Determining appropriate sizes at harvest for species shared by the commercial trap and recreational fisheries in New South Wales

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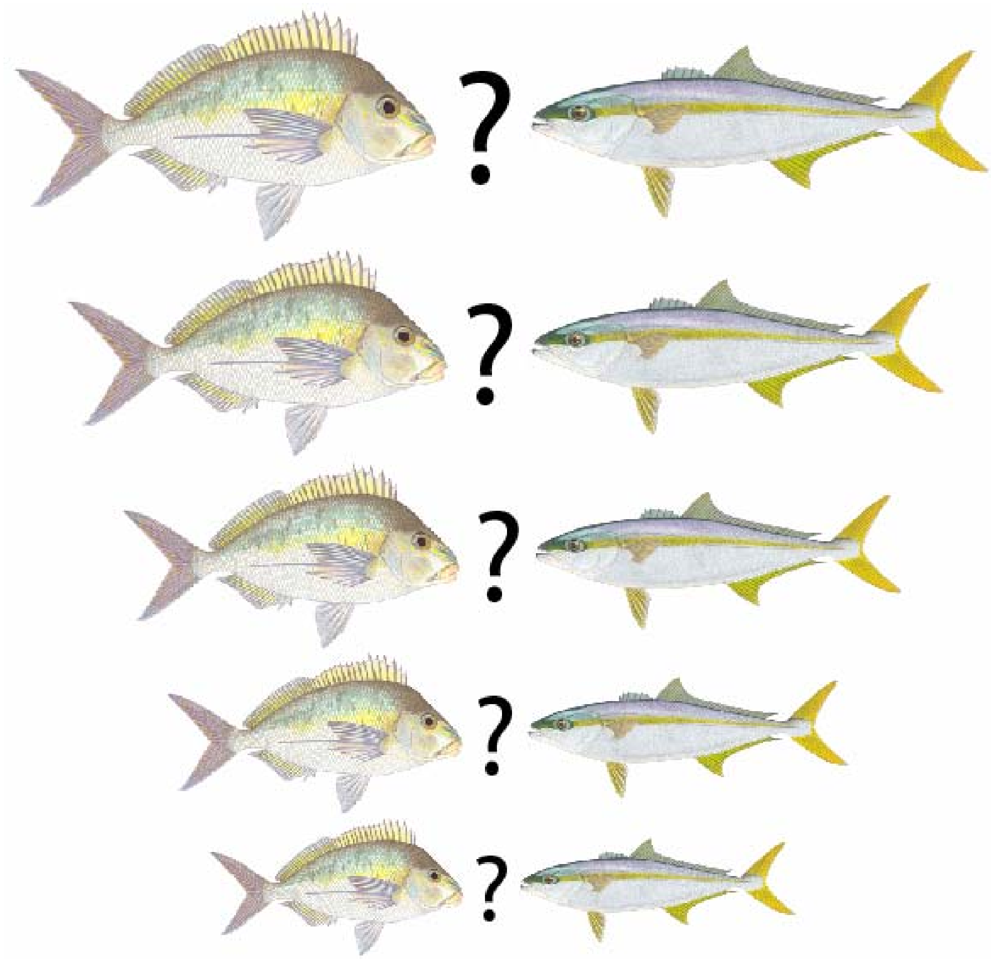

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NON-TECHNICAL SUMMARY

2004/035	Determining appropriate sizes at harvest for species shared by the commercial trap and recreational fisheries in New South Wales

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OBJECTIVES:

1) To develop a framework based on biological, economic and social information by which appropriate harvest sizes can be determined.

2) To recommend appropriate sizes at harvest for primary species shared by the commercial trap and recreational fisheries in NSW.

3) Where appropriate to recommend minimum legal lengths for species across all fisheries.

NON TECHNICAL SUMMARY:

Outcomes Achieved
The study has achieved all of the outcomes proposed. New information on the biology and fisheries for coastal species that are important to both commercial and recreational fishers has been provided. The work done on six species (rubberlip morwong, tarwhine, blackspot pigfish, maori wrasse, red rockcod and pearl perch) has provided the first information available for the east coast of Australia and often for the entire species. The new information on age, growth, sexual maturity, spawning seasons, mortality estimates and fishery landings has already been incorporated into improved resource assessments for these species. In addition, new analyses were done using existing information on another seven species and the results will be used in future resource assessments. Information on the biology, fisheries and market prices for 13 species were used in developing a framework that can be used when determining appropriate sizes at first harvest. The framework encourages management objectives to be clearly defined and incorporates the available information in a transparent manner. The multi-criteria decision analysis (MCDA) method is used to determine how well different lengths at first harvest satisfy management objectives, and provides an optimal solution based on relative weightings of importance of each objective. The MCDA framework is used to recommend optimal sizes at first harvest for all 13 species based on biological information.

There has been concern that many exploited coastal species in NSW are in decline, and that there is insufficient biological or fishery information on which to assess their stock status and base management decisions. There has also been ongoing debate regarding sensible management of these coastal species, particularly with respect to suitable minimum legal lengths and gear selectivity in the demersal trap fishery. This study aims to increase knowledge of the biology and fisheries for coastal species that are harvested by commercial and recreational fishers. New information is used in improved resource assessments and in demonstration of a framework that can be used when setting minimum sizes at first harvest, through either minimum legal lengths or gear selectivity.

Analyses of biological and fishery information for 13 important species indicated that, in general, these coastal species in NSW are heavily exploited. Five of the 13 species are assessed as being overfished, six fully fished and two moderately fished. The proportion of the catch taken by recreational fishers is increasing and many species are now predominantly harvested by this sector. This suggests that recreational fishing pressure is a major contributing present-day factor in the decline of many species. The relative increases in catch by the recreational and charterboat fisheries highlight the importance of incorporating landings from these sectors into fishery assessments.

The species studied were characterised by being generally long-lived (15 to 50 years), and maturing sexually at relatively small sizes and young ages (2 to 3 years old). Landings of species with a long history of exploitation were dominated by a few young age classes, resulting in relatively high estimates of total mortality (from age-based catch curves) and low estimates of natural mortality (based on maximum age). Those species that have historically been considered as by-catch (e.g., blackspot pigfish, red rockcod, maori wrasse and sweep) were characterised by age compositions in landings that were based on many year classes with relatively large numbers of older fish in landings. The concern for these species is that, as their popularity with fishers increases (due to declines in more desirable species), they too have the potential to become severely depleted if their sizes at first harvest are not set at levels that promote sustainability of stocks.

A major conclusion from the present study is that local biological information is required for assessment and management of local fisheries. Basic life-history traits such as age, growth, longevity, sizes and ages at sexual maturity and reproductive seasons were shown to vary substantially between populations of the same species in other states (e.g., tarwhine, pearl perch, ocean leatherjackets, bream, mulloway, snapper and silver trevally). Each population may therefore respond differently to exploitation and management based on non-local biological parameters may be high risk.

The multi-criteria decision analysis (MCDA) framework for deciding on the 'best' size at which to first harvest a species is a major improvement on existing arrangements because it: (i) requires objectives of management to be clearly stated; (ii) can integrate all available information; (iii) documents trade-offs between conflicting objectives and stakeholders, and; (iv) encourages transparent decision making and accountability. The optimal solutions from the MCDA are therefore publicly defensible and can be used to justify management decisions. The MCDA may provide additional benefits including: (i) identifying areas where information is lacking and; (ii) providing a mechanism for performance assessment of management changes in achieving the pre-defined objectives.

In demonstrating the MCDA framework we have recommended sizes at first harvest for 13 species, based only on information on biology and sustainability. Recommended sizes are greater than the current minimum legal lengths for all species except for rubberlip morwong. This observation suggests that current management arrangements may not be promoting the sustainability of fisheries for these species. We therefore urge fisheries managers to incorporate objectives that pertain to sustainability when using the MCDA framework to decide on appropriate sizes at first harvest. Finally, once appropriate sizes at first harvest are determined managers must decide whether they are implemented through regulated minimum legal lengths, gear selectivity or both.

KEYWORDS: Minimum legal lengths, multi-criteria decision analysis, age, growth, reproduction, morwong, tarwhine, blackspot pigfish, maori wrasse, red rockcod, pearl perch, ocean leatherjackets, bream, yellowtail kingfish, mulloway, snapper, sweep, silver trevally.

1. INTRODUCTION

1.1. Background

This project was supported by funding from the Fisheries Research & Development Corporation (FRDC), the New South Wales Recreational Fishing Saltwater Trust and the New South Wales Department of Primary Industries (NSW DPI). The project was initiated in response to concerns that many species harvested by the NSW Ocean Trap & Line Fishery and offshore recreational fishers were in decline and there existed little biological information on which to base assessments or management decisions. A previous FRDC funded project on trap mesh selectivity (FRDC project No. 98/138) identified several species that either had inappropriate minimum legal lengths (MLLs) or were being harvested at sizes that were too small. An outcome from this previous project was that commercial fish traps in ocean waters of NSW were to incorporate escape panels of 50 x 75 mm mesh to reduce the capture of small fish. Associated with the implementation of escape panels in fish traps was a debate about the appropriate sizes at which many important species should be harvested by both commercial and recreational fishers. NSW DPI currently control the size at first harvest of species though gear selectivity and regulated MLLs.

Consultation with commercial and recreational fishing representatives, the Nature Conservation Council and NSW DPI scientists and managers resulted in the conclusions that: (i) all important coastal species should be examined for potential growth overfishing, and; (ii) appropriate sizes at harvest should be set for these species across all fisheries.

1.2. Need

Previous FRDC funded studies on the biology and fisheries for exploited coastal species in NSW have concluded that they were growth overfished (e.g., snapper, project no. 93/074; silver trevally, project no. 97/125; yellowtail kingfish, project no. 97/126 and; mulloway, project no. 2002/05). Many other coastal species are in decline and may also be growth overfished, yet there is insufficient information available to make these assessments. The growth overfished status and declines in landings apparent for coastal species could be addressed by increasing the size at which they are recruited to the fishery. Currently, most species either have MLLs that are too small or do not have MLLs at all.

Currently there are no formal policies for setting MLLs in NSW (or elsewhere in Australia), and fisheries management agencies justify the use of MLLs for a range of reasons. Generally justification revolves around protecting juvenile fish; however in practice MLLs appear to be rarely set at sizes big enough to do so. This may be because factors other than those directly related to protecting juveniles are influencing the decision making process. There is a need for a framework that can assist decision makers by allowing longer-term benefits to be weighed against short-term costs when setting MLLs.

1.3. Objectives

1) To develop a framework based on biological, economic and social information by which appropriate harvest sizes can be determined.
2) To recommend appropriate sizes at harvest for primary species shared by the commercial trap and recreational fisheries in NSW.
3) Where appropriate, to recommend minimum legal lengths for species across all fisheries.

2. GENERAL MATERIALS AND METHODS

Information on the biology and fisheries for six species in NSW were investigated for the first time during the present study. Those species were rubberlip morwong (*Nemadactylus douglasii*), tarwhine (*Rhabdosargus sarba*), blackspot pigfish (*Bodianus unimaculatus*), maori wrasse (*Opthalmolepis lineolatus*), red rockcod (*Scorpaena cardinalis*) and pearl perch (*Glaucosoma scapulare*). The methods described in the present chapter are generic for these six species; however more detailed methods are described in their individual chapters. Routine sampling was done between January 2005 and January 2006, and some supplementary material was collected during 2006. Information on ocean leatherjackets (*Nelusetta ayraudi*), yellowfin bream (*Acanthopagrus australis*), yellowtail kingfish (*Seriola lalandi*), mulloway (*Argyrosomus japonicus*), snapper (*Pagrus auratus*), sweep (*Scorpis lineolatus*) and silver trevally (*Pseudocaranx dentex*) was sourced from previous studies that are referenced in each specific chapter.

2.1. Landings in NSW

The exploitation status of each species was taken from the current (2005/06) NSW DPI Aquatic Resource Assessment (RAS) designations. The characteristics of the categories of exploitation status are provided in Table 2.1.

Trends in landings through time were described for the NSW commercial and recreational fisheries. Commercial catch and effort information was sourced from the NSW DPI commercial catch records. Commercial catch rate was calculated as a catch per unit of effort (CPUE) for the major method used to catch each species. The catch reporting procedure allowed calculation of CPUE for 1997/98 onwards. The most recent estimates of recreational catches in NSW (landed and released) for each species were obtained from the National Recreational and Indigenous Fishing Survey for the period April 2000 to March 2001 (Henry & Lyle, 2003). In some instances the estimated weights of landed catches were recalculated using the observed average sizes in recreational landings (Steffe *et al.*, 1996).

The lengths of fish in landed catches were documented for commercial and recreational fisheries in NSW. The lengths of fish in the commercial fishery were obtained either during the present study, from previously published studies or from the ongoing NSW DPI Resource Assessment Monitoring Program. Species measured as a part of the present study were done so either at the Sydney Fish Markets or at regional fishermen's co-operatives. Species with a forked tail (e.g., tarwhine) were measured as fork length (FL), and species with a rounded tail (e.g., red rockcod) were measured as total length (TL), to the nearest whole centimetre below the true length. Only fish caught by the method of fish trapping were measured because the study is concerned with the commercial Ocean Trap & Line Fishery. The sizes and proportions of fish discarded by commercial fishers were sourced from previous studies.

The lengths of fish retained by recreational trailerboat fishers were sourced from Steffe *et al.* (1996). The lengths of fish retained by NSW charterboat fishers were sourced from the NSW DPI charterboat database for the period 2001 to 2003. All charterboat operators in NSW are required by law to submit daily logs detailing their retained catch. These daily logs provide information on the areas fished, as well as numbers and lengths of retained species. Fish are required to be measured as FL. In addition to the information on the retained charterboat catch, we enlisted the help of several volunteer charterboat operators to collect information (species, lengths) on their discarded catch.

Table 2.1. Characteristics of the categories of exploitation status used by NSW DPI.

Category	Characteristics
Recruitment Overfished	• Recruitment is being significantly or measurably suppressed as a result of a small spawning biomass. • Other characteristics of an 'overfished' stock (see below) are likely to be evident. • Unequivocal determination will require a well-calibrated population model or stock-recruitment relationship.
Overfished	• Fishing mortality rates are more than double natural mortality rates. • Estimates of biomass are less than 30% of the estimated unfished stock. • Catch rates are less than 30% of the initial catch rates. • Length and age distributions unstable (excessively affected by recruitment, too few age or size classes in the exploitable population given a species' life history). • Trends in length/age compositions are evident which indicate increasing (and/or excessive) fishing mortality. • The spawning potential ratio is less than 20%.
Growth Overfished	• Yield per recruit would increase if length at first capture was increased or fishing mortality decreased.
Fully Fished	• Fishing mortality is approximately the same as natural mortality. • Estimates of the biomass are greater than 30% of the estimated unfished biomass. • Catch rates have been steady for 5 – 10 years and/or catch rates are greater than 30% of initial catch rates. • Length and age distributions are stable. • Species are fished throughout their entire geographic range.
Moderately Fished	• Fishing mortality is less than half of natural mortality. • Estimates of the biomass are greater than 70% of the estimated unfished biomass. • Catch rates are greater than 70% of initial catch rates. • Species are fished in most of their geographic range but non-fishing areas are known to exist.
Lightly Fished	• Fishing mortality less than 25% of natural mortality. • Estimates of the biomass are greater than 90% of the estimated unfished biomass. • Catch rates are greater than 90% of initial catch rates. • Only small proportions of the geographic range are fished. • Markets would likely limit catch and effort.
Uncertain	• A significant amount of evidence has been collected and considered, but there are inconsistent or contradictory signals in the data that preclude determination of exploitation status.
Undefined	• Catch data are available but no reasonable attempt has been made to determine exploitation status.

2.2. Reproduction

The gonads of fish of both sexes were macroscopically examined and a reproductive stage assigned according to the developmental criteria outlined in Tables 2.2 and 2.3. Stages were adapted from those used by Leavastu (1965). Fish were weighed to the nearest 0.1g, the gonads were then removed and weighed to the nearest 0.01g.

Table 2.2. Macroscopic ovary staging schedule used to assign reproductive stages to female fish.

Stage	Characteristics
1- Immature	Ovaries small and threadlike, white in colour. Determination of sex difficult.
2- Developing/Resting	Ova visible inside ovaries and are white or pale yellow. Some large, clear ova may be visible in resting ovaries. A blood vessel runs along the dorso-lateral surface of the ovary, smaller ramifying vessels branching off may also be visible.
3- Ripe	Ovaries are much larger than Stage 2. Only the large blood vessel is obvious. Ovary wall thin and easily ruptured. Hydrated ova visible through ovary wall.
4- Running Ripe	Ova shed through genital pore with gentle pressure on abdomen. Largest blood vessel still obvious.
5- Spent	Ovary flaccid, tough and leathery. May be bloodshot toward posterior end. Some large, clear residual ova remain. Many ova of smaller size classes may be visible.

Table 2.3. Macroscopic teste staging schedule used to assign reproductive stages to male fish.

Stage	Characteristics
1- Immature	Testes small and threadlike, white in colour. Determination of sex difficult.
2- Developing/Resting	Testes cream in colour, fragile, flattened and strap-like, and lie up against body wall. Posterior end tubular and white in resting testes.
3- Ripe	Testes much larger than Stage 2. Posterior end is white where milt is accumulating.
4- Running Ripe	White milt extruded with gentle pressure on abdomen. Testes soft and white.
5- Spent	Testes rubbery, reduced in size and bloodshot.

Gonadosomatic indices (GSI) were calculated using the following equation:

$$GSI = (W_g / W_w) * 100$$

Where: W_g = gonad weight, and W_w = whole fish weight.

The size and age at sexual maturity of both sexes for each species was estimated using the gonad stage assignments (Tables 2.2 and 2.3). Fish were classed as being either mature (> stage 2 during the spawning season or > stage 1 outside of the spawning season) or immature (< stage 3 during the spawning season or stage 1 outside of the spawning season). Targeted sampling during the spawning season was not possible for all species due to the short nature of the study and a lack of knowledge of spawning seasons. The proportion of fish assigned as being mature in each 1 cm length class or year class was calculated and logistic curves were fitted to the data using non-linear least squares procedures in Microsoft Excel (Solver).

2.3. Age and growth

Estimates of age were made by examining otolith sections. One of each pair of sagittal otoliths was embedded in resin, sectioned transversely through the core using a diamond saw (Gemmasta, Shell-lap Supplies P/L), and the section mounted on a glass microscope slide. The section was then viewed using a compound microscope using reflected light against a black background. Opaque zones visible in the otolith sections were scored, and measurements were made from the core to each opaque zone and to the otolith edge. All measurements were made along the dorsal edge of the sulcus using a microscope mounted video camera (Pixelink PL-A662) interfaced with a computer running Image Pro Plus (Media Cybernetics Inc.) image analysis software.

Marginal increment analyses were used to examine the periodicity of opaque zone appearance in otoliths of the species assessed during the study. The marginal increment was defined as follows: for fish aged 0+ years as the distance (in mm) from the core to the otolith edge along the dorsal edge of the sulcus; for fish aged 1+ as the distance from the first opaque zone to the otolith edge as a proportion of the first complete annulus, and; for fish aged 2+ and greater as the distance from the most recently completed opaque zone to the otolith edge as a proportion of the last completed increment. These measurements were made for all fish collected for age determination. In addition, each otolith margin was assigned as being either opaque or translucent when its section was examined for age determination. The timing of appearance of opaque otolith edges was also used to examine annual periodicity in otolith growth.

An ageing protocol was developed for each species. Generally, classifications into age classes were done based on a universal birth date (set at the middle of the spawning season), the number of opaque zones counted, the state of the otolith edge (either translucent or opaque) and the month of capture. Ages were estimated to be the age class plus the proportion of the year following the universal birthday to the date of capture.

All otoliths from each species were re-read to examine the precision of our estimates of counts of opaque zones. The coefficient of variation (cv) for the two readings for each otolith was calculated and an average across all otoliths for each species obtained after the method described in Kimura and Lyons (1991) and Campana (2001).

The size-at-age data were fitted to the von Bertalanffy growth function (VBGF):

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

Where L_t is the length at age t, L_∞ is the asymptotic length, k is the rate at which the curve approaches the L_∞, and t_0 is the theoretical age of the fish at zero length. The growth curves for male and female fish from each species were compared using the analysis of residual sums of squares (ARSS) method (Chen *et al.*, 1992).

Estimates of the age composition in commercial landings were made using the size compositions determined and age-length keys. The age-length keys were determined after the methods of Kimura (1977) and Lai (1993) and were constructed using the estimates of size-at-age determined in each of the chapters for each species.

2.4. Mortality estimates

Estimates of total mortality (Z) were made from the slope of the descending limb of the catch curve (i.e., by fitting a regression to the natural logarithm of age frequency against age for all fully recruited age classes). The method assumes constant spawning recruitment and survival for all cohorts. This method was considered suitable for the present study because for most species there was only a snapshot of age composition data. More robust estimates of Z could be obtained in future studies, if time series of age composition data exist, by using longitudinal catch curves. Longitudinal catch curves estimate mortality for each year class and so do not require the assumption of constant spawning recruitment.

An estimate of natural mortality (M) was made after the method of Hoenig (1983) for exploited populations based on either 1% or 5% of fish attaining the maximum age for the species.

Estimates of fishing mortality (F) were made by subtracting the estimates of M from Z.

2.5. Market price

Information on the sizes of fish within each size-grade, and the average price ($/kg) for each species and size-grade sold through the Sydney Fish Markets was obtained for 2005/06.

2.6. Per recruit analyses

Yield and $ per recruit analyses (YPR & $PR) were done for each species using the described information on growth, mortality and value. Analyses were done using the most likely estimates of mortality rates. The per recruit analyses were done using a variant of the Beverton & Holt (1957) model described in www.fishbase.org as case III. The model describes YPR in terms of exploitation rate (E = F/Z) and size at first capture (length at capture/L_∞). This approach was used because in the present study we required information that was related to fish length rather than age. Input parameters include the von Bertalanffy growth function parameters and estimates of mortality rates. Values of $PR were calculated as the YPR at each length multiplied by the value ($/kg) of that size of fish when sold through the Sydney Fish Markets. In cases where fish were smaller than those currently landed (due to current MLLs, market preference or gear selectivity) they were assigned an average $/kg for the smallest size-grade.

The standard caveats regarding the interpretation of YPR apply. In particular we have done the analyses for the most likely point estimates of mortality only. This approach is reasonable given that the information is being generated only to be used in the demonstration of the framework for determining appropriate sizes at first harvest in Chapter 16. However, any future assessments would benefit from examining the per recruit analyses using a range of mortality estimates. In addition, YPR in the framework in Chapter 16 is being used as a proxy for yield from the resource. Yield is the product of YPR and the number of fish in the catch.

2.7. Spawning potential ratio

The spawning potential ratio (SPR) is an index of the reproductive health of an exploited population. The SPR is a proxy for the ability of a population to spawn sufficient eggs to provide adequate recruitment. The SPR is measured as the potential number of eggs able to be spawned by a fished population as a proportion of the potential number of eggs able to be spawned by an unfished population. The potential number of eggs spawned is calculated by the summing the number of mature females in each age class in the population multiplied by their fecundity. Fecundity here was assumed to be proportional to body weight.

Threshold levels of SPR to ensure population persistence have been examined by Mace & Sissenwine (1993) with the conclusion that larger demersal fish like gadoids (cods) can persist at relatively low levels of SPR, while smaller demersal species and pelagic species require relatively high levels of SPR to ensure population replacement. The recommended conservative threshold level of SPR for species for which the stock-recruitment relationship is unknown is 0.30 (Mace &

Sissenwine, 1993). However, this level may be too conservative for the larger demersal species and a threshold of 0.20 is often used for such species (Goodyear, 1993). There are no stock-recruitment data for the species assessed in the present study; however because of their life-history patterns and habits a threshold SPR level of 0.2 is applied. Note that the SPR of 0.2 is a threshold, not a target, and that levels below the threshold should be avoided.

2.8. Information fact sheets

Information of relevance to discussions of MLLs was compiled for each species in colour fact sheets. The information was presented as total lengths in these fact sheets. The fact sheets are provided as examples of the type of information that stakeholders could be given to assist in making comment on future size-limit reviews.

3. BIOLOGY AND FISHERY FOR RUBBERLIP MORWONG

3.1. Introduction

Rubberlip morwong (*Nemadactylus douglasii*) of the family Cheilodactylidae are distributed along the south-eastern Australian coastline in continental shelf waters from Moreton Bay in Queensland to Wilsons Promontory in Victoria. They can also be found along the east coast of Tasmania to Storm Bay and are also present around the north island of New Zealand (www.fishbase.org). Rubberlip morwong are variously known as blue or grey morwong and porae in New Zealand. Morwongs are characterised by having enlarged pectoral fins, small mouths with large fleshy lips and a pelagic early juvenile stage known as a 'paperfish' (Lowry & Cappo, 1999).

In NSW, rubberlip morwong are an important component of the offshore commercial and recreational fisheries. The recreational catch is estimated to be approximately three times the commercial catch. The majority (~ 80%) of commercially landed rubberlip morwong are landed in the Ocean Trap & Line Fishery, of which ~ 82% are taken using demersal fish traps. Rubberlip morwong ranked as the 5th highest in importance by weight in the NSW demersal trap fishery during 2005/06. There is currently a MLL of 28 cm TL for rubberlip morwong in NSW.

Prior to the present study almost nothing was known of the biology or fishery for rubberlip morwong. In this chapter we investigate the biology and fishery for rubberlip morwong and present information that will assist in determining an appropriate size at first harvest.

3.2. Materials and methods

The majority of rubberlip morwong were sampled according to the methods outlined in Chapter 2. Fish smaller than the MLL were collected by observers' onboard commercial vessels. Additional sampling to estimate the size at sexual maturity was done during the spawning season in May 2006. During this time 251 rubberlip morwong were examined and their stage of reproductive maturity assigned. These fish were chosen to span the expected sizes through which fish would be maturing and ranged from 17 to 33 cm FL. Modal progression of small rubberlip morwong off the coast of NSW was followed to assist in identification of the first annual opaque zone. These size compositions were obtained from cruise reports for the FRV *Kapala* whilst using fish trawling gear during 1993 and 1994.

3.3. Results

3.3.1. Landings in NSW

3.3.1.1. Current exploitation status

Rubberlip morwong are listed as being FULLY FISHED in NSW (2005/06). They were previously listed as being UNDEFINED and the 2005/06 assessment was based on preliminary information from the current project and long term declines in catch rates and average sizes.

3.3.1.2. Trends in catch

Reported commercial landings of rubberlip morwong have declined steadily from ~ 600 t per year during the early 1980s to ~ 50 t per year since 2001/02 (Fig. 3.1). This decline has been associated with a decline in catch rates since 1997/98, although a slight improvement has been evident during the past 3 years (Fig. 3.1). The most recent estimate of the recreational harvest in NSW was ~ 140 tonnes between April 2000 and March 2001 (Henry & Lyle, 2003).

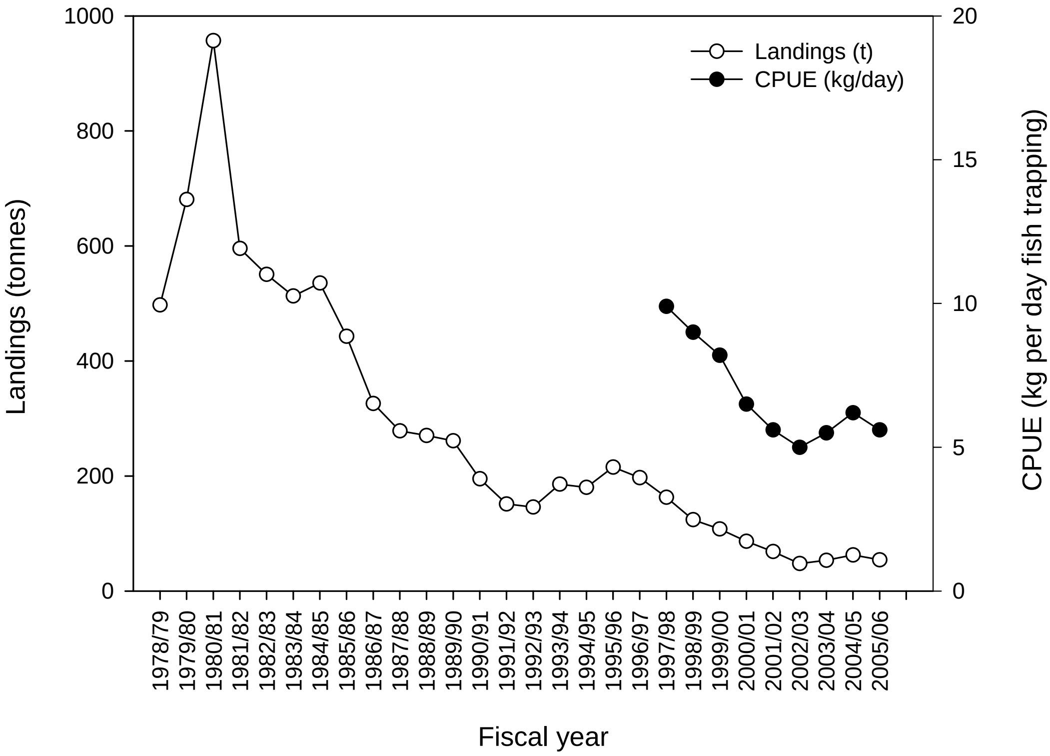


Figure 3.1. Reported commercial landings and catch rates (kg per day fish trapping) of rubberlip morwong in NSW. Source: NSW DPI Resource Assessment System.

