be tempered with the uncertainty associated with the various data and model assumptions; although this should not be used as a basis for management inaction. Indeed, the precautionary approach dictates that management should be more prudent given greater uncertainty. The transparent and comprehensive nature of the assessment should enable all stakeholders involved in the fishery to make more informed decisions concerning the management of the resource, with a thorough understanding of the associated uncertainties and risks. Overall, the analyses and modeling facilitated a critical assessment of the spotted mackerel fishery; thereby, making more effective use of the catch data and past biological research on the species. The assessment has provided a basis for Queensland and New South Wales fisheries managers, and their relevant advisory committees to consider sustainable levels of fishing and management objectives for the fishery. Operational objectives and trigger points for the fishery, however, need to be defined to guide future management strategies. Recent management measures also need to be assessed in the future, and more prudent actions may be needed, if fishing pressure increases in the recreational sector or the commercial catch quota is exceeded.

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1. Introduction

Spotted mackerel (*Scomberomorus munroi*) is an inshore, schooling species that inhabits coastal waters of northern Australia and southern Papua New Guinea (Munro 1943, Collette and Russo 1984). Together with school mackerel (*S. queenslandicus*) and grey or broad-barred Spanish mackerel (*S. semifasciatus*), these species collectively known as “small” or “lesser” mackerel, support important commercial and recreational fisheries throughout Queensland, the Northern Territory, Western Australia, and to a lesser extent northern New South Wales.

In 1999-2000, commercial catches of spotted mackerel in Queensland increased significantly in response to the development of overseas export markets, where subject to management intervention an increase in effort was likely to continue while attractive prices were being offered and overseas markets continued to expand. Concurrently, anecdote suggested that recreational catches had decreased significantly, leading to major concerns about the ecological sustainability of the Australian east coast spotted mackerel fishery. Moreover, similar mackerel and other pelagic schooling fisheries overseas have a history of over-fishing and stock decline (Beverton 1990, Hilborn and Walters 1992, Overholtz 2002).

This assessment, therefore, arose in response to the growing concerns of all stakeholders for the sustainability of the Australian east coast spotted mackerel fishery. The highly aggregated, near surface schooling behaviour of the stock coupled with its predictable seasonal movements along the east coast allows ease of targeting by both commercial and recreational fishers; thereby making the stock susceptible to over-fishing and stock collapse. An assessment of the status of the fishery is considered essential to enable the evaluation of existing management arrangements and to satisfy the ecological sustainable assessment requirements of the Commonwealth Government’s Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

Distribution

Spotted mackerel are endemic to the Australasian region, occurring in coastal waters, generally less than 100 m in depth (Kailola *et al.* 1993). The species distribution extends throughout coastal waters of northern Australia and southern Papua New Guinea, where they tend to inhabit offshore open waters (Collette and Russo 1980, 1984). Spotted mackerel are restricted to the northern coast of Australia from the Abrolhos Islands region of Western Australia to Coffs Harbour and Kempsey in central New South Wales, and the southern coast of Papua New Guinea from Kerema to Port Moresby (Collette and Russo 1980). The main fishery for spotted mackerel occurs on the Australian east coast from Innisfail to Moreton Bay (Fig. 1.1).

Stock structure

The Australian east coast spotted mackerel fishery is comprised of a single unit stock that undertakes seasonal spawning and feeding movements along the Queensland and New South Wales coasts (Fig. 1.1). Genetic, age and growth, catch monitoring, tag-recapture, and otolith elemental data provide support for this putative stock structure and indicate that the majority of spotted mackerel along the Queensland east coast comprise a single exploitable stock (Begg *et al.* 1997, Begg 1998, Begg *et al.* 1998a, 1998b, Begg and Sellin 1998, Cameron and Begg 2002).

Electrophoretic analysis of spotted mackerel caught at several sites between Bowen (northern Queensland) and Iluka (northern New South Wales) found no significant differences in allele frequencies, indicating that spotted mackerel throughout this geographic range form a common gene pool or unit stock (Begg *et al.* 1998b). Likewise, similar patterns in growth and otolith elemental constituents between spotted mackerel samples collected from the same locations as the genetic data provide strong evidence for the existence of a single east coast stock (Begg *et al.* 1998a, Begg and Sellin 1998). Tag-recapture and commercial fisheries catch data also support the assumption of a single unit stock which undertakes a seasonal movement each year, where recaptured spotted mackerel moved nearly the length of the Queensland east coast, demonstrating a consistent seasonal shift in location (Begg *et al.* 1997). Although tagged spotted mackerel from Hervey Bay have been recaptured in waters off Innisfail, providing direct evidence that the east coast stock extends at least that far north and covers the geographic range of the major east coast fishing grounds, the extent and continuity of the northern boundary of the Australian east coast spotted mackerel stock is uncertain (Begg *et al.* 1997).

In this assessment, we evaluate the Australian east coast spotted mackerel fishery from northern Queensland (Far north region) to northern New South Wales waters (Fig. 1.1).

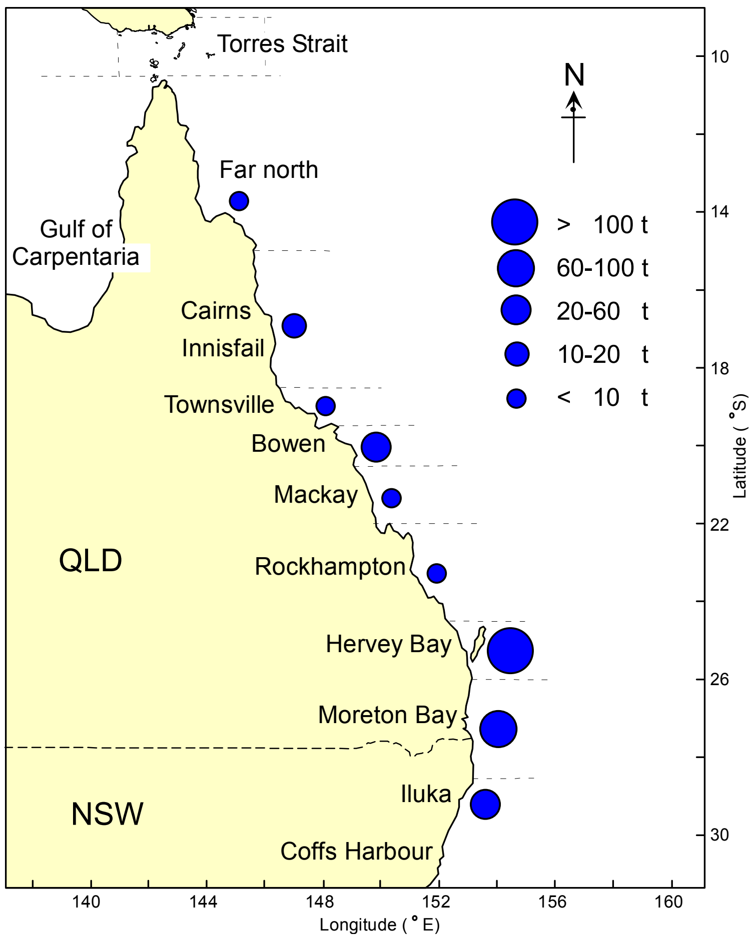

Fig. 1.1. Statistical regions in Queensland (QLD) and New South Wales (NSW) used for analysis of mackerel catches, and main fishing regions of the Australian east coast spotted mackerel fishery. Circles represent average commercial catches of spotted mackerel, fishing years 1988-2002.

Biology and ecology

Spotted mackerel spawn between August and October in northern Queensland waters, from Mackay to south of Townsville (Begg 1998). Peak spawning occurs in September. Anecdote suggests that other areas south of Mackay such as Shoalwater Bay, are also possible spawning grounds. Spotted mackerel spawn in oceanic waters that may result in pelagic eggs and larvae being dispersed southward by the East Australian Current, thereby facilitating conditions necessary for stock homogeneity (Begg 1998). Larvae and juveniles of other *Scomberomorus* species have been found in estuarine and coastal habitats (Jenkins *et al.* 1984, 1985, Thorrold 1992, 1993), but little is known about the early life history stages of spotted mackerel and their associated habitats. Moreover, this paucity of information is complicated by species identification problems with the early life history stages.

Spotted mackerel grow quickly for the first three years of life, and demonstrate sex-specific growth rates, with females tending to grow faster and to larger sizes (Begg and Sellin 1998; see Chapter 2). Considerable variation in length is found for any given age of spotted mackerel, where spotted mackerel have been aged up to 7 years. Sexual maturity is reached within the first 2 years of life.

Spotted mackerel form large schools that undertake seasonal spawning and feeding movements along the Queensland east coast (Begg *et al.* 1997). Following spawning in late winter and early spring in northern Queensland waters, the majority of the stock appears to undertake a summer feeding movement to southern Queensland and northern New South Wales waters, returning in autumn and early winter. The timing and extent of these movements are most likely related to water temperature and clarity, and baitfish distributions. Spotted mackerel are piscivorous predators throughout their life history, feeding mainly on pelagic Clupeoid baitfish such as anchovies and pilchards (Begg and Hopper 1997). This large-prey fast growth strategy ensures rapid growth through the early life stages that are vulnerable to predation.

Environment

Little is known about the links between the environment and ecological sustainability of the Australian east coast spotted mackerel fishery. *Scomberomorus* species are found in tropical and temperate coastal waters, generally at or above thermal fronts of about 20 °C. Distribution and movement patterns of spotted mackerel have been suggested to be related to these fronts (Munro 1943). Coupled with these movement-temperature associations are the predator-prey relationships upon which the species depend. Understanding these relationships is central to identifying environmental and biotic effects that influence the distribution, recruitment and population dynamics of the spotted mackerel stock, and ultimately the sustainability of the fishery.

Fishery description

Anecdote suggests that commercial fishing of spotted mackerel commenced in the 1960s (K. Riley, pers. comm.), although it wasn't until the 1990s that significant catches were reported. Likewise, development of the recreational fishery for spotted mackerel most likely occurred along a similar timeline to the commercial fishery. Spotted mackerel on the east coast are mostly caught between Innisfail and Moreton Bay (Fig. 1.1), using a variety of different gear types, and characteristically form highly seasonal and localised fisheries throughout their distribution (Begg *et al.* 1998a). Major fisheries at Bowen target spawning aggregations of spotted mackerel and those at Hervey Bay and Moreton Bay target feeding aggregations (Begg *et al.* 1997).

Commercial fishing techniques for spotted mackerel have changed in the last few decades from a mixture of troll line fishing and set gill nets to the more recent practice in the 1990s, prior to management intervention, of using monofilament ring or run-around gill nets (Cameron and Begg 2002). Ring netting involved visually locating mackerel in the surface waters and then running the net around the school of fish. As the net was retrieved, fish became enmeshed as the encircled area decreased. In Bowen, commercial fishers favoured 12.7 cm mesh net, in Hervey Bay 10.2 cm mesh, and in Moreton Bay 9.5 cm mesh. Spotted mackerel are highly vulnerable to ring nets as they tend to aggregate in tight schools, mesh well and do not jump. Recent management intervention (December 2002), however, resulted in the banning of netting for spotted mackerel, with commercial fishers now restricted to hook and line.

Commercially caught spotted mackerel is marketed and retailed either fresh or frozen as whole or gilled and gutted fish, trunks, fillets or cutlets (Kailola *et al.* 1993). Since 1997, the markets for spotted mackerel changed substantially with the development of valuable export markets, primarily in Japan, for whole fresh fish (Williams 2002). Previous to these export markets, all spotted mackerel landed were destined for the domestic markets, with significant quantities sold fresh in the Brisbane and Sydney markets. Demand for spotted mackerel from overseas markets is expected to increase in the future, while attractive prices are being offered and overseas markets continue to expand. Flooding of markets and resulting lower prices with excess fish in good weather conditions was once a common occurrence in the Australian east coast spotted mackerel fishery, but has now become less frequent with the development of the export markets (Williams 2002) and the banning of ring netting.

Recreational anglers fish for spotted mackerel mostly from boats (Cameron and Begg 2002), but also beaches, headlands, and other shore-based structures such as bridges, piers and jetties. Recreational fisheries for spotted mackerel are similar to commercial fisheries in being highly localised, seasonal activities, reflecting the spatial and temporal availability of the species. Recreational fishing for spotted mackerel is particularly important south of Townsville, and also for visiting interstate recreational anglers who target the winter run of spotted mackerel in northern Queensland waters (Cameron and Begg 2002). Recreational anglers fish for spotted mackerel using hand lines or rod and reel, with either natural or artificial baits. Angling techniques include trolling, spinning and setting of live or dead baits. Trolling involves a boat trailing artificial lures or baits. When a fish is hooked and landed, trolling typically continues in the same area until fish are no longer caught. Spinning is a dynamic process that involves casting a lure into the water and retrieving it at a rapid pace (Begg 1997).

Conflict between commercial and recreational fishers has been developing over the past decade. Much of the debate and conflict has arisen owing to a lack of information, disagreement over the comparative harvest of each sector, and potential allocation disputes over the resource. In addition, anecdotal evidence and reports from recreational fishers of declining catch rates of spotted mackerel in some recognised fishing grounds, and patchy occurrence during recognised peak fishing seasons has further fuelled the debate over the sustainability of the Australian east coast spotted mackerel fishery.

Management history

Addressing sustainability concerns and management of the Australian east coast spotted mackerel fishery is the responsibility of the Queensland Department of Primary Industries and Fisheries (DPI&F). Prior to recent management intervention (Table 1.1), the DPI&F and Inshore Finfish Management Advisory Committee (MAC), acknowledged that measures were needed to reduce the risk that spotted mackerel may be caught beyond a sustainable level (*i.e.*, total catch > sustainable yield; $F > F_{MSY}$). The New South Wales Department of Primary Industries (NSW DPI) are also jointly responsible for the management of the spotted mackerel fishery as the east coast stock extends into northern New South Wales waters; albeit that the majority of the fishery occurs in Queensland waters.

Historically, the spotted mackerel fishery in Queensland was managed through a variety of input controls including constraints on the number of vessels that could operate in the fishery (*i.e.*, limited entry), specification of those vessels and associated fishing gears, and recreational size and in-possession (*i.e.*, bag) limits. More recently, however, output controls were introduced to manage the fishery, in particular an annual total allowable commercial catch (TACC) (Table 1.1).

Research history

Prior to the Fisheries Research and Development Corporation (FRDC) Project 92/144 (Cameron and Begg 2002) that generated a series of publications, there had been little directed research conducted on the Australian east coast spotted mackerel fishery (Table 1.2). Although this FRDC project provided fundamental baseline information on the biology and sector interactions within the fishery, there still remains little known about the reproductive potential and early life history stages of spotted mackerel including their development, distribution, fecundity, recruitment and nursery and spawning habitats. Fisheries-independent measures of stock size and sustainability of the resource are also lacking.

Table 1.1. History of spotted mackerel management.

Year	Management
1984	Limited entry for net and line fisheries (*i.e.*, no new vessel licences issued).
1990 (May 22)	Repeal of section 35 of the *Fishery and Industry Organisation and Marketing Act* making the sale of recreational catches unlawful.
1995 (Dec 1)	Minimum legal size of 50 cm TL. Recreational in-possession (bag) limit of 30 spotted mackerel.
1997 (Dec 19)	Declaration of Dugong Protection Areas and resultant netting area restrictions (commenced 12 January 1998).
2002 (Apr 8)	Investment warning for the catch of spotted mackerel by any fishing method.
2002 (Dec 6)	Minimum legal size of 60 cm TL. Recreational in-possession limit of 5 spotted mackerel. Annual TACC of 140 t (1 July – 30 June). Commercial line operators required to report, before the fish are landed on shore, any catches greater than 15 spotted mackerel caught within a 24 hour period.
2002 (Dec 6) [1]	Prohibition on the use of nets to target spotted mackerel (but deferred until May 2003). Commercial in-possession limit of 150 spotted mackerel. Commercial incidental net catch in-possession limit of 15 or less spotted mackerel.
2003 (May 1)	No netting for spotted mackerel allowed – end of the phasing in period.
2003 (Dec 19)	Incidental commercial net catch of 15 or less spotted mackerel – clarification in legislation.

[1]Although the netting ban was implemented into legislation from 6 December 2002, it was phased in so that net fishers had until 1 May 2003 to cease operations. Furthermore, from 6 December 2002 to 30 April 2003, fishers could continue to net for spotted mackerel with an in-possession limit of 150 fish. However, from the 1 May 2003, fishers could only take incidental catches of 15 fish or less by net and 150 in-possession by line. Due to a drafting oversight, allowing the incidental commercial net catch of 15 fish or less was not entered into legislation until 19 December 2003, but it was intended to apply from 6 December 2002.

Table 1.2. History of spotted mackerel research.

Year	Author	Research
1943	Munro	Taxonomic review of Australian *Scomberomorus* species, including spotted mackerel, describing nomenclature, distribution and morphological features. Identified spotted mackerel as *S. niphonius*, Japanese Spanish mackerel.
1980	Collette and Russo	Identified spotted mackerel as a separate species from *S. niphonius*.
1981	Lewis	Screened spotted mackerel from Australian waters for genetic polymorphisms, as part of a broader study of the ecological genetics of Scombrids.
1982	Okera	Macroscopically estimated the maturation stage of gonads from spotted mackerel sampled in the Arafura Sea and Gulf of Carpentaria.
1984	Collette and Russo	Described the morphology, systematics and distribution of 18 species of *Scomberomorus*, including spotted mackerel, to clarify relationships and systematic position within the Family Scombridae.
1997	Begg	Species coexistence, stock structure and fisheries management of spotted mackerel in Queensland east coast waters.
1997	Begg *et al.*	Movements and stock structure of spotted mackerel in Australian east coast waters.
1997	Begg and Hopper	Feeding patterns of spotted mackerel in Queensland east coast waters.
1998	Begg	Reproductive biology of spotted mackerel in Queensland east coast waters.
1998	Begg and Sellin	Age and growth of spotted mackerel in Queensland east coast waters.
1998	Begg *et al.*	Genetic variation and stock structure of spotted mackerel in northern Australian waters.
1998	Begg *et al.*	Stock discrimination of spotted mackerel in Queensland east coast waters using otolith elemental analysis.
2002	Cameron and Begg	Fisheries biology and interaction in the northern Australian small mackerel fishery. Gill net drop-out in the spotted mackerel ring net fishery.
2002	Anonymous	DPI&F spotted mackerel workshop and preliminary assessment.
2003	Ward and Rogers	Review of current and future research needs for mackerel (*Scomberomorus*) in northern Australian waters.
In prep	Barker *et al.*	DPI&F Long Term Monitoring Program of spotted mackerel.
Present	Begg *et al.*	Stock assessment of the Australian east coast spotted mackerel fishery.

Monitoring history

The Australian east coast spotted mackerel fishery is monitored by the DPI&F and NSW DPI through the use of compulsory commercial fishery logbooks, DPI&F recreational fishery surveys, and more recently as part of the DPI&F Long Term Monitoring Program (LTMP). Historical data to monitor and evaluate the status of the fishery are also available from the Queensland Fish Board, FRDC Project 92/144 (Cameron and Begg 2002), SUNTAG, and south east Queensland boat ramp creel surveys (Ferrell and Sumpton 1996, Sumpton 2000).

The Queensland Fish Board collected data from 1936-1980 on its operations and receivals as required by the various Fisheries Acts, and reported these data in an aggregated annual format. Recently, these data were compiled and entered into an appropriate database; with landing weights for each market species reported by district or month (Robins, unpublished data). These data were not representative of the complete historical landings, however, as those destined for interstate or international export were not required to pass through the Fish Board, while anecdote suggests that a number of private companies handled fisheries landings independently and black-market selling occurred. It is uncertain, therefore, what proportion of the total Queensland fisheries landings these data represent, although the high fixed prices that were offered by the Fish Board at the time, most likely means that these data represent the majority of the legal catch (Williams, pers. comm.; Hoyle 2003).

The DPI&F Commercial Fisheries Information System (CFISH) collects data from Queensland's commercial fishers through a compulsory logbook program that commenced in 1988. The data are reported on a daily basis and includes information on location fished, catch by species, weight landed and fishing gear used (Williams 2002). No data are available on discards, search time or typically on fishing effort when no fish are caught; data essential for developing reliable indices of fish abundance.

The NSW DPI also provides information on the commercial sector of the fishery through an analogous logbook program that commenced in 1984. Prior to March 1997, commercial fishers were required to complete a monthly catch return that did not link catch and effort data. Fishers were required to indicate the main fishing method for the month, total number of days fished and species and quantities landed. The catch and effort information collected through the returns were not specific to each method or species. Since the introduction of restricted fisheries in March 1997, the catch reporting requirements changed to a monthly catch return linked directly to effort information (Makin, pers. comm.).

The DPI&F Recreational Fisheries Information System (RFISH) collects data biennially from Queensland's recreational fishers as part of a two-stage sampling program. The first stage involves a State-wide telephone survey to determine the number of people participating in recreational fishing and their fishing characteristics. The second stage involves individual recreational fishers voluntarily maintaining a diary about their daily fishing activities. Results from these two stages are combined to provide estimates of State-wide estimates of recreational fish catches (Higgs 2001). These surveys have been conducted in 1997, 1999 and 2002. Furthermore, the inaugural National Recreational and Indigenous Fishing Survey (NRIFS) was conducted in 2000/2001 to provide Nation-wide estimates of recreational fish catches (Henry and Lyle 2003), which can be used to supplement the RFISH data.

The DPI&F LTMP collects biological information for priority fisheries species on an annual basis to provide data for stock assessments. Information is collected on species abundance and population structure including age, length and sex data. Monitoring of the east coast spotted mackerel fishery commenced in 2000 and involved commercial catch sampling from the main fishing locations of Bowen, Hervey Bay and Moreton Bay (Table 1.3-1.4) (Barker *et al.* In prep.).

The FRDC Project 92/144 (Cameron and Begg 2002) collected age, length, sex and maturity data for spotted mackerel sampled from Queensland commercial and recreational catches in 1992-1995 (financial years). Some data were also collected from recreational catches in New South Wales. The extent and distribution of these data varied according to year, region, month and fishing gear (Table 1.3-1.4). In addition, more directed surveys (of registered recreational boat owners) than those of the current RFISH program, provided estimates of the 1995 recreational catch of spotted mackerel in Queensland waters, including telephone, mail, diary and interstate visitor caravan surveys.

Table 1.3. Number of spotted mackerel aged in the FRDC Project 92/144 (1992-1994) and DPI&F LTMP (2000-2002) that were used in this assessment to characterise the fishery. Fishing years = financial years.

Fishing year	Gear	Number of spotted mackerel aged												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1992	Line	2	7		1	2			10			5	63	90
	Net[1]											1		1
	Net[3]	57								1			20	78
	Net[4]								80	51				131
1993	Line	3	23	1		1	1	47	7		1	2	64	150
	Net[3]	8	147	66						5		56	101	383
	Net[4]								160					160
	Net[5]									1	4			5
1994	Line									48	2	1	14	65
	Net[3]	106											88	194
	Net[4]									111				111
	Net[5]								1					1
2000	Net[3]		170											170
2001	Line			11										11
	Net[2]		6											6
	Net[3]		3											3
2002	Net[2]	9												9
	Net[3]	106												106
Total		291	356	78	1	3	1	47	258	217	7	65	350	1674

[1]Unspecified net; [2]9.5 cm mesh net; [3]10.2 cm mesh net; [4]12.7 cm mesh net; [5]15.3 cm mesh net.

Table 1.4. Number of spotted mackerel measured in the FRDC Project 92/144 (1992-1995), DPI&F LTMP (2002), SUNTAG Program (all years) and DPI&F creel surveys (1995, 1999) that were used in this assessment to characterise the fishery. Fishing years = financial years.

Fishing year	Gear	Number of spotted mackerel measured												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991	Line	37		1	2	26	9	23	15	44	3	1	129	290
1992	Line	6	36	2	6	96	19	20	46	2	12	33	651	929
	Net[1]											3		3
	Net[2]		28											28
	Net[3]	461								1			243	705
	Net[4]								90	61				151
1993	Line	36	25	1	9	97	2	58	10		12	14	595	859
	Net[2]		40											40
	Net[3]	8	328	78						5		56	322	797
	Net[4]								536					536
1994	Line	33	38	56	46	20	22	9	13	104	8	79	206	634
	Net[3]	276											324	600
	Net[4]									132				132
1995	Line	55	2		10	11	13	115	12	96	25	30	81	450
	Net[2]		53											53
	Net[3]	354										607	216	1177
	Net[4]									554				554
1996	Line		3	13	2			34	9	3	7	1	135	207
1999	Line	29			1			3			8	12	119	172
2002	Line	1			1	1	6	4			1		2	16
	Net[2]	359	456											815
	Net[3]	243	721									120	181	1265
	Net[4]								302		8			310
Total		1898	1730	151	77	251	71	266	1033	1002	84	956	3204	10723

[1]Unspecified net; [2]9.5 cm mesh net; [3]10.2 cm mesh net; [4]12.7 cm mesh net.

The SUNTAG Program, formerly known as the Sportfish Tagging Program, is a voluntary tagging program between the Australian National Sportfish Association (ANSA) and the DPI&F. Tagging has been conducted since 1985 on priority species and provides information for a range of dedicated research projects. Over 3000 spotted mackerel have been tagged to date, with a recapture rate of about 1.8%. Length-at-tagging data were used in this assessment to supplement other data, but in particular for those years when there were no dedicated research or monitoring programs (1991, 1996, 1999) (Table 1.4).

Similarly, length data collected as part of the DPI&F recreational boat ramp (on-site) creel surveys conducted in south east Queensland were used to supplement the FRDC and LTMP data (Ferrell and Sumpton 1996, Sumpton 2000). In 1995 and 1999, a total of 143 and 42 spotted mackerel were measured during the surveys.

Data collected from the research and monitoring programs, therefore, were synthesized and reported in this document and form the basis of the assessment for the Australian east coast spotted mackerel fishery.

Objectives

This assessment was conducted in response to the growing concerns of all stakeholders for the sustainability of the Australian east coast spotted mackerel fishery, and the necessary requirements of the EPBC Act. The highly aggregated, near surface schooling behaviour of the stock coupled with its predictable seasonal movements along the east coast allows ease of targeting by both the commercial and recreational sectors; thereby making the stock susceptible to over-fishing and stock collapse. The objectives of this assessment, therefore, were the following:

1. To collate available biological, historical fisheries, and commercial and recreational catch and effort data on the Australian east coast spotted mackerel fishery.
2. To review the extent and quality of all available data to determine the potential for a formalised assessment of the Australian east coast spotted mackerel fishery.
3. To optimise use of all available data to describe current trends in the fishery, and if data permits, undertake a formalised assessment of the status of the Australian east coast spotted mackerel fishery.
4. To advise on monitoring, reporting and/or further research required to improve or enable future assessments of the Australian east coast spotted mackerel fishery.

2. Population dynamics

Growth

Fork length – total length relationship

A linear model was fitted to spotted mackerel length data collected from the FRDC Project 92/144 (Begg and Sellin 1998, Cameron and Begg 2002). Data were pooled across fishing regions, gears, months, years (1993-1995) and sexes (Table 2.1). The fitted model was used to convert fork length (FL) to total length (TL) measurements (Table 2.2, Fig. 2.1).

Table 2.1. Number of spotted mackerel measured in the FRDC Project 92/144 (1992-1994) that were used in this assessment to convert fork length (FL) to total length (TL) measurements (cm).

Fishing year	Gear	Number of spotted mackerel measured												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1992	Line	2	3											5
1993	Line					5	1							6
1994	Line									3	3			6
	Net[1]	104												104
Total		106	3			5	1			3	3			121

[1]10.2 cm mesh net.

Table 2.2. Linear regression model for converting fork length (FL) to total length (TL) measurements (cm) (TL = a + b*FL). Residual standard error: 0.8602 (std of fit in cm) on 119 degrees of freedom; Multiple R^2: 0.97; F-statistic: 3606 on 1 and 119 degrees of freedom (d.f.), the p-value is 0, n=121.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix	
Intercept	6.3406	1.0167	6.24	<0.0001	1.0336336	-0.01740970
FL	1.0314	0.0172	60.05	<0.0001	-0.0174097	0.00029498

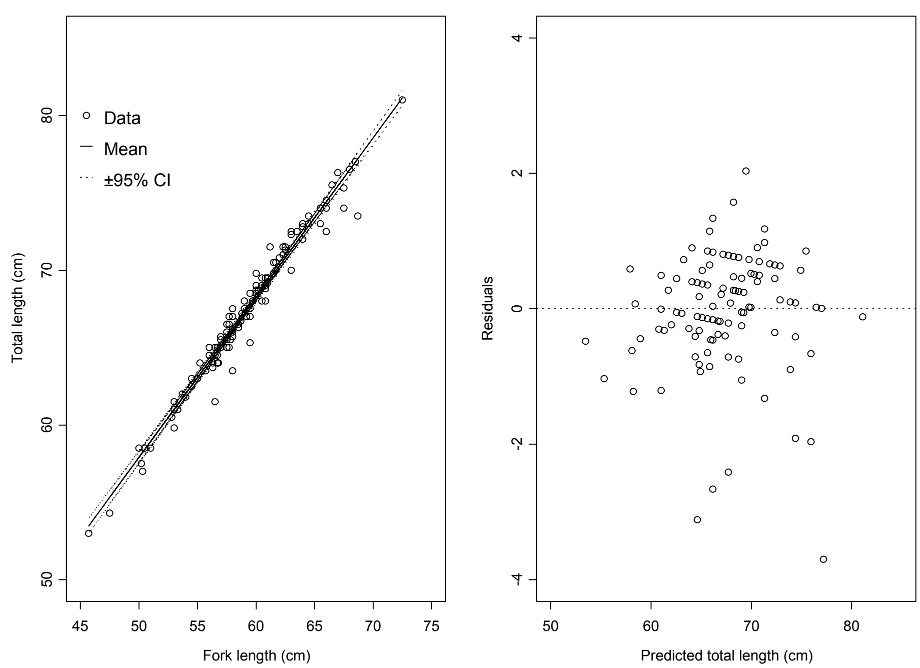

Fig. 2.1. Fork length – total length (cm) relationship of spotted mackerel, data pooled across fishing years 1993-1995.

Total length – weight relationship

Non linear least squares regression models were fitted to sex-specific spotted mackerel total length (TL) and fish weight data collected from the FRDC Project 92/144 (Begg and Sellin 1998, Cameron and Begg 2002) and the DPI&F LTMP (Barker *et al.* In prep.). Data were pooled across fishing regions, gears, months and years (1991-1993 and 2000-2002) (Table 2.3). Seasonal patterns in length-weight relationships could not be estimated because of sample limitations, with most of the data collected between November and February. Results from the models, therefore, principally represent the November to February length-weight relationships. The fitted models were used to predict fish body weight (kg) from total length (TL, cm) measurements (Table 2.4, Fig. 2.2).

Table 2.3. Number of spotted mackerel measured and weighed in the FRDC Project 92/144 (1992-1994) and DPI&F LTMP (2000-2002) that were used in this assessment to convert total length (TL, cm) to fish body weight (kg).

Fishing year	Gear	Number of spotted mackerel measured and weighed												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991	Line						1							1
1992	Line				1			2					41	44
	Net[2]	58											20	78
1993	Line		21										10	31
	Net[2]	8	106	78						5		55	103	355
	Net[4]										1			1
2000	Net[2]		183											183
2001	Line			11										11
2002	Net[1]	359	456											815
	Net[2]	162	721									125	181	1189
	Net[3]								302		8			310
Total		587	1487	89	1	0	1	2	302	5	9	180	355	3018

[1]9.5 cm mesh net; [2]10.2 cm mesh net; [3]12.7 cm mesh net; [4]15.3 cm mesh net.

Table 2.4. Non linear least squares regression models for predicting fish body weight (kg) from total length (TL, cm) ($Wt = a*TL^b$).

(A) Data pooled across sexes (n=3018). Residual standard error: 0.19399 (std of fit in kg) on 3016 d.f. (R^2=0.72).

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix	
a	1.16486e-6	8.42977e-8	13.82	<0.0001	7.11e-15	-1.42e-09
b	3.37027	1.68571e-2	199.93	<0.0001	-1.42e-09	2.84e-04

(B) Females (n= 383). Residual standard error: 0.20425 (std of fit in kg) on 381 d.f. (R^2=0.95).

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix	
a	1.78703e-6	3.03403e-7	5.89	<0.0001	9.21e-14	-1.19e-08
b	3.25467	3.93161e-2	82.78	<0.0001	-1.19e-08	1.55e-03

(C) Males (n= 316). Residual standard error: 0.23725 (std of fit in kg) on 314 d.f. (R^2=0.90).

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix	
a	7.34056e-6	5.03159e-6	1.46	0.1453	2.53e-11	-8.16e-07
b	2.91509	1.62206e-1	17.97	<0.0001	-8.16e-07	2.63e-02

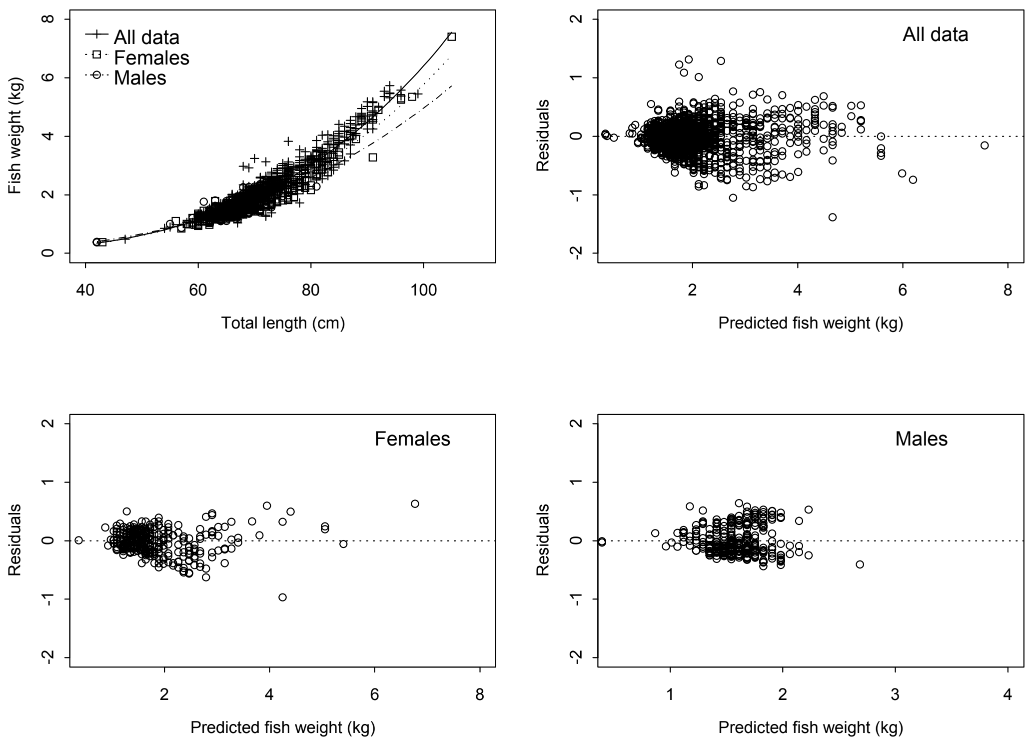

Fig. 2.2. Total length (cm) – weight (kg) sex-specific relationships of spotted mackerel, data pooled across fishing years 1991-1993 and 2000-2002.

Von Bertalanffy growth relationship

Non linear least squares regression models were fitted to sex-specific spotted mackerel total length and age data collected from the FRDC Project 92/144 (Begg and Sellin 1998, Cameron and Begg 2002) and the LTMP (Barker *et al.* In prep.). Final age estimates involved multiple reads where otoliths collected in the FRDC Project were aged twice, once each by two independent readers. In contrast, otoliths collected in the LTMP were aged three times by two independent readers. Where multiple reads disagreed, the final age was estimated to be the majority between reads when the difference between reads was less than or equal to two years of age. Age data that disagreed by more than two years between readers were excluded from the analysis. About 9% and 1% of the FRDC and LTMP data, respectively, were excluded. Final data for analysis were pooled across fishing regions, gears, months and years (1992-1994 and 2000-2002) (Table 2.5).

The fitted von Bertalanffy growth models were used to predict total length (TL, cm) from age (years) (Fig. 2.3, Table 2.6). Length based growth curves were estimated for the von Bertalanffy growth parameters according to the following equation:

$$L_t = L_\infty(1 - e^{-K[t-t_0]}) \qquad (2.1)$$

where, L_t = length (cm) at age t (years); L_∞ = asymptotic average maximum fish length; K = growth rate coefficient that determines how quickly the maximum length is attained; and t_0 = hypothetical age at which the species has zero length (*i.e.*, fixes position of curve along x-axis and can affect the steepness of the curve) (Haddon 2001).

Table 2.5. Number of spotted mackerel measured and aged in the FRDC Project 92/144 (1992-1994) and DPI&F LTMP (2000-2002) that were used in this assessment to convert total length (TL, cm) to age (years).

Fishing year	Gear	Number of spotted mackerel measured and aged												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1992	Line	2	7		1	2			10			5	63	90
	Net[1]											1		1
	Net[3]	57								1			20	78
	Net[4]								80	51				131
1993	Line	3	23	1		1	1	47	7		1	2	64	150
	Net[3]	8	147	66						5		56	101	383
	Net[4]								160					160
	Net[5]									1	4			5
1994	Line									48	2	1	14	65
	Net[3]	106											88	194
	Net[4]									111				111
	Net[5]								1					1
2000	Net[3]		170											170
2001	Line			11										11
	Net[2]		6											6
	Net[3]		3											3
2002	Net[2]	9												9
	Net[3]	106												106
Total		291	356	78	1	3	1	47	258	217	7	65	350	1674

[1]Unspecified net; [2]9.5 cm mesh net; [3]10.2 cm mesh net; [4]12.7 cm mesh net; [5]15.3 cm mesh net.

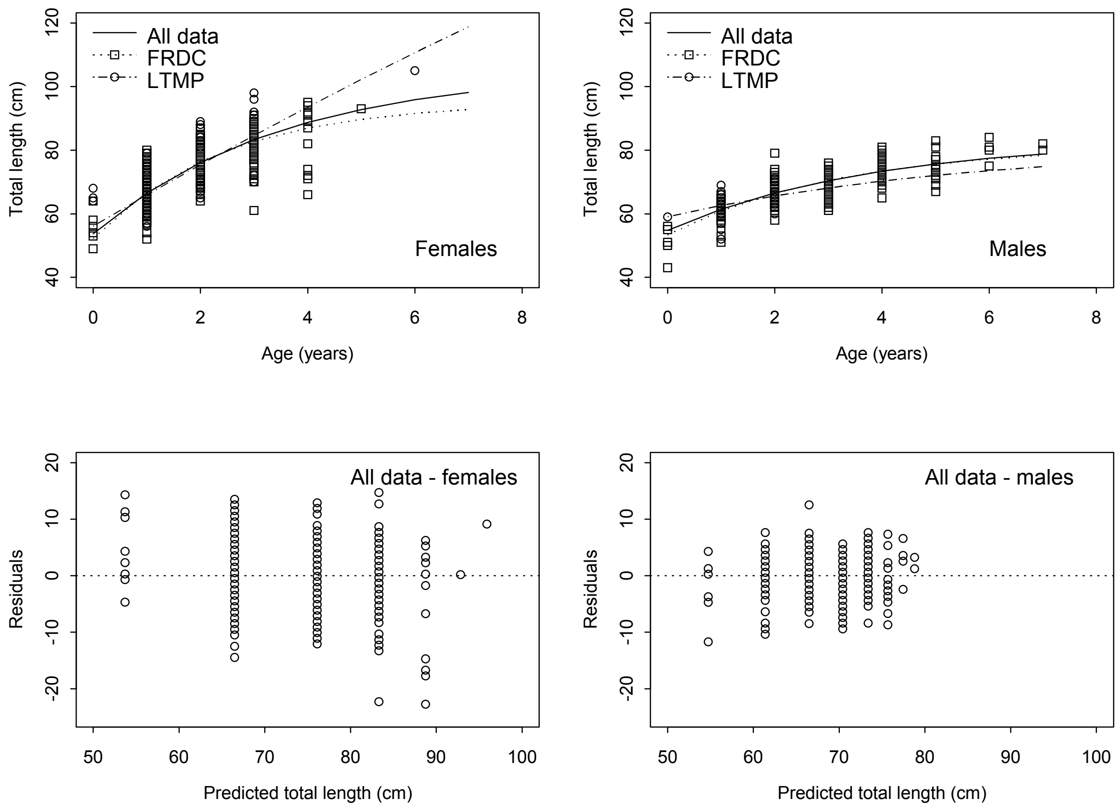

Fig. 2.3. Sex-specific von Bertalanffy growth models used to predict total length (cm) from age (years). Age zero refers to 0+ fish (likewise for other age groups).

Table 2.6. Sex-specific von Bertalanffy growth parameters (L_∞, K, t_0) used to predict total length (TL, cm) from age (years).

(A) Female data pooled across years (n=922). Residual standard error: 4.47115 (std of fit in cm) on 919 d.f.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix		
L_∞	105.1330	5.13149	20.48770	<0.0001	26.3322	-0.2400	-1.4240
K	0.286023	0.0474028	6.03387	<0.0001	-0.2400	0.0022	0.0137
t_0	-2.499750	0.2951540	-8.46931	<0.0001	-1.4240	0.0137	0.0871

(B) Female data from FRDC Project, fishing years 1992-1994 (n=673). Residual standard error: 4.48554 (std of fit in cm) on 670 d.f.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix		
L_∞	95.0674	2.95058	32.21990	<0.0001	8.7059	-0.1657	-0.6357
K	0.415341	0.0576364	7.20623	<0.0001	-0.1657	0.0033	0.0134
t_0	-1.921030	0.2367790	-8.11317	<0.0001	-0.6357	0.0134	0.0561

(C) Female data from LTMP, fishing years 2000-2002 (n=249). Residual standard error: 4.18531 (std of fit in cm) on 246 d.f.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix		
L_∞	380.4470	596.95200	0.637317	0.5245	356351.2	-36.1412	-905.44
K	0.0306899	0.0605675	0.506705	0.6128	-36.1413	0.0037	0.0924
t_0	-5.1980400	1.5579100	-3.336540	0.0009	-905.437	0.0924	2.4271

(D) Male data pooled across years (n=752). Residual standard error: 2.84111 (std of fit in cm) on 749 d.f.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix		
L_∞	83.1926	1.92391	43.24150	<0.0001	3.7014	-0.0651	-0.7768
K	0.266619	0.0345305	7.72125	<0.0001	-0.0651	0.0012	0.0148
t_0	-4.024360	0.4349610	-9.25223	<0.0001	-0.7768	0.0148	0.1892

(E) Male data from FRDC Project, fishing years 1992-1994 (n=696). Residual standard error: 2.76403 (std of fit in cm) on 693 d.f.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix		
L_∞	81.4858	1.44284	56.47580	<0.0001	2.0818	-0.0482	-0.4524
K	0.312635	0.0344251	9.08158	<0.0001	-0.0482	0.0012	0.0117
t_0	-3.401840	0.3477130	-9.78348	<0.0001	-0.4524	0.0117	0.1209

(F) Male data from LTMP, fishing years 2000-2002 (n=56). Residual standard error: 3.4733 (std of fit in cm) on 53 d.f.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix		
L_∞	81.4851	109.08300	0.747004	0.4584	11899.00	-116.26	-2856.87
K	0.173365	1.06724	0.162443	0.8716	-116.26	1.14	28.06
t_0	-7.426900	26.33210	-0.282047	0.7780	-2856.87	28.06	693.38

Maximum age and length

The oldest spotted mackerel aged in either the FRDC (1992-1994) or LTMP (2000-2002) data were two 7 year old males, 80 and 82 cm TL, respectively (1992, 1993). The largest male aged was 84 cm TL (1992), and the heaviest 2.8 kg (1993). The oldest female spotted mackerel aged was 6 years old, 105 cm TL and 7.4 kg (2001). This was also the largest and heaviest female spotted mackerel aged.

Sex ratio

Length based sex ratios were estimated for spotted mackerel and applied to the different length distributions collected in 1991-1996, 1999 and 2002 (Cameron and Begg 2002, Barker *et al.* In prep.). Data were pooled across fishing regions, gears, months and years (Table 1.4; Appendix 2). An increasing trend of greater numbers of females in the population at larger sizes was observed in the data. The final length based sex ratios, therefore, were based on observed data and an assumed 50:50 sex ratio up until 75 cm; the length at which the proportion of females began to consistently increase (Appendix 2). Observed data were then used for increasing 5 cm length intervals (*i.e.*, 50-74 cm 50%; 75-79 cm: 60%; 80-84 cm: 84%; ≥85 cm: 100% females). Sex-specific age length distribution keys (ALKs) were applied to the sex differentiated length distributions to derive the final age structures used in the assessment.

Age structure

Sex-specific ALKs were derived for spotted mackerel because of the significant differential growth between the sexes. The ALKs were derived from total length and age data collected from the FRDC Project 92/144 (Cameron and Begg 2002) and the LTMP (Barker *et al.* In prep.) (Appendix 2). This enabled two discrete periods (1992-1994 and 2000-2002) of the fishery to be represented. However, owing to data limitations with the LTMP sampling and relative similarities in growth trends for males, all data were pooled to form a single ALK for each spotted mackerel sex (Table 2.7). Data were also pooled across regions, fishing gears, months, and for total lengths greater than or equal to the 99th length percentile. Although data limitations necessitated the use of a single sex-specific ALK for each year this was far from ideal as it failed to account for potential periodic strong and weak year classes due to variable recruitment. The final ALKs were used to estimate sex-specific age structures from the sex differentiated length distributions collected in 1991-1996, 1999 and 2002 for the different fishing gears (line, net mesh 9.5 cm, 10.2 cm, 12.7 cm) (Table 1.4).

Table 2.7. Final sex-specific age length distribution keys (ALKs) used for spotted mackerel. Data were pooled across fishing years (1992-1994 and 2000-2002), regions and gears. Values in bold are mean estimates for lengths in which no data were available. Estimates based on proportions for length intervals before and after missing length. Females less than 50 cm TL were all assumed to be 0+ age group.

TL (cm)	**Females**								**TL (cm)**	**Males**							
	Age group (years)									**Age group (years)**							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
<50	**1.00**								<50	1.00							
51	**0.50**	**0.50**							51	0.50	0.50						
52		1.00							52		1.00						
53	1.00								53		1.00						
54	0.67	0.33							54	**0.33**	**0.67**						
55	**0.58**	**0.42**							55	0.67	0.33						
56	0.50	0.50							56	1.00							
57		1.00							57		1.00						
58	0.60	0.40							58		0.83	0.17					
59		1.00							59	0.14	0.86						
60		1.00							60		0.91	0.09					
61		0.93		0.07					61		0.70	0.20	0.10				
62		1.00							62		0.56	0.38	0.06				
63		1.00							63		0.29	0.63	0.08				
64	0.03	0.95	0.02						64		0.26	0.71	0.03				
65	0.01	0.97	0.01						65		0.22	0.73	0.02	0.02			
66		0.96	0.03		0.01				66		0.15	0.68	0.17				
67		0.99	0.01						67		0.01	0.66	0.31		0.01		
68	0.02	0.92	0.06						68			0.52	0.43	0.05			
69		0.91	0.09						69		0.04	0.40	0.49	0.06	0.01		
70		0.80	0.15	0.05					70			0.28	0.66	0.06			
71		0.71	0.21	0.06	0.03				71			0.05	0.79	0.15	0.02		
72		0.50	0.36	0.11	0.04				72			0.02	0.61	0.35	0.02		
73		0.33	0.61	0.06					73			0.03	0.42	0.39	0.16		
74		0.28	0.67		0.06				74			0.03	0.33	0.43	0.20		
75		0.13	0.83	0.04					75				0.56	0.32	0.08	0.04	
76		0.10	0.87	0.03					76				0.17	0.83			
77		0.10	0.86	0.05					77					0.63	0.38		
78		0.06	0.88	0.06					78					0.58	0.42		
79		0.08	0.88	0.04					79			0.17		0.83			
80		0.06	0.83	0.11					>80					0.30	0.20	0.30	0.20
81			0.81	0.19													
82			0.55	0.36	0.09												
83			0.63	0.38													
84			0.75	0.25													
85			0.33	0.67													
86				1.00													
87			0.38	0.50	0.13												
88			0.20	0.80													
89			0.14	0.71	0.14												
90				1.00													
91				0.67	0.33												
>92				0.40	0.40	0.10	0.10										
Total	0.014	0.654	0.246	0.070	0.013	0.001	0.001	0.000	Total	0.011	0.114	0.340	0.348	0.141	0.037	0.005	0.003

Sex-specific age structures derived from the respective ALK were combined to form a single final age structure for each year's catch in which there was fish length data and used as input into the stock assessment model (Table 2.8, Fig. 2.4). The combined age structure for each year's catch was appropriately weighted by multiplying each fishing sector's catch distribution of fish lengths from each region by the proportion of the total catch (tonnes) taken by that sector from that region. Overall, the spotted mackerel population was highly dependent on young fish, with 1-3 year olds being the dominant age groups (Fig. 2.4). This age structure was consistent across all years, with a typically highly truncated distribution. Based on these age structures and the underlying growth patterns, we assumed for purposes of the assessment that spotted mackerel could live for up to 10 years of age.

Table 2.8. Final age structures (proportions) of spotted mackerel from 1991-1996, 1999 and 2002. These were used as input into the assessment model.

Fishing	**Proportion of catch-at-age group +**										
year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1991	0.121	0.393	0.253	0.151	0.059	0.014	0.006	0.003	0.000	0.000	0.000
1992	0.042	0.537	0.267	0.112	0.033	0.007	0.002	0.001	0.000	0.000	0.000
1993	0.017	0.436	0.299	0.158	0.068	0.017	0.003	0.002	0.000	0.000	0.000
1994	0.086	0.427	0.259	0.146	0.059	0.016	0.005	0.002	0.000	0.000	0.000
1995	0.035	0.596	0.243	0.086	0.031	0.008	0.001	0.001	0.000	0.000	0.000
1996	0.064	0.501	0.241	0.138	0.038	0.010	0.007	0.002	0.000	0.000	0.000
1999	0.054	0.560	0.246	0.090	0.035	0.011	0.002	0.001	0.000	0.000	0.000
2002	0.003	0.419	0.274	0.225	0.064	0.013	0.001	0.001	0.000	0.000	0.000

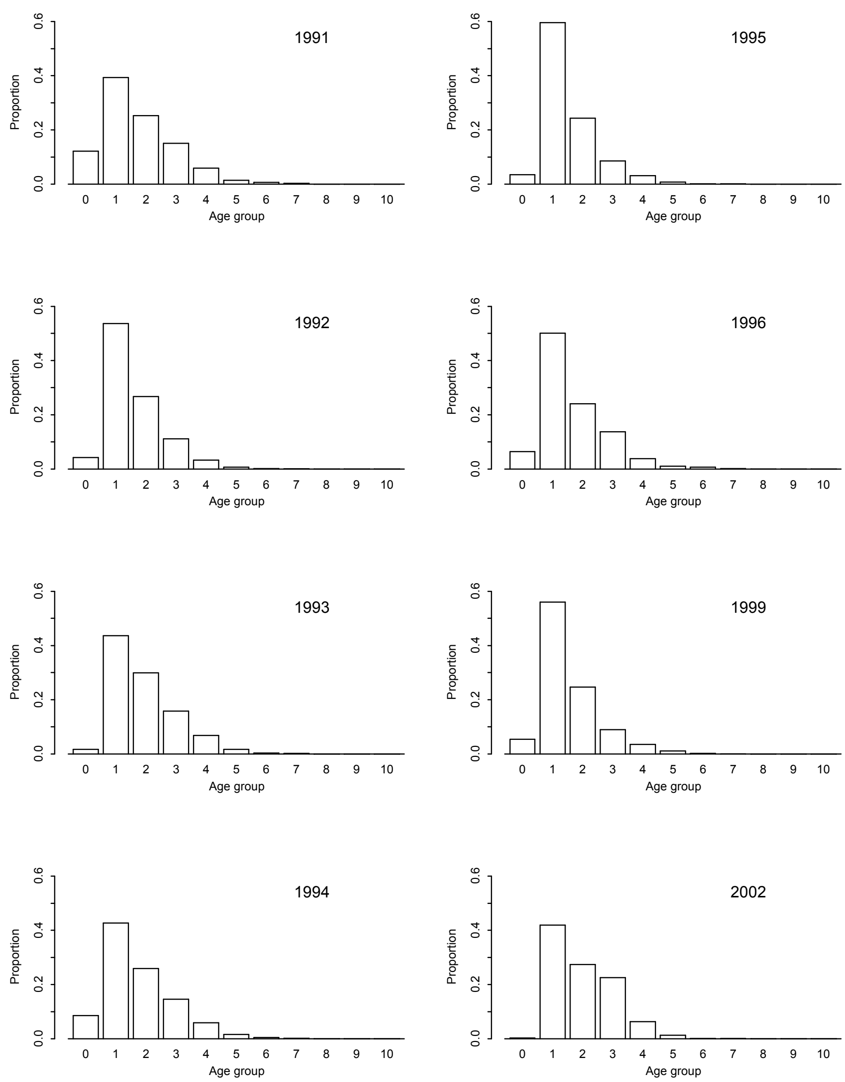

Fig. 2.4. Final age structures of spotted mackerel from 1991-1996, 1999 and 2002 that were used in the assessment model.

Maturity

Logistic regression analysis was used to estimate sex-specific length and age based maturity ogives for spotted mackerel from total length and macroscopically determined maturity data (immature: Stage I; mature: Stage II-VI females, II-IV males) collected from the FRDC Project 92/144 (Cameron and Begg 2002). Data were pooled across the peak spawning months of August-October (fishing years 1992-1994) (Begg 1998) (Table 2.9, 2.10). GLMs for binary regression (McCullagh and Nelder 1989) were used to predict the probability (*p*) of a spotted mackerel being mature. The probability *p* was modelled using a logistic-link (*i.e.*, logit) function and binomial error distribution, and related through a linear regression function with total length (TL) and age as covariates. The fitted models were applied to the sex-specific length distributions to estimate the proportion mature at each length and age, respectively (Table 2.11-2.18). Female and male spotted mackerel matured about 60 cm (±95%CI 57-63 cm) and 52 cm (±95%CI 47-56 cm) TL, respectively, within 1-2 years of age (Fig. 2.5, 2.6, and see Fig. 2.3).

Table 2.9. Number of spotted mackerel measured and macroscopically staged in the FRDC Project 92/144 (1992-1994) that were used in this assessment to estimate proportion mature. Fishing years = financial years.

Fishing year	Gear	Number of spotted mackerel measured and macroscopically staged												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1992	Line								12					12
	Net[1]									1				1
	Net[2]								87	61				148
1993	Line								7		1			8
	Net[1]									5				5
	Net[2]								182					182
	Net[3]									1	1			2
	Net[4]								1					1
1994	Line									84	5			89
	Net[2]									112				112
	Net[3]									1				1
Total									289	265	7			561

[1]10.2 cm mesh net; [2]12.7 cm mesh net; [3]15.3 cm mesh net; [4]17.8 cm mesh net.

Table 2.10. Number of spotted mackerel aged and macroscopically staged in the FRDC Project 92/144 (1992-1994) that were used in this assessment to estimate proportion mature. Fishing years = financial years.

Fishing year	Gear	Number of spotted mackerel aged and macroscopically staged												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1992	Line								10					10
	Net[1]									1				1
	Net[2]								77	51				128
1993	Line								7		1			8
	Net[1]									5				5
	Net[2]								157					157
	Net[3]									1	1			2
1994	Line									48	2			50
	Net[2]									96				96
Total									251	202	4			457

[1]10.2 cm mesh net; [2]12.7 cm mesh net; [3]15.3 cm mesh net.

Table 2.11. Analysis of deviance table for binomial model covariate (TL, cm) in determining the probability of a female spotted mackerel being mature. All data combined.

Fitted term	d.f.	Deviance	Mean deviance	Chi square	Probability
TL	1	97.66059	97.66059	97.66059	<.0001
Residual	196	48.59532	0.247935		
Total	197	146.2559			

Table 2.12. Parameter estimates and standard errors from the binary regression analysis (TL as covariate) of the probability of a female spotted mackerel being mature.

Parameter	Estimate	S.E.	T Statistic	Probability	Covariance matrix	
Constant	-20.8931	4.307465	-4.85045	<.0001	18.5542557	-0.3029194
TL	0.349625	0.070581	4.953557	<.0001	-0.3029194	0.00498163

Table 2.13. Analysis of deviance table for binomial model covariate (TL, cm) in determining the probability of a male spotted mackerel being mature. All data combined.

Fitted term	d.f.	Deviance	Mean deviance	Chi square	Probability
TL	1	38.08455	38.08455	38.08455	<.0001
Residual	361	53.47375	0.148127		
Total	362	91.55831			

Table 2.14. Parameter estimates and standard errors from the binary regression analysis (TL as covariate) of the probability of a male spotted mackerel being mature.

Parameter	Estimate	S.E.	T Statistic	Probability	Covariance matrix	
Constant	-13.813	3.0447	-4.53674	<.0001	9.2702002	-0.1498838
TL	0.265116	0.049643	5.340439	<.0001	-0.1498838	0.002464445

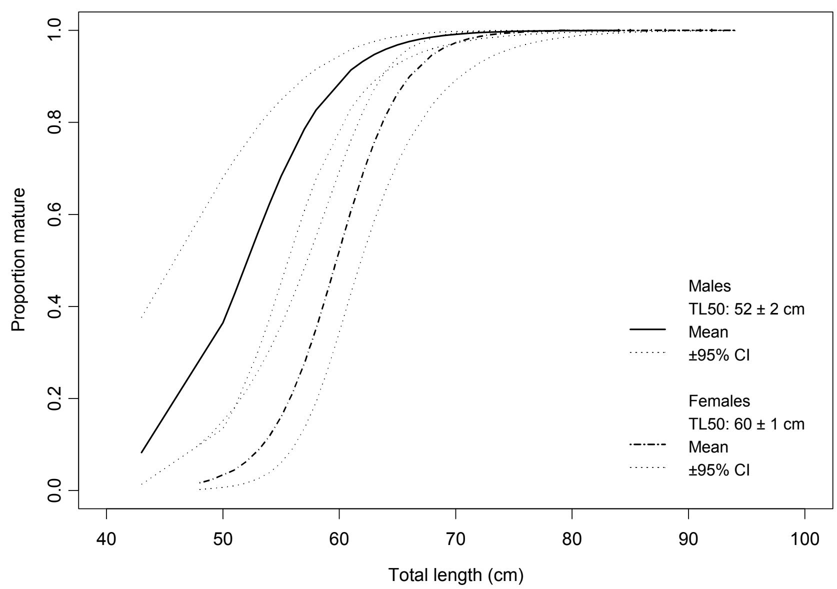

Fig. 2.5. Sex-specific binary regression models used to predict the probability of a spotted mackerel being mature based on total length (TL, cm). TL50 = mean length of population at 50% maturity (±S.E.).

Table 2.15. Analysis of deviance table for binomial model covariate (age, years) in determining the probability of a female spotted mackerel being mature. All data combined.

Fitted term	d.f.	Deviance	Mean deviance	Chi square	Probability
Age	1	62.39713	62.39713	62.39713	<.0001
Residual	150	21.56491	0.143766		
Total	151	83.96204			

Table 2.16. Parameter estimates and standard errors from the binary regression analysis (age as covariate) of the probability of a female spotted mackerel being mature.

Parameter	Estimate	S.E.	T Statistic	Probability	Covariance matrix	
Constant	-2.631988	1.092091	-2.410043	0.0172	1.1926636	-0.9450584
Age	4.146439	1.025935	4.041620	0.0001	-0.9450584	1.0525425

Table 2.17. Analysis of deviance table for binomial model covariate (age, years) in determining the probability of a male spotted mackerel being mature. All data combined.

Fitted term	d.f.	Deviance	Mean deviance	Chi square	Probability
Age	1	27.80106	27.80106	27.80106	<.0001
Residual	303	23.22526	0.076651		
Total	304	51.02632			

Table 2.18. Parameter estimates and standard errors from the binary regression analysis (age as covariate) of the probability of a male spotted mackerel being mature.

Parameter	Estimate	S.E.	T Statistic	Probability	Covariance matrix	
Constant	-0.3193287	0.7828845	-0.4078874	0.6836	0.6129082	-0.270163
Age	2.1507304	0.5193215	4.1414236	<.0001	-0.270163	0.2696948

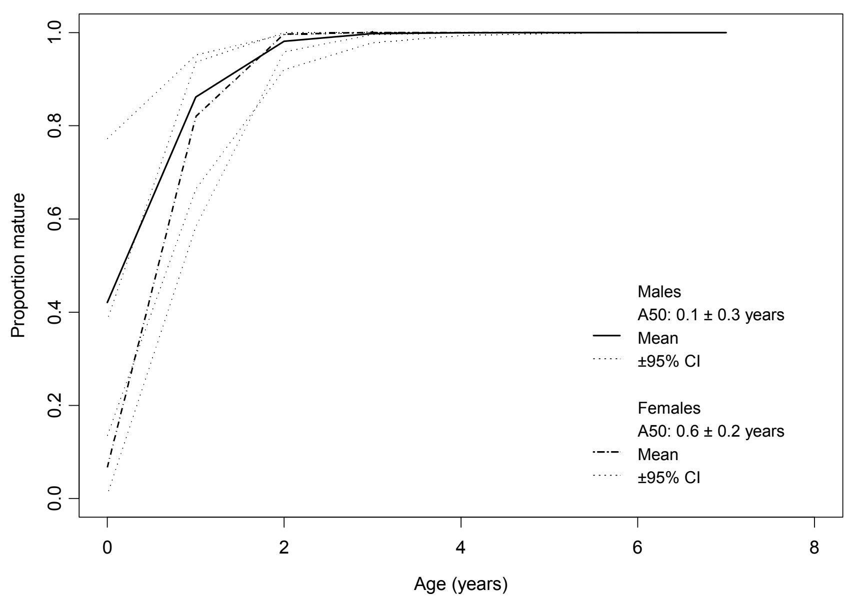

Fig. 2.6. Sex-specific binary regression models used to predict the probability of a spotted mackerel being mature based on age (years). A50 = mean age of population at 50% maturity (±S.E.).

Fecundity

A non linear least squares regression model was fitted to spotted mackerel total length and total potential fecundity data collected from the FRDC Project 92/144 (Begg 1998, Cameron and Begg 2002). Data were pooled across fishing years (1993-1995). The exponential fitted model was used to predict numbers of eggs from total length (TL) measurements (Table 2.19, Fig. 2.7).

Table 2.19. Non linear least squares power regression model for predicting number of eggs from total length (TL, cm) (Eggs=a*TL^b). Residual standard error: 209.704 (std of fit in thousands of eggs) on 12 d.f. (R^2=0.92).

Parameter	Estimate	S.E.	T Statistic	Probability	Covariance matrix	
a	3.23507e-007	1.14235e-006	0.283194	0.7819	1.304967e-012	-9.08365e-007
b	4.93960	7.95308e-001	6.210930	<0.0001	-9.08365e-007	6.325155e-001

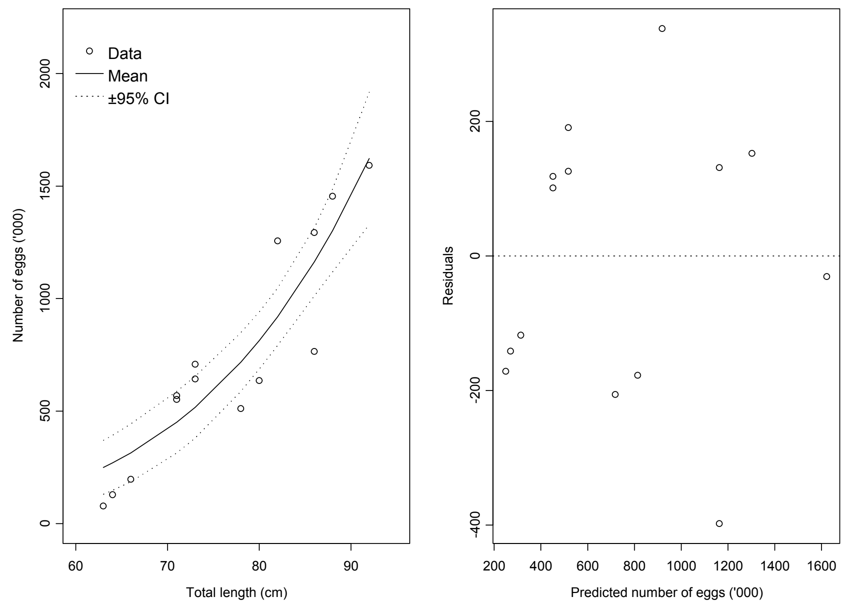

Fig. 2.7. Total length (TL, cm) – number of eggs ('000) fecundity relationship of spotted mackerel, data pooled across fishing years 1993-1995.

Natural mortality

Natural mortality (*M*) is a key parameter in most stock assessments, but is one of the most difficult to estimate due to its confounding effects with recruitment and fishing mortality (Quinn and Deriso 1999). Estimates of *M* are typically unreliable (Hilborn and Walters 1992, Sparre and Venema 1998), and represent a major uncertainty in the assessment of spotted mackerel. In the recent Australian east coast Spanish mackerel (*Scomberomorus commerson*) assessment, model results were extremely sensitive to estimates of *M*, with widely varying interpretations of stock status (Welch *et al.* 2002). As direct measurements of *M* are difficult to obtain, most assessments have attempted to approximate life history proxies or estimates which can be assumed proportional to *M* and which are easier to measure. *M* is usually assumed to be a fixed constant, although in reality it is a random variable over time, age, size and year class (Quinn and Deriso 1999). The usual assumption that *M* remains constant for all age (size) groups, therefore, is probably unrealistic (Haddon 2001). Typically, however, it is only for unexploited stocks that *M* can be estimated directly (Sparre and Venema 1998), such as for those in "no-take" marine protected areas (Mapstone *et al.* 2004).

Life history proxies or variants of growth have been demonstrated to be related to longevity and are often used to estimate *M* (Rikhter and Efanov 1977, Gunderson 1980, Pauly 1980, Hoenig 1983, Gunderson and Dygert 1988). Generally, species with a fast growth rate (*i.e.*, high *K*) tend to have a high *M*, and those with a slow growth rate a low *M*. Larger fish (*i.e.*, high L_∞) also tend to have fewer predators than smaller fish, and hence a lower *M*. Further, as most biological processes increase at higher temperatures, *M* has been suggested to be related to ambient temperature (Pauly 1980). A number of these proxies, however, are problematic in that their estimates of *M* are dependent on the representativeness of the older age groups in the samples (Sparre and Venema 1998, Quinn and Deriso 1999).

In this assessment, we used several methods for estimating the *M* of spotted mackerel. Similar to the recent Spanish mackerel assessment (Welch *et al.* 2002), Hoenig's (1983) equation was used to estimate *M* from the assumed age of the oldest fish in the population according to the following:

$$M = e^{1.44-0.982\log(Maximum\ Age)} \tag{2.2}$$

where, *Maximum Age* of spotted mackerel was assumed to be 10 years based on the trajectory of the von Bertalanffy growth models; albeit that the oldest fish aged was 7 years.

Pauly's (1980) equation was also used to estimate *M* based on the von Bertalanffy growth parameters and ambient temperature according to the following:

$$M = e^{(-0.0152-0.279\log L_{\infty}+0.6543\log K+0.4634\log T)} \tag{2.3}$$

where, L_{∞} = asymptotic average maximum fish length (94 cm); *K* = growth rate coefficient (0.276); and *T* = mean ambient seawater temperature (24.83 °C). The von Bertalanffy growth parameters were those derived from the average of the combined data sex-specific parameters (Table 2.6A, D). *T* was estimated as the mean sea surface temperature (SST) from data for those months and regions where the commercial catch for a region was >10% in any given month (pooled across fishing years 1988-2002) (Table 2.20). This temperature-catch association reflected the general migratory distribution of spotted mackerel in a given year.

Table 2.20. Australian east coast spotted mackerel commercial catch (t) and proportions, by month and region, pooled across fishing years 1988-2002 (see Chapter 3). SST data from those months and regions where catch >10% (indicated in bold) were used to estimate an overall mean SST for the Pauly (1983) *M* equation. Regions: Towns = Townsville; Rock = Rockhampton; Hervey = Hervey Bay; Moreton = Moreton Bay.

Month	Commercial spotted mackerel catch (t)								
	Far north	Cairns	Towns	Bowen	Mackay	Rock	Hervey	Moreton	NSW
Jan	<1	<1	0	1	1	3	375	165	45
Feb	0	<1	<1	<1	<1	1	103	91	43
Mar	<1	<1	<1	1	<1	1	45	43	70
Apr	<1	1	<1	<1	<1	2	16	28	91
May	<1	<1	<1	1	<1	2	1	11	31
Jun	<1	1	<1	2	<1	1	<1	12	11
Jul	<1	61	1	184	3	9	<1	3	1
Aug	<1	64	1	159	7	27	1	2	1
Sep	1	5	2	67	13	5	1	3	<1
Oct	<1	1	<1	3	6	3	3	1	<1
Nov	<1	<1	<1	<1	3	4	104	23	2
Dec	0	<1	<1	<1	1	3	412	60	11

Month	Proportion of commercial spotted mackerel catch								
	Far north	Cairns	Towns	Bowen	Mackay	Rock	Hervey	Moreton	NSW
Jan	0.00	0.00	0.00	0.00	0.00	0.01	**0.64**	**0.28**	0.08
Feb	0.00	0.00	0.00	0.00	0.00	0.00	**0.43**	**0.38**	**0.18**
Mar	0.00	0.00	0.00	0.00	0.00	0.01	**0.28**	**0.27**	**0.44**
Apr	0.00	0.00	0.00	0.00	0.00	0.01	**0.11**	**0.21**	**0.66**
May	0.00	0.00	0.01	0.02	0.01	0.05	0.02	**0.24**	**0.66**
Jun	0.00	0.05	0.01	0.08	0.01	0.05	0.01	**0.42**	**0.37**
Jul	0.00	**0.23**	0.00	**0.70**	0.01	0.03	0.00	0.01	0.01
Aug	0.00	**0.24**	0.00	**0.61**	0.03	0.10	0.00	0.01	0.00
Sep	0.01	0.05	0.02	**0.70**	**0.13**	0.05	0.01	0.03	0.00
Oct	0.00	0.04	0.02	**0.19**	**0.35**	**0.17**	**0.18**	0.03	0.02
Nov	0.00	0.00	0.00	0.00	0.02	0.03	**0.77**	**0.17**	0.01
Dec	0.00	0.00	0.00	0.00	0.00	0.01	**0.85**	**0.12**	0.02

Pauly (1983) modified this equation to compensate for fish schooling behaviour and was the estimate we used for spotted mackerel:

$$M = 0.8e^{(-0.0152 - 0.279\log L_{\infty} + 0.6543\log K + 0.4634\log T)} \qquad (2.4)$$

where, Pauly's (1980) estimator was lowered by 20% because of the assumed increase in survival for a schooling fish species.

Estimates of *M* for spotted mackerel were extremely similar between the Hoenig (1983) and Pauly (1983) methods (Table 2.21). For the assessment, however, we used the Pauly (1983) estimator as it captures more of the stock and environmental characteristics experienced throughout the life history of the species, and is less influenced by sample limitations associated with the oldest age groups. The estimate of 0.42 equates to an annual instantaneous mortality rate of 34% (*i.e.*, 66% survival), and is similar to those for other *Scomberomorus* species (*e.g.*, 0.2-0.5) (Arreguin-Sanchez *et al.* 1995, Govender 1995, Al-Hosni and Siddeek 1999, Welch *et al.* 2002).

Table 2.21. Estimates of natural mortality (*M*) for spotted mackerel based on life history proxies of Hoenig (1983) and Pauly (1983). Hoenig estimate was based on a 10 year old spotted mackerel; Pauly estimate based on schooling species and mean growth estimates for males and females.

Method	Estimate of *M*
Hoenig	0.44
Pauly (schooling)	0.42
Average	0.43

Stock-recruitment steepness

The relationship between spawning stock size and recruitment is another critical input required for stock assessment. This relationship defines how much the spawning stock can be reduced before recruitment is not sufficient enough to replace those being caught; a situation known as recruitment over-fishing. Annual recruitment to a fish population is essential for a sustainable fishery, but is naturally highly variable due to the complex interactions of the spawning stock and the environment, and thus is very difficult to quantify.

A number of models have been used to describe stock-recruitment relationships (Ricker 1954, Schaefer 1954, Beverton and Holt 1957, Ricker 1975, Deriso 1980, Schnute 1985), although in this assessment we assumed the Beverton-Holt (1957) model. This model was devised to incorporate density-dependent survival rates reflecting intra-cohort competition for critical resources and is defined by the following (see Haddon 2001):

$$R = \frac{S}{\alpha + \beta S} e^{\varepsilon} \qquad (2.5)$$

$$R = \frac{aS}{b + S} e^{\varepsilon} \qquad (2.6)$$

where, R = recruitment; S = spawning stock size; β = asymptotic limit (*i.e.*, $1/\beta$); α = inversely related to rate at which curve attains asymptote and thereby determines relative steepness near origin; a = maximum number of recruits produced (*i.e.*, $1/\beta$); and b = spawning stock (a/β) needed to produce on average, recruitment equal to half that of the maximum ($a/2$). The initial steepness is approximated by $a/b = 1/\alpha$ which occurs when S is very small. The error term (e^{ε}) indicates that the residual errors between the relationship and observed data are expected to be lognormal. The asymptote of the relationship is given by the value of parameter a, while the initial steepness (h) is approximated by the value of (*a*/*b*) which occurs when *S* is very small (*i.e.*, expected recruitment at 20% of the virgin spawner stock size) (Haddon 2001). The higher the steepness, the smaller the spawning stock size required to reach the recruitment asymptote (Fig. 2.8). Stocks with high steepness tend to have higher resilience to fishing than stocks with low steepness. The Beverton-Holt model derives from a balance between density-independent and density-dependent juvenile mortality, and implies that the larger the spawning stock the faster the juveniles will die (Haddon 2001).

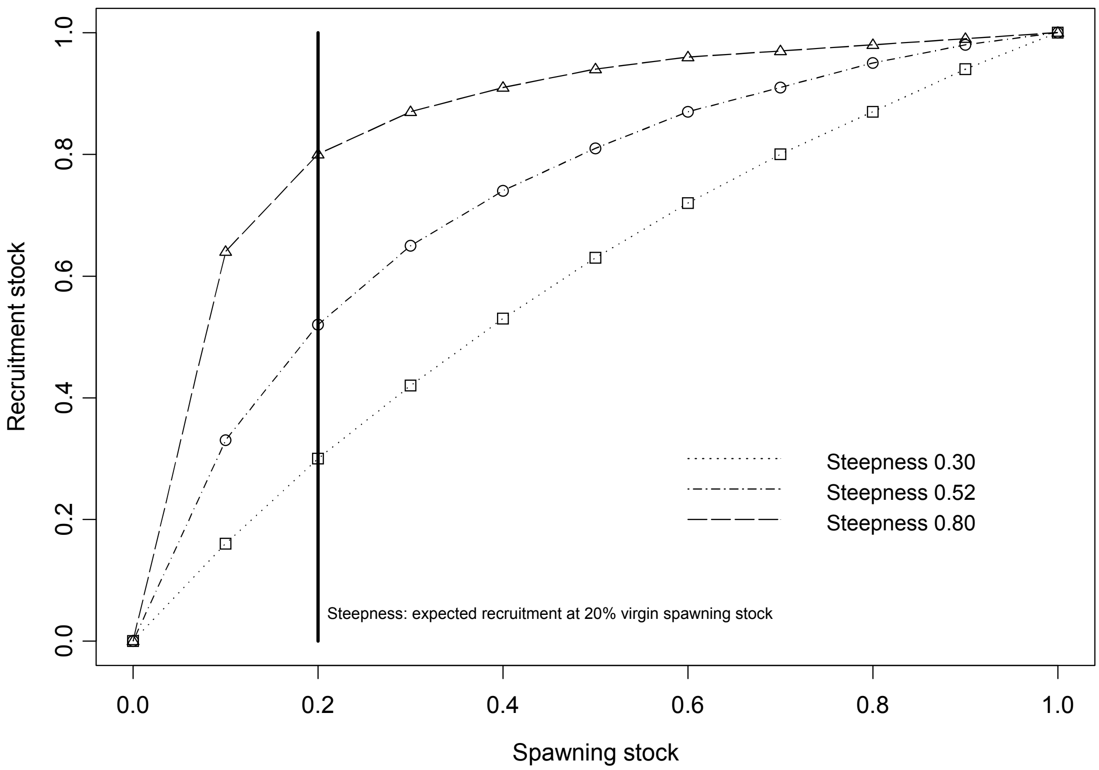

Fig. 2.8. Hypothetical example of stock-recruitment curves with different steepness. Virgin spawning and recruitment stock sizes are equal to 1, with the figure scaled proportionally. Solid line defines steepness as the expected recruitment at 20% of virgin spawning stock. Stocks with high steepness tend to have high resilience to fishing, but can dramatically collapse if fished too heavy; stocks with low steepness have lower resilience to fishing and can exhibit a gradual fish down effect over time.

Stock-recruitment relationships provide information on the productivity of a population, and as such are required in stock assessments and management strategy evaluations (MSE) to project the population and fishery forward in time to examine different management scenarios. Likewise, this was our main purpose for using such a relationship in the spotted mackerel assessment. Not surprisingly, to directly estimate the stock-recruitment relationship for a population involves an extensive time series of data, both on the spawning stock and recruitment; data sources which are not available for spotted mackerel. Consequently, we used data from other similar species to derive a proxy stock-recruitment relationship for spotted mackerel.

Myers *et al.* (1999) examined over 700 stock-recruitment relationships from fisheries around the world and found that the maximum annual reproductive rate (r_{max}) was relatively constant within species and varied little among species. These results support the use of maximum annual reproductive rates as empirical priors in data limited/moderate situations, and were the basis for the assumed stock-recruitment relationship used for spotted mackerel. The estimated general stock-recruitment steepness (h) related to r_{max} according to the following:

$$h = \frac{r_{max}}{4 + r_{max}} \qquad (2.7)$$

where, h = steepness measuring the expected recruitment at 20% of the virgin spawner stock size (Myers *et al.* 1999). From Myers *et al.'s* (1999) study we estimated that the average steepness for a variety of tuna and mackerel species was about 0.52 (Table 2.22). In the assessment, therefore, we assumed that this value was also reflective of the underlying stock-recruitment relationship for spotted mackerel.

Table 2.22. Estimated maximum annual reproductive rates (r_{max}) at low population sizes for Scombridae species (mackerel and tuna) (Myers *et al.* 1999). The r_{max} of 4.46 ≈ 0.52 steepness (h) was used in the base assessment for spotted mackerel.

Scombridae species	r_{max}	***h***
Atlantic bluefin tuna (*Thunnus thynnus*)	5.2	0.56
Bigeye tuna (*Thunnus obesus*)	5.3	0.57
Chub mackerel (*Scomber japonicus*)	2.4	0.38
Southern bluefin tuna (*Thunnus maccoyii*)	2.9	0.42
Yellowfin tuna (*Thunnus albacares*)	9.3	0.70
Atlantic bluefin tuna (*Thunnus thynnus*)	5.2	0.56
Average (back-transform $\log_e(r_{max})$)	4.5	0.52

3. Fishery

The statistical or "fishing" regions used in this assessment for the Queensland east coast correspond to those in Williams (2002), except for the Northern Dry region, which was divided into Bowen and Townsville to reflect the historical significance of the Bowen region for spotted mackerel (Table 3.1, Fig. 1.1). Annual commercial catches of all mackerel species in Queensland were estimated from historic Queensland Fish Board data and compulsory individual fisher logbook data, collected as part of the DPI&F CFISH program. All catch data were converted to whole fish weight using the product conversion factors (fillet=1.608; trunk=1.176; gilled and gutted=1.048) derived for Spanish mackerel (Mackie and Lewis 2001). If the product type was not specified in the logbooks then it was assumed to be whole fish and no conversion factor was applied. In addition, annual catch data were reported in financial or fishing years (*i.e.*, "fishing year" 2002 equates to July 2002-June 2003). This period reflects the biology, common movements and seasonal pattern of fishing for spotted mackerel, and is the period for setting the annual TACC. The CFISH data used in this assessment were from July 1988 to June 2003 (*i.e.*, fishing years 1988-2002). Data collected in the first six months of the CFISH program (January – June 1988) were excluded because of preliminary difficulties and probable non compliance associated with the introduction of the logbooks, and the resultant incomplete fishing year in the assessment.

Table 3.1. Fishing regions used in analysis of mackerel catch and effort data. CFISH regions correspond to those used in Williams (2002), except for the Northern Dry region which was divided into Bowen and Townsville to reflect the historical significance of the Bowen region for spotted mackerel.

Fishing region	CFISH region	Latitude (°S)		Longitude (°E)	
		Minimum	Maximum	Minimum	Maximum
Torres Strait	-	9.00	10.50	141.00	146.00
Gulf	Gulf	10.51	19.00	138.00	142.50
Far north	Far north	10.51	15.00	142.51	155.00
Cairns	Northern wet	15.01	18.50	142.51	155.00
Townsville	Northern dry	18.51	19.50	142.51	155.00
Bowen	Northern dry	19.51	20.50	142.51	155.00
Mackay	Swains	20.51	22.00	142.51	155.00
Rockhampton	Capricorn	22.01	24.50	142.51	155.00
Hervey Bay	Fraser-Burnett	24.51	26.00	142.51	155.00
Moreton Bay	Moreton	26.01	28.50	142.51	155.00

Commercial sector

Historic Queensland Fish Board data

Mackerel have been commercially caught from Queensland waters since at least 1945, as reported in the Queensland Fish Board data. No mackerel species identification, however, was provided in these data. The Fish Board data extend from 1945 to 1980, after which there were no commercial catches recorded until the CFISH program commenced in 1988. Historically, significant quantities of mackerel were caught from Queensland waters with reported landings up to 855 t in 1974 (Fig. 3.1). Anecdote suggests that most of these historic landings were Spanish mackerel, with targeted commercial fishing for spotted mackerel assumed to have commenced in about 1960 (K. Riley, pers. comm.).

The annual proportion of spotted mackerel in these historic mackerel landings was assumed to be a constant ratio derived from the more recent species specific DPI&F CFISH commercial logbook data. An historic short- (1990-1991) and long-term (1988-2002) average ratio of spotted mackerel to all mackerel species were estimated and applied to the total catches. The proportion of spotted mackerel relative to all mackerel species in 1990-1991 was estimated to be about 5.6%, while the long-term average was about 12%. The short-term 5.6% average ratio was applied to the total mackerel Fish Board data because it was assumed to better reflect the historic targeting behaviour of fishers. As a result, it was estimated that the average annual catch of spotted mackerel between 1960 and 1980 was 35 t, ranging between 25 t in 1961 to 48 t in 1974 (Fig. 3.1). The long-term 12%

average ratio was applied to the total mackerel Fish Board data as a model sensitivity test in the assessment (see Table 6.4, 7.2).

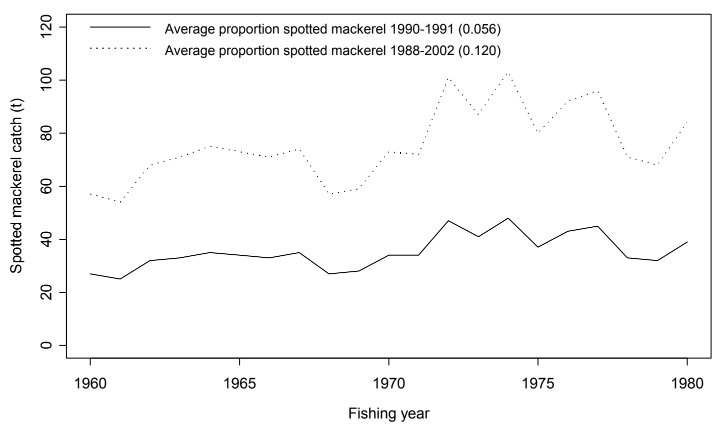

Fig. 3.1. Annual historic commercial catch (t) of all mackerel species and estimated spotted mackerel from Queensland east coast waters, fishing years 1960-1980. Spotted mackerel catches based on historic short-term (1990-1991) and long-term (1988-2002) species ratios derived from CFISH logbook data. Spotted mackerel fishery assumed to have commenced in 1960.

Queensland compulsory logbook (CFISH) data

Several mackerel species are commercially caught from Queensland waters each year, with Spanish, grey and spotted mackerel contributing most to the total catch (Table 3.2, Fig. 3.2). Lesser, but significant quantities of school and shark (*Grammatorcynus bicarinatus*) mackerel are also caught. Likewise, significant quantities of unspecified mackerel are reported in the logbooks each year, ranging from 10-131 t (average = 79 t) (Table 3.2). Reporting of unspecified mackerel is most likely the result of species mis-identification problems or ease of reporting by fishers and a lack of an awareness about the importance of reporting at a finer taxonomic scale.

Spotted mackerel are almost exclusively caught along the Queensland east coast, with very little taken from the Gulf of Carpentaria and Torres Strait (Fig. 3.3). Commercial catches of spotted mackerel have increased over the years, reaching a peak of 410 t in 2000 (Fig. 3.2). Relative to the other mackerel species, spotted mackerel are predominantly caught from the Bowen and Cairns (*i.e.*, Innisfail) regions during winter and early spring (July-September), and from Hervey Bay and Moreton Bay during late spring and summer (November-February) (Fig. 3.3-3.5). Spotted mackerel caught from Bowen are predominantly spawning fish, while those from Hervey Bay and Moreton Bay are involved in the annual southerly feeding movement (Begg *et al.* 1997, Begg and Hopper 1997, Begg 1998).

Table 3.2. Annual commercial catch (t) of all mackerel species from Queensland waters including the Torres Strait and Gulf of Carpentaria, fishing years 1988-2002. Unspecified refers to unknown mackerel catch reported in logbooks.

Fishing year	Mackerel species catch (t)					
	Grey	School	Shark	Spanish	Spotted	Unspecified
1988	236	2	19	539	11	29
1989	270	7	52	590	18	10
1990	282	9	84	611	42	12
1991	210	4	58	537	44	44
1992	139	16	64	597	116	116
1993	88	24	55	619	104	88
1994	143	27	66	626	88	115
1995	169	23	69	610	106	105
1996	248	45	59	680	188	131
1997	421	35	72	901	174	125
1998	307	43	53	821	112	72
1999	313	84	48	754	311	106
2000	318	93	46	565	410	94
2001	433	49	53	705	165	80
2002	332	81	38	806	272	54

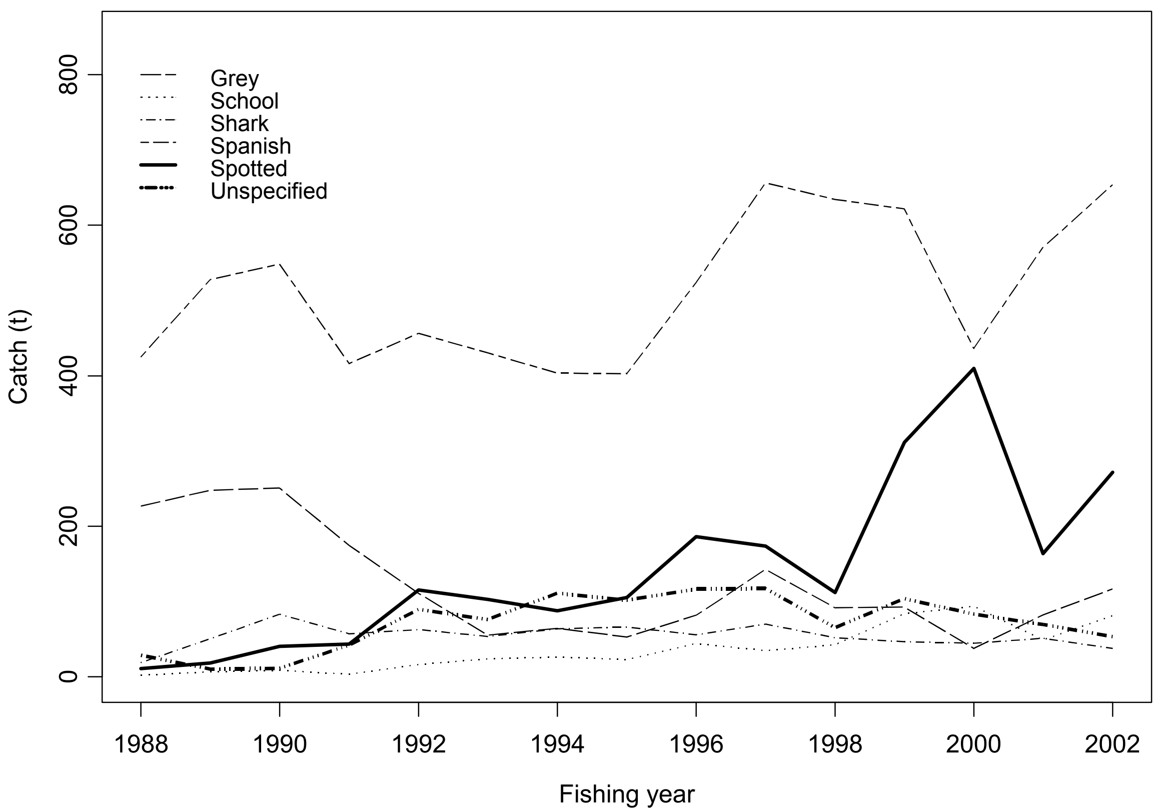

Fig. 3.2. Annual commercial catch (t) of all mackerel species from Queensland east coast waters (excluding the Torres Strait and Gulf of Carpentaria), fishing years 1988-2002. Unspecified = unknown mackerel catch reported in logbooks.

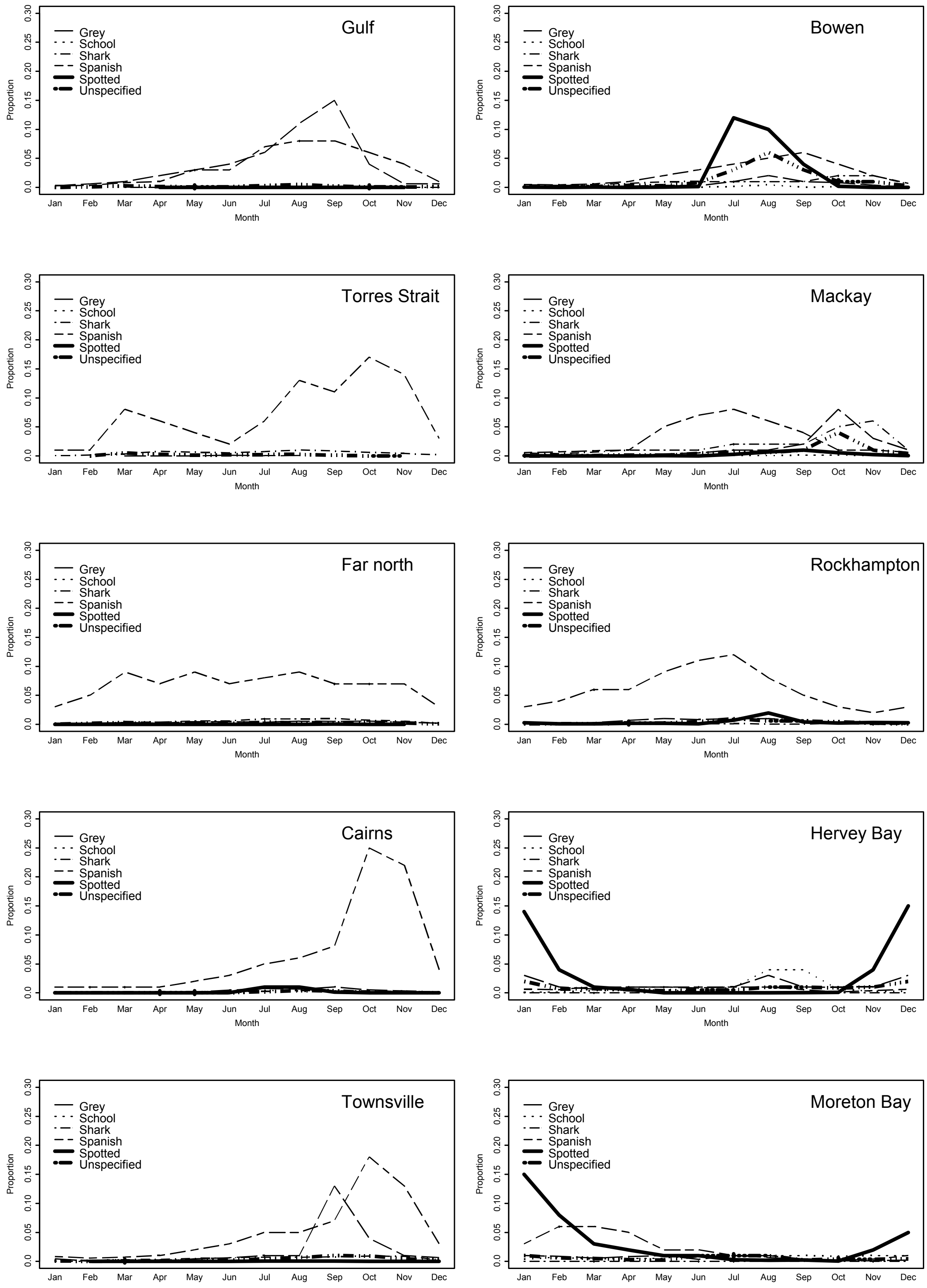

Fig. 3.3. Proportion of individual mackerel species commercially caught from each region and month in Queensland waters, combined fishing years 1988-2002. Sum of all proportions in each region sums to one.

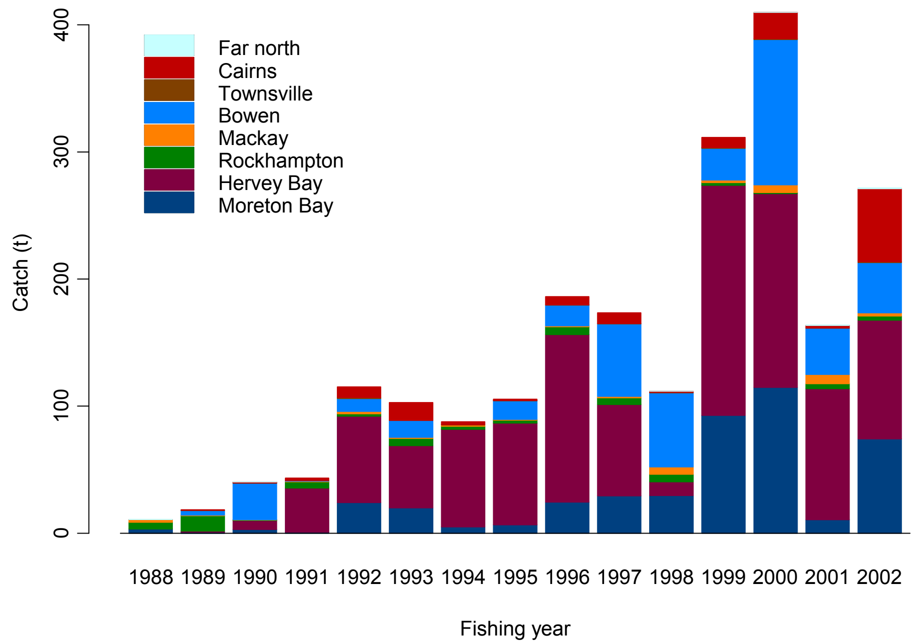

Fig. 3.4. Annual regional commercial catch (t) of spotted mackerel from Queensland east coast waters, fishing years 1988-2002.

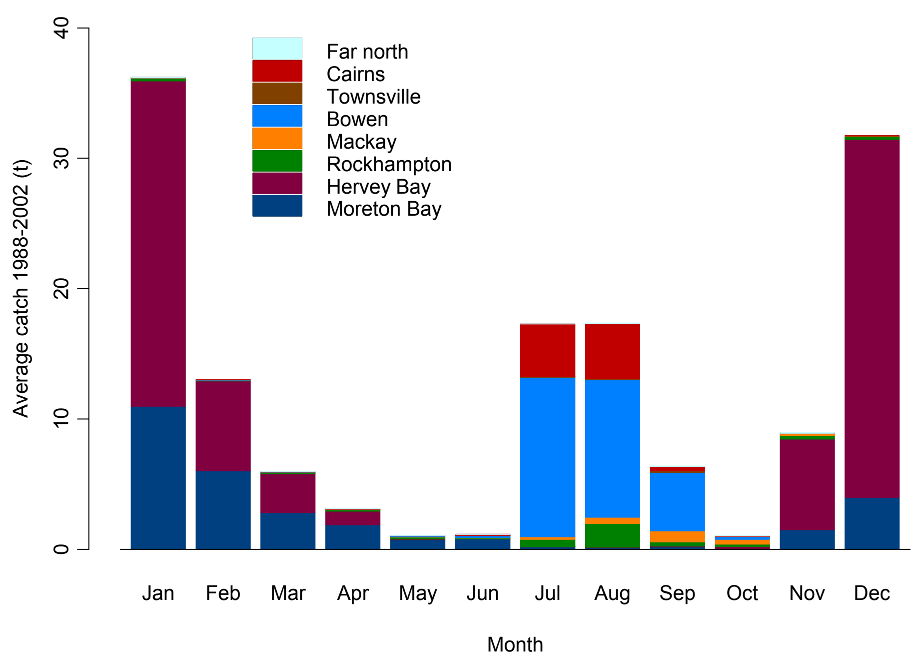

Fig. 3.5. Average monthly commercial catch (t) of spotted mackerel from Queensland east coast waters, fishing years 1988-2002.

Historically, spotted mackerel were caught using a variety of set gill nets and line fishing methods (Fig. 3.6). Since 1997, the use of ring nets was the main reported method of capture, although anecdote suggests that this occurred far earlier, where the recent trend is more a reflection of improved reporting of fishing method in the logbooks. Coincidentally, 1997 was also around the time when the export markets for whole spotted mackerel commenced (Williams 2002), and from 2000 was almost solely the preferred market product type (Fig. 3.7). Reported commercial fishing effort (*i.e.*, number of boats and days fished) in the spotted mackerel fishery has increased slightly over the past decade, except in 2002, where a significant increase in the number of days fished was observed, possibly in response to the investment warning issued that year (Fig. 3.8, 3.9).

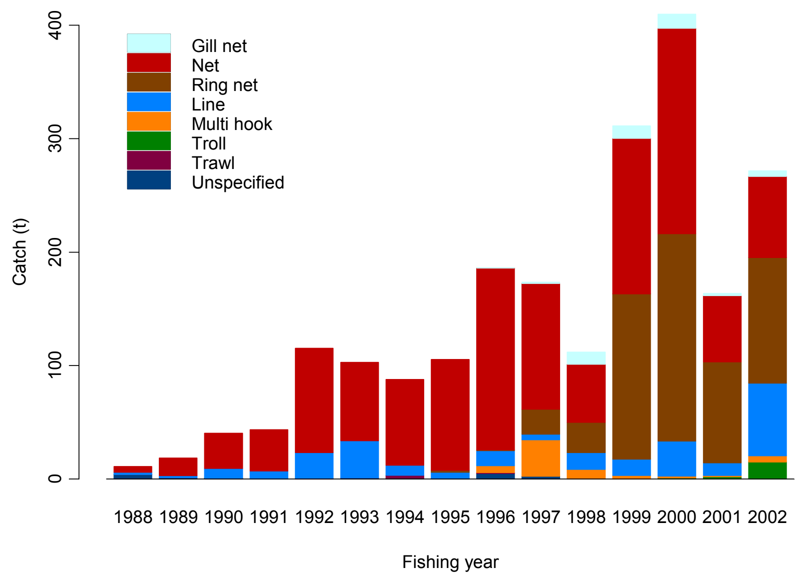

Fig. 3.6. Annual commercial catch (t) of spotted mackerel from Queensland east coast waters by fishing gear, fishing years 1988-2002. Gill net = set gill net; Net = unspecified gill net; Multi hook = long line.

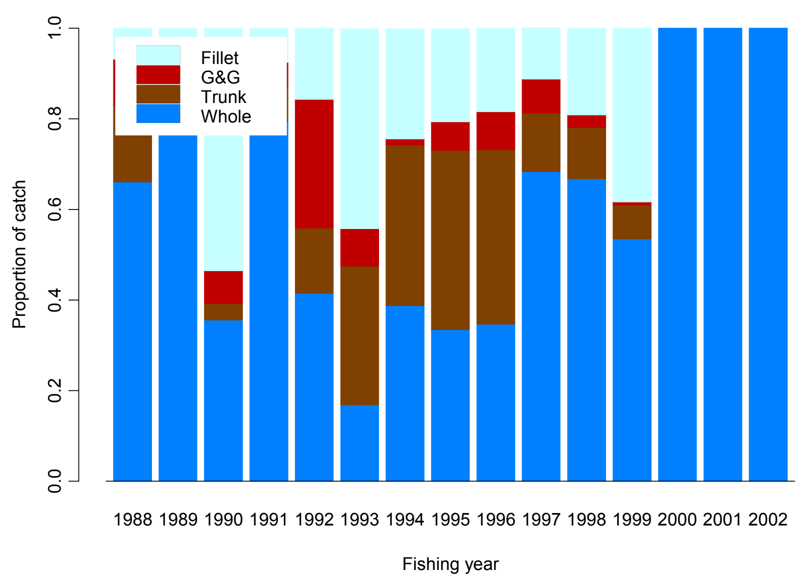

Fig. 3.7. Annual proportion of commercial catch (t) of spotted mackerel from Queensland east coast waters by product type, fishing years 1988-2002. G&G = gilled and gutted.

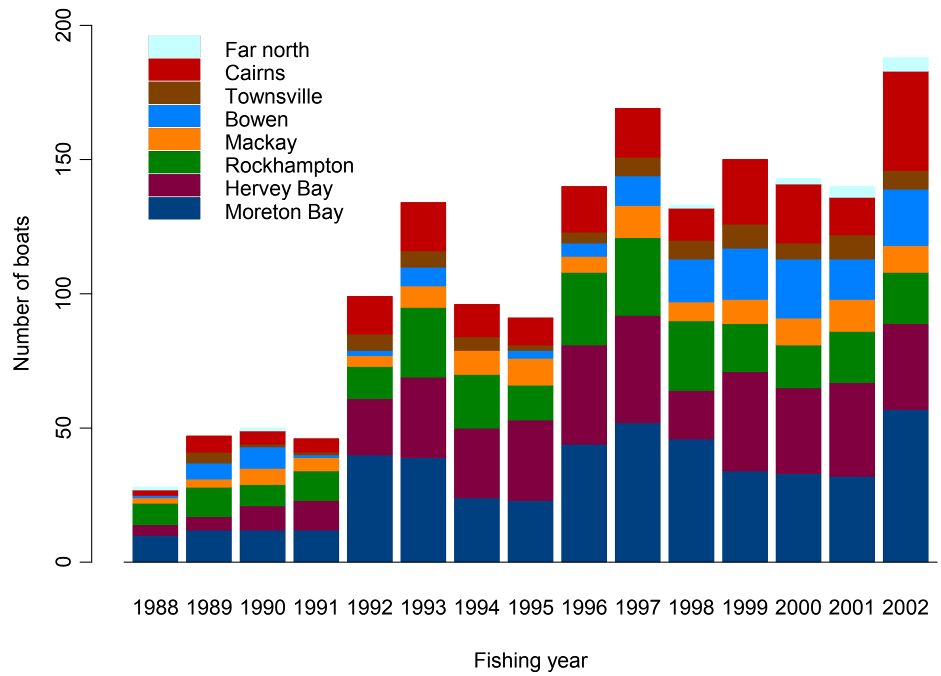

Fig. 3.8. Annual number of commercial boats catching spotted mackerel from Queensland east coast waters, fishing years 1988-2002.

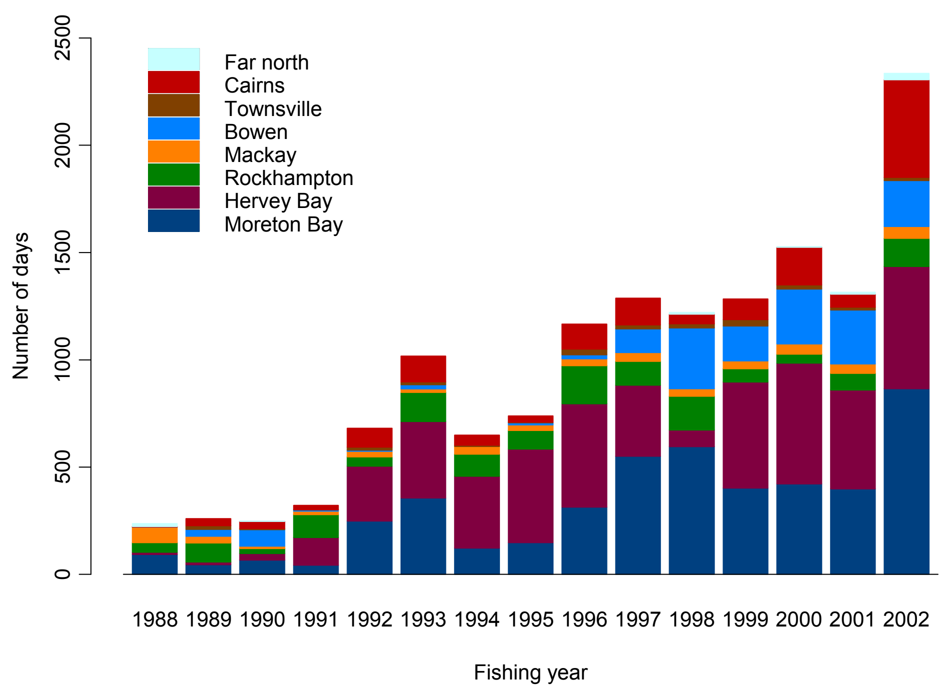

Fig. 3.9. Annual number of days fished commercially for spotted mackerel from Queensland east coast waters, fishing years 1988-2002.

New South Wales compulsory logbook data

Similar to Queensland, several mackerel species are commercially caught each year from New South Wales waters (Fig. 3.10). Spotted mackerel comprise a relatively small component of the total mackerel species catch, with a peak catch of about 55 t in 1999. Likewise, small, but occasionally significant quantities of unspecified mackerel are reported in the logbooks each year, with a peak reported catch of 52 t in 1994 (Fig. 3.10).

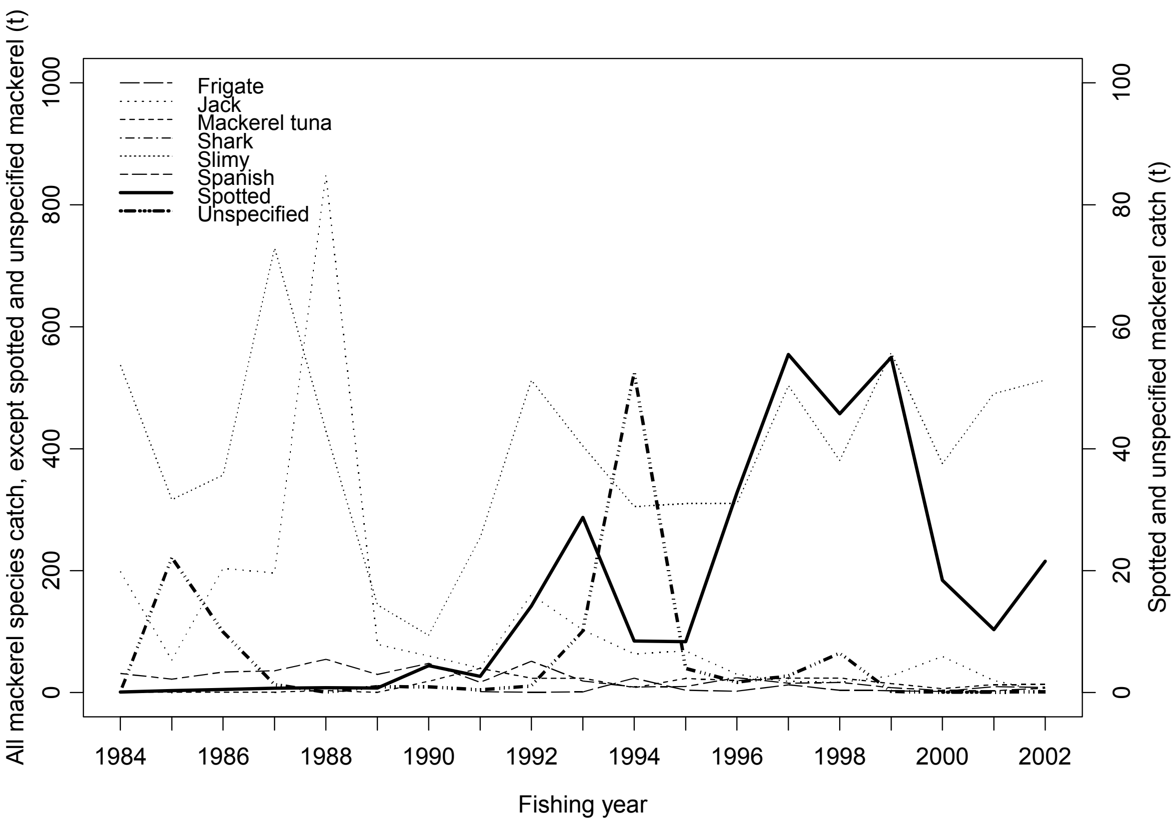

Fig. 3.10. Annual commercial catch (t) of all mackerel species from New South Wales waters, fishing years 1984-2002.

Spotted mackerel are mostly caught throughout summer and autumn (January-May) from northern New South Wales waters (Fig. 3.11). A variety of fishing methods were reported to catch spotted mackerel, with line fishing the main commercial method used (Fig. 3.12). Spotted mackerel commercially caught in New South Wales are processed and retailed as whole or gilled and gutted product, with some trunked (*i.e.*, head removed and gutted) for the domestic markets.

Fishing effort in New South Wales is more difficult to quantify than that in Queensland because of reporting vagrancies in the New South Wales commercial logbook program. The reported number of boats in New South Wales has increased over the past decade, reaching a peak in 1998, with 155 boats reporting some spotted mackerel catch (Fig. 3.13). The number of days fished, however, is less certain and of limited use because effort is reported as the number of days fished for an entire month and is not specific to any particular method or fish species.

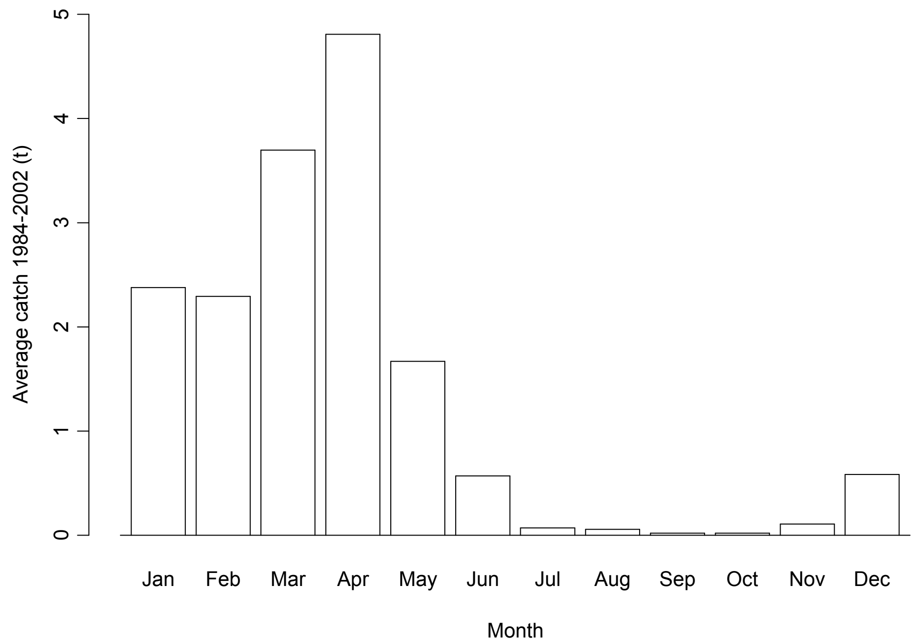

Fig. 3.11. Average monthly commercial catch (t) of spotted mackerel from NSW waters, fishing years 1984-2002.

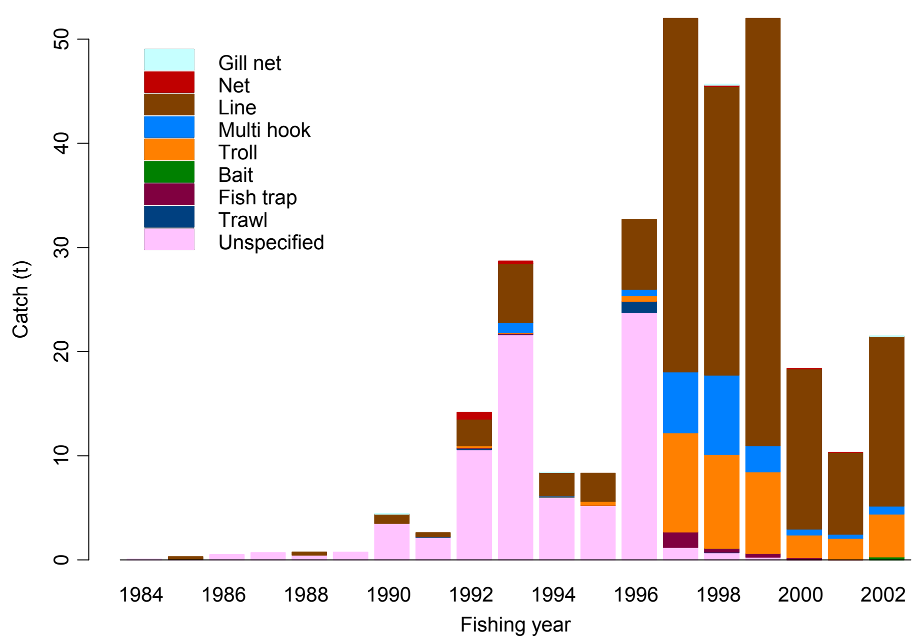

Fig. 3.12. Annual commercial catch (t) of spotted mackerel from NSW waters by fishing gear, fishing years 1984-2002. Gill net = set gill net; Net = unspecified gill net; Multi hook = long line.

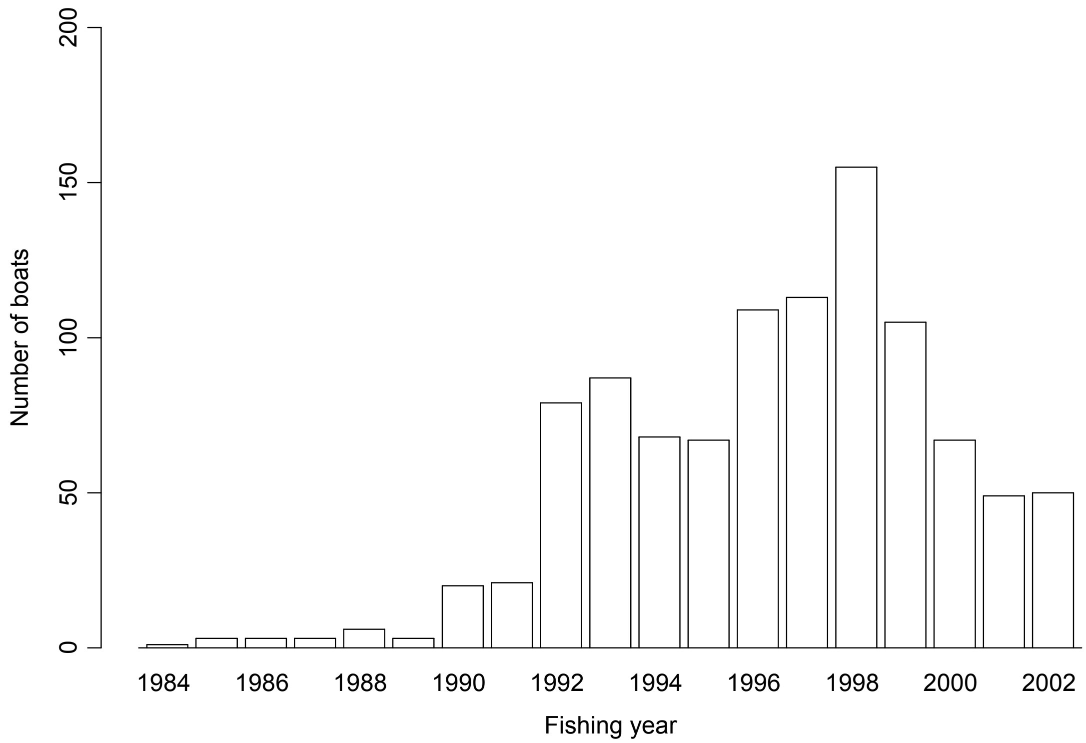

Fig. 3.13. Annual number of commercial boats catching spotted mackerel from NSW waters, fishing years 1988-2002.

Recreational sector

Length weight distribution data

The mean total length (TL) of recreationally caught spotted mackerel tagged and released as part of the SUNTAG Program, has decreased in some regions from 1985-2003, particularly in Moreton Bay (Fig. 3.14). In other regions, however, the average size of recreationally caught spotted mackerel has not changed much over the past 19 years.

Applying the spotted mackerel length-weight relationship (see Chapter 2) to the fish lengths from different regions and years indicated that the average length and weight of a recreationally caught spotted mackerel was about 65 cm TL and 1.64 kg (Table 3.3). In contrast, the average sized commercially caught spotted mackerel was about 70 cm TL and 1.92 kg (Table 3.4). The recreationally caught mean weight of spotted mackerel was used in this assessment to derive total catches in tonnes for the recreational sector.

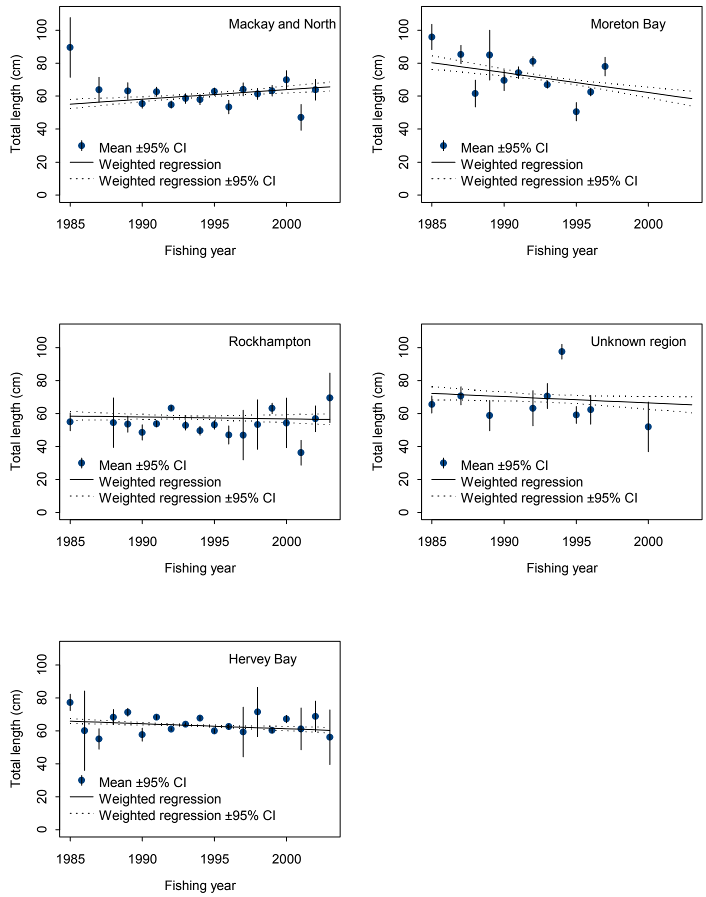

Fig. 3.14. Annual mean total length (±95% confidence intervals) of spotted mackerel by fishing region from Queensland east coast waters as calculated from the SUNTAG data, 1985-2003.

Table 3.3. Mean total length (TL, cm) and weight (kg) of recreationally caught spotted mackerel from Queensland east coast waters (S.D. = standard deviation).

Data source	Region	Fishing year	Mean TL (cm)	S.D.	Number measured	Mean weight (kg)
FRDC 92/144 Daily fishing diaries	Far north to Moreton Bay	1994	65	13	210	1.75
FRDC 92/144 Daily fishing diaries	Far north to Moreton Bay	1995	62	8	152	1.33
FRDC 92/144 Fish tag returns	Far north to Moreton Bay	1992-1995	63	7	39	1.35
FRDC 93/074 Boat ramp surveys	Moreton Bay	1995	67	12	143	1.87
FRDC 98/120 Boat ramp surveys	Moreton Bay	1999	66	9	42	1.67
Overall	*All regions*	*All years*	*65*	*11*	*586*	*1.64*

Table 3.4. Mean total length (TL, cm) and weight (kg) of commercially caught spotted mackerel from Queensland east coast waters (S.D. = standard deviation).

Data source	Region	Fishing year	Mean TL (cm)	S.D.	Number measured	Mean weight (kg)
FRDC 92/144	Bowen	1992	76	6	151	2.54
	Bowen	1993	73	5	187	2.22
	Bowen	1994	75	6	132	2.43
	Bowen	1995	76	5	554	2.54
LTMP	Bowen	2002	76	7	310	2.54
Overall	*Bowen*		*75*	*6*	*1334*	*2.43*
FRDC 92/144	Hervey Bay	1992	69	5	79	1.83
	Hervey Bay	1993	69	4	407	1.83
	Hervey Bay	1994	64	5	299	1.42
	Hervey Bay	1995	64	4	1177	1.42
LTMP	Hervey Bay	2002	67	4	1276	1.66
Overall	*Hervey Bay*		*66*	*4*	*3238*	*1.58*
FRDC 92/144	Moreton Bay	1992	69	3	28	1.83
	Moreton Bay	1993	69	3	87	1.83
	Moreton Bay	1995	66	3	53	1.58
LTMP	Moreton Bay	2002	71	3	852	2.02
Overall	*Moreton Bay*		*71*	*3*	*1020*	*2.02*
FRDC 92/144	Cairns – Rockhampton	1992-1994	67	8	184	1.66
Overall	*All regions*	*All years*	*70*	*5*	*5776*	*1.92*

Queensland charter fishing logbook data

Commercial fishing charter boats have been operating for many years in Queensland waters, but have only recently been required to report their catch as part of the DPI&F charter boat logbook program. The logbook program was voluntary when it was first introduced in 1992, but was made compulsory for all charter boat operators in 1996.