3.3.1.3. Length measurements

Commercial landings

The sizes of rubberlip morwong captured by trap and line fishers were measured at the Sydney Fish markets and regional co-ops during the study. A total of 2,820 rubberlip morwong were measured and ranged between 21 and 52 cm FL (Fig. 3.2). Relatively few (~ 7%) rubberlip morwong were greater than 35 cm FL.

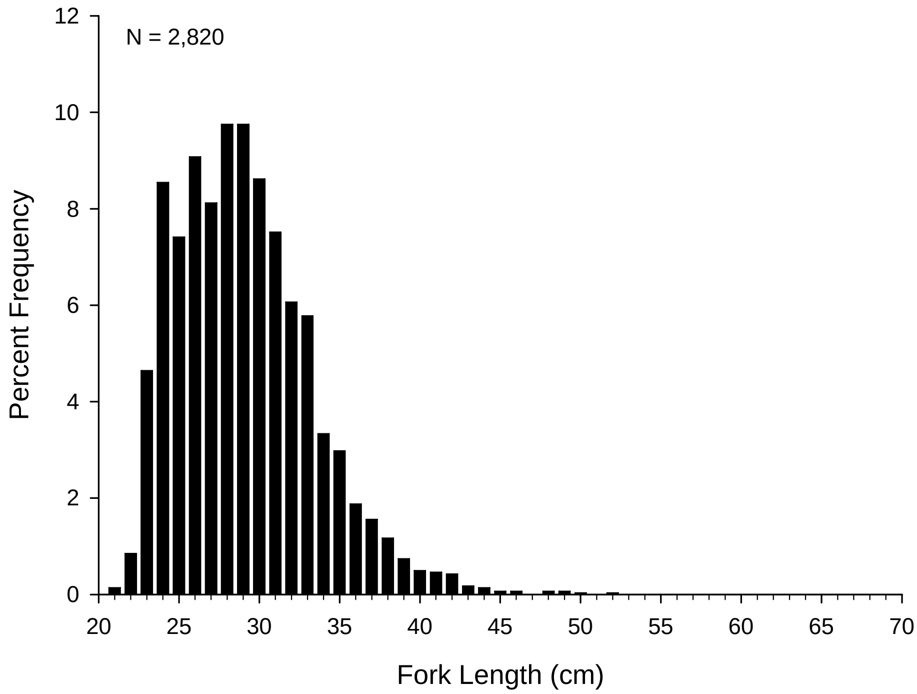


Figure 3.2. The lengths of rubberlip morwong landed by the NSW trap and line fishery during 2005/06.

Data from a previous FRDC funded project showed that rubberlip morwong as small as 18 cm FL are retained in fish traps covered with 50mm hexagonal wire and that ~ 25% of the catch is under the MLL and discarded (Stewart & Ferrell, 2001).

Recreational landings

Rubberlip morwong landed by recreational fishers are, on average, larger than those landed by commercial fishers, with the most abundant length classes being ~ 35 to 40 cm FL (Fig. 3.3). The sizes of rubberlip morwong reported by charterboat fishers during 2001 to 2003 (Fig. 3.4) were similar to those measured from trailerboat fishers and suggests that the sizes of fish available to line fishers has not changed markedly between the early 1990s and early 2000s.

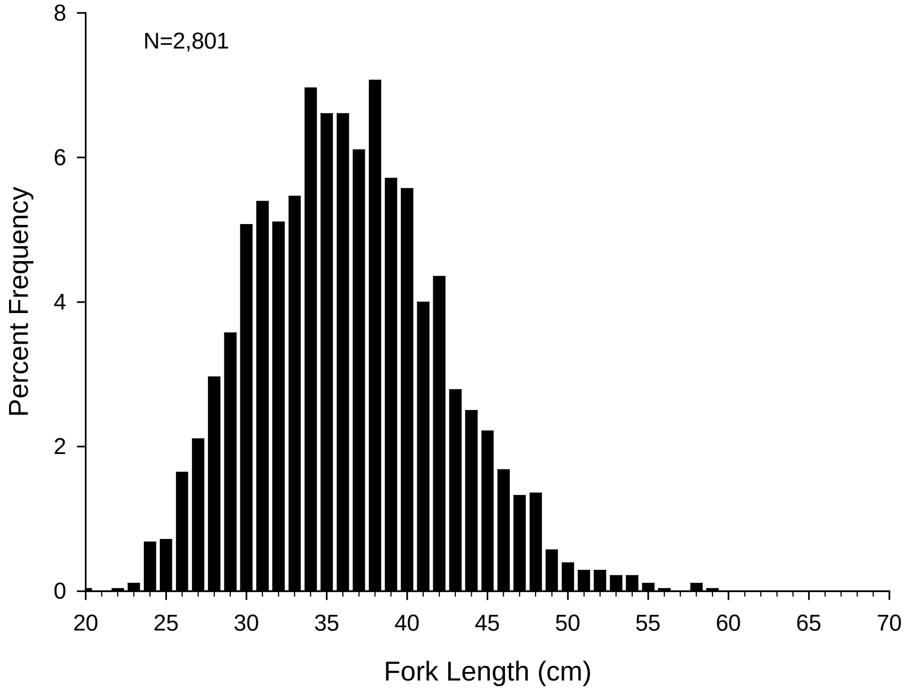


Figure 3.3. The lengths of rubberlip morwong landed by offshore trailerboat fishers 1993/94 and 1994/95. Source: Steffe *et al.*, 1996.

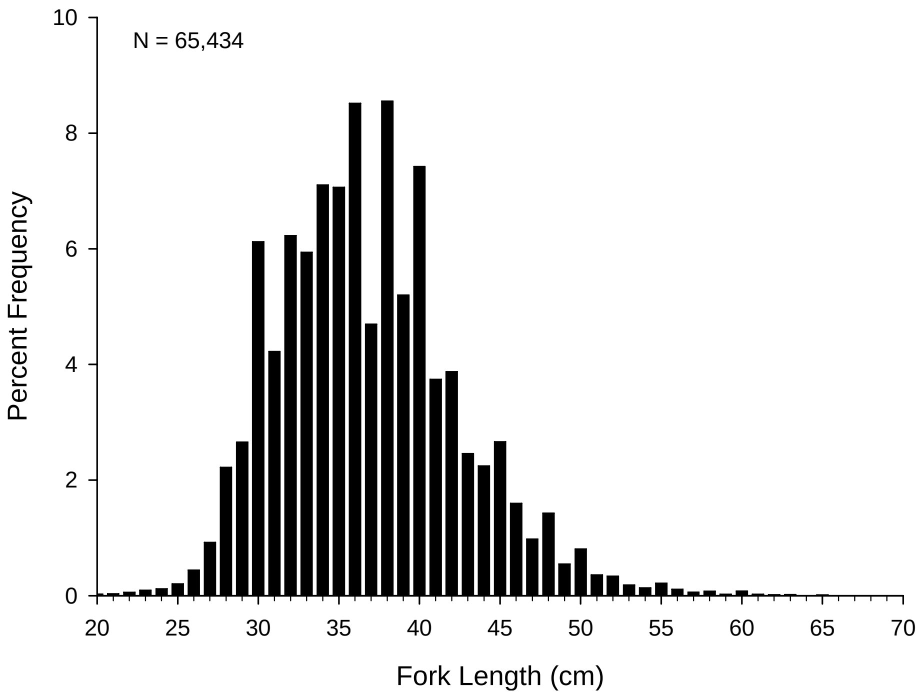


Figure 3.4. The lengths of rubberlip morwong measured by NSW charterboat operators 2001 to 2003.

Rubberlip morwong smaller than the MLL of 28 cm TL are rarely captured by recreational fishers and as a result only a small proportion are discarded. Only eight rubberlip morwong were reported as being discarded by voluntary logbook fishers and they ranged between 23 and 33 cm FL.

The TL to FL relationship for rubberlip morwong was described by the equation:

$TL = 1.18*FL + 0.57$ ($r^2 = 0.994$)

3.3.2. Reproduction

There were significantly more males (427) than females (358) observed during the present study (chi-square test, $p < 0.05$). The overall ratio of M:F was 1:0.84.

3.3.2.1. Seasonality of spawning

Rubberlip morwong displayed a spawning period between April and June (Figs 3.5 & 3.6). Running ripe females were observed during May and June and spent fish were present during June, August and September.

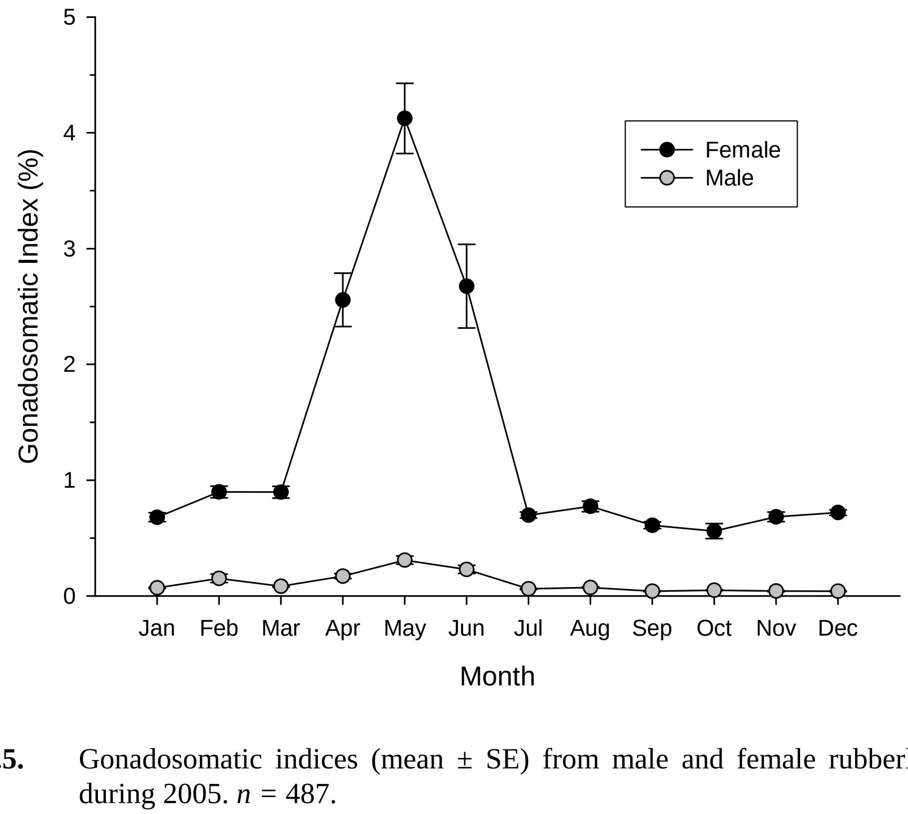


Figure 3.5. Gonadosomatic indices (mean ± SE) from male and female rubberlip morwong during 2005. *n* = 487.

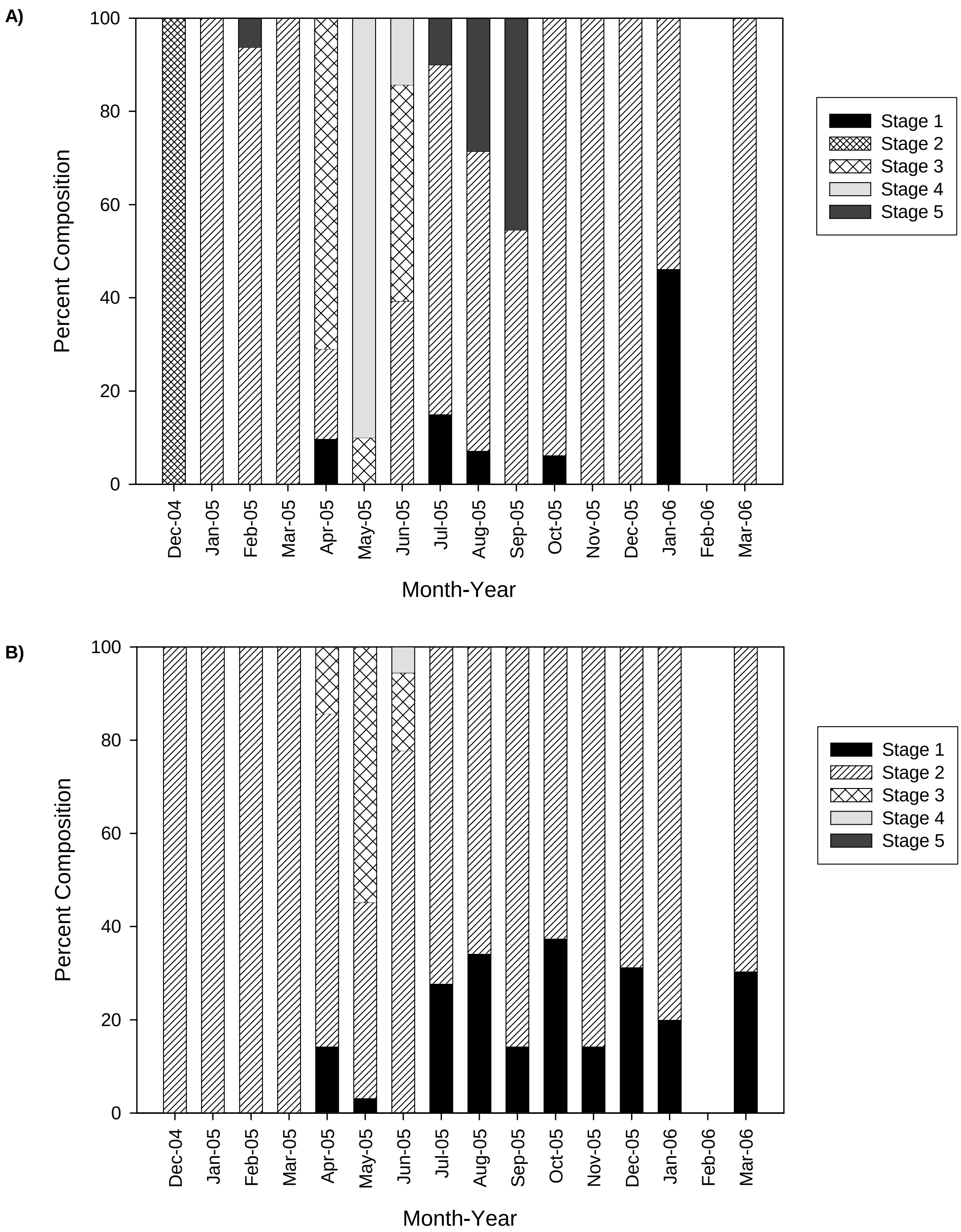


Figure 3.6. Monthly gonad stages of A) female and B) male rubberlip morwong.

3.3.2.2. Size at maturity

There was no significant difference between maturity curves for males and females (Wald's test, $p > 0.05$). The data were therefore combined and showed that rubberlip morwong matured at between ~ 19 and 26 cm FL, with 50% being mature at 21.2 cm FL (~ 25.5 cm TL) (Fig. 3.7).

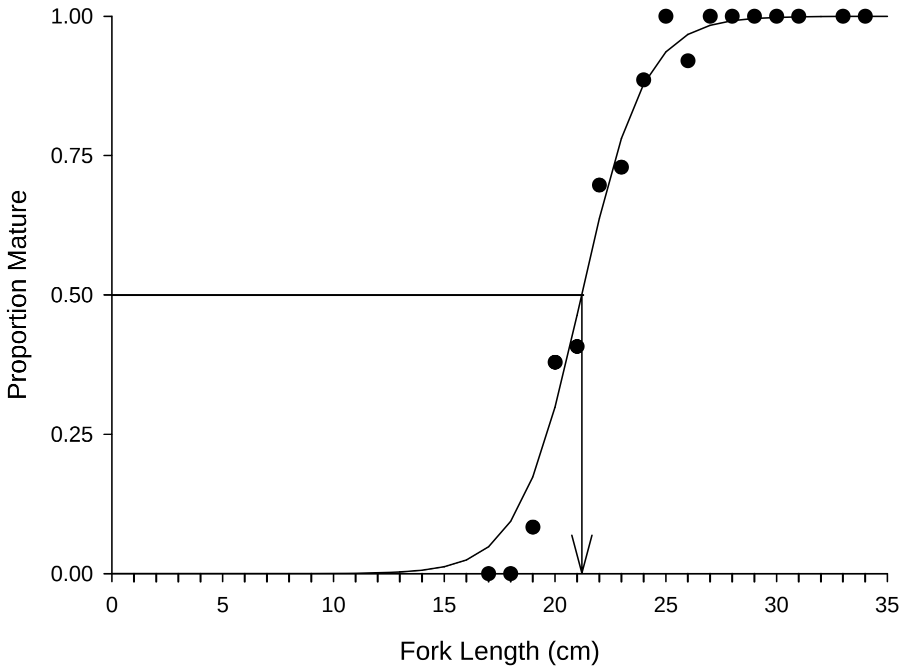


Figure 3.7. Reproductive maturity data with fitted logistic curve for rubberlip morwong. The arrow indicates the size at 50% maturity. $n = 272$.

3.3.3. Age and growth

3.3.3.1. Ageing procedure and validation

The size and age at which the first true annual opaque zone was formed was estimated by following the size compositions for small rubberlip morwong taken during surveys by the FRV *Kapala* (Fig. 3.8). Rubberlip morwong are spawned around May (Fig. 3.5) and the 0+ cohort was apparent as fish ~ 11 cm FL during the first yearly quarter. These fish were therefore ~ 9 months old. Newly formed opaque zones in rubberlip morwong were identified by March (Fig. 3.9), approximately 10 months after the universal birthday. Algorithms were therefore developed to correct for errors due to this discrepancy between time of birth and time of opaque zone appearance. The first algorithm addressed over-ageing fish sampled between the time of opaque zone identification (March) and the universal birthday (15th May) by removing 1 from the opaque zone count. Fish sampled between the birthday and February retained their opaque zone count. The second algorithm then addressed errors from identifying newly formed opaque zones near the otolith margin between the birthday and February. Fish with narrow otolith margins (a marginal increment < 0.4) during these months were deemed to have had a recently formed opaque zone identified and their opaque zone counts were adjusted by subtracting 1. Finally, ages were adjusted to include days between the universal birthday and capture date.

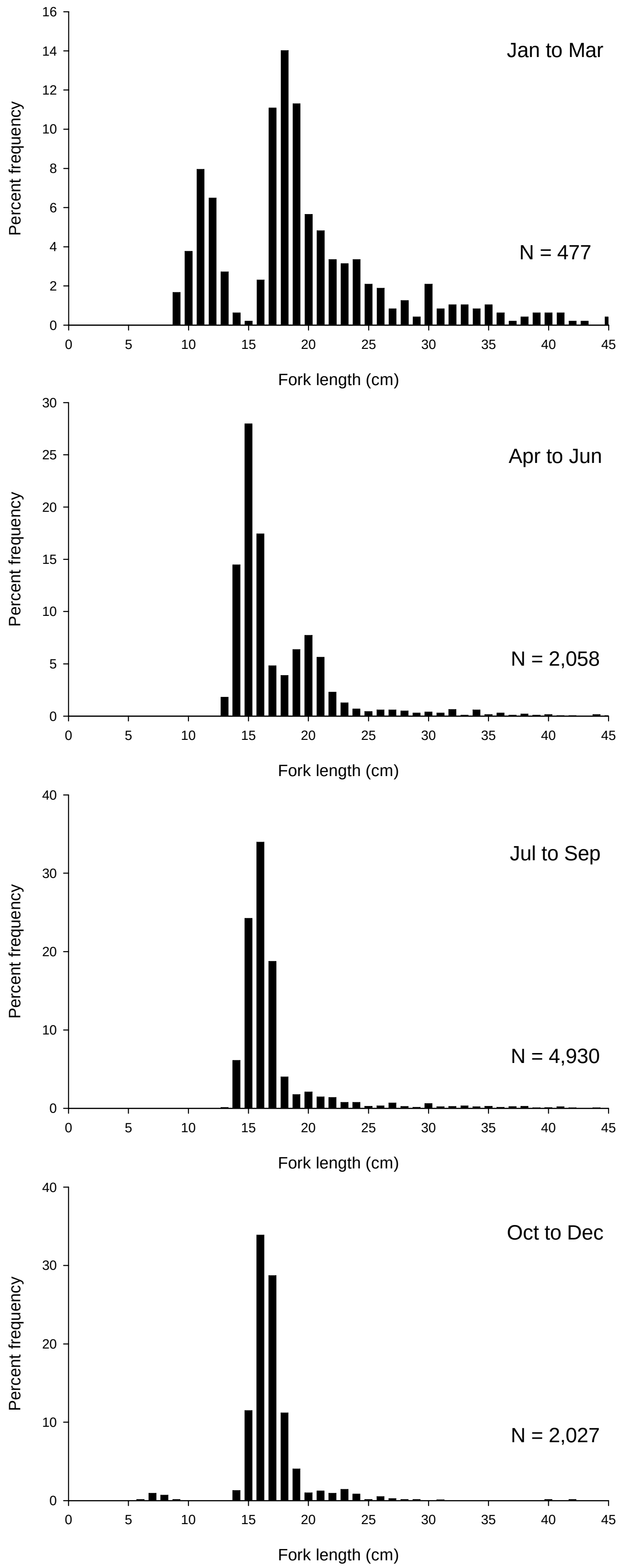


Figure 3.8. The sizes of rubberlip morwong captured by the FRV *Kapala* for each yearly quarter.

Patterns in monthly marginal increments (Fig. 3.9) and the proportions of otoliths having opaque edges (Fig. 3.10) were consistent with annual periodicity of opaque zone formation. Considerable variation in marginal increments occurred each month, but a seasonal pattern was evident with low values in March and higher values throughout the rest of the year. Otoliths with opaque edges were most common during November to January, and by March most otoliths were assessed as having completed opaque zones relatively near to the otolith edge.

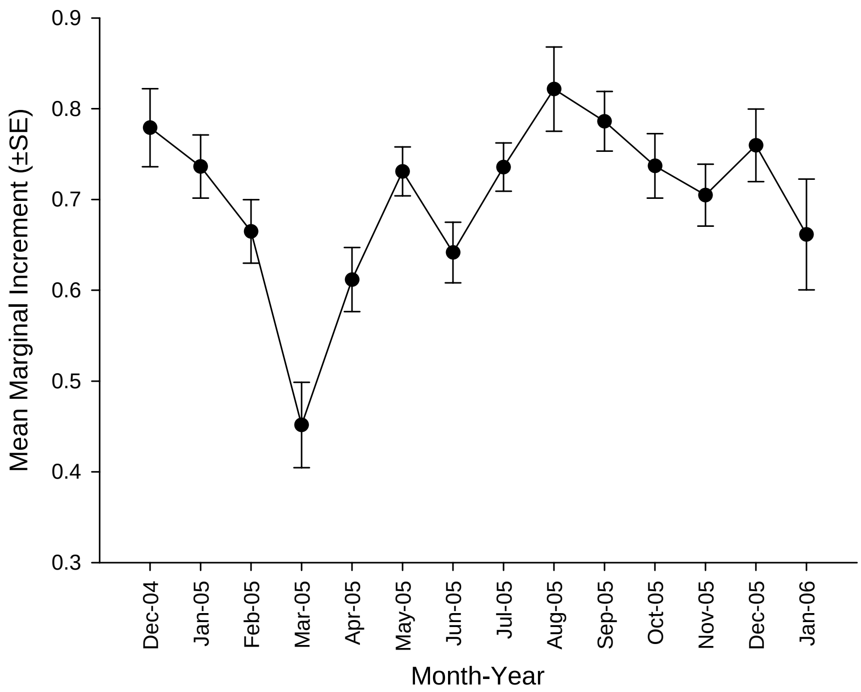


Figure 3.9. Mean (±SE) marginal increment values for rubberlip morwong.

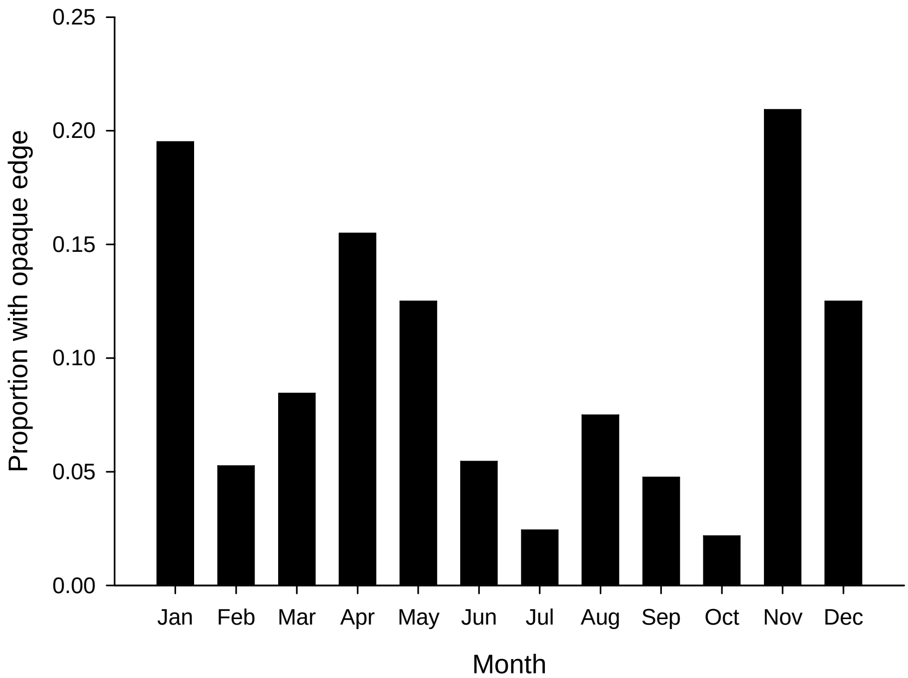


Figure 3.10. Monthly proportions of otoliths having opaque edges for rubberlip morwong.

3.3.3.2. Growth model

Male and female rubberlip morwong had significantly different growth curves (ARSS, $F_{(3, 581)} = 54.5$, $p < 0.001$) (Table 3.1 and Fig. 3.11). There were no differences in mean size at age between sexes for fish aged 1 or 2 (t-tests, $p > 0.05$ in each case), and males were significantly larger than females in all older ages classes (t-tests, $p < 0.05$).