Similar to the commercial sector, several mackerel species are caught by the charter sector from Queensland waters each year, with Spanish mackerel contributing most to the total catch (Fig. 3.15). Lesser quantities of spotted, school and shark mackerel are caught each year (<5 t), while significant quantities of unspecified mackerel are also reported (Fig. 3.15).

Generally, spotted mackerel are only prominent in the catches of charter boats operating in Moreton Bay, and to a lesser extent Hervey Bay (Fig. 3.16). Relative to the other mackerel species, spotted mackerel are mainly reported to be caught by the charter sector during winter and spring (June-October) (Fig. 3.16). These patterns, however, conflict with those of the commercial sector (Fig. 3.3), possibly indicating problems with fish species identification in the charter sector.

Fig. 3.15. Annual charter fishing catch (t) of all mackerel species from Queensland east coast waters, fishing years 1992-2002.

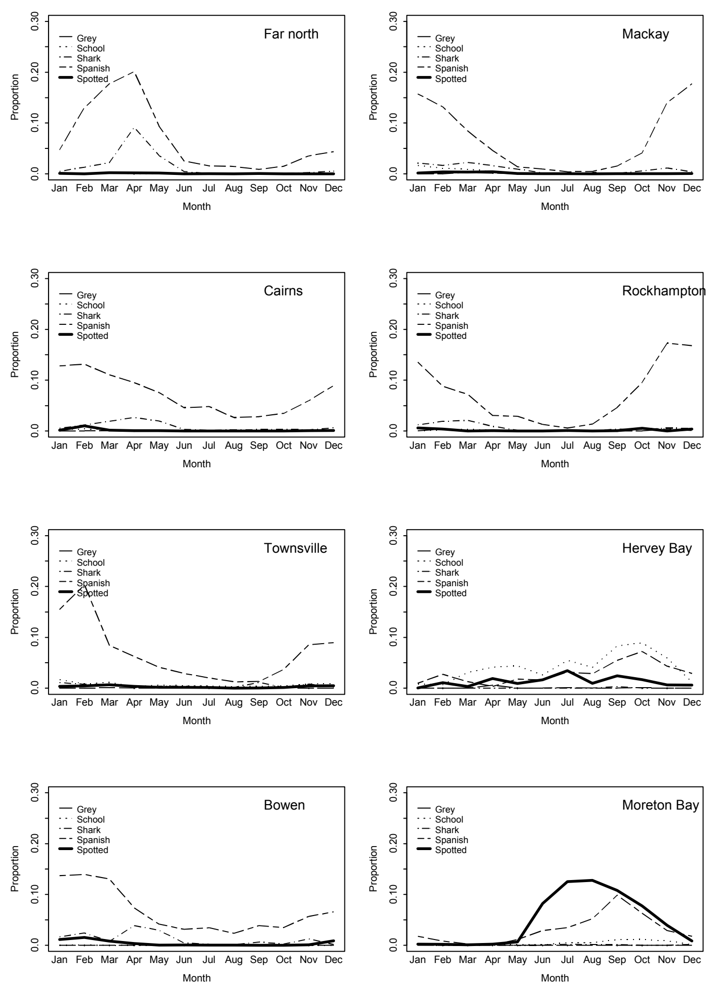

Fig. 3.16. Proportion of individual mackerel species caught from charter boats in each region and month in Queensland waters, combined fishing years 1992-2002. Sum of all proportions in each region sums to one.

Queensland recreational fishing survey (FRDC) data

Estimates of recreational spotted mackerel catches from Queensland waters in 1995 were derived from telephone, mail, diary and interstate visitor caravan surveys of registered recreational boat owners (Cameron and Begg 2002; Table 3.5). The surveys were directed at those anglers who specifically targeted or caught small mackerel species, including spotted mackerel, unlike the RFISH surveys which are more generic and aim to capture total recreational fishing effort for all species. From the more directed surveys, about 30,927 spotted mackerel and 5,241 unspecified mackerel were estimated to be harvested by recreational anglers in 1995 (Cameron and Begg 2002). Spotted mackerel accounted for about 41% of the total recreational estimated catch of mackerel in 1995. Applying this proportion to derive the assumed number of spotted mackerel in the unspecified mackerel catch (*i.e.*, 2,164) and the recreationally caught mean weight of 1.57 kg for spotted mackerel (Table 3.3; weighted average of mean fish weights from 1994 and 1995 fishing years) to the total number of spotted mackerel (*i.e.*, 30,927 + 2,164 = 33,091), about 52 t of spotted mackerel were estimated to be harvested in 1995.

Table 3.5. Recreational catch numbers of mackerel from Queensland east coast waters in the 1995 FRDC, 1997, 1999 and 2002 RFISH, and 2000 NRIFS survey years (Gulf of Carpentaria excluded; Torres Strait not part of NRIFS Survey; standard errors in parenthesis).

Mackerel species	FRDC 1995	RFISH 1997	RFISH 1999	NRIFS 2000	RFISH 2002
Grey	4196	6859 (3746)	4835 (2033)	415 (66)	1533 (592)
School	26246	59906 (11071)	64849 (15229)	15121 (2398)	40110 (7647)
Shark	935	3802 (2789)	1564 (591)	9168 (1454)	6010 (1088)
Spanish	7344	34816 (8440)	56038 (9974)	62173 (9859)	37555 (4501)
Spotted	30927	209814 (20720)	86321 (11990)	129338 (20510)	52661 (7397)
Unspecified	5241	90913 (13639)	74081 (17034)	66237 (10503)	95373 (11849)
Total	74889	406110 (28826)	287687 (27746)	282452 (44790)	233242 (16594)

Queensland recreational fishing survey (RFISH, NRIFS) data

Recreational catches estimated for all mackerel species from Queensland east coast waters declined from about 406,000 fish in 1997 to 233,000 in 2002 (Table 3.5). Five mackerel species were reported in the recreational fishing surveys (grey, school, shark or salmon, Spanish and spotted mackerel). Unspecified mackerel were a significant component of the catches estimated (Table 3.5). Spotted mackerel were more commonly reported in the survey year of 1997, while the frequency of all mackerel species was more evenly spread in the other survey years and in most regions (Fig. 3.17-3.20). Estimated recreational catches of spotted mackerel were about 210,000, 86,000 and 53,000 fish from the 1997, 1999 and 2002 RFISH survey years, respectively. For the same years, the unspecified mackerel catches were about 91,000, 74,000 and 95,000 fish. Similarly, the recreational catch estimated in 2000 from the NRIFS was about 129,000 spotted mackerel and 66,000 unspecified mackerel (Table 3.5).

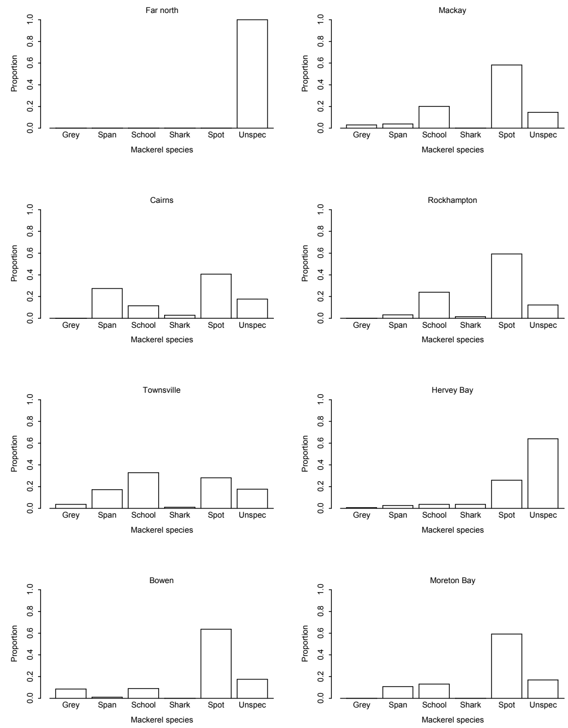

Fig. 3.17. Mackerel species frequency (as a proportion) by fishing region from Queensland east coast waters as calculated from the 1997 RFISH diary weights. Span = Spanish mackerel; Unspec = unspecified mackerel.

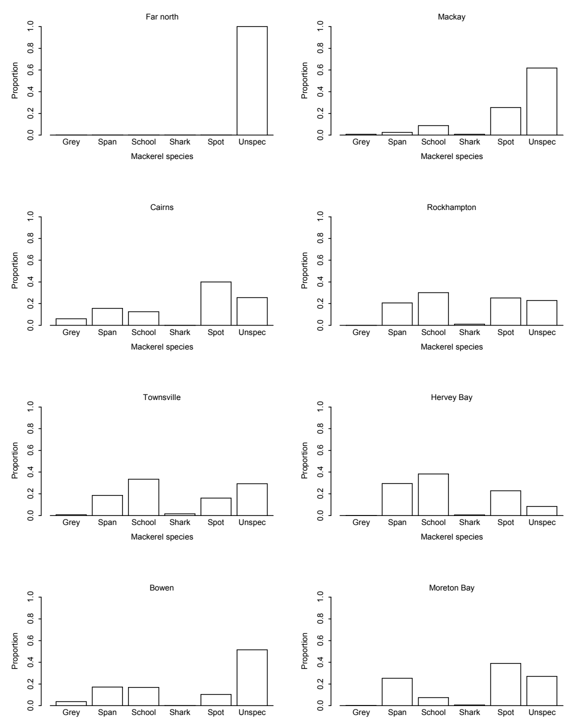

Fig. 3.18. Mackerel species frequency (as a proportion) by fishing region from Queensland east coast waters as calculated from the 1999 RFISH diary weights. Span = Spanish mackerel; Unspec = unspecified mackerel.

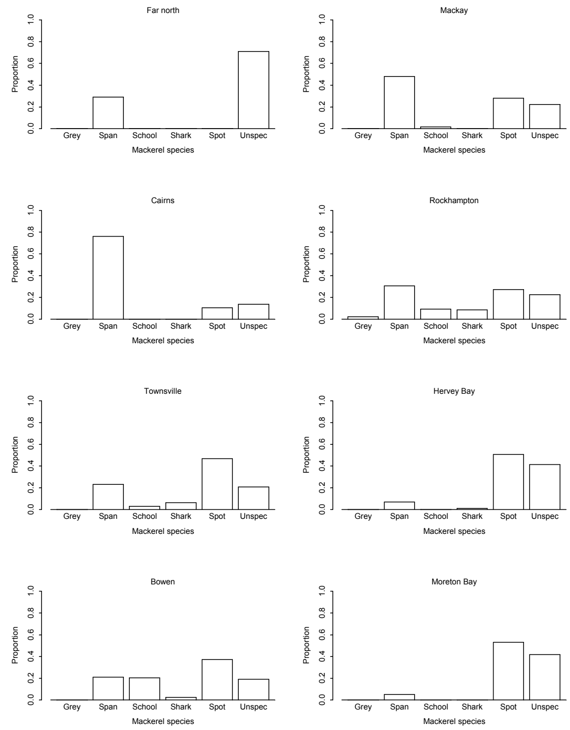

Fig. 3.19. Mackerel species frequency (as a proportion) by fishing region from Queensland east coast waters as calculated from the 2000 NRIFS diary weights. Span = Spanish mackerel; Unspec = unspecified mackerel.

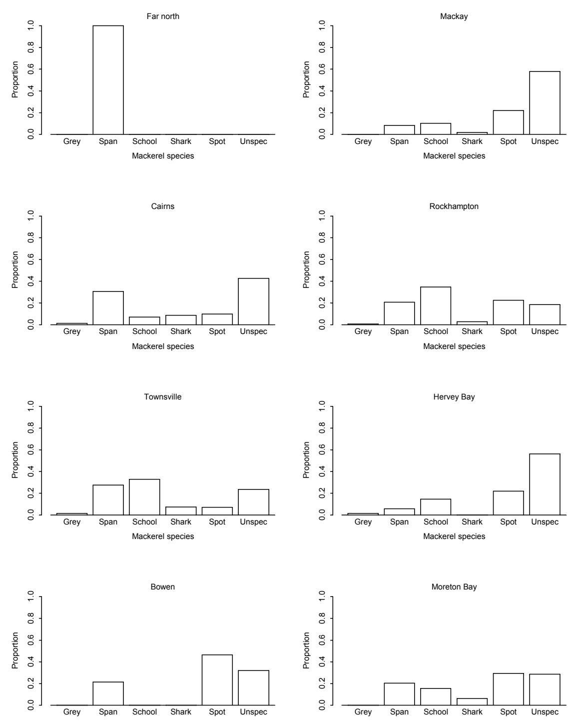

Fig. 3.20. Mackerel species frequency (as a proportion) by fishing region from Queensland east coast waters as calculated from the 2002 RFISH diary weights. Span = Spanish mackerel; Unspec = unspecified mackerel.

New South Wales recreational fishing survey data

Estimates of recreational spotted mackerel catches from New South Wales waters were derived from State-wide creel survey data collected in the 1990s (Steffe *et al.* 1996) and telephone and diary survey data collected in 2000, as part of the NRIFS (Henry and Lyle 2003) (Table 3.6). In Steffe *et al.'s* (1996) extensive surveys of recreational anglers, only Spanish and spotted mackerel were reported in recreational catches, while the National survey only reported on unspecified mackerel catches, with no finer mackerel species identification provided.

Table 3.6. Estimated recreational catch numbers and weights of spotted mackerel from New South Wales waters in 1993 and 1994 fishing years, and 2000 NRIFS survey year (standard errors in parenthesis).

Survey	Fishing year	Proportion spotted mackerel	Number of fish	Weight (t)
Steffe	1993	0.84720	3139 (769)	5 (1.2)
Steffe	1994	0.46564	652 (101)	1 (0.2)
NRIFS	2000	0.84720[1]	21794 (14049)	35 (22.5)
NRIFS	2000	0.46564[1]	11979 (10415)	19 (16.7)
NRIFS	2000	0.65642[1]	16886 (12366)	27 (20)

[1]Proportion of spotted mackerel in recreational catch based on creel survey results of Steffe *et al.* (1996).

In the two separate creel surveys conducted in 1993-1994 and 1994-1995, Steffe *et al.* (1996) estimated that the proportion (by numbers) of spotted mackerel in the total recreational mackerel catch was about 85% and 47%, respectively (Table 3.6). Using mean fish weights estimated from recreational catch data, these proportions equated to about 5 t and 1 t in each of the respective fishing years. Furthermore, using these proportions, as well as the average (66%), we estimated that the recreational catch of spotted mackerel from New South Wales waters had increased to between 19-35 t in 2000 (Table 3.6). These estimates assumed that there was no change in species composition in the catches over the surveys, and the reported mackerel species were identified correctly. The latter assumption is also true for the reported logbook data of all fishing sectors.

By-product and by-catch

Typically, very little by-product or by-catch species are caught when targeting spotted mackerel (Cameron and Begg 2002), although this will vary depending on method of fishing. Prior to recent management intervention in 2002, ring netting was the main method of fishing. This method was highly specific in catching spotted mackerel, where only occasionally were school and grey mackerel, long-tail and mackerel tuna, bonito, shark and trevally retained and sold (Williams 2002). Similar species are also captured when line fishing for spotted mackerel, including Spanish and shark mackerel. Fall-out or non-capture mortality from ring nets for any species of fish in the spotted mackerel fishery was not detected during research activities (Cameron and Begg 2002).

Relatively few sub-legal or undersize fish are discarded when targeting spotted mackerel, although potential numbers will most likely increase for line caught spotted mackerel with the introduction of the 60 cm TL minimum legal size (MLS) in 2002 (Fig. 3.21). The proportion of undersize spotted mackerel that are line caught may be expected to increase from about 12% to 28% with the change in MLS from 50 cm to 60 cm. Likewise, the proportion of undersize spotted mackerel that would have been caught using 9.5, 10.2 and 12.7 cm mesh nets would also have been expected to increase slightly, relative to the specific selectivity properties of the different mesh sizes (Cameron and Begg 2002) (Fig. 3.21).

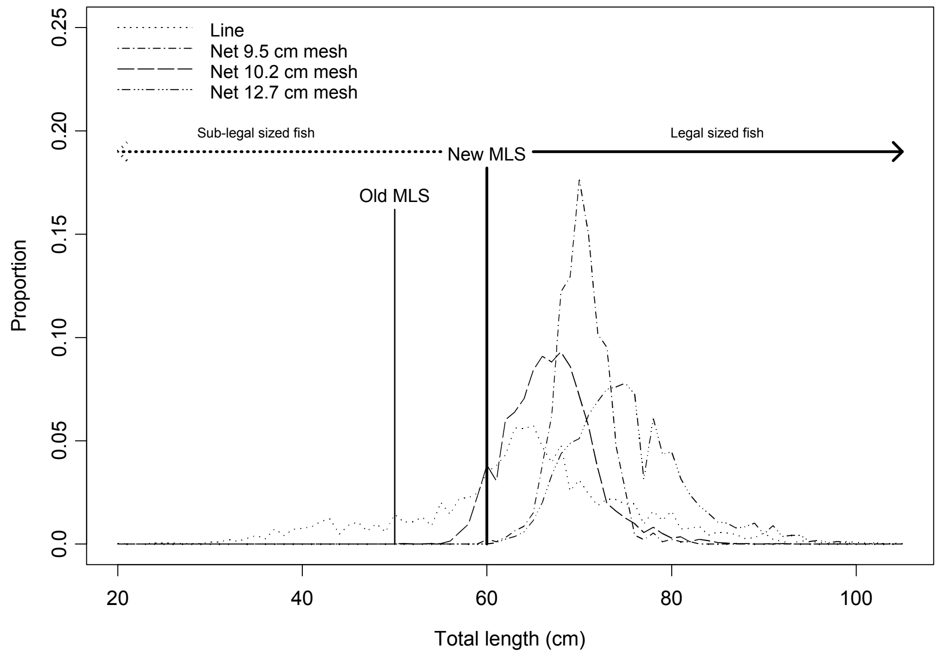

Fig. 3.21. Spotted mackerel total length (cm) distributions by fishing gear from Queensland east coast and New South Wales waters, pooled across fishing years (Line: 1985-2003; Net: 1992-1995, 2002). MLS = minimum legal size.

Post release mortality

Little is known about the post release mortality of line caught and subsequent release of spotted mackerel, although anecdote suggests this to be significant unless the fish are returned quickly (*i.e.*, < 20 sec) to the water upon retrieval (Begg *et al.* 1997). In this assessment we assumed that all fish captured were retained, and hence, did not account for post release mortality.

4. Allocation of unspecified mackerel catch

The reported commercial and recreational spotted mackerel catches are used as the basis for this stock assessment because it is assumed that these are a function of fishing effort and abundance of the population, where the level of catch over time may reflect changes in the proportion of the population caught, changes in the abundance of spotted mackerel, or both. Stock assessments based on reported catch landings are required to calculate fishing mortality rates (*i.e.*, proportion of the population caught), sustainable management reference points (*e.g.*, maximum sustainable yield – MSY), and future risks of over-fishing (O'Neill *et al.* 2004). Stock assessments based on under-reported landings may result in lower estimates of population size and therefore lower management reference points (*e.g.*, quotas) calculated. In contrast, stock assessments based on over-reported landings may result in greater estimates of population size and therefore greater management reference points calculated. Hence, it is essential to justify the process of allocating commercial or recreational unspecified mackerel catches to spotted mackerel catches.

Significant quantities of unspecified mackerel are reported in the commercial logbooks each year, with up to 131 t and 52 t, from Queensland and New South Wales, respectively (Table 3.2, Fig. 3.10). In addition, State-wide diary surveys estimated that 50,000 to 100,000 individual unspecified mackerel were reportedly caught each year by recreational fishers from Queensland waters (Higgs 1998, 2001). These reportings of unspecified mackerel are a result of problems in identification of mackerel species and the lack of incentives for commercial and recreational fishers to record catches of mackerel to species level (Cameron and Begg 2002). Failure of commercial fishers to report species of mackerel has not generally improved since the commercial logbook programs commenced (Table 3.2). A certain proportion of unspecified mackerel are spotted mackerel and this proportion will change considerably between fishing sectors (commercial and recreational), years, months and regions.

Consequently, due to the significant quantities of unspecified mackerel that are reported in any given year and the introduction of an annual TACC to manage the fishery, we considered it essential to estimate the proportion that may have been spotted mackerel. The TACC specifies the total amount of spotted mackerel that can be legally caught and sold each year and as such all spotted mackerel, including that which is unspecified, needs to be accounted for in the TACC if it is to be set at an appropriate and meaningful level. If all unspecified mackerel were simply excluded from the assessment then more conservative TACC and management reference points would be estimated. In contrast, if all unspecified mackerel were assumed to be spotted mackerel than more inflated management reference points would be estimated.

Allocations of unspecified mackerel to spotted mackerel, therefore, were examined separately for: 1) Queensland commercial logbooks (CFISH); 2) New South Wales commercial logbooks; 3) Queensland charter logbooks; 4) Queensland Recreational Fishing Information System (RFISH); and 5) Queensland catches estimated in the National Recreational and Indigenous Fishing Survey (NRIFS). We demonstrate that binary regression models (McCullagh and Nelder 1989) are more reliable at identifying unspecified mackerel catches as spotted mackerel than DPI&F commercial catch decision rules or simple aggregated species catch proportion rules.

Allocation methods

Binary regressions

The analyses used generalised linear models (GLMs) for binary regression (McCullagh and Nelder 1989). Binary regression models were applied to all mackerel catches reported to the species codes in each State (Table 4.1) and for only those catches where a number or weight of fish were caught and retained. These data were coded with one of two values: 1 for a spotted mackerel catch and 0 for a non-spotted mackerel catch. The capture of a spotted mackerel occurred according to the probabilities P(spotted mackerel) = p and P(not a spotted mackerel) = 1-p. The probability p was modelled using a logistic link (*i.e.*, logit) function and binomial error distribution, and related through a linear regression function of factors and covariates. Forward stepwise selection was used to determine the significant covariates for the final GLMs based on analysis of deviance and residual deviance plots. The binary regressions on each data source are detailed below.

Table 4.1. List of mackerel species and reporting codes for Queensland and NSW commercial logbooks used in binary regression analysis.

State	Species common name	Species code
Queensland	School mackerel	441014
Queensland	Spotted mackerel	441015
Queensland	Grey mackerel	441018
Queensland	Shark mackerel	441025
Queensland	Spanish mackerel	441902
New South Wales	Jack mackerel	337002
New South Wales	Slimy mackerel	441001
New South Wales	Spanish mackerel	441007
New South Wales	Frigate mackerel	441009
New South Wales	Mackerel tuna	441010
New South Wales	Spotted mackerel	441015
New South Wales	Shark mackerel	441025

Queensland and New South Wales commercial logbooks

Forward stepwise regression was used to define the final model components for the Queensland commercial catch data as follows:

$$Logit(P) = \text{Constant + Region + Gear + Month + Fishing year + } \log_e(\text{Weight of fish caught}) \quad (4.1)$$

where, P = probability of spotted mackerel; Region = Gulf of Carpentaria, Torres Strait, Far north, Cairns, Townsville, Bowen, Mackay, Rockhampton, Hervey Bay, Moreton Bay and Unspecified; Gear = gill net, net, ring net, line, multi hook, troll, trawl and unspecified; Month = January to December; Fishing year = financial years 1988/89 to 2002/03; and the covariate term $\log_e$(Weight of fish caught) allowed a linear effect on catch size in determining the probability of spotted mackerel. Factor reference levels for this analysis were the region of Bowen, fishing gear gill net, month of January and fishing year 1988/89.

Forward stepwise regression was also used to define the final model components for the New South Wales commercial catch data as follows:

$$Logit(P) = \text{Constant + Gear + Month + Fishing year + } \log_e(\text{Weight of fish caught}) \quad (4.2)$$

where, P = probability of spotted mackerel; Gear = gill net, net, line, multi hook, troll, bait net, fish trap, trawl and unspecified; Month = January to December; Fishing year = financial years 1984/85 to 2002/03; and the covariate term $\log_e$(Weight of fish caught) allowed a linear effect on catch size in determining the probability of spotted mackerel. Factor reference levels for this analysis were the fishing gear bait net, month of January and fishing year 1984/85.

Queensland charter logbooks

Forward stepwise regression was used to define the final model components for the Queensland charter boat catch data as follows:

$$Logit(P) = \text{Constant + Fishing year + Month + Region} + \log_e(\text{Number of fish caught}) + \log_e(\text{Number of fish caught})^2 + \log_e(\text{Weight of fish caught}) \quad (4.3)$$

where, *P* = probability of spotted mackerel; Fishing year = financial years 1992/93 to 2002/03; Month = January to December; Region = Gulf of Carpentaria, Torres Strait, Far north, Cairns, Townsville, Bowen, Mackay, Rockhampton, Hervey Bay, Moreton Bay and Unspecified; and the covariate terms $\log_e$(Number of fish caught) and $\log_e$(Number of fish caught)^2 allowed for a quadratic effect and $\log_e$(Weight of fish caught) allowed a linear effect on the probability of a catch being spotted mackerel. The linear and quadratic covariates together modelled the average fish weight to classify a catch as either spotted mackerel or not. Factor reference levels for this analysis were the fishing year 1992/93, month of January and region of Bowen.

Queensland recreational fishing surveys (RFISH)

Allocating unspecified mackerel to spotted mackerel for recreational catches was compared using two approaches. The first approach used simple species proportion rules. Survey diary "weighting factors" were used to calculate the proportion of unspecified mackerel to allocate as spotted mackerel from the four Queensland diary surveys (1997, 1999, 2002 RFISH and 2001 NRIFS). The diary weights represent the combination of two sources of information: 1) the imputed number of trips fished by all anglers in each survey quarter, age class, gender and region of residence; and 2) the average catch per person per fish species. The product of these two data sources, summed across the relevant strata, expand the sample diary catches into that taken by all anglers in Queensland (*i.e.*, diary weights). These weights assume that there had been no change in participation rates of recreational fishing over the survey period. The weighting factors provided by the DPI&F were used to partition all unspecified mackerel catches into species and fishing regions as follows:

- For every diary recorded catch, we defined the fishing region based on the the angler's reported nearest town to their fishing location.
- Diary weights were then summed by the mackerel species (including unspecified) and fishing region.
- The proportion of each mackerel species in each region was calculated by dividing each species weights by the total of all weights.
- The estimated number of unspecified mackerel to allocate as spotted mackerel was calculated by multiplying the proportion of spotted mackerel by the estimated number of unspecified mackerel caught. Variances and standard errors were similarly apportioned.

The second approach used binary regression to adjust the unspecified mackerel "weighting factors" according to the probability of being spotted mackerel. Forward stepwise regression was used to define the final model components for the Queensland recreational catch data as follows:

$$Logit(P) = \text{Constant + Survey year + Region} + \log_e(\text{Hours fished}) + \log_e(\text{Hours fished})^2 + \log_e(\text{Number of fish caught}) \quad (4.4)$$

where, *P* = probability of spotted mackerel; Survey year = 1997, 1999 and 2002; Region = Far north, Cairns, Townsville, Bowen, Mackay, Rockhampton, Hervey Bay and Moreton Bay; and the covariate terms $\log_e$(Hours fished), $\log_e$(Hours fished)^2 and $\log_e$(Number of fish caught) allowed for the number of hours fished (quadratic effect included) and number of fish caught by each angler. Factor reference levels for this analysis were the survey year 1997 and region of Bowen.

National Recreational and Indigenous Fishing Survey (NRIFS)

Forward stepwise regression was used to define the final model components for the Queensland recreational catch data as follows:

$$Logit(P) = \text{Constant + Region + } \log_e\text{(Number of fish caught) + } \log_e\text{(Hours fished)} \\ + \log_e\text{(Number of people fishing) + } \log_e\text{(Number of people fishing)}^2 \quad (4.5)$$

where, P = probability of spotted mackerel; Region = Gulf of Carpentaria, Far north, Cairns, Townsville, Bowen, Mackay, Rockhampton, Central Coast, Hervey Bay, Moreton Bay and South East Queensland; and the covariate terms $\log_e$(Number of fish caught), $\log_e$(Hours fished), $\log_e$(Number of people fishing) and $\log_e$(Number of people fishing)^2 allowed for the number of hours fished by each fishing group, the number of people fishing in each group (quadratic effect included) and the number of fish caught by each group. Bowen was used as the region reference level.

Allocating unspecified mackerel

The probability of a catch being spotted mackerel was calculated for all data analysed in the binary regressions (*i.e.*, where the mackerel species were identified) and for all unspecified mackerel catches. For the commercial or charter unspecified mackerel catches, the probabilities calculated were multiplied by their catches and summed over the fishing years (y) to estimate the unspecified catch to allocate as spotted mackerel according to the following equation:

$$\sum_y P(\text{spotted mackerel} \mid \text{catch} > 0) \times \text{catch} \quad (4.6)$$

Likewise for the unspecified mackerels reported in the recreational surveys, the probabilities multiplied by their diary weights provided an estimate of the unspecified weights to allocate as spotted mackerel according to the following equation:

$$\sum_y P(\text{spotted mackerel} \mid \text{catch} > 0) \times \text{diary weights} \quad (4.7)$$

The proportion of these allocated spotted mackerel weights in each region were calculated by dividing their total weights by the total of all mackerel weights. The number of unspecified mackerel allocated to spotted mackerel was calculated by multiplying the proportion of spotted mackerel allocated by the estimated number of unspecified mackerel caught. Variances and standard errors were similarly apportioned.

DPI&F decision rules

As a follow on from the DPI (now DPI&F) Spotted Mackerel Workshop conducted on the 6-7 March 2002 and as a recommendation from the Inshore Finfish MAC, the DPI&F developed a set of rules for allocating Queensland commercial unspecified mackerel catches to spotted mackerel (Table 4.2). These rules were used to finalise the Queensland spotted mackerel TACC of 140 t implemented on the 1 July 2003. The rules govern that *all* unspecified mackerel catches that meet certain spatial, seasonal and fishing gear criteria are allocated to spotted mackerel. Unspecified mackerel catches were excluded in the allocation process where the fishing gears were unknown.

Table 4.2. DPI&F decision rules used to allocate unspecified mackerel catches to spotted mackerel based on latitude, month and fishing gear.

Rule	Region	Latitude (°S)		Month		Gear	Mesh size (mm)	
		Minimum	Maximum	Minimum	Maximum		Minimum	Maximum
1	Far north	10.50	19.50	6	9	Line	-	-
2	Innisfail	17.00	19.50	6	9	Net	110	140
3	Bowen	19.50	20.50	6	9	Line	-	-
4	Bowen	19.50	20.50	6	9	Net	110	140
5	Mackay	20.50	22.00	6	9	Net	110	140
6	Hervey Bay	24.00	26.00	1	4	Line	-	-
7	Hervey Bay	24.00	26.00	10	12	Line	-	-
8	Hervey Bay	24.00	26.00	1	4	Net	75	130
9	Hervey Bay	24.00	26.00	10	12	Net	75	130
10	Moreton Bay	26.00	28.50	1	4	Line	-	-
11	Moreton Bay	26.00	28.50	10	12	Line	-	-
12	Moreton Bay	26.00	28.50	1	4	Net	75	125
13	Moreton Bay	26.00	28.50	10	12	Net	75	125
14	Moreton Bay	26.00	28.50	10	12	Net	-	-

Species catch proportion rules

Species catch proportion rules were trialed on Queensland commercial unspecified mackerel catches only (*i.e.*, not New South Wales or recreational). The unspecified mackerel catches were disaggregated based on the proportion of spotted mackerel catches being greater than 50% of the regional catch of all mackerel species (grey, school, shark, Spanish and spotted) for net and line fishing gears (Table 4.3, 4.4). This algorithm allocated *all* unspecified mackerel to spotted mackerel as follows (Table 4.5):

- Net fishing in the Bowen region in July.
- Net fishing in the Hervey Bay region between the months of November to Febuary inclusive.
- Net fishing in the Moreton Bay region between the months of November to March inclusive.
- Net fishing in unspecified regions between the months of December to January inclusive.
- Line fishing in the Moreton Bay region in December.

Table 4.3. Proportions of regional monthly commercial net catch of spotted mackerel to other mackerel species caught by nets. Proportions based on data pooled for all fishing years 1988-2002. Proportions in bold indicate those region-month interactions where spotted mackerel were >50% of total mackerel catch. Regions: Gulf = Gulf of Carpentaria; Towns = Townsville; Rock = Rockhampton; Unspec = Unspecified.

Month	Proportion of regional catch of spotted mackerel to other mackerel for all net gear types									
	Gulf	Torres Strait	Far north	Cairns	Towns	Bowen	Mackay	Rock	Hervey Bay	Moreton Bay	Unspec
Jan	0.00	0.00	0.00	0.00	0.00	0.06	0.07	0.17	**0.68**	**0.77**	**0.52**
Feb	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.11	**0.61**	**0.67**	0.20
Mar	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.49	**0.57**	0.00
Apr	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.22	0.42	0.00
May	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.03	0.01	0.20	0.01
Jun	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.02	0.00	0.25	0.00
Jul	0.00	0.00	0.00	0.01	0.00	**0.68**	0.05	0.03	0.00	0.05	0.03
Aug	0.00	0.00	0.00	0.02	0.01	0.48	0.14	0.24	0.00	0.03	0.02
Sep	0.00	0.00	0.02	0.00	0.00	0.39	0.14	0.07	0.01	0.00	0.03
Oct	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.11	0.04	0.01	0.00
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	**0.57**	**0.50**	0.06
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	**0.70**	**0.67**	**0.51**

Table 4.4. Proportions of regional monthly commercial line catch of spotted mackerel to other mackerel species caught by line. Proportions based on data pooled for all fishing years, 1988-2002. Proportion in bold indicate the region-month interaction where spotted mackerel was >50% of total mackerel catch. Regions: Gulf = Gulf of Carpentaria; Towns = Townsville; Rock = Rockhampton; Unspec = Unspecified.

Month	Proportion of regional catch of spotted mackerel to other mackerel for line gear types										
	Gulf	Torres Strait	Far north	Cairns	Towns	Bowen	Mackay	Rock	Hervey Bay	Moreton Bay	Unspec
Jan	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.24	0.38	0.03
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.13	0.29	0.04
Mar	0.00	0.00	0.00	0.01	0.00	0.04	0.01	0.00	0.05	0.16	0.01
Apr	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.16	0.00
May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.17	0.01
Jun	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.06	0.04
Jul	0.00	0.00	0.00	0.26	0.01	0.05	0.00	0.05	0.00	0.03	0.05
Aug	0.00	0.00	0.00	0.26	0.01	0.07	0.00	0.09	0.00	0.07	0.02
Sep	0.00	0.00	0.00	0.02	0.00	0.02	0.01	0.05	0.01	0.16	0.01
Oct	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.03	0.10	0.00
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.09	0.48	0.01
Dec	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.03	0.39	**0.53**	0.43

Table 4.5. Species catch proportion rules used to allocate unspecified mackerel catches to spotted mackerel based on region, month and fishing gear.

Rule	Region	Month		Gear
		Minimum	Maximum	
1	Bowen	7	7	Net
2	Hervey Bay	1	2	Net
3	Hervey Bay	11	12	Net
4	Moreton Bay	12	12	Line
5	Moreton Bay	1	3	Net
6	Moreton Bay	11	12	Net
7	Unspecified	1	1	Net
8	Unspecified	12	12	Net

Catch allocation results

Queensland commercial logbooks

Queensland commercial fishers reported five different mackerel species in the DPI&F compulsory logbooks (grey, school, shark or salmon, Spanish and spotted mackerel). Unspecified mackerel were a significant component of the catch (Table 3.2). The overlapping regional and monthly catch of the different mackerel species made simple identification of spotted mackerel catches unclear (Fig. 3.3). The binary regression analysis identified significant changes in the probability of a Queensland commercial catch of mackerel being spotted mackerel between fishing regions, gears, months, years and the weight of mackerel caught (Table 4.6). Table 4.7 contains the regression parameter estimates and standard errors for the various model effects.

Table 4.6. Forward stepwise analysis of deviance. The model factors and covariates are ordered by their significance, from highest to lowest, in determining the probability of a spotted mackerel catch.

Fitted terms	d.f.	Deviance	Mean deviance	Chi square	Probability
Region	10	25457.24	2545.72	2545.72	<.0001
Gear	7	7395.52	1056.50	1056.50	<.0001
Month	11	3044.52	276.77	276.77	<.0001
Fishing year	14	2954.46	211.03	211.03	<.0001
$\log_e$(Weight of fish caught)	1	696.43	696.43	696.43	<.0001
Residual	276869	71893.53	0.26		
Total	276912	111441.70	0.40		

Table 4.7. Parameter estimates and standard errors (S.E.) from the binary regression analysis of the probability of a Queensland commercial catch of mackerel being spotted mackerel. Regions: Gulf = Gulf of Carpentaria.

Fitted terms	Parameter	Estimate	S.E.	T statistic	Probability
Constant	Constant	-3.991	0.102	-39.231	<.0001
Region	Bowen	0.000	-	-	-
Region	Gulf	-4.763	0.166	-28.729	<.0001
Region	Torres Strait	-5.873	0.826	-7.107	<.0001
Region	Far north	-2.999	0.130	-23.121	<.0001
Region	Cairns	-0.572	0.044	-13.064	<.0001
Region	Townsville	-2.285	0.079	-28.912	<.0001
Region	Mackay	-0.854	0.056	-15.195	<.0001
Region	Rockhampton	0.092	0.045	2.067	0.0387
Region	Hervey Bay	0.402	0.043	9.259	<.0001
Region	Moreton Bay	1.557	0.040	38.742	<.0001
Region	Unspecified	-0.609	0.124	-4.917	<.0001
Gear	Gill net	0.000	-	-	-
Gear	Net	1.084	0.050	21.600	<.0001
Gear	Ring net	3.082	0.079	38.899	<.0001
Gear	Line	-0.541	0.050	-10.870	<.0001
Gear	Multi hook	-0.530	0.057	-9.352	<.0001
Gear	Troll	-0.476	0.068	-6.990	<.0001
Gear	Trawl	-0.009	0.213	-0.041	0.9674
Gear	Unspecified	1.265	0.102	12.378	<.0001
Month	Jan	0.000	-	-	-
Month	Feb	-0.435	0.044	-9.846	<.0001
Month	Mar	-0.803	0.046	-17.356	<.0001
Month	Apr	-0.995	0.048	-20.576	<.0001
Month	May	-1.403	0.054	-26.155	<.0001
Month	Jun	-1.722	0.061	-28.435	<.0001
Month	Jul	-0.620	0.044	-14.180	<.0001
Month	Aug	-0.568	0.043	-13.339	<.0001
Month	Sep	-1.159	0.048	-24.208	<.0001
Month	Oct	-1.635	0.060	-27.217	<.0001
Month	Nov	-0.855	0.048	-17.881	<.0001
Month	Dec	0.074	0.041	1.824	0.0682
Fishing year	1988	0.000	-	-	-
Fishing year	1989	-0.105	0.095	-1.101	0.2711
Fishing year	1990	-0.026	0.096	-0.274	0.7839
Fishing year	1991	0.481	0.093	5.162	<.0001
Fishing year	1992	1.214	0.084	14.525	<.0001
Fishing year	1993	1.775	0.080	22.129	<.0001
Fishing year	1994	1.403	0.084	16.664	<.0001
Fishing year	1995	1.366	0.083	16.479	<.0001
Fishing year	1996	1.594	0.079	20.127	<.0001
Fishing year	1997	1.725	0.081	21.405	<.0001
Fishing year	1998	1.596	0.080	19.918	<.0001
Fishing year	1999	1.637	0.081	20.287	<.0001
Fishing year	2000	1.888	0.080	23.582	<.0001
Fishing year	2001	1.637	0.081	20.316	<.0001
Fishing year	2002	2.092	0.078	26.880	<.0001
Covariate	$\log_e$(Weight of fish caught)	0.206	0.008	26.240	<.0001

The probability of a Queensland commercial catch of mackerel being reported as spotted mackerel was significantly greater when caught using ring nets, and from the traditional spotted mackerel fishing regions of Moreton Bay and Hervey Bay during summer, and Bowen during winter (Fig. 4.1). From 1993, the probability of a spotted mackerel being reported by a commercial fisher also increased (Fig. 4.1). Overall, the binary regression calculated a low probability of commercial unspecified mackerel catches being spotted mackerel (Fig. 4.2). The regression tended to slightly under-estimate the total catches of spotted mackerel compared to the actual reported catches (Fig. 4.3), due mainly to the influence of unspecified (*i.e.*, unknown) nets in Hervey Bay and Bowen. In 1988, 1989 and 1991 spotted mackerel catches were over-estimated by the regression and in all other years catches were under-estimated (Fig. 4.3). The binary regression estimated that the proportion of unspecified mackerel allocated as spotted mackerel varied from 1 t in 1988 to 42 t in 1999 (Table 4.8).

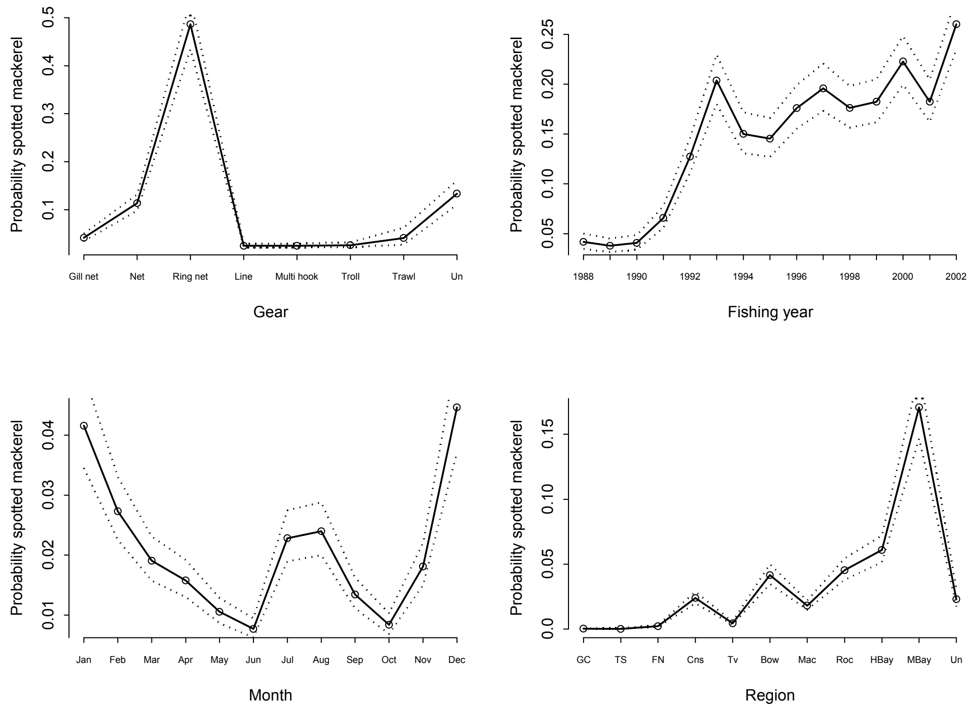

Fig. 4.1. The probability of a Queensland commercial catch of mackerel being spotted mackerel increased from 1993 and was higher when caught using ring nets, in the months of December and January, and from Moreton Bay, Hervey Bay and Bowen. The solid lines demonstrate the average main effects on the probabilities and the dotted lines are 95% confidence intervals. Gear: Un = unspecified. Regions: GC = Gulf of Carpentaria; TS = Torres Strait; FN = Far north; Cns = Cairns; Tv = Townsville; Bow = Bowen; Mac = Mackay; Roc = Rockhampton; HBay = Hervey Bay; MBay = Moreton Bay; Un = Unspecified.

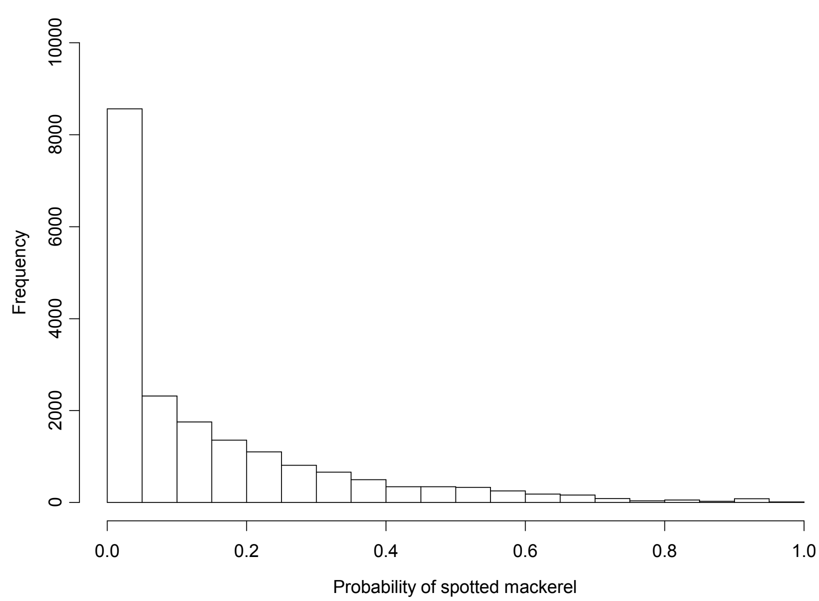

Fig. 4.2. Histogram of the spotted mackerel probabilities assigned to the unspecified mackerel catches (n=18955). Most unspecified mackerel catches had a low probability of being spotted mackerel.

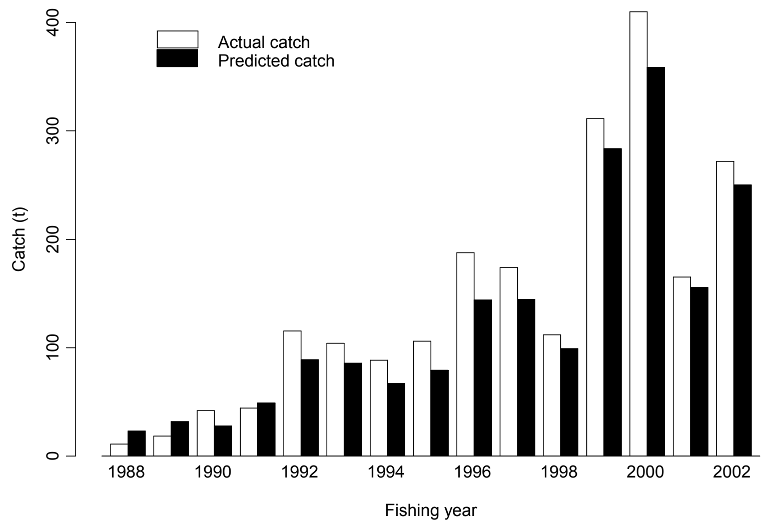

Fig. 4.3. The binary regression model slightly under-estimated the Queensland commercial catches of spotted mackerel across fishing years, 1988-2002. All specified fishing gears predicted reasonably well, although the under-estimates were due to the unspecified netting methods recorded in Hervey Bay and Bowen.

Table 4.8. Total mackerel catches (t) taken by Queensland commercial fishers from fishing years 1988-2002, including Gulf of Carpentaria and Torres Strait. The results of using binary regression to allocate unspecified mackerel to spotted mackerel catches are shown.

Fishing year	Grey	School	Shark	Spanish	Spotted	Unspecified	Unspecified allocated to spotted	Total spotted
1988	236	2	19	539	11	29	1	12
1989	270	7	52	590	18	10	1	19
1990	282	9	84	611	42	12	1	43
1991	210	4	58	537	44	44	7	51
1992	139	16	64	597	116	116	27	142
1993	88	24	55	619	104	88	22	126
1994	143	27	66	626	88	115	30	118
1995	169	23	69	610	106	105	21	127
1996	248	45	59	680	188	131	32	220
1997	421	35	72	901	174	125	31	205
1998	307	43	53	821	112	72	13	125
1999	313	84	48	754	311	106	42	354
2000	318	93	46	565	410	94	35	445
2001	433	49	53	705	165	80	16	182
2002	332	81	38	806	272	54	19	291

The DPI&F decision and species catch proportion rules were less conservative methods for allocating unspecified mackerel to spotted mackerel catches, as all unspecified mackerel catches that fulfilled the particular criteria (or rules) were allocated as spotted mackerel (Table 4.9, 4.10); albeit that the final allocations were quite similar (Table 4.11). A number of the DPI&F decision rules were also poor criteria for classifying spotted mackerel, as seven of the 14 rules resulted in greater catches for species other than spotted mackerel (Table 4.9). In contrast, the species catch proportion rules sufficiently captured those criteria that were specific to spotted mackerel catches (Table 4.10). For all years combined (1988-2002), 300 t of unspecified mackerel were allocated to spotted mackerel using the binary regression method, while 389 t and 262 t were allocated using the DPI&F decision and species catch proportion rules, respectively.

Although, the catch allocations were reasonably consistent between the different methods, we preferred the binary regression as it was a more objective, statistical approach that optimised all available data to best depict spotted mackerel catches. This method was endorsed by the Spotted Mackerel Stock Assessment Steering Committee (4 February 2004) and Inshore Finfish MAC Scientific Advisory Group (24 March 2004) (see Appendix 3).

Table 4.9. Total mackerel catches (t) taken by Queensland commercial fishers pooled across fishing years 1988-2002 based on the DPI&F decisions rules for allocating unspecified mackerel to spotted catches. Unspecified mackerel catch allocated to spotted mackerel according to each rule.

Rule	Grey	School	Shark	Spanish	Spotted	Unspecified
1	47	24	97	2057	130	20
2	8	4	0	<1	1	6
3	<1	<1	59	205	12	25
4	53	8	0	<1	374	166
5	3	<1	0	0	14	8
6	2	6	<1	152	8	<1
7	<1	3	<1	59	9	1
8	142	20	<1	8	494	98
9	123	21	0	6	468	101
10	<1	4	<1	193	65	2
11	<1	7	<1	18	26	1
12	14	17	<1	<1	157	17
13	2	28	<1	<1	19	7
14	4	28	<1	5	57	12

Table 4.10. Total mackerel catches (t) taken by Queensland commercial fishers pooled across fishing years 1988-2002 based on the species catch proportion rules for allocating unspecified mackerel to spotted catches. Unspecified mackerel catch allocated to spotted mackerel according to each rule.

Rule	Grey	School	Shark	Spanish	Spotted	Unspecified
1	15	2	5	16	180	45
2	133	5	<1	12	466	88
3	128	12	0	7	503	97
4	0	2	<1	14	19	1
5	31	12	<1	32	241	24
6	3	20	<1	5	56	8
7	<1	0	<1	1	2	<1
8	<1	0	<1	1	1	<1

Table 4.11. Total mackerel catches (t) taken by Queensland commercial fishers from fishing years 1988-2002.

Fishing year	Unspecified allocated to spotted mackerel			Total spotted mackerel + Binary	Total spotted mackerel + DPI&F rules	Total spotted mackerel + Catch rules
	Binary	DPI&F rules	Catch rules			
1988	1	3	4	12	14	15
1989	1	<1	<1	19	19	19
1990	1	3	4	41	43	44
1991	7	15	18	50	58	61
1992	27	35	44	142	150	159
1993	22	25	13	125	128	116
1994	30	47	27	118	135	115
1995	21	46	20	126	151	125
1996	33	34	26	219	220	212
1997	31	50	6	204	223	179
1998	13	26	5	125	138	117
1999	42	30	38	353	341	349
2000	35	40	38	445	450	448
2001	16	18	6	180	182	170
2002	20	16	12	292	288	284

New South Wales commercial logbooks

New South Wales commercial fishers reported seven different mackerel species in their compulsory logbooks (frigate, jack, shark, slimy, Spanish and spotted mackerel and mackerel tuna). Unspecified mackerel were a significant component of the catch in any given year (Fig. 3.10). The binary regression analysis identified significant changes in the probability of a New South Wales commercial catch of mackerel being spotted mackerel between fishing regions, gears, months, years and the weight of mackerel caught (Table 4.12). Table 4.13 contains the regression parameter estimates and standard errors for the various model effects.

Table 4.12. Forward stepwise analysis of deviance. The model factors and covariates are ordered by their significance, from highest to lowest, in determining the probability of a spotted mackerel catch.

Fitted terms	d.f.	Deviance	Mean deviance	Chi square	Probability
Gear	10	2313.14	231.31	231.31	<.0001
Fishing year	18	1780.56	98.92	98.92	<.0001
Month	11	608.37	55.31	55.31	<.0001
$\log_e$(Weight of fish caught)	1	21.50	21.50	21.50	<.0001
Residual	20147	11469.18	0.57		
Total	20187	16192.75	0.80		

The probability of a New South Wales commercial catch of mackerel being reported as spotted mackerel was relatively low, irrespective of the year, month or fishing gear used (Fig. 4.4). Overall, the binary regression calculated a low probability of commercial unspecified mackerel catches being spotted mackerel (Fig. 4.5), and predicted total catches of spotted mackerel reasonably well from 1997, when reporting procedures improved (Fig. 4.6). From 1984 to 1998 spotted mackerel catches were over-estimated by the regression, while in the latter years the catches tended to be under-estimated (Fig. 4.6). The binary regression estimated that the proportion of unspecified mackerel allocated as spotted mackerel was typically less than 1 t in any given year (Table 4.14).

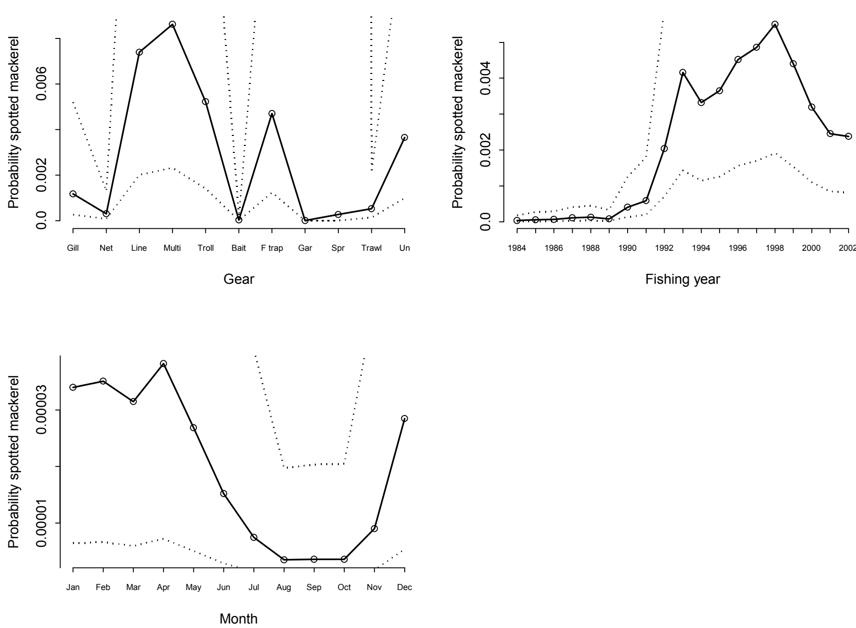

Fig. 4.4. The probability of a New South Wales commercial catch of mackerel being reported as spotted mackerel was relatively low, although it increased with line and multi hook fishing gear, and was higher from 1993 to 1999 and in the months of December to May. The solid lines demonstrate the average main effects on the probabilities and the dotted lines are 95% confidence intervals. Gear: Gill = gill net; Net = unspecified net; Multi = multi hook (longline); Bait = bait net; F trap = fish trap; Gar = garfish net; Spr = spear; Un = Unspecified.

Table 4.13. Parameter estimates and standard errors (S.E.) from the binary regression analysis of the probability of a NSW commercial catch of mackerel being spotted mackerel.

Fitted terms	Parameter	Estimate	S.E.	T statistic	Probability
Constant	Constant	-10.733	0.860	-12.480	<.0001
Gear	Bait	0.000	-	-	-
Gear	Gill net	3.542	0.651	5.439	<.0001
Gear	Net	2.194	0.624	3.517	0.0004
Gear	Line	5.389	0.537	10.043	<.0001
Gear	Multi hook	5.543	0.545	10.165	<.0001
Gear	Troll	5.040	0.539	9.345	<.0001
Gear	Fish trap	4.933	0.566	8.721	<.0001
Gear	Garfish net	-1.996	6.512	-0.307	0.7592
Gear	Spear	2.082	25.793	0.081	0.9357
Gear	Trawl	2.747	0.585	4.696	<.0001
Gear	Unspecified	4.680	0.539	8.686	<.0001
Fishing year	1984	0.000	-	-	-
Fishing year	1985	0.541	0.873	0.620	0.5356
Fishing year	1986	0.704	0.827	0.851	0.3945
Fishing year	1987	1.191	0.762	1.562	0.1183
Fishing year	1988	1.340	0.741	1.807	0.0708
Fishing year	1989	0.913	0.798	1.143	0.2529
Fishing year	1990	2.484	0.689	3.604	0.0003
Fishing year	1991	2.858	0.687	4.159	<.0001
Fishing year	1992	4.096	0.668	6.132	<.0001
Fishing year	1993	4.810	0.667	7.213	<.0001
Fishing year	1994	4.584	0.668	6.861	<.0001
Fishing year	1995	4.680	0.668	7.005	<.0001
Fishing year	1996	4.894	0.666	7.350	<.0001
Fishing year	1997	4.967	0.666	7.459	<.0001
Fishing year	1998	5.091	0.666	7.646	<.0001
Fishing year	1999	4.867	0.667	7.302	<.0001
Fishing year	2000	4.545	0.669	6.794	<.0001
Fishing year	2001	4.282	0.670	6.389	<.0001
Fishing year	2002	4.249	0.669	6.349	<.0001
Month	Jan	0.000	-	-	-
Month	Feb	0.032	0.087	0.365	0.7148
Month	Mar	-0.077	0.084	-0.926	0.3546
Month	Apr	0.116	0.083	1.393	0.1636
Month	May	-0.236	0.095	-2.482	0.0131
Month	Jun	-0.806	0.124	-6.515	<.0001
Month	Jul	-1.521	0.177	-8.608	<.0001
Month	Aug	-2.286	0.265	-8.611	<.0001
Month	Sep	-2.254	0.265	-8.496	<.0001
Month	Oct	-2.253	0.273	-8.239	<.0001
Month	Nov	-1.331	0.179	-7.419	<.0001
Month	Dec	-0.178	0.114	-1.562	0.1183
Covariate	$\log_e$(Weight of fish caught)	0.071	0.015	4.640	<.0001

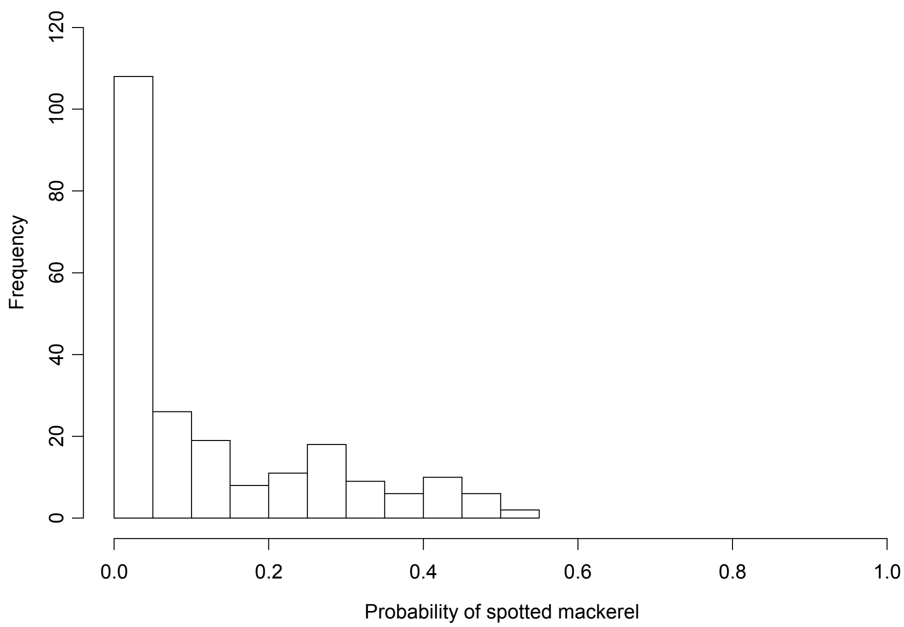

Fig. 4.5. Histogram of the spotted mackerel probabilities assigned to the unspecified mackerel catches (n=223). Most unspecified mackerel catches had a low probability of being spotted mackerel.

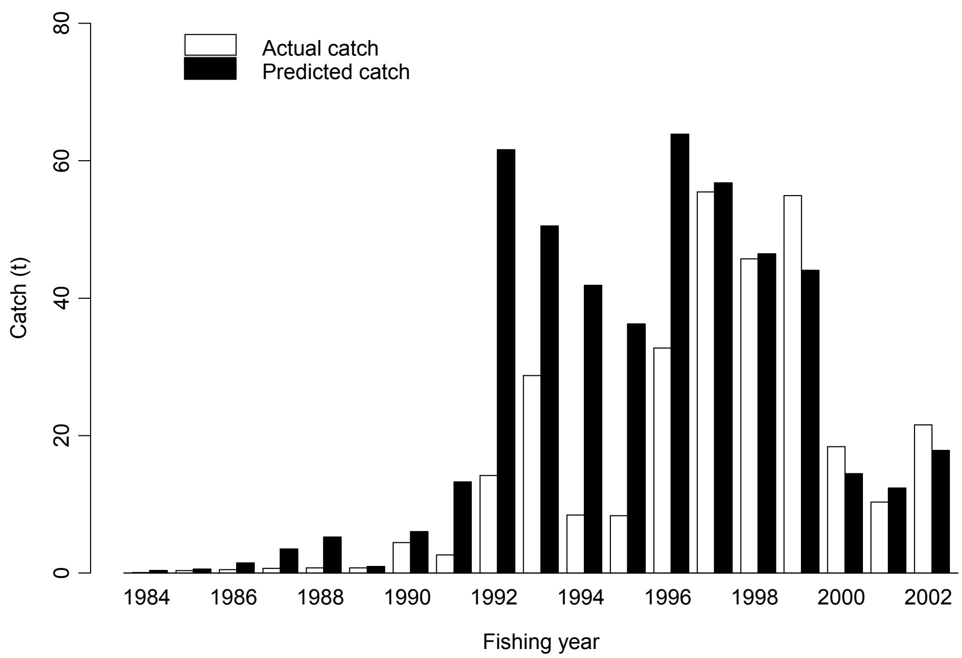

Fig. 4.6. The binary regression model predicted the New South Wales commercial catches of spotted mackerel reasonably well in the latter years from 1997, when reporting increased in quality. The over-prediction in early years was due to the unspecified gear types. When unspecified gears were removed from the model the predictive power was much improved.

Table 4.14. Total mackerel catches (t) taken by New South Wales commercial fishers from fishing years 1984-2002. Unspec = unspecified mackerel.

Fishing year	Frigate	Jack	Mackerel tuna	Shark	Slimy	Spanish	Spotted	Unspec	Unspec allocated to spotted	Total spotted
1984	0	198	1	0	537	31	<1	<1	<1	<1
1985	0	53	<1	0	316	22	<1	22	<1	<1
1986	0	204	<1	0	357	33	1	10	<1	1
1987	0	196	1	0	729	35	1	1	<1	1
1988	0	849	3	0	428	54	1	<1	<1	1
1989	0	79	<1	0	144	29	1	1	<1	1
1990	0	60	18	0	94	48	4	1	<1	4
1991	1	40	40	0	254	16	3	<1	<1	3
1992	<1	160	23	0	512	51	14	1	<1	14
1993	1	102	23	0	404	18	29	10	<1	29
1994	23	63	8	0	305	9	8	52	<1	8
1995	4	68	23	0	309	10	8	4	1	9
1996	2	30	19	0	310	24	33	2	<1	33
1997	12	18	24	<1	503	15	55	3	<1	55
1998	4	16	24	0	381	16	46	6	<1	46
1999	3	27	14	0	557	8	55	<1	<1	55
2000	1	59	6	0	375	3	18	<1	<1	18
2001	9	19	13	0	490	3	10	<1	<1	10
2002	8	1	13	0	512	7	22	<1	<1	22

Queensland charter logbooks

Over the past 11 years, charter boats have reported a combined total mackerel catch of 252 t, consisting of five species (grey, school, shark or salmon, Spanish and spotted mackerel) (Fig. 3.15). Spanish mackerel were the most frequent species reported across the regions, with spotted mackerel charter catches only common in Moreton Bay (Fig. 3.16). The dominant seasonal pattern of Spanish mackerel made identification of spotted mackerel catches unclear.

The binary regression analysis identified significant changes in the probability of a charter catch of mackerel being spotted mackerel between fishing regions, months, years, and with the number and weight of mackerel caught (Table 4.15). Table 4.16 contains the regression parameter estimates and standard errors for the various model effects. The probability of a charter catch of mackerel being reported as spotted mackerel was very low at only 1% in the first three years of reporting catches, but increased marginally in 1995 and remained relatively constant at about 5% to 8% up to 2002 (Fig. 4.7). The probability of a charter fisher catching a spotted mackerel was generally higher in December, January and August, and from Moreton Bay (Fig. 4.7).

Table 4.15. Forward stepwise analysis of deviance. The model factors and covariates are ordered by their significance, from highest to lowest, in determining the probability of a spotted mackerel catch.

Fitted terms	d.f.	Deviance	Mean deviance	Chi square	Probability
Region	10	2455.803	245.5803	245.58	<.001
$\log_e$(Weight of fish caught)	1	381.8858	381.8858	381.89	<.001
$\log_e$(Number of fish caught)	1	705.8545	705.8545	705.85	<.001
Month	11	83.116	7.556	7.56	<.001
Fishing year	10	47.7449	4.7745	4.77	<.001
$\log_e$(Number of fish caught)^2	1	6.9157	6.9157	6.92	0.009
Residual	14715	5538.61	0.3764		
Total	14749	9219.93	0.6251		

Table 4.16. Parameter estimates and standard errors (S.E.) from the binary regression analysis of the probability of a charter catch of mackerel being spotted mackerel. Regions: Gulf = Gulf of Carpentaria.

Fitted terms	Parameter	Estimate	S.E.	T statistic	Probability
Constant	Constant	-2.8000	26.7000	-0.11	0.916
Fishing year	1992	0.0000	-	-	-
Fishing year	1993	-0.5000	27.2000	-0.02	0.986
Fishing year	1994	1.1000	26.7000	0.04	0.968
Fishing year	1995	3.3000	26.7000	0.13	0.900
Fishing year	1996	2.8000	26.7000	0.10	0.917
Fishing year	1997	3.0000	26.7000	0.11	0.909
Fishing year	1998	3.3000	26.7000	0.13	0.900
Fishing year	1999	3.3000	26.7000	0.12	0.901
Fishing year	2000	3.3000	26.7000	0.13	0.900
Fishing year	2001	3.3000	26.7000	0.12	0.901
Fishing year	2002	3.0000	26.7000	0.11	0.910
Month	Jan	0.0000	-	-	-
Month	Feb	-0.7090	0.1810	-3.92	<.001
Month	Mar	-0.6090	0.1660	-3.66	<.001
Month	Apr	-0.7930	0.1720	-4.62	<.001
Month	May	-0.7750	0.1770	-4.39	<.001
Month	Jun	-0.3930	0.1800	-2.19	0.029
Month	Jul	-0.2410	0.1780	-1.36	0.174
Month	Aug	0.1270	0.1700	0.74	0.457
Month	Sep	-0.2720	0.1760	-1.54	0.123
Month	Oct	-0.2720	0.1800	-1.52	0.130
Month	Nov	-0.7980	0.2180	-3.67	<.001
Month	Dec	-0.1070	0.1880	-0.57	0.569
Region	Bowen	0.0000	-	-	-
Region	Gulf	0.6750	0.1630	4.13	<.001
Region	Torres Strait	-5.0100	5.5300	-0.91	0.365
Region	Far north	-1.4170	0.2210	-6.42	<.001
Region	Cairns	-0.9810	0.1620	-6.05	<.001
Region	Townsville	-1.3600	0.2140	-6.34	<.001
Region	Mackay	-0.7910	0.1780	-4.45	<.001
Region	Rockhampton	-1.2770	0.2470	-5.16	<.001
Region	Hervey Bay	0.3090	0.1620	1.90	0.057
Region	Moreton Bay	3.0940	0.1620	19.16	<.001
Region	Unspecified	-2.1640	0.9820	-2.20	0.027
Covariate	$\log_e$(Number of fish caught)	1.2480	0.1190	10.46	<.001
Covariate	$\log_e$(Number of fish caught)^2	0.1137	0.0430	2.65	0.008
Covariate	$\log_e$(Weight of fish caught)	-1.6411	0.0587	-27.94	<.001

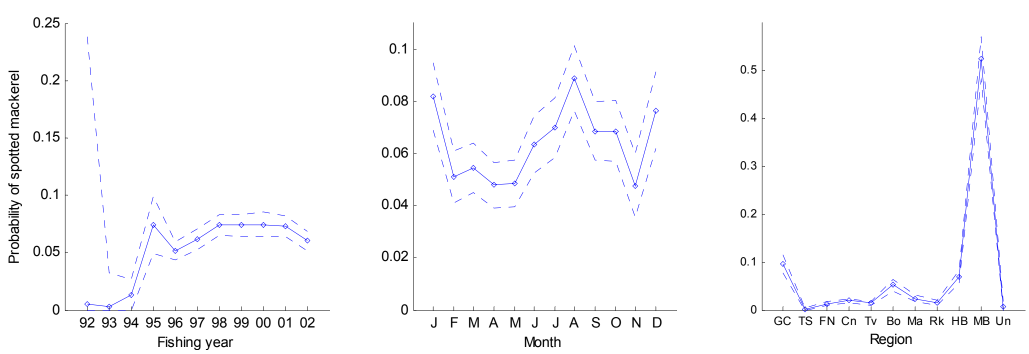

Fig. 4.7. The probability of a charter catch of mackerel being spotted mackerel was constant at about 5% to 8% between 1995 and 2002, higher in the months of December, January and August, and higher in Moreton Bay. The solid lines demonstrate the average main effects on the probabilities and the dotted lines are 95% confidence intervals. Regions: GC = Gulf of Carpentaria; TS = Torres Strait; FN = Far north; Cn = Cairns; Tv = Townsville; Bo = Bowen; Ma = Mackay; Rk = Rockhampton; HB = Hervey Bay; MB = Moreton Bay; Un = Unspecified.

Mackerel catch weights and numbers were used to model average fish weights (Fig. 4.8). The probabilities of spotted mackerel increased when larger numbers of fish were caught, but decreased with heavy catch weights. This result showed that larger average fish weights generally associated with Spanish mackerel catches, compared to smaller average fish weights that associated with spotted or school mackerel.

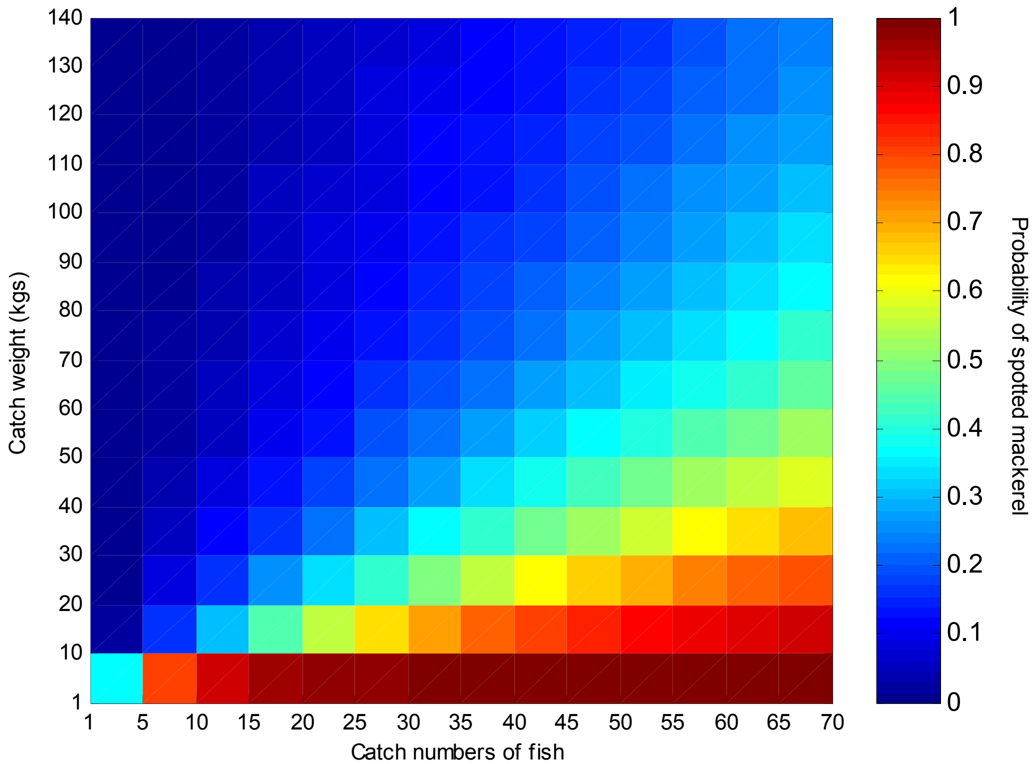

Fig. 4.8. Matrix plot showing the probability of charter mackerel catch being spotted mackerel increases with larger numbers of fish caught, but decreases for heavy catch weights.

Overall, the binary regression calculated a low probability of charter catches of unspecified mackerel being spotted mackerel (Fig. 4.9). The model predicted total catches of spotted mackerel by fishing years reasonably well compared to the actual reported catches (Fig. 4.10), although the binary regression tended to under-estimate the Bowen and Moreton Bay spotted mackerel catches in 1997. In 1997, the Bowen and Moreton Bay spotted mackerel catches were about 0.5 t and 1.3 t, respectively. The binary model, however, predicted only about 0.1 t from Bowen and 1 t from Moreton Bay. The different nature of spotted mackerel catches in 1997 may require a more complex model. A Fishing year * Region interaction only marginally improved the predictions and the gain in precision was not significant for the additional number of parameters in the model. Overall, the reported catch of unspecified mackerel has increased from about 2 t in the 1996/97 fishing year to 12 t in 2002/03 (Table 4.17). The binary regression model estimated that < 1 t of unspecified mackerel were generally spotted mackerel. As with all the fishing sectors, we assumed that the identifications of the reported mackerel species by the recreational charter sector were correct.

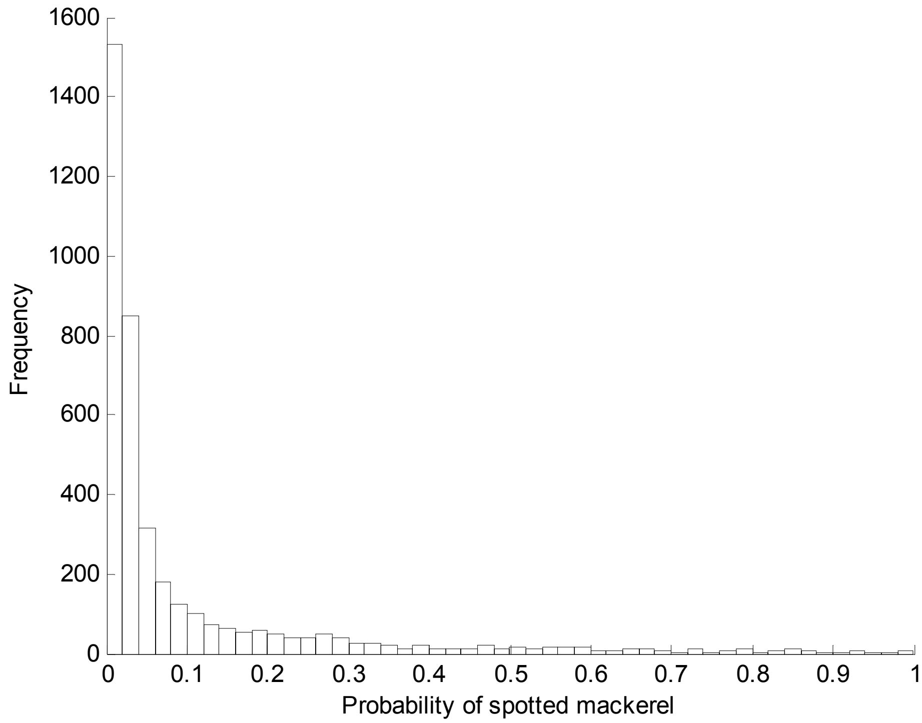

Fig. 4.9. Histogram of the spotted mackerel probabilities assigned to the unspecified mackerel catches (n=3959). Most unspecified mackerel catches had low probability of being spotted mackerel.

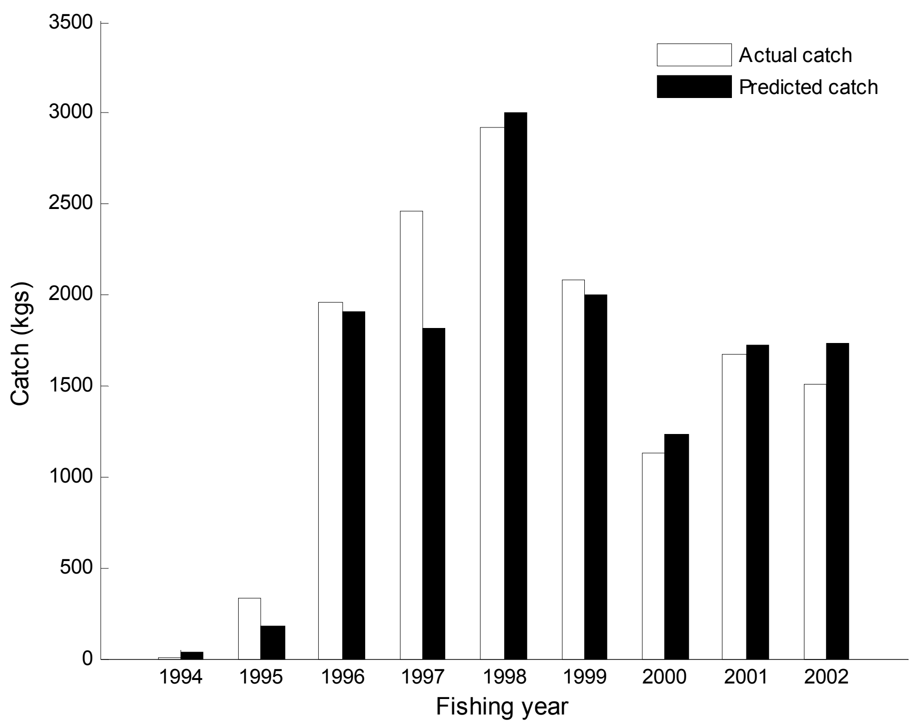

Fig. 4.10. The binary regression model predicted the charter catches of spotted mackerel reasonably well across fishing years, 1994-2002.

Table 4.17. Total mackerel catches (kg) taken by charter boats from 1992-2002. The results of using binary regression to allocate unspecified mackerel to spotted mackerel catches are shown.

Fishing year	Grey	School	Shark	Spanish	Spotted	Unspecified	Unspecified allocated to spotted	Total spotted
1992	0	0	0	22	0	0	0	0
1993	0	0	0	346	0	0	0	0
1994	0	547	28	6903	10	117	0	10
1995	8	193	55	6103	333	276	69	402
1996	107	1711	2396	20887	1957	1991	287	2244
1997	149	1918	1881	19941	2460	965	188	2648
1998	167	3396	1356	19608	2921	9820	972	3893
1999	74	1589	1027	23186	2079	7917	285	2364
2000	39	1683	1209	19745	1128	4889	365	1494
2001	177	3216	1371	19042	1669	8060	532	2201
2002	42	4983	2178	24142	1510	12131	668	2178

Queensland recreational fishing surveys (RFISH)

Five mackerel species were reported in the Queensland recreational fishing surveys (grey, school, shark or salmon, Spanish and spotted mackerel). Unspecified mackerel were a significant component of the catches estimated (Table 3.5). The broad spread of mackerel species reported made identification of spotted mackerel catches unclear (Fig. 3.17, 3.18, 3.20). The binary regression analysis identified significant changes in the probability of a recreational catch of mackerel being spotted mackerel between survey years, fishing regions, time spent fishing and numbers of mackerel caught (Table 4.18). Table 4.19 contains the regression parameter estimates and standard errors for the various model effects.

The probability of a recreational catch of mackerel being reported as spotted mackerel was lower in 2002 than 1997 and 1999, and generally higher in the southern fishing regions (Fig. 4.11). As well, the probability of a recreational catch of mackerel being spotted mackerel was lower for longer times spent fishing, and higher when large numbers of mackerel were caught (Fig. 4.12). Overall, the binary regression calculated mixed probabilities of recreational catches of unspecified mackerel being spotted mackerel (Fig. 4.13). The probabilities were generally bimodal with unspecified mackerel having no clear low or high probability of being spotted mackerel. The regression predicted that the total catches of spotted mackerel by fishing years were comparable to the actual reported catches (Fig. 4.14). In 1996 and 1997, spotted mackerel catches were under-estimated by the regression and in all other years catches were over-estimated (Fig. 4.14). Adjusted recreational catch numbers of spotted mackerel varied if just the diary weights or diary weights and the binary regression together were used to allocate unspecified mackerel as spotted mackerel catches (Table 4.20). The binary regression estimated about 21 t less of unspecified mackerel were spotted mackerel compared to using just the diary weights in 1997. In 1999 and 2002, the binary regression estimated about 6 t and 33 t more of unspecified mackerel were spotted mackerel compared to using just the diary weights.

Table 4.18. Forward stepwise analysis of deviance. The model factors and covariates are ordered by their significance, from highest to lowest, in determining the probability of a spotted mackerel catch.

Fitted terms	d.f.	Deviance	Mean deviance	Chi square	Probability
RFISH survey year	2	25.602	12.801	12.80	<.001
Region	9	69.288	7.699	7.70	<.001
$\log_e$(Number of hours fished)	1	9.055	9.055	9.06	0.003
$\log_e$(Number of hours fished)^2	1	6.180	6.180	6.18	0.013
$\log_e$(Number of fish caught)^2	1	30.864	30.864	30.86	<.001
Residual	912	1118.066	1.226		
Total	926	1259.056	1.360		

Table 4.19. Parameter estimates and standard errors (S.E.) from the binary regression analysis of the probability of a recreational mackerel catch being spotted mackerel. Regions: Gulf = Gulf of Carpentaria.

Fitted terms	Parameter	Estimate	S.E.	T statistic	Probability
Constant	Constant	-0.8030	0.4640	-1.73	0.083
Fishing year	1997	0.0000	-	-	-
Fishing year	1999	-0.1640	0.1770	-0.93	0.354
Fishing year	2002	-0.4460	0.1790	-2.49	0.013
Region	Bowen	0.0000	-	-	-
Region	Gulf	-0.3970	0.7650	-0.52	0.604
Region	Far north	-2.1800	9.8800	-0.22	0.825
Region	Cairns	-0.3230	0.3600	-0.90	0.369
Region	Townsville	-0.9100	0.3900	-2.34	0.020
Region	Mackay	0.5170	0.3570	1.45	0.148
Region	Rockhampton	-0.2650	0.3380	-0.78	0.434
Region	Hervey Bay	0.5210	0.3530	1.48	0.140
Region	Moreton Bay	0.7480	0.3100	2.41	0.016
Region	Unspecified	1.4380	0.8900	1.62	0.106
Covariate	$\log_e$(Number of hours fished)	0.6860	0.4910	1.40	0.162
Covariate	$\log_e$(Number of hours fished)^2	-0.3360	0.1490	-2.26	0.024
Covariate	$\log_e$(Number of fish caught)^2	0.5032	0.0921	5.46	<.001

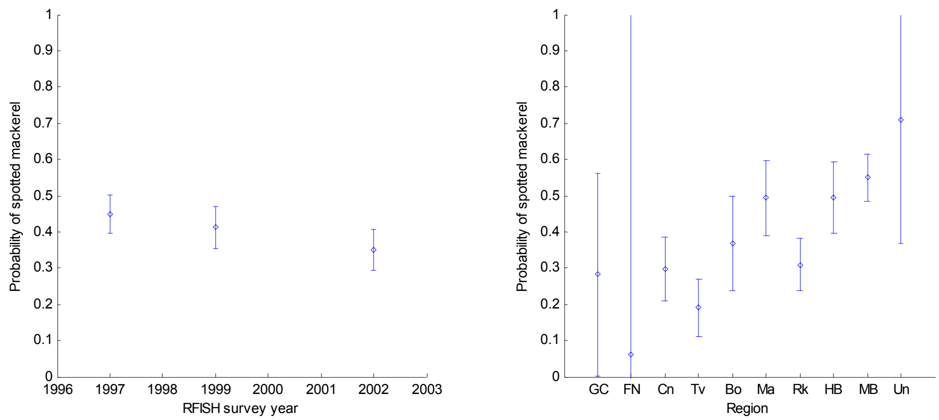

Fig. 4.11. The probability of a recreational catch of mackerel being spotted mackerel was lower in 2002 compared to 1997 and 1999, and generally higher in the southern fishing regions. Regions: GC = Gulf of Carpentaria; FN = Far north; Cn = Cairns; Tv = Townsville; Bo = Bowen; Ma = Mackay; Rk = Rockhampton; HB = Hervey Bay; MB = Moreton Bay; Un = Unspecified.

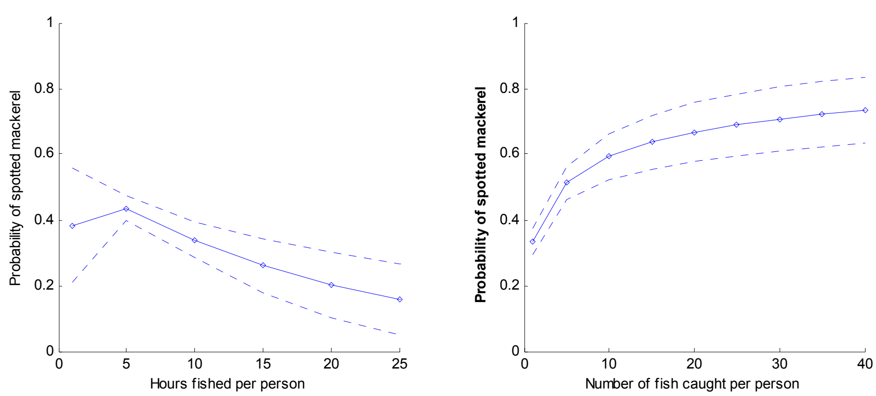

Fig. 4.12. The probability of a recreational catch of mackerel being spotted mackerel was lower for longer times spent fishing, and higher for larger numbers of mackerel caught.

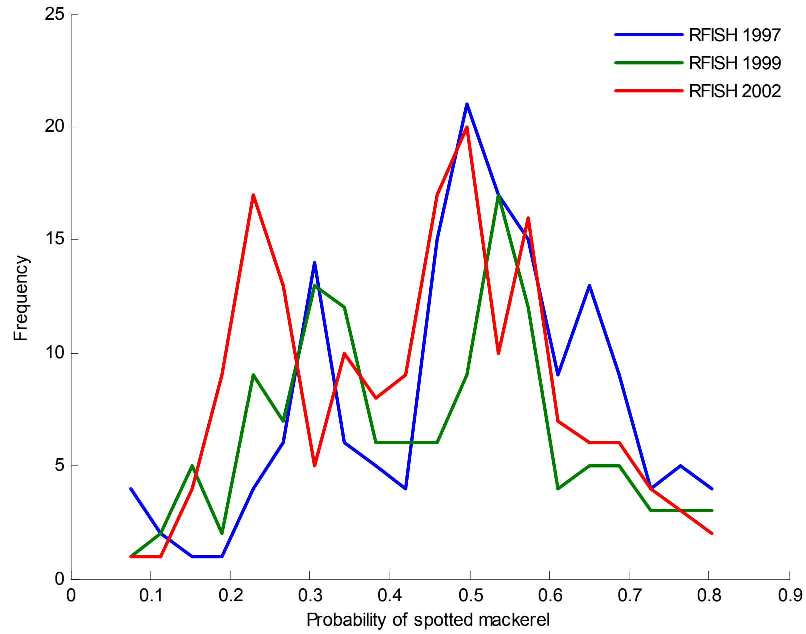

Fig. 4.13. Histogram of the spotted mackerel probabilities assigned to the recreational unspecified mackerel catches in 1997, 1999 and 2002. The probabilities were generally bimodal with unspecified mackerel catches generally having no clear low or high probability of being spotted mackerel.

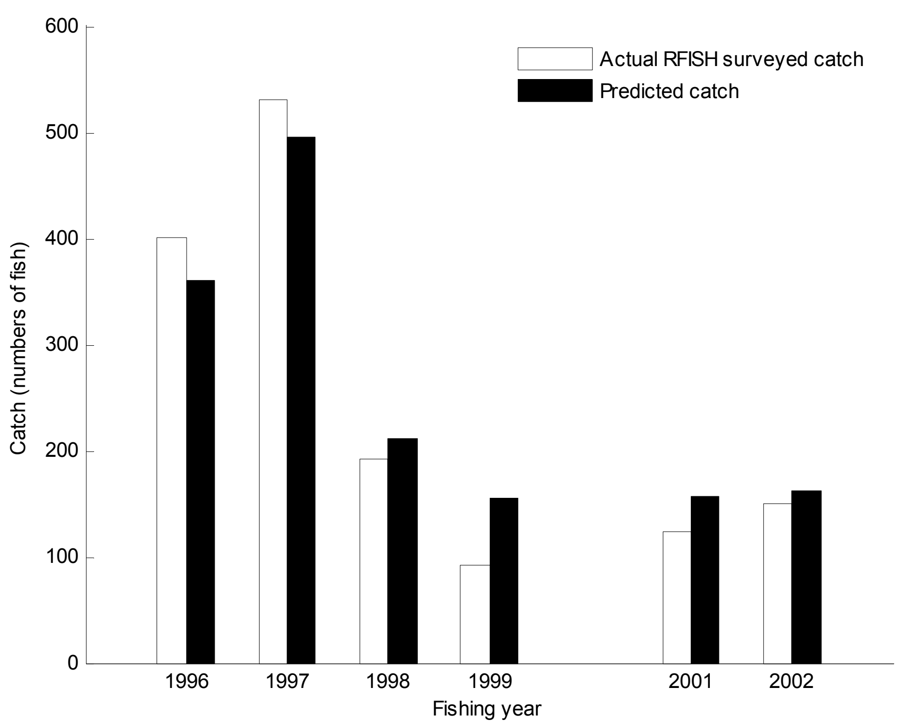

Fig. 4.14. The binary regression predicted the recreational total catches of spotted mackerel reasonably well across the fishing years.

Table 4.20. Adjusted recreational catch numbers of spotted mackerel (standard errors in parenthesis) if just diary weights or diary weights and the binary regression together were used to allocate unspecified mackerel as spotted mackerel catches. n = number of fish; t = tonnes of fish.

Fishing year	Spotted mackerel (n)	Spotted mackerel (t)	Unspecified mackerel (n)	Unspecified to spotted (n)	Total spotted mackerel (n)	Total spotted mackerel (t)
1997 weights only	209,814	344	90,913	61,633	271,446	445
	(20,720)	(34)		(11,230)	(23,567)	(39)
1997 weights + binary				48,490	258,303	424
				(9,961)	(22,990)	(38)
1999 weights only	86,321	142	74,081	32,426	118,746	195
	(11,990)	(20)		(11,510)	(16,620)	(27)
1999 weights + binary				36,482	122,802	201
				(11,954)	(16,931)	(28)
2002 weights only	52,661	86	95,373	36,721	89,382	147
	(7,397)	(12)		(7,179)	(10,308)	(17)
2002 weights + binary				56,976	109,637	180
				(9,158)	(11,772)	(19)

National Recreational and Indigenous Fishing Survey (NRIFS)

Five mackerel species were reported in the 2000 National Recreational and Indigenous Fishing Survey (grey, salmon or shark, school, Spanish and spotted) (Table 3.5). Spotted and unspecified mackerel were a significant proportion of the catch estimated from each fishing region (Fig. 3.19). Once again, the broad spread of mackerel species reported made identification of spotted mackerel catches unclear. The binary regression analysis identified significant changes in the probability of a recreational catch of mackerel being spotted mackerel between fishing regions, time spent fishing, number of anglers in each fishing group and number of mackerel caught (Table 4.21). Table 4.22 contains the regression parameter estimates and standard errors for the various model effects.

The probability of a recreational catch of mackerel being spotted mackerel was lower for longer times spent fishing and larger sized fishing groups (Fig. 4.15). Overall, the binary regression calculated a spread of probabilities, with no clear low or high probabilities, of recreational catches of unspecified mackerel being spotted mackerel (Fig. 4.16). From the data analysed, the regression predicted a total catch of 641 spotted mackerel compared to the actual reported catch of 615 fish; the model tended to over-estimate by only 4.2%. Adjusted recreational catch numbers of spotted mackerel varied if just the diary weights or diary weights and the binary regression together were used to allocate unspecified mackerel as spotted mackerel catches (Table 4.23). The binary regression estimated about 16 t less of unspecified mackerel were spotted mackerel compared to using just the diary weights in 2000.

Table 4.21. Forward stepwise analysis of deviance. The model factors and covariates are ordered by their significance, from highest to lowest, in determining the probability of a spotted mackerel catch.

Fitted terms	d.f.	Deviance	Mean deviance	Chi square	Probability
$\log_e$(Number of fish caught)	1	22.221	22.221	22.22	<.001
Region	9	22.239	2.471	2.47	0.008
$\log_e$(Number of hours fished)	1	3.653	3.653	3.65	0.056
$\log_e$(Number of people fishing)	1	2.812	2.812	2.81	0.094
$\log_e(\text{Number of people fishing})^2$	1	5.788	5.788	5.79	0.016
Residual	195	232.213	1.191		
Total	208	288.926	1.389		

Table 4.22. Parameter estimates and standard errors (S.E.) from the binary regression analysis of the probability of a recreational mackerel catch being spotted mackerel. Regions: Gulf = Gulf of Carpentaria.

Fitted terms	Parameter	Estimate	S.E.	T statistic	Probability
Constant	Constant	-0.556	0.595	-0.94	0.349
Covariate	$\log_e$(Number of fish caught)	0.856	0.226	3.79	<.001
Region	Bowen	0.000	-	-	-
Region	Gulf	1.120	1.100	1.02	0.306
Region	Cairns	-0.440	1.180	-0.37	0.708
Region	Townsville	-0.200	0.487	-0.41	0.682
Region	Mackay	0.311	0.517	0.60	0.547
Region	Rockhampton	0.377	0.554	0.68	0.495
Region	Central Coast	2.170	1.100	1.97	0.049
Region	Hervey Bay	1.197	0.825	1.45	0.147
Region	Moreton Bay	2.000	1.250	1.60	0.109
Region	South East Queensland	1.681	0.788	2.13	0.033
Covariate	$\log_e$(Number of hours fished)	-0.359	0.273	-1.31	0.190
Covariate	$\log_e$(Number of people fishing)	2.659	0.964	2.76	0.006
Covariate	$\log_e$(Number of people fishing)^2	-1.597	0.723	-2.21	0.027

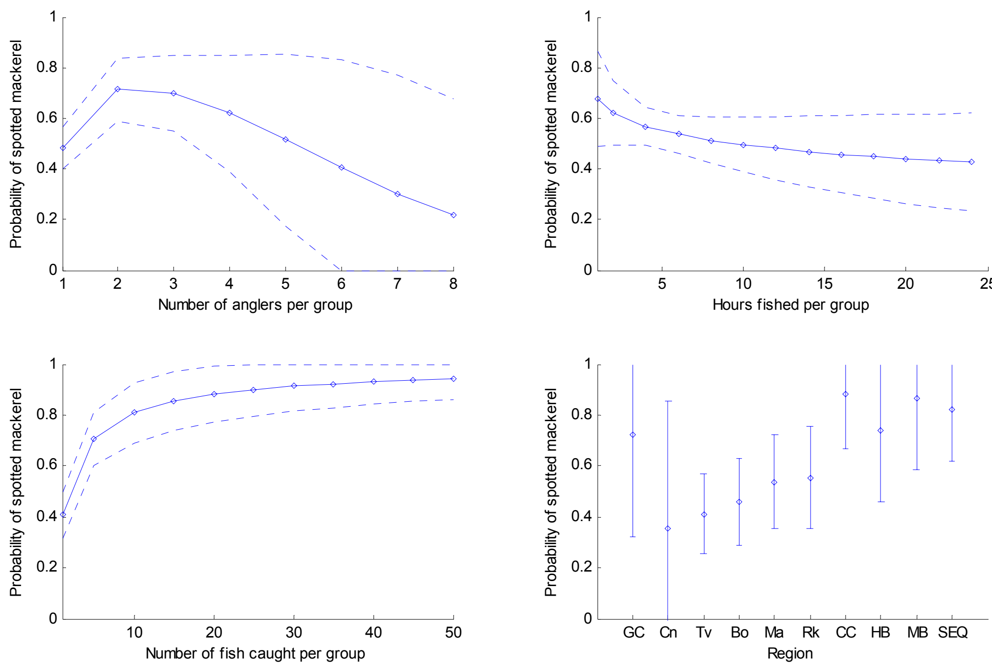

Fig. 4.15. The probability of a recreational catch of mackerel being spotted mackerel was lower for larger sized fishing groups, lower for longer times spent fishing, higher for larger numbers of mackerel caught and generally higher in the southern fishing regions on the east coast. Regions: GC = Gulf of Carpentaria; Cn = Cairns; Tv = Townsville; Bo = Bowen; Ma = Mackay; Rk = Rockhampton; CC = Central Coast; HB = Hervey Bay; MB = Moreton Bay; SEQ = South East Queensland.

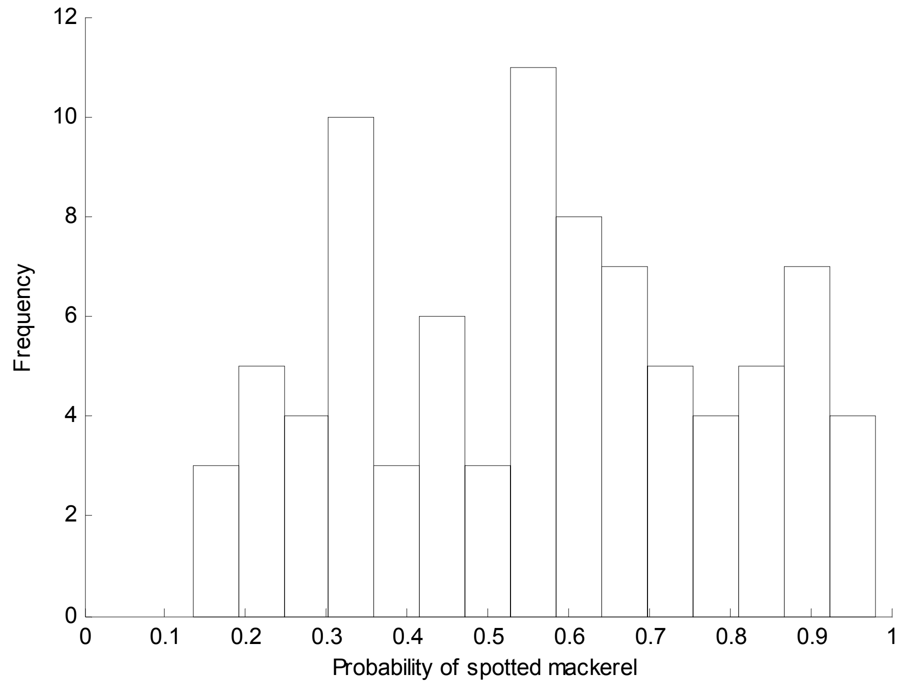

Fig. 4.16. Histogram of the spotted mackerel probabilities assigned to the recreational unspecified mackerel catches in 2000. The probabilities were quite spread with unspecified mackerel catches having no clear low or high probability of being spotted mackerel.

Table 4.23. Adjusted recreational catch numbers of spotted mackerel (standard errors in parenthesis) from NRIFS if just diary weights or diary weights and the binary regression together were used to allocate unspecified mackerel as spotted catches. n = number of fish; t = tonnes of fish.

NRIFS 2000	Spotted mackerel (n)	Spotted mackerel (t)	Unspecified mackerel (n)	Unspecified to spotted (n)	Total spotted mackerel (n)	Total spotted mackerel (t)
Weights only	129,338	212	66,237	41,933	171,271	281
	(33,226)	(54)			(38,235)	(63)
Weights + binary	129,338	212	66,237	31,951	161,289	265
	(33,226)	(54)			(37,104)	(61)

5. Standardised catch rates

Catch statistics are used as the basis of stock assessments in many fisheries. Trends in catch over time may reflect changes in the proportion of the population caught, changes in abundance of the target species, or both, owing to catch being a function of fishing effort and abundance of the fished population (Quinn and Deriso 1999). Stock assessments based on unstandardised (*i.e.*, raw) catch and effort data can produce biased predictions owing to efficiency changes in types and levels of fishing effort through time and between fishing operations or sectors. Furthermore, similar mackerel and other pelagic schooling fisheries to Australia's east coast spotted mackerel fishery have a history of over-fishing and stock decline with little indication of stock problems provided through unstandardised measures of fishery-dependent catch and effort data. Problems exist with using unstandardised and fishery-dependent data as indicators of stock status because of the schooling behaviour of the resource where catch rates may remain high even if fish stocks are being seriously depleted; a situation known as hyperstability (Hilborn and Walters 1992) (Fig. 5.1). There is a need, therefore, to standardise average catches, for example by employing a regression model (Hilborn and Walters 1992), to reduce the biases or variation in the data by accounting for factors affecting relative abundance and fishing efficiency. This results in a time series of catch and effort data that most likely is more representative of trends in population abundance.

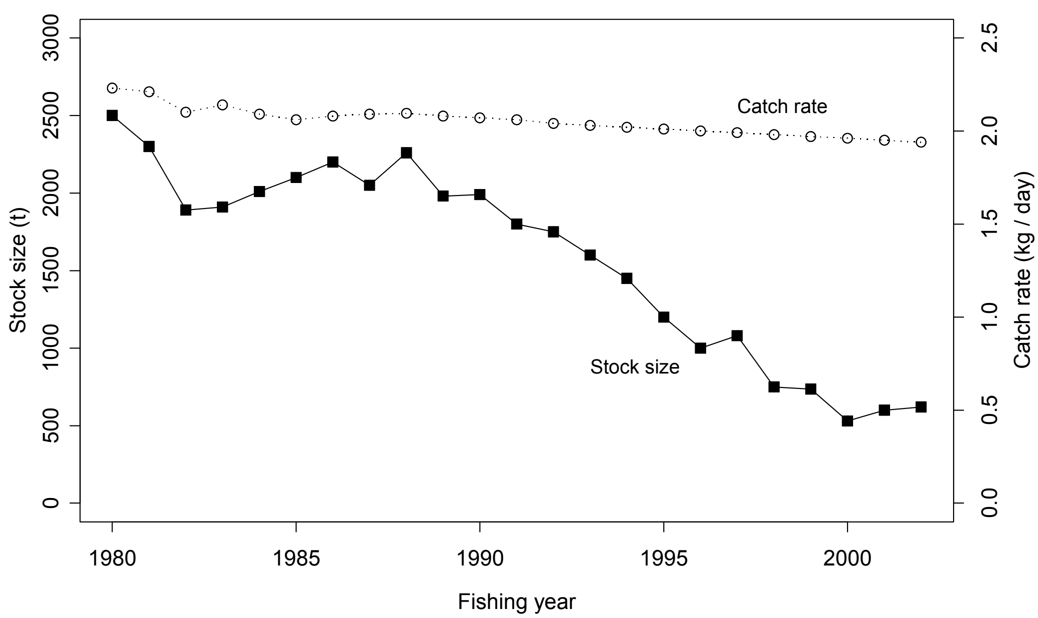

Fig. 5.1. Hypothetical example of hyperstable relationship between population (stock) size and catch rates; as stock size declines catch rates remain steady.

A number of studies have been published on standardisation of catch and effort data (Hall and Penn 1979, Robins *et al.* 1998, Bishop *et al.* 2000, Salthaug and Godø 2001, O'Neill *et al.* 2003, Maunder and Punt 2004). Generalised linear regression models (GLMs) have been used to estimate changes in relative fishing power, standardise average catches in the Queensland trawl fishery (O'Neill *et al.* 2003) and quantify the effects of global positioning systems (GPS) on average catches in Australia's northern prawn fishery (Robins *et al.* 1998). Bishop *et al.* (2000) further developed the analysis of Robins *et al.* (1998) by using a generalised estimating equations (GEE) regression approach to account for spatial and temporal correlations in the data. In contrast to the regression approach, Salthaug and Godø (2001) used a model for standardisation based on the relative fishing power between pairs of vessels fishing at the same time and place to estimate fishing power relative to a "standard" vessel; but see also Hall and Penn (1979). However, this method requires data with high spatial resolution and assumes that the chosen standard vessel's fishing power remains constant throughout the analysed period.

Standardisations of finfish catch and effort data have also been regularly used in a number of domestic and international fisheries. In southern Queensland, general linear regressions were used to standardise commercial catch rates of yellowfin bream, dusky flathead, mullet, summer whiting, tailor and stout whiting (Dichmont *et al.* 1999, Hoyle *et al.* 2000, O'Neill 2000). In addition, a two component binary and truncated negative binomial model was used to analyse recreational catches from three estuaries in southern Queensland which validated improved measures of fishing effort to estimate total recreational catches (O'Neill and Faddy 2003a, b). Internationally, logbook catches from tuna seiners were standardised using a regression model to make annual estimates of abundance adjusted for fishing mode, speed, capacity, use of aerial assistance, net dimensions and sea surface temperature (SST) (Allen and Punsley 1984).

In this assessment, generalised linear regression models were used to standardise annual catch rates of the Australian east coast spotted mackerel stock and compare relative fishing powers between the different fishing methods. The analysis considered a number of different climate variables thought to affect the catchability (and subsequent catch rate) of spotted mackerel including the Southern Oscillation Index (SOI), wind speed and direction, SST and lunar phase. *Scomberomorus* species are found in tropical and temperate coastal waters, generally at or above thermal fronts of about 20 °C, which have been postulated to influence distribution limits and movement patterns of the species (Munro 1943). Likewise, mackerel catches have been suggested to be related to lunar phase, with Spanish mackerel found to form spawning aggregations during the dark moon phases (Tobin and Mapleston 2004). In addition, fishers commonly report that spotted mackerel catches are influenced by weather and sea conditions, where during unfavourable conditions (*i.e.*, strong winds) catches are lower because of reduced access and visibility that restricts targeting of surface feeding mackerel schools (Cameron and Begg 2002). Standardised annual catch rates were used in this assessment as a relative index of population abundance.

Catch rate analysis methods

Climate data

Data on the monthly SOI, and daily 9 a.m. recorded wind speed, wind direction and mean sea level pressure (MSLP) were collated by the Australian Bureau of Meteorology (http://www.bom.gov.au/; list of weather stations used see Table 5.1). Weekly average SST was also extracted from the IRI/LDEO Climate Data Library (http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.GLOBAL/; Reyn_Smith OIv2 data set).

The SOI was calculated from monthly fluctuations in air pressure differences between Tahiti and Darwin. Sustained negative values of the SOI often indicate El Niño events, which are characterised by warming of the central and eastern tropical Pacific Ocean, a decrease in the strength of the Pacific Trade Winds and a reduction in rainfall over eastern and northern Australia. In contrast, positive values of the SOI (*i.e.*, La Niña events) are associated with cooling of the central and eastern tropical Pacific Ocean, stronger Pacific Trade Winds and higher rainfall and warmer sea temperatures to the north of Australia. The most recent strong El Niño and La Niña events were in 1997/98 and 1988/89, respectively. A moderate La Niña event occurred in 1998/99, which weakened back to neutral conditions before reforming for a shorter period in 1999/2000.

The SOI was calculated by the Australian Bureau of Meteorology using the Troup SOI method, which is the standardised anomaly of the Mean Sea Level Pressure (MSLP) difference between Tahiti and Darwin. It was calculated as follows:

$$SOI = 10\frac{(P_{diff} - P_{diffav})}{SD(P_{diff})} \quad (5.1)$$

where, P_{diff} = average monthly Tahiti MSLP minus average monthly Darwin MSLP; P_{diffav} = long-term average of P_{diff} for the respective month; and $SD(P_{diff})$ = long-term standard deviation of P_{diff} for the respective month. The multiplication by 10 is a convention. Using this convention, the SOI ranges from about –35 to about +35, and the value of the SOI can be quoted as a whole number. The SOI is usually computed on a monthly basis, with values over longer periods such as a year being sometimes used. Short-term (*i.e.*, daily or weekly) values of the SOI convey limited information about the current state of the climate, and accordingly the Bureau of Meteorology does not issue them.

Table 5.1. The weather stations used to represent each fishing region. These stations provided daily 9 a.m. recorded wind speed, wind direction and mean sea level pressure (MSLP). The Bureau of Meteorology collated the data. Justification of selection stations is provided in the Results. MO = Meteorological Office.

Region	Station name	Station number
Far north	Lockhart River Airport	28008
Cairns	Cairns Aero	31011
Townsville	Townsville Aero	32040
Bowen	Bowen Airport	33257
Bowen	Bowen Airport	33007
Mackay	Mackay MO	33119
Rockhampton	Gladstone Airport	39326
Rockhampton	Gladstone Radar	39123
Rockhampton	Yeppoon The Esplanade	33294
Hervey Bay	Bundaberg Aero	39128
Hervey Bay	Bundaberg Aero	39015
Hervey Bay	Sandy Cape Lighthouse	39085
Moreton Bay	Brisbane Aero	40223
Moreton Bay	Brisbane Aero	40842
Moreton Bay	Cape Moreton Lighthouse	40043
Moreton Bay	Gold Coast Seaway	40764
New South Wales	Cape Byron Lighthouse	58009
New South Wales	Coffs Harbour MO	59040

Records of daily wind speed and direction at 9 a.m. were obtained from representative stations located near the coast in each fishing region (Table 5.1). The wind data were transformed into two components: one measuring the strength of the east-west on-off shore winds ($Wind_{east\text{-}west}$); and the second measuring the strength of the north-south along-shore winds ($Wind_{north\text{-}south}$). The following equations were used to quantify the wind components:

$$Wind_{east-west} = Speed_{km/hr} \sin(Direction_{degrees}) \quad (5.2)$$

$$Wind_{north-south} = Speed_{km/hr} \cos(Direction_{degrees}) \quad (5.3)$$

where, $Direction_{degrees}$ = zero when the wind was from due north. Analysis of variance (ANOVA) was used to test for significant differences between wind components at the different weather stations. Station means were compared using the Least Significant Difference (LSD) test (Montgomery 1997). The results were used to select representative weather stations for each fishing region. The individual wind components were then associated with their relevant catch records for the standardisation catch rate analysis.

The average SSTs analysed were produced weekly on a one-degree grid, and linked to the spotted mackerel fishing regions (Table 5.2). The data used *in situ* and satellite SSTs, plus SSTs simulated by sea-ice cover. Before the SSTs were computed, the satellite data were adjusted for biases using the method of Reynolds (1988) and Reynolds and Marsico (1993) (see http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.GLOBAL/). From 1990, the SST weeks were centred on Wednesday, compared to the 1980s which were centred on Sunday. This reflected when the best satellite data were available. The average SSTs were calculated for one-degree grids with the first grid of each array centred on 0.5 °E and 89.5 °S. The points move eastward to 359.5 °E and northward to 89.5 °N. There was no SST analysis over land. The land values were filled by a Cressman interpolation to produce a complete grid for possible interpolation to other grids. A land sea mask defined the ocean and land areas.

Table 5.2. The one-degree (decimal degrees) centre points for SST grids used for each fishing region.

Region	Latitude (°S)	Longitude (°E)
Far north	-11.50	143.50
Far north	-12.50	143.50
Far north	-13.50	143.50
Far north	-14.50	143.50
Cairns	-15.50	146.50
Cairns	-15.50	145.50
Cairns	-16.50	145.50
Cairns	-16.50	146.50
Cairns	-17.50	145.50
Cairns	-17.50	146.50
Townsville	-18.50	147.50
Townsville	-18.50	146.50
Bowen	-19.50	148.50
Mackay	-20.50	150.50
Mackay	-20.50	149.50
Mackay	-21.50	149.50
Mackay	-21.50	150.50
Rockhampton	-22.50	151.50
Rockhampton	-23.50	151.50
Hervey Bay	-24.50	153.50
Hervey Bay	-24.50	152.50
Hervey Bay	-25.50	152.50
Hervey Bay	-25.50	153.50
Moreton Bay	-26.50	153.50
Moreton Bay	-27.50	153.50
New South Wales	-28.50	153.50
New South Wales	-29.50	153.50
New South Wales	-30.50	153.50

In addition, it was suspected that spotted mackerel catch rates vary with lunar phase. Consequently, variation in catch rates was tested against a calculated luminance measure (ranging between 0 = New moon and 1 = Full moon) (Courtney *et al.* 2002). This luminance measure followed a cycle sinusoidal pattern and was replicated and advanced by 7 days (~ 0.25 lunar phase) to approximate the cosine of the luminance (Fig. 5.2). Together these patterns were periodic and model a cyclic variation in catch rates corresponding to new moon, rising moon, full moon and waning moon phases. The approach used only two degrees of freedom in the catch rate analysis compared to the 4 factor levels defined by Courtney *et al.* (2002).

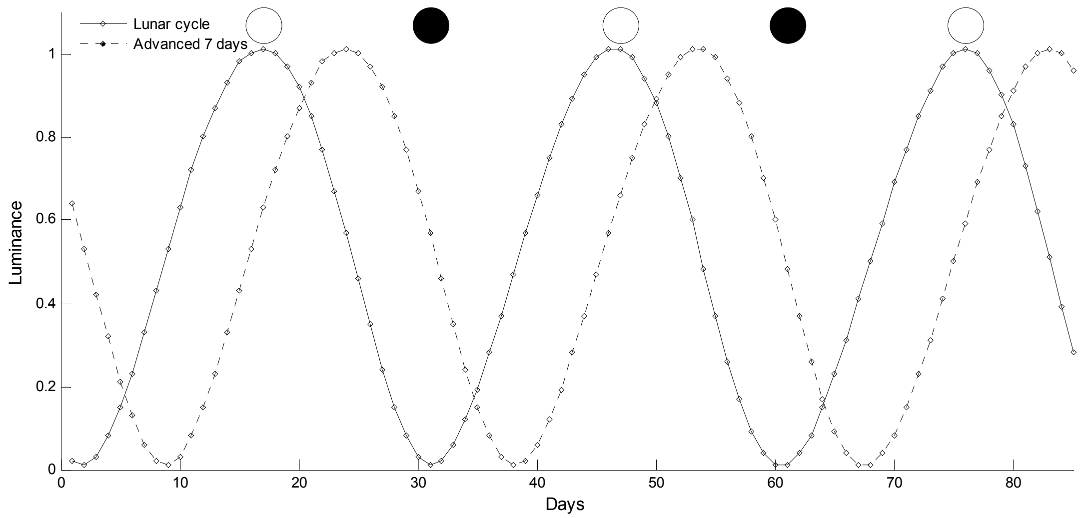

Fig. 5.2. The lunar phase cycle (solid line) illustrated over 85 days. The dashed line illustrates the lunar cycle advanced by seven days (~ 0.25 phase).

Catch data

The analyses were based on Queensland and New South Wales spotted mackerel catches over 15 fishing years from 1988 to 2002 (Table 5.3, 5.4). The analyses used reported spotted mackerel catches from the following sources:

- Queensland commercial logbook catches from 1988 to 2002.
- Queensland recreational charter logbook catches from 1994 to 2002.
- Queensland recreational fishing surveys (diary logbooks; offsite method) from 1997, 1999, and 2002 reported through the Recreational Fishing Information System (RFISH).
- Queensland recreational fishing survey (diary log books; offsite method) from 2000 reported through the National Recreational and Indigenous Fishing Survey (NRIFS).
- South east Queensland boat ramp (on-site) creel surveys conducted during 1994, 1995, 1998, and 1999 (Ferrell and Sumpton 1996, Sumpton 2000).
- Queensland recreational fishing surveys (diary logbooks; offsite method) from 1994 and 1995 (Cameron and Begg 2002).
- New South Wales monthly commercial logbook catches from 1988 to 2002.

The Queensland commercial logbook data consisted of reported daily catches compared to the New South Wales data which were reported as total monthly catches. The spatial resolution of catches for all data was according to the fishing regions defined in Fig. 1.1 and Table 3.1. In order to omit the inconsistent, limited and hence, less reliable data, commercial spotted mackerel catches reported to bait, fish trap and trawl methods were excluded from the analysis (Table 5.3, 5.4). The data consisted of only those spotted mackerel catches where a number of fish were caught and retained (*i.e.*, catches > 0). No data were available on searching effort, including the use of spotter planes, to find spotted mackerel or on fishing effort where no spotted mackerel were caught.

Table 5.3. Number of commercial and recreational catches analysed by fishing region. Net = unspecified net. Note bait, fish trap and trawl methods were excluded from the analysis.

Region	Gill net	Net	Ring net	Line	Multi hook	Troll	Bait	Fish trap	Trawl	Charter	Recreational	Total
Far north	5	3	1	49	2	4	0	0	0	36	0	100
Cairns	3	37	2	1095	172	118	0	0	0	121	54	1602
Townsville	9	28	0	112	35	13	0	0	1	56	56	310
Bowen	59	402	367	299	106	19	0	0	0	74	65	1391
Mackay	16	223	22	138	75	44	0	0	0	90	132	740
Rockhampton	27	357	45	665	177	45	0	0	5	25	149	1495
Hervey Bay	304	2791	1039	239	63	28	0	0	17	223	115	4819
Moreton Bay	287	772	133	2336	792	216	0	0	3	604	329	5472
NSW	8	10	0	1343	161	378	3	42	18	0	0	1963
Total	718	4623	1609	6276	1583	865	3	42	44	1229	900	17892

Table 5.4. Number of commercial and recreational catches analysed by fishing year. Net = unspecified net. Note bait, fish trap and trawl methods were excluded from the analysis.

Fishing year	Gill net	Net	Ring net	Line	Multi hook	Troll	Charter	Recreational
1988	0	93	0	76	0	0	0	0
1989	0	81	0	116	0	0	0	0
1990	1	81	0	151	0	1	0	0
1991	0	151	0	175	0	0	0	0
1992	0	329	0	378	0	5	0	0
1993	0	439	0	608	2	3	0	30
1994	1	420	0	252	2	2	3	269
1995	0	487	4	290	0	3	15	108
1996	1	606	5	411	173	13	186	102
1997	39	444	49	324	711	105	182	81
1998	112	262	59	761	265	87	230	88
1999	171	304	291	617	153	61	187	41
2000	153	398	398	597	60	76	104	96
2001	102	266	354	493	64	123	156	51
2002	138	262	449	1027	153	386	166	34

Statistical analysis

The analysis used a generalised linear model (GLM) with gamma-distributed errors and log-link function (McCullagh and Nelder 1989). The response variable was based on individual commercial or recreational catches over a unit of time for a given fishing region. Because fishing effort is included in our analysis as an explanatory variable, the findings were pertinent to both catch and catch rates. Statistical fishing regions were used in the analysis to account for spatial variation in spotted mackerel abundance at a given time (Fig. 1.1, Table 3.1). Likewise, fishing (*i.e.*, financial) years, rather than calendar years, were used in the analysis as this period better depicts when spawning and recruitment to the fishery occurs.

The final model considered the reported spotted mackerel catch associated with the number of units and type of fishing effort (*e.g.*, days fished by commercial line operations or the number of fishers in a recreational fishing group), fishing year, month, region, lunar phase and climate/weather conditions. Catches were predicted according to the catch-biomass relationship of Hilborn and Walters (1992):

$$C_{vrym} = B_{rym} E_{vryme} q_{vryme} \qquad (5.4)$$

where, C_{vrym} = catch of the *v*th commercial or recreational operation in region *r*, during fishing year *y*, and month *m*; B_{rym} = biomass or abundance of spotted mackerel; E_{vryme} = number and type of fishing effort (*e*); and q_{vryme} = measure of spotted mackerel catchability. The logarithm of the catch-biomass relationship (Equation 5.4) was reduced to an additive form (Equation 5.5), rather than the original multiplicative form, and defined in a GLM as the following:

$$\log_{\text{link}}(\mathrm{C}_{vrym}) = \beta_0 + \mathbf{X}_1^{\mathbf{T}}\boldsymbol{\beta}_1 + \boldsymbol{\beta}_2 \log(\mathrm{E}_{vryme}) + \mathbf{X}_3^{\mathbf{T}}\boldsymbol{\beta}_3 + \varepsilon \tag{5.5}$$

where, β_0 = model intercept to be estimated; $\boldsymbol{\beta}_1$, $\boldsymbol{\beta}_2$ and $\boldsymbol{\beta}_3$ = vector parameters to be estimated; $\mathbf{X}_1^{\mathbf{T}}$ and $\mathbf{X}_3^{\mathbf{T}}$ were design matrices for $\boldsymbol{\beta}_1$ and $\boldsymbol{\beta}_3$; and ε = gamma error term. The biomass term, $\boldsymbol{\beta}_1$, was expressed by the additive effects of different factors including fishing region (*r*), fishing year (*y*) and month (*m*). The effort term, $\boldsymbol{\beta}_2$, standardised for the amount and type of fishing effort (*e*) for each fishing operation (*v*), region, fishing year and month, and the catchability of spotted mackerel, $\boldsymbol{\beta}_3$, was expressed by the additive effects of different factors including lunar phase, SOI and wind direction and speed. The fishing year coefficients from vector $\boldsymbol{\beta}_1$ were treated as the annual catch rate index of abundance, standardised for the other terms in the model. The rows of the design matrices correspond to the individual catches analysed and the columns correspond to the parameters in $\boldsymbol{\beta}_1$ or $\boldsymbol{\beta}_3$.