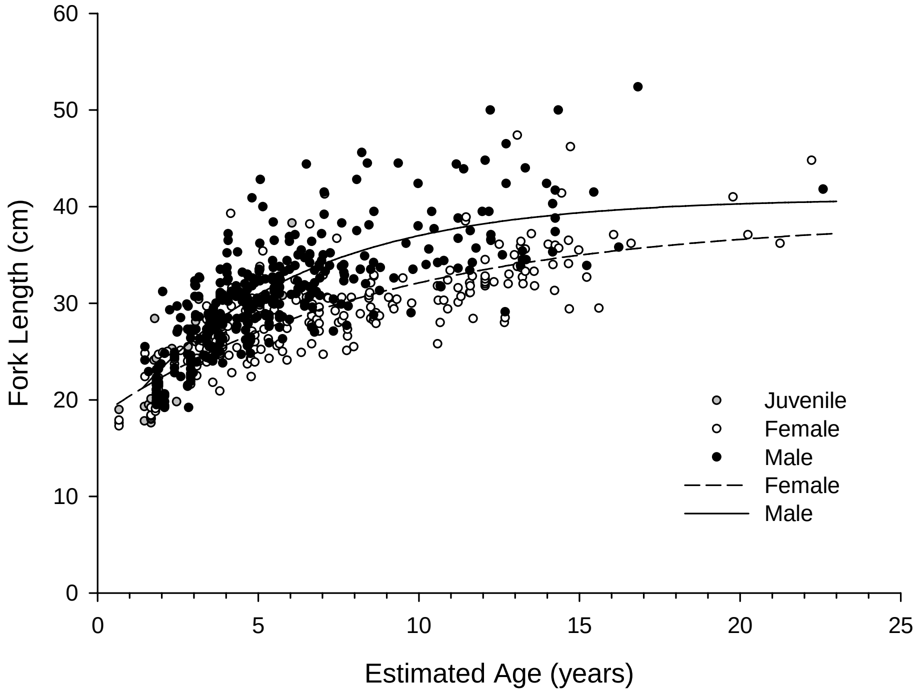


Figure 3.11. Size at age data with fitted von Bertalanffy growth curves for rubberlip morwong.

Table 3.1. von Bertalanffy growth function parameters (± SE) for male and female rubberlip morwong.

	Males	**Females**	**Combined**
L_∞ cm	40.88 (0.69)	38.75 (0.71)	36.71 (0.67)
k year^{-1}	0.19 (0.01)	0.11 (0.02)	0.24 (0.07)
t_0 years	-2.48 (0.04)	-5.61 (0.13)	-1.98 (0.06)

3.3.3.3. Age composition of landed catch

The age-length key for rubberlip morwong generated during this project (Table 3.2) was combined with the length frequency composition information from commercial landings (Fig. 3.2) to estimate the age composition in commercial landings. Rubberlip morwong are fully recruited to the fishery at ~ three years of age and the fishery is currently dominated by fish between two and seven years old (Fig. 3.12). There is a relatively strong presence of fish aged ~ 10 to 12 years old.

Table 3.2. Age-length key for rubberlip morwong.

Fork Length Class (cm)	Age																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
16.9			1																					1
17.9	3	2																						5
18.9		8																						8
19.9	1	13	5																					19
20.9		11	2	1																				14
21.9		12	5	1																				18
22.9		5	10	1	2																			18
23.9		4	5	5	2																			16
24.9		5	11	15	5	2	1	1																40
25.9		1	4	12	8	5	1	2																34
26.9			1	18	8	2		1																30
27.9			5	12	7	5	6	3	1															39
28.9		1	1	16	8	9	3	3	6		1	1	2											51
29.9			4	4	6	5	5	3	2	3	1		1		1	1								36
30.9				9	18	10	7	6	2	3	2	2												59
31.9			1	4	10	8	10		2		3	5	1	1	1									46
32.9				4	6	10	4	4	4	2	1	2	6	2		1								46
33.9				1	4	8	4	4	3	1	1	2	1	5		1								35
34.9						2	4	1	2		3	1	1	2	2									18
35.9					2	1	4	2			1	1	2	3	3		1							20
36.9					1	4	1	1		1		1	3	1	3		1					1		18
37.9					1		2		1		1	1	1	1	1		1				1			11
38.9						1	2	1	1	1		3			1									10
39.9					1			1	1		1	1	1											6
40.9					1	1									1									3
41.9								2							2	1				1			1	7
42.9						1			1	1			1	1										5
43.9												1												1
44.9							1		1	1		1	1	1									1	7
45.9									1															1
46.9													1		1									2
47.9														1										1
48.9																								0
49.9																								0
50.9													1		1									2
51.9																								0
52.9																	1							1
n	4	62	55	103	90	74	55	35	28	13	16	22	23	18	17	4	4	0	0	1	1	1	2	628

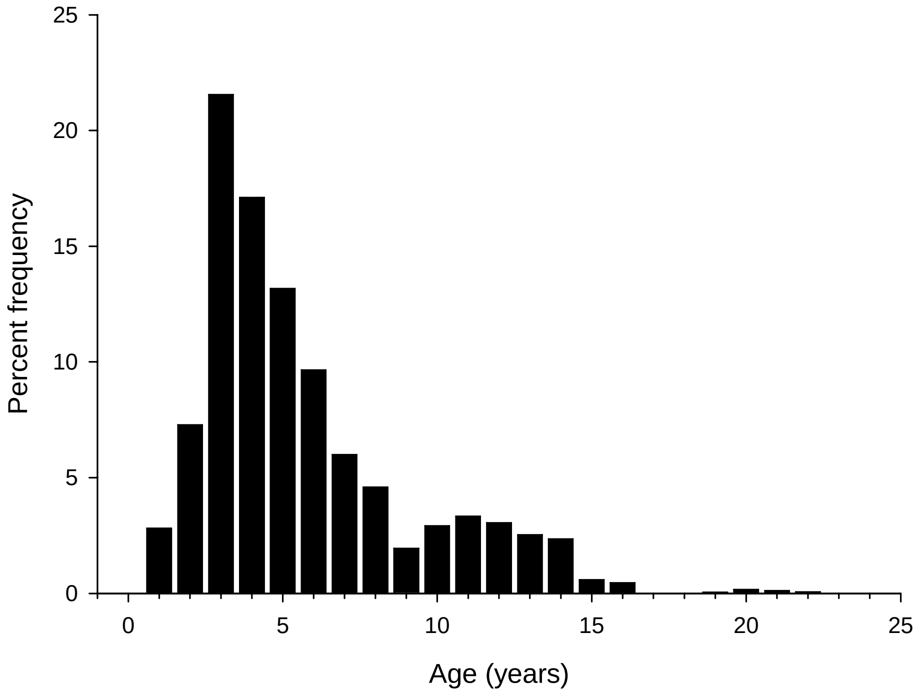


Figure 3.12. Age composition of rubberlip morwong in commercial landings.

3.3.4. Mortality estimates

The estimate of total mortality (Z) made from the slope of the descending limb of the catch curve for rubberlip morwong, fitted between ages 3 and 16, was 0.25 (Fig. 3.13). Age 16 was chosen because there were no 17 year old fish sampled.

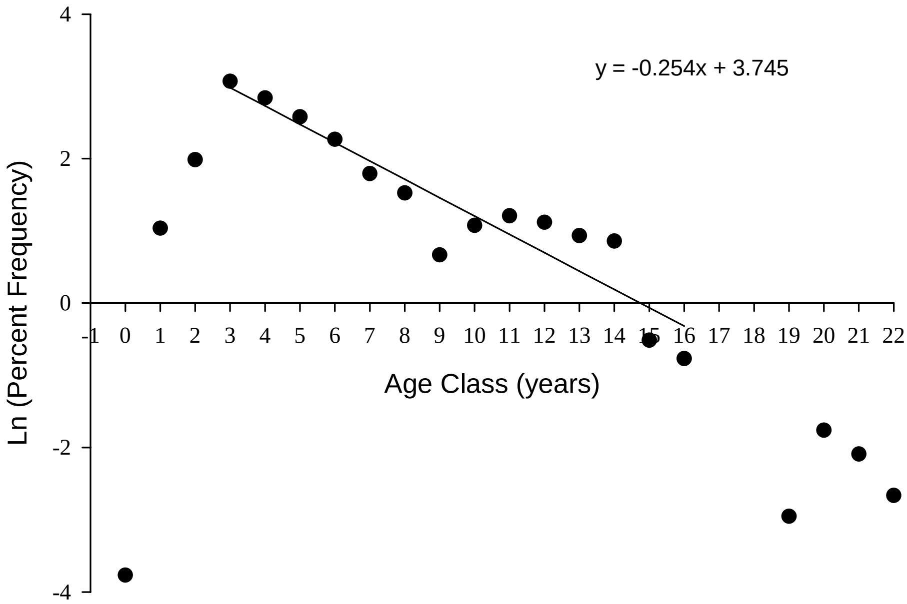


Figure 3.13. Catch curve for rubberlip morwong.

An estimate of natural mortality was made using the method of Hoenig (1983) using a maximum age of 22 years. Due to the short nature of the study and the fact that rubberlip morwong are likely to attain greater ages than observed here, (based on a reported maximum size of 74 cm (Hutchins & Swainston, 1986)) we applied the model that 5% of fish were likely to attain the maximum observed age of 22 years. The best estimate of M was therefore 0.14. Assuming that 1% of fish attain 21 years gives an estimate of M = 0.21.

3.3.5. Market price

Rubberlip morwong sold through the Sydney Fish Markets are graded according to the following schedule:

Small	28 to 34 cm
Medium	34 to 40 cm
Large	40 to 45 cm
Extra large	> 45 cm

Average prices for rubberlip morwong sold through the Sydney Fish markets during 2005/06 indicate that “Extra large” fish attain the greatest price per kg (Fig. 3.14). “Small” fish sold, on average, for $1.53/kg while “Extra large” fish sold for an average of $4.48/kg.

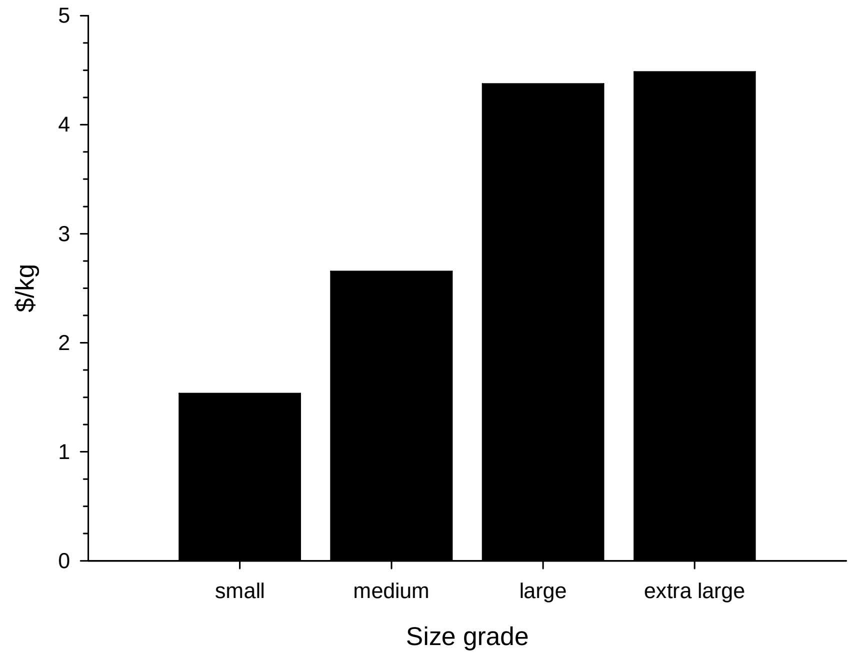


Figure 3.14. Average price information by size grade for rubberlip morwong sold through the Sydney Fish Markets 2005/06.

3.3.6. Per recruit analyses

Per recruit analyses were done using the following parameters:

L_∞ = 36.71 cm
K = 0.24 yr-1
T_0 = -1.98 yr
M = 0.14
Z = 0.25
F = Z-M = 0.11
E = F/Z = 0.44
M/K = 0.56

The market price and size grade information were as described above. L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation the yield per recruit is maximised at 23 cm FL (~ 28.0 cm TL) and that $ per recruit is maximised at 34 cm FL (~ 40. 8 cm TL) (Fig. 3.15). At the current MLL of ~ 23 cm FL rubberlip morwong are not growth overfished and are close to the maximum sustainable yield at current levels of fishing mortality (Fig. 3.16).

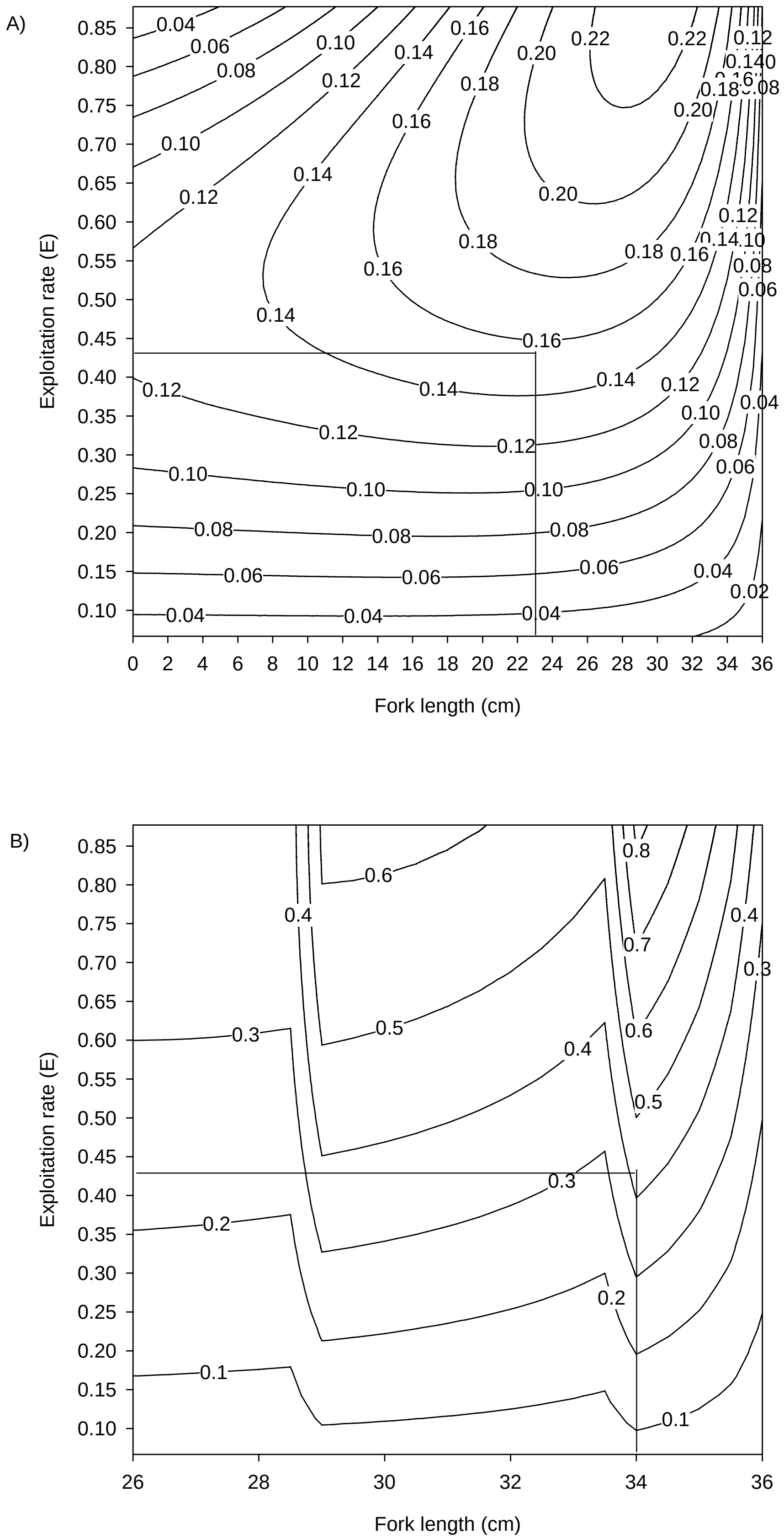


Figure 3.15. Yield and $ per recruit isopleths for rubberlip morwong. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

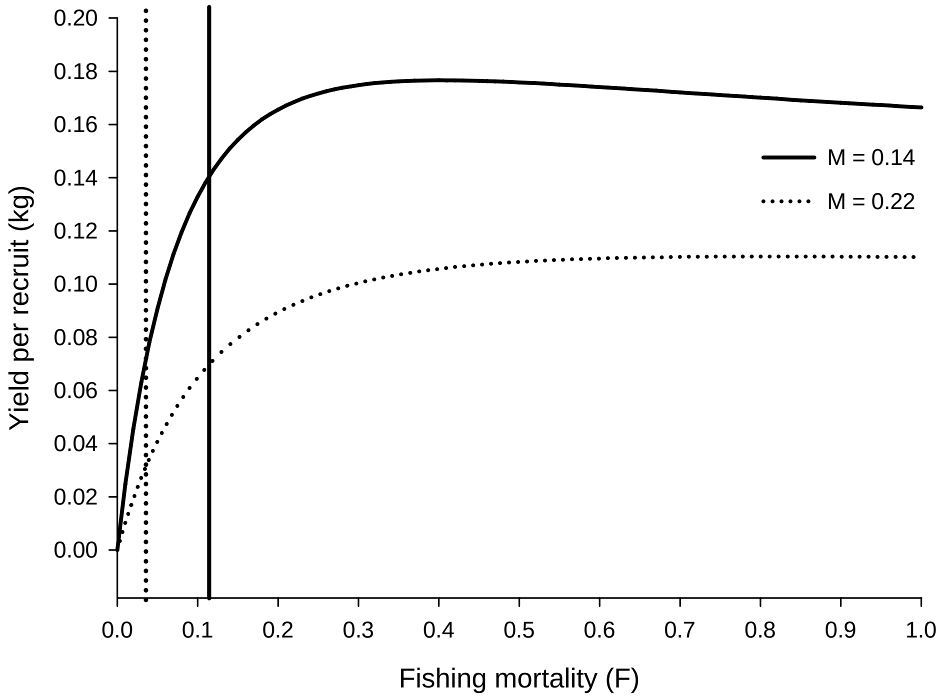


Figure 3.16. Yield per recruit values at the current MLL of ~ 23 cm FL for different values of M. The vertical lines indicate current levels of F associated with each level of M.

3.3.7. Spawning potential ratio

The SPR for rubberlip at current levels of mortality and a MLL of 23 cm FL is ~ 0.53 (Fig. 3.17). This is well above the threshold level of 0.2.

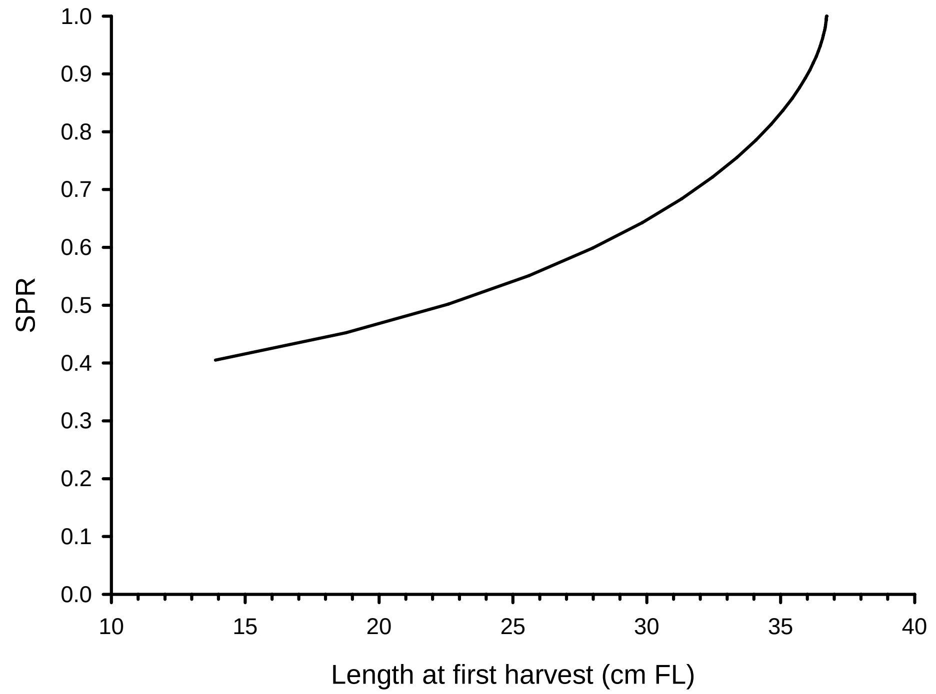


Figure 3.17. Spawning potential ratio for rubberlip morwong at current levels of exploitation for a range of sizes at first harvest.

3.3.8. *Information fact sheet*

Relevant material from this chapter was collated into an information fact sheet for rubberlip morwong (Fig. 3.18). Lengths were reported as total lengths.

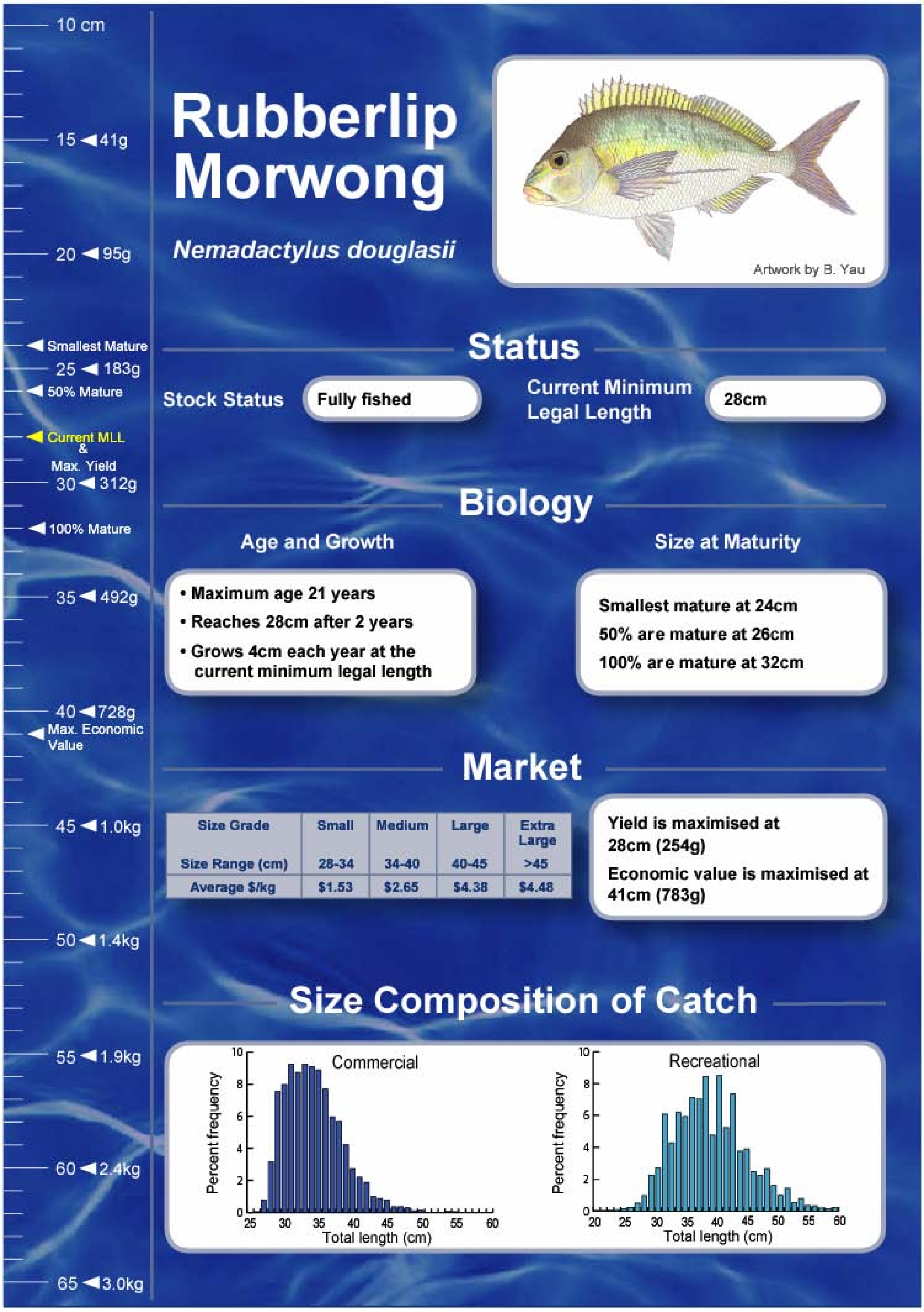


Figure 3.18. Information fact sheet for rubberlip morwong.

3.4. Discussion

This study has provided the first detailed examination of the biology and fishery for rubberlip morwong. Their exploitation status of FULLY FISHED in NSW is reasonable given that: (i) they mature at a smaller size than the current MLL; (ii) the age structure in the commercial fishery is not solely based on very young fish; (iii) they are not growth overfished; (iv) the size composition in recreational landings has remained similar since the early 1990s (but see below), (v) commercial catch rates have stabilized, albeit at historically low levels, and; (vi) the SPR is above the threshold level.

However, there is some evidence that they may be overfished and careful monitoring of landings is required. Trends of concern include: (i) a long-term decline in commercial landings and catch rates; and (ii) a long-term decline in the average size of commercially landed fish and potentially for recreationally landed fish (see discussion below).

The sizes of rubberlip morwong landed in the NSW commercial fishery have been monitored since the early 1970s and indicate a steady decline since the late 1980s (NSW DPI unpublished data). Landings between 1972 and 1990 had a modal peak at ~ 30 cm FL and ~ 10% of fish were > 40 cm FL; however the modal peak is now at ~ 27 cm FL with few fish larger than 40 cm FL. Such a decline in sizes of fish may be cause for concern, but the sizes of fish landed by recreational and charterboat line fishers has been constant during a similar period. The modal peak in line caught fish has remained at ~ 36 cm FL since 1994/95 with very few fish within 5 cm greater than the MLL of ~ 23 cm FL. However, it is noted that the quality of information from trailerboat landings during the early 1990s is very good, whilst that provided by the charterboat logbook system in NSW is known to be poor. It is known that a lot of charterboats record fish length as TL, even though they are supposed to measure FL, and peaks in the landings at 5 cm intervals indicates that measurements may be approximated. The difference between TL and FL for a rubberlip morwong of ~ 35 cm TL is ~ 6 cm and any real changes in the sizes landed may therefore have been masked by misreporting. This highlights the importance of quality control when running any logbook program and this problem must be addressed by NSW DPI charterboat managers as a matter of urgency. Given the low level of confidence in the charterboat data it will be assumed that the trends in commercial length data are the best indicator of changes in the size composition in the stock.

It is likely that the selectivity of hooks used in offshore fishing precludes the capture of most rubberlip morwong smaller than 30 cm FL, whereas commercial fish traps retain all rubberlip morwong encountered (Stewart & Ferrell, 2003). A consequence of the different selectivity of fishing gears used by commercial and recreational fishers is that commercial trap fishers currently discard ~ 25% of rubberlip morwong captured whilst recreational and charterboat fishers do not have a discarding issue. A proposed introduction of 50 x 75 mm welded mesh ‘escape panels’ in fish traps in NSW is predicted to reduce the commercial by-catch levels to ~ 10%. The discard mortality rate of rubberlip morwong is unknown.

The age composition in commercial landings and associated estimate of total mortality (Z) from the fitted catch curve is indicative of a stock that has not been fished down to a level that relies on young fish recently recruited to the fishery. The relatively low numbers of fish aged nine years old may represent either: (i) a year of relatively low recruitment; or (ii) higher levels of recruitment of 10 to 12 year old fish. The estimates of $Z = 0.25$ (from the catch curve) and $M = 0.14$ to 0.22 (based on 5% and 1% of fish attaining 21 years old) indicate that $F < M$ and therefore $E < 0.5$. The more conservative estimate of $M = 0.14$ used in the present study may be an over-estimate based on findings for the closely related tarakihi (*Cheilodactylus macropterus*) in New Zealand. Vooren (1977) reported an estimate of $M \approx 0.08$ based the age structure of a lightly fished population of

tarakihi. If M is much lower than the estimate of 0.14 then rubberlip morwong may be growth overfished. Better estimates of M should therefore be the focus of future work.
Per recruit analyses indicate that the yield per recruit for rubberlip morwong at current levels of exploitation is maximised at 23 cm FL (~ 28 cm TL). Rubberlip morwong are a relatively lowly priced fish and their value sold through the Sydney Fish Markets varies with size grade. “Large” and “Extra-large” fish fetch ~ three times the price per kg as “Small” graded fish. The $ per recruit analysis shows the influence of the relatively higher prices per kg attained by “Large” and “Extra-large fish” with a maximum $ per recruit being attained at ~ 34 cm FL (~ 41 cm TL). The estimate of M affects the value of the yield per recruit but does not change the shape of the curve or the conclusion that rubberlip morwong are not growth overfished. Conclusions from these per recruit analyses are that: (i) current yield per recruit is close to the maximum; and (ii) increases in the value of the resource could be achieved by increasing the size/age at first capture. Given the relatively low prices attained by “Small” rubberlip morwong and recreational fishers do not capture small fish; an increase in MLL may be an astute management option. Substantial increases in egg production are likely to result from an increase in size at capture (see SPR results).