Forward stepwise regression was used to select optimal model parameters ($p < 0.05$) and provide asymptotic standard errors for all parameter estimates. As a result of recommendations from the Stock Assessment Steering Committee (4 February 2004; see Appendix 3), a range of weighting values were examined to reduce the hyperstability effect of certain fishing effort types or the target/non-target fishing for spotted mackerel (Table 5.5, 5.6). Each of the weighting structures was examined singularly and with the fishing method weights interacting with the pseudo target/non-target weights (*e.g.*, Weighting structure 3 multiplied by Weighting structure 4). Generally, all the analyses of model residuals supported the use of the GLM assuming constant coefficient of variation; model goodness of fit improved by removing the net fishing catches. Definition of the final model components is detailed in the Results. An example of the GENSTAT code used for estimating the catch rates for line fishing only and no weighting structures applied is defined as follows:

```
"General Model. Line fishing"
MODEL [DISTRIBUTION=gamma; LINK=logarithm; DISPERSION=*;weights=glmwtsline] kept_wt
FITINDIVIDUALLY [PRINT=model,summary,estimates,accumulated; CONSTANT=estimate;
FPROB=yes;\  TPROB=yes; FACT=9]
fishyear+region+month+effort_type+effort_type.effort_quantity+soi+\
north_south_wind+north_south_wind_squared+lunar_sine+lunar_cos
```

Table 5.5. Three weighting structures were compared according to the different fishing methods: 1) no weights applied – all fishing methods treated equally; 2) mixed weights where all netting types were weighted low because of assumed tendency for more hyperstable catch rates; and 3) weights where all netting types were excluded. Net = unspecified net. Note that the minor incidental Bait, Fish trap and Trawl catches were omitted, *i.e.* zero weights.

Sector	Fishing method	1. No weights	2. Mixed weights	3. Nets excluded
Commercial	Gill net	1	0.5	0
Commercial	Net	1	0.1	0
Commercial	Ring net	1	0.1	0
Commercial	Line	1	1	1
Commercial	Multi hook	1	1	1
Commercial	Troll	1	1	1
Commercial	Bait	0	0	0
Commercial	Fish trap	0	0	0
Commercial	Trawl	0	0	0
Charter	Line	1	1	1
Recreational	Line	1	1	1

Table 5.6. Two additional pseudo weighting structures (4 & 5) were examined to account for target and non-target catches: 4) weights applied according to the inverse of the percentile catch group; and 5) weights reducing the effect of extreme large and incidental catches on the analysis. The table shows the relative percentiles of the catch distributions taken by each fishing method and the relevant weightings. Net = unspecified net.

Effort type	10th Percentile	25th Percentile	Median	75th Percentile	90th Percentile
Gill net	3.8	7.5	18	58	162.7
Net	7	22	126.08	373.6	632.4
Ring net	35	110	261	485.2	771.2
Line	4.824	10	26.2	70	166.4
Multi hook	5	11.26	25.73	60	108.4
Troll	5	10	25.15	72	162
Charter	2	3	6	13	26
Recreational	1.47	1.49	2.94	6.6	11.9
Additional weightings					
4. 1/percentile group	1 / 2.5	1 / 2.5	1 / 5	1 / 5	1 / 10
5. Pseudo non target & non incidental	1 / 2	1 / 2	1	1	1 / 10

Catch rate analysis results

Climate data

Historical daily 9 a.m. records on wind speed and direction were available and complete for only one coastal weather station in each of the Far north, Townsville and Bowen fishing regions (Table 5.1). These stations were used to represent the winds in each of these regions. However, wind data from a number of stations were available for the other regions, and there were some significant differences (Table 5.7).

Table 5.7. Least Significant Differences (LSD) between the average wind components for the weather stations within each fishing region from July 2000 to June 2003. The letters A, B and C denote groupings with significant differences in average winds ($p < 0.05$); letters that are the same indicate no significant difference. The bold rows indicate selected weather stations to represent each fishing region.

Region	Weather stations	North – south winds		East – west winds	
		Test mean	Grouping	Test mean	Grouping
Cairns	Cooktown	0.39	A	0.51	A
	Cairns Airport	**0.61**	**A**	**0.35**	**A**
	Innisfail	-1.26	B	-2.21	B
	Cardwell	-2.62	C	-1.68	B
	LSD	*0.883*		*0.916*	
Rockhampton	St Lawrence	-3.47	B	-1.82	B
	Rockhampton	0	A	0.3	A
	Yeppoon	**-0.58**	**A**	**0.24**	**A**
	Gladstone Airport	**0.1**	**A**	**0.22**	**A**
	Gladstone Radar	**0.21**	**A**	**-0.09**	**A**
	LSD	*0.858*		*0.884*	
Hervey Bay	**Bundaberg**	**-0.46**	**A**	**0**	**A**
	Sandy Cape	**-3.56**	**B**	**2.3**	**B**
	Double Island Point	0	A	-1.5	C
	LSD	*1.306*		*1.291*	
Moreton Bay	**Cape Moreton**	**0.63**	**A**	**-1.19**	**A**
	Brisbane Airport	**-0.34**	**A**	**-0.13**	**A,B**
	Gold Coast Seaway	**0.25**	**A**	**0.37**	**B**
	Coolangatta	-1.66	B	0.38	**B**
	LSD	*1.301*		*1.232*	
New South Wales	**Byron Bay**	**0.03**	**A**	**-0.04**	**A**
	Coffs Harbour	**-0.73**	**A**	**0.21**	**A**
	Port Macquarie	-2.88	B	-3.46	B
	LSD	*1.351*		*1.354*	

In the Cairns region, similar winds were recorded between the Cairns Airport and Cooktown stations, but stronger southerly and westerly winds from Innisfail and Cardwell (Table 5.7). Based on this result, the Cairns airport station was selected to represent winds in this region. In the Rockhampton region, similar winds were reported from the Rockhampton, Yeppoon, and Gladstone stations, but the winds recorded from St Lawrence had stronger southerly and westerly wind components. The wind data from the coastal stations of Yeppoon and Gladstone were averaged to relate to catches in the Rockhampton region, while the Rockhampton station was excluded because of its distance from the coast. Similarly, the Bundaberg and Sandy Cape stations were averaged and used to relate winds to catches from the Hervey Bay region because of their closer vicinity to the main spotted mackerel fishing area inside Fraser Island. In the Moreton Bay region, winds were averaged across the stations of Cape Moreton, Brisbane Airport and the Gold Coast Seaway because of similar north-south wind components. Winds recorded from Coolangatta suggested stronger southerlies compared to the other three stations. In New South Wales, winds measured at Byron Bay and Coffs Harbour were averaged given their similarity. The station in Port Macquarie was excluded due to its more southerly location and stronger southerly and westerly wind components (Table 5.7).

Figures 5.3 and 5.4 provide a summary of the north–south and east–west wind components. Southerly winds tend to predominate over northerly winds in all regions, except during winter in northern New South Wales. Of note was the much stronger southerly winds recorded in Bowen. Westerly winds tend to predominate over easterly winds during winter, except in the Far north. Average sea surface temperatures (SSTs) dropped cumulatively between regions from north to south at about 0.5 degrees (Fig. 5.5). Overall, the SSTs were about four degrees cooler in northern New South Wales waters than the Far north; but also note the consistent seasonal pattern between regions. Figure 5.6 shows the Southern Oscillation Index (SOI) between 1984 and 2002. Over this time, more years had a negative SOI. In Queensland, years with negative SOI (El Niño) often associate with below average rainfall and years with positive SOI (La Niña) often associate with above average rainfall.

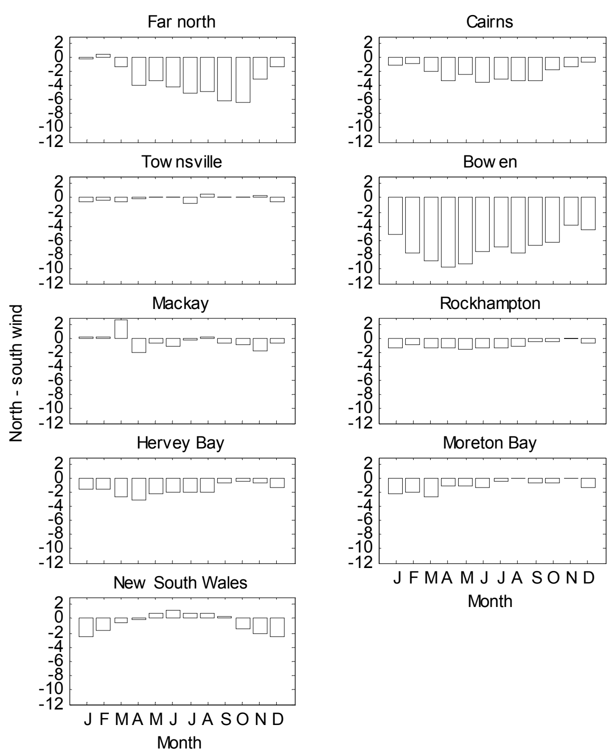

Fig. 5.3. Average monthly north-south winds for each fishing region, fishing years 1988-2002. Positive values represent winds from the north. Negative values represent winds from the south. Southerly winds tend to predominate over northerly winds, except in northern New South Wales during winter.

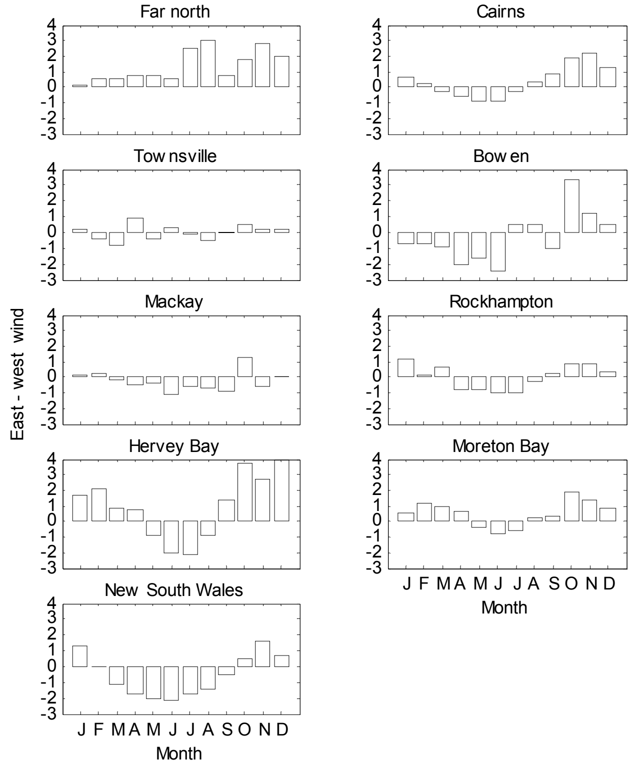

Fig. 5.4. Average monthly east-west winds for each fishing region, fishing years 1988-2002. Positive values represent winds from the east. Negative values represent winds from the west. Westerly winds tend to predominate over easterly winds during winter, except in the Far North.

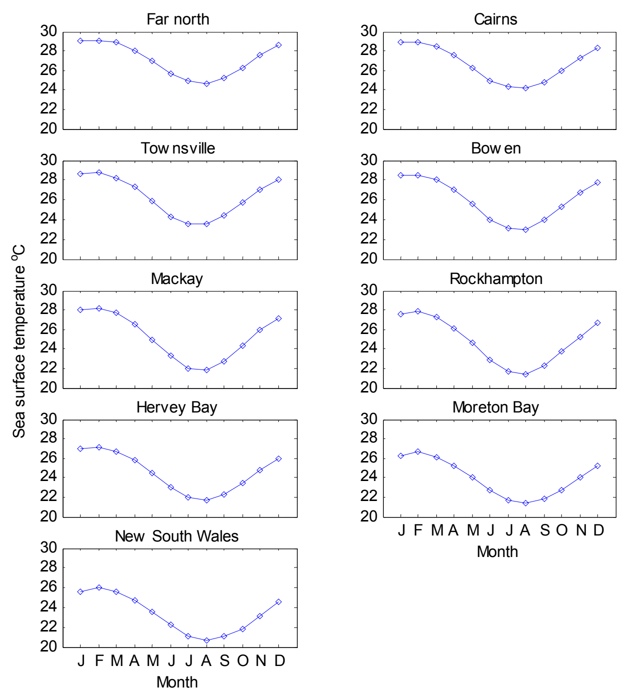

Fig. 5.5. Average monthly sea surface temperature (SST) for each fishing region, fishing years 1988-2002. SSTs drop cumulatively at about 0.5 degree between regions from north to south; the temperatures were about four degrees cooler in northern New South Wales than the Far north; also note the consistent seasonal pattern.

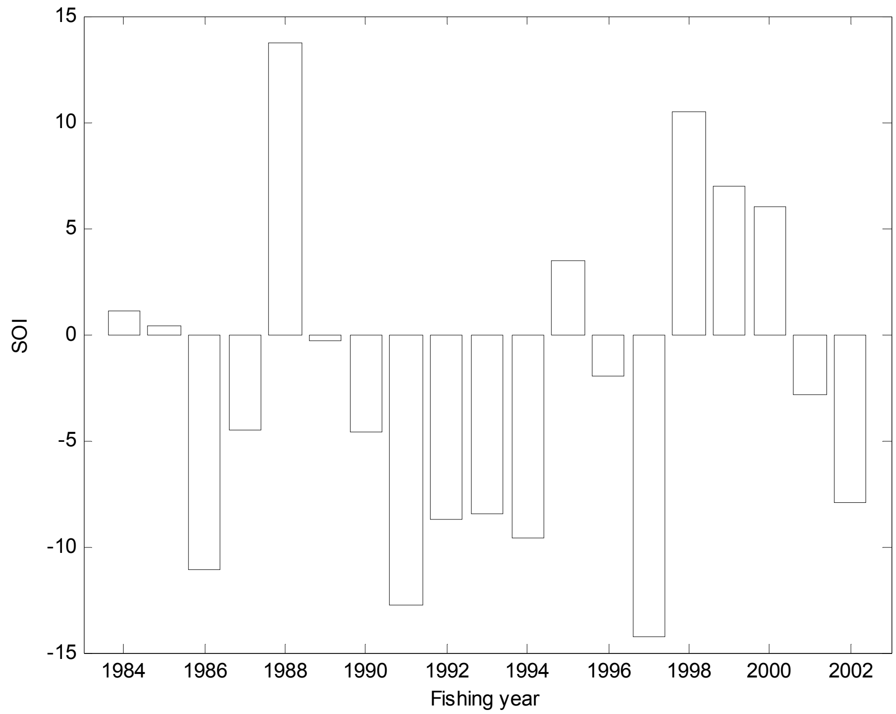

Fig. 5.6. The Southern Oscillation Index (SOI) between 1984 and 2002. In Queensland, years with negative SOI (El Niño) often associate with below average rainfall and years with positive SOI (La Niña) often associate with above average rainfall. Note that there have been more years with negative SOI.

Catch data

The generalised linear modeling of spotted mackerel catches (>0) identified significant changes in average catches between fishing years, regions, months, strength of north-south winds, lunar cycle, SOI and the amount and type of fishing effort (Table 5.8). Figure 5.7 provides a summary of the relative-standardised-average-catch-rates of spotted mackerel by fishing effort types between 1988 and 2002 fishing years. This figure illustrates the time series of catches available and the inconsistent variability in standardised catch rates between fishing effort types. The majority of data resulted from commercial line and unspecified net fishing. The term “catch rates” is used hereon to refer to the spotted mackerel relative-standardised-average-catch-rates.

The different fishing types showed dissimilarity in catch rates trends. Catch rates from unspecified net types were stable between 1991 and 1998, but increased significantly in 1999 and 2000 and then decreased in 2001 and 2002 to the levels estimated between 1991 and 1998 (Fig. 5.7A). Reported ring net catch rates were highest between 1998 and 2000, but decreased in 2001 and 2002 (Fig. 5.7B). Gill net catch rates showed a slight declining trend between 1996 and 2002 (Fig. 5.7C). Commercial line catch rates declined between 1990 and 1995, but have stabilised since (Fig. 5.7D). Trolling catch rates showed a very marginal increase between 1992 and 2002 (Fig. 5.7E). Multi hook and charter catch rates showed no significant trends (Fig. 5.7F, G). Recreational catch rates declined between 1993 and 2002 (Fig. 5.7H). The one consistency across most of the different fishing effort types was the increase in 2002 catch rates, except for ring netting and charter fishing catch rates, which were steady. The descriptions above for Figure 5.7 were based on interpreting the trends in average catch rates; however, the 95% confidence intervals need to be also considered when comparing catch rates between specific years.

Table 5.8. Forward stepwise analysis of deviance. The model factors and covariate are ordered by their significance, from highest to lowest, in determining the spotted mackerel catch (>0) (R^2=0.47).

Fitted terms	d.f.	Deviance	Mean deviance	Chi square	Probability
Fishing year	14	1931.365	137.955	98.50	<.001
Region	10	7340.994	734.099	524.16	<.001
Month	11	1939.783	176.344	125.91	<.001
Fishing effort type / gear	7	10419.650	1488.521	1062.82	<.001
Fishing effort * effort type	7	691.845	98.835	70.57	<.001
SOI	1	35.110	35.110	25.07	<.001
North – south winds	1	32.153	32.153	22.96	<.001
North – south winds^2 (quadratic)	1	14.062	14.062	10.04	0.002
Lunar cycle (~sine effect)	1	4.705	4.705	3.36	0.067
Lunar cycle (+ 7 days ~cosine effect)	1	11.568	11.568	8.26	0.004
Residual	17748	24856.750	1.401		
Total	17802	47277.980	2.656		

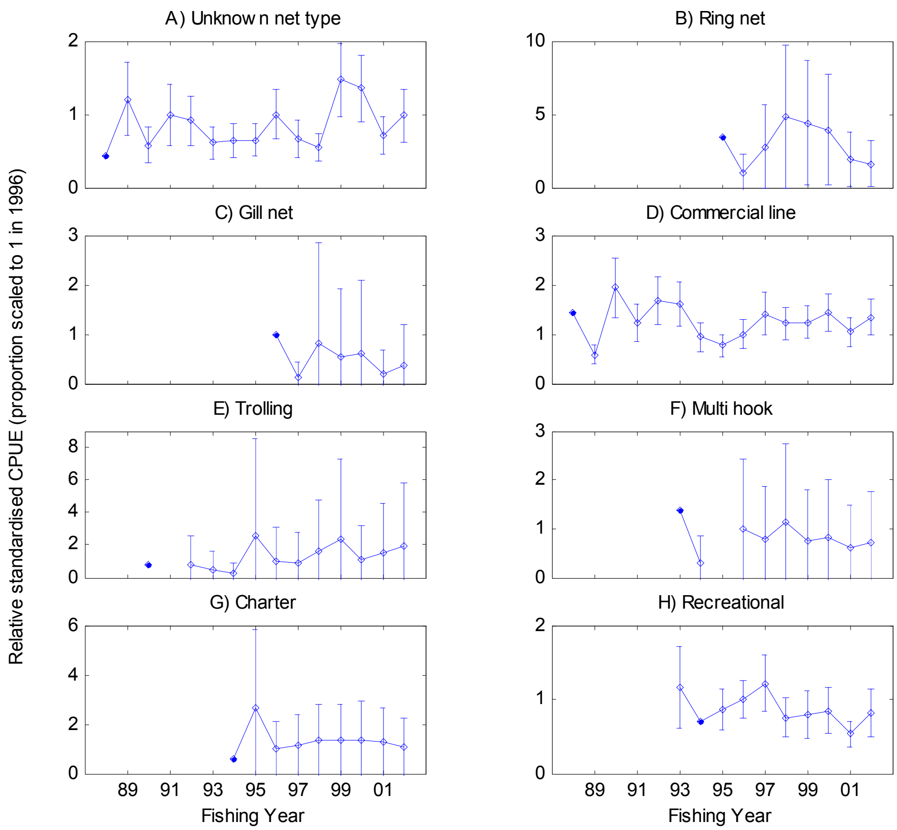

Fig. 5.7. Annual relative-standardised-average-catch-rates by fishing effort type. The catch rate patterns vary inconsistently between fishing types. Error bars represent the 95% confidence intervals. Standardised to 1996 = 1 to enable different fishing types to be compared.

The unified catch rate analysis including all fishing effort types and different weighting structures (Table 5.5, 5.6) were comparatively similar between the mixed (Fig. 5.8D, E, F) and nets excluded (Fig. 5.8G, H, I) weightings. The estimated proportional change in catch rates declined from 1990 to 1995. The catch rates increased slightly thereafter and remained stable. Estimated catch rates using no weightings on the fishing effort types increased between 1988 and 2002 (Fig. 5.8A, B, C). The pseudo target/non-target weightings had little influence on the analysis.

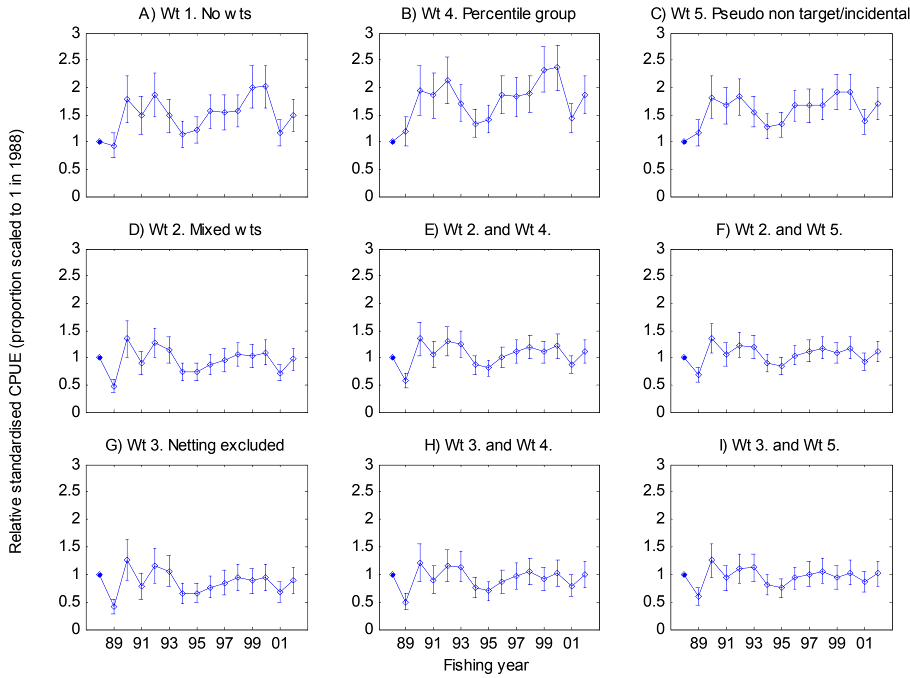

Fig. 5.8. Average relative catch-rates standardised across the fishing effort types assuming different weighting structures (weightings defined in Table 5.5-5.6). The catch rate patterns were comparatively similar between the mixed (D, E and F) and nets excluded (G, H, and I) weightings. Estimated catch rates using no weightings on the fishing effort types were increasing (A, B, C). The pseudo target and non-target weighting had little influence on the analysis. Error bars represent the 95% confidence intervals. Standardised to 1988 = 1.

The parameter estimates for each fishing year from three analyses using mixed weightings (Weight 2), weights excluding net fishing (Weight 3), and just commercial line fishing (no weights) were considered best to reflect catch rates in the fishery due to the elevated hyperstability of net fishing (Table 5.9). Catch rates for commercial line fishing (no weights) were used in the assessment (Fig. 5.7D, Table 5.9).

Table 5.9. The standardised catch rates (proportional) and standard errors for each fishing year from the generalised linear modeling of spotted mackerel catches using A) mixed weightings (Wt 2), B) weights excluding net fishing (Wt 3), and C) just commercial line fishing (no weights). The parameter estimates were similar between analyses and are considered the best to reflect catch trends in the fishery. The catch rates for commercial line fishing (no weights) were used in the assessment. Catch rates standardised to 1988 = 1.

Fishing year	Mixed	SE	Nets excluded	SE	Commercial line	SE
1988	1.000	-	1.000	-	1.000	-
1989	0.480	0.062	0.416	0.067	0.403	0.067
1990	1.342	0.166	1.261	0.195	1.346	0.218
1991	0.895	0.110	0.783	0.121	0.845	0.137
1992	1.272	0.142	1.147	0.161	1.160	0.172
1993	1.132	0.122	1.054	0.143	1.126	0.161
1994	0.741	0.083	0.649	0.092	0.651	0.102
1995	0.737	0.080	0.656	0.091	0.533	0.078
1996	0.871	0.092	0.768	0.102	0.697	0.099
1997	0.952	0.105	0.839	0.116	0.985	0.157
1998	1.053	0.108	0.947	0.122	0.843	0.115
1999	1.031	0.107	0.877	0.115	0.859	0.119
2000	1.093	0.114	0.940	0.124	0.996	0.138
2001	0.723	0.076	0.681	0.091	0.727	0.104
2002	0.970	0.102	0.891	0.118	0.935	0.132

Estimated average relative fishing power was considerably higher for ring net fishing compared with the other line fishing effort types (Fig. 5.9). In addition, about 10% to 20% and 6% to 8% marginal higher catch rates (or higher fishing power) were associated with light northerly winds and the rising moon phase, respectively (Fig. 5.10). Sea surface temperature ($p \approx 0.257$), mean sea level pressure ($p \approx 0.756$), and east-west wind strengths ($p \approx 0.271$) had no significant association with catch rates of spotted mackerel. The SOI had a very weak, but significant association of higher catch rates of spotted mackerel with negative SOI (parameter estimate = -0.012; standard error = 0.002; t=-7.38; $p < 0.001$). There was no evidence of significantly correlated parameters between model components.

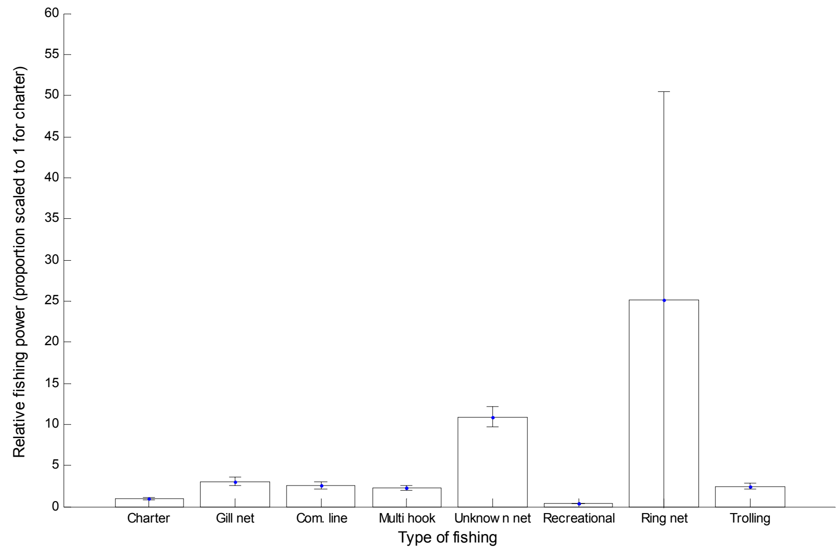

Fig. 5.9. Comparison of average relative fishing power between the fishing types. Fishing powers were scaled proportionally against charter fishing, which was set equal to 1. The results show that ring netting was about 25 times more powerful compared to charter fishing. The analysis used all catch rates and no weightings. Error bars represent the 95% confidence intervals.

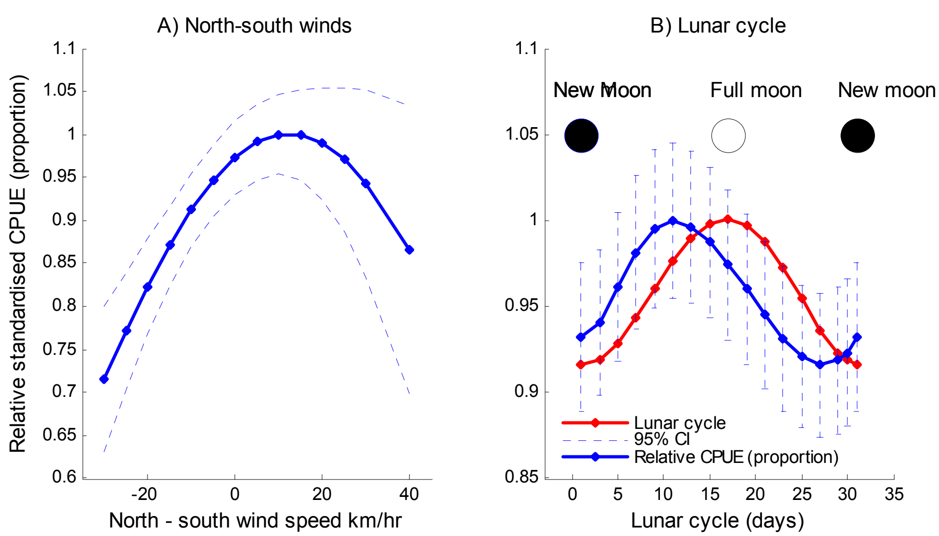

Fig. 5.10. Comparison of average relative-standardised-catch-rates for changing A) north-south wind speeds and B) lunar phase. Positive wind values are from the north. Negative winds are from the south. The predictions show that higher catch rates associate with light northerly winds and the rising moon phase. The dotted lines represent 95% confidence intervals. To convert wind speeds to knots divide km/hr by 1.852.

The standardised residuals from the generalised linear modeling showed no evidence to suggest that the model was inadequate for describing the data. Figure 5.11A and B shows that the standardised residuals had a satisfactory normal pattern and no pattern when plotted against the predicted catches (log-link applied). There were only four notable large residuals greater than 4 out of the 17,803 catches analysed. The influence of these data points had little effect upon the estimation of the model parameters. For example, removing their effect resulted in little change in the parameter estimates, suggesting the model captured these observations reasonably well and that it accurately modelled the spotted mackerel catches. Unsurprisingly, there was some curvature in the normality plot due to the skewness of the catches (Fig. 5.11C). An alternative general linear model using a normal distribution to analyse the log transformation of the spotted mackerel catches was compared. This model reduced the curvature in the normality plot but produced very similar predictions, when biased corrected, to the gamma model. Given this, the gamma model was accepted as the assumption of constant coefficient of variation was generally met (Fig. 5.11D). Figure 5.11E shows that the observed distribution of the spotted mackerel catches was highly skewed.

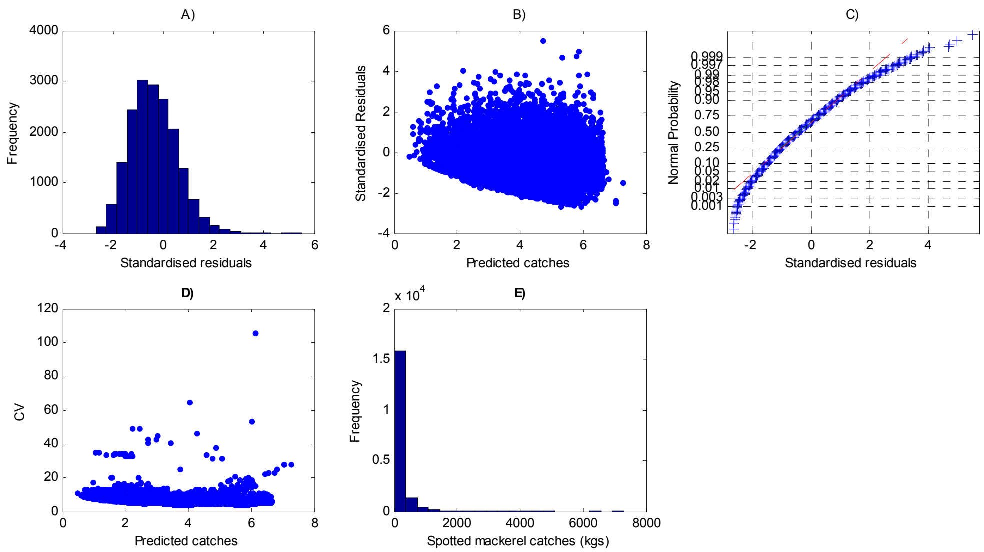

Fig. 5.11. The standardised residuals from the generalised linear model (gamma distribution, log-link) show A) satisfactory normal pattern B) no pattern when plotted against the predicted catches (log transformed), C) curvature in the normality plot due to the skewness of the catches, and D) the assumption of constant coefficient of variation was generally met. Subplot E) shows the observed distribution of the spotted mackerel catches was highly skewed.

Hyperstability and spotted mackerel catch rates

Spotted mackerel catch rates varied according to fishing years, regions, months, strength of north-south winds, lunar cycle, SOI and the amount and type of fishing effort. Catch rates appeared to decline from 1990 to 1995, increasing slightly thereafter, before remaining relatively stable. As expected and supporting the anecdote, catch rates of spotted mackerel increased with favourable weather conditions such as light northerly winds (*i.e.*, <20 km/hr) and negative SOI. Favourable weather and sea conditions would both increase the targeting efficiency of fishers, while maintaining the integrity of surface feeding schooling mackerel; thereby leading to greater catch rates. In contrast, catch rates were found not to be influenced by temperature, while slightly higher catch rates were associated with the rising moon phase (unlike Spanish mackerel; see Tobin and Mapleston 2004). Estimated average relative fishing power was also considerably higher for ring net fishing than the other line fishing effort types.

Although we analysed the spotted mackerel catch rates in a robust manner, the question remains as to what type of relationship exists between average catch rates and spotted mackerel abundance?

Figure 5.1 shows a possible example (hypothetical) relationship between catch rates and fish abundance. In this example, the catch rates remain high and relatively stable as stock size declines. This type of relationship is called hyperstability (Hilborn and Walters 1992), and is expected where searching for fish is highly efficient. For example, when recorded fishing effort typically relates only to where and when fish are concentrated and caught (but stock size could actually be in decline). Two real examples of hyperstable fishing patterns include exploitation of fish in spawning aggregations and purse seining for easily discovered schools of pelagic baitfish (Hilborn and Walters 1992). Likewise, historical catch rates resulting from ring netting of schools of spotted mackerel would also expect to be hyperstable. These catch rates would certainly not be proportional to stock size (*i.e.*, catch rates don't decline as the stock size declines). Hyperstability is a dangerous characteristic for catch rates of a fishery to exhibit. For the fishers, it means not suffering declines in catch rates as stock size changes. But for the managers, it offers considerable risks of the stock declining without catch rates indicating the actual underlying population trend. Some of the major fishery collapses around the world have been ascribed to hyperstability; for example the Peruvian anchoveta and North Sea herring among the more spectacular (Hilborn and Walters 1992).

Catch rates of spotted mackerel are most likely hyperstable due to their highly aggregated, near surface schooling behaviour and predictable seasonal movements along the east coast that allows ease of targeting by both commercial and recreational fishers. Spotted mackerel are also relatively easy to catch once a school of fish has been found, and once located can be caught in large numbers, particularly using netting methods. As with other fisheries, spotted mackerel are easier to catch as fishing knowledge improves. Although, hyperstable catch rates of spotted mackerel would certainly be evident and exaggerated when using net catch data, we attempted to minimise the influence of this phenomenon by using weighting factors with a preference for line fishing methods.

In this assessment, we examined a range of weighting factors with the aim of reducing the hyperstability effect of certain fishing effort types for spotted mackerel (Table 5.5, 5.6). Each of the weighting factors was examined singularly and with the fishing method weights interacting with the pseudo target/non-target weights. We assumed that by removing or minimizing the influence of netting catch rates that a more reliable index of abundance was produced. Furthermore, we considered that the parameter estimates derived for each fishing year from the three analyses using mixed weightings (Weight 2), weights excluding net fishing (Weight 3) and commercial line fishing (no weights) best reflected the catch rates in the fishery and the underlying population abundance due to the elevated hyperstability of net fishing (Table 5.9). However, there is some concern that our estimated relative standardised catch rates may still exhibit hyperstability.

Hyperstability in a fishery can partly be minimised with more accurate measures of effort. Two database issues, therefore, would need to be addressed for this to occur and result in an improvement on our catch rate analysis used in this assessment. Currently, the DPI&F logbooks only contain information relating to actual catches of spotted mackerel, and only at a daily resolution of effort. If data were provided on actual search times and when zero catches occur, a more accurate portrayal of fishing effort could be included in the analysis, leading in turn to a more accurate representation of population abundance. In addition, future catch rate analyses will need to consider the impacts of recent and significant management measures that have been implemented in the fishery (*i.e.*, prohibition of nets to target spotted mackerel, commercial in-possession limit of 150 spotted mackerel, etc.; see Chapter 1), which were not an issue in the time series used in this assessment.

6. Total catches

The annual total catches for the Australian east coast spotted mackerel fishery that were used in this assessment included data from the Queensland and New South Wales commercial and recreational sectors. Total catches were estimated separately for two periods of the history of the fishery (fishing years 1960-1987 and 1988-2002); reflective of data availability. The fishery was assumed to have commenced in 1960 (see Chapter 3).

Total catches of spotted mackerel for each year of the historic period (1960-1987) included:

- Queensland commercial catch from Queensland Fish Board data (1960-1980).
- New South Wales commercial catch of 1 t based on the average catch of spotted mackerel for the initial years of the logbook data (1984-1988) (Table 4.14).
- Average total catch for years in which no data were available based on a generalised regression model.

The annual proportion of spotted mackerel in the historic Queensland Fish Board mackerel landings (1960-1980) was assumed to be a constant ratio derived from the more recent species differentiated DPI&F commercial logbook (CFISH) data (see Chapter 3). The proportion of spotted mackerel relative to all mackerel species from the CFISH data in 1990 and 1991 was estimated to be about 5.6%. This proportion was applied to the total mackerel Fish Board data for each year to estimate the annual historic commercial catch of spotted mackerel. Data for 1990 and 1991 were selected to estimate the relative proportion of spotted mackerel as it was assumed that these better reflected the targeting behaviour of commercial fishers in the historic period. In contrast, the long-term average (1988-2002) which included the period of more recent high catches was about 12%, and was used as an input sensitivity to the assessment model (*i.e.*, high historical catch – see Table 6.4, 7.2).

In those years where there were no data available (1981-1987) or only commercial data (1960-1980) a generalised linear model (GLM) with a log-link function was used to estimate the average total catch. The GLM regression model was fitted to the nominal total catches for 1988-2002 and projected back to 1960 (Table 6.1, Fig. 6.1). Average model estimates for each year were assumed to represent the respective annual total catch. The difference between the average model estimates and the commercial catches in which there were data were assumed to represent the unaccounted recreational catches.

Table 6.1. Generalised linear model with log-link function used to predict annual historic total catches. Total catch = exp(*a* + *b*.year). Residual deviance: 1.795 on 13 d.f.; (R^2=0.48).

Parameter	Estimate	S.E.	T Statistic	Probability	Covariance matrix	
a	-147.10473178	44.30862787	-3.320002	0.0055	1963.2545040	-0.9840829
b	0.07664804	0.02220979	3.451093	0.0043	-0.9840829	0.0004932746

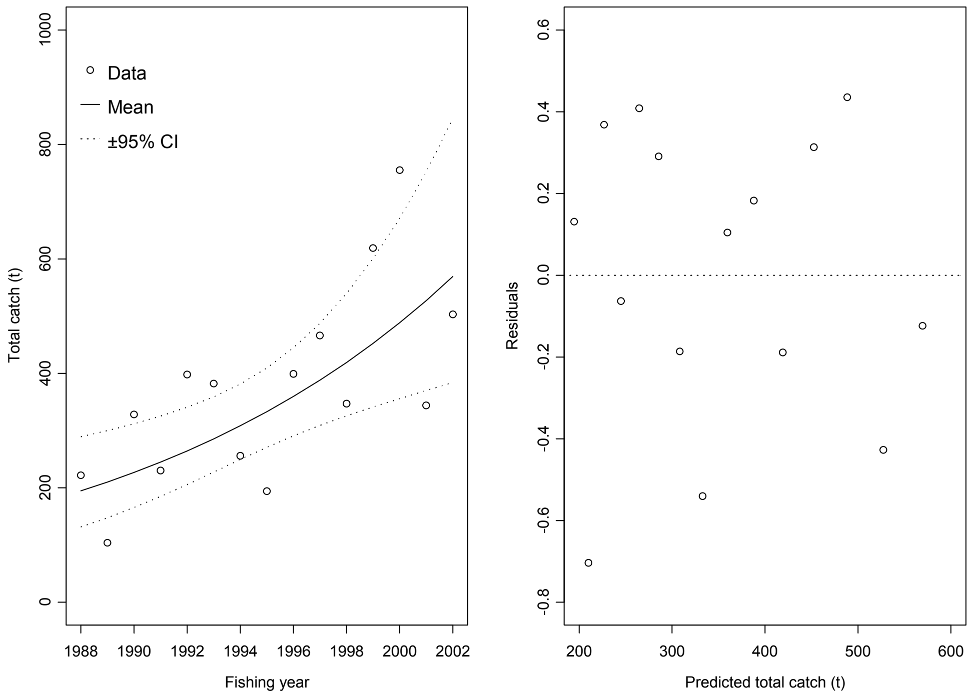

Fig. 6.1. Predicted total catches and residuals from GLM regression for fishing years 1988-2002.

Total catches of spotted mackerel for each year of the more recent period (1988-2002) included:

- Actual reported catches for spotted mackerel from the Queensland and New South Wales commercial logbooks (plus binary model allocated unspecified mackerel catch; Table 4.11 and 4.14).
- Queensland recreational survey catch estimates for 1995 (52 t; Cameron and Begg 2002), 1999 (201 t), 2000 (265 t) and 2002 (180 t). The 1999, 2000 and 2002 estimates included binary model allocations for unspecified mackerel (Table 4.20). The 1997 RFISH estimate was excluded because of species identification issues with the initial survey, and concerns that it may have been an extreme overestimate.
- New South Wales recreational survey catch estimates for 1993 (5 t), 1994 (1 t) and 2000 (27 t) (Table 3.6). The 2000 estimate was based on the average proportion of spotted mackerel in the catch from the previous two surveys.
- Estimated Queensland recreational catch for 1988-1994, 1996-1998 and 2001 when there was no actual survey conducted.
- Estimated New South Wales recreational catch for 1988-1992, 1995-1999 and 2001-2002 when there was no actual survey conducted.

In those years when there were no surveys conducted to estimate Queensland recreational catches (1988-1994, 1996-1998, 2001), estimates were based on the average recreational relative effort for the years in which data were available (Table 6.2). Recreational catches for the fishing years 1995, 1999, 2000 and 2002 were divided by their corresponding commercial line standardised catch rate (*i.e.*, GLM yearly coefficient; Table 5.9, 6.2) to derive four estimated levels of standardised effort. The yearly catch rate coefficient was assumed to represent trends in stock abundance. The estimates of standardised effort were then averaged and assumed to be constant at this level for the years of missing data. The average relative measure of effort (*i.e.*, 197.533) was then multiplied by the respective yearly coefficient from the commercial line standardised catch rate to provide an estimate of recreational catch for those years in which no direct data were available.

Table 6.2. Queensland recreational catches for fishing years in which surveys were conducted. Catch rate = standardised commercial line CPUE (GLM yearly coefficient). Average relative effort calculated to derive recreational catches for those years in which no surveys were conducted.

Fishing year	Catch (t)	Catch rate	Relative effort
1995	52	0.533	97.561
1999	201	0.859	233.993
2000	265	0.996	266.064
2002	180	0.935	192.513
Average	*175*	*0.831*	*197.533*

A similar approach was used to estimate the New South Wales recreational catches for those years in which no surveys were conducted (1988-1992, 1995-1999, 2001-2002). Estimates for these years were based on the average recreational catch for the years in which data were available (*i.e.*, 11 t; average catch for 1993, 1994 and 2000) as detailed for the Queensland recreational catch above (Table 6.3).

Table 6.3. New South Wales recreational catches for fishing years in which surveys were conducted. Catch rate = standardised commercial line CPUE (GLM yearly coefficient). Average relative effort calculated to derive recreational catches for those years in which no surveys were conducted.

Fishing year	Catch (t)	Catch rate	Relative effort
1993	5	1.126	4.440
1994	1	0.651	1.536
2000	27	0.996	27.108
Average	*11*	*0.924*	*11.028*

An additional sensitivity to the assessment model related to total catches included a low recreational catch estimate upon which the total catches were based (*i.e.*, low recreational catch – see Table 6.4, 7.2). These total catch estimates were based on 50% of the recreational catches for each year from 1988-2002, and assuming the generalised regression approach of these total catches for the historic period.

The estimated total catches for spotted mackerel, therefore, have increased significantly since the fishery was assumed to have commenced in 1960 (Table 6.4, Fig. 6.2). Total catches reached a peak of about 755 t in 2000, just prior to the investment warning in 2002. Major uncertainties in the total catches relate to the magnitude of the historical catches and the recreational component because of the methodological approaches and limitations associated with the use of State-wide telephone and diary survey based estimates.

Table 6.4. Total Queensland and New South Wales commercial (com) and recreational (rec) catches of spotted mackerel used in the assessment, fishing years 1960-2002. Total catches estimated are those of the “best” estimate used in the assessment, and also those based on the high historic catches and low recreational catches for sensitivity analysis.

Fishing year	Estimated spotted mackerel catch (t)						
	QLD com	**NSW com**	**QLD rec**	**NSW rec**	**Total**	**High historic**	**Low rec**
1960	27	1	0	0	33	85.574	12.751
1961	25	1	0	0	35	84.245	13.899
1962	32	1	0	0	38	100.75	15.150
1963	33	1	0	0	40	105.42	16.514
1964	35	1	0	0	43	111.93	18.001
1965	34	1	0	0	46	112.44	19.621
1966	33	1	0	0	49	112.94	21.388
1967	35	1	0	0	53	119.29	23.313
1968	27	1	0	0	57	105.63	25.411
1969	28	1	0	0	61	110.97	27.699
1970	34	1	0	0	65	128.31	30.192
1971	34	1	0	0	69	130.66	32.910
1972	47	1	0	0	74	163.83	35.873
1973	41	1	0	0	79	154.01	39.102
1974	48	1	0	0	85	175.02	42.622
1975	37	1	0	0	91	157.04	46.459
1976	43	1	0	0	97	174.05	50.641
1977	45	1	0	0	104	183.90	55.200
1978	33	1	0	0	112	165.59	60.169
1979	32	1	0	0	120	169.27	65.585
1980	39	1	0	0	128	191.95	71.489
1981	0	1	0	0	137	199.48	77.925
1982	0	1	0	0	147	207.83	84.940
1983	0	1	0	0	157	216.19	92.586
1984	0	1	0	0	168	225.38	100.92
1985	0	1	0	0	180	235.41	110.01
1986	0	1	0	0	192	245.43	119.91
1987	0	1	0	0	206	257.13	130.70
1988	12	1	198	11	222	222	117.5
1989	19	1	80	4	104	104	62
1990	43	4	266	15	328	328	187.5
1991	51	3	167	9	230	230	142
1992	142	14	229	13	398	398	277
1993	126	29	222	5	382	382	268.5
1994	118	8	129	1	256	256	191
1995	127	9	52	6	194	194	165
1996	220	33	138	8	399	399	326
1997	205	55	195	11	466	466	363
1998	125	46	167	9	347	347	259
1999	354	55	201	9	619	619	514
2000	445	18	265	27	755	755	609
2001	182	10	144	8	344	344	268
2002	291	22	180	10	503	503	408

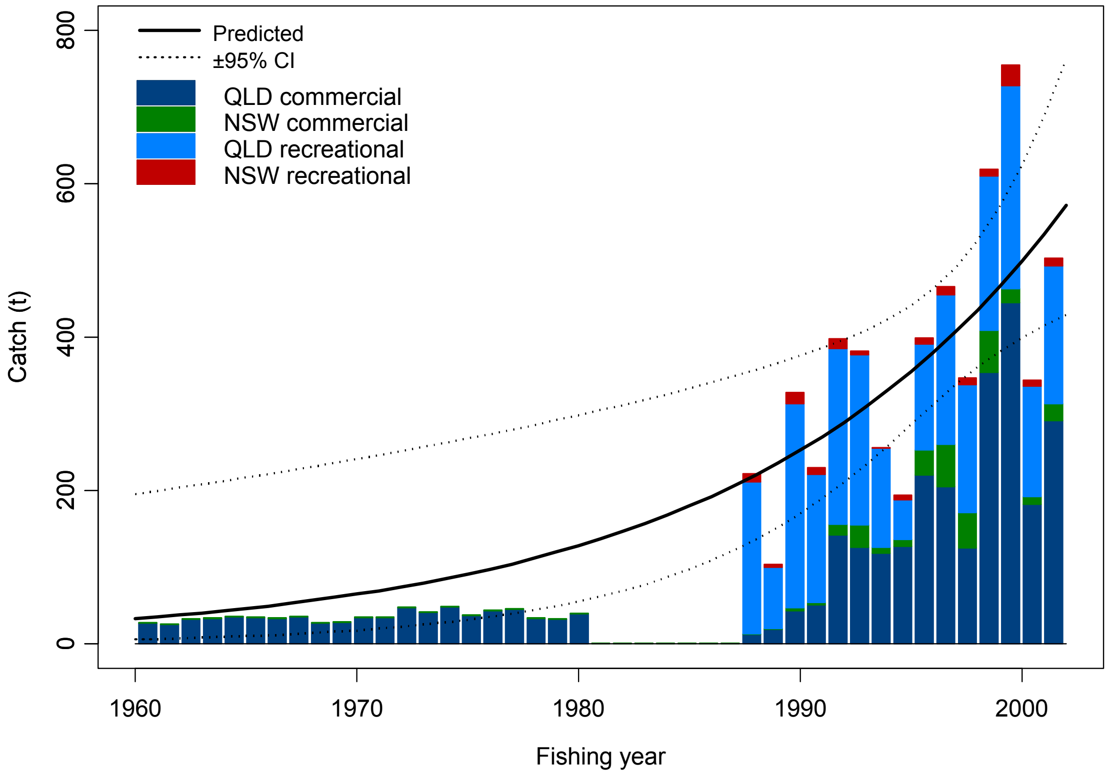

Fig. 6.2. The estimated spotted mackerel total catch (t), fishing years 1960-2002.

7. Stock assessment

Early assessments of spotted mackerel were limited to simple interpretations of trends in un-standardised catch statistics (Williams 1997, 2002), which are difficult to interpret and suffer from hyperstability (see Chapter 5). Following, in March 2002, the first preliminary stock assessment by DPI&F (formerly DPI) was presented at the DPI Spotted Mackerel Workshop, and involved two analyses. The first was an equilibrium yield-per-recruit (YPR) analysis that ignored stock-recruitment relationships and assumed constant recruitment. This analysis indicated that the then minimum legal size of 50 cm TL was below the average size at first maturity, as well as the optimum size of capture to maximise YPR, which was estimated to be about 60-65 cm (Fig. 7.1). The second analysis used an age-structured population dynamics model (similar to that used in this assessment and described below) that was not restricted to the constant per-recruit equilibrium assumptions. The model was presented at the 2002 Workshop for discussion only and to highlight paucity in some data and parameters. The results, however, indicated a decline in population size between 1996 and 2001 (Fig. 7.2). The 90% confidence intervals on these predictions demonstrated that the uncertainty was quite large. In addition to this uncertainty, the model used only limited age-structured data and approximated recreational catches using the recreational/commercial catch ratio of 41.2% of Cameron and Begg (2002), which in reality could vary significantly from year to year.

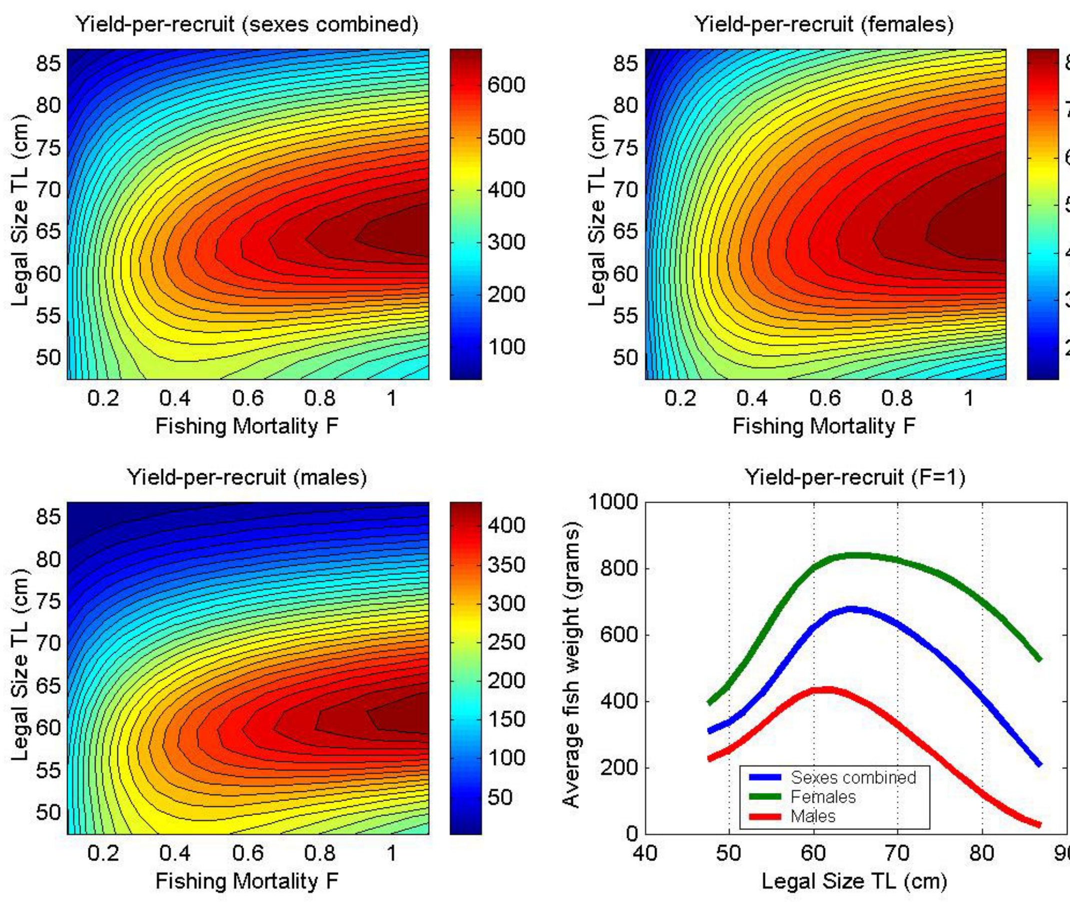

Fig. 7.1. The yield-per-recruit (YPR) analysis presented at the DPI Spotted Mackerel Workshop in March 2002. The isopleths use a range of fishing mortalities to illustrate the region of maximum yield (red region). The line plot illustrates the cross-section of the isopleths when fishing mortality (F) = 1.

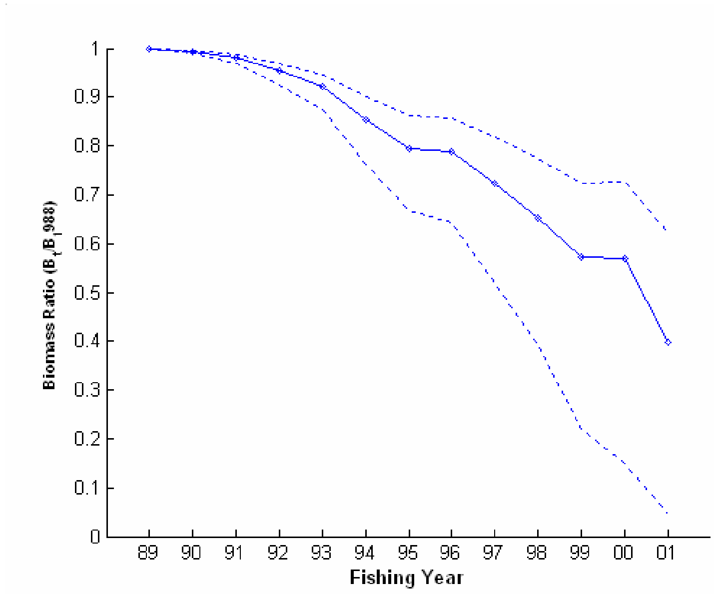

Fig. 7.2. The preliminary age-structured assessment in 2002 predicted that biomass, expressed as a ratio to 1989 biomass, declined significantly between 1996 and 2001. The dotted lines represent the 90th percentiles.

In this assessment, we applied a sex-specific age-structured population dynamics model to evaluate the status of the Australian east coast spotted mackerel fishery. The model built upon the assessment model developed for Spanish mackerel and used in the preliminary analysis of spotted mackerel for the 2002 Workshop. A range of biological and effort reference points were assessed to evaluate various potential management strategies for spotted mackerel. Reference points for a fishery are used as key assessment and management tools to indicate the stage at which a resource is declared to be in some danger of overexploitation or is at an unwanted state (see Chapter 9). A number of measures can be used as reference points, but developing reference points for a particular fishery is complex. Their definition is reliant on detailed analyses and their accuracy depends on data quality and quantity, having a reliable index of population abundance, uncertainties with estimating exploitation rates, and the practicality of monitoring the fishery in relation to the reference points (Hilborn 2002; see Chapter 9).

Reference points are typically used to manage a number of important fisheries throughout the world (Sissenwine and Shepherd 1987, Patterson 1992, Govender 1995, Staples 1996, Richards *et al.* 1998, Gabriel and Mace 1999, Mace 2001, Hilborn 2002, Cadrin *et al.* 2004). In Australia, two examples include restricting fishing effort to achieve maximum sustainable yield (MSY) in the Australian northern prawn (Dichmont *et al.* 2001) and Queensland spanner crab fisheries (Brown *et al.* 2001), where annual changes in catch rates are used in decision rules to set total allowable catches (TACs). In the Canadian west coast prawn, shrimp and mollusc fisheries, reference points have been used to set TACs or fishing effort (Leaman 1993). In most of these fisheries, the reference points used for target fishing was MSY, fishing effort or fishing mortality required to attain MSY (*i.e.*, E_{MSY}, F_{MSY}), and the yield or catch when fished at F_{MSY} (*i.e.*, $Y(F_{MSY})$). However, because of the uncertainty surrounding the actual value of MSY and its variability from year to year, it is now universally accepted that F_{MSY} is no longer a valid fishery target reference point, although it can be acceptable as a maximum-limit reference point (Garcia and Staples 2000, Deriso 2001). In addition, MSY is not sustainable when the stock size is less than the biomass that produces MSY (*i.e.*, B_{MSY}), and so catches may not be sustainable when total catches are greater than the sustainable yields (*i.e.*, $F > F_{MSY}$). Staples (1996) correctly highlights that appropriate biomass reference points with acceptable risks for some pelagic fish stocks may be as high as 40-60% of virgin (*i.e.*, un-fished; B_0) population sizes (*i.e.*, B_{MSY} about 0.4-0.6 B_0). A biomass reference point of B_{MSY} equal to about 0.4 B_0 was also used in this assessment.

The type of reference point described above (*i.e.*, $Y(F_{MSY})$) is typically known as a limit. A hypothetical example of a limit could be if we think that the fishery will be over-fished if the biomass of spotted mackerel drops below 1000 t. The other use of reference points refers to aiming towards a target state of fishing and/or resource that is considered to be desirable. As another hypothetical example, we might believe the fishery will produce the most yield, and most profit for industry, if there were 3000 t of spotted mackerel alive in the sea. We would therefore try to manage the fishery (*i.e.*, fishing effort) to approach this biomass level – our target reference point.

In August 2000, the Northern Territory Department of Business, Industry and Resource Development (DBIRD) held a stock assessment workshop on Spanish mackerel resources led by Dr Carl Walters from the University of British Columbia, Canada. Walters recommended that management strategies for Spanish mackerel should use fishing mortality equal to about half that of natural mortality (*i.e.*, F~0.5M) as a target reference point to indicate a safe long-term sustainable catch. Tagging studies were considered as the most precise method to calculate F, but significant research was still required before this could occur. Walters also recommended that if Ecological Sustainable Objectives (ESO) were to be achieved, clear standards of population dynamics must be incorporated and maintained in the assessment and management process. Walters spent considerable time detailing how clear standards for optimal stock assessments had changed over the past 20 years. While in 1980 it had generally been accepted that levels of F could equal levels of M, repeated experiences with fishery collapses had indicated that far more conservative levels were required. Patterson (1992) found that 80% of pelagic fisheries had collapsed when F=M, and proposed a more conservative F=0.6M standard. The workshop, therefore, commenced with a suggestion for the acceptance of a standard maximum F. A standard of F larger than 0.5M was assumed to be appropriate for species where selectivity is directed to age groups some years after the commencement of maturity. However, it was considered that the early selectivity of age groups in many tropical Australian species, such as Spanish and spotted mackerel, dictated that the conservative F=0.5M would be more appropriate. Similarly, in this assessment we examined 0.5M as a potential target reference point.

Methods

Age-structured population dynamics model

An age-structured population dynamics (stock) model was used to calculate yearly exploitable population numbers and biomass of spotted mackerel (referred to in this assessment as the "Spotted mackerel Age-structured Model"; SAM). The model was first developed for Spanish mackerel in the Northern Territory (Buckworth 2004), and was recently adapted for the Queensland east coast Spanish mackerel assessment (O'Neill and McPherson 2000, Welch *et al.* 2002, Hoyle 2003). This model was modified to apply to spotted mackerel and expanded to estimate model parameters through maximum likelihood or a Bayesian algorithm, calculate various management quantities such as MSY, and conduct forward projections in a Monte Carlo framework. The model used an age-structured approach that considered the survival of 0+, 1+, …, 10+ old spotted mackerel for both male and female fish. The main data sources for the model were the total catches (Table 6.4), catch rates (Table 5.9) and age structures (Table 2.8, Fig. 2.4). The annual total catches included data from the Queensland and New South Wales commercial and recreational catches (Fig. 6.2). The fishery was assumed to have commenced in 1960.

The population dynamics were assumed to follow the standard Baranov catch equations (Quinn and Deriso 1999). The initial numbers of mackerel for each age group and sex or gender in 1960 was:

$$N_{1960,g,a} = 0.5N_0e^{-Ma} \qquad (7.1)$$

where, $N_{1960,g,a}$ = spotted mackerel population in the 1960 fishing year (assumed virgin stock) for the gender g (male or female) and age group a (0+ to 10+ years); N_0 = estimated recruitment in 1960 (both sexes combined); M = natural mortality rate; and the 0.5 fraction equally allocated the recruitment into male and female fish.

The age-structured time dynamic calculations after 1960 followed the equations:

$$N_{y,g,a} = \begin{cases} R_y & \text{for } a = 0 \\ N_{y-1,g,a-1} e^{-M} (1 - S_{g,a-1} U_{y-1}) & \text{for } a = 1...10 \end{cases} \tag{7.2}$$

where, R_y = calculated annual recruitments for the fishing years 1961 to 2002; S_a = fishing selectivity by age; and U = harvest rate (*i.e.*, total catch/exploitable biomass).

Annual recruitment was calculated as a function of spawning stock size through the Beverton-Holt stock-recruitment relationship (see Quinn and Deriso 1999, Haddon 2001; see Chapter 2):

$$R_y = \frac{Eggs_{y-1}}{(\alpha + \beta Eggs_{y-1})} \tag{7.3}$$

where, R_y = conditional mean recruitment during the fishing year y; $Eggs$ = calculated index of spawning stock size; and α and β = parameters for the stock-recruitment relationship. The stock-recruitment parameters α and β were defined using the following equations to have more biological meaning:

$$\alpha = \frac{Eggs_{1960}(1-h)}{4h(0.5R_{1960})} \tag{7.4}$$

$$\beta = \frac{5h-1}{4h(0.5R_{1960})} \tag{7.5}$$

$$h = \frac{r_{max}}{4 + r_{max}} \tag{7.6}$$

where, h = steepness measuring the expected recruitment at 20% of the virgin spawner stock size (*i.e.*, $\frac{R_{0.2Eggs_{1960}}}{R_{1960}}$).

The parameter r_{max} can also be used directly to define the Beverton-Holt stock-recruitment relationship by:

$$\alpha' = \frac{r_{max}(0.5R_{1960})}{Eggs_{1960}} \tag{7.7}$$

$$\beta' = \frac{r_{max} - 1}{Eggs_{1960}} \tag{7.8}$$

$$R_y = \frac{\alpha' Eggs_{y-1}}{(1 + \beta' Eggs_{y-1})} \tag{7.9}$$

The spawning stock index, $Eggs_y$, was calculated from the sum-product across the ages a:

$$Eggs_y = \sum_a N_{y,a}\ Fecundity_a\ Maturity_a \tag{7.10}$$

where, *Fecundity* = average number of eggs at age derived from the fecundity-length relationship (Table 2.19); and *Maturity* = average proportion of mature females at age derived from the length-based maturity ogive and von Bertalanffy growth relationships (Table 2.6, 2.12).

Annual harvest rate (U_y) was calculated by:

$$U_y = \frac{C_y}{\sum_a S_{g,a} N_{y,g,a} w_{g,a}} \tag{7.11}$$

where, C_y = observed total catch (t) for year *y*; and $w_{g,a}$ = average fish weight at age for each gender derived from the von Bertalanffy growth and length-weight relationships (Table 2.4, 2.6).

The fishing selectivity $S_{g,a}$ was calculated directly for each gender and age using the logistic equation (Haddon 2001):

$$S_{g,a} = \frac{1}{1 + e^{-\log(19)\frac{Mean\ Length_{g,a} - Length_{50,g}}{Length_{95,g} - Length_{50,g}}}} \tag{7.12}$$

where, $Length_{50}$ = estimated total length at which fishing selectivity is 50%; and $Length_{95}$ = estimated total length at which fishing selectivity is 95%.

The exploitable biomass (*B*; t) at the start of each fishing year was estimated by the following:

$$B_y = \sum_{g,a} N_{y,g,a} S_{g,a} w_{g,a} \tag{7.13}$$

and the mid-fishing year (*midy*) exploitable biomass:

$$B_{midy} = \sum_{g,a} N_{y,g,a} e^{-M/2} S_{g,a} (1 - U_y/2) w_{g,a} \tag{7.14}$$

The model calculated catch (t) was given by:

$$\hat{C}_y = \sum_{g,a} N_{y,g,a} S_{g,a} U_y w_{g,a} \tag{7.15}$$

The model calculated average catch rates was given by:

$$C\hat{P}UE = qB_{midy} \tag{7.16}$$

where, q = average catchability, was calculated by:

$$q = \frac{1}{n} \sum_{y=1988}^{2002} \frac{CPUE_y}{B_{midy,y}} \tag{7.17}$$

where, n = number of fishing years (15).

In total, three parameters were estimated in the age-structured model. These parameters and those assumed are outlined in Table 7.1.

Table 7.1. List of parameters used in the stock model.

Estimated parameters	Fixed parameters (assumed known)
Virgin recruitment: R_{1960}	Annual natural mortality *M*: 0.42
Length at 50% selectivity: $Length_{50}$	Stock-recruitment r_{max}: 4.5
Length at 95% selectivity: $Length_{95}$	Length-weight relationship: see Chapter 2
	Growth curve: see Chapter 2
	Maximum age group: 10+

The model was fit to the observed catch age structures (as a proportion) from the fishing years 1991 to 1996, 1999 and 2002, and standardised catch rates from 1988 to 2002. The 'fminunc' MATLAB nonlinear Quasi-Newton optimization procedure was used to conduct the estimation by maximum likelihood (MATLAB 2002). The negative log-likelihood function considered here had two normal components. The first was based on the age structure of the catch (as a proportion):

$$-\log L_1 = \frac{n}{2}(\log(2\pi) + 2\log(\sigma) + 1) \qquad (7.18)$$

where, n = number of observed age groups; π = 3.14159265358979; and σ = standard deviation:

$$\sigma = \sqrt{\frac{\sum_{y,a}(cp_{y,a} - c\hat{p}_{y,a})^2}{n}} \qquad (7.19)$$

where, $cp_{y,a}$ = observed cumulative proportion of the catch-at-age in fishing year *y, and* $c\hat{p}$ was the predicted cumulative proportion of the catch-at-age. The second log-likelihood (-logL_2) was for the standardised catch rates and used the same normal formulation above. The standard deviation σ for the catch rates was:

$$\sigma = \sqrt{\frac{\sum_{y=1988}^{2002}(CPUE_y - C\hat{P}UE_y)^2}{n}} \qquad (7.20)$$

where, n = number of observed catch rates; *CPUE* = generalised linear model standardised-fishing-year coefficients (surrogate for standardised catch rates); and $C\hat{P}UE$ = predicted catch rate (or coefficients) in each fishing year.

The total negative log likelihood for the model was $-\log L_1 + -\log L_2$.

Model assumptions

Overall, the main assumptions of the age-structured model were:

- Stock equilibrium in 1960.
- Stock recruitment steepness = 0.52.
- No recruitment deviations from stock-recruitment relationship.
- Constant monthly natural mortality.
- Constant average fish growth.
- Constant maturity.

- Constant fecundity.
- Constant selectivity.
- Common Age Length Key through time.
- Accurate representation of total catch.
- Standardised catch rate proportional to abundance.

Model sensitivity

In most stock assessments where input parameters within the model are deterministic (*i.e.*, fixed), the effects on the results of entering different parameter values are tested. This is known as model sensitivity analysis. This means that it is necessary to select parameter values that best represent our knowledge of the resource and treat these as the base case against which any changes are being compared. Table 7.2 lists the different sensitivity tests that we conducted on the model. Only one sensitivity parameter was changed at a time, and 13 different scenarios were examined.

Natural mortality (*M*), stock-recruitment steepness (*h*), age structure and catch rate data were each examined for their influence on model results. In addition, total catches based on high historical and low recreational catches (Table 6.4, Fig. 7.3) and fixed net/line selectivities were examined. The net selectivities used in the sensitivity analysis were calculated using the gill net selectivity functions of Cameron and Begg (2002). The line selectivities were based on a normal cumulative density function based on the minimum legal size and standard deviations from the von Bertalanffy growth curves for each sex. The individual selectivity functions for each spotted mackerel sex, mesh net size, and line fishing were combined based on the net/line catches to form a weighted average that was applied to each year of age structure data.

Table 7.2. A total of 13 different sensitivities were run with the age-structured stock model. Natural mortality (*M*), stock-recruitment steepness (*h*), age structure, catch rate (CPUE) data and other factors were examined for their influence on model results.

Model sensitivity run	*M*	*h*	Age data	CPUE data	Others
1	0.42	0.52	Yes	Yes	
2	0.42	0.38	Yes	Yes	
3	0.32	0.38	Yes	Yes	
4	0.52	0.38	Yes	Yes	
5	0.52	0.52	Yes	Yes	
6	0.32	0.52	Yes	Yes	
7	0.42	0.52	Yes	No	
8	0.42	0.65	Yes	Yes	
9	0.42	0.52	Yes	Yes	High historical catch
10	0.42	0.52	Yes	Yes	Low recreational catch
11	0.42	0.52	Yes	Yes	Fixed ring net selectivity
12	N(0.42, 5%)	LogN(0.52)	Yes	Yes	MCMC
13	N(0.42, 5%)	LogN(0.52)	Yes	No	MCMC

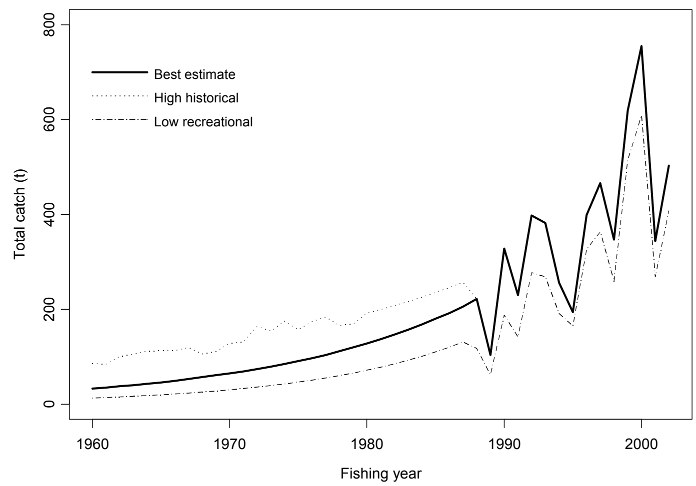

Fig. 7.3. Total catch estimates used in sensitivity analysis including those of "best" estimate, high historical and low recreational catches (see Table 6.4).

Reference points

The calculations of management equilibrium reference points were based on optimizing the dynamics of the age-structured stock model through harvest rates (*i.e.*, fishing mortality). The dynamics of the models were optimized for three reference points: 1) harvest rate (*U*) or fishing mortality (*F*) at maximum sustainable yield (MSY) (F_{MSY}); 2) $0.75F_{MSY}$; and 3) fishing mortality equal to half that of natural mortality F=0.5M. Note that *F* relates to annual instantaneous fishing mortality (log scale) and *U* relates to annual harvest rates (proportional scale), where $F = -\log(1-U)$. The first reference point for F_{MSY} is universally accepted as a limit (Garcia and Staples 2000). The second and third reference points are considered as target levels of fishing because of the uncertainty around the actual value of MSY and its variability from year to year. Figure 7.4 is a hypothetical example graphically illustrating these reference points.

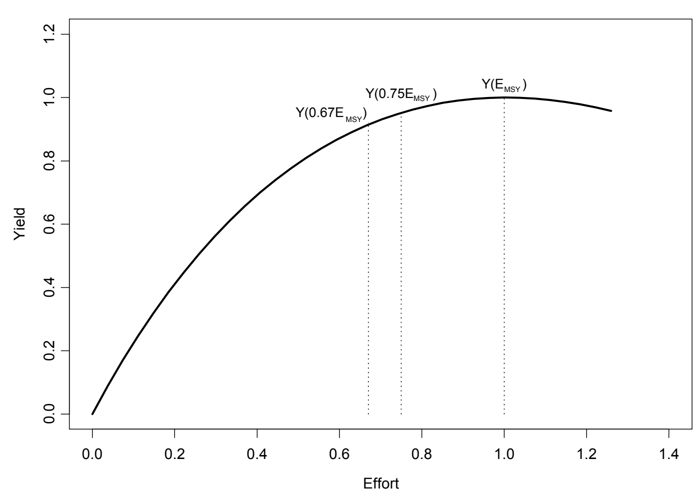

Fig. 7.4. Hypothetical example showing how the various equilibrium reference points relate. Maximum sustainable yield (MSY) is the largest reference point shown, the next smallest is 0.75 of MSY Effort, and 0.67 of MSY Effort (fishing effort corresponds to fishing mortality). From the spotted mackerel results $F_{0.5M}$ is similar to $0.75F_{MSY}$; in this example $F_{0.1}$ is similar to 0.67 of MSY Effort. Note that similar catches can be obtained across the reference points in the long-term, even if fishing effort was reduced to 0.75 or 0.67 of F_{MSY}.

Bayesian stock assessment

The metropolis algorithm (Hastings 1970, Punt and Hilborn 1997) was applied to the age-structured stock model to compare the outcomes with the maximum likelihood optimizations (Table 7.2; Model 12 and 13 for comparison). The algorithm, also known as Monte Carlo Markov Chain (MCMC), involved selecting initial parameter values for virgin recruitment (R_{1960}), selectivity ($Length_{50}$ and $Length_{95}$), stock-recruitment (r_{max}) and natural mortality (M), and generating a Markov chain. The algorithm was set up to sample every 10th value of the Markov chain. This was to ensure that the covariance between selected parameter values was sufficiently small that it can be safely ignored. The algorithm proceeded as follows:

1. Select an initial state for the model using the maximum likelihood estimates, base case stock-recruitment (r_{max}) and natural mortality (M).
2. Run the stock model with these parameter values, storing the likelihood against the parameters for virgin recruitment (R_{1960}), selectivity ($Length_{50}$ and $Length_{95}$), stock-recruitment (r_{max}) and natural mortality (M).
3. Calculate an additional normal likelihood for stock-recruitment (r_{max}) and natural mortality (M);

   $$\log L_{r_{max},M} = \frac{\log_e(r_{max}) - \log_e(\bar{r}_{max})}{2\sigma^2} + \frac{M - \overline{M}}{2(0.2M)^2}$$

   where, σ = log standard deviation of the mean (log (r_{max})) (*i.e.*, σ = 0.539125657709493; mean (log (r_{max})) = 1.4973118641302), and 5% standard deviation was allowed on M. This likelihood constrained r_{max} and M to their prior distributions; the time series of data limited the reliability to estimate unconstrained posteriors.
4. Define a vector of tolerances (or prior distributions) for the five parameters. The algorithm cycles a large number of times after this step.
5. Generate a proposed random parameter vector from the prior distributions.
   a. Uniform distribution for virgin recruitment (R_{1960}) and selectivity ($Length_{50}$ and $Length_{95}$) along the Markov chain.
   b. Normal distribution for the stock-recruitment parameter log(r_{max}) and natural mortality (M) along the Markov chain.
6. Run the stock model and store the two likelihoods.
7. Generate two random numbers from the uniform distribution on the interval [0, 1].
8. For the first model likelihood, if the ratio of the new likelihood to the old was greater than the first random number accept the new virgin recruitment (R_{1960}) and selectivity ($Length_{50}$ and $Length_{95}$) parameters and store the likelihood to compare in the next cycle.
9. For the additional likelihood, if the ratio of the new likelihood to the old was greater than the second random number accept the new stock-recruitment (r_{max}) and natural mortality (M) parameters and store the likelihood to compare in the next cycle.
10. If the ratios of either the new likelihoods to the old are less than the random numbers reject the new parameters; re-use the current parameters and likelihoods to compare in the next cycle.

Steps seven to ten (refer to a cycle) were repeated 10,000 times. The vector of tolerances was updated each cycle. For more detail on the basis of this algorithm see Punt and Hilborn (1997). The sample-importance-resample (SIR) algorithm was also used, but it only selected very few random parameter combinations (~1%). The MCMC algorithm has been reported to be more adequate and robust than the SIR for catch-at-age data (*i.e.*, age-based assessments) (Punt and Hilborn 1997).

Management strategy evaluation

On completion of the stock assessment, the performance of different catches and reference points were tested through a series of simulations. The algorithm for the simulations was similar to the Monte Carlo forward projection methods used by Richards *et al.* (1998). Details of the uncertainties are shown in Table 7.3. The algorithm proceeded as follows:

1. Optimise the base stock assessment model to the observed age structures and catch rates.

2. Construct error distributions (see Table 7.3).
3. Draw a random parameter vector from the error distributions estimated in Step 2.
4. Use the random parameters to drive the model and obtain a sample historical trajectory for the stock.
5. Choose a catch to test (*e.g.*, 300 t or $0.75F_{MSY}$).
6. Project the operating model forward 20 years. Recruitment is simulated under a stock-recruitment relationship with lognormal error.
7. The process from Steps 3-6 is repeated 1000 times to obtain a large number of trajectories; each of which reflected the correlations among model parameters estimated.

Table 7.3. Details of the uncertainties allowed for in the simulations. The italic syntax represents MATLAB functions. Graphical display of the error distributions and their justifications are presented in the Results section.

Parameters	Sampling and error distributions
Virgin recruitment (R_{1960}) Selectivity ($Length_{50}$ and $Length_{95}$)	1000 by three matrix of maximum likelihood parameter estimates corresponding to random variation in r_{max} and M.
Annual natural mortality (M)	*normrnd*(0.42, 0.05,1000, yrs) The *normrnd* function generated 1000 by number-of-years (yrs) matrix of normal random M values with mean 0.42 and standard deviation of 5%.
Stock-recruitment (r_{max})	*exp(normrnd*(log(r_{max}), std(log(r_{max})),1000,1)) The *exp* and *normrnd* functions generated log-normal random variations of r_{max}. Standard deviation (std) from Table 7.1.
Predicted recruitment errors ($\varepsilon_{S/R}$)	exp(*normrnd*(0, 0.25, yrs, 1000)) The exponential function returned log-normal errors with a log-mean of zero and log standard deviation for the *S/R* fits for every fishing-year (yrs) recruitment; 1000 variations were produced.
Growth: Mean length at age	*mvnrnd*([L_∞, K, t_0], cov, 1000) The *mvnrd* function returned a 1000-by-3 matrix of random growth parameters chosen from the multivariate normal distribution with maximum likelihood estimates [L_∞, K, t_0], and covariance cov. This was calculated for both male and female fish.
Maturity at age	*mvnrnd*(*binomial params*, cov, 1000) The *mvnrnd* function returned a 1000-by-2 matrix of random binomial parameters chosen from the multivariate normal distribution with least squares estimates, and covariance cov. The binomial parameters calculate the proportion of females mature at age; used in spawning stock index.

The expected median outcomes and probabilities indicating risks of over-fishing were summarised in a management strategy evaluation (MSE) (Smith 1994). MSE involves assessing the consequences of a range of fishing strategies and presents the results in a way that lays bare the trade-offs in performance across a range of management objectives. The approach does not define a final fishing strategy or decision. It only provides information on which to base management choices, given a set of management objectives. To fully understand the structure of the MSE, the following key elements and definitions were used:

- The *fishing strategies* were the catches allowed from the fishery each year. The fishing strategies examined included constant MSY (F_{MSY}), $0.75F_{MSY}$, 0.5*M*, and set catches ranging from 200 to 500 t.
- The *management strategy* was the decision not to change the catches once the fishing strategies were implemented.
- The *management objectives* considered biological sustainability and commercial/recreational sustainability.
- A number of different *performance measures* or *indicators* were used to gauge each *fishing strategy* against the *management objectives*.
    1. One quantitative measure of biological sustainability was used:
        - The risk over a 20-year period of management that the stock size will fall below the long-term equilibrium population biomass that results from fishing the stock at maximum sustainable yield (B_{MSY}).

2. Two quantitative measures of commercial/recreational sustainability were used:
   - The median total catch expected over the 20-year period of management.
   - The median catch rate over the 20-year period of management.

Model projections were conducted over a 20 year period from 2004-2023. The 2003 total catch was based on the preceding 2002 catch where it was assumed similar catch rates existed, although the commercial catch was reduced considerably with the introduction of the catch quota of 140 t. Consequently, the total catch for 2003 used in the projections was estimated to be the 2002 total catch (503 t) minus the 2002 Queensland commercial catch (291 t), plus the introduced commercial quota of 140 t (*i.e.*, 503 – 291 + 140 = 352 t). However, in 2003 the quota was not fully taken, with only 70 t estimated. It was assumed that the recreational catch in 2003 was similar to that in 2002. Therefore, the total catch used in the projections for 2003 was 282 t (*i.e.*, 503 – 291 + 70 = 282 t).

Results

Stock assessment

Results from the stock assessment indicated a significant decline in the exploitable biomass of spotted mackerel since the assumed commencement of the fishery in 1960, particularly between 1995 and 2001 when the greatest catches were observed (Fig. 7.5). Current (2002) biomass levels were estimated to be at 33-63% of unfished or virgin biomass levels (Fig. 7.6). All models tested demonstrated a similar pattern of decline, although the results were more pessimistic when only the age structure data were used to tune the model (Model 7). Notably, results from the MCMC model runs (Model 12 and 13) were similar to the base model run tuned to both the age structure and CPUE data (Model 1) (Fig. 7.6). The levels of uncertainty in the biomass estimates were greater in the more recent years of the fishery (Fig. 7.5).

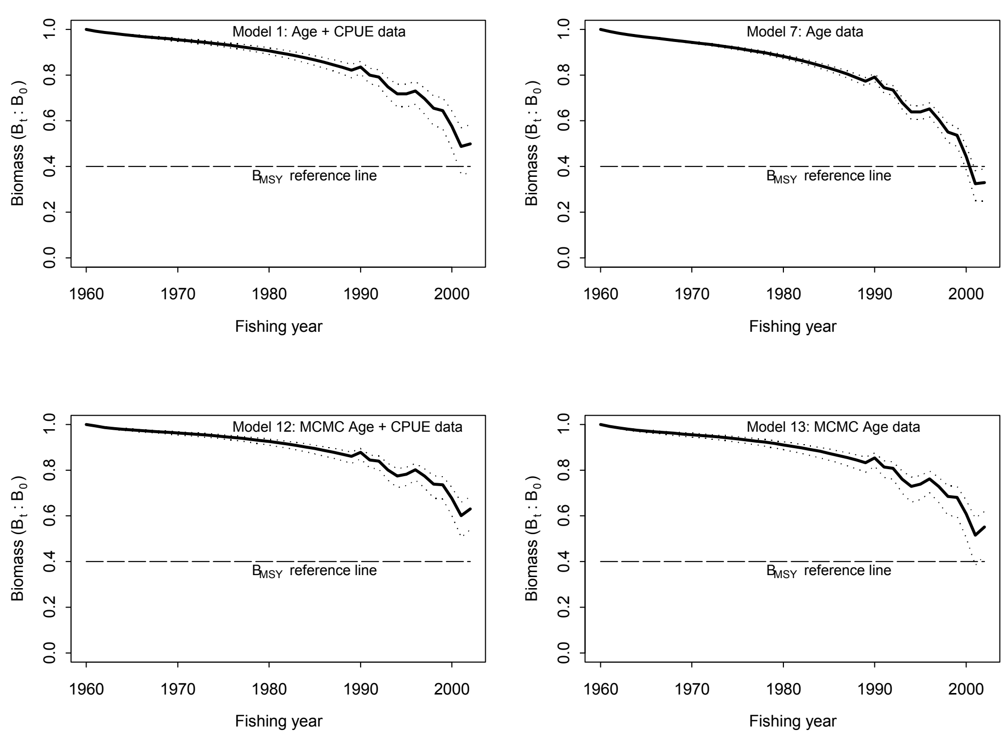

Fig. 7.5. The predicted median exploitable biomass of spotted mackerel between 1960 and 2002, for sensitivity Models 1 and 7, and the MCMC Models 12 and 13. The different model sensitivities are defined in Table 7.2. The predicted exploitable biomass of spotted mackerel declined significantly between 1995 and 2001. Dotted lines represent 90% confidence intervals.

The sensitivity analysis demonstrated that the assessment model was quite robust (Fig. 7.5). Similar biomass ratios and management quantities were estimated from the different model runs, irrespective of the parameter combinations tested (Table 7.6, Fig. 7.6, 7.7). Only for Model 7, was the spotted mackerel exploitable biomass in 2002 predicted to be below that which would sustain MSY (B_{MSY}). The base model (Model 1), which included both the age structure and CPUE data, estimated $Y(F_{MSY})$ to be about 366 t, in contrast to Model 7 which estimated $Y(F_{MSY})$ to be about 296 t (Table 7.6, Fig. 7.7).

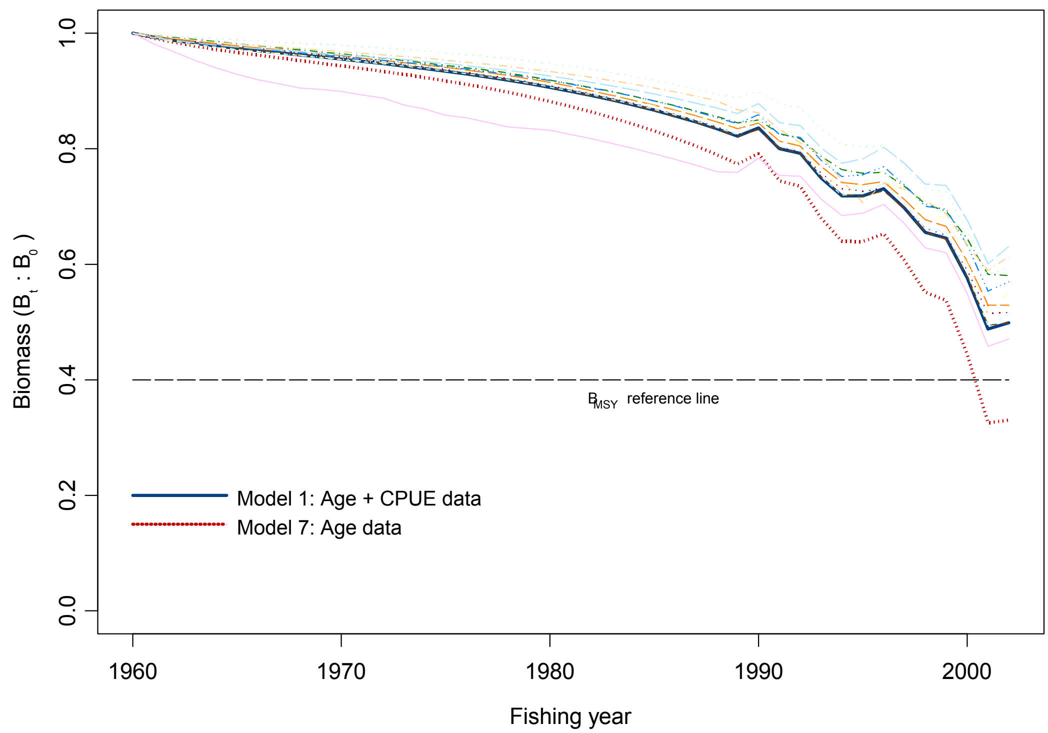

Fig. 7.6. The predicted exploitable biomass of spotted mackerel declined significantly between 1995 and 2001. The results were similar for all model runs, except Model 7 which predicted the 2002 population to be below the exploitable biomass that supports MSY (B_{MSY}: dashed reference point line).

Table 7.6. The equilibrium management quantities for 13 model sensitivities. Numbers within parentheses refer to 90% confidence intervals.

Model sensitivity run	$Y(F_{MSY})$ (t)	$Y(0.75F_{MSY})$ (t)	Y(0.5M) (t)
1	366 (304:430)	349 (289:410)	347 (291:405)
2	300 (238:360)	285 (225:341)	290 (230:348)
3	314 (195:423)	297 (185:401)	277 (171:384)
4	309 (255:378)	293 (241:358)	288 (172:365)
5	406 (342:489)	386 (324:466)	390 (329:460)
6	351 (293:408)	334 (279:389)	334 (277:386)
7	296 (273:316)	282 (261:302)	277 (256:297)
8	428 (367:487)	411 (352:468)	357 (305:406)
9	358 (312:406)	342 (297:388)	337 (294:383)
10	341 (244:438)	325 (232:417)	320 (229:411)
11	570 (258:866)	540 (244:821)	559 (253:849)
12	345 (276:471)	327 (261:450)	336 (271:411)
13	314 (244:399)	298 (231:380)	299 (236:351)

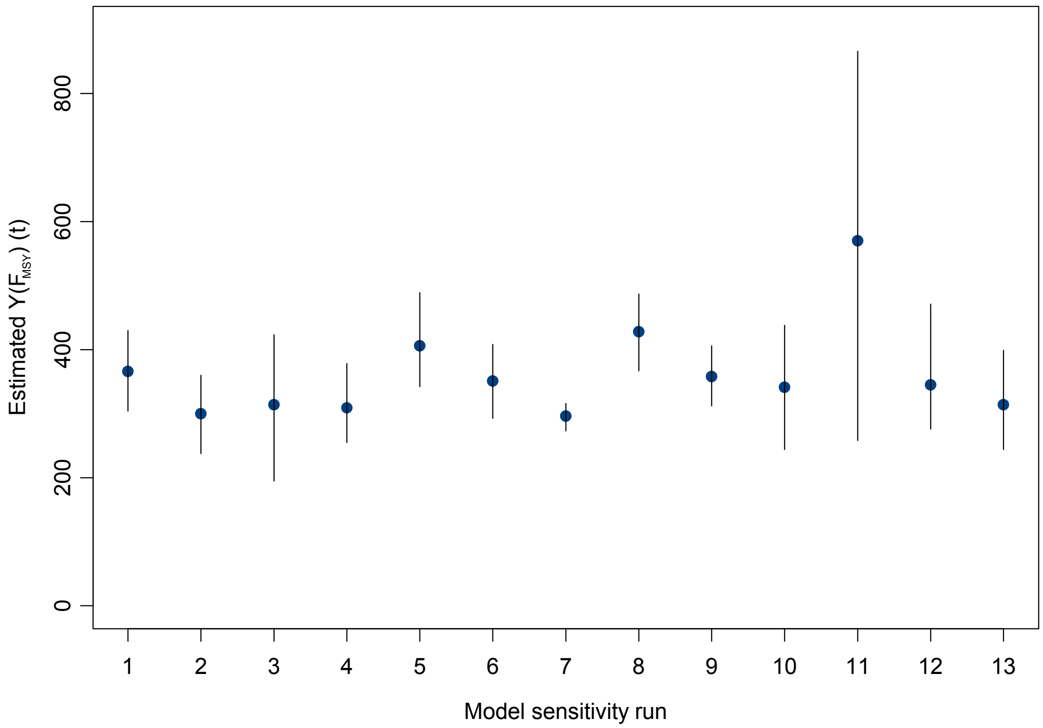

Fig. 7.7. Estimated equilibrium maximum sustainable yield (*i.e.*, total catch or yield when fished at F_{MSY}; $Y(F_{MSY})$) for the different model sensitivities (defined in Table 7.2). The vertical lines represent the 90% confidence interval.

Similar model fits were observed for all model runs. Base model run 1 and closely related Model 7, predicted the cumulative age structures reasonably well as demonstrated by the goodness of fit plots for each year, although these tended to under-estimate the one to three year age groups (Fig. 7.8, 7.9). Model 1 predicted a slight declining trend in catch rates over time, with only one significant standardised residual in 1990 of -4.539 (Fig. 7.10). The influence of this 1990 catch rate upon estimation of parameters was small in the sense that parameter estimators varied little if the 1990 catch rate was excluded. Furthermore, parameter correlations with R_{1960} were generally low for all models, except in the MCMC model run 13 (Table 7.7-7.9). Model 11 was a single parameter model (*i.e.*, fixed selectivity, only R_{1960} estimated). The parameter correlations in MCMC Model 13 were more notable due to the short time-series of catch-at-age frequencies that did not provide enough contrast for estimation when uncertainty was allowed in natural mortality (M) and stock-recruitment (r_{max}). However, when the CPUE data were also used (Model 12), more robust parameters were estimated with much lower correlations. When values of M and r_{max} were assumed and only the catch-at-age frequencies were used (Model 7) the solutions of virgin recruitment (R_{1960}) and selectivity ($Length_{50}$, $Length_{95}$) were unique. We considered the assumed values of M and r_{max} used in this assessment were reasonable based on the available data and literature. Therefore, we consider Model 7 output an important contribution to defining the status of spotted mackerel, especially when standardised catch rates may be hyperstable.

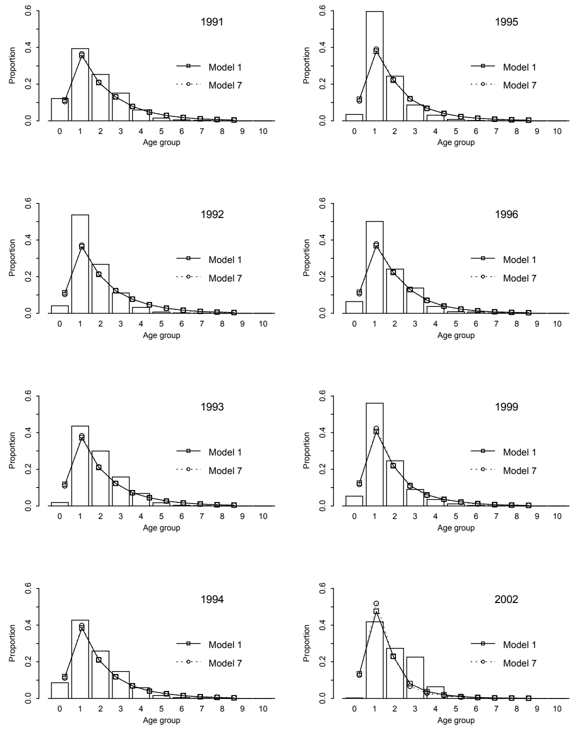

Fig. 7.8. Goodness of fit plots: observed (bars) and predicted (line) age structures from Model 1 (age structure and CPUE data) and Model 7 (only age structure data).

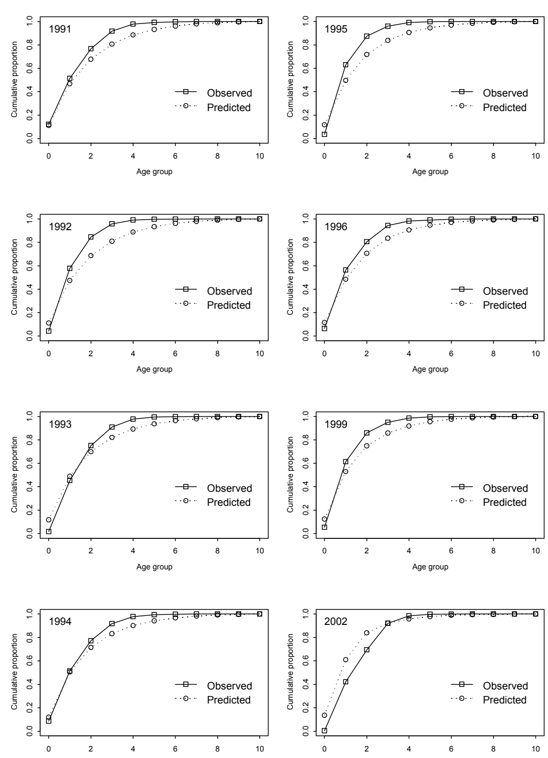

Fig. 7.9. Goodness of fit plot for Model 1: the age-structured model predicted the observed cumulative age-structures reasonably well. However, it did tend to under-estimate the one to three year age groups in 1992 and 1995. This was due to the model restriction of the average stock-recruitment relationship.

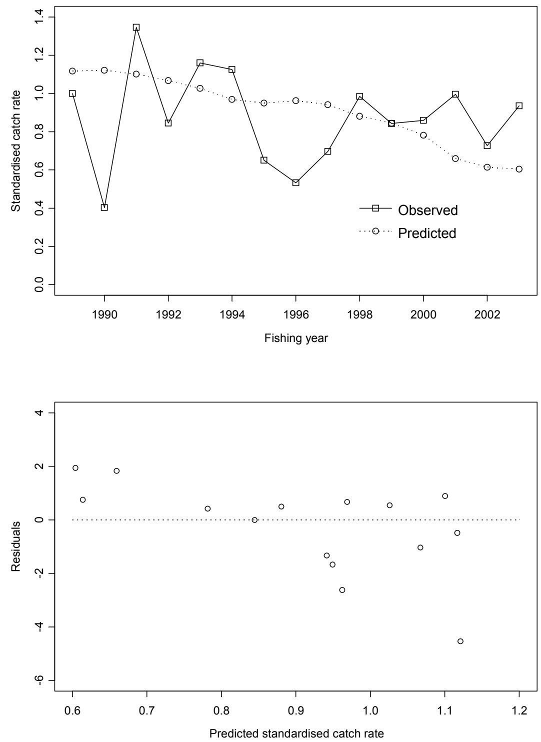

Fig. 7.10. Goodness of fit plot for Model 1: observed (squares) and predicted (circles) standardised catch rates. The age-structured model predicted the slight declining trend of the catch rates over time.

Table 7.7. Parameter correlations for model sensitivity runs 1-10. Three parameter models: R_{1960}; $Length_{50}$; and $Length_{95}$. Parameter correlations were generally low, except for marginal correlation between R_{1960} and $Length_{50}$ for Model 10.

Model sensitivity run	Parameter correlation		
	R_{1960} : $Length_{50}$	R_{1960} : $Length_{95}$	$Length_{50}$: $Length_{95}$
1	-0.23575	-0.11239	0.89735
2	-0.18565	-0.10618	-0.92372
3	-0.07006	-0.03763	0.99877
4	0.07397	0.07886	0.99994
5	-0.13453	-0.13251	0.99998
6	0.29790	0.38451	0.79601
7	-0.03085	0.10922	0.85600
8	0.14309	0.19636	0.99292
9	-0.10721	-0.09389	0.99928
10	-0.51631	-0.14837	-0.01226

Table 7.8. Parameter correlations for model sensitivity run 12 (tuned to both the age structure and CPUE data). Five parameter model: R_{1960}; $Length_{50}$; $Length_{95}$; r_{max}; and M. Parameter correlations were generally low, with marginal correlation between $Length_{50}$ and M.

	R_{1960}	$Length_{50}$	$Length_{95}$	r_{max}	M
R_{1960}	1	-0.03041	-0.30221	0.07285	-0.04394
$Length_{50}$	-0.03041	1	-0.03324	-0.08325	0.41982
$Length_{95}$	-0.30221	-0.03324	1	-0.06214	0.09983
r_{max}	0.07285	-0.08325	-0.06214	1	0.05849
M	-0.04394	0.41982	0.09983	0.05849	1

Table 7.9. Parameter correlations for model sensitivity run 13 (tuned to only the age structure data). Five parameter model: R_{1960}; $Length_{50}$; $Length_{95}$; r_{max}; and M. Parameter correlations were generally moderate to high.

	R_{1960}	$Length_{50}$	$Length_{95}$	r_{max}	M
R_{1960}	1	-0.76448	-0.26420	-0.48967	-0.10754
$Length_{50}$	-0.76448	1	0.43977	0.32290	0.31813
$Length_{95}$	-0.26420	0.43977	1	0.10754	-0.00879
r_{max}	-0.48967	0.32290	0.10754	1	-0.02673
M	-0.10754	0.31813	-0.00879	-0.02673	1

Management strategy evaluation

The catch projections used in the management strategy evaluation (MSE) were based on Model 1 (tuned to both the age structure and CPUE data) and Model 7 (tuned to only the age structure data). For both models, increasing levels of constant catch had concomitant increasing levels of over-fishing risk, over both the short- (5 years) and long-term (20 years) (Table 7.10). Based on Model 1, the status quo catch for 2003 of about 350 t (if TACC of 140 t was fully realised) has about a 28% risk of the exploitable biomass being below B_{MSY}, if this was set at a constant level for the next 20 years (Table 7.10). In contrast, if fishing effort at F_{MSY} was set as a catch strategy for the next 20 years then there would be a 50% risk of the exploitable biomass being below B_{MSY}, while the recommended strategy of 0.5*M* would have only a 26% risk (Table 7.11). Furthermore, stock increases and associated increased catch rates (CPUE) would only be expected to occur for total catch strategies less than status quo (Fig. 7.11, 7.12).

Table 7.10. The performance of seven different constant catch tonnages (200-500 t) in relation to the short- (5 years) and long-term (20 years) exploitable biomass of spotted mackerel. The table summarises over-fishing probabilities (risk) in relation to the biomass reference point that supports maximum sustainable yield (B_{MSY}) and expected median population sizes ($B_{MSY} \approx 0.4B_0$). The results assumed base case steepness and base case natural mortality in Model 1 (tuned to both the age structure and CPUE data) and Model 7 (tuned to only the age structure data).

Catch (t)	5yr Probability $B_{t+5}<B_{MSY}$		20yr Probability $B_{t+20}<B_{MSY}$		5yr Biomass ratio B_{t+5}/B_0		20yr Biomass ratio B_{t+20}/B_0	
	Model 1	Model 7	Model 1	Model 7	Model 1	Model 7	Model 1	Model 7
200	0.09	0.59	0.03	0.39	0.62	0.33	0.74	0.52
250	0.13	0.68	0.06	0.54	0.59	0.28	0.67	0.32
300	0.17	0.74	0.14	0.73	0.56	0.23	0.60	0.01
350	0.22	0.82	0.28	0.89	0.52	0.17	0.52	0.00
400	0.28	0.87	0.48	0.96	0.49	0.11	0.42	0.00
450	0.35	0.91	0.70	0.99	0.45	0.09	0.24	0.00
500	0.45	0.95	0.84	1.00	0.42	0.07	0.04	0.00

Table 7.11. The performance of three different constant catch strategies (F_{MSY}, $0.75F_{MSY}$, 0.5*M*) in relation to the short- (5 years) and long-term (20 years) exploitable biomass of spotted mackerel. The table summarises over-fishing probabilities (risk) in relation to the biomass reference point that supports maximum sustainable yield (B_{MSY}) and expected median population sizes ($B_{MSY} \approx 0.4B_0$). The results assumed base case steepness and natural mortality in Model 1 (tuned to both the age structure and CPUE data) and Model 7 (tuned to only the age structure data).

Catch rate	5yr Catch (t)	20yr Catch (t)	5yr Probability $B_{t+5}<B_{MSY}$	20yr Probability $B_{t+20}<B_{MSY}$	5yr Biomass ratio B_{t+5}/B_0	20yr Biomass ratio B_{t+20}/B_0
Model 1						
F_{MSY}	465	420	0.40	0.50	0.44	0.40
$0.75F_{MSY}$	398	394	0.22	0.23	0.50	0.50
0.5M	381	373	0.20	0.26	0.52	0.51
Model 7						
F_{MSY}	241	288	0.75	0.60	0.30	0.36
$0.75F_{MSY}$	204	275	0.63	0.35	0.35	0.47
0.5M	197	262	0.56	0.31	0.37	0.50

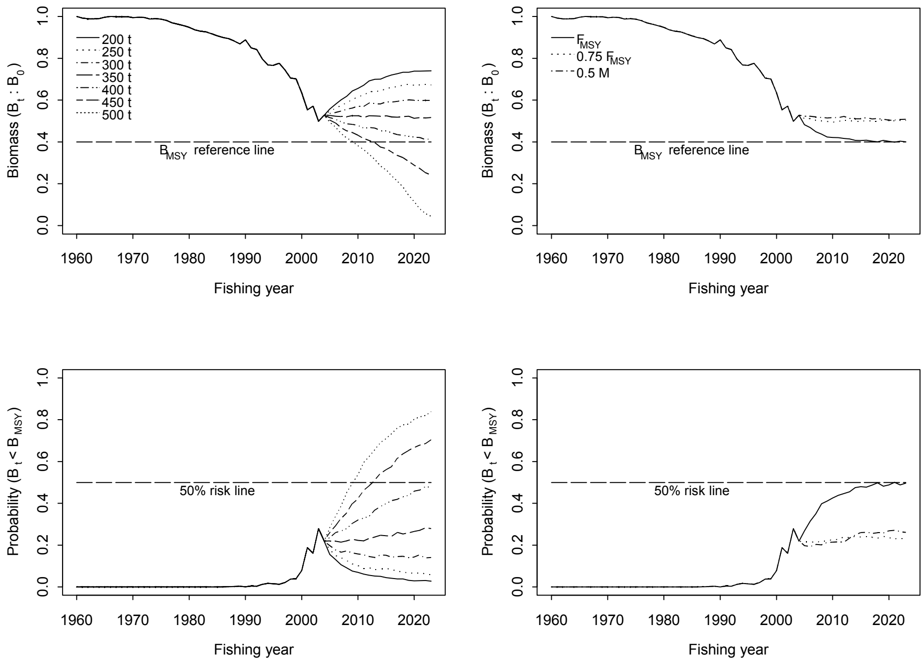

Fig. 7.11. The expected biological outcomes for spotted mackerel from allowing constant catch tonnages (200-500 t) or catch strategies (F_{MSY}, $0.75F_{MSY}$, $0.5M$). The plot summarises the expected median exploitable population sizes (biomass; $B_{MSY} \approx 0.4B_0$) and over-fishing probabilities (risks) in relation to the biomass reference point that supports maximum sustainable yield (B_{MSY}). The results assumed the base case steepness and natural mortality in Model 1 (tuned to both the age structure and CPUE data).

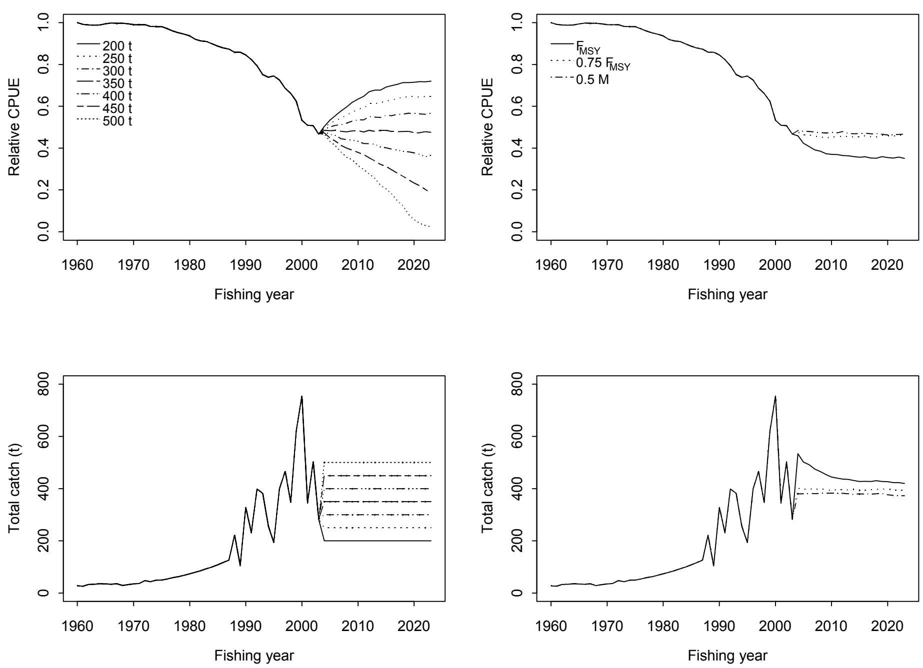

Fig. 7.12. The expected commercial/recreational outcomes from allowing constant catch tonnages (200-500 t) or catch strategies (F_{MSY}, $0.75F_{MSY}$, $0.5M$). The plot summarises the expected median proportional change in catch rates and total catch tonnages. The results assumed the base case steepness and natural mortality in Model 1 (tuned to both the age structure and CPUE data).

Projections for Model 7 (tuned to only the age structure data) demonstrated the influence of not including the (potentially hyperstable) CPUE data as an index of population abundance. Results from these projections were far more pessimistic (Table 7.10). Based on Model 7, the status quo catch for 2003 of about 350 t (if TACC of 140 t was fully realised) has about a 89% risk of the exploitable biomass being below B_{MSY} after 20 years (Table 7.10). In contrast, if F_{MSY} was set as the constant catch strategy then there would be a 60% risk of the exploitable biomass being below B_{MSY}, while the recommended strategy of 0.5*M* would have a 31% risk (Table 7.11). Stock rebuilding and associated increased catch rates (CPUE) would only be expected to occur for total catch strategies less than 250 t (Fig. 7.13, 7.14).

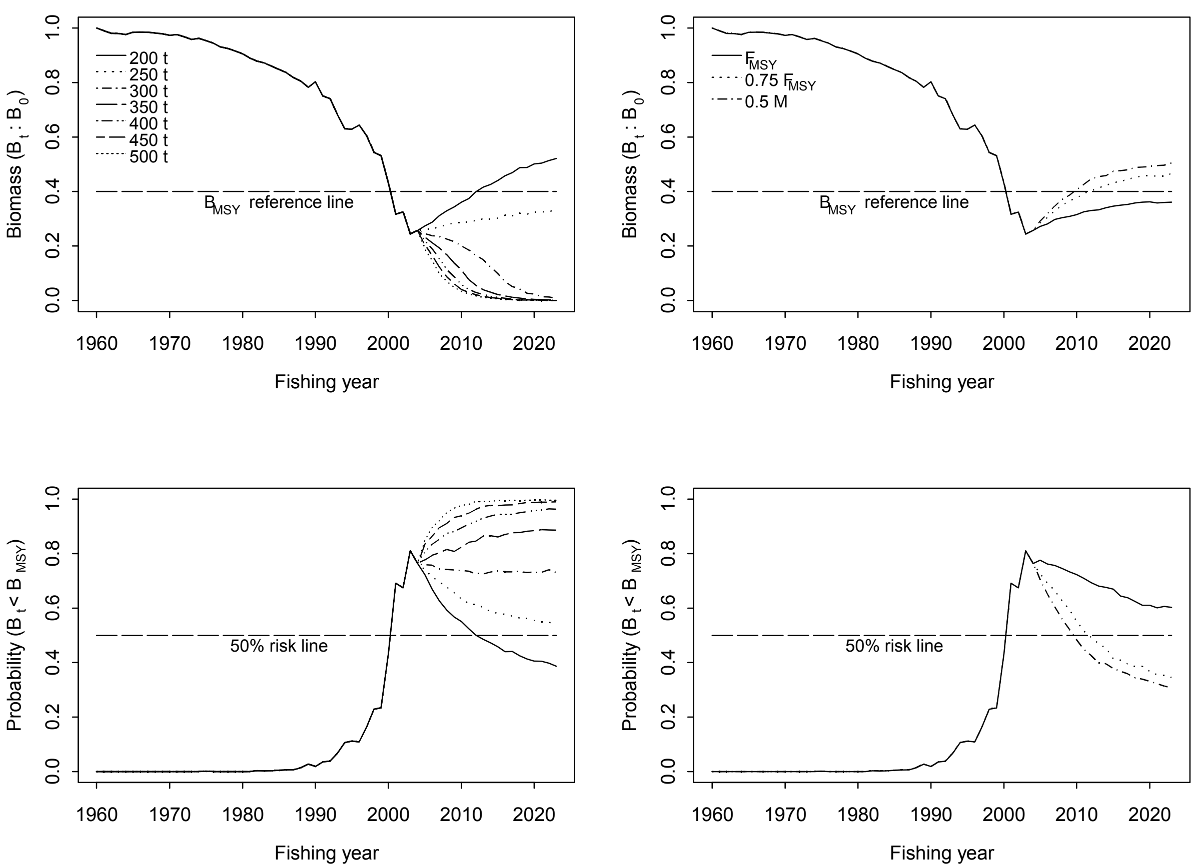

Fig. 7.13. The expected biological outcomes for spotted mackerel from allowing constant catch tonnages (200-500 t) or catch strategies (F_{MSY}, $0.75F_{MSY}$, 0.5*M*). The plot summarises the expected median exploitable population sizes ($B_{MSY} \approx 0.4B_0$) and over-fishing probabilities (risks) in relation to the biomass reference point that supports maximum sustainable yield (B_{MSY}). The results assumed the base case steepness and natural mortality in Model 7 (tuned to only the age structure data).

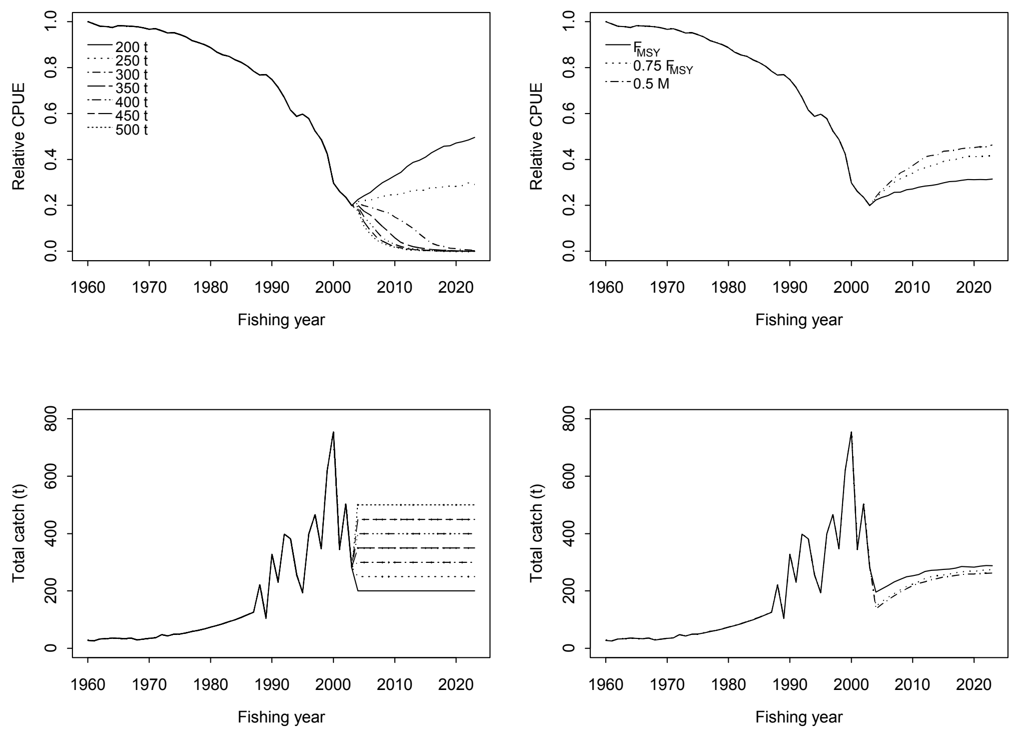

Fig. 7.14. The expected commercial/recreational outcomes from allowing constant catch tonnages (200-500 t) or catch strategies (F_{MSY}, $0.75F_{MSY}$, 0.5*M*). The plot summarises the expected median proportional change in catch rates and total catch tonnages. The results assumed the base case steepness and natural mortality in Model 7 (tuned only to the age structure data).

Discussion

This stock assessment is the most comprehensive attempt to evaluate the status of spotted mackerel. The assessment used all available biological and fisheries data to provide an indication of the current level of exploitation and sustainability of the Australian east coast spotted mackerel fishery. Results from the assessment suggest that the stock is most likely being harvested near or exceeding maximum sustainable levels, and is at risk of being over-fished with biomass levels at 33-63% of unfished or virgin biomass levels. Furthermore, model projections for the management strategy evaluation indicate that catches need to decline from current rates to ensure the likelihood of the stock size increasing within acceptable levels of risk. The results, however, need to be tempered with the uncertainty associated with the various data and model assumptions; although this should not be used as a basis for management inaction. Indeed, the precautionary approach dictates that management should be more prudent given greater uncertainty (FAO 1995a, b).

In this assessment, we used an age-structured stock model (*e.g.*, Quinn and Deriso 1999, O'Neill and McPherson 2000, Hoyle 2002, Welch *et al.* 2002) to analyse the population dynamics and status of spotted mackerel along the Australian east coast. The model used lognormal likelihoods to estimate critical parameters of virgin recruitment and selectivity (Table 7.1). The model also assumed that standardised catch rates were a reliable index of population abundance; although greater weighting was allowed to the age structure data. The flexibility in the model and sensitivity analyses conducted, further allowed this assumption (and others) to be tested, where greater confidence was placed in results derived from the model using only the age structure data (Model 7; Table 7.2) because of the potentially hyperstable nature of the catch rates (see Chapter 5 and 8). Moreover, the Monte Carlo methodology used in the assessment was particularly applicable as the simulations allowed for uncertainty in all model parameters (Richards *et al.* 1998). Consequently, the simulations facilitated critical assessment of the important levels of risks associated with, and yields that can be taken from the fishery. Model outcomes were highly influenced by some parameters, particularly stock-recruitment and natural mortality.

The assessment used known and derived fundamental biological relationships on growth, maturity, natural mortality, stock-recruitment and reproductive output of spotted mackerel (see Chapter 2). In conjunction with the estimated parameters of virgin recruitment and selectivity (Table 7.1), the assumed parameters of stock-recruitment and natural mortality were the main drivers underlying the dynamics of the population. Concomitantly, estimates for these assumed parameters were also highly uncertain, being proxies derived from data for other congeneric species (*i.e.*, Pauly 1983, Myers *et al.* 1999). The stock-recruitment relationship is the key input to determine the status of this fishery, comprised mainly of 1 to 3 year old fish, but is also one of the most uncertain. Collection of the data required to directly estimate stock-recruitment, as well as natural mortality, however, is not foreseeable in the near future for spotted mackerel.

The estimated total catches of spotted mackerel were also responsible for the apparent population trends and status of the fishery; albeit given the uncertainty associated with these estimates. The assessment included estimated historical catches prior to the compulsory Queensland and New South Wales commercial logbook systems implemented in 1988 and 1984, respectively, as well as the significant, but most likely poorly estimated recreational catches (see Chapter 6). In addition, the assessment was based on a time series of only eight years of ageing data and 15 years of standardised catch rate data. Although greater confidence was placed in the model results using only the age structure data (Model 7), it must be recognised that the age structures were derived from a single Age Length Key (ALK), using data opportunistically collected and pooled across several years. Consequently, the age structures to which the models were fit may not be representative of a particular year because the pooled ALK would tend to minimize apparent differences among years. Thus, if there was an apparent decline in older fish over time, the pooled ALK would probably result in an under-estimate of the actual decline. In addition, the pooled ALK would minimise the data contrast of any strong or weak year classes; thereby, effectively smoothing year class strength. The pooled ALK, however, was necessary because of insufficient ageing data in any given year.

The assessment indicated that the 2002 biomass of spotted mackerel was most likely below or near the over-fishing limit reference point of B_{MSY}; depending on the assumed candidate model (*i.e.*, Model 1 and 7). Biomasses between 1996 and 2001 declined considerably as a result of increasing total catches, where catches for 5 of the past 7 years were above the MSY limit reference point estimated for Model 1 (366 t), and all 7 years for Model 7 (296 t) (see Fig. 7.5, 7.6). Although the results for Model 1 (based on CPUE and age structure data) were slightly more optimistic than Model 7 (based only on age structure data), the declining biomass trends did not reflect the relatively stable CPUE trends (see Table 5.9, Fig. 5.8). The poor fit of the model results to the CPUE data, therefore, suggests that the standardised catch rates may not reflect the underlying population abundance of spotted mackerel and that hyperstability may still be an issue for this data series. Consequently, results from Model 7 should be considered the most appropriate.

The parameterisation of the stock-recruitment relationship, using the measure of steepness from Myers *et al.* (1999), helped considerably to define the status of spotted mackerel in relation to virgin stock size (B_0) and the biomasses (B_{MSY}) that support maximum sustainable yields. Sensitivities of assuming different stock-recruitment relationships were reported confirming past concerns of possible stock decline with increasing catches; especially catch of the spawning stock in Bowen (Williams 2002). The model results across the sensitivity analyses suggested that catches from four of the past six years of fishing were probably too high to promote higher or stable biomasses in the future (*i.e.*, catches exceeded MSY). Moreover, the model projections suggested that catches of greater than 300-350 t have a high risk of reducing the population in relation to MSY. The 2003 total catch of about 350 t (if the TACC of 140 t had been fully realised), therefore, has a moderate to high risk in relation to MSY. The projection results show lower risks and higher catch rates at lower catches; although this depends on what is an acceptable level of risk and catch rate.

The assessment results as they stand, based on the best available data, provide a credible hypothesis on the state of spotted mackerel along the Australian east coast. We are certain that these results and others in the future will need to be discussed in detail, as they should. In addition, the assessment needs further refinement including:

1. *Fishing power and catch rate standardisation*. The commercial and recreational logbooks need to be modified to record all target searching effort and zero catches to allow a more accurate estimate of CPUE. Fishing gear, technology, and search information is needed to address fishing power issues. More accurate and representative data of fishing effort will reduce the uncertainty and hyperstability issues associated with the catch rate time series.