Rubberlip morwong were observed to have an autumn/winter spawning period, with most spawning occurring during May. This is the same as reported for the red morwong off the NSW coast (Lowry & Cappo, 1999). Jackass morwong (*N. macropterus*) are reported to spawn during summer/autumn (Han, 1964) while banded morwong spawn during autumn (McCormick, 1989). Rubberlip morwong mature at ~ 20 cm FL (~ 25.5 cm TL), slightly smaller than the current MLL of 28 cm TL. Therefore, most rubberlip morwong will be able to spawn at least once before being retained. Males and females matured at a similar size and, based on their growth rates, appear capable of spawning during the second winter following the one in which they are born. Male rubberlip morwong do not have the pronounced orbital tubercles of red and banded morwong (Lowry & Cappo, 1999) and it is not possible to differentiate the sexes without dissecting them.

Annual periodicity of opaque zone formation in rubberlip morwong was validated by the patterns in otolith marginal increments and edge status that were consistent with being annual. Opaque zones are formed during spring and early summer and are generally completed by early autumn. Opaque zones in Red morwong are reported to form during winter/spring (Lowry & Cappo, 1999). Morwongs are reported to have very long larval lives, with a pelagic phase known as a ‘paperfish’ (Lowry & Cappo, 1999). This larval phase has been reported to be up to 9 to 12 months. It is not known whether rubberlip morwong also have this extended larval phase, but if they do then it is likely that the opaque zone scored as being the first opaque zone during the present study is formed after approximately 18 months. The presence of a ‘paperfish’ stage could be examined by detailed examination of daily growth increments in the otoliths of young fish.

Growth in rubberlip morwong appears typical of temperate reef associated species along eastern Australia. Growth is rapid initially and sexual maturity is attained after ~ 2 to 3 years, after which growth slows substantially. Male rubberlip morwong grew at a similar rate to females during the first few years but were, on average, larger than females thereafter. This is in contrast to the findings for red morwong (Lowry, 2003) who reported no differences in growth rates between sexes, but that females grew older than males. Female jackass morwong have been reported to grow faster and larger than males (Smith, 1982) and tarakihi females also grow larger than males (Vooren, 1977).

A maximum age of 21 years was observed for rubberlip morwong during the present study, but it is likely that they can attain greater ages than this. The largest fish we sampled was 62 cm TL, yet the maximum size reported for this species is 74 cm (Hutchins & Swainston, 1986) and the chances of sampling very old fish during a short study are low. Maximum ages for other morwongs have been reported as 40 years for red morwong (Lowry, 2003), 59 years for banded morwong (*C. spectabilis*) (Lowry & Cappo, 1999) and > 50 years for jackass morwong (*C. macropterus*) (Vooren, 1973).

4. BIOLOGY AND FISHERY FOR TARWHINE

4.1. Introduction

Tarwhine (*Rhabdosargus sarba*) is a teleost fish of the family Sparidae (Seabreams) commonly found in subtropical inshore waters of the Indo-West Pacific including the Red Sea, East Africa, Madagascar, Japan, China, and Australia (Radebe *et al.* 2002, www.fishbase.org). In Australia, tarwhine are found on both the east (southern Queensland to Gippsland Lakes) and west (Coral Bay to Albany) coasts where they are exploited by both commercial and recreational fisheries (Hutchins & Swainston, 1986; Kailola *et al.*, 1993). Tarwhine in NSW are primarily taken by the commercial Estuary General (EG) and Ocean Trap and Line (OTL) fisheries, as well as by recreational anglers.

This species uses nearshore coastal waters or estuaries as nursery areas and, as an adult, moves offshore into deeper waters where it spawns (Wallace, 1975; Potter & Hyndes, 1999; Smith & Suthers, 2000).

The maximum sizes and ages attained by *R. sarba* vary enormously throughout its worldwide distribution. These range from 30.0 cm TL and 8 years in the Arabian Gulf (El-Agamy, 1989) to 68.3 cm TL and 16 years in South Africa (Radebe *et al.*, 2002). Indeed, even within Australian waters, maximum sizes and ages differ substantially between the east (45 cm- Kuiter, 1993) and west (~ 37.5 cm- Hesp *et al.*, 2004a) coasts. Even amongst locations on the West Australian (WA) coast, Hesp *et al.* (2004a) found differences in growth of tarwhine sampled from Shark Bay in the north compared to those collected from the lower Swan River Estuary and nearshore marine waters in the south.

Tarwhine, like many sparid fishes throughout the world, possesses a unique gonad called an ovotestis, made up of ovarian and testicular zones separated by connective tissue (Besseau & Brusle-Sicard, 1995; Hesp & Potter, 2003). Within the family Sparidae, a diverse range of reproductive styles are present: a number of species are reported to be protogynous hermaphrodites; others protandrous hermaphrodites, as well as gonochorists (Buxton & Garratt, 1990). *R. sarba* has been considered a protandrous hermaphrodite in Hong Kong and South Africa (Yeung & Chan, 1987; Garratt, 1993; Radebe *et al.*, 2002), and more recently as a rudimentary hermaphrodite in WA waters (Hesp & Potter, 2003; Hesp *et al.*, 2004b). Spawning occurs between mid-late winter and late spring (July-November) in WA, and maturity (50%) occurs at 17.0 – 17.7 cm TL and two to three years of age (Hesp & Potter, 2003; Hesp *et al.*, 2004b). Age-at-maturity was estimated to be 1.8 years in South Africa (Radebe *et al.*, 2002).

To date no basic biological information has been collected for tarwhine in NSW waters, despite their importance to both commercial and recreational fisheries. The aims of this chapter therefore, were to describe: (i) the growth and longevity; (ii) the spawning season and size/age-at-maturity, and; (iii) the fisheries for tarwhine in NSW.

4.2. Materials and methods

Tarwhine were sampled from commercial fisher catches at the Sydney Fish Markets. Fish were also collected by NSW DPI staff involved in other research projects (e.g., Fishery Independent Surveys). Fish were processed and analyses of growth, reproduction and fishery done as outlined in Chapter 2.

4.2.1. Preliminary histological analyses of gonads

A small number of tarwhine gonads were specially selected for preliminary histological analysis. Six gonads were chosen: two ovaries both containing hydrated ova (one stage 3 (ripe), and one stage 4 (running ripe)), two testes (both stage 4) and 2 stage 4 ovotestes consisting primarily of testicular tissue. Gonads were removed from tarwhine during dissection and fixed in 10% FAACC (Formalin-Acetic-Acid-Calcium-Chloride) solution for at least one week, before being transferred to 70% alcohol for storage.

Gonad tissue samples were dissected from fixed specimens, placed between foam biopsy sponges within plastic cassettes, and preserved until processing in an automated tissue processor (Tissue Tek®VIP). The tissues were embedded in paraffin wax (Paraplast™) and sectioned at 7µm thickness using an American Optical microtome. Sections were floated onto slides pre-coated with poly-L-lysine to facilitate adhesion and stained with Mayer's haemotoxylin and eosin. Coverslips were mounted onto slides using DPX mountant. Digital images of histological sections were captured using the microscope, camera and computer setup described in Chapter 2.

4.2.2. Age validation experiment

To examine otolith growth and the timing of opaque zone formation and appearance in otoliths of tarwhine, a vital stain was used to mark the otoliths of wild-caught captive fish (Gray & Kendall, unpublished).

Juvenile tarwhine (n = 125, FLs ~ 50 – 80 mm) were collected using a beach seine from seagrass beds in Botany Bay (33º59'S, 151º11'E) between February and April 2005. These fish were transported in aerated 20L buckets back to the aquarium facility at the Cronulla Fisheries Research Centre where they were kept in 1000L flow through seawater tanks. Tarwhine were immersed in an alizarin complexone bath at a concentration of 30mg/L for 24 hours to stain their otoliths on 1st May 2005. Fish were then sampled monthly (10/month) for one year (1st June 2005- 1st June 2006) to examine their otolith growth subsequent to the alizarin mark. Five fish were left in captivity for a further six months until sampled on 1st December 2006.

The otoliths from all fish were examined after the experiment was terminated. Otoliths were sectioned and viewed as described in Chapter 2. The distances from the otolith core to the alizarin mark, to any identified opaque zones, and to the otolith edge, were measured using the microscope, camera and computer setup described in Chapter 2.

4.3. Results

4.3.1. Landings in NSW

4.3.1.1. Current exploitation status

Tarwhine are currently listed as being FULLY FISHED in NSW (2006/07). They were previously listed as being UNDEFINED (2001/02 – 2005/06). The assessment of FULLY FISHED was able to be made now that biological and fishery information for NSW has been obtained as a result of the research presented in this chapter.

4.3.1.2. Trends in catch

Reported commercial landings of tarwhine have been highly variable since 1990/91 (Fig 4.1). Despite this high variability, landings have declined from ~ 75t/yr in the period 1990/91 to 1996/97 to ~ 35t/yr since 2001/02. Over the period of greatest decline in landings (2000/01 – 83.3t to 2002/03 – 23.8t), there was also a decline in catch rates (16.6 kg/day in 2000/01 to 1.7 kg/day in 2002/03). In recent years, however, landings and catch rate have improved slightly (Fig. 4.1).

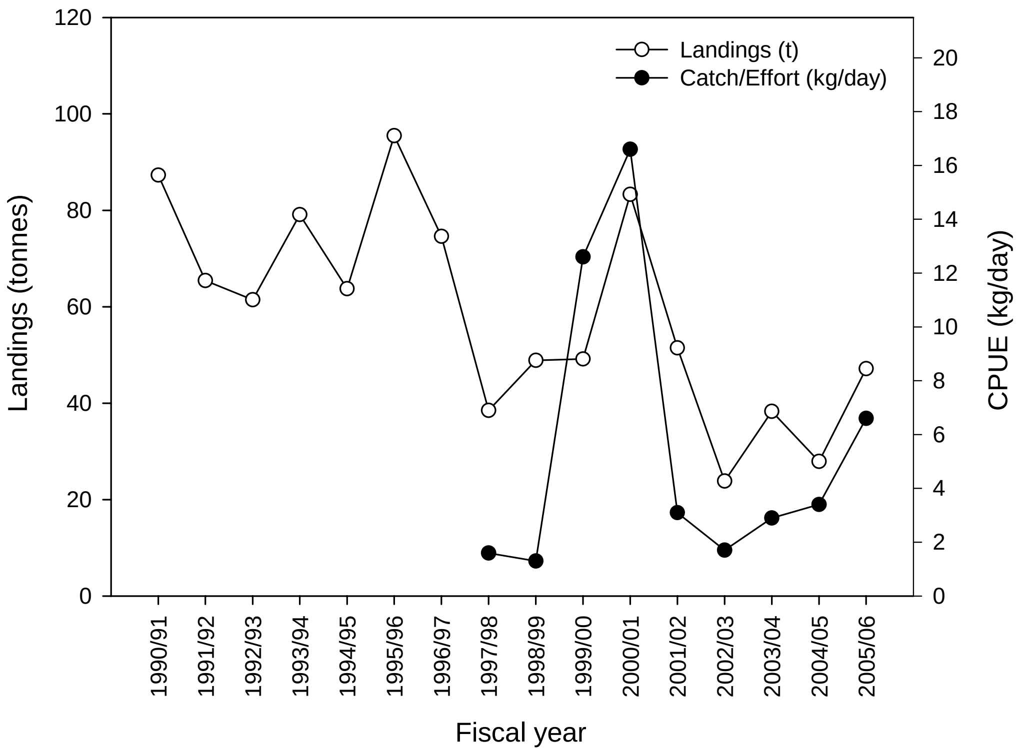


Figure 4.1. Reported commercial landings (all methods), and catch rates for mesh netting, for tarwhine in NSW. Source: NSW DPI Resource Assessment System.

4.3.1.3. Length measurements

Commercial landings

The sizes of tarwhine captured by trap and line fishers were measured at the Sydney Fish Markets and regional co-ops during the study. A total of 630 tarwhine were measured and ranged in size from 16 to 30 cm FL (Fig. 4.2). The majority (~ 69%) of the commercial trap and line catch of tarwhine is comprised of fish between 17 and 20 cm FL (~ 19.4 – 22.8 cm TL). The most commonly caught length class of fish was 18 cm FL (24.1%). Very few fish (8.1%) larger than 25 cm FL were caught during 2005/06 (Fig. 4.2).

Recreational landings

The sizes of tarwhine landed by recreational fishers (Figs 4.3 & 4.4) were substantially different to those landed by commercial fishers (Fig. 4.2). The majority of tarwhine landed by trailerboat (~ 64%) and charterboat (~ 62%) fishers were between 24 and 28 cm FL (~ 27.4 – 32.0 cm TL). The most commonly caught length classes of fish were 24 cm FL (20.4% trailerboat) and 26 cm FL (17.1% charterboat). Many more large (> 25 cm FL) tarwhine were landed by trailerboat (~ 56%) and charterboat (~ 81%) fishers, compared with commercial fishers (8.1%; Figs 4.2, 4.3 & 4.4).

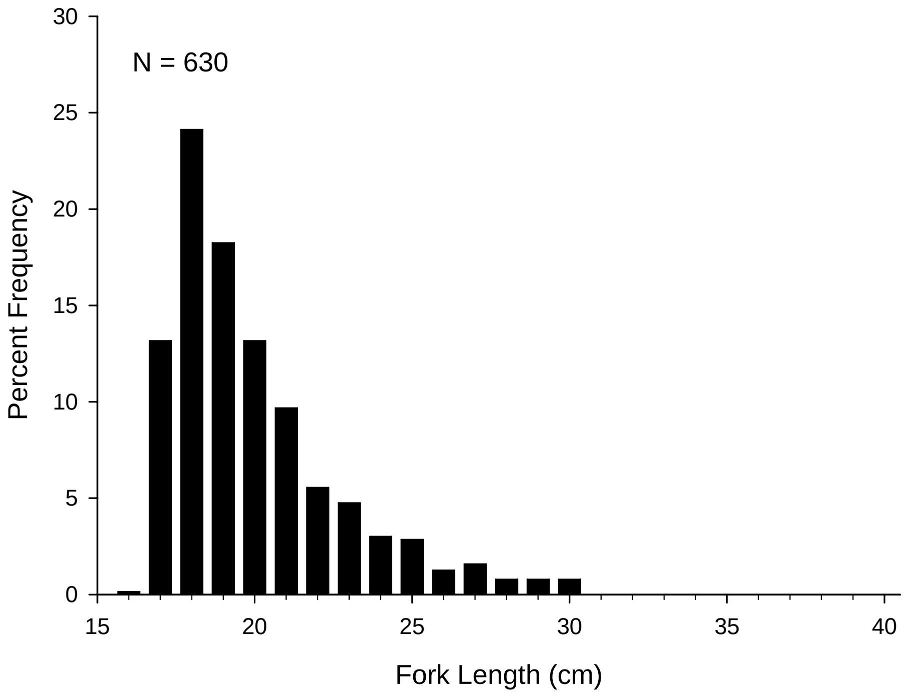


Figure 4.2. The lengths of tarwhine landed by the NSW trap and line fishery during 2005.

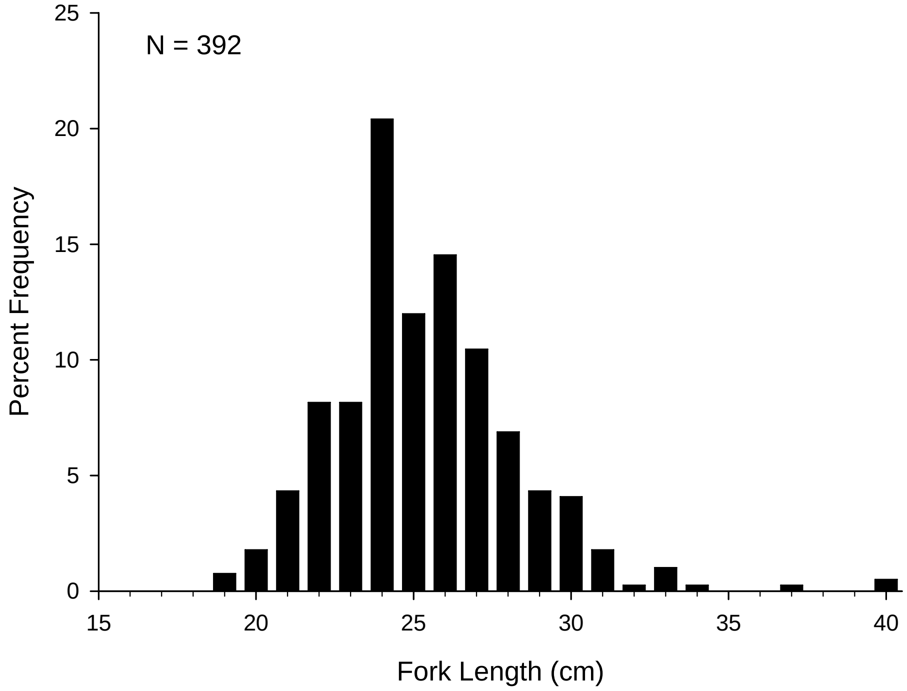


Figure 4.3. The lengths of tarwhine landed by offshore trailerboat fishers during 1993/94 and 1994/95. Source: Steffe *et al.* 1996.

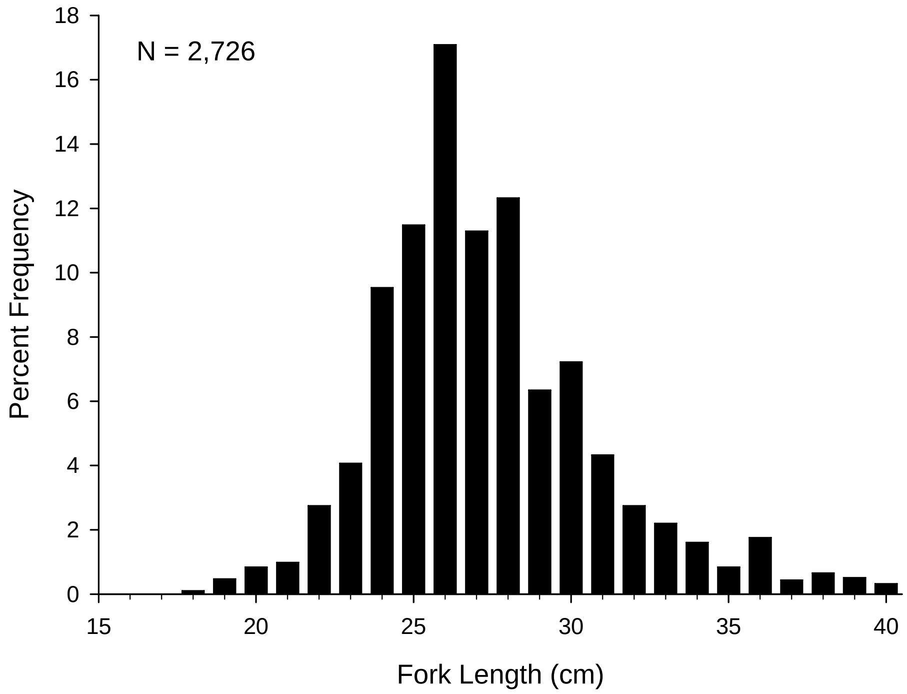


Figure 4.4. The lengths of tarwhine measured by NSW charterboat operators 2001 to 2003.

4.3.2. Reproduction

4.3.2.1. Seasonality of spawning

Gonadosomatic indices

Peaks in tarwhine GSI for both males and females occurred in July, although elevated GSI values were evident between May and August (Fig. 4.5). The maximum GSI values for males and females were 4.04 ± 0.77% and 2.97 ± 0.27% respectively (Fig. 4.5). During the peak spawning period (i.e., July), the ovaries and testes of tarwhine were approximately 6 and 16 times their non-spawning weights, respectively.

Macroscopic staging

The highest proportions of female and male fish with reproductively active [stage 3 (ripe), stage 4 (running ripe) and stage 5 (spent)] gonads occurred between May and August (Figs 4.6A & 4.6B). Between May and August, reproductively active testes made up 71 – 86% of testes sampled. Reproductively active ovaries made up 60-88% of ovaries sampled during the same period. For the remainder of the year, most ovaries and testes were estimated to be stage 2 (resting).

4.3.2.2. Size at maturity

The maturity curves and estimated sizes at 50% maturity were not significantly different for male (L_{50}: 19.88 ± 0.24 cm) and female (L_{50}: 19.83 ± 0.21 cm) tarwhine (Wald's test, $p > 0.05$). The data were combined and showed that tarwhine mature between 16 and 21 cm FL, with 50% being mature at 19.85 ± 0.16 cm FL (Fig. 4.7).

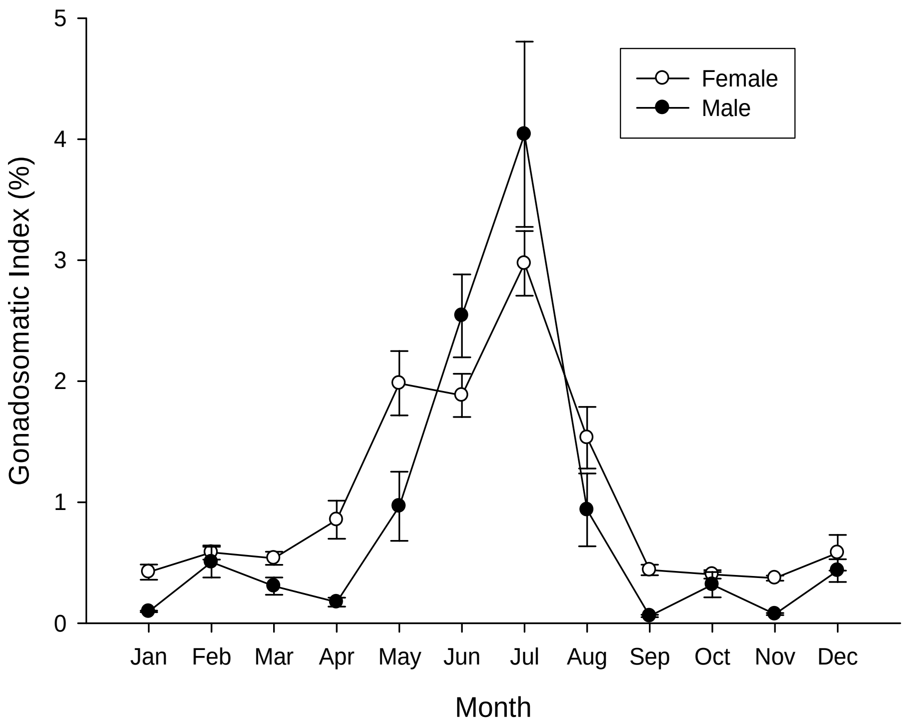


Figure 4.5. Gonadosomatic indices (mean GSI ± SE) for male and female tarwhine.

4.3.2.3. Sex ratio

The number of female tarwhine sampled was significantly greater than the number of males ($\chi^2 = 15.45$, $p < 0.05$; Fig. 4.8). The sex ratio ranged from 1:1 (female:male) in November, to 2.4:1 in July. The overall average sex ratio for all fish collected was 1.5:1. Only in December was the sex ratio slightly biased towards males (0.9:1).

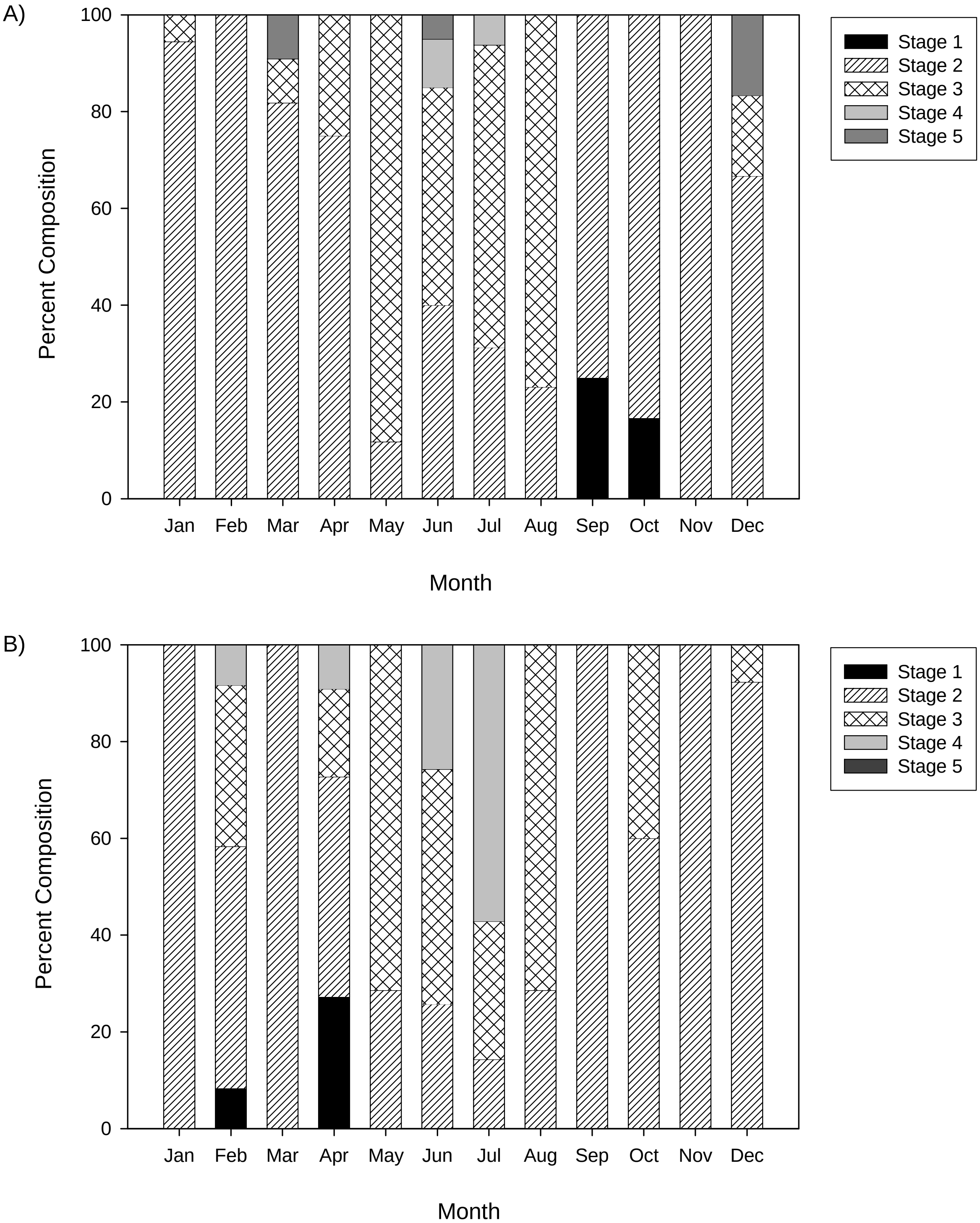


Figure 4.6. Monthly gonad stages of A) female and B) male tarwhine.

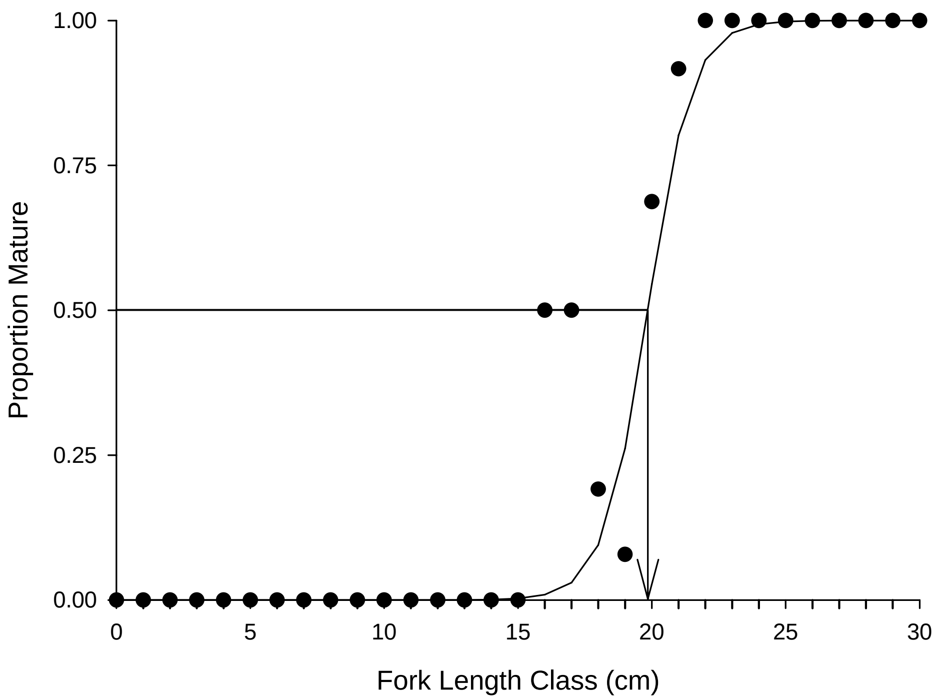


Figure 4.7. Reproductive maturity data with fitted logistic curve for tarwhine (n = 410). Arrow indicates size at 50% maturity.