2. *Fishery-independent aerial surveys of the spawning stock in Bowen*. Investigation into the utility of these surveys as a means of providing an index of population abundance should be of high importance to assist with on-going catch rate standardisation. The importance of having a catch rate index that is linearly related to abundance cannot be over-emphasised; but most likely unattainable for spotted mackerel. This index, however, can be improved by including survey estimates (Punt *et al.* 2001a) such as those from fishery-independent aerial surveys or data from tagging methods such as gene-tagging, etc.

3. *Historical catch data*. Significant uncertainty remains regarding the status of spotted mackerel in the earlier years of the assessment. Historic data on total catches should be acquired from industry and processors to help develop priors for starting stock biomass ratios.

4. *Commercial logbook data*. It is recommended that catch estimates obtained from logbook data are validated. Historic commercial unloading data are probably available, for at least some boats and could be used as a source of validation. If unloading data are obtained, even if it is only for some boats, a generalised linear model can be run to validate the logbook catches.

5. *Recreational catch data*. Significant uncertainty remains with the magnitude of the recreational catches. A comprehensive review of the catches and uncertainty reported in the RFISH and NRIFS data needs to be undertaken, recognising the more directed surveys of Cameron and Begg (2002) designed specifically to estimate spotted mackerel catches.

6. *Biological data*. Review and corroborate estimates of natural mortality (M) and fecundity, especially with respect to fish size, to improve accuracies of the calculated management quantities such as MSY.

7. *Model development*. Develop a seasonal assessment model to investigate the effects of possible closures on spawning stock sizes. Enhancements to the model should be made using monthly time-steps to capture seasonal movement and spawning dynamics of spotted mackerel, particularly if seasonal management strategies are to be assessed.

Furthermore, collaborative stock assessment and management should commence with the relevant Queensland and New South Wales fisheries agencies; especially for setting operational objectives, trigger points and target levels of fishing effort and/or catch.

Overall, the analyses and modeling facilitated critical assessment of the spotted mackerel fishery; thereby, making more effective use of the catch data and past biological research on the species. The assessment has provided a basis for Queensland and New South Wales fisheries managers, and their relevant advisory committees to consider sustainable levels of fishing and management objectives for the fishery. The management strategy evaluation and model projections quantified the trade-offs between particular management strategies in relation to a series of reference points and started the discussion of target management objectives for the fishery. The projection results do not define a final reference point, management strategy or the future status of the stocks, but rather provide expected outcomes that may be used by decision makers to help select appropriate fishing strategies to achieve target objectives. The relevance of this assessment to management is very high, especially since the management of spotted mackerel, and other inshore finfish, is to be formalised. The current management does not define any management responses that could be used to restrict fishing effort to levels that are sustainable. Fishery management advisory committees and working groups should participate fully to discuss and develop the strategies and timelines to achieve the management objectives. These strategies can be assessed by the management strategy evaluation method. The continuation of this work is required for this fishery to achieve optimal management to its objective of sustainability.

8. Alternate models

Several alternate assessment models were examined to evaluate the relative performance, robustness and uncertainty associated with the population trends derived from the Spotted mackerel Age-structured Model (SAM) (see Chapter 7). Evaluating alternate models is a necessary and pragmatic approach to stock assessment (Hilborn and Walters 1992, Haddon 2001), and should be conducted whenever possible.

Surplus production (biomass dynamics) model

Surplus production or biomass dynamics models are the simplest fisheries assessment models that evaluate the dynamics of a stock as these only consider changes in exploitable biomass (Schaefer 1954, 1957, Ricker 1975, Hilborn and Walters 1992, Polacheck *et al.* 1993). These models simplify all aspects of production (*i.e.*, recruitment, growth and mortality) into a single function, where the stock is considered as undifferentiated biomass (Haddon 2001). The surplus production relates to the production from a stock above that required to replace biomass losses due to natural mortality (*i.e.*, stock equilibrium), and theoretically would be available for catch. A typical management strategy, therefore, would aim to maintain the stock at a size that would maximise the surplus production, and hence the potential catch or yield (Haddon 2001). Maximum sustainable yield (MSY) and the associated effort or fishing mortality that generates MSY (E_{MSY}, F_{MSY}) given the respective biomass (B_{MSY}) are basic reference points estimated from surplus production models.

The initial surplus production models, typically, assumed that the stocks were in equilibrium (Schaefer 1954, 1957), although there were exceptions (Pella and Tomlinson 1969). Stocks in equilibrium were assumed to be at some level of biomass that produced a certain quantity of surplus production, and where at each level of fishing effort there was an equilibrium sustainable yield (Haddon 2001).The basic assumption is that the yield taken from a stock in equilibrium is surplus production. Equilibrium based models, however, are fraught with uncertainty and often result in overly optimistic advice as exploited fish stocks are rarely in equilibrium (Prager 1995).

Surplus production models have now been developed using a non-equilibrium approach to better represent the dynamics of fish populations (Prager 1994, Haddon 2001). A major benefit (but also limitation) of these models is that they are far more simplistic than the age-structured model used in this assessment. Surplus production models are the least data intensive, only requiring a time series of catch and a relative abundance index (*i.e.*, CPUE). Consequently, these models have been extensively used for data poor fisheries; albeit that these are strongly based on some tentative assumptions. One of the major assumptions is that catch rates are linearly related to stock biomass, which may not be accurate for a schooling species such as spotted mackerel whose catch rates are prone to hyperstability (see Chapter 5). Any conclusions, therefore, drawn from surplus production models need to be tempered with caution (Haddon 2001).

We used a non-equilibrium surplus production model (ASPIC) as defined in the NOAA Fisheries Toolbox (Version 2.0) (Prager 1995) to examine potential biomass trends of spotted mackerel relative to results derived from our Spotted mackerel Age-structured Model (SAM). The Stock-Production Model Incorporating Covariates (ASPIC) fits a non-equilibrium logistic (Schaefer) production model to catch and effort (or CPUE) data. The model was used to estimate *r* (intrinsic rate of population growth), MSY, ratio of biomass at beginning of first year of time series to the biomass at which MSY can be attained, and *q* (catchability coefficient = proportion of total stock taken by one unit of fishing effort). The estimated 1960-2002 catches (Table 6.4) and the commercial line CPUE data (Table 5.9) for spotted mackerel were used in an exploratory ASPIC run. For further details on the model see Prager (1994, 1995).

Virtual population analysis (VPA) model

Virtual population analysis (VPA) or cohort analysis are a form of age-structured population models (Megrey 1989, Hilborn and Walters 1992, Quinn and Deriso 1999). Age-structured models, as the name implies, differentiates the stock into discrete age groups or cohorts; an obvious advantage over surplus production models that assume undifferentiated biomass. The more realistic differentiation of the stock into age groups enables age-structured models to better represent the underlying population dynamics, although the increased complexity also has associated costs with parameter estimation and data requirements. VPA models follow the dynamics of each cohort separately, combining them when information on the total catches or population dynamics such as recruitment, are required (Haddon 2001). These models assume that after each cohort has recruited to the stock there is no immigration or emigration and so abundance can only decrease exponentially through time; thereby providing information on the total mortality imposed on the stock.

VPA refers to a class of age-structured models that rely upon the knowledge of final fishing mortality rates or final abundances and back-calculation of numbers-at-age in the fished population (Haddon 2001). These models attempt to back-calculate a matrix of numbers-at-age that would have given rise to the observed catches. Essentially, numbers in the population are projected backwards in time, given knowledge of all ages in the last (or terminal) year and the last age group in all years, until estimates are obtained of the original recruitments. VPA models require data on the total weight of the catch and numbers-at-age in the catch. Ideally, for each year of the fishery there will be an estimate of the relative numbers caught in each age group, while an index of relative abundance is required to associate the model to changes in stock size through time (Haddon 2001). Data requirements are stringent in that there can be no years of missing information.

We used a VPA model calibrated with catch rates (ADAPT) to evaluate the catch-at-age of spotted mackerel. The ADAPTive framework uses a non linear least squares fit to calibrate a VPA against independent indices of abundance (Gavaris 1991). The VPA/ADAPT model in the NOAA Fisheries Toolbox (Version 2.0) is based on a deterministic algorithm that sequentially calculates a matrix of stock numbers at age; and was the model used to compare potential biomass trends in the spotted mackerel fishery relative to results from our Spotted mackerel Age-structured Model (SAM). The VPA/ADAPT algorithm back-calculates previous stock sizes using catch-at-age data, current year stock size estimates and assumptions about fishing mortality relationships between age groups.

The proportion at age data for 1991-2002 that we used in the ADAPT model were based on the observed data for those years where data were available (1991-1996, 1999, 2002), and the average proportions for those years in which there were no data (Table 8.1). The similarity in age distributions between years in which there were data (Fig. 2.4) was the basis for the assumption of using the average proportions at age for 1997, 1998, 2000 and 2001. The average sex-specific weights at age derived from the von Bertalanffy growth (Table 2.6) and length-weight (Table 2.4) functions were then used to estimate the total mean weight-at-age (Table 8.2), catch in numbers and catch-at-age (Table 8.3). The commercial line CPUE values estimated for 1991-2002 (Table 5.9) were prorated by the same proportion-at-age data to calibrate terminal estimates of abundance (1 January 2003) (Table 8.4). A constant maturity-at-age ogive was used across years (Table 8.5). In addition, the timing of spawning was estimated to represent 2 months (*i.e.*, 0.17) after the start of the fishing year in July, and the instantaneous fishing mortality (*F*) on age group 7 was set at the same *F* as that for age group 6. These values and assumptions were used as input to the VPA/ADAPT model.

Table 8.1. Final age structures (proportions) of spotted mackerel used in VPA/ADAPT model. Age structures for 1991-1996, 1999 and 2002 based on observed data (see Table 2.7, 2.8). Values in bold represent years of missing data and are estimated from the average proportions for those years in which data were available.

Fishing year	Proportion of catch-at-age group +							
	0	1	2	3	4	5	6	7
1991	0.121	0.393	0.253	0.151	0.059	0.014	0.006	0.003
1992	0.042	0.537	0.267	0.112	0.033	0.007	0.002	0.001
1993	0.017	0.436	0.299	0.158	0.068	0.017	0.003	0.002
1994	0.086	0.427	0.259	0.146	0.059	0.016	0.005	0.002
1995	0.035	0.596	0.243	0.086	0.031	0.008	0.001	0.001
1996	0.064	0.501	0.241	0.138	0.038	0.010	0.007	0.002
1997	**0.053**	**0.484**	**0.260**	**0.138**	**0.048**	**0.012**	**0.003**	**0.001**
1998	**0.053**	**0.484**	**0.260**	**0.138**	**0.048**	**0.012**	**0.003**	**0.001**
1999	0.054	0.560	0.246	0.090	0.035	0.011	0.002	0.001
2000	**0.053**	**0.484**	**0.260**	**0.138**	**0.048**	**0.012**	**0.003**	**0.001**
2001	**0.053**	**0.484**	**0.260**	**0.138**	**0.048**	**0.012**	**0.003**	**0.001**
2002	0.003	0.419	0.274	0.225	0.064	0.013	0.001	0.001
Average	*0.053*	*0.484*	*0.260*	*0.138*	*0.048*	*0.012*	*0.003*	*0.001*

Table 8.2. Mean weights-at-age (kg) of spotted mackerel used in VPA/ADAPT model. Values based on sex-specific von Bertalanffy growth (Table 2.6) and length-weight functions (Table 2.4).

Sex	Mean weight-at-age group + (kg)							
	0	1	2	3	4	5	6	7
Females	0.76	1.53	2.37	3.19	3.92	4.53	5.04	5.44
Males	0.86	1.20	1.51	1.79	2.02	2.20	2.36	2.48
Average	*0.81*	*1.36*	*1.94*	*2.49*	*2.97*	*3.37*	*3.70*	*3.96*

Table 8.3. Numbers of catch-at-age of spotted mackerel used in VPA/ADAPT model. Mean weights are sum-products of proportions-at-age and average mean weights-at-age. Bold values are based on average proportions of catch-at-age. Numbers catch ('000) is total catch (t) divided by mean weight (kg).

Fishing year	Catch total (t)	Mean weight (kg)	Numbers catch ('000)	Numbers of catch-at-age group +							
				0	1	2	3	4	5	6	7
1991	230	1.76	131	15831	51449	33063	19744	7759	1892	729	397
1992	398	1.69	235	9819	126319	62861	26290	7753	1577	365	145
1993	382	1.86	205	3585	89432	61360	32407	14007	3581	634	340
1994	256	1.77	144	12431	61675	37467	21129	8519	2271	682	258
1995	194	1.65	117	4098	69987	28581	10055	3589	909	175	82
1996	399	1.72	231	14791	115884	55807	32054	8722	2240	1549	419
1997	466	**1.75**	266	14004	128495	69193	36746	12867	3179	880	363
1998	347	**1.75**	198	10428	95682	51523	27362	9581	2367	655	270
1999	619	1.66	372	19991	208462	91674	33523	13189	4156	744	280
2000	755	**1.75**	431	22689	208184	112104	59534	20847	5151	1426	588
2001	344	**1.75**	196	10338	94855	51078	27126	9499	2347	650	268
2002	503	1.91	264	746	110443	72280	59412	16940	3374	364	153

Table 8.4. Catch rate (CPUE – relative abundance) -at-age of spotted mackerel used in VPA/ADAPT model. CPUE is that of commercial line used in assessment (Table 5.9).

Fishing year	CPUE	CPUE-at-age group +							
		0	1	2	3	4	5	6	7
1991	0.845	0.103	0.334	0.215	0.128	0.050	0.012	0.005	0.003
1992	1.160	0.048	0.623	0.310	0.130	0.038	0.008	0.002	0.001
1993	1.126	0.020	0.492	0.338	0.178	0.077	0.020	0.003	0.002
1994	0.651	0.056	0.278	0.169	0.095	0.038	0.010	0.003	0.001
1995	0.533	0.018	0.316	0.129	0.045	0.016	0.004	0.001	0.000
1996	0.697	0.045	0.350	0.169	0.097	0.026	0.007	0.005	0.001
1997	0.985	0.052	0.479	0.258	0.137	0.048	0.012	0.003	0.001
1998	0.843	0.044	0.406	0.219	0.116	0.041	0.010	0.003	0.001
1999	0.859	0.046	0.482	0.212	0.077	0.030	0.010	0.002	0.001
2000	0.996	0.053	0.484	0.260	0.138	0.048	0.012	0.003	0.001
2001	0.727	0.038	0.353	0.190	0.101	0.035	0.009	0.002	0.001
2002	0.935	0.003	0.394	0.258	0.212	0.060	0.012	0.001	0.001

Table 8.5. Proportions mature-at-age of female spotted mackerel used in VPA/ADAPT model. Proportions based on maturity age based binary regression (Fig. 2.6).

Fishing year	Proportion of females mature-at-age group +							
	0	1	2	3	4	5	6	7
1991	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1992	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1993	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1994	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1995	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1997	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00
2001	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.11	0.91	1.00	1.00	1.00	1.00	1.00	1.00

Statistical catch-at-age model

Statistical catch-at-age or integrated analysis models are another form of age-structured population models (Legault and Restrepo 1998, Punt *et al.* 2001b). In contrast to VPA models, statistical catch-at-age models use forward projection to estimate population abundances given estimates of abundance in the initial year. Knowledge is assumed of all ages in the first year and the first age group in all years (recruitment), projecting the age groups forward through time and ages (Haddon 2001). Survivorship of each age group in each year is calculated and used to complete the numbers-at-age matrix. The predicted catch-at-age matrix is then compared to the observed data and the model fit optimised using an objective function. Statistical catch-at-age models require catch-at-age data and information to associate the model to stock abundance (*i.e.*, CPUE) (Haddon 2001). The less stringent data requirements of these models compared to VPA models means that these are more useful for data limited fisheries with an opportunistic or short history of detailed age-structured information. The age-structured model used in Chapter 7 (*i.e.*, SAM) was also a statistical catch-at-age model.

The final exploratory model, therefore, that we used to compare results from our age-structured model (SAM) was an analogous statistical catch-at-age population model (ASAP) as defined in the NOAA Fisheries Toolbox (Version 2.0) (Legault and Restrepo 1998). The Age-Structured Assessment Program (ASAP) is a flexible forward model that allows the assumptions of gear specific fishing mortality to be separated into year and age components and constant catchabilities for scaling observed indices of abundance to be relaxed and changed over time. This flexibility provides an increased ability of ASAP to fit models and less reliance on assumptions that are considered too stringent (Legault and Restrepo 1988). Although, ASAP has the flexibility to test a range of parameter estimates and assumptions we did not explore these possibilities in great detail; referring instead to the sensitivity runs conducted with SAM (Table 7.6). The estimated 1960-2002 catches (Table 6.4) and the 1988-2002 commercial line CPUE data (Table 5.9) for spotted mackerel were used in an ASAP model run with similar assumptions to those used in SAM. In addition, the age structures for 1991-1996, 1999 and 2002 (Fig. 2.4), natural mortality (0.43), stock recruitment steepness (0.52) and maturity (Table 8.5) and mean weights-at-age (Table 8.2) were used as model input. Virgin biomass (B_0) was assumed to be the biomass at 1960, and an age selectivity shape parameter was estimated from the model.

Model evaluation

Results from the surplus production model (ASPIC) were in stark contrast to those expected for the life history of spotted mackerel. Biomass estimates from ASPIC were at extremely high and unrealistic levels (>100 million t) as the model attempted to fit to the relatively flat CPUE time series. Consequently, the only way that the model could reconcile the CPUE trend over a period of greatly increasing catches was if the increased catches were still only a very small portion of the total stock. Furthermore, the model estimated that the intrinsic rate of population growth (*r*) was extremely low (0.1). However, for a species such as spotted mackerel that grows extremely fast and matures in the first year, we should expect an *r* that is much higher (*e.g.*, 0.5-1.0). The ASPIC results, therefore, only make sense if (1) our current knowledge about the life history of spotted mackerel is completely wrong, (2) the population biomass is extremely large with extensive components not available to exploitation, or (3) the CPUE data are not accurately portraying the underlying population abundance. If the more logical latter reason is accepted, then the results suggest that we should adopt the age-structured model that is not being tuned by catch rates (*i.e.*, SAM Model 7). This is further supported by the fact that the population trends predicted by all the models do not mimic the CPUE time series.

In contrast, results from the VPA/ADAPT model were relatively similar to those from SAM Model 7 (*i.e.*, tuned only to age structures) (Fig. 8.1). Although there was a large difference in the perception of stock development in the 1990s, the terminal biomass estimates from the VPA/ADAPT model were similar to those from our age-structured model (Fig. 8.1). Notably, results from all the models suggested a declining biomass with increased fishing mortality on the spotted mackerel population in the latter years of the fishery when the greater catches occurred. Also, results from the VPA/ADAPT model demonstrate that the scaling used in SAM (*i.e.*, the 1960 recruitment estimate) was not unreasonable, because the different models have similar biomass estimates for the late 1990s, early 2000s. Given the uncertainty in catch-at-age (*i.e.*, a pooled-year ALK, opportunistic length and age samples, missing years, etc), results from the VPA/ADAPT model should be considered merely as an exploration into the population trends suggested by the catch-at-age data.

ASAP and SAM are functionally similar statistical catch-at-age models. The results from both these models demonstrated their sensitivity to CPUE and the importance of the underlying stock-recruitment relationship driving the population dynamics. Similar patterns in biomass and recruitment were observed for the different models, although biomass and recruitment were scaled higher in the ASAP model (Fig. 8.1). A distinguishing feature between these models and the VPA/ADAPT model is that the latter assumes that the observed catch-at-age is measured without error, unlike the statistical catch-at-age models (Legault and Restrepo 1998). Similar to the CPUE data, however, there is also some uncertainty around the pooled ALK and the representativeness of the data used to derive the age structures.

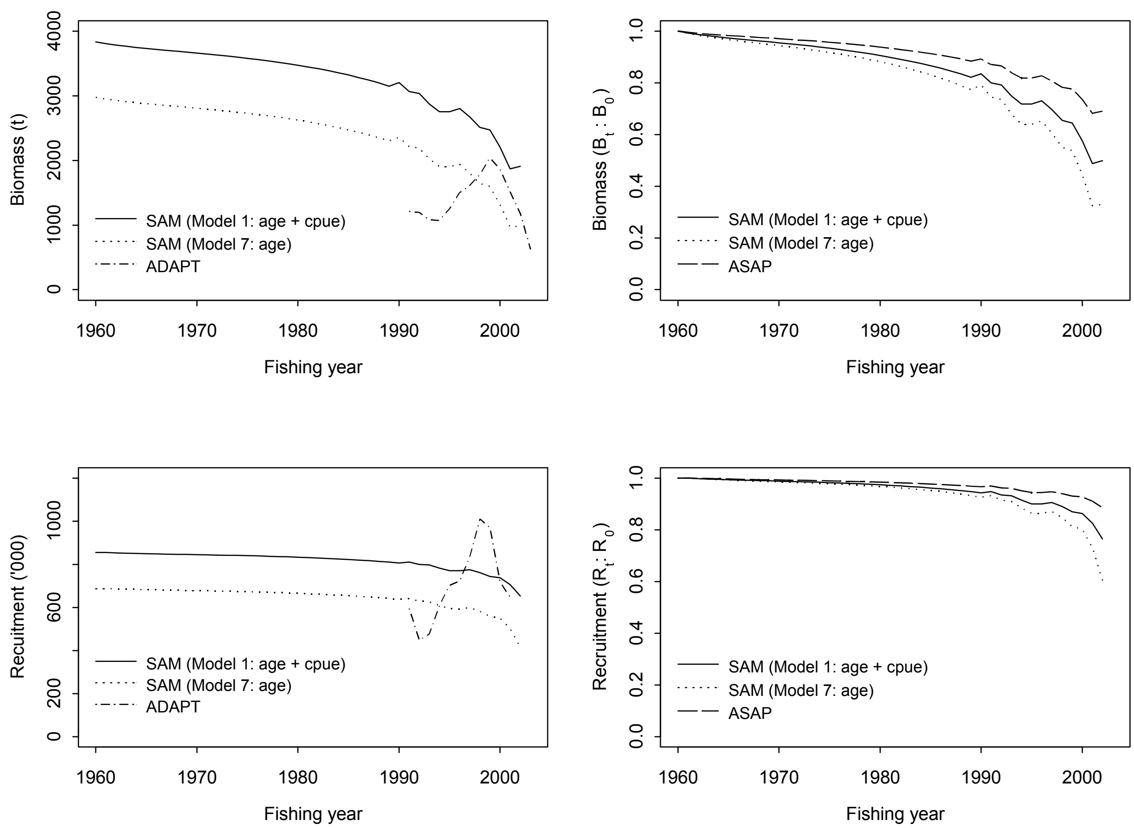

Fig. 8.1. The predicted absolute and relative median exploitable biomass and recruitment of spotted mackerel between 1960 and 2003 for the Spotted mackerel Age-structured Model (SAM) 1 (tuned to both the age structure and CPUE data) and Model 7 (tuned to only the age structure data), VPA/ADAPT and ASAP models.

Overall, results from the alternate models showed the sensitivity associated with some of the key input data and assumptions. In particular, results from the models suggested that the relatively flat standardised catch rate (CPUE) data may still not be a good indicator of population abundance; undoubtedly being affected by hyperstability. Furthermore, for CPUE data to be of use in these models, particularly surplus production models, contrast in the data is needed to be informative about the dynamics of the population. If change in stock size cannot be detected reliably (*i.e.*, via a CPUE index) then stock assessment will be difficult and unreliable (Haddon 2001). SAM Model 7, therefore, where catch rates were not used to tune the model, should be considered as the preferred candidate model for estimating biomass trends and reference points and providing management advice.

9. Reference points

A reference point in its most generic form is a measure of stock status (Gabriel and Mace 1999), and is often used by management to dictate or guide fisheries catch strategies (see Chapter 7). Reference points are used as key assessment and management tools to determine the desirability of actions (*e.g.*, excessive fishing mortality rates) or effects (*e.g.*, sustainable biomass) (Cadrin *et al.* 2004). A number of measures can be used as reference points (Sissenwine and Shepherd 1987, Gabriel and Mace 1999, Garcia and Staples 2000), but developing them for a particular fishery is complex and depends on the type, quantity and quality of available data (Hilborn 2002). Furthermore, which reference point to use will depend on the objective to be met.

A variety of approaches have been used to estimate reference points, ranging from simple congeneric species analogies and descriptive proxies for data poor fisheries to highly-informative analytical models that account for life history characteristics (Gabriel and Mace 1999, Cadrin *et al.* 2004). Each approach has it strengths and weaknesses for reference point estimation, but ultimately which approach to use will depend on the level of available data. Cadrin *et al.* (2004) introduced a hierarchical or tiered approach to reference point estimation, which dictated that reference points be determined by the method that most reliably captures the salient population and fishery dynamics, given the data available. The hierarchical approach begins from simple analyses that require less stock assessment information to highly complex models that require extensive research and monitoring programs. In this Chapter, we follow this approach in evaluating a range of reference points for determining sustainable catch strategies of spotted mackerel. We synthesise the data presented in the previous Chapters with respect to quality and quantity, and build on the reference point estimation presented in Chapter 7 and alternate assessment models in Chapter 8.

Data requirements

Reference point estimation for spotted mackerel was assessed in terms of data type, quantity (*i.e.*, representativeness in time and space), and quality or uncertainty (Table 9.1). Data uncertainty was assessed both quantitatively and qualitatively with respect to stock assessment purposes. Where available, a quantitative measure or proxy for each data type was provided by the CV for a key parameter or covariate used to describe the data. For example, the CV on the *b* coefficient of the length-weight relationship (weight = $a\text{TL}^b$). In addition, a qualitative measure of uncertainty (Low, Moderate, High) was provided that described the representativeness, biases or perceptions of the data quality. A summary of the data types used in this assessment is provided to enable the uncertainty in the models and subsequent reference points to be evaluated in a transparent, hierarchical framework (Table 9.1).

The data types used in the assessment and reference point estimation were categorised in terms of life history and fishery characteristics. Uncertainty in the data types was a common problem (as in all assessments) and varied according to representativeness of data coverage, degree of extrapolation for years of missing data, use of proxies or species analogies when no data were available, etc. Most of the data types were considered to have moderate to high uncertainty. Information on life history characteristics of spotted mackerel was provided by two independent sampling programs; FRDC Project 92/144 (fishing years 1991-1995) and the DPI&F LTMP (2000-2002). In contrast, the fishery characteristics were mostly provided by the various commercial logbook and recreational survey programs.

Life history characteristics

Life history data types used in the reference point estimations included length-weight, growth, maturity, fecundity and stock-recruitment relationships, maximum age, age structures, natural mortality (*M*) and stock structure (Table 9.1)

Table 9.1. Data sources used in the estimation of reference points for sustainable catch strategies of spotted mackerel. Data type, quantity and quality (*i.e.*, uncertainty) synthesised for hierarchical approach to reference point estimation. Quantitative estimate of data uncertainty used when available (CV), otherwise qualitative estimate. Uncertainty for stock assessment purpose evaluated as: L = low (high quality data or parameter estimate, extensive and representative data coverage, low variation in estimate); M = moderate (data or parameter estimate available, but poor quality or wide variation in estimate and possible misrepresentation of stock status); H = high (no data available, difficulty in interpretation, possibly biased perception of stock status).

Data source	Type	Comments	Fishing year	Region (State)	Number of samples	Parameter or Covariate	CV	Uncertainty
Life history	Length-weight	Females	1991-1993 2000-2002	QLD	383	*b*	0.01	M
		Males			316	*b*	0.06	M
		All			3018	*b*	0.01	M
	Growth	Females	1992-1994 2000-2002	QLD	922	L_∞	0.05	M
		Males			752	L_∞	0.02	M
	Maximum age	Predicted	1992-1994 2000-2002	QLD	1674			M
	Age structure	Single ALK	1991-1996 1999, 2002	QLD	10723			M-H
	Maturity	Females	1992-1994	QLD	197	TL L50	0.20 0.02	M
		Females	1992-1994	QLD	151	Age A50	0.25 1.67	M-H
	Fecundity		1993-1995	QLD	13	*b*	0.16	H
	M	Pauly estimate						H
	Stock-recruitment	Myers *et al.* approach				*h*	0.23	H
	Stock structure	Single stock						L
Fishery	Historical	QLD Fish Board	1960-1980	QLD				H
	Commercial	Logbooks	1988-2002	QLD				M
	Commercial	Logbooks	1984-2002	NSW				M
	Recreational	FRDC	1995	QLD				M-H
		RFISH	1997	QLD		424 t	0.09	H
		RFISH	1999	QLD		201 t	0.14	H
		NRIFS	2000	QLD		265 t	0.23	H
		RFISH	2002	QLD		180 t	0.11	H
	Recreational	Steffe	1993	NSW		5 t	0.24	M-H
		Steffe	1994	NSW		1 t	0.20	M-H
		NRIFS	2000	NSW		27 t	0.74	H
	Recreational	Missing years	1988-1994, 1996, 1998, 2001					H
	CPUE	Hyperstability						H
	Selectivity							H

Like most of the data types, the length-weight and growth relationships were considered of moderate uncertainty because these were derived from several years of opportunistic fishery-dependent data, and used when no data were available. The growth relationships were also influenced by the limited size range in the data with few small fish collected because of minimum legal size restrictions. Maximum age (10 years) was moderately uncertain as it was based on the modeled growth trajectory of fishery-dependent samples; albeit that the eldest fish aged was 7 years. No data were available on an unexploited period of the fishery to validate this assumption.

Greater uncertainty was considered in the age structures (moderate to high) as these were based on a single Age Length Key (ALK), pooled across several years of opportunistic and patchily distributed sampling (Table 9.1). An average age structure was also used for those years when no data were available in the VPA model, although the data suggested that this was a reasonable assumption considering the similarity in age structures for years in which data were available (see Fig. 2.4).

Furthermore, the DPI&F LTMP most likely under-sampled the fishery for age data in the more recent years (see monitoring requirements in Chapter 10). Ageing of spotted mackerel, however, has low ageing error (<10%), although there can be difficulties in assigning fish to the correct year class because of interpretation in the otolith edge marginal increment.

Estimates of length and age at maturity were of moderate to high uncertainty (Table 9.1). Greater uncertainty was in the age than the length based measures as reflected in the higher CVs. Maturity ogives were estimated for spotted mackerel based on a limited number of samples pooled across several years of data collection. Uncertainty also exists in the representativeness of these samples with respect to other potential spawning grounds and times. Similarly, there was high uncertainty in the estimated fecundity relationship as this was based on only 13 samples, and accounted for no periodicity in spawning, variation in age, etc.

Two of the greatest uncertainties in any stock assessment are the estimates of natural mortality (*M*) and the stock-recruitment relationship. Likewise, in this assessment both these estimates had high uncertainty (Table 9.1). No data were available on either *M* or stock-recruitment for spotted mackerel. *M* was based on a relationship derived in a meta-analysis approach involving a broad suite of species (Pauly 1983), where uncertainty exists in all the parameters used (K, L_∞, T – Equation 2.4), while stock-recruitment was derived from a similarly borrowed approach involving analogous species (Myers *et al.* 1999). In addition, no information exists on recruitment for spotted mackerel, particularly at low stock sizes, which r_{max} and subsequently, steepness (h) are based on.

The assumption of a single east coast stock of spotted mackerel was considered to have low uncertainty. Genetic, age and growth, catch monitoring, tag-recapture and otolith elemental data support this assumption and indicate that the majority of spotted mackerel along the Queensland east coast comprise a single exploitable stock (Begg *et al.* 1997, Begg 1998, Begg *et al.* 1998a, 1998b, Begg and Sellin 1998). The extent of the northern boundary of the stock distribution, however, is less certain, although catches are limited in waters north of Cairns (Fig. 3.3, 3.4).

Fishery characteristics

Fishery data types used in the reference point estimations included the historical and contemporary catches from the commercial and recreational fishing sectors, catch rates (*i.e.*, CPUE) and selectivity patterns (Table 9.1).

High uncertainty exists in the historical total catches that were based on the Queensland Fish Board data (1960-1980). These data were not representative of the complete historical landings as those destined for interstate or international export were not required to pass through the Fish Board, while anecdote suggests that a number of private companies handled fisheries landings independently and black-market selling occurred (see Chapter 3). In addition, data on the historical catches of the New South Wales commercial sector and the entire recreational sector were missing, where these contributions were assumed from the extrapolated exponential approach based on the total catches from more recent years (see Chapter 6). Furthermore, uncertainty exists in when the actual fishery commenced, as Fish Board data on undifferentiated mackerel landings go back to at least 1945, but based on anecdote from a single fishing region we have assumed that the fishery commenced in 1960. Also, no species differentiated catches were reported in the historical landings, necessitating us to estimate the relative proportion of spotted mackerel in these catches (see Chapter 3).

Lower uncertainty exists in the contemporary Queensland and New South Wales commercial catches than the historical catches (Table 9.1), although this is tempered by the general caveats that are associated with a mandatory logbook reporting system. Reliability in the data is also influenced by the issue of species identification and the need to allocate unspecified reported mackerel as spotted mackerel (see Chapter 4).

The greatest uncertainty in the total catches were the recreational estimates as these were based on expansion factors related to the survey design and population demographics (Table 9.1). Slightly lower uncertainty exists with the 1995 Queensland and 1993-1994 New South Wales estimates as these were based on more directed surveys designed specifically to estimate spotted mackerel catches (Cameron and Begg 2002) and creel survey or intercept methods with none of the recall biases (Steffe *et al.* 1996) that are associated with the RFISH and NRIFS data, respectively; although the expansion factor issue still applies. Lower uncertainty also exists for the 1995 survey estimates because the sample frames selected were aligned to provide a more accurate coverage of those fishers that recreationally targeted or caught mackerel species (Cameron and Begg 2002). This differed from the RFISH surveys which sample frames do not distinguish between those fishers likely to capture mackerel from those that do not. The FRDC survey expansion factor extrapolations of total catches were also based on boat multiplications, unlike the RFISH extrapolations, which are based on the entire angling population in Queensland. In addition, we are less certain about the 1997 RFISH estimate as this had greater species identification problems associated with the survey methodology and was significantly higher than any other year. High uncertainty also exists for those years in which no recreational surveys were conducted, where those catches were based on an assumed constant catch rate and average relative fishing effort derived from previous surveys (see Chapter 6). Species identification problems and allocation of unspecified mackerel add to the uncertainty.

Catch rate or CPUE data also have high uncertainty because of the hyperstability issue associated with the schooling behaviour of spotted mackerel (Table 9.1). Even given the standardised approach to estimate CPUE (see Chapter 5), the relatively flat time series was not captured by any of the assessment models (see Chapter 7, 8). Consequently, we have high uncertainty in the appropriateness of CPUE as an index of population abundance for spotted mackerel.

Likewise, estimates of selectivity in the fishery are highly uncertain (Table 9.1). In our age-structured model (SAM) we assumed a logistic selection pattern where spotted mackerel were fully selected at age 1, although in the VPA model a different selection pattern was observed, with full recruitment to the fishery not occurring until 3 to 4 years of age. The catch-at-length distributions by fishing gear (Fig. 3.21) also suggested that an older selection pattern may be evident in the fishery. Until further investigations are conducted into selectivity in the fishery, then these data types remain highly uncertain.

Estimation methods

Following the hierarchical approach to reference point estimation (Cadrin *et al.* 2004) we examined a range of methods from simple historical proxies to age-based production models.

Historical proxies

The historical proxies included: 1) average long-term yield (LTY); 2) maximum constant yield (MCY) (Anon. 2002a); and 3) Delphi survey estimate (Anon. 2002b).

The first historical proxy for MSY was based on the average long-term yield (LTY) of the total catches (1990-1998). This proxy assumed that catches were accurately reported and relatively stable (*i.e.*, sustainable).

The second historical proxy, MCY was used in the recent Spanish mackerel stock assessment (Welch *et al.* 2002), and is an alternative to MSY when faced with uncertainty. MCY represents the average yield or catch that can be taken from a stock accounting for natural variability, and is a method of estimating the TAC for the fishery (Welch *et al.* 2002). MCY was estimated for the total catch according to the following:

$$MCY = cY_{av} \quad (9.1)$$

where, c = natural variability factor which is lower for fish stocks of greater variability (Table 9.2); and Y_{av} = average yield (*i.e.*, catch) over a determined time series that shows no systematic trend in catch or effort (1990-1998) and is longer than half the exploited life span of the species (Anon. 2002a).

The third historical proxy for MSY was derived from the Delphi survey technique at the DPI Spotted Mackerel Workshop (2002), which was dependent on the respondents' perception of the fishery being informative and accurate.

Table 9.2. Relationship between natural mortality (*M*) and the natural variability factor (*c*) used in the estimation of MCY (Anon. 2002a).

Natural mortality (*M*)	Natural variability factor (*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

Rago's replacement ratio

Total catch and CPUE from 1988 to 2002 were analysed using Rago's replacement ratio (NEFSC 2002). The method derives the level of standardized effort that allows the population to replace itself using information from total catch and indices of relative stock size (*e.g.*, CPUE). The rate of change in the stock size index is derived as the ratio of stock size in a given year to the average stock size in previous years (*e.g.*, for the lifespan of spotted mackerel a four-year average was considered to be appropriate). The log rate of change is regressed on the log effort (catch/CPUE=effort). The level of effort that is expected to produce a rate of change equal to one is the replacement ratio. Given that relative exploitation rates greater than the replacement rate are not usually sustainable, the replacement rate should be considered as a limit reference point. Unfortunately, there was not a negative relationship between rate of population change and effort for spotted mackerel. Therefore, an estimate of the replacement ratio was not possible. The principal assumption for this application is that CPUE is a reliable index of stock size. If there is hyperstability in catch rates, because of schooling or the absence of search time in effort statistics (see Chapter 5), catch rates may continue to be high while the stock decreases. Therefore, there was little guidance on sustainable levels of effort from Rago's replacement ratio.

Surplus production model

As described in Chapter 8, a biomass dynamics model (ASPIC, Prager 1994) was applied to 1960-2002 total catches and 1988-2002 CPUE data. Unfortunately, no estimate of MSY was possible within reasonable constraints, because there was little contrast in the CPUE time series. A relatively constant CPUE during the recent period of great increases in catch implies an extremely large stock size that is not appreciably reduced by the recent removals. A corollary of this possibility is that the population growth rate is extremely slow, which contradicts our perception of the species' life history, one of the more certain aspects of our current knowledge of the stock. Similar to the application of Rago's replacement ratio, a critical assumption for this ASPIC application is that CPUE is a reliable index of stock size. If there is hyperstability, catch rates may continue to be high while the stock decreases, and there is little guidance on biological reference points for spotted mackerel from surplus production or biomass dynamics models.

Dynamic pool calculations

Information on life history (growth, maturity, fecundity and natural mortality) and fishery selectivity were used to derive yield per recruit (Thompson and Bell 1934) and total biomass, spawning biomass and egg production per recruit (Gabriel *et al.* 1989, Goodyear 1993). The alternative stock assessment models (SAM, Chapter 7; ADAPT, Chapter 8) offer substantially different perspectives on selectivity, with the youngest age at full selection being age-1 from SAM and age-4 from ADAPT. Although the selection derived from SAM is probably more reliable, because of uncertainties in catch-at-age, the selectivity from ADAPT was considered to assess sensitivity to the selectivity assumption. The fishing mortality that produces maximum yield per recruit (F_{max}) was not well defined using either selectivity assumption (Fig. 9.1). The estimate of $F_{0.1}$ was 0.206 assuming full selectivity at age-1, which maintains 56% of maximum egg-production per recruit ($F_{0.1}$ assuming age-4 full recruitment was 0.147, which maintains 86% of maximum egg production). Although there may be information on sustainable fishing levels from dynamic pool models (*e.g.*, $F_{0.1}$ is a viable candidate for a target *F*), the implicit assumption of constant recruitment, regardless of the level of *F* or % maximum egg production, may be risky.

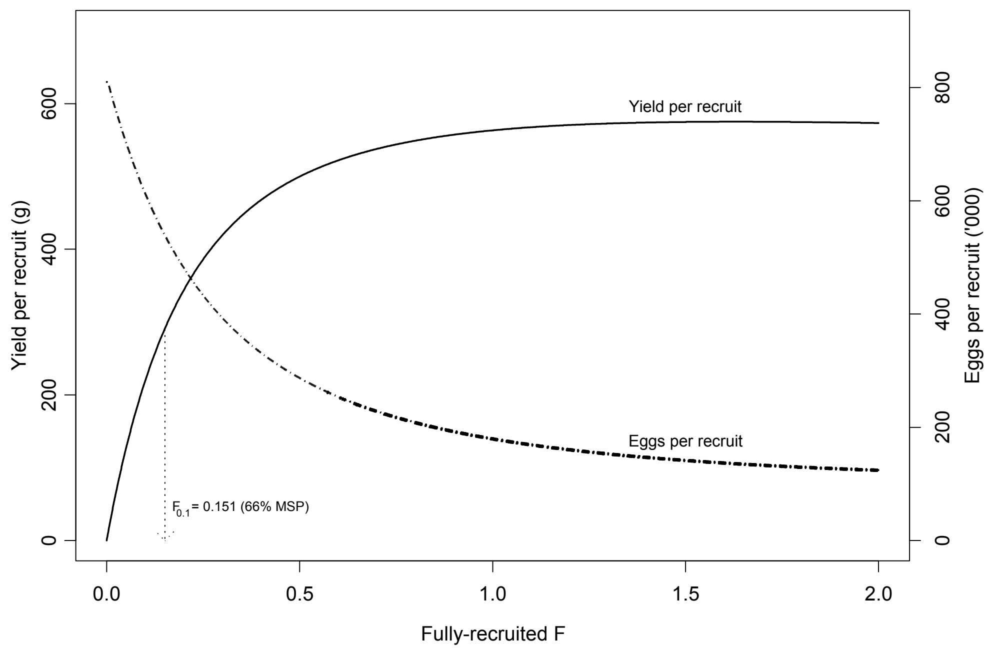

Fig. 9.1. Yield per recruit, assuming full selectivity at age-1.

Age-based production models

The most complex method used to estimate reference points in this hierarchical approach was our sex-specific age-structured population dynamics model (SAM) that accounted for explicit life history characteristics of spotted mackerel (see Chapter 7). Although the two SAM configurations (with and without CPUE, see Chapter 7) had similar selectivity estimates, the estimate of 1960 recruitment was substantially different (see Chapter 8). Therefore, two age-based production calculations were considered, according to the two SAM model results. The $Y(F_{MSY})$ reference points derived directly from the assessment models, assuming equilibrium conditions, were 366 t (SAM Model 1) and 296 t (SAM Model 7) (Chapter 7). All alternative configurations indicate that recent catches have not been sustainable. Results from the models, however, suggested that the uncertain and relatively flat standardised catch rate (CPUE) data may not be a good indicator of population abundance; undoubtedly being affected by hyperstability, and hence reference points derived from SAM Model 7, where catch rates were not used to tune the model, should be considered as the preferred candidate reference points.

Hierarchical approach to reference points

The variety of methods used to estimate a selection of reference points, from simple historical proxies to highly complex age-based production models via a systematic and transparent hierarchical approach, provided the framework to evaluate candidate reference points for determining sustainable catch strategies of spotted mackerel (Table 9.3).

Table 9.3. Reference point estimation methods, critical inputs, data and assumptions, and reference points estimated. *M* = natural mortality; *c* = natural variability factor which is lower for fish stocks of greater variability; MCY = maximum constant yield; LTY = average long-term yield; CPUE = catch per unit effort (catch rates); MSY = maximum sustainable yield; YPR = yield per recruit; F = fishing mortality; $F_{0.1}$ = fishing mortality rate corresponding to 10% of the slope of the YPR curve at the origin (Gulland and Borema 1973); F_{max} = fully recruited fishing mortality rate which produces the maximum yield per recruit (Gabriel and Mace 1999); F_{MSY} = fishing mortality rate which produces MSY; Y(F_{MSY}) = yield when fished at F_{MSY}; and MSP = maximum spawning potential; and B_{MSY} = biomass which produces MSY.

Method	Critical input parameters and data	Assumptions	Reference point estimated
Historical proxy	Average long-term yield (total catches; 1990-1998)	Catches are accurate and have been relatively stable (*i.e.*, sustainable)	LTY = 333 t
	Average long-term yield (total catches; 1990-1998) *M* = 0.43 *c* = 0.6 Life span – maximum age	Catches are accurate and have been relatively stable (*i.e.*, sustainable) Recruitment is constant	MCY = 200 t
	DELPHI	People's perceptions are accurate	Median = 313 t
Rago's replacement ratio	Total catches CPUE Life span – maximum age	Catches are accurate CPUE indicates stock size	No apparent relationship between population rate of change (issue of CPUE) and exploitation rate
Surplus production model	Total catches CPUE (commercial line)	Simple logistic population growth Catches are accurate CPUE indicates stock size	MSY not estimated within constraints No reasonable estimate
Dynamic pool model (YPR)	Growth (male and female – yield) *M* (both) Maturity (female – length based; predicted length at age, and maturity at age), Fecundity Selectivity (various model estimates; SAM 1, SAM 7, ADAPT)	Constant recruitment Constant F and *M* throughout the lifetime of a cohort Accurate growth, maturity, fecundity and natural mortality	$F_{0.1}$ = 0.206 (56% MSP) (SAM 1, 7) F_{max} - undefined
Age-based production model	Stock recruitment relationship (SAM 1, SAM 7) Life history information Selectivity (various model estimates; SAM 1, SAM 7)	Beverton-Holt stock-recruit relationship Population at equilibrium Constant F and M throughout the lifetime of a cohort Accurate growth, maturity, fecundity and natural mortality	Y(F_{MSY}) = 366 t (SAM 1) Y(F_{MSY}) = 296 t (SAM 7)

From this selection, a suite of target (*i.e.*, desirable) and limit (*i.e.*, avoidable) candidate reference points were chosen that may be considered appropriate for the management of spotted mackerel (Table 9.4). These reference point estimates were generally consistent with the SAM catch projections (see Chapter 7) because these levels of catch appear to be sustainable and maintain biomass greater than B_{MSY}. At the lower tier of the hierarchy, based on simple historical proxies for sustainable catch levels, a target total catch for the fishery was estimated to be 200 t with a limit of 333 t. The target catch estimated from the more conservative maximum constant yield (MCY) provides a buffer from the assumed average long-term yield (LTY). Although these proxies are simple to estimate and based on only a time series of total catch, their utility is tempered by the inherent uncertainty and tentative assumptions associated with the magnitude of the catch (Table 9.3), particularly with respect to the recreational sector (see Chapter 6). This uncertainty, however, should direct management to the more conservative target catch of MCY, rather than the limit catch of LTY, if these proxies are considered appropriate.

Table 9.4. Candidate reference points for spotted mackerel. MCY = maximum constant yield; LTY = average long-term yield; TACC = total allowable commercial catch; F_{MSY} = fishing mortality rate which produces MSY; $Y(F_{MSY})$ = yield or catch when fished at F_{MSY}; and *M* = natural mortality.

Method	Target catch (t)	Limit catch (t)
Historical proxy	MCY = 200	LTY = 333 (TACC = 140)
Age-based production model	$Y(0.75F_{MSY})$ = 282 Y(0.5*M*) = 277	$Y(F_{MSY})$ = 296

In contrast, the age-based production model estimated a target total catch for the fishery of 277-282 t and a limit of 296 t (Table 9.4). These estimates were based on the assessment model using only the age structure data (Chapter 7; SAM Model 7), thereby avoiding the uncertainty associated with the potentially hyperstable catch rates. Unlike the simple historical proxies, however, the age-based production model estimated reference points require extensive biological and fishery information with associated assumptions of population equilibrium (Table 9.3). These more complex life history models though are considered to best represent the underlying dynamics of the population.

Discussion

A selection of candidate reference points may be considered appropriate for setting target and limit catches for the management of the spotted mackerel fishery. This selection is a balance between data and model assumptions, complexity and uncertainty, and the management objectives to be met. The hierarchical approach to reference point estimation lays bare these assumptions and uncertainties in a systematic and transparent manner so managers and other stakeholders can make more informed decisions regarding the selection of candidate reference points for the fishery (Cadrin *et al.* 2004). This approach also enables the identification of data limitations, weak or untested assumptions, and gaps in our knowledge with respect to the fishery and the life history of the species that require further research. Ultimately, we should be attempting to move up the hierarchy as our knowledge improves to provide more informative management advice to guide sustainable catch strategies for the spotted mackerel fishery.

The nominal 2003 total catch of 350 t (if the TACC of 140 t was fully realised) for the spotted mackerel fishery was above all the estimated candidate reference points, irrespective of the data and models used (Table 9.4). This suggests that the stock is most likely being harvested near or exceeding maximum sustainable levels, and is at risk of being over-fished. Similar mackerel stocks overseas have been fished down to low levels leading to recruitment over-fishing and stock decline (FAO 1996, Hoyle 2002). Management of the spotted mackerel fishery, therefore, may need to consider more prudent actions in accordance with the precautionary approach to ensure the long-term sustainability of the fishery. Recent management intervention of a total allowable commercial catch (TACC) (*i.e.*, limit) of 140 t is one step towards achieving this objective (see Table 1.1). However, with a theoretical limit for the total catch of 296 t and recommended target of 277 t (F=0.5M, Walters pers. comm.), the relatively unconstrained and poorly estimated recreational catch could compromise the effect of the TACC or any other catch targets/limits set for the fishery. Consequently, the selection of candidate reference points for setting appropriate catch strategies for the fishery should consider the impacts and management of all sectors, and not rely solely on the regulation of any one sector. Moreover, data and model uncertainty should not be used as a basis for management inaction, but instead as dictated by the precautionary approach, provide a greater prompt for management intervention.

The determination of candidate reference points for the fishery highlights the conundrum between data uncertainty and management action. The variety of methods used to estimate reference points each have their strengths and weaknesses, but which reference point to use will depend on the level of available data and the method that most reliably captures the salient population and fishery dynamics (Gabriel and Mace 1999, Hilborn 2002, Cadrin *et al.* 2004). Selecting meaningful reference points for the fishery is a challenging process that should involve all relevant stakeholders to ensure the transparency of the hierarchical approach is maintained, understood and formally adopted. Fundamental to this process is the specification of all the underlying assumptions and data uncertainties that encompass the candidate reference points and their estimation methods. In comparison to other exploited fish stocks, one could argue that the spotted mackerel stock is in a far better position regarding some key assumptions, particularly those concerning virgin biomass and the commencement of the fishery. Some fish stocks have been exploited for hundreds of years where stakeholders have no idea of pre-exploitation levels; unlike the spotted mackerel stock which most likely has only been harvested over the past four decades.

Reference point estimation, therefore, is a complex process accounting for data richness, representativeness, and uncertainty. Selection of candidate reference points should be informed by the use of alternate methods and their assumptions. Likewise, sensitivity analyses should be conducted to identify the influence of critical assumptions in the estimation process and to direct future research and monitoring programs (Cadrin *et al.* 2004).

10. Monitoring

The uncertainty associated with this (or any other) stock assessment and subsequent reference points and management advice derived from the related analysis and models is a function of the quality and extent of the input data. The choice of assessment model and associated degree of complexity that can be used to evaluate the status of the spotted mackerel fishery is also dependent on the actual types of data available (see Chapter 8). Similarly, according to the hierarchical approach to reference point estimation suggested by Cadrin *et al.* (2004) and used in this assessment (see Chapter 9), reference points need to be estimated by the method that most reliably captures the fundamental population and fishery dynamics, given the data available. Research and monitoring programs, therefore, should be directed towards providing the necessary data required for model parameters and reference point estimation. These programs should attempt to provide more detailed information through a systematic data collection framework, so that more sophisticated models can be applied to enable higher tiered reference points to be estimated (Cadrin *et al.* 2004), and greater certainty in model predictions.

Various forms of monitoring and opportunistic or project oriented research provided the necessary data used in this current age-structured assessment of spotted mackerel (see Chapter 1). The assessment data came from a range of sources, but relied heavily on Queensland's commercial and recreational fishing databases, as well as fishery-dependent spotted mackerel length and age data from FRDC Project 92/144 (fishing years 1991-1995) and the DPI&F LTMP (2000-2002). In 2002, the DPI&F LTMP collected spotted mackerel length and age data, resulting in the measurement of 2655 fish from 35 commercial ring net catches (265 fish were aged; no otolith marginal-edge measurements taken). All fish were essentially sampled from Hervey Bay and Moreton Bay. Only one catch of seven fish was obtained from recreational anglers. No sampling was conducted for the 2003 fishing year. The continuation of the spotted mackerel LTMP, however, is essential if further data- or model-based assessments are to be conducted for this fishery.

There are two important background considerations for the monitoring of spotted mackerel: 1) stock structure; and 2) regional and seasonal patterns in abundance. The Australian east coast spotted mackerel fishery is assumed to comprise a single unit stock that undertakes seasonal spawning and feeding movements along the Queensland east coast (see Chapter 1). Genetic, age and growth, catch monitoring, tag-recapture and otolith elemental data support this assumption (Begg *et al.* 1997, 1998a, 1998b, Begg and Sellin 1998). Spotted mackerel movement is also systematic as illustrated by large commercial catches taken in northern Queensland waters during late winter and early spring and in southern Queensland waters during summer (Fig. 3.5). Large recreational catches of spotted mackerel are generally taken in southern Queensland waters (Fig. 10.1). Also of note is the change in average spotted mackerel length, and therefore age structure, caught along the Queensland east coast (Fig. 10.2). Larger fish tend to be caught by line fishing in southern Queensland waters, and (before management intervention in 2002) by ring netting in northern Queensland waters. This geographic and sector-specific heterogeneity in catches of spotted mackerel demonstrates the need to monitor catches spatially from both the commercial and recreational fishing sectors.

Consequently, we used two statistical methods (random effects modeling and power analysis) to analyse the fish length data used in this assessment to determine an effective and optimal monitoring strategy for spotted mackerel. Results from these analyses were used to provide advice on when, where, and the number of catches (or number of fish) to monitor to enable future assessments of the Australian east coast spotted mackerel fishery.

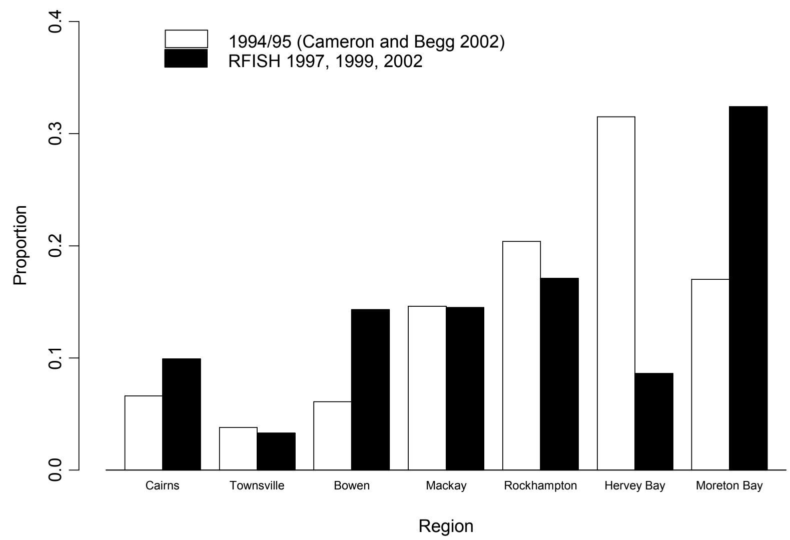

Fig. 10.1. Average regional pattern in recreational catch of spotted mackerel. Larger catches were taken in southern Queensland waters.

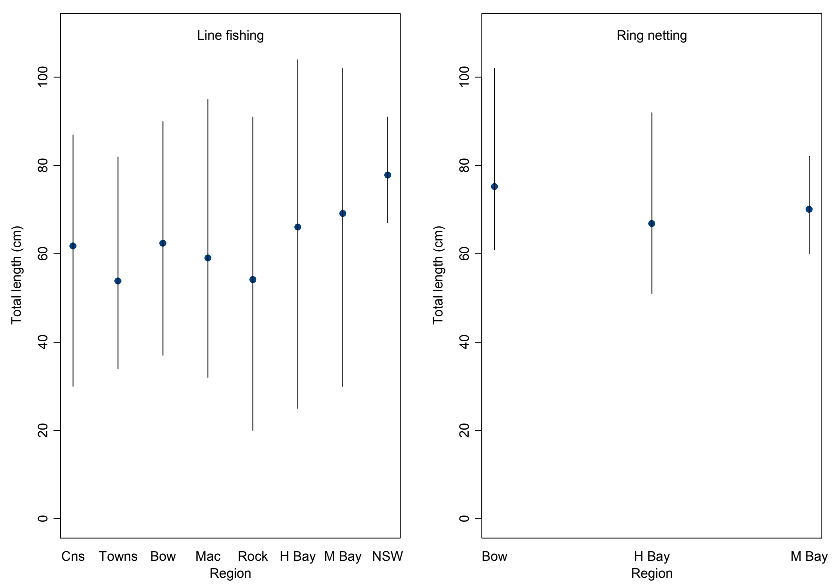

Fig. 10.2. Spotted mackerel average lengths for commercial line fishing and ring netting. Regions: Cns = Cairns; Towns = Townsville; Bow = Bowen; Mac = Mackay; Rock = Rockhampton; H Bay = Hervey Bay; M Bay = Moreton Bay. The vertical lines illustrate the length ranges (minimum and maximum).

Methods

Random effects model

Length frequency data available from 1985 to 2002 (Table 10.1) were analysed using a linear random effects model (Montgomery 1997). The analysis facilitated the estimation of the variance components. That is, a linear model with random effects which partitions the variance in the data into components. Random effects are those factors that can be treated to represent a random selection from the overall population. For example, the 10,000+ spotted mackerel length frequencies recorded since 1985 originated from many different commercial and recreational fishing trips (or daily catches), which is a possible random selection from the total number of trips/catches between 1985 and 2002 inclusive. Like generalised linear models (GLMs), random effects models can be used to analyse unbalanced data sets. But unlike GLMs, they can also measure more than one source of variation in the data, thus providing an estimate of the variance components associated with the random terms in the model. The linear random effects model is applicable here because it can be used to obtain information on sources and sizes of variability in the spotted mackerel length data. This is of particular interest where the relative size of different sources of variability must be assessed to design a more effective sampling strategy for spotted mackerel.

Table 10.1. The spotted mackerel length data used in the random effects model.

Data source	Gear	Fishing year	Number of fish
Cameron and Begg (2002)	Ring net	1992-1994	4776
DPI&F LTMP	Ring net	2002	2390
ANSA	Line	1985-2003	2957
Ferrell and Sumpton (1996)	Line	1995	143
Sumpton (2000)	Line	1999	42
Cameron and Begg (2002)	Line	1991-1995	713
DPI&F LTMP	Line	2001	37

The analysis used a linear random effects model assuming normally distributed errors to provide estimates of the variance components. The response variable was based on the individual fish total lengths and the findings are pertinent to both average fish lengths and frequency distributions. The data were stratified into eight regions along the Australian east coast: 1) Cairns, 2) Townsville, 3) Bowen, 4) Mackay, 5) Rockhampton, 6) Hervey Bay, 7) Moreton Bay, and 8) New South Wales; based on the region definitions described in previous chapters (Fig. 1.1, Table 3.1). Fishing years were used to define the annual cycle of the fishery. Months were analysed as nested factors within each fishing year. This recognised that the months in one year were not identical to the months in other years (months could also be assumed identical between years by coding as a fixed main effect). One other model factor was used to complete the analyses. Model 1 used the different fishing gears (line vs. different net types) to define sources of variation in fish sizes. Model 2 treated the fishery as line only and excluded all net caught fish to reflect the recent changes in management (*i.e.*, prohibition of nets to target spotted mackerel) (see Table 1.1).

No transformations on the data were required and the standardised residuals were normally distributed with no pattern when plotted against their fitted values. Definitions of the two different analyses were as follows:

$$TL = \text{Constant} + \text{Fishing year(Month)} + \text{Region} + \text{Gear} \quad (10.1)$$

where, in Model 1, *TL* = spotted mackerel total length (cm); Constant = fixed model component; Fishing year = 1985 to 2002; Month = January to December; Region = Cairns, Townsville, Bowen, Mackay, Rockhampton, Hervey Bay, Moreton Bay and New South Wales; and Gear = line and 9.5, 10.2, 12.7 cm mesh net. Fishing year(Month), Region and Gear were random model components.

$$TL = \text{Constant} + \text{Fishing year(Month)} + \text{Region} \quad (10.2)$$

where, in Model 2 (only line caught fish), *TL* = spotted mackerel total length (cm); Constant = fixed model component; Fishing year = 1985 to 2002; Month = January to December; and Region = Cairns, Townsville, Bowen, Mackay, Rockhampton, Hervey Bay, Moreton Bay and New South Wales. Fishing year(Month) and Region were random model components.

Power analysis

The main considerations in designing a monitoring strategy for spotted mackerel are whether the fish collected and measured are representative of the total catch and whether they are able to show true changes, or trends, in fish age or length. In stock assessment, changes in age structure or length frequency typically highlight patterns in recruitment, fishing mortality and fishing gear selectivity. In order to model these patterns, a long time series of representative data are needed. The ability to detect true changes in spotted mackerel age or length frequencies, *e.g.* due to the effect of increasing fishing mortality, which occurs over and above the amount of variation that the natural population exhibit can be quantified through power analysis. In statistics the term "power" refers to the ability to detect a true increasing or decreasing trend. Several factors affect power, such as the number of catches sampled, variability of the samples, and magnitude of the difference or trend to be detected. Designs with small samples sizes and high variability will have low power. If the size of the difference or trend is small compared with the natural population variability it will be difficult to detect.