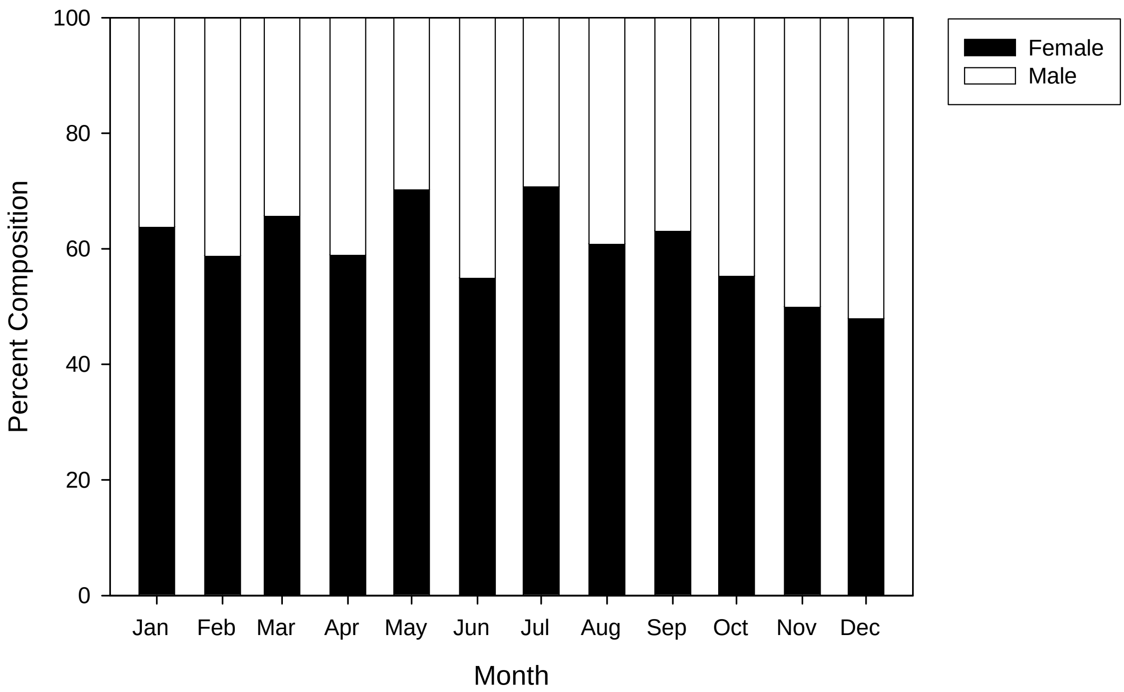


Figure 4.8. Monthly sex ratios for tarwhine sampled during 2005 (n = 404).

4.3.2.4. Preliminary histological analyses of gonads

Preliminary microscopic analyses of the structure of tarwhine gonads indicated that (at least for stage 3 and 4 ovaries and testes) our macroscopic staging schedule was relatively accurate. Ovotestes were identified in adult tarwhine (Fig. 4.9), and were confirmed by histological analysis (Table 4.1). Ovotestes consisted primarily of functional testicular or ovarian tissue and small amounts of non-functional gonad tissue from the other sex (Fig. 4.10). The small amount of non-functional gonad tissue present in each ovotestis was often extremely difficult to detect macroscopically.

Figure 4.9. Ovotestes from three adult tarwhine (23.4, 22.6, 30.0 cm FL respectively). All three ovotestes consist primarily of testicular tissue but with a small amount of brown-coloured ovarian tissue adjacent.

Table 4.1. The macroscopic and microscopic characteristics of reproductively active (stage 3 and 4) tarwhine gonads. Macroscopic characteristics were determined by external examination. Microscopic characteristics were determined by histological analyses.

Sex	Stage	Macroscopic Characteristics	Microscopic Characteristics
Female	3	Ripe ovary containing hydrated oocytes.	Ovary contains mostly mature oocytes, some immature.
Female	4	Running ovary containing hydrated oocytes.	Ovary contains mostly mature oocytes, some immature.
Male	3	Ripe ovotestis consisting mainly of testicular tissue.	Ovotestis consisting mainly of testicular tissue containing spermatozoa in addition to an adjacent smaller lobe of ovarian tissue containing immature oocytes.
Male	4	Running ovotestis consisting mainly of testicular tissue.	Ovotestis consisting mainly of testicular tissue containing spermatozoa in addition to an adjacent smaller lobe of ovarian tissue containing immature oocytes.
Male	4	Running teste.	Testicular tissue containing spermatozoa.
Male	4	Running teste.	Testicular tissue containing spermatozoa.

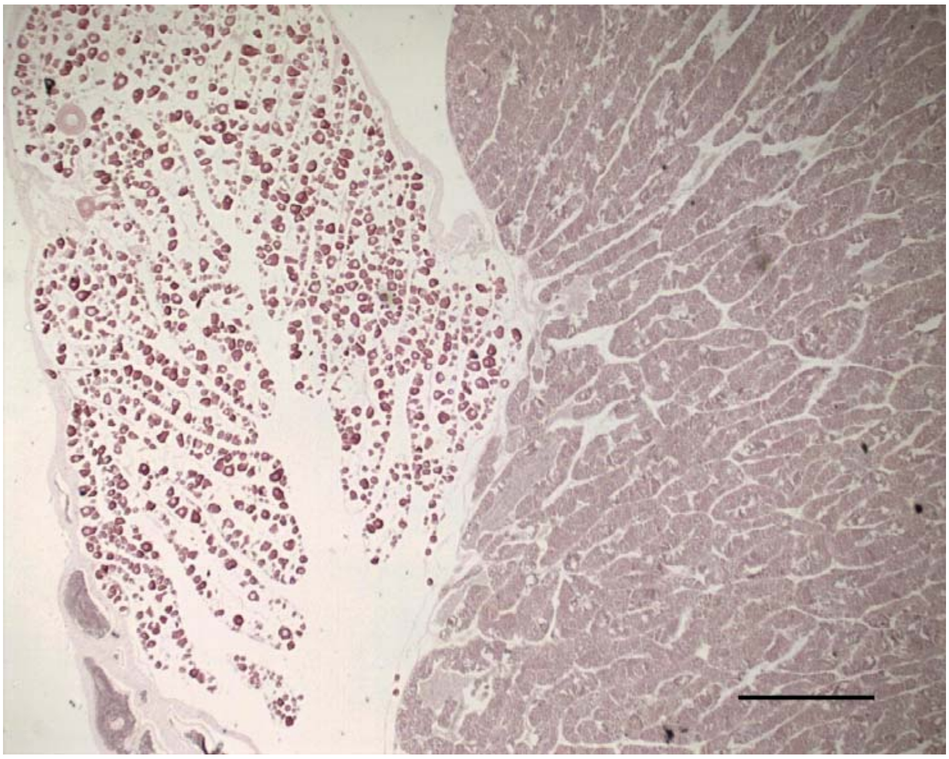


Figure 4.10. Histological section of ovotestis from an adult tarwhine (23.5 cm FL). The gonad consisted primarily of functional testicular tissue (RHS) containing spermatozoa in addition to an adjacent smaller lobe of ovarian tissue (LHS) containing immature oocytes. Scale bar is 1mm.

4.3.3. Age and growth

4.3.3.1. Ageing procedure and validation

Age validation experiment

The alizarin mark was easily identified as a thin red band under reflected light. Ninety-six percent (125 of 130) fish immersed in the alizarin bath showed marks in sections of their otoliths. None of the fish marked had formed an opaque zone prior to the alizarin band (Fig. 4.11). For the first three months after alizarin marking, the otoliths of all fish sampled had no opaque zones counted (Fig. 4.11). An opaque zone subsequent to the alizarin mark first became visible in September. In September, two of the 10 fish sampled had formed their first opaque zone. By October, all fish sampled had formed their first opaque zone. By December 2006 two opaque zones had formed in all fish sampled (Fig. 4.11). Otolith growth was slower for the first four months (June – September 2005: average 0.005 mm/month) than during the rest of the year (October 2005 – May 2006: average 0.022 mm/month) (Fig. 4.11).

The average distance between the alizarin mark and the otolith edge became greater with each months sample, especially after the first opaque zone had become visible (i.e., September – October 2005 onwards; Fig. 4.12). Fish sampled in December 2006 which had two opaque zones visible continued this trend with the otoliths becoming thicker with time (Fig. 4.12).

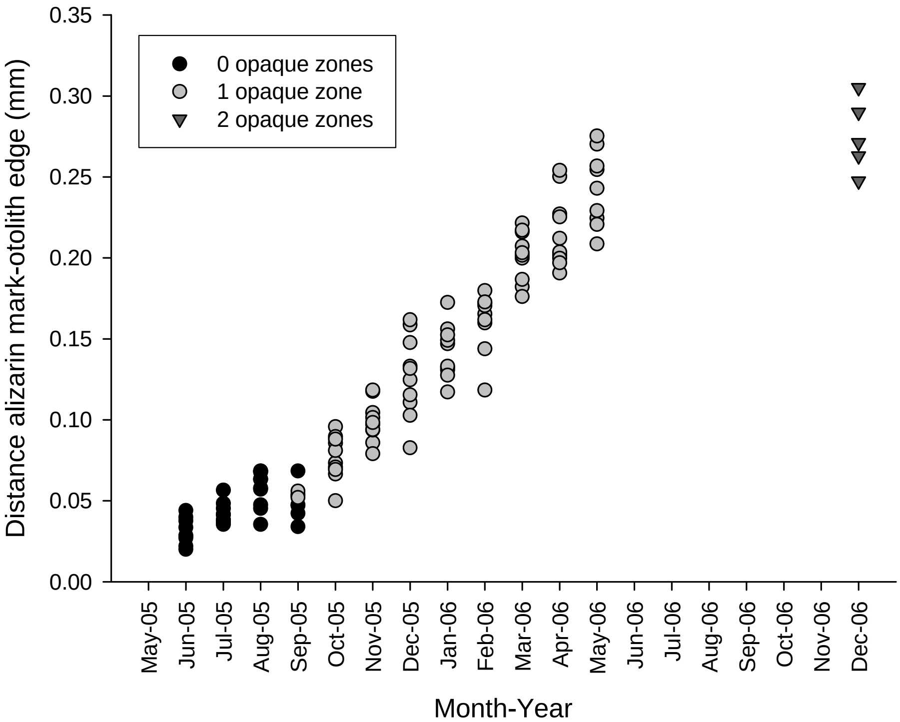


Figure 4.11. Distances (mm) from the alizarin mark to the otolith edge for tarwhine marked in May 2005 and kept in captivity. All fish had no opaque zones prior to marking. Source: Gray & Kendall, unpublished.

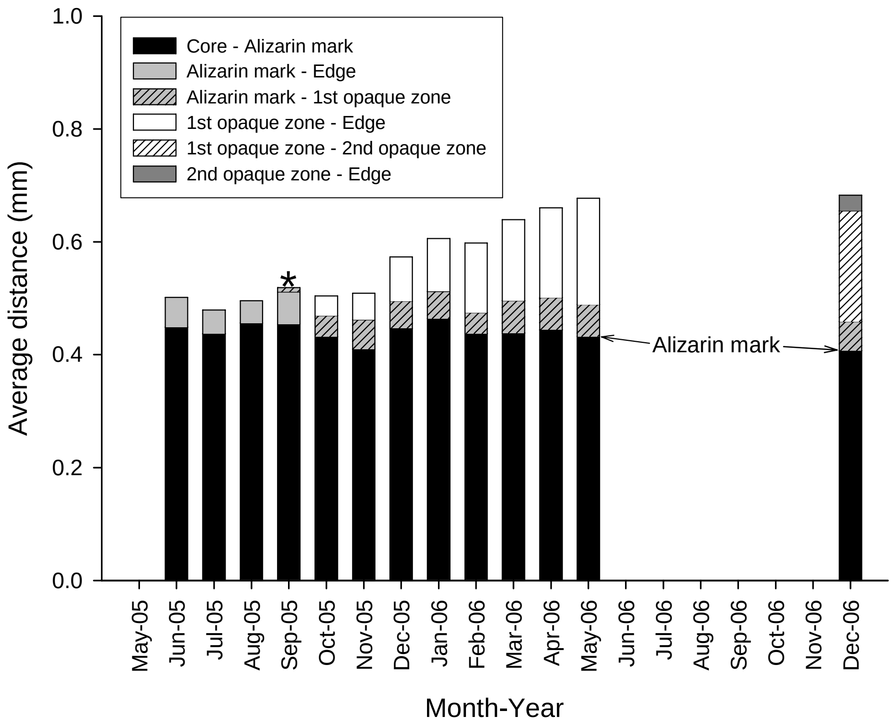


Figure 4.12. Average distances (mm) between the core, alizarin mark, opaques zones and the otolith edge for tarwhine marked in May 2005 and kept in captivity. Arrows indicate the position of the alizarin mark. *n* = 10 for all months sampled except Dec-06 (*n* = 5). * indicates that in Sep-05 two of the 10 fish had formed an opaque zone, the other 8 had not. Source: Gray & Kendall, unpublished.

Appearance of tarwhine otoliths

Sectioned tarwhine otoliths were very easy to interpret. Opaque and translucent zones were clearly discernable and identifying and counting opaque zones was straightforward (Fig. 4.13). The core was always a dense opaque region, followed by a broad translucent region and then a very distinct opaque band, which was scored as the first annulus (Fig. 4.13). The maximum number of opaque zones counted was 15 (see Fig. 4.13). The coefficient of variation (cv) averaged across all ages was 0.037.

Figure 4.13. Sectioned tarwhine otolith viewed using reflected light at x2 magnification. Fifteen opaque zones were counted in this section (●). Scale bar is 1 mm.

Marginal increment analyses

The monthly marginal increments for tarwhine with both one opaque zone and two or more opaque zones showed considerable variation each month (Figs 4.14A & B) but with a seasonal pattern of low values in spring/summer (October to January) (Figs 4.15). September to December were the months where some fish had identifiable opaque zones near their otolith edges while others still had a broad translucent edge (Figs 4.14A & B). The distribution of marginal increments therefore, suggests that opaque zone formation is completed between September and December. Since, irrespective of the number of opaque zones in the otolith, the mean monthly marginal increment rose and declined only once during the year (Fig. 4.15) it was concluded that a single opaque zone is laid down annually and therefore, the number of opaque zones could be used to estimate the age of tarwhine.

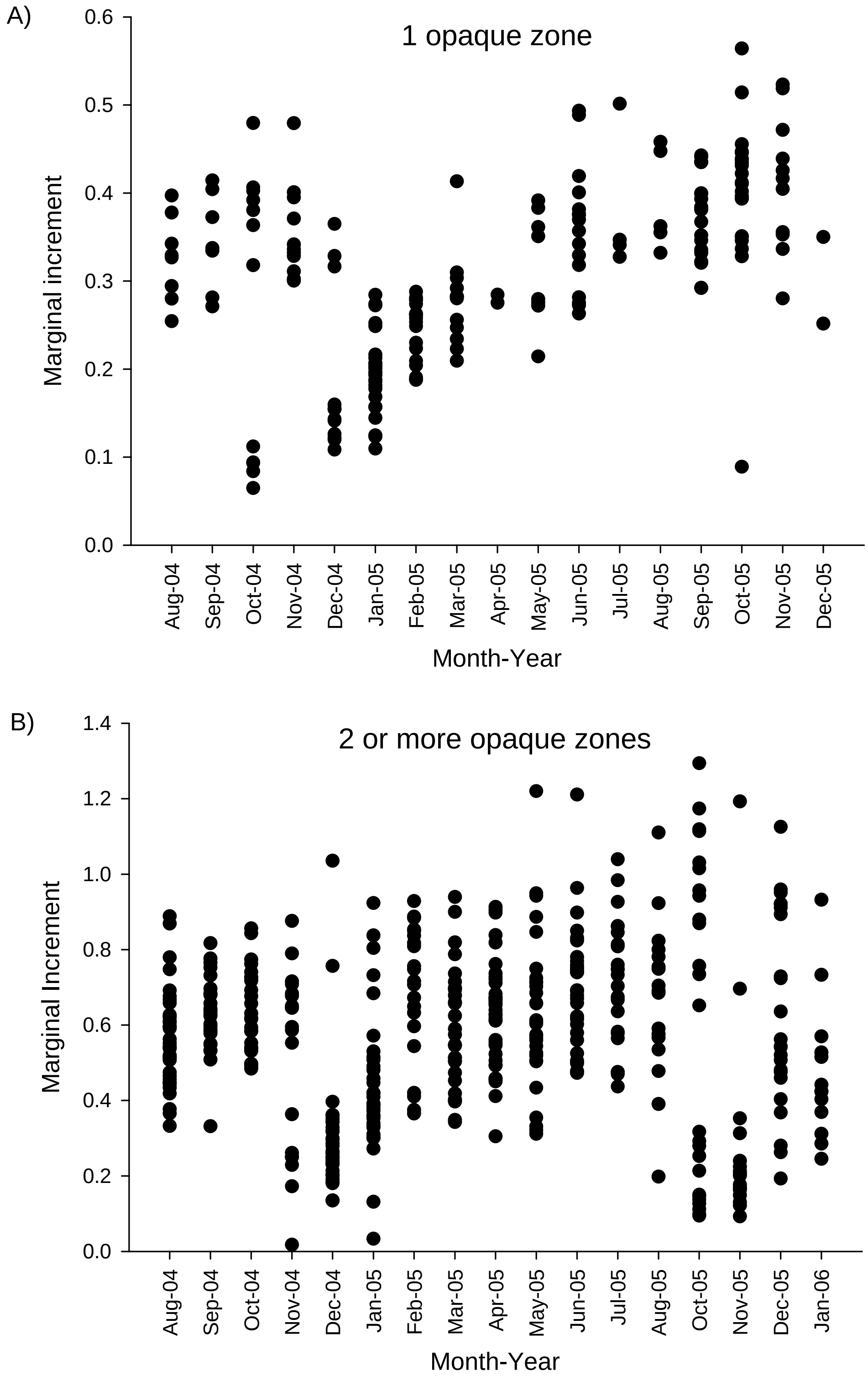


Figure 4.14. Marginal increment plots for tarwhine with A) one opaque zone counted (n = 202), and B) with two or more opaques zones counted (n = 448).

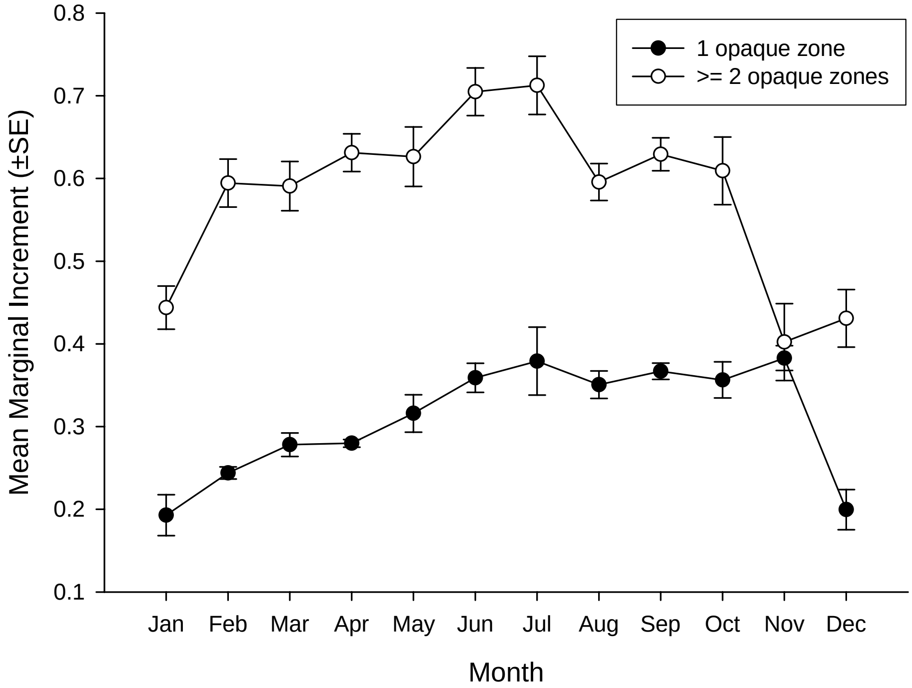


Figure 4.15. Mean (±SE) marginal increment values for tarwhine with one opaque zone (●), and two or more opaque zones (○). Sample sizes are the same as for Fig. 4.14.

Edge analysis

The proportion of tarwhine otoliths with opaque edges each month supports the marginal increment analyses and is consistent with annual periodicity of opaque zone formation. The highest proportion of otoliths having opaque edges occurred during October (followed by November and December), while much lower proportions were seen during the remainder of the year (Fig. 4.16).

Development of ageing protocol

As the time of increment formation varies between fish, it was necessary to allow for this variation in estimating age. Otoliths were assigned as having either a wide or narrow edge and this classification varied depending on how many opaque zones were present (Table 4.2). The marginal increments were measured as described in the methods and varied depending on whether the fish were aged 1+, or 2+ years and older. Fish with no opaque zones possessed a wide edge if they were sampled between July and October and the distance from the core to the otolith edge was within the 95% confidence interval of the distance from the core to the first opaque zone in all other fish examined (0.38 – 0.59 mm).

Table 4.2. Classification of tarwhine otolith edges. MI is marginal increment as defined above.

No. opaque zones	**Edge status**	
	Wide	Narrow
1	MI ≥ 0.2	MI < 0.2
≥2	MI ≥ 0.4	MI < 0.4

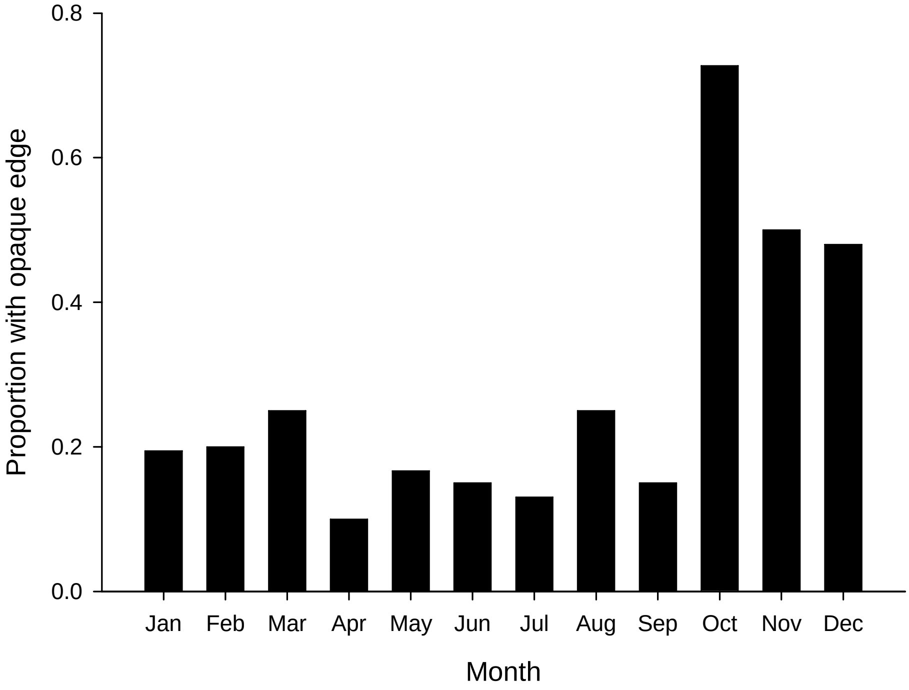


Figure 4.16. Monthly proportions of otoliths having opaque edges for tarwhine (*n* = 281).

After examining the distribution of marginal increments each month (Fig. 4.14) and identifying those in which some fish had opaque zones near to the otolith edge while other fish had a broad translucent edge, a model was developed to convert counts of opaque zones to age classes. This model was based on the month of capture and width of the otolith edge (Fig. 4.14). A universal birth date of 1st July was assigned to tarwhine (based on the middle of the spawning season – Figs 4.5 & 4.6). The first opaque zone in tarwhine otoliths is completed sometime between September and October (Fig. 4.11) when the fish are between 14 and 15 months old. Opaque zones in tarwhine otoliths with more than 1 opaque zone are completed between October and January (Fig. 4.14). Therefore, the number of opaque zones in tarwhine otoliths equalled the age class for all fish sampled, except for those with wide edges (indicating that the most recently forming opaque zone was not yet completed) between the universal birth date (1st July) and when all opaque zone formation was completed (October for fish with no opaque zones and January for the remainder). Therefore, for fish with otoliths with wide edges sampled between these times, the fish was considered about to form an opaque zone and therefore its zone count was increased by one to assign the fish to the correct age class. The number of days from the universal birth date to the capture date (as a proportion of a year) was also added to the age class to give the final age estimate for each fish.

4.3.3.2. Growth model

There was no difference in the growth of male and female tarwhine (ARSS $F_{(3, 577)} = 2.38$, $p > 0.05$), therefore the data for each sex were pooled (Fig. 4.17). Both males and females grew quickly, and reached (on average) 11.1 cm FL after one year, and ~ 16.6 cm FL after two years. The two oldest fish collected were both males, estimated ages 15.7 and 16.5 years old (27.1 and 27.6 cm FL respectively). The oldest female fish was estimated to be 11.6 years old (29.1 cm FL). Of the three largest fish collected, two were males 30.5 and 30.3 cm FL (estimated 10.9 and 11.3 years old respectively), along with one female which was 30.3 cm FL (estimated 5.9 years old) (Fig. 4.17).

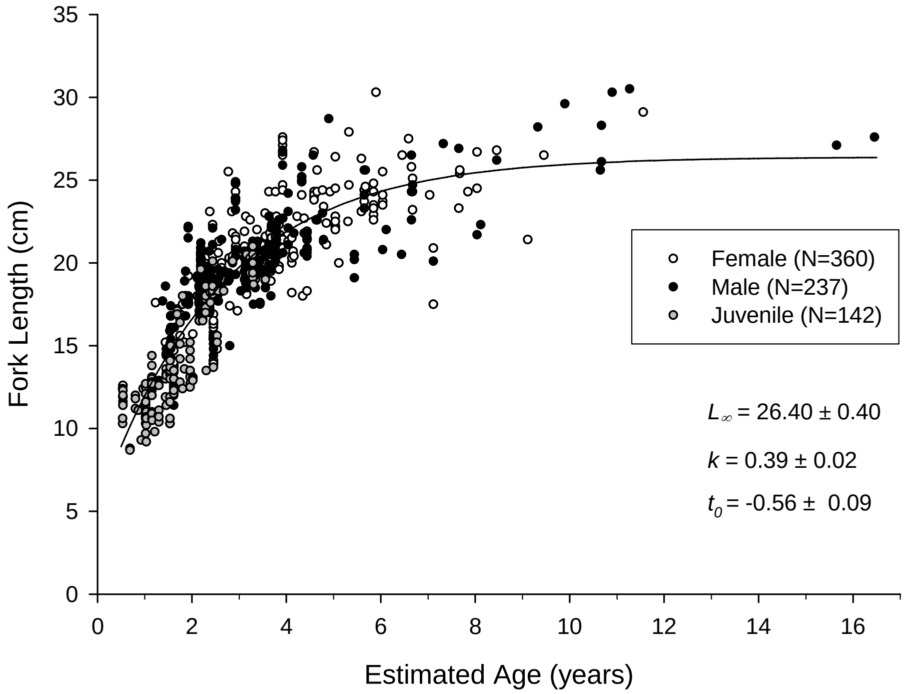


Figure 4.17. Size at age data with fitted von Bertalanffy growth curve for tarwhine ($n = 739$).