Accurate monitoring of spotted mackerel fish lengths (and in turn age structures) requires an appropriate number of catches, regions and years sampled to be able to detect a trend. All these considerations can be related to power analysis. Calculating the power of detecting trends in fish length or age structure is difficult and requires estimates of the variance. The random effects modeling described above provided these estimates. An Excel worksheet for power analyses of specified means was used to determine the power for a given scenario of mean fish lengths between four monitoring regions (O'Neill and Thomson 1998). A range of possible sample sizes (number of catches and fish) were tested for anticipated mean fish sizes (≈ 65 cm TL).

Results

The random effects models showed significant variation in spotted mackerel lengths between gear types, regions and months (Table 10.2). Model 2, however, is more relevant as the fishery is now restricted to line fishing only. This model estimated that the seasonal and regional sources of variation together represented 67% of the variance in the length data. These seasonal and regional factors correlate with the systematic movement of the stock; located in northern Queensland waters during winter and southern Queensland waters during summer. The two sources of variation, therefore, can be simplified together for designing a sampling strategy.

Table 10.2. The estimated variance components from the spotted mackerel length data. All model terms were significant (p<0.05).

Model	Random effects term	Variance component	Percent of total error
1	Fishing year	11.44	3
	Fishing year(Month)	114.76	35
	Region	30.74	9
	Gear	137.60	42
	Residual	35.49	11
2	Fishing year	7.46	4
	Fishing year(Month)	114.28	54
	Region	26.58	13
	Residual	63.53	30

The power analysis results were dependent on the amount of variance and target amount of change in measuring average fish size (Fig. 10.3, Table 10.3). The variance components calculated in Model 2 should be taken as it relates to sampling the line fishery only. Powers larger than 0.8 were used to suggest appropriate sample sizes, due to these powers being more effective in detecting change with 95% confidence (Thomas 1994). The results indicated that a 5 cm change in average fish size (*e.g.*, from 70 cm to 65 cm) would likely be detected if about 30 catches (assuming a catch rate of 4 fish), equating to about 150 fish, were sampled equally from each of the four regions analysed (*i.e.*, Townsville-Innisfail, Bowen, Hervey Bay and Moreton Bay). The number of catches will be less for higher catch rates. Table 10.4 demonstrates that commercial line fishers have much higher catch rates than recreational fishers. Slightly improved powers would be achieved if the number of catches and fish were optimally sampled according to total catches, by fishing sector, and in each region.

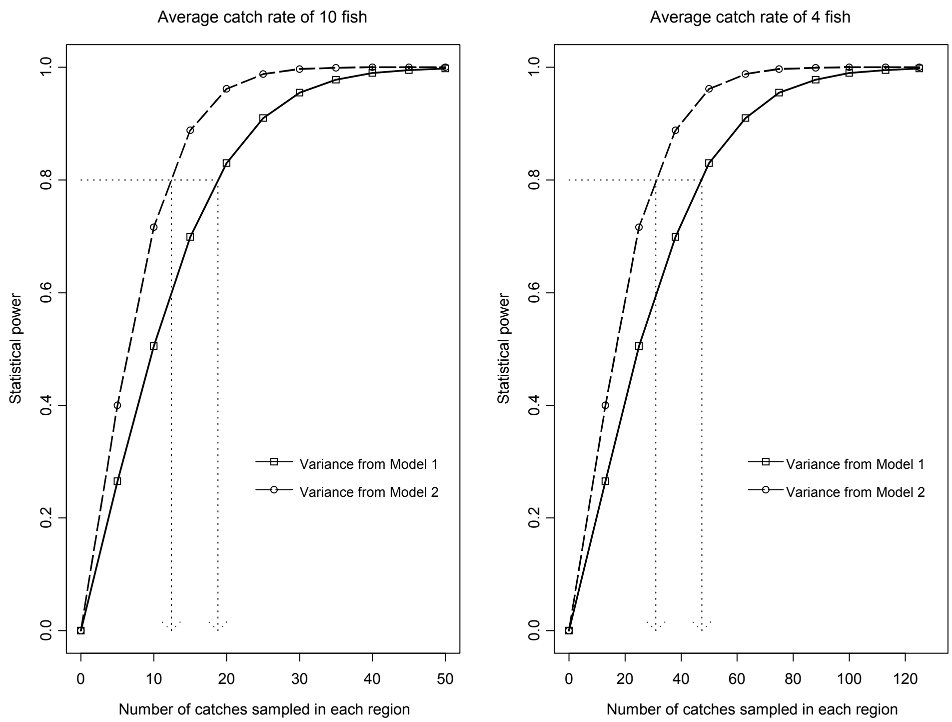

Fig. 10.3. Power to detect a 5 cm change in average spotted mackerel total length for sample sizes assuming an average catch rate of 10 and 4 fish, respectively. The sample sizes (converted to number of catches for comparison) relate to sampling a fishing region. Powers larger than 0.8 are generally considered to be effective for detecting change with 95% confidence. The results are tabulated below (Table 10.3).

Table 10.3. The powers to detect a 5 cm change in average spotted mackerel total length. The sample sizes (numbers of fish and converted to number of catches) relate to each fishing region. Var = variance.

Sample size			Power	
Number of catches (assuming 10 fish/catch)	**Number of catches (assuming 4 fish/catch)**	**Number of fish**	**5 cm change Var = Model 1**	**5 cm change Var = Model 2**
0	0	0	0.000	0.000
5	13	50	0.265	0.400
10	25	100	0.505	0.716
15	38	150	0.699	0.888
20	50	200	0.830	0.962
25	63	250	0.910	0.988
30	75	300	0.955	0.997
35	88	350	0.978	0.999
40	100	400	0.990	1.000
45	113	450	0.995	1.000
50	125	500	0.998	1.000

In summary, the random effects modeling and power analysis show the importance of monitoring spotted mackerel lengths every year, with samples ideally collected across the regions from all line fishing sectors (listed in Table 10.4). Generally for trend detection more sampling units, that is sample more individual catches and in turn fish, is preferred than to increase sampling the number of fish with only a few fishers and catches. If more spotted mackerel are measured from many different catches, the variation in fish lengths between fishing groups or trips can be minimised from the trend detection. Strategies to reduce variances need to have strict guidelines on when, where and how sampling should be undertaken. More catches measured within each region will decrease the within–region variance. Fig. 10.2 can be used as a guide to the typical variation in fish lengths between regions.

Table 10.4. Spotted mackerel average and median daily catches by line fishing sector.

Line fishing sector	Average catch	Median catch	Minimum	Maximum
Commercial line	35	14	1	1175
Commercial multi hook	26	13	1	465
Commercial troll	32	13	1	483
Charter	4	2	1	47
Recreational	4	2	1	73

Discussion

Monitoring

Sampling fish

Before a monitoring program can be devised the objectives need to be clearly stated and understood. There is a difference in a monitoring strategy that seeks to follow simple trends in data for a stock on a long-term basis than one that seeks to collect information for stock assessment. The DPI&F LTMP strategy should aim for the second objective; to provide data of a quality and type needed for stock assessment.

The statistical analysis demonstrated that it is important to sample the different line fishing sectors and that spatial resolution to the data is essential if the objective is to collect information for stock assessment. While there was also significant temporal variation to the fish length frequencies, this variation does relate to the regional patterns. Any monitoring strategy that has no sector (commercial vs. recreational line) or spatial resolution of the data is fundamentally flawed when it has been demonstrated that there are significant differences in the fish lengths among these sampling strata. Consequently, we recommend the minimum sampling of at least 600 fish from both the recreational and commercial line sectors across two broad regions: 1) northern Queensland (Townsville – Bowen); and 2) south east Queensland (Hervey Bay – Moreton Bay). This equates to a minimum sample each year of 600 fish distributed across the 2 fishing sectors and 2 regions (*i.e.*, sampling target of 150 fish per sector per region); all fish should be sexed and aged. Furthermore, based on the median daily catch by sector (Table 10.4), a minimum of 20 catches should be sampled from the commercial sector and 150 from the recreational sector. The number of recreational catches will be influenced by the daily bag limit of 5 spotted mackerel; although this is not typically reached (Table 10.4). Likewise, the commercial catches will be influenced by the daily limit of 150 spotted mackerel. Accordingly, although some commercial catches of over 50 fish can be measured at times, it is important that many sampling units (one sampling unit ≈ trip catch) are sampled rather than sampling large numbers of fish from only a few fishers. Logistically this will probably mean that more fish are measured from some regions, since on some sampling days it is possible to measure significantly more fish from only a few commercial catches. We recognise that this places an additional workload on field staff, but the recommended data collection strategy would minimise the significant between-fisher catch variation in fish lengths.

Ageing fish

In the previous sections and paragraphs we have focused on the monitoring of spotted mackerel catches and fish lengths. In addition to this we now comment on the considerations and number of fish required for ageing to calculate age frequencies of the catch.

Accurate and precise ageing is vital since the current stock assessment is age-based. The fact that July-September is commonly the time of spawning (*i.e.*, when annuli are laid down) creates a number of difficulties in interpretation as some fish may have a visible opaque edge on their otoliths, whereas the bulk of the stock may have a translucent edge. Tobin and Mapleston (2003) clearly show this issue for Spanish mackerel otoliths. It is a well-known fact that growth checks (opaque bands) become visible during different months for different ages (Francis *et al.* 1992), and this is even more noticeable when whole otoliths are used rather than sectioned otoliths. That is, edge interpretation problems increase with age. It is vitally important for this edge interpretation problem to be recognised in any ageing protocol, particularly if samples are to be obtained at different times of the year (*e.g.*, as would be the case if spotted mackerel samples were collected from northern and southern Queensland). The accuracy and precision of the age data would be greatly enhanced if an algorithm was developed (Francis *et al.* 1992) which assigned age in months (using the distance of the marginal edge) rather than just the ring count and then allocated fish to an appropriate year class. Unless the ageing algorithm incorporates this information then ages can potentially be inaccurate by 1 year. This amount of error is critical when the majority of the catch consists of 1 to 3 year old fish, where mis-assigned ages can cause impacts on model outputs.

Examination of the DPI&F LTMP ageing database found that no otolith edge measurements or description (see Tobin and Mapleston 2003) were recorded. It is important that this is done in the future. It is recognised that if fish for ageing are always collected at the same time, ages can be adjusted when viewing otoliths by looking at the relative position of the edge and using this to make a consistent visual assessment. However, if samples are collected at different times or if age structures shift there is considerable scope for error if just “age” (*i.e.*, the number of rings) is recorded rather than the number of annuli and measurement of the marginal increment. Measures describing marginal increments (see Tobin and Mapleston 2003) allow different algorithms for assigning age groups to be tested in the future. A microscope-to-computer-to-screen setup should be used to accurately and quickly measure the marginal increments.

Given that size is a poor predictor of age in this species, due to the variability in growth between and within the sexes, it is important that the size distribution of the fish aged is identical to the size distribution of the measured catch. Provided that sampling is “truly” random, albeit that this is difficult to achieve in the field, there is little need to collect large numbers of fish to measure and then resample from this for ageing. Power analysis suggested that about 30 catches ~ 150 fish from each region was an adequate sample size to detect a 5 cm difference in length. For similar statistical power to detect change in age frequencies, we would also recommend the ageing of a total of 600 fish otoliths. If the monitoring results in significant numbers of measured fish (many more than 600), then the construction of annual sex-specific age length keys (ALKs) can be done proportionally rather than optimally by length group. In addition, if there are any gaps in the ALKs (as was the case for the single sex-specific ALKs used in this assessment), smoothing methods that use stochastic growth curves to iteratively fill in the gaps should be used in the future.

As well as being the sample size suggested by the power analysis, this otolith sample can also be derived based on rules used in New South Wales and New Zealand fisheries research organizations. Their target is to collect 20 otoliths for each length group. Given that 90% of the catch is now between 60 and 90 cm in length this would divide the length frequency distribution into 30 x 1 cm length groups (*i.e.*, 30 length groups x 20 fish = 600). Sampling approximately 300 fish from both the northern and southern Queensland regions would be adequate to construct an ALK and allow some spatial resolution to the data. This level of sampling is appropriate for incorporation of age data into current assessment models. Sampling spotted mackerel from the catch for biological information (*i.e.*, age, sex, etc), however, may prove very demanding (*e.g.*, from the commercial sector when whole fish are sold) making it logistically difficult and costly. Fish may have to be purchased so that they can be dissected and the relevant biological information obtained.

The potential recommended monitoring strategy, therefore, for the collection of spotted mackerel samples each year is the following:

1. Measure a minimum of 600 fish from both the recreational and commercial line sectors across northern Queensland (Townsville – Bowen) and south east Queensland (Hervey Bay – Moreton Bay). Samples in northern Queensland should be collected from July to October, and in south east Queensland from November to March. A minimum of 20 catches should be sampled from the commercial sector and 150 from the recreational sector, distributed across the regions in proportion to the total catch. The optimal sampling allocation strategy should be determined on the sector-region specific catch from the preceding year. For example, if 30% of the recreational catch was taken from northern Queensland waters, then a similar proportion of the samples should be allocated to that region.

2. Randomly select catches to sample.

3. Measure all fish from each catch. If more than the 150 daily limit in a commercial catch, then measure 150 fish randomly, but record the total number of fish in the catch so that the sample can be weighted appropriately and a scaling factor applied to the total sample catch.

4. From as many catches as possible, collect otoliths from all fish. Randomly select otoliths for ageing if required from the catches. Sex all fish when removing otoliths.

5. Age all otoliths and measure or describe the marginal increments.

6. Record the capture date, location, sector and fishing method (*e.g.*, lure, bait, target, non-target, etc) for each sampled fish. In addition record the size (number and/or weight) of the catch from which it was sampled. This will allow appropriate weighting factors to be calculated to derive the ALKs, length frequency distributions and age structures. This, in turn, will allow the tracking of year class strengths in the assessment.

Sampling the recreational catch

There are several options that can be used for sampling the recreational catch, but all will suffer from an inability to sample as cost effectively as the commercial sector. Nevertheless in the case of spotted mackerel it is essential that the recreational sector be sampled. The following describes some possible sampling options for this sector:

1. *Use RFISH diaries to collect mackerel length information*. Recreational anglers can record the length of spotted mackerel caught (as well as those discarded) in diaries as part of the regular RFISH biennial survey. This approach was successful with 354 spotted mackerel measured in 1995 using specifically designed diaries for mackerel, with pictures to clarify species identification (Cameron and Begg 2002); these measurements were representative when compared with creel survey data (Ferrell and Sumpton 1996). Such a strategy, however, could suffer from recall bias and require a policy shift in terms of the design of the RFISH survey. Despite these concerns, this strategy remains a sampling option in the future.

2. *Charter boat diaries.* Currently an index of size is recorded for spotted mackerel taken by charter boats in Queensland. Operators are required to record catch numbers and average weight and it may be possible for selected operators to collect additional information. However, the total spotted mackerel catch taken by this sector is small (~ 2-3 t). Given this low catch, it would also need to be established whether the catches of this sector are truly representative of the broad recreational catch. The current "size index" that is recorded in charter logbooks may be useful as a rough guide to broad scale changes in the length structure of the fishery, but it lacks sufficient precision to enable it to be used in a stock assessment.

3. *Use specific anglers to collect frames and other biological material.* This method has previously been used successfully to collect spotted and school mackerel samples from the recreational

sector (Cameron and Begg 2002). There are always keen recreational anglers who are willing to assist research by collecting biological information. This method was also used by the CRC Reef Research Centre who used tackle stores as a collection point for recreationally caught Spanish mackerel frames (Tobin and Mapleston 2003). Examination of recreational spotted mackerel catches per group show that the average is about four fish (Table 10.4). This means that considerable resources would be required to sample the recreational sector in this manner. Given the low average catch, about 80-100 individual catches would need to be sampled before 300-400 fish were recorded.

4. *Collection of material from fishers returning from fishing trips*. This is essentially an access point creel survey that relies on meeting fishers as they return to boat ramps after a fishing trip. This method was used in Moreton Bay and measured 143 spotted mackerel in 1995 and 42 in 1999 (Ferrell and Sumpton 1996, Sumpton 2000). Creel census would be the most accurate method to monitor recreationally caught spotted mackerel, as well as other species, and the sampling sites could be optimized to collect larger numbers of fish. This approach is a good way of collecting data for a range of species, which is needed, but it is probably not feasible just for spotted mackerel.

Other considerations for monitoring

Other than the ageing and biological information there are important ongoing data sources that are used in the assessment and monitoring of spotted mackerel. These data should also be given appropriate consideration and are summarised below:

1. *Annual commercial catch data from the CFISH data system*. There is uncertainty about the large catch of “unspecified mackerel” that has not been allocated to a particular species within the CFISH database, although we attempted to minimise this effect using binary regression models (see Chapter 4). The logbooks also must be modified to record details on fishing effort including search times and zero catches to address the issue of hyperstable catches, as well as information on discards.

2. *Annual Queensland Fish Board data from 1960 to 1980*. Like the CFISH data, these suffer from a lack of a clear definition of each of the mackerel species and in this case it is difficult to formulate decision rules for allocating the catch to spotted mackerel.

3. *Data collected from the RFISH recreational catch and effort surveys during 1997, 1999 and 2002*. These surveys contain data on spotted mackerel catches (including discards) throughout Queensland based on diary records of a sample of recreational anglers. Again, there is some uncertainty about the species identification in many of the records as a high proportion of catches are recorded as “mackerel” only and are not assigned to a particular species group. Also the magnitude of the 1997 spotted mackerel catch estimate is questionably very large by a factor of more than two compared to the other surveys.

4. *New South Wales commercial catch*. The magnitude of this commercial catch is small compared to Queensland (~20-50 t).

A tag-recapture program is an alternate/complementary data source to the ageing data that could be considered for this species to provide reliable estimates of annual exploitation rates. These estimates, however, would only be reliable if a high reporting rate of tagged fish recaptures were achieved. But, before this can be achieved significant advances must be made in high tagging intensity and low tagging mortality rate over short periods. Tagging may become more effective if Northern Territory and Queensland fisheries researchers can reduce tag loss/mortality rates for Spanish mackerel with the use of an alternate genetic tag (*i.e.*, gene-tag) currently being tested (Buckworth, unpublished data). This work is essential to validating the current stock assessment model. It is an area of research that should be closely monitored by the DPI&F, as if successful could be applied to spotted mackerel and other species. The costs and benefits of tagging versus fishery-dependent data can be better compared once this pilot research is complete.

Research into the development of other fishery-independent methods to estimate stock abundance would also be extremely valuable for this stock, given the high uncertainty in the use of fishery-dependent, most likely, hyperstable catch rate data as an index of abundance. Similar mackerel fisheries overseas have a history of over-exploitation and stock decline with little indication of stock problems provided through standard measures of fishery-dependent catch and effort data. Problems exist with using fisheries-dependent data as indicators of stock status because of the schooling behaviour of the resource where catch rates may remain high even if fish stocks are being seriously depleted. Investigations into the utility and cost-effectiveness of aerial surveys or egg production methods as fisheries-independent estimates of stock abundance would be beneficial.

In addition to the monitoring and catch data used in the stock assessment model, it is also important to appreciate the model input parameters (Table 10.5). An analysis of some model sensitivities is given in the stock assessment chapter (see Chapter 7), but there are several points that are relevant to collecting more data. Much of these data were sourced from only 1994-1995 (Cameron and Begg 2002). The Beverton-Holt recruitment steepness parameter (r_{max}) was based on parameters derived from the Scombrid fish family (Myers *et al.* 1999). The fecundity relationship was based on limited data and improvement is required to calculate spawning indices more accurately for different age or size groups.

Overall, the need for more age-structured data collected from both the commercial and recreational sectors is of greatest importance to improve the assessment of spotted mackerel. It is also important to collect length and age-structured data from a number of regions that encompass the main fishing grounds along the Queensland east coast. Annual estimates of catch-at-age and fishery-independent information on stock size will ultimately lead to more precise stock assessments and reduced uncertainty to evaluating risk of alternative management actions.

Table 10.5. List of input parameters for the Spotted mackerel Age-structured Model (SAM) used in this assessment. The respective values are reported in Chapter 2 and 7.

Parameter
L_∞ (asymptotic mean maximum length); sexes separated
K (von Bertalanffy growth rate); sexes separated
t_0 (theoretical age at length 0); sexes separated
Maximum age
Minimum legal size (TL)
Length weight parameters; sexes separated
M (natural mortality); sexes combined
Sea surface temperature
Length at maturity curve (TL); sexes separated
Fecundity at length and age curve
Stock recruitment steepness or r_{max} (maximum reproductive rate at low population size)

11. Discussion

This assessment arose in response to the growing concerns by all stakeholders in 2002 for the sustainability of the Australian east coast spotted mackerel (*Scomberomorus munroi*) fishery. Spotted mackerel comprise a single stock along the east coast, and undertake annual spawning and feeding movements throughout its distribution (Begg *et al.* 1997, 1998a, 1998b). The highly aggregated, near surface schooling behaviour of the species, coupled with its predictable seasonal movements allows ease of targeting by both commercial and recreational fishers, thereby making the stock highly susceptible to stock decline and fishery collapse. The spotted mackerel commercial catch of over 400 t in 2000 was more than double the average annual commercial catch between 1995 to 1999, which was in contrast to anecdotal evidence that the recreational catch had declined (Anon. 2002b) (Chapter 3). In addition, the relatively recent development of a valuable export market for spotted mackerel significantly increased commercial targeting of the species, where an increase in effort was likely to continue while attractive prices were being offered and overseas markets continued to expand (Williams 2002). Addressing sustainability concerns of the Australian east coast spotted mackerel fishery is a major priority of the DPI&F and Inshore Finfish MAC, who acknowledged that management measures needed to change to reduce the risk that spotted mackerel may be harvested beyond a sustainable level. Recent management measures have included a total allowable commercial catch (TACC) of 140 t and a reduced recreational bag limit of 5 spotted mackerel (Chapter 1), although further intervention may be required to ensure the long-term sustainability of the fishery.

All indications from the assessment, besides the relatively flat CPUE time series (Chapter 5), suggest that the spotted mackerel stock is most likely being harvested near or exceeding maximum sustainable levels, and is at risk of being over-fished. Biomass trends from the age-structured population dynamics model (Chapter 7) and alternate assessment models (Chapter 8) demonstrate significant declines in the stock over the past 10 years, particularly during the mid-1990s to early-2000s when catches were at their peak (Chapter 6). Similar mackerel fisheries have a history of over-fishing with little indication of stock decline provided through standard measures of fishery-dependent catch rate or CPUE statistics (FAO 1996, Hoyle 2002, Welch *et al.* 2002); the same type of data and statistics used to estimate CPUE in this assessment (Chapter 5). Problems exist with using fisheries-dependent CPUE data as indicators of stock status because of the schooling behaviour of the resource where catch rates may remain high even if fish stocks are being seriously depleted; as may be the case for spotted mackerel where none of the models fitted the CPUE data particularly well. However, despite these problems with potentially hyperstable catch rates there is no fisheries-independent estimate of the size of the spotted mackerel stock, reinforcing the uncertainty that exists between stakeholders about the sustainability of current catch levels. Management, therefore, should consider the applicability of alternate fisheries-independent methods for estimating the stock size of spotted mackerel such as aerial surveys (Lutcavage *et al.* 1997, Nakashima and Borstad 1997, Cowling *et al.* 2002), egg production surveys (Alheit 1993, Priede and Watson 1993, Borchers *et al.* 1997) or the developing gene-tag approach (Buckworth, unpublished data) that have been successfully used for other pelagic fish species.

The assessment used all available biological and fisheries data to provide an indication of the current level of exploitation and sustainability of the spotted mackerel fishery (Chapter 2, 3, 6). Model results indicate that the stock is most likely over-exploited with biomass levels at 33-63% of unfished or virgin biomass levels and that catches may need to decline from current rates (if TACC of 140 t was fully realised) to ensure the likelihood of stock increases within acceptable levels of risk (Chapter 7). Lower risks and higher catch rates were predicted for the fishery at lower catches, although this depends on what is an acceptable level of risk and catch rate. Although the best available data were used to determine the status of the stock and inform an appropriate level of risk, there was an inherent level of uncertainty associated with the data and model assumptions that also need to be considered (Chapter 9). Major levels of uncertainty exist in the key biological parameters of natural mortality, stock-recruitment and reproductive output, as well as in the fisheries data of the historical and recreational catches; perhaps the greatest uncertainty in the assessment. Sensitivity analyses identified the potential influence of some of these effects and emphasised where further research and monitoring is required to develop our knowledge of the status of the fishery.

The continuation of a structured and well-designed monitoring program (*i.e.*, DPI&F LTMP) for spotted mackerel is essential if further data- or model-based assessments are to be conducted for the fishery. Results from the assessment indicate that long-term monitoring of spotted mackerel should encompass both the commercial and recreational fishing sectors and have spatial coverage of the stock and its main fishing grounds along the Australian east coast (Chapter 10). Power analysis estimated that about 600 fish are required for ageing, collected from numerous fishing trip-catches. While the importance of sampling the recreational catch was also identified, the logistics of such a sampling strategy needs to be carefully evaluated and the costs fully understood. Other than monitoring spotted mackerel length and age, it is important that the collection of commercial and recreational catch data is ongoing and validated. Commercial logbooks and recreational fishing diaries need to be modified to record detailed effort information including search times and zero catches to address the issue of hyperstable catch rates, particularly if these are ever going to be used as a valid index of the underlying population abundance. Notably, management has moved to an output based system with the TACC, which makes an estimate of stock size critical for adaptive management of the fishery.

Management of the spotted mackerel fishery, therefore, may need to consider more prudent actions in the future in accordance with the precautionary approach to ensure the long-term sustainability of the fishery. For example, if fishing pressure increases, management may need to consider other strategies besides the recently implemented commercial catch quota, increased MLS to protect a larger component of the spawning stock, etc; although at present the TACC is not being fully realised. The transparent and comprehensive nature of this assessment should enable all stakeholders and managers involved in the spotted mackerel fishery to make more informed decisions concerning the management of the resource, with an understanding of the associated uncertainties and risks. The choice of management actions to implement in the future should be examined in a management strategy evaluation framework, similar to the approach used in this assessment, to determine the trade-offs between particular management actions and the management objectives to be met; coupled with the associated levels of risk.

This stock assessment is the most comprehensive attempt to evaluate the status of the Australian east coast spotted mackerel fishery. The assessment used all available biological and fisheries data to provide an indication of the current level of exploitation and sustainability of this fishery. The results, however, need to be tempered with the uncertainty associated with the various data and model assumptions; although this should not be used as a basis for management inaction. Indeed, the precautionary approach dictates that management should be more prudent given greater uncertainty. The transparent and comprehensive nature of the assessment should enable all stakeholders involved in the fishery to make more informed decisions concerning the management of the resource, with a thorough understanding of the associated uncertainties and risks. Overall, the analyses and modeling facilitated a critical assessment of the spotted mackerel fishery; thereby, making more effective use of the catch data and past biological research on the species. The assessment has provided a basis for Queensland and New South Wales fisheries managers, and their relevant advisory committees to consider sustainable levels of fishing and management objectives for the fishery. Operational objectives and trigger points for the fishery, however, need to be defined to guide future management strategies. Recent management measures also need to be assessed in the future, and more prudent actions may be needed, if fishing pressure increases in the recreational sector and/or the commercial catch quota is met or exceeded.

12. Research and monitoring recommendations

In summary, we provide the following recommendations for the future research and monitoring of the Australian east coast spotted mackerel fishery to improve and develop this stock assessment:

- Need to continue the DPI&F LTMP for spotted mackerel. The monitoring program, however, needs a more comprehensive and structured approach to the collection of appropriate age-structured data for spotted mackerel from both the commercial and recreational sectors to improve the assessment. It is also important to collect length and age-structured data from a number of the main fishing regions along the east coast of Queensland. [***Urgent & Critical***]

- Need for a better measure of effort in the commercial logbooks and recreational diaries to provide a more reliable indicator of CPUE, and in turn, stock abundance. Fishers should be encouraged to record search and fishing times, and days when zero catches occurred to minimise the effect of hyperstable catch rates when these data are used in catch rate analyses and assessment models. [***Urgent & Critical***]

- Need for better species identification in the commercial logbooks and recreational diaries to minimise the uncertainty of unspecified mackerel in the total catch estimates. [***Important***]

- Need for a review of the historical data to confirm the assumed commencement of the fishery and magnitude of the catches. [***Important***]

- Need to examine the selectivity of spotted mackerel vs. their availability to determine the appropriate selectivity functions to be used in the assessment. The preliminary selectivity functions of Cameron and Begg (2002) should be re-estimated and developed further to determine the historical significance of net catches. [***Important***]

- Need to re-evaluate the protocols used to age spotted mackerel to ensure future consistency in the assessment (Ward and Rogers 2003). Measures of otolith marginal increments should be collected to allow algorithms for assigning age groups to be tested in the future to minimise ageing errors or biases. [***Important***]

- Need for a fishery-independent measure of changes in stock size. Currently, only fishery-dependent CPUE data are available to provide an estimate of stock abundance, and these are prone to hyperstable catch rates. Aerial or pelagic egg surveys, and/or genetic tagging methods should be examined as an alternate stock abundance/biomass estimate to CPUE data. [***Important***]

- Need for a more comprehensive investigation into the fecundity and spawning of spotted mackerel. The initial fecundity estimates of Begg (1998) were based on very few samples, with no consideration of spawning frequency. More detailed information on the fecundity-age relationship, and investigations into anecdotal reports of alternate spawning grounds are required. [***Important***]

- Need to investigate the recruitment processes and associated nursery grounds of the early life history stages. Very little is known about these early stages, which are critical to recruitment and year class strength. [***Important***]

- Need to understand the significance of the environmental-catch distributions of spotted mackerel. Research into the movement and distribution patterns of spotted mackerel relative to temperature, water clarity, baitfish distributions and other abiotic factors may provide information that can be used in predictive models of future catches. [***Optional***]

- Need for a periodic review and update of the assessment as determined by the requirements of the DPI&F. Operational objectives need to be defined for future management strategy evaluation. [***Critical***]

- Need for a systematic and transparent stock assessment review process. This process should include the formation of a steering committee involving the representation of all relevant stakeholders, an independent peer-review of the assessment, and all related reports and presentations to have a clear and concise statement of the review process that the assessment has undergone. [***Critical***]

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Appendix 1: External scientific review

The following external independent scientific review of the assessment was provided by Dr Christopher Legault at the National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, USA. Responses to individual comments are provided in italics and where applicable have been incorporated into the assessment. The original review has been amended and presented below to reflect the formatting of the revised report.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
166 Water Street
Woods Hole, MA 02543-1026

Review of
Assessment of the Ecological Sustainability of the
Australian East Coast Spotted Mackerel Fishery
by Gavin A. Begg, Michael F. O'Neill, Steven X. Cadrin, and Mikaela A. J. Bergenius.

Reviewer
Christopher M. Legault
Research Fishery Biologist
National Marine Fisheries Service
Northeast Fisheries Science Center
166 Water Street, Woods Hole, MA, USA

This is one of the more comprehensive assessments that I have ever reviewed. The authors are to be commended for the breadth and depth of their analyses. There is no attempt to hide the resulting uncertainty in the results due to the limited nature of available data. The presentation is logical, for the most part, with good flow within sections. However, the ordering and connections among sections was not always intuitive. The information provided in the assessment is sufficient to make management decisions. The authors have certainly met the objectives of this assessment presented in Chapter 1.

There are two "big picture" questions that should be decided at the policy level prior to the next assessment of this species. Given the large uncertainties in the data, would a combined mackerel assessment be a better approach to take than a number of species specific assessments that must make large assumptions about the species composition of combined mackerel statistics? This question should be approached from both a biological perspective, noting the differences among species that would contribute to changes in management, as well as an economic perspective of the cost/benefit of the combined versus split approaches. The other question is what level of investment in data collection and analysis is appropriate for this species? Little economic information is presented in the assessment to allow determination of the importance of this fishery to the nation. Given the small catches, relative to many other pelagic species, it may be acceptable to use relatively imprecise but cheap monitoring methods to manage this fishery. Conversely, if this fishery is deemed considerably important, a structured data collection system based on many of the recommendations presented in this report could lead to a much more precise assessment of current status and the impact of management decisions. The following comments and suggestions are based on the assumption that the latter approach is more likely to occur.

Major Comments

Given the order of presentation, it was difficult to follow the decisions made regarding stock status. This is because reference points were presented within the stock assessment sections (7 & 8) but then later discussed in the reference points section (9) without clear connection made between these sections. For example, in section 7.3 the statement is made that the stock is over-exploited because the current biomass is between 33 and 50% of the unexploited biomass. However, the biomass reference point is determined to be 40% of the unexploited biomass. Thus, some of the models result in an over-exploited status (B<Bref) while others do not (B>Bref). The conclusion that the stock is over-exploited is not supported by all models. Invoking the precautionary approach in this case seems appropriate due to the large uncertainties in the basic data.

Response: The chapters were ordered in the assessment to first demonstrate the model results from our baseline age-structured population dynamics model (Chapter 7). Following, several alternate assessment models were examined to evaluate the relative performance, robustness and uncertainty associated with the population trends derived from our base model (Chapter 8). Evaluating alternate models is a recommended approach to stock assessment, and should be conducted whenever possible (see Hilborn and Walters 1992, Haddon 2001). Associated with the results from these two Chapters were related reference points. The final reference point chapter assimilated all information in the assessment to derive a list of potential candidate reference points, from which management could base decisions (Chapter 9), as well as being able to evaluate the appropriateness of the reference points presented in the earlier Chapters. We agree that not all the models may support the stock being near or exceeding sustainable levels, but importantly all show a similar pattern of decline with biomass levels estimated to be at 33-63% of unfished or virgin biomass levels. Notably, our preferred base model, not incorporating catch rate data because of concerns over hyperstability, indicated that the spotted mackerel exploitable biomass in 2002 was predicted to be below that which would sustain MSY. In addition, the nominal 2003 total catch of 350 t (if the TACC of 140 t was fully realised) was above all the estimated candidate reference points, irrespective of the data and models used, suggesting that the stock is most likely being harvested near or exceeding maximum sustainable levels, and is at risk of being over-fished. However, we also state that the results need to be tempered with the uncertainty associated with the various data and model assumptions. Ultimately, we agree that the precautionary approach needs to be invoked, hence our support for the results from model run 7 (i.e., tuned only to age structure data).

The generalized linear models (GLMs) applied to catch per unit effort (CPUE) to form indices of abundance are inconsistent among data sources. In some cases interaction terms are included while in other cases only main effects are considered. A more systematic approach to GLM application to CPUE data, including random effect models, has been taken in International Commission for the Conservation of Atlantic Tuna (ICCAT) (see e.g. Ortiz and Diaz. 2004. ICCAT Coll. Vol. Sci. Pap. 56(4): 1481-1495, available in pdf on the ICCAT website). The use of reduction of deviance as the criteria to select the best model may prove useful in this situation.

Response: All data sources (i.e., effort types) were treated consistently in the GLMs, and forward stepwise regression using reduction of deviance was used as the criteria to select optimal parameters (see Chapter 5 Methods). Although we acknowledge that mixed or random effect models are useful, we have found that the GLM and LMM derived abundance indices are usually quite similar. Future assessments may want to compare abundance indices derived from the different models.

The simulation exercise conducted to demonstrate the sampling program required to detect a change in average size needs to be linked more closely with actual observations. For example, in Figure 3.14 there are many interannual changes of mean length greater than 5 cm that are most likely due to low sample sizes, but may also be due to recruitment events. Extending the simulation exercise to link fishing mortality rates to actual changes in mean size would improve the justification for the recommended sampling program. This is because the change in mean size from 70 to 65 cm has a much different meaning than a change in mean size from 50 to 45 cm. Furthermore, changes in mean size can easily be caused by changes in gear selectivity as well as strong recruitment events, which should both be explored in the simulation exercise.

Response: We agree that the sampling program required to detect a change in average size needs to be linked more closely with actual observations. The purpose of the analysis was simply to provide some guidance on the type and amount of data needed to be collected to detect a 5 cm change. Once the data is collected through the revised monitoring program of the DPI&F, other analyses will be conducted to explain potential reasons for observed differences.

Diagnostics for the various models are not presented adequately to fully judge if the results are reasonable. Correlations among estimated parameters are not presented and not all model fits are shown. While the document is already large and adding this information would increase it even more, these diagnostics can be quite informative and show when models have and have not arrived at a unique solution. This is particularly true when data are limited and many assumptions must be made just to create the basic input data for the model.

Response: Parameter correlations for all model runs and related text were added to the stock assessment Chapter, as too was a plot of the fitted catch rate data.

<u>Minor Comments</u>

Table 1.4 The legend describes data available for 1998, but this year is not shown in the table.

Response: The Table caption was corrected to reflect that the data was collected in 1999.

Section 3.4 Is mortality the issue instead of survival?

Response: The corresponding text was changed to mortality instead of survival.

How have regulations impacted the various catch per unit effort measures? Is the hypothesized hyperstability merely a byproduct of changing regulations?

Response: Recent management regulations did not impact on the catch rate analysis as these were not implemented for the data time series analysed. Future catch rate analyses and assessments, however, will need to consider the impacts of recent and significant management measures that have been implemented in the fishery (i.e., prohibition of nets to target spotted mackerel, commercial in-possession limit of 150 spotted mackerel, etc).

Is there a seasonal aspect to the length-weight relationship that should be included?

Response: There is no seasonal aspect to the length-weight relationship because of data limitations, with most of the data collected between November and February. Results from the models, therefore, principally represent the November to February length-weight relationships.

Fig. 2.3 Should ages be increased by 0.5 so that don't observe a 50 cm age 0 fish? This change will not impact Linf or K, but will change t0 significantly.

Response: The ages were not increased by 0.5 for the growth relationships. This does not change the expected lengths at age or growth parameters. However, it was noted in the Table caption that age zero refers to 0+ fish. This may need to be considered in future assessments and analysis of growth.

Fig. 2.4 vs Sex ratio section it is not clear which is the "final" age structures used.

Response: The final age structures used in the assessment are provided in Table 2.8 and Fig. 2.4. Information on sex ratios were moved before the age structure section, and the text was modified to clarify the final age structures used in the assessment.

Pg. 24 and 26 How do rates compare to the Spanish mackerel of Florida (*Scomberomorus maculatus*)?

Response: Vital population rates (i.e., natural mortality and steepness) used in this assessment for spotted mackerel were comparable to other Scombrid species. Sensitivity analysis also enabled the evaluation of the assumed values, which seemed reasonable given data limitations.

Pg. 26 It is confusing to define h as the slope at the origin and the redefine it as R/Rvirg at 20% Svirg within the same paragraph.

Response: The text was changed to be consistent, where steepness is defined as the expected recruitment at 20% of the virgin spawner stock size.

Use different symbols for alpha and beta in eqs 7.4 and 7.5 vs 7.7 and 7.8 to avoid confusion.

Response: Different symbols were used for alpha and beta to identify the different Beverton-Holt equations.

Eq. 7.17 assumes a normal error distribution for the residuals of observed and predicted CPUE. This relationship is more commonly assumed to be lognormal which is accomplished simply by logging the numerator and denominator in the sum.

Response: We agree that it is technically more correct to calculate the geometric mean for q, but decided against its use as there is little difference in this case, and the same outcomes from the assessment are produced. In addition the geometric mean for q needs to be bias corrected which is often overlooked.

Chapter 7 (model assumptions) is missing assumptions of constant maturity and fecundity, constant selectivity, equilibrium in 1960, and no recruitment deviations from estimated stock-recruitment relationship.

Response: The extra assumptions of the model were added to the text.

Fig. 7.5 Why are the sensitivity runs not symmetric about the base model? Is it due to the choice of sensitivities or to model instability?

Response: The model runs were not symmetric about the base model because of the choice of sensitivities used in the assessment.

Section 7.2.1 I do not understand the use of the cumulative density function (cdf) when comparing observed and predicted age distributions. One could have age 2 underestimated by the same amount as age 3 overestimated resulting in no deviation in age 3 cdf. Why not use the probability density function (pdf) instead?

Response: We use the cdf when comparing observed and predicted age distributions, as we are fitting a cdf at each age in the model. We agree though that if age 3 is over-estimated by the same amount as age 2 is under-estimated then it is correct to say that the number of fish aged 3 or less has been fitted exactly. However, using a pdf would become inaccurate at older ages and require an arbitrary "cut off" age. In addition, we believe using the cdf better reflects the error in ageing. The two goodness of fit plots (Fig. 7.7, 7.8) demonstrate the model fit to the age structure data.

Pg. 111 Model development should include estimation of recruitment as deviations from stock-recruitment curve.

Response: Our data time series of age structures and catch rates were not long enough or lacked contrast to estimate robust deviations from the stock-recruitment curve. Instead, we used a minimal parameter approach to be more robust to estimate R_0, assuming r_{max}.

Table 8.1 legend is missing the word "not" before available.

Response: Table caption was changed to indicate that the values in bold represent years of missing data and are estimated from the average proportions for those years in which data were available

Table 8.4 Given difficulty deriving age proportions, why not just tune VPA to aggregate index?

Response: As the assessment is age-based and corresponding age structures were derived for the population models, we consider it important to fully utilise the ageing data such as for each age group, rather than as an aggregate index.

Pg. 121 One can determine the uncertainty in M from the Pauly equation by incorporating uncertainty in the von B parameters in a Monte Carlo simulation.

Response: Although we agree with the suggestion, it is dependent upon assuming that the Pauly equation is correct. However, we consider this equation to be highly uncertain, and hence, considered the best approach to testing M to be through sensitivity analysis. This was the approach we used.

Table 9.3 and elsewhere the notation Fmsy = 366 t is a bit strange to me because F is usually a fishing mortality rate in the US. Perhaps using Y(Fmsy) = 366 t, meaning yield when fished at Fmsy, would be easier. However, the notation used may be the standard in Australia.

Response: The notation was changed throughout the report.

Just below Table 9.4 why does added complexity in model structure lead to higher catch?

Response: We are not inferring that added complexity in model structure leads to higher catch. The text was clarified.

Pg. 134 Truly random sampling is very difficult to achieve in the field.

Response: We acknowledge that 'truly' random sampling is difficult to achieve in the field, and have noted so in the text.

Pg. 135 Should the optimal sampling scheme use just the prior year's data or an average of a few prior years' data to increase stability in the estimates and avoid wild fluctuations from year to year?

Response: We believe the optimal sampling scheme should use the prior year's data because the length and age data is to be collected as part of an annual time series for stock assessment. Consequently, the year to year fluctuations are important.

Pg. 136 It is unclear how data on discards from commercial and recreational fisheries will be collected.

Response: In the monitoring Chapter we recommend that information on discards be recorded as part of the compulsory commercial logbook program. Discards are already recorded in the recreational fishing diaries as part of the RFISH surveys.

Appendix 2: Age length distributions keys

Table 1. Female age length distributions (actual number aged) for data collected in FRDC Project 92/144 (1992-1994), DPI&F LTMP (2000-2002) and all data pooled across years, regions and fishing gears.

TL	FRDC (1992-1994)									LTMP (2000-2002)									Combined data								
	0	1	2	3	4	5	6	7	Total	0	1	2	3	4	5	6	7	Total	0	1	2	3	4	5	6	7	Total
43									0									0									0
44									0									0									0
45									0									0									0
46									0									0									0
47									0									0									0
48									0									0									0
49	1								1									0	1								1
50									0									0									0
51									0									0									0
52		2							2									0		2							2
53	2								2									0	2								2
54	2	1							3									0	2	1							3
55									0									0									0
56	1								1		1							1	1	1							2
57		4							4		1							1		5							5
58	3	2							5									0	3	2							5
59		7							7		2							2		9							9
60		8							8		4							4		12							12
61		9		1					10		5							5		14		1					15
62		25							25		5							5		30							30
63		29							29		29							29		58							58
64	1	31	1						33	1	25							26	2	56	1						59
65		31							31	1	36	1						38	1	67	1						69
66		37	2		1				40		34							34		71	2		1				74
67		42							42		27	1						28		69	1						70
68		36	2						38	1	24	2						27	1	60	4						65
69		39	2						41		13	3						16		52	5						57
70		27	5	1					33		6	1	1					8		33	6	2					41
71		20	6	2	1				29		4	1						5		24	7	2	1				34
72		13	10	2	1				26		1		1					2		14	10	3	1				28
73		6	10	1					17			1						1		6	11	1					18
74		5	12		1				18									0		5	12		1				18
75		2	19	1					22		1							1		3	19	1					23
76		2	27	1					30		1							1		3	27	1					31
77		2	18	1					21									0		2	18	1					21
78		1	15	1					17									0		1	15	1					17
79		1	23	1					25		1							1		2	23	1					26
80		1	15	2					18									0		1	15	2					18
81			16	4					20			1						1			17	4					21
82			6	4	1				11									0			6	4	1				11
83			9	6					15			1						1			10	6					16
84			6	3					9			3						3			9	3					12
85			3	6					9									0			3	6					9
86				5					5									0				5					5
87			2	4	1				7			1						1			3	4	1				8
88				4					4			1						1			1	4					5
89				5	1				6			1						1			1	5	1				7
90				2					2									0				2					2
91				1	1				2				1					1				2	1				3
92					1				1				1					1				1	1				2
93						1			1									0						1			1
94					2				2									0					2				2
95					1				1									0					1				1
96									0				2					2				2					2
97									0									0									0
98									0				1					1				1					1
99									0									0									0
100									0									0									0
101									0									0									0
102									0									0									0
103									0									0									0
104									0									0									0
105									0							1		1							1		1
Total	10	383	209	58	12	1	0	0	673	3	220	18	7	0	0	1	0	249	13	603	227	65	12	1	1	0	922

Table 2. Female age length distributions (proportions) for data collected in FRDC Project 92/144 (1992-1994), DPI&F LTMP (2000-2002) and all data pooled across years, regions and fishing gears.

TL	FRDC (1992-1994)								LTMP (2000-2002)								Combined data							
	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
43																								
44																								
45																								
46																								
47																								
48																								
49	1.00																1.00							
50																								
51																								
52		1.00																1.00						
53	1.00																1.00							
54	0.67	0.33															0.67	0.33						
55																								
56	1.00									1.00							0.50	0.50						
57		1.00								1.00								1.00						
58	0.60	0.40															0.60	0.40						
59		1.00								1.00								1.00						
60		1.00								1.00								1.00						
61		0.90		0.10						1.00								0.93		0.07				
62		1.00								1.00								1.00						
63		1.00								1.00								1.00						
64	0.03	0.94	0.03						0.04	0.96							0.03	0.95	0.02					
65		1.00							0.03	0.95	0.03						0.01	0.97	0.01					
66		0.93	0.05		0.03					1.00								0.96	0.03		0.01			
67		1.00								0.96	0.04							0.99	0.01					
68		0.95	0.05						0.04	0.89	0.07						0.02	0.92	0.06					
69		0.95	0.05							0.81	0.19							0.91	0.09					
70		0.82	0.15	0.03						0.75	0.13	0.13						0.80	0.15	0.05				
71		0.69	0.21	0.07	0.03					0.80	0.20							0.71	0.21	0.06	0.03			
72		0.50	0.38	0.08	0.04					0.50		0.50						0.50	0.36	0.11	0.04			
73		0.35	0.59	0.06							1.00							0.33	0.61	0.06				
74		0.28	0.67		0.06													0.28	0.67		0.06			
75		0.09	0.86	0.05						1.00								0.13	0.83	0.04				
76		0.07	0.90	0.03						1.00								0.10	0.87	0.03				
77		0.10	0.86	0.05														0.10	0.86	0.05				
78		0.06	0.88	0.06														0.06	0.88	0.06				
79		0.04	0.92	0.04						1.00								0.08	0.88	0.04				
80		0.06	0.83	0.11														0.06	0.83	0.11				
81			0.80	0.20							1.00								0.81	0.19				
82			0.55	0.36	0.09														0.55	0.36	0.09			
83			0.60	0.40							1.00								0.63	0.38				
84			0.67	0.33							1.00								0.75	0.25				
85			0.33	0.67															0.33	0.67				
86				1.00																1.00				
87			0.29	0.57	0.14						1.00								0.38	0.50	0.13			
88				1.00							1.00								0.20	0.80				
89				0.83	0.17						1.00								0.14	0.71	0.14			
90				1.00																1.00				
91				0.50	0.50							1.00								0.67	0.33			
92					1.00							1.00								0.50	0.50			
93						1.00																1.00		
94					1.00																1.00			
95					1.00																1.00			
96												1.00								1.00				
97																								
98												1.00								1.00				
99																								
100																								
101																								
102																								
103																								
104																								
105															1.00								1.00	
Total	0.015	0.569	0.311	0.086	0.018	0.001	0.000	0.000	0.012	0.884	0.072	0.028	0.000	0.000	0.004	0.000	0.014	0.654	0.246	0.070	0.013	0.001	0.001	0.000

Table 3. Male age length distributions (actual number aged) for data collected in FRDC Project 92/144 (1992-1994), DPI&F LTMP (2000-2002) and all data pooled across years, regions and fishing gears.

TL	FRDC (1992-1994)									LTMP (2000-2002)									Combined data								
	0	1	2	3	4	5	6	7	Total	0	1	2	3	4	5	6	7	Total	0	1	2	3	4	5	6	7	Total
43	1								1									0	1								1
44									0									0									0
45									0									0									0
46									0									0									0
47									0									0									0
48									0									0									0
49									0									0									0
50	2								2									0	2								2
51	1	1							2									0	1	1							2
52									0		1							1		1							1
53		2							2									0		2							2
54									0									0									0
55	2								2		1							1	2	1							3
56	1								1									0	1								1
57		3							3		1							1		4							4
58		5	1						6									0		5	1						6
59		3							3	1	3							4	1	6							7
60		3							3		7	1						8		10	1						11
61		6	2	1					9		1							1		7	2	1					10
62		6	4	1					11		3	2						5		9	6	1					16
63		2	14	2					18		5	1						6		7	15	2					24
64		6	25	1					32		3							3		9	25	1					35
65		6	32	1	1				40		5	4						9		11	36	1	1				49
66		5	38	10					53		4	2						6		9	40	10					59
67			40	21		1			62		1	5						6		1	45	21		1			68
68			33	27	3				63									0			33	27	3				63
69			27	33	4	1			65		3							3		3	27	33	4	1			68
70			17	42	4				63			1						1			18	42	4				64
71			2	48	9	1			60			1						1			3	48	9	1			61
72			1	33	19	1			54									0			1	33	19	1			54
73			1	16	15	6			38									0			1	16	15	6			38
74			1	10	13	6			30									0			1	10	13	6			30
75				14	8	2	1		25									0				14	8	2	1		25
76				2	10				12									0				2	10				12
77					5	3			8									0					5	3			8
78					7	5			12									0					7	5			12
79			1		5				6									0			1		5				6
80					2		1	1	4									0					2		1	1	4
81					1	1	1		3									0					1	1	1		3
82								1	1									0								1	1
83						1			1									0						1			1
84							1		1									0							1		1
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101									0									0									0
102									0									0									0
103									0									0									0
104									0									0									0
105									0									0									0
Total	7	48	239	262	106	28	4	2	696	1	38	17	0	0	0	0	0	56	8	86	256	262	106	28	4	2	752

Table 4. Male age length distributions (proportions) for data collected in FRDC Project 92/144 (1992-1994), DPI&F LTMP (2000-2002) and all data pooled across years, regions and fishing gears.

TL	FRDC (1992-1994)								LTMP (2000-2002)								Combined data							
	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
43	1.00																1.00							
44																								
45																								
46																								
47																								
48																								
49																								
50	1.00																1.00							
51	0.50	0.50															0.50	0.50						
52										1.00								1.00						
53		1.00																1.00						
54																								
55	1.00									1.00							0.67	0.33						
56	1.00																1.00							
57		1.00								1.00								1.00						
58		0.83	0.17															0.83	0.17					
59		1.00							0.25	0.75							0.14	0.86						
60		1.00								0.88	0.13							0.91	0.09					
61		0.67	0.22	0.11						1.00								0.70	0.20	0.10				
62		0.55	0.36	0.09						0.60	0.40							0.56	0.38	0.06				
63		0.11	0.78	0.11						0.83	0.17							0.29	0.63	0.08				
64		0.19	0.78	0.03						1.00								0.26	0.71	0.03				
65		0.15	0.80	0.03	0.03					0.56	0.44							0.22	0.73	0.02	0.02			
66		0.09	0.72	0.19						0.67	0.33							0.15	0.68	0.17				
67			0.65	0.34		0.02				0.17	0.83							0.01	0.66	0.31		0.01		
68			0.52	0.43	0.05														0.52	0.43	0.05			
69			0.42	0.51	0.06	0.02				1.00								0.04	0.40	0.49	0.06	0.01		
70			0.27	0.67	0.06						1.00								0.28	0.66	0.06			
71			0.03	0.80	0.15	0.02					1.00								0.05	0.79	0.15	0.02		
72			0.02	0.61	0.35	0.02													0.02	0.61	0.35	0.02		
73			0.03	0.42	0.39	0.16													0.03	0.42	0.39	0.16		
74			0.03	0.33	0.43	0.20													0.03	0.33	0.43	0.20		
75				0.56	0.32	0.08	0.04													0.56	0.32	0.08	0.04	
76				0.17	0.83															0.17	0.83			
77					0.63	0.38															0.63	0.38		
78					0.58	0.42															0.58	0.42		
79			0.17		0.83														0.17		0.83			
80					0.50		0.25	0.25													0.50		0.25	0.25
81					0.33	0.33	0.33														0.33	0.33	0.33	
82								1.00																1.00
83						1.00																1.00		
84							1.00																1.00	
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Total	0.010	0.069	0.343	0.376	0.152	0.040	0.006	0.000	0.018	0.679	0.304	0.000	0.000	0.000	0.000	0.000	0.011	0.114	0.340	0.348	0.141	0.037	0.005	0.003

Appendix 3: Steering committee meeting

Australian East Coast Spotted Mackerel Stock Assessment
Steering Committee Meeting
4th February 2004
Minutes

Attendence:
Don Kinsey (Chair), David Bateman (SunFish), Gavin Begg (CRC Reef), Paul Bell (DPI&F), Darren Cameron (GBRMPA), Malcolm Dunning (DPI&F), Mark Doohan (DPI&F), Jim Higgs (DPI&F), George Leigh (DPI&F), Mark Lightowler (DPI&F), Michael O'Neill (DPI&F), Duncan Souter (QSIA), Fran Trippett (DPI&F)

Timetable:
Attendees suggested that the outcomes of the Stock Assessment should be presented to the SAG a day before the MAC meeting at the end of March 2004. As a result of consideration by the MAC and a stakeholder workshop (time to be determined), the objectives for the MSE can be articulated and worked into the model.

Unspecified commercial mackerel catch:
- Noted close correlation between 3 estimate approaches.
- Some discussion on whether all 3 estimate methods could be combined and an average used but rejected on the grounds of duplication of data.
- Noted that the Spanish mackerel allocation process is likely to reduce the quantity of unspecified mackerel as fishers attribute mackerel to their catch histories. The allocation process will take around 3 months to complete which is outside the timeframes of the spotted mackerel stock assessment but figures in the model can be adjusted down the track.
- Attendees agreed to employ the binary model approach because the approach takes into account a broad range of information while the other two methods take a broad-brush stroke approach.
- Suggested developing a simplified explanation of the binary method for the fisher workshops.

Species identification for recreational catches:
- 1997 survey had no drawings for identification while the later two RFISH surveys did. Noted that the unspecified data was lower in 1997 and suggested that armed with the drawings, fishers were less confident to guess the species.
- While there was no confidence as to species identification, agreed that relying on past information, even if inaccurate was necessary. Must attempt to improve the integrity of future surveys.

Unspecified mackerel recreational catches:
- Agreed that unspecified mackerel catch was significant and could not be ignored. There should be consistency with the commercial catch analysis.
- To achieve consistency and to incorporate as much information into the analysis as possible, the binary approach was supported as the most appropriate choice.

Mean weights:
- David Bateman had concerns over mean weight estimate for recreational fishing. He suggested its too low and will undermine recreational catches. Suggested using numbers as well as weights in the assessment for people to make their own conclusions.
- Generally agreed to use mean weights suggested by researchers.

Recreational catch estimates:
- Noted that the NRIFS tended to under-estimate catches compared to RFISH data.
- Discussion about the different nature of the RFISH survey methodology and the 1995 FRDC methodology.

- 1995 survey was more targeted toward mackerel fishers. Intensive investigation with quality contact giving more confidence in species identification and estimates of catches but potentially biased.
- Rfish was spread across state, taking broader, less biased sample. Brief contact by phone, less confidence in species identification.
- Were concerns expressed about such a large extrapolation up for the RFISH methodology?
- Suggested looking at the number of boats in each region and the size of boats going out.
- Noted that estimates are based on retained fish.
- Questioned the accuracy of data where 1997 was more than two times the commercial catch while in the other 4 years, it is half the commercial catch. Possible explanations:
  - market availability for commercial catches in later years
  - fish missed Hervey Bay in 1997, few commercial catches but picked up by recreational fishers in Moreton Bay etc. Data supports in early 1998 large decrease in commercial catches of Hervey Bay and increases in recreational catches in Moreton Bay for that period.
- Suggestion to drop 1997 data from the analysis but suggestion not widely supported. Unresolved issue. Agreed to a range of recreational fishing scenarios taking into account various factors.

Catch rate analysis:

- Noted catch rates were down in 1994-5, supports differences between 1995 survey and RFISH surveys.
- Noted general downward trend.
- Concern that the 0s have not been taken into account for catch rates. Incidental catches would bring figures down. Pointed out that standardisation would address these problems to a certain degree. Weightings for hyper stability take into account those targeting and not targeting.
  - Recommended: extra category for target/non target with additional weightings.
- Although there were concerns about assuming catch rate is indicative of abundance, agreed to use it subject to the appropriate weightings considering there are only a few years worth of age structure data.
- Concerns about using gear from New South Wales because of the generalised way fish are reported. Also concerns about how fishers would perceive the use of gear that intuitively would not be used for taking spotted mackerel. The question to ask is whether the capture of spotted mackerel taken by a particular method has anything to do with the abundance of spotted mackerel.
  - Suggested:
    - taking out fish trap and purse seine net data but noted that its inclusion does not alter the rate significantly
    - investigating the trawl and longline catches for accuracy
    - considering leaving out commercial line data and using other line data (except charter information from Moreton Bay)
    - contacting New South Wales about trolling to investigate whether the method would be used to take spotted mackerel
    - looking at, on a regional basis, where schooling mackerel is targeted (e.g., Innisfail) and separating those from other line data. Apply different weightings.
    - taking out years up to 1990 because of inaccuracy of early data.
    - picking out a sample of fishers that haven't changed their operations but generally rejected as this might cause bias.
    - Duncan Souter preferred using mixed weights because it seems more sensitive to differences.

Biology:

- Noted with interest.

Management implications for stock assessment:

- Noted that the in possession limit of 150 fish was implemented 6th December 2002 and not 1st May 2003.
- The netting ban was implemented into the legislation from 6th December but was phased in so that netters had until 1 May to cease operations. For the purpose of the stock assessment, two periods should be taken into account. From 6 December 2002 to 30 April 2003 fishers could continue to net for spotted mackerel with an in possession limit of 150 fish. From 1 May 2003 fishers could only take incidental catches of 15 fish or less by net (see below for discretion by boating patrol) and 150 in possession by line.
- While technically incidental catches of 15 or less were permitted from 19th December, it was originally intended that it would apply from the date of the netting ban. Boating Patrol had provided discretion to those who had incidental catches prior to the rectification on 19 December. For the purposes of the stock assessment, incidental catches should be taken as having applied from the effective implementation of the netting ban on 1st May 2003 (and not the date the ban was entered into the legislation (see above).
- Additional management changes:
    - Section 35 in the *Fishery and Industry Organisation and Marketing Act* where sale of recreational catches became unlawful (March? 1990).
    - Investment warning for the taking of spotted mackerel by any method (11 April 2002)
    - Declaration of Dugong Protection Areas/buybacks?

Management strategy evaluation:

- Noted that stakeholders would be developing the objectives for the MSE.
- Suggested building economic factors (e.g., more economical for ring netters to take spotted mackerel etc) and management costs (e.g., cost recovery) into the MSE.

General summary:

- Will use binary method for unspecified recreational and commercial catches of mackerel.
- Will look at different scenarios of various catch rates for recreational estimates.
- Will use target v. non-target and investigation of specific fishing methods for the catch rate analysis.

Appendix 4: Intellectual property

No patentable or marketable products or processes have arisen from this research. All results will be published in scientific and non-technical literature. The raw data from compulsory fishing logbooks remains the intellectual property of the Queensland Department of Primary Industries and Fisheries and the New South Wales Department of Primary Industries. Raw catch data provided by individual fishers to project staff remains the intellectual property of the fishers. Intellectual property accruing from the analysis and interpretation of raw data vests jointly with the CRC Reef Research Centre and the Principle Investigators.

Appendix 5: Staff

Principal Investigators: Gavin Begg, Michael O'Neill

Co-Investigator: Steven Cadrin

Research Assistant: Mikaela Bergenius

Database Manager: Gary Carlos

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