4.3.3.3. Age composition of landed catch

The age-length key for tarwhine (Table 4.3) was applied to the commercial size composition data (Fig. 4.2) to obtain an estimate of the age composition in landings. Tarwhine were fully recruited to the commercial fishery at two years old and the majority (~ 80%) of commercially caught tarwhine were three years old or less (Fig. 4.18).

Table 4.3. Age-length key for tarwhine.

FL Class (cm)	Age (years)																	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
8	2																	2
9	1	3																4
10	2	20																22
11	7	12																19
12	6	26	1															33
13		26	6															32
14		17	5															22
15		10	11															21
16		11	10															21
17		13	46	3				1										63
18		6	67	16	3													92
19		2	31	63		1												97
20			33	68	10	3	2	2										118
21		1	8	30	14				1	1								55
22		2	2	19	6	7	2		1									39
23			6	1	4	7	3	1										22
24			4	4	9	7	4	2	1									31
25			1	1	5	2	3	2			1							15
26				3	2	2	2	1	3	1	1							15
27				3		1	1	1								1	1	8
28					1					1	1							3
29										1		1						2
30						1					1	1			1			4
n	18	149	231	211	54	31	17	10	6	4	4	2	0	0	1	1	1	740

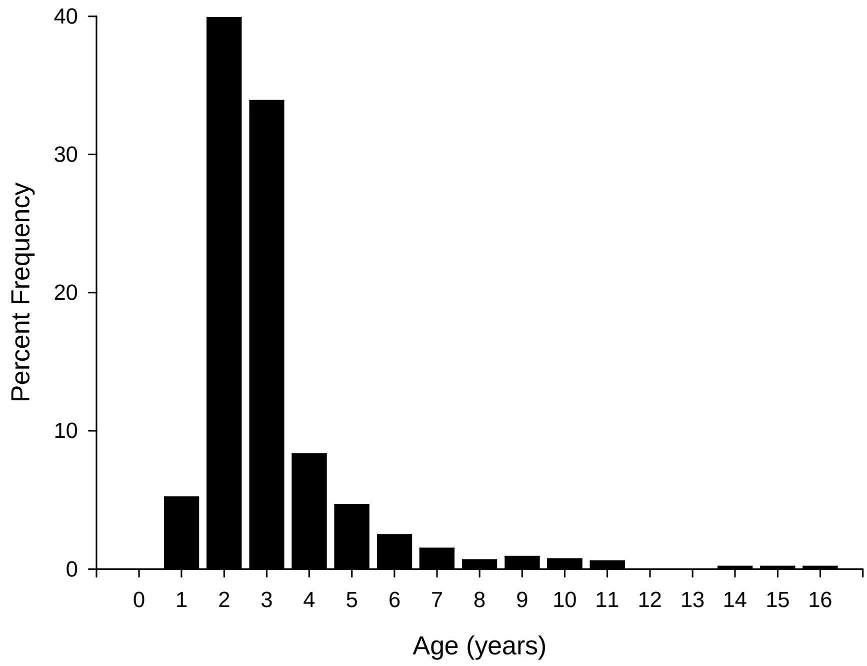


Figure 4.18. Age composition of tarwhine in commercial landings.

4.3.4. Mortality estimates

Estimates of total mortality (Z) made from the slope of the descending limb of the catch curve for tarwhine, fitted between ages two and 11, was 0.50 (Fig. 4.19). Independent estimates of natural mortality (M) based on the method of Hoenig (1983) using a maximum age of 16 years ranged between 0.19 and 0.29. Estimates of fishing mortality (F), made by subtracting M from Z, therefore ranged from 0.21 to 0.31.

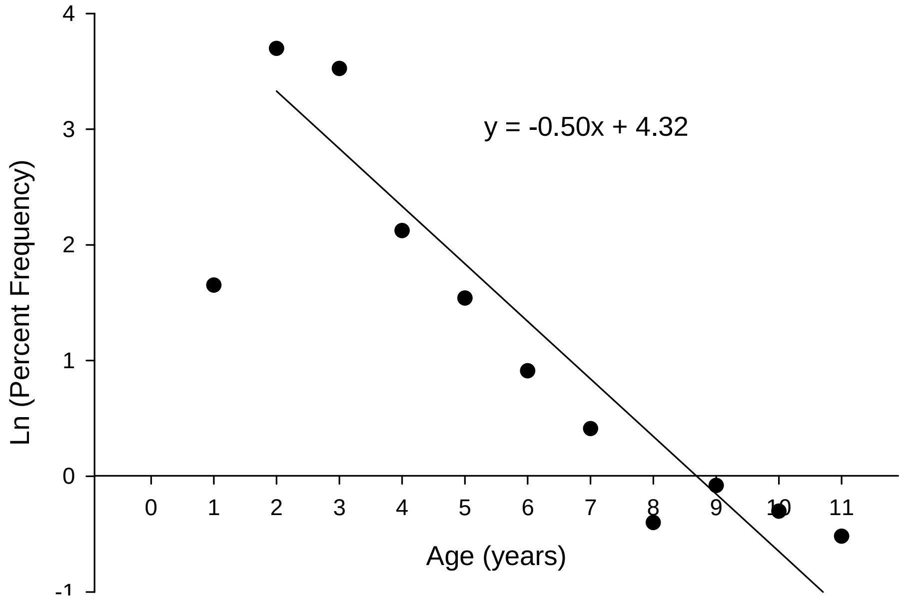


Figure 4.19. Catch curve for tarwhine.

4.3.5. Market price

Tarwhine sold through the Sydney Fish Markets are graded according to the following schedule:

Small	20 to 24 cm
Medium	24 to 30 cm
Large	> 30 cm

Average prices for tarwhine sold through the Sydney Fish Markets during 2005/06 indicate that "Small" fish sell for considerably less ($4.96/kg) than "Medium" ($6.35/kg), or "Large" ($6.44) graded fish (Fig. 4.20).

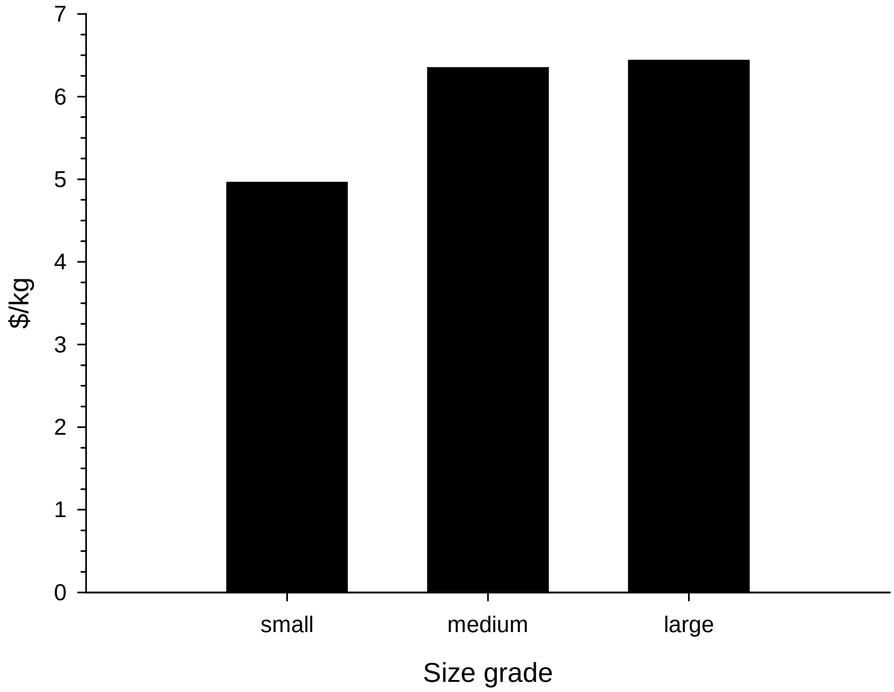


Figure 4.20. Average price information by size grade of tarwhine.

4.3.6. Per recruit analyses

Per recruit analyses were done using the following parameters:

L_∞ = 26.40 cm
K = 0.39 yr^{-1}
T_0 = -0.56 yr
Z = 0.50
M = 0.21
F = Z–M = 0.31
E = F/Z = 0.62
M/K = 0.54

The market price and size grade information used were as described above. L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation that yield per recruit is maximised at 19 cm FL (~ 21.7 cm TL) and that $ per recruit is maximised at 22 cm FL (~ 25.1 cm TL) (Figs 4.21A & B). At the current MLL of ~ 17.6 cm FL tarwhine are not growth overfished and are close to the maximum sustainable yield at current levels of fishing mortality (Fig. 4.22).

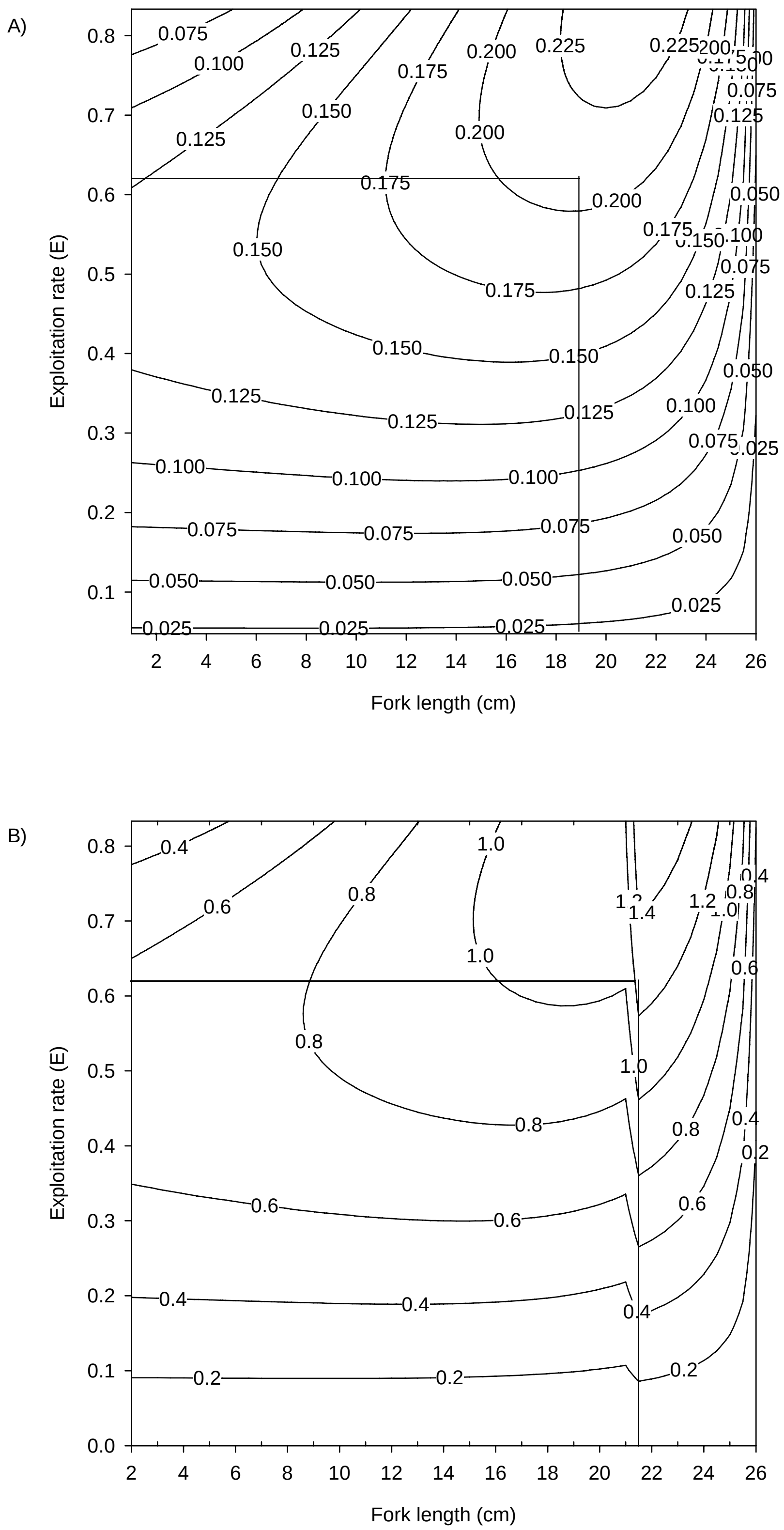


Figure 4.21. Yield and $ per recruit isopleths for tarwhine. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

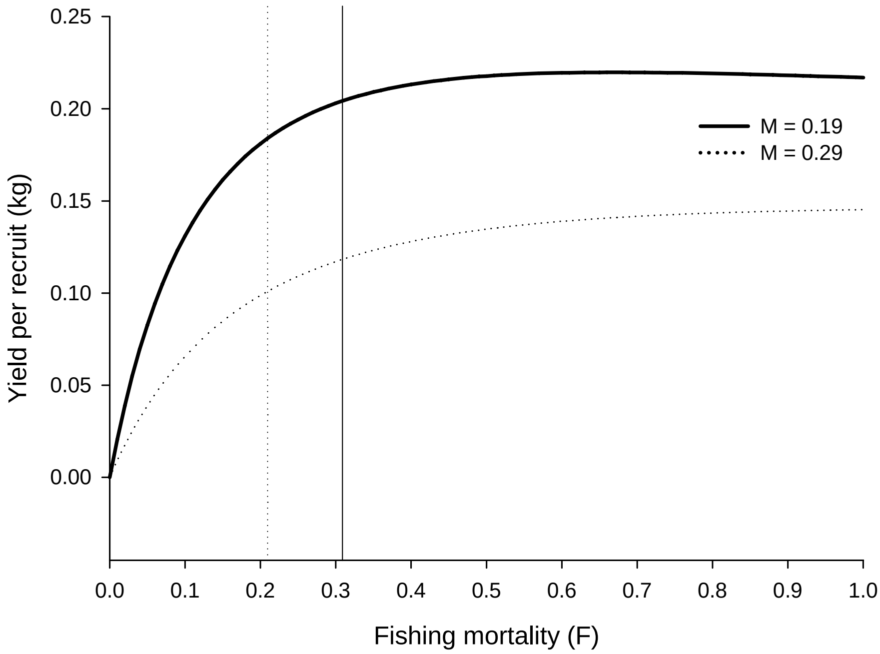


Figure 4.22. Yield per recruit values at the current MLL of 20 cm TL (~ 17.6 cm FL) for different values of M. The vertical lines indicate current levels of F associated with each level of M.

4.3.7. Spawning potential ratio

The SPR for tarwhine at current levels of mortality and the current MLL of 17.6 cm FL is ~ 0.31 (Fig. 4.23). This is well above the threshold level of 0.2 and indicates that at current levels of exploitation that tarwhine should be producing sufficient eggs to sustain the population. However, increasing the length at first harvest will produce considerable increases in egg production.

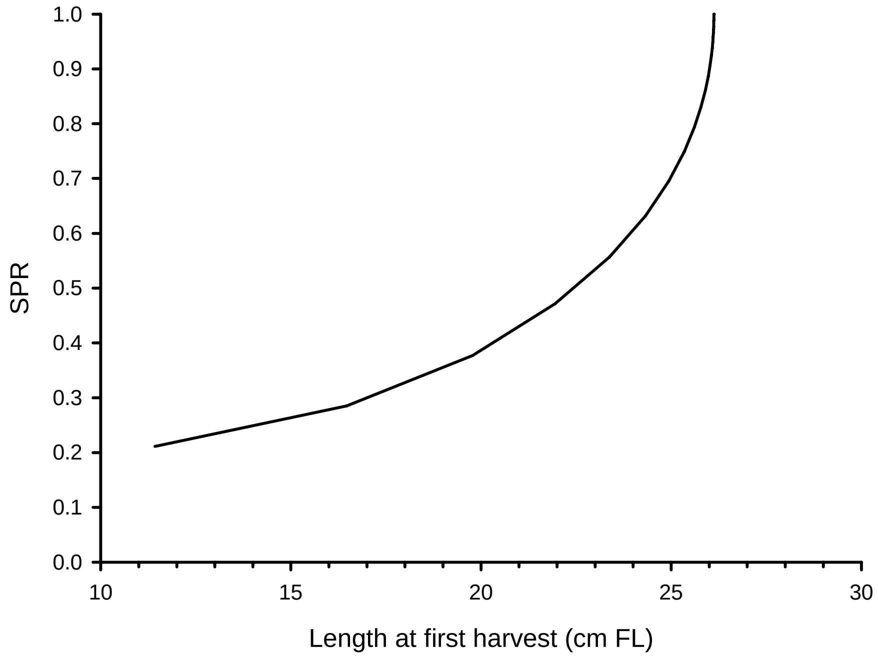


Figure 4.23. Spawning potential ratio for tarwhine at current levels of exploitation for a range of sizes at first harvest.

4.3.8. *Information fact sheet*

Relevant material from this chapter was collated into an information fact sheet for tarwhine (Fig. 4.24). Information was presented as total lengths.

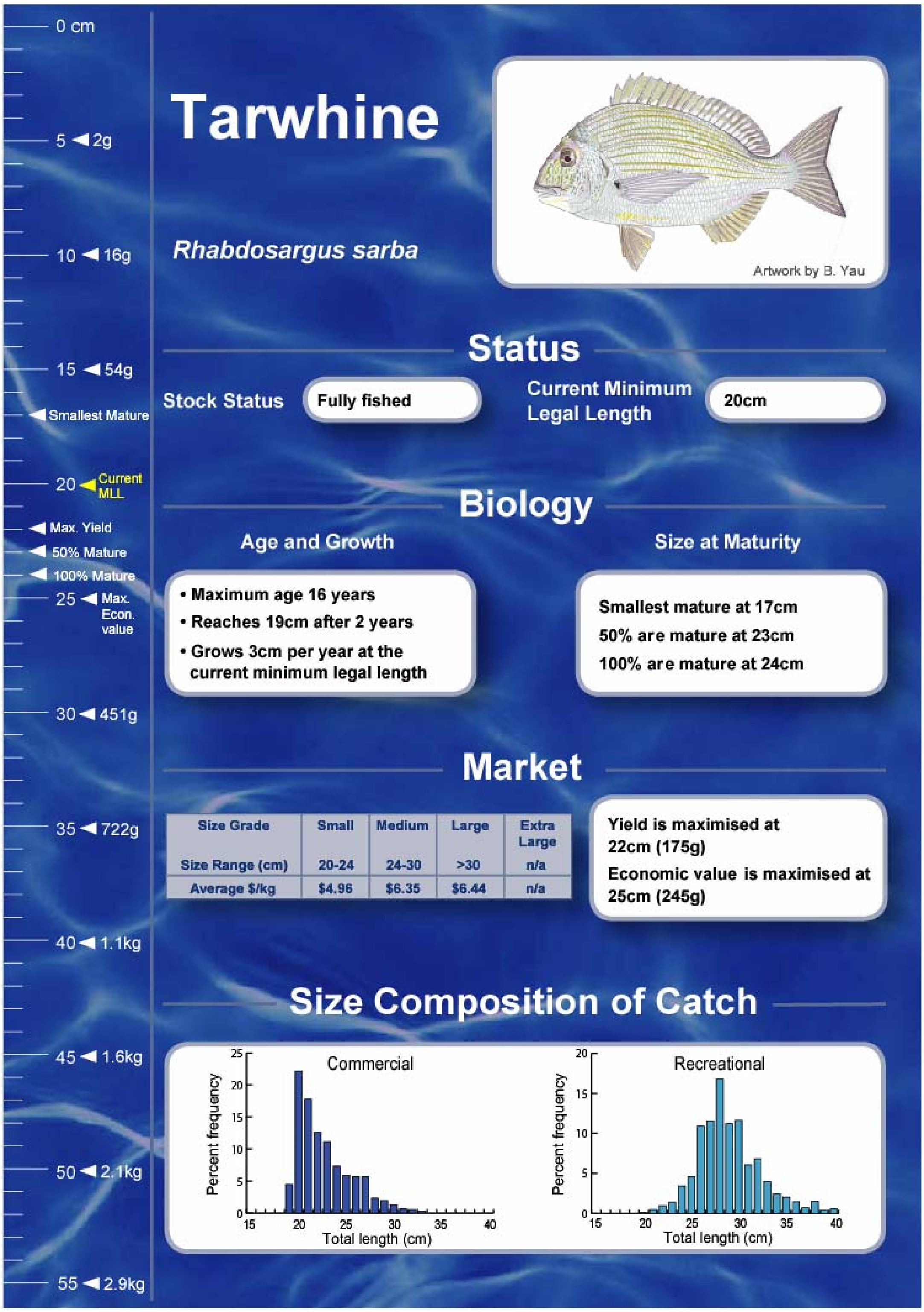


Figure 4.24. Information fact sheet for tarwhine.

4.4. Discussion

This study has provided the first detailed examination of the biology and fishery for tarwhine in NSW. Their exploitation status of FULLY FISHED in NSW is reasonable given that: (i) fishing mortality (F) is approximately the same as natural mortality (M); (ii) the size composition in recreational landings has remained similar from the mid-1990s to mid-2000s; (iii) they are not growth overfished; (iv) commercial catch rates have been relatively stable recently; and (v) they are fished throughout their entire geographic range (in NSW).

However, there is some concern for the stock and careful monitoring of landings is required. Trends of concern include: (i) the majority of fish mature at a larger size than the current MLL; (ii) the age structure in the commercial fishery is based largely on young fish; and (iii) there has been a long-term decline in commercial landings.

The lengths of commercially caught tarwhine are not routinely monitored, and thus comparisons with historical length data are not possible here. Despite the considerable difference in the size frequency distributions of commercial and recreational tarwhine catches, the sizes of fish landed by trailerboat and charterboat line fishers has been fairly constant between 1993-94 (Fig. 4.3) and 2001-03 (Fig. 4.4). The modal peak in recreational line caught fish has in fact shifted up from 25 cm FL (1993-94) to 26 cm FL (2001-03). Very few fish within 5 cm above the MLL of 17.6 cm FL (20 cm TL) were landed by recreational fishers in either of the data collection periods.

The considerable difference in the sizes of tarwhine in commercial landings when compared with recreational landings may be caused by several factors. Tarwhine use estuaries as nursery areas and, after growing to sexually mature adult sizes, move offshore into deeper water where they spawn (Wallace, 1975; Potter & Hyndes, 1999; Smith & Suthers, 2000; Hesp & Potter, 2003; Hesp *et al.*, 2004a). Most commercially caught tarwhine in NSW are landed by the Estuary General Fishery (~ 50%) primarily using mesh nets in estuaries (NSW DPI catch data). The Ocean Trap and Line Fishery primarily catch larger tarwhine using fish traps on offshore reefs, but lands only ~ 10% of the reported catch. The majority of commercially landed tarwhine are therefore small fish and the sizes of tarwhine seen in commercial landings reflect this. The tendency of tarwhine to move offshore when they have reached a certain size (Hesp & Potter, 2003; Hesp *et al.*, 2004a) also means that it is unlikely that the offshore trailerboat or charterboat (which primarily operates offshore) fisheries would encounter many small tarwhine. In addition, it is also likely that the selectivity of hooks used in offshore fishing precludes the capture of small tarwhine.

The peak spawning period for tarwhine in NSW indicated by monthly GSIs occurs in July. However, some spawning activity does occur throughout late austral autumn and for the entirety of winter (May – August) as indicated by GSI values elevated above those occurring throughout the rest of the year. Further evidence of this spawning season is also provided by macroscopic staging which showed that highest proportions of reproductively active gonads occurred between May and August. Larval tarwhine have been recorded in the coastal waters off Sydney from April to December (Gray *et al.*, 1992). Monthly trends in GSI and gonad staging have previously demonstrated that tarwhine in WA are also primarily winter spawners (with a peak in June – July) in temperate marine waters as well as in Shark Bay, a tropical embayment 800 km further north (Hesp & Potter, 2003). In KwaZulu-Natal (South Africa) spawning also takes place during winter and spring (July – November) (Wallace, 1975; Whitfield, 1998).

Apart from being a good indicator of spawning seasonality, trends in gonadosomatic indices may provide an insight into the spawning behaviour of a species (Sadovy 1996). Although the spawning behaviour of tarwhine has not been observed, in this study GSI for males (4.04 ± 0.77) was greater than that of females (2.97 ± 0.27) during the spawning season. The large size of the testes suggests that tarwhine are group spawners and that sperm competition is high (Sadovy, 1996). Pair-spawning sparids such as *Chrysoblephus laticeps* have been shown to have low male GSI (~ 10% of females GSI) during the spawning season (Buxton 1990). Further evidence for tarwhine group spawning is the notable lack of sexual dimorphism (pers. obs.). Similar conclusions based on testes size and the similarity of the sexes has previously been made for other sparid fishes in South Africa (*Argyrozona argyrozona*: Brouwer & Griffiths, 2005, *Rhabdosargus globiceps*: Griffiths *et al.*, 2002).

The L_{50} for tarwhine in this study was 19.85 ± 0.16 cm FL (~ 22.7 cm TL) and was similar for both males and females. Tarwhine in NSW begin to mature at 16 cm FL (~ 18.2 cm TL) and all fish are mature by 21 cm FL (~ 24.0 cm TL). In WA, L_{50}s were also similar for both males and females in all water bodies sampled, but were significantly larger for fish collected from temperate marine waters (20.6 – 21.8 cm TL) compared to those sampled from the Swan River Estuary (17.1 – 17.7 cm TL) or Shark Bay (17.0 – 17.3 cm TL) (Hesp & Potter, 2003). In other parts of the world, size at maturity ranges from 18.0 cm TL (L_{75}) in the Arabian Gulf (El-Agamy, 1989) to 26.0 cm TL (L_{50}) in South Africa (Wallace, 1975). Tarwhine in NSW therefore, appear to mature at slightly larger sizes than those from the Arabian Gulf or WA, but at a smaller size than those from South Africa. The L_{50} estimated in this study corresponds to an age of approximately 2.9 years, and is similar to that found for tarwhine in WA (two to three years: Hesp & Potter, 2003), South Africa (1.8 years: Radebe *et al.*, 2002), and the Arabian Gulf (two to three years: El-Agamy, 1989). The current MLL at capture for tarwhine in NSW is 20 cm TL. Since tarwhine reach L_{50} at a size (~ 22.7 cm TL) which is slightly larger than their current MLL for retention in NSW, the majority of the individuals of this species will not have the opportunity to spawn at least once before they are legally allowed to be fished.

Late gonochorism (rudimentary hermaphroditism), protandry, protogyny, and simultaneous hermaphroditism are recognized reproductive strategies within the family Sparidae (e.g., Smale, 1988; Buxton & Garratt, 1990; Hesp & Potter, 2003; Hesp *et al.*, 2004b; Brouwer & Griffiths, 2005). Tarwhine have been variously considered to be rudimentary hermaphrodites in WA (Hesp & Potter, 2003), and also protandrous hermaphrodites in other parts of their global range (Yeung & Chan, 1987; Garratt, 1993; Radebe *et al.*, 2002). The preliminary microscopic examination of the gonads of tarwhine in this study was not rigorous enough to reveal specifically what reproductive style is employed by this species in NSW waters. However, several pieces of indirect evidence suggest rudimentary hermaphroditism. The most obvious of these is the similarity in mean size of the sexes (unpubl. data). In protandrous species the males mature at smaller sizes than the females and all sex changing individuals have a size intermediate between those of the two sexes. Males and females of rudimentary hermaphrodites have a similar mean size range and intersexual states are all small and non-functional (Buxton & Garratt, 1990). In addition, many adult tarwhine of similar mean size in this study possessed ovotestes consisting primarily of functional testicular or ovarian tissue and small amounts of non-functional gonad tissue from the other sex (Fig. 4.10). It has been previously suggested that many sparids classified as protandrous hermaphrodites are not different from those that have been classified as rudimentary hermaphrodites (i.e., progressing from an immature hermaphroditic interval to either a male with ovarian rudiments or a female with male rudiments – Buxton & Garratt, 1990). Finally, the equitable sizes of ovaries and testes indicated by GSI values (Fig. 4.5) also suggests that this species is a rudimentary hermaphrodite. In protandrous species GSI is much greater in females than in males (Buxton & Garratt, 1990). It was difficult to ascertain whether gonads of immature/juvenile tarwhine consisted of a combination of male and female tissues, but some recently mature tarwhine certainly did (Fig. 4.9); however we did not specifically examine the gonads of immature tarwhine microscopically. Hesp & Potter (2003) have previously shown that the vast majority of mature tarwhine in WA contain gonads in which only testicular or ovarian tissue could be detected macroscopically. Clearly macroscopic evaluations of gonad content and structure need to be backed by detailed histological and behavioural evidence in order to determine the reproductive style of this species.

The clear and consistent appearance of sectioned tarwhine otoliths was reflected by high re-reading precision (cv = 0.037). This average cv of 0.04 is at the lower end of the generally reported range (Campana 2001). Total agreement in opaque zone counts occurred for 668 of 737 otoliths that were re-read (90.6%). A further 8.8% of otoliths had a difference of one in opaque counts between the first and second reads, the remaining 0.5% (just four otoliths) a difference of two. Discrepancies between first and second reads were always due to difficulty in the identification of opaque zones near the otolith edge (particularly in older fish) (see Fig. 4.13).

The annual periodicity of opaque zone formation in the otoliths of tarwhine has been validated by both use of a vital stain to mark the otoliths of captive fish, and also by analysis of variations in the marginal increment in otoliths taken from fish sampled from the wild. Marking the otoliths of wild-caught captive fish with alizarin complexone showed that opaque zones are formed during late winter – early spring but do not become visible on the edge of all otoliths until mid-spring (October: Figs 4.11 & 4.12). Marginal increment analyses and the proportion of otoliths having opaque margins showed repeated seasonal patterns, consistent with the annual formation of opaque zones in otoliths (Figs 4.14, 4.15 & 4.16). Results from marginal increment analyses suggest that opaque zones in wild fish collected from almost the entire NSW coast (Clarence River-Bermagui) are formed sometime in spring-early summer (September – December). Marginal increment analyses for tarwhine in WA showed similar patterns to those presented here (Hesp *et al.*, 2004a). These results support the model developed from the age validation experiment study that opaque zones become visible on the otolith edge during spring/summer but may not be scored as complete until summer.

Tarwhine collected as part of this study demonstrated growth pattern typical of many teleost fishes (Stewart and Hughes, 2005; Stewart and Hughes, 2006; Kingsford and Hughes, 2005). Tarwhine are less than three mm TL at hatching and settle into estuarine seagrass (*Zostera capricorni*) meadows at 10.5 – 12.5 mm TL (Neira *et al.*, 1998; Smith & Suthers, 2000). Fitting the von Bertalanffy growth function to the size-at-age data for tarwhine showed that early growth is extremely rapid and both males and females reach ~ 11.1 cm FL after one year and 16.6 cm FL after two years (Fig. 4.17). Tarwhine growth slows markedly after 1 year, and after 5 years may achieve a length of, on average ~ 23.3 cm FL. Growth of male and female tarwhine in this study was similar, and is consistent with results from comparisons of male and female growth from three different habitats in WA (Hesp *et al.*, 2004). Our model of tarwhine growth in NSW was also similar to that developed for tarwhine in WA (Hesp *et al.*, 2004). Tarwhine in NSW grow at a similar rate and reach a similar size at one year of age (11.1 cm FL) to fish from WA (~ 10.8 – 12.5 cm FL; Hesp *et al.*, 2004a) and from India (~ 15.4 cm FL; Patnaik, 1973), but growth is slower and size smaller than tarwhine from South Africa at age one (19.5 cm FL; Radebe *et al.*, 2002). Average maximum sizes (L_∞ = 26.40 cm FL) are also similar to those estimated in WA (23.3 – 26.9 cm FL), however are considerably smaller than the ~ 32.8 cm FL estimated for tarwhine from the Arabian Gulf (El-Agamy, 1989) or the 71.5 cm FL estimated for tarwhine from South Africa (Radebe *et al.*, 2002).

The maximum size observed during this study (30.5 cm FL/34.9 cm TL) was similar to that recorded by Hesp *et al.* (2004) in WA, but considerably smaller than the maximum reported for this species in Australia (45 – 50 cm TL; Hutchins & Swainston, 1986). Maximum sizes for tarwhine collected for studies in other parts of the world have ranged from 30.0 cm TL for fish from the Arabian Gulf (El-Agamy, 1989), 39.0 cm TL from India (Patnaik, 1973), to 68.3 cm FL (78.2 cm TL) for fish from South Africa (Radebe *et al.*, 2002). Given that we did not sample any tarwhine close to the maximum size recorded in NSW, it is possible that the maximum age for tarwhine in NSW may be older than our oldest fish. However, the maximum age estimated during this study (16 years) does compare well with maximum ages estimated for tarwhine in other studies from

counts of opaque zones in otoliths (13 years in WA: Hesp *et al.*, 2004, 16 years in South Africa: Radebe *et al.*, 2002).
It appears as though tarwhine in NSW are more similar in growth rate and maximum size and age to tarwhine from WA than those from other parts of the world (e.g., India, the Arabian Gulf, South Africa). This may be due to differences in habitat, distribution, exploitation, or gear selectivity, but it has been previously suggested that the populations currently reported to be *R. sarba* may consist of more than one species (Kuiter 1993). Indeed Hesp *et al.* (2004a) have suggested that this view is also consistent with the conclusion that tarwhine are protandrous hermaphrodites in South Africa (Garratt 1993) and Hong Kong (Yeung & Chan, 1987), but rudimentary hermaphrodites in WA (Hesp & Potter, 2003) and appear to be also in NSW (current study).

The age composition in commercial landings is possibly suggestive of a stock that has been fished down to a point which relies on very young fish constituting the bulk of the catch (~ 80% < three years old: Fig. 4.18). However, the associated estimate of total mortality (Z) of 0.50, comprised of natural mortality estimate (M) of 0.19 – 0.29 and fishing mortality (F) of 0.21 – 0.31, is indicative of a stock that is not currently being overfished as exploitation rate (E) is ≈ 0.5 (= 0.42 – 0.62).

Per recruit analyses indicate that the yield per recruit for tarwhine at current levels of exploitation is maximised at 19 cm FL (~ 21.7 cm TL). Tarwhine fetch relatively good prices at auction and their value sold through the Sydney Fish Markets does vary substantially with size grade. 'Medium' and 'Large' graded fish fetch ~ 1.5 times the price per kg as 'Small' graded fish (Fig. 4.20). As a result, $ per recruit analysis shows the influence of the relatively higher prices per kg attained by larger graded fish with the maximum $ per recruit being slightly larger than maximum YPR at 22 cm FL (~ 25.1 cm TL).

The estimate of M affects the value of the yield per recruit but does not change the shape of the curve or the conclusion that tarwhine are not growth overfished. Conclusions from these per recruit analyses are that: (i) current yield per recruit is very close to the maximum possible; (ii) any increases in size/age at first capture will only increase yield per recruit for ~ two cm of additional length (after which any further increases in size/age at first capture will not increase yield); and (iii) increases in the value of the resource could be achieved by increasing the size/age at first capture. Given the relatively low prices attained by 'Small' graded tarwhine and the fact that recreational fishers do not land many small fish, a small increase in MLL may be an astute management option. In addition, substantial increases in egg production are likely to result from an increase in size at capture.

5. BIOLOGY AND FISHERY FOR BLACKSPOT PIGFISH

5.1. Introduction

The eastern black-spot pigfish (*Bodianus unimaculatus)* is a member of the family Labridae, commonly known as wrasses. They are a large and diversified family with 60 genera and around 400 species (Gomon *et al.* 1994). There are at least 31 species of the genus *Bodianus* world-wide, 12 of which occur in Australian waters; however revision of the genus is being assessed (Gomon, 2006). The black-spot pigfish belongs to a species complex that was previously thought to be a single widespread species: however two species are currently recognised, an eastern (*B. unimaculatus*) and a western species (*B. vulpinus*). The eastern black-spot pigfish is widely distributed throughout the southern Pacific including south-eastern Australia from Noosa (Qld) to Port Phillip Bay (Vic), Easter Island, Lord Howe Island, the Kermadec Islands and New Zealand, and the western black-spot pigfish occurs along the west coast from Shark bay to Cape Naturaliste.

Member of the genus *Bodianus* (including blackspot pigfish) are generally colourful, protogynous hermaphrodites that are sexually dichromatic. They are highly sought after as aquarium specimens and some species are valuable targets of commercial and recreational fisheries. Blackspot pigfish are a key secondary species in the NSW Ocean Trap and Line fishery, where they are caught almost exclusively in demersal fish traps. They are a premium species for sale through the Sydney Fish Markets where they attain one of the highest prices of any finfish. They are a highly desirable catch for recreational fishers and the NSW recreational catch is thought to be three to four times the commercial catch.

Prior to this study, little information was available on the biology or fishery for blackspot pigfish anywhere. This chapter aims to provide information on age, growth, longevity, reproduction and fishery landings that may be used to improve our knowledge and management of blackspot pigfish. The information is presented in a manner that may assist managers when determining an appropriate size at first harvest.

5.2. Materials and methods

During the present study blackspot pigfish were separated by sex according to the presence of ovaries or testes. Data on the lengths of blackspot pigfish landed by commercial fish trappers were also obtained from Stewart & Ferrell (2001) who separated sexes based on their external appearance. Blackspot pigfish are hermaphrodites and the size at sex change was estimated by plotting the proportions of males in each length class and fitting a logistic curve to the data. All other sampling and analyses were done as described in Chapter 2.

5.3. Results

5.3.1. Landings in NSW

5.3.1.1. Current exploitation status

Blackspot pigfish are currently listed as being FULLY FISHED in NSW (2005/06). They were previously listed as being UNDEFINED and the 2005/06 assessment was based on information from this project. Blackspot pigfish were assessed as being FULLY FISHED because estimates of natural mortality were similar to fishing mortality, they are long-lived and commercial catch rates have remained steady.

5.3.1.2. Trends in catch

Reported commercial landings of blackspot pigfish reached a peak between 1995/96 and 1997/98 (~ 8.4t/yr) (Fig. 5.1). In the period since 1997/98 there has been a steady decline in landings to a historical low of 3.1t in 2005/06. During this period of decline in landings commercial effort also declined, and catch rates for fish trapping have remained relatively stable at ~ 0.6 kg/day since 1997/98 (Fig. 5.1).

The best estimate of the recreational harvest of blackspot pigfish in NSW is that from offshore trailerboat fishers between 1993 and 1995 (Steffe *et al.*, 1996), and averaged 8.6 tonnes per year. Blackspot pigfish were part of a species complex 'wrasse/tuskfish/gropers' during the National Recreational and Indigenous Fishing Survey (Henry & Lyle, 2003) and their specific harvest during the survey could not determined. Charterboat fishers in NSW have reported an average of three tonnes per year of blackspot pigfish since 2000/01.

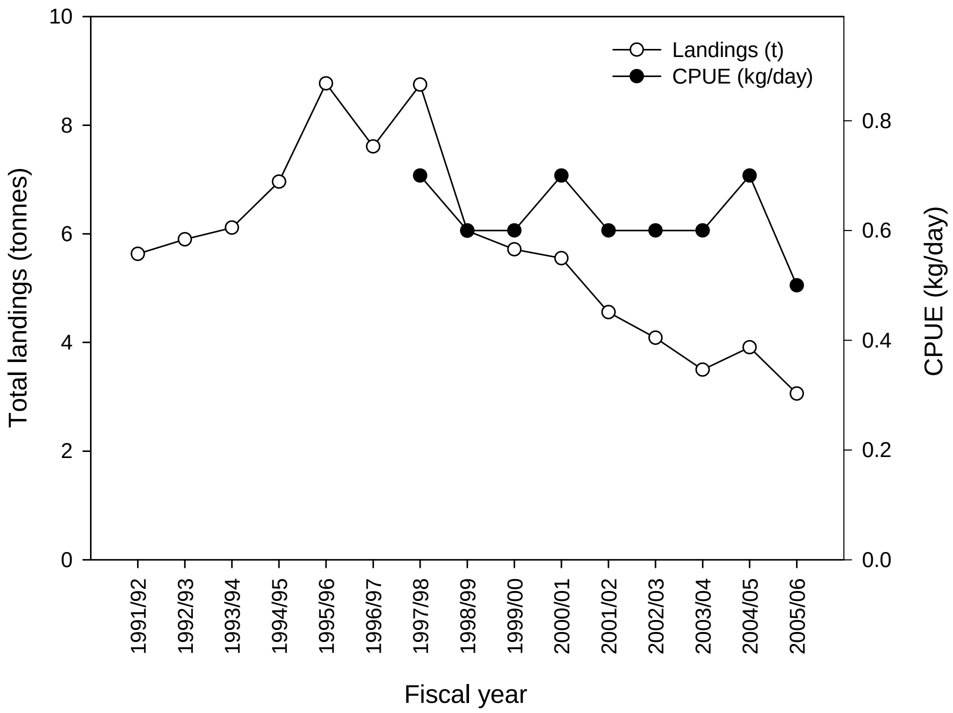


Figure 5.1. Reported commercial landings and catch rates (kg per day fish trapping) of blackspot pigfish in NSW. Source: NSW DPI Resource Assessment System.

5.3.1.3. Length measurements

Commercial landings

The sizes of blackspot pigfish captured by trap and line fishers were measured at the Sydney Fish Markets during the study. A total of 509 blackspot pigfish were measured and ranged in size from 22 cm to 40 cm FL (Fig. 5.2). The majority (~ 95%) of the commercial trap and line catch of blackspot pigfish was comprised of fish between 25 and 35 cm FL. The most commonly caught length class of fish was 30 cm FL (15.1%). The sizes of fish measured during the present study were similar to those measured during 2000 (Stewart & Ferrell, 2001); however there was a greater percentage (8.8%) of large (> 35 cm) fish measured during 2000. Males were, on average, substantially larger than females (Fig. 5.3). No blackspot pigfish have been observed to be discarded by commercial fish trappers (Stewart & Ferrell, 2001).

Recreational landings

Blackspot pigfish landed by recreational fishers are, on average, similar in size to those landed by commercial fishers (Figs 5.4 & 5.5). The most common size classes (FL) of fish landed by trailerboat (31 cm), charterboat (30 cm) and commercial (30 cm) fishers were very similar. More large (> 35 cm) fish were landed by charterboat (~ 18%) than trailerboat (~ 6.3%) fishers and both groups landed more large fish than commercial fishers (4.3%). Recreational fishers also retain more small (< 25 cm) fish than commercial fishers. There is no information on discarding of blackspot pigfish by recreational fishers; however discarding is thought to be negligible because of their excellent eating qualities.

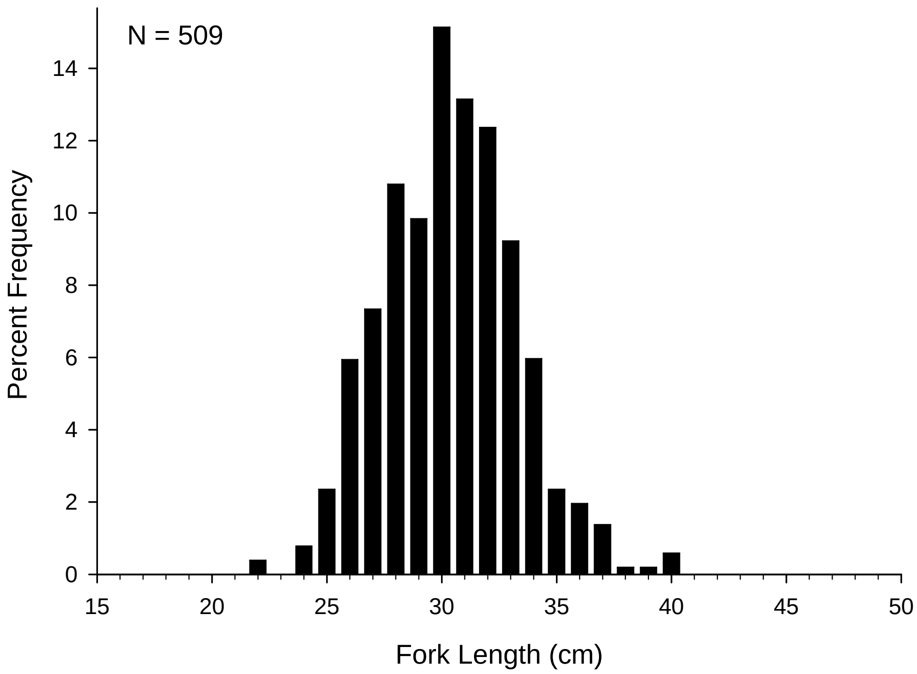


Figure 5.2. The lengths of blackspot pigfish landed by the NSW trap and line fishery during 2005/06.

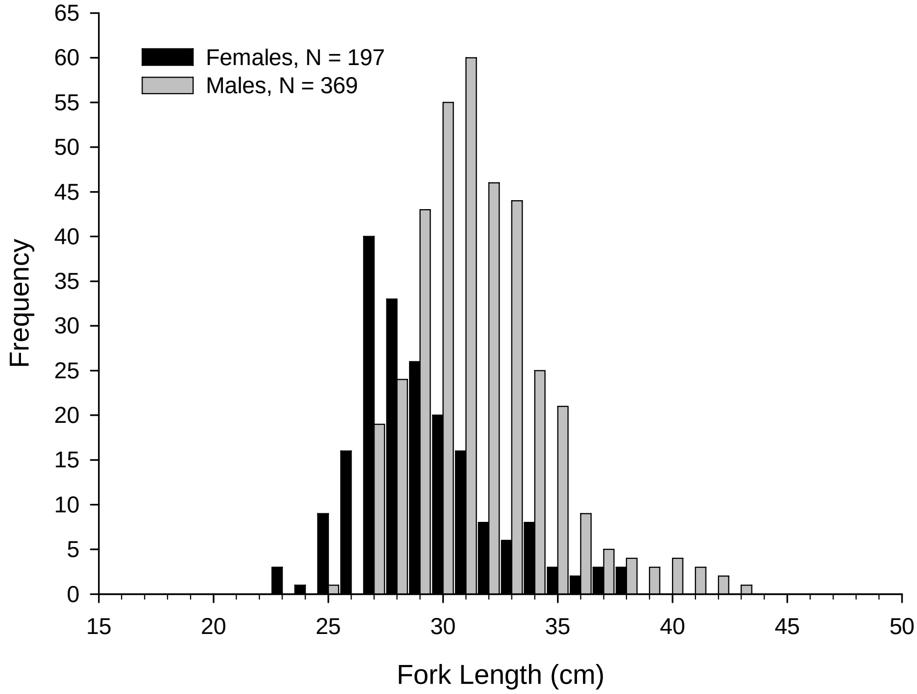


Figure 5.3. The lengths of male and female blackspot pigfish landed by commercial fishers 1999/00 to 2005/06.

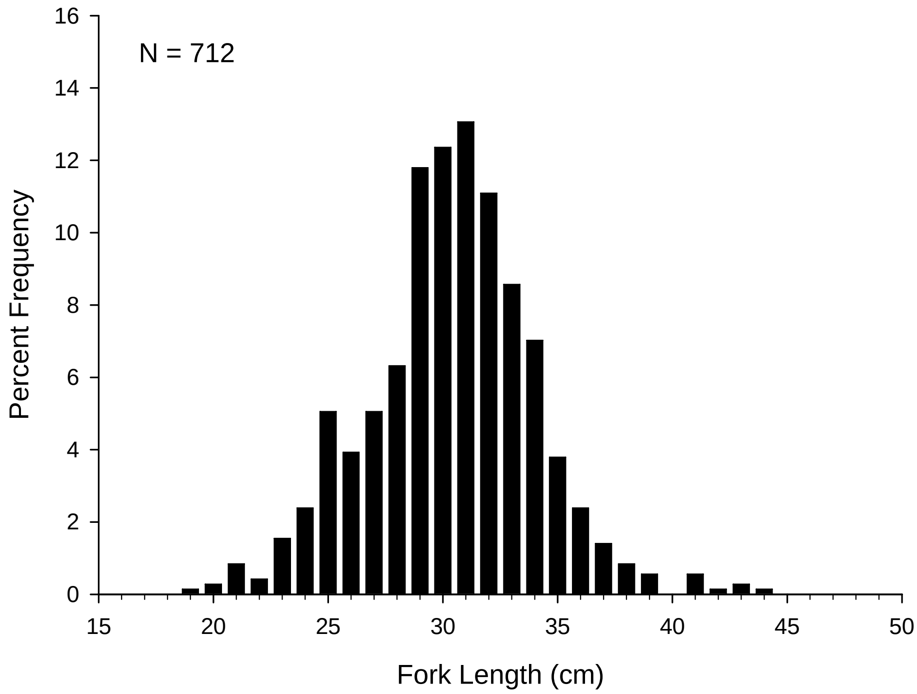


Figure 5.4. The lengths of blackspot pigfish landed by offshore trailerboat fishers during 1993/94 and 1994/95. Source: Steffe *et al.*, 1996.

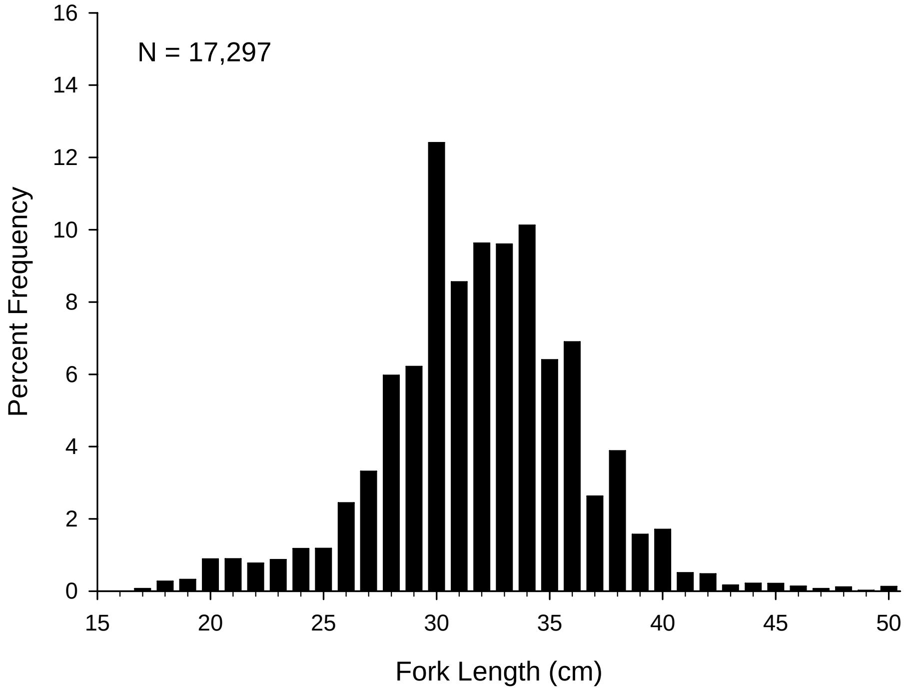


Figure 5.5. The lengths of blackspot pigfish measured by NSW charterboat operators from 2001 to 2003.

5.3.2. Reproduction

5.3.2.1. Seasonality of spawning

Gonadosomatic indices

Peaks in blackspot pigfish GSI for both males and females occurred in June, although elevated GSI values were evident from March to August (Fig. 5.6). The maximum GSI values for males and females were 3.70 ± 0.48% and 0.28 ± 0.02% respectively. During the peak spawning period (i.e., June), the ovaries and testes of blackspot pigfish were approximately nine and six times their non-spawning weights, respectively.

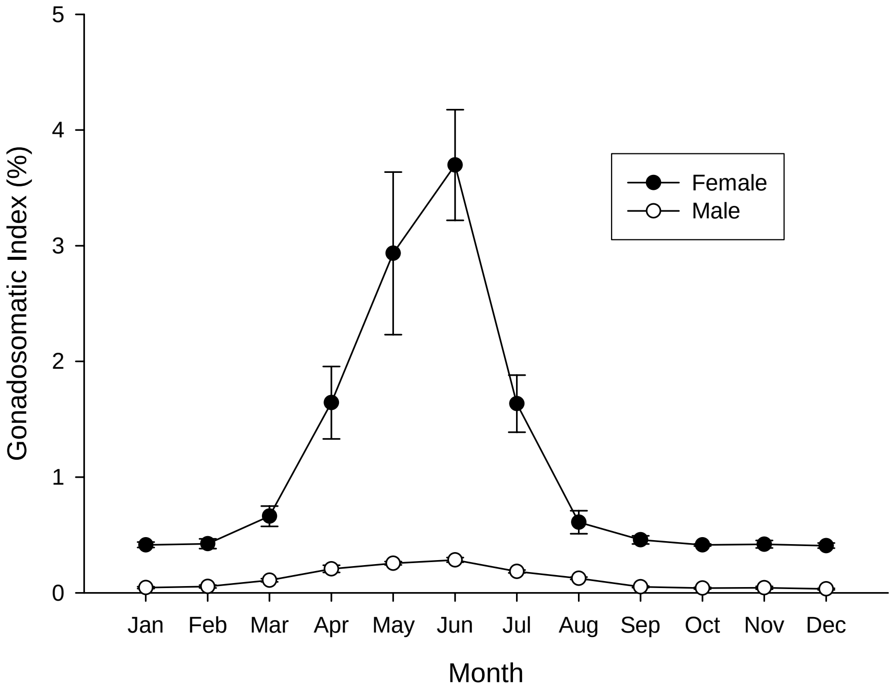


Figure 5.6. Gonadosomatic indices (mean GSI ± SE) for male (n = 144) and female (n = 98) blackspot pigfish.

Macroscopic gonad staging

Female fish with reproductively active [stage 3 (ripe) and stage 4 (running ripe)] gonads occurred between February and July (Fig. 5.7A). During these months, reproductively active ovaries represented between 12.5% (March) and 100% (June) of ovaries sampled. Running ripe female fish were collected from April to July. One spent (stage 5) female was sampled in October. All other female fish collected during the remainder of the study were estimated to have developing/resting (stage 2) ovaries. No stage 1 (immature fish) were sampled.

Male fish with reproductively active gonads occurred in February, April and June – July (Fig. 5.7B). During these months, reproductively active testes represented 8 – 44% of testes sampled. No running ripe (stage 4) male fish were collected during the study, and only three spent fish were collected (two in June and one in July). For the remainder of the year, all testes were estimated to be stage 2. No immature male fish were collected.

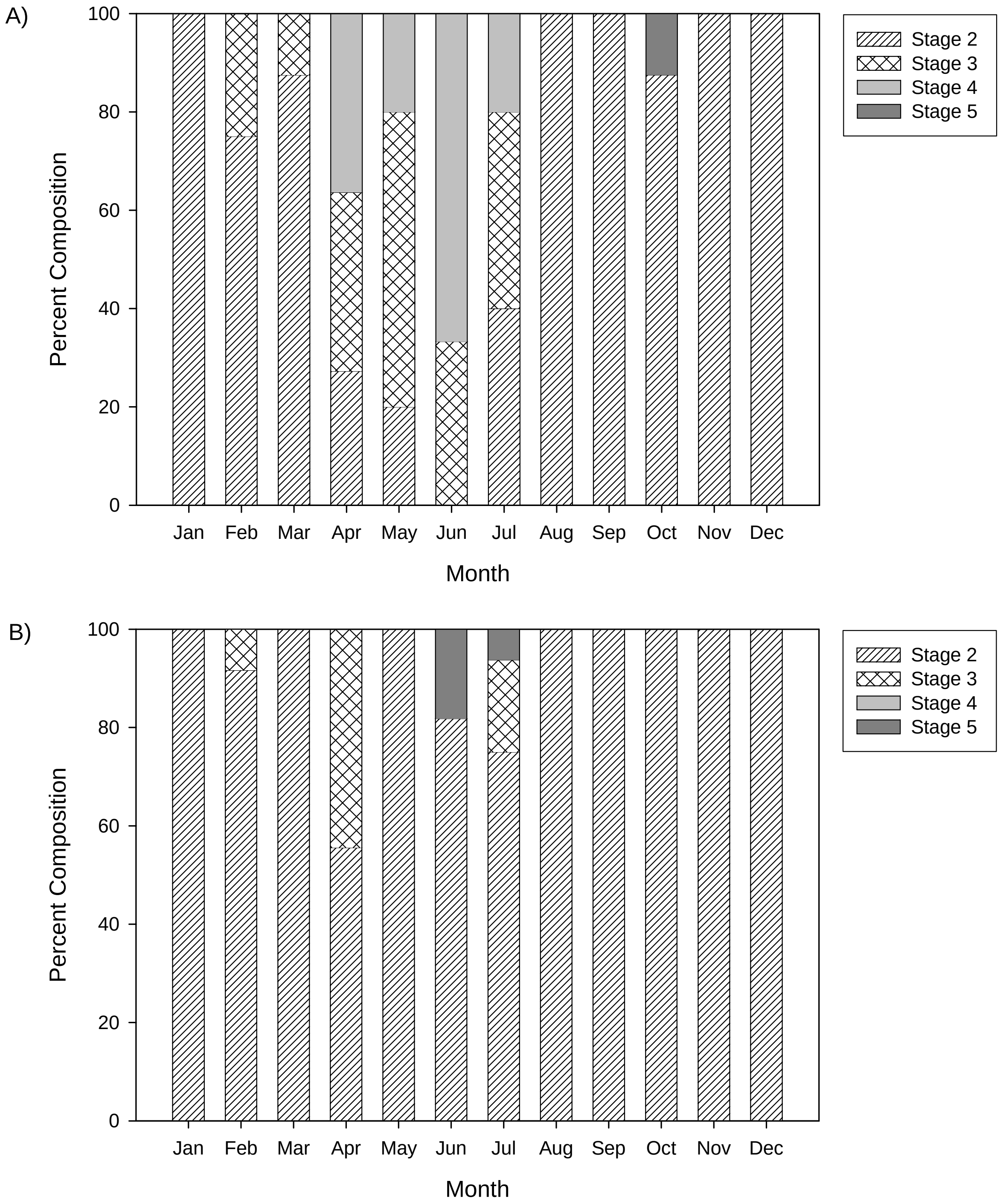


Figure 5.7. Monthly gonad stages of A), female, and B), male blackspot pigfish.

5.3.2.2. Size at maturity

No immature blackspot pigfish were collected during the course of this study (see 5.3.2.1). The smallest fish collected during the study was a female which was 22.1 cm FL that had stage 2 (developing/resting ovaries). The smallest male fish collected during the project was 24.2 cm FL.

Nine blackspot pigfish were collected which we considered to be in the process of changing sex from female to male. These fish possessed colouration intermediate between that of initial phase female and the terminal phase male (Fig. 5.8). The elongated caudal fins and prominent white dorsal spot of the male are not present in intermediate fish or females. The black spot on the dorsal fin (from which the fish derives its name) and dark dorsal and anal fin margins are present in males and intermediately coloured individuals, but not females. However, the characteristic dash pattern of the female is also present in intermediate individuals, but absent in males.

Figure 5.8. Sexual dimorphism in blackspot pigfish. The centre two fish display colouration intermediate between that of the initial phase female (bottom) and terminal phase male (top).

Some preliminary histological analyses of the gonads of these intermediate coloured individuals confirmed that sex inversion was taking place. These analyses showed that the gonad consisted of testicular tissue, but with immature ova distributed throughout (Fig. 5.9).

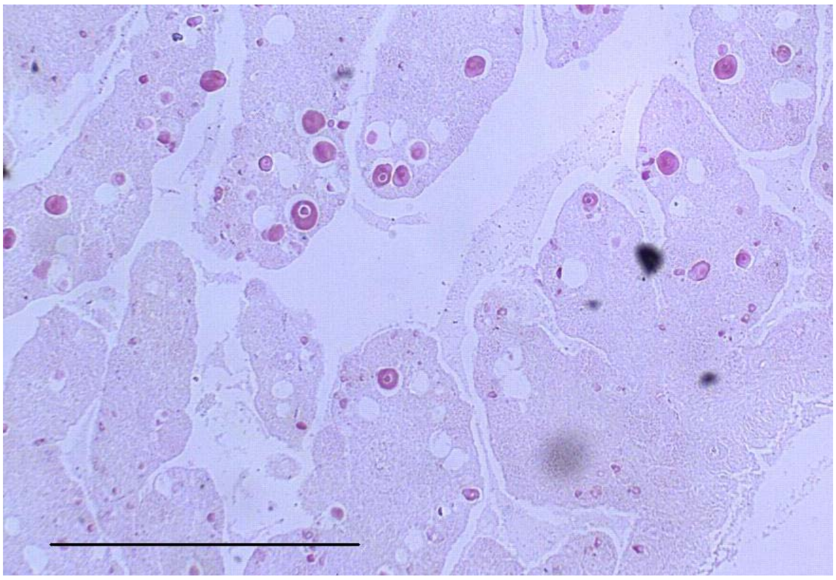


Figure 5.9. A histological section of the gonad of an intermediate coloured individual. The gonad consists primarily of testicular tissue, but with immature ova distributed throughout. Scale bar is 0.5 mm.

The estimated length at which 50% of females had changed to males was 28.93 ± 0.46 cm FL (range 24 – 37 cm FL; Fig. 5.10).

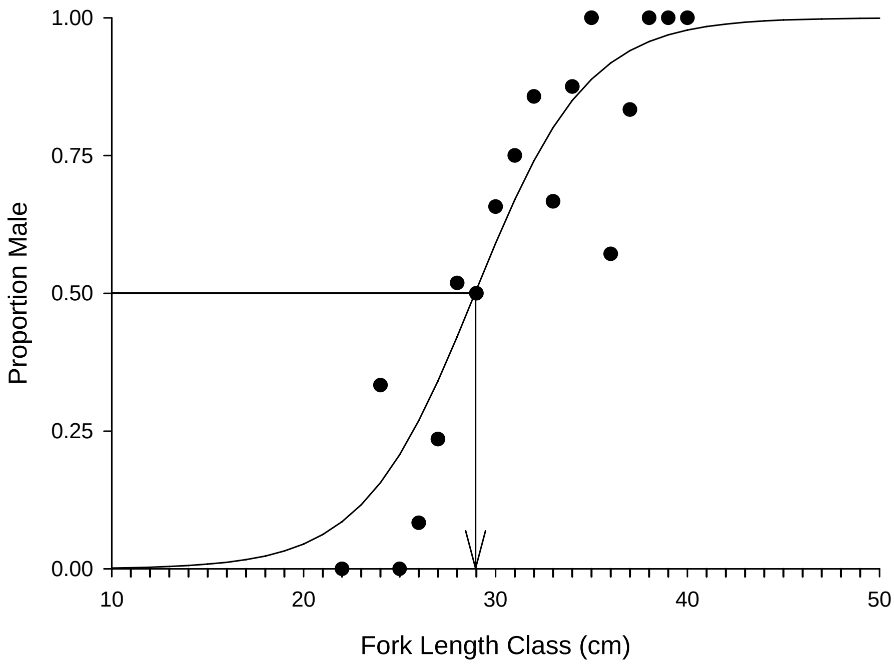


Figure 5.10. The proportion of males in each length class of blackspot pigfish.

5.3.2.3. Sex ratio

The number of male blackspot pigfish landed by commercial fishers was significantly greater than the number of females ($\chi^2 = 9.128$, $p < 0.05$; Fig 5.11). The sex ratio ranged from 0.8:1 (male:female) in April, to 3.0:1 in May. The overall average sex ratio of males to females was 1.47:1.

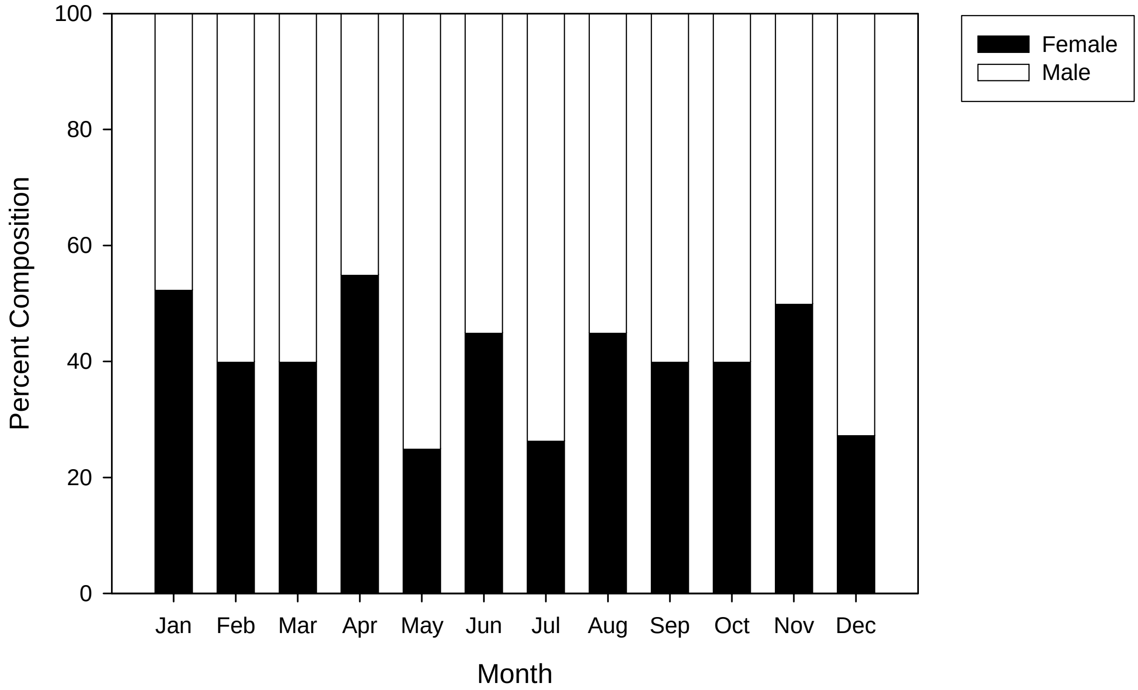


Figure 5.11 Monthly sex ratios for blackspot pigfish sampled from the Sydney Fish Markets (*n* = 242) during 2005.

5.3.3. Age and growth

5.3.3.1. Ageing procedure and validation

Appearance of blackspot pigfish otoliths

Sectioned blackspot pigfish otoliths were relatively simple to interpret and opaque zones easily counted (Fig 5.12). The core was always a largely opaque region, followed by a translucent region and then a very distinct opaque band, which was scored as the first annulus. The maximum number of opaque zones counted was 31. The coefficient of variation (cv) averaged across all ages was 0.065.

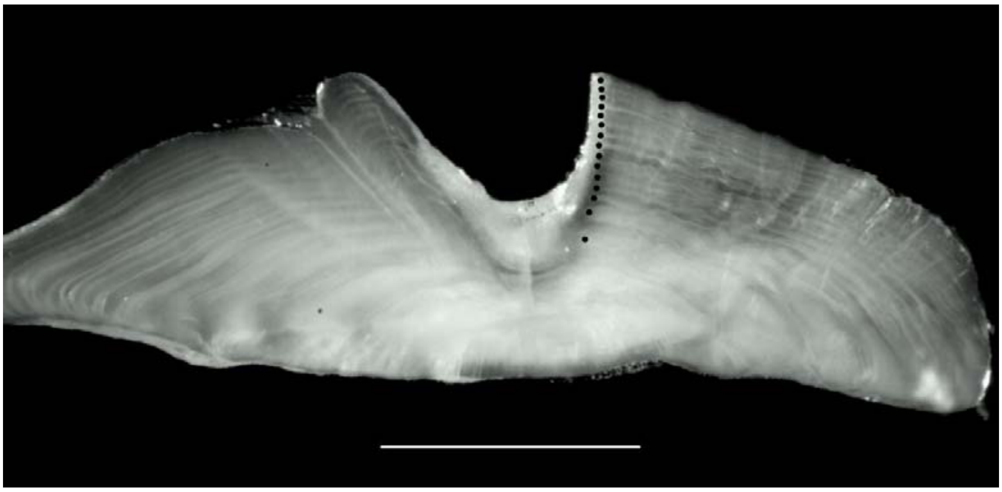


Figure 5.12. A sectioned blackspot pigfish otolith viewed using reflected light (at 2x magnification). Fifteen annuli were counted in this section. Scale bar is 1 mm.

Marginal increment analyses

The monthly marginal increments for blackspot pigfish showed considerable variation each month (Fig 5.13) but with a seasonal pattern of highest values in late autumn – winter (May to August) and lows during summer.

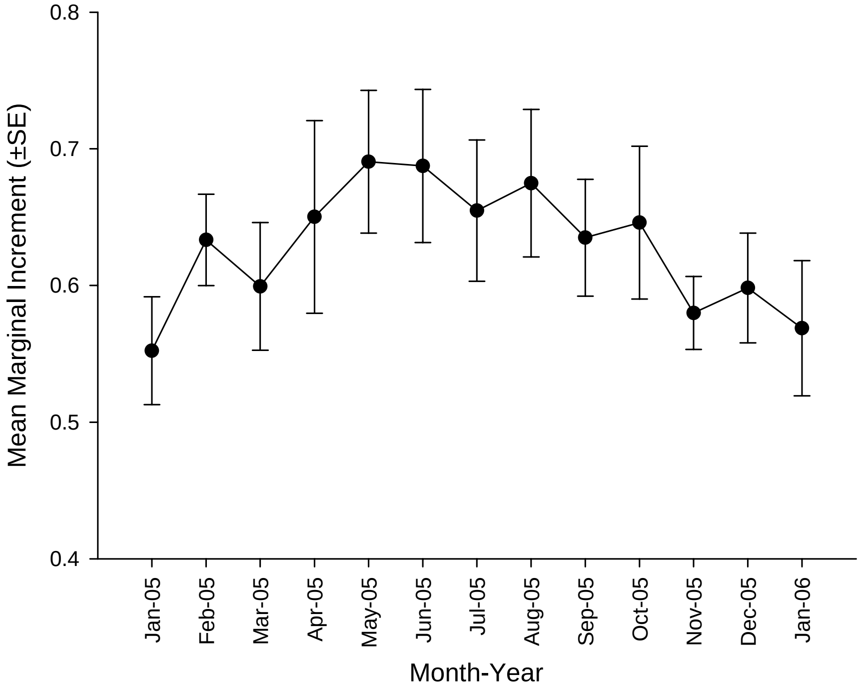


Figure 5.13. Mean (±SE) marginal increment values for blackspot pigfish (n = 210).

Edge analysis

The proportion of blackspot pigfish otoliths with opaque edges each month supports the marginal increment analyses and is consistent with annual periodicity of opaque zone formation. The highest proportion of otoliths having opaque edges occurred during winter (July and August), while lower proportions were seen during the remainder of the year (Fig. 5.14).

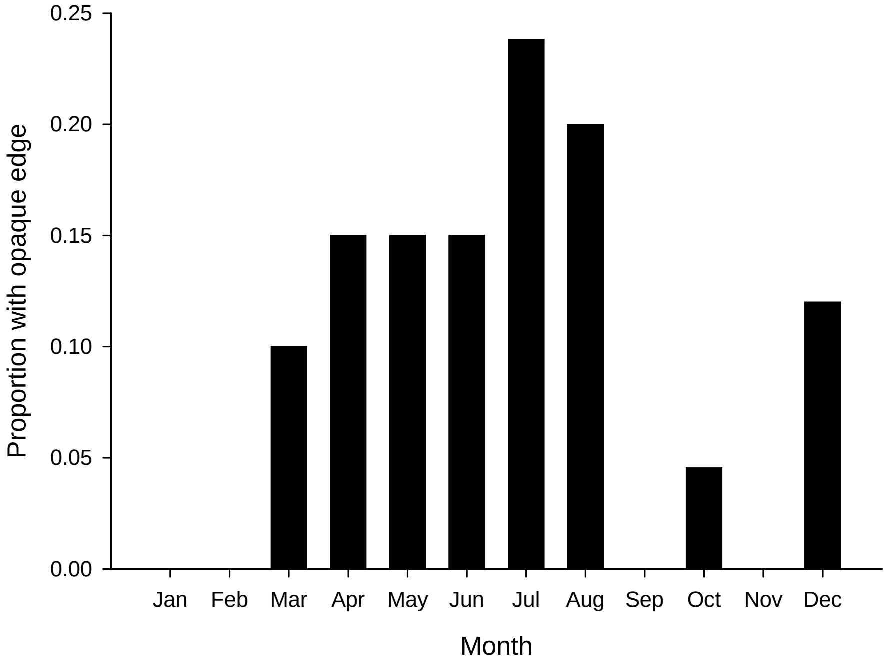


Figure 5.14. Monthly proportions of otoliths having opaque edges for blackspot pigfish (n = 250).

Development of ageing protocol

Opaque zones in otoliths were counted, and the fish placed into an age class according to opaque zone count only. The use of marginal increment information for each otolith in assigning age class to blackspot pigfish was not attempted because of the considerable variation in the data. A universal birthday was set at 1st June, which was the middle of the GSI-defined spawning period (March – August Fig. 5.6). The number of days from this universal birthday to the date of capture (as a proportion of a year) was then added to give the final age in years.

5.3.3.2. Growth model

The growth of male and female blackspot pigfish was not compared because they are protogynous hermaphrodites. The data were therefore pooled and the von Bertalanffy growth model fitted (Fig. 5.15). The parameter t_0 was constrained to -0.03 to account for the size-at-hatching of the related congeneric species *B. rufus* and *B. diplotaenia* for which this information was available (2.2 – 2.4 mm TL: Wellington & Robertson, 2001).

Very few young blackspot pigfish were collected during the study (only four fish were estimated to be less than five years old), and as a result early growth was difficult to model. Blackspot pigfish attain ~ 26.8 cm FL after 5 years, and 32.1 cm FL after 10 years. The twenty oldest fish collected were all males, the oldest of which was estimated to be 31.6 years old (32.0 cm FL). The oldest female fish was estimated to be 16.9 years old (36.6 cm FL). The largest fish collected were males, the biggest being 40.7 cm FL (estimated age 26.3 years old). The largest female fish sampled was 37.5 cm FL (estimated age 15.4 years old).

Intermediate individuals (*n* = 9) ranged in size from 27.9 to 33.1 cm FL and in estimated age from 4.6 to 12.6 years old (Fig. 5.15).

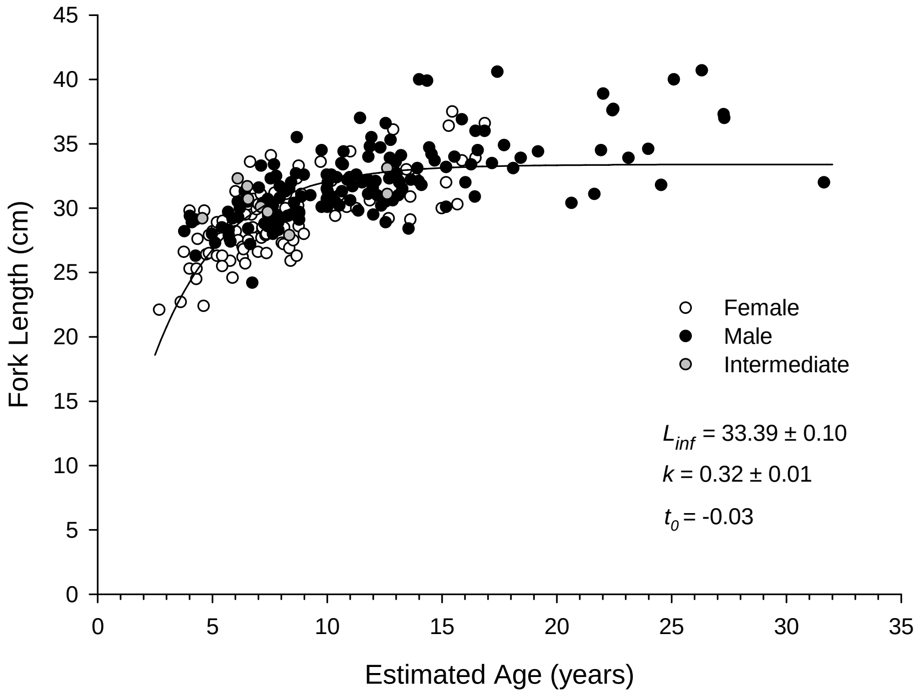


Figure 5.15. Size at age data with fitted von Bertalanffy growth curve for blackspot pigfish (*n* = 249).

5.3.3.3. *Age composition of landed catch*

The age-length key for blackspot pigfish (Table 5.1) was applied to the commercial size composition estimate (Fig. 5.2) to obtain an estimate of the age composition in commercial landings (Fig. 5.16). The majority (~ 83%) of commercially caught blackspot pigfish were between five and 15 years old (Fig 5.16). Few (7.5%) blackspot pigfish less than 5 years old were observed in commercial catches, and no zero or 1 year olds. There was evidence of variable recruitment, with relatively low numbers of fish aged 9, 14 and 19 years old.

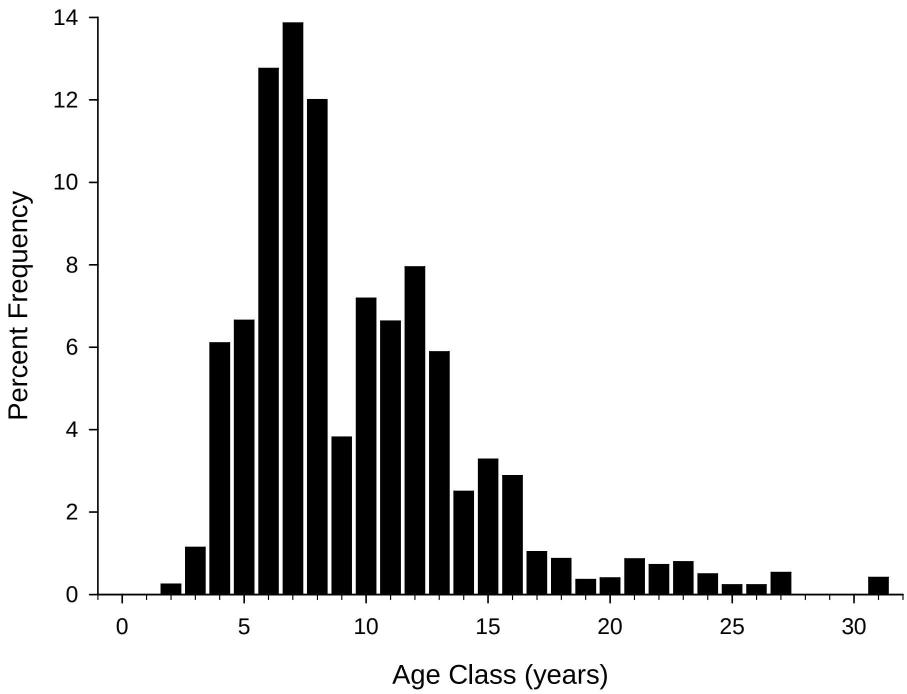


Figure 5.16. Age composition of blackspot pigfish in commercial landings.

Table 5.1. Age-length key for blackspot pigfish.

Fork Length Class (cm)	Age (years)																																
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
22			1	1	1																												3
23																																	0
24					1	1	1																										3
25					2	2	1		1																								6
26				1	3	2	3	1	2																								12
27					2	4	6	2	4																								18
28				1	2	5	3	11	3				1	1																			27
29					5	3	4	5	6		1	1	2	1																			28
30							8	6	4	2	5	3	3	1	1	2	1				1												37
31							3	4	4	2	3	3	2	2	1							1			1								26
32							1	2	4	1	6	4	2	6		1	1															1	29
33							1	2	1	1	1	1	4	2	1	2	2	1	2					1									22
34								1			1	4	1	1	2	1	1	1		1		1		1									16
35										1			1																				2
36													2			2	3																7
37																1							2					2					5
38																							1										1
39															1																		1
40															1			1								1	1						4
n	0	0	1	3	16	17	31	34	29	7	17	16	18	14	7	9	8	3	2	1	1	2	3	2	1	1	1	2	0	0	0	1	247

5.3.4. *Mortality estimates*

The estimate of total mortality (Z) made from the slope of the descending limb of the catch curve for blackspot pigfish, fitted between ages seven and 27, was 0.20 (Fig 5.17). Age seven was chosen because it was the most abundant age class and age 27 was chosen because there were no observed 28 year old fish.

Estimates of natural mortality (M) based on the method of Hoenig (1983) using a maximum age of 31 years ranged between 0.10 and 0.15 (assuming 5% and 1% of the population attaining T_{max} respectively). Estimates of fishing mortality (F), made by subtracting M from Z, therefore ranged from 0.05 to 0.10.

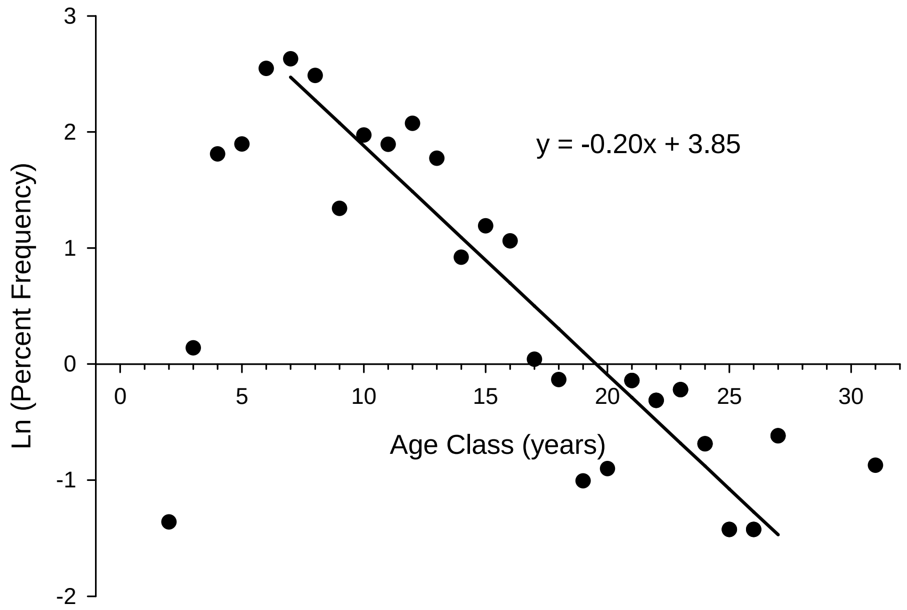


Figure 5.17. Catch curve for blackspot pigfish.

5.3.5. Market price

Blackspot pigfish sold through the Sydney Fish Markets are graded according to the following schedule:

Small	< 25 cm
Medium	25 to 35 cm
Large	> 35 cm

Average prices for blackspot pigfish sold through the Sydney Fish Markets during 2003/04 and 2005/06 indicate that "Small" ($24.23/kg) and "Medium" ($24.56/kg) graded fish sold, on average, for slightly more than "Large" fish ($21.71/kg) (Fig. 5.18).

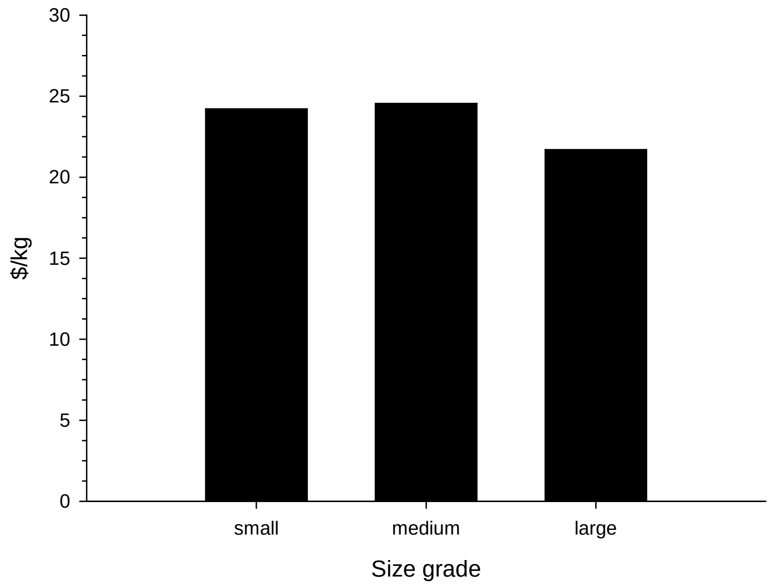


Figure 5.18. Average price information by size grade of blackspot pigfish.

5.3.6. Per recruit analyses

Per recruit analyses were done using the following parameters:

L_∞ = 33.39 cm
K = 0.32 yr^{-1}
T_0 = -0.03 yr
Z = 0.20
M = 0.10
F = Z–M = 0.10
E = F/Z = 0.50
M/K = 0.31

The market price and size grade information used were as described above. L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate. The results indicate that at present levels of exploitation that yield per recruit is maximised at ~ 24 cm FL and that $ per recruit is maximised at ~ 24.5 cm FL (Fig. 5.19).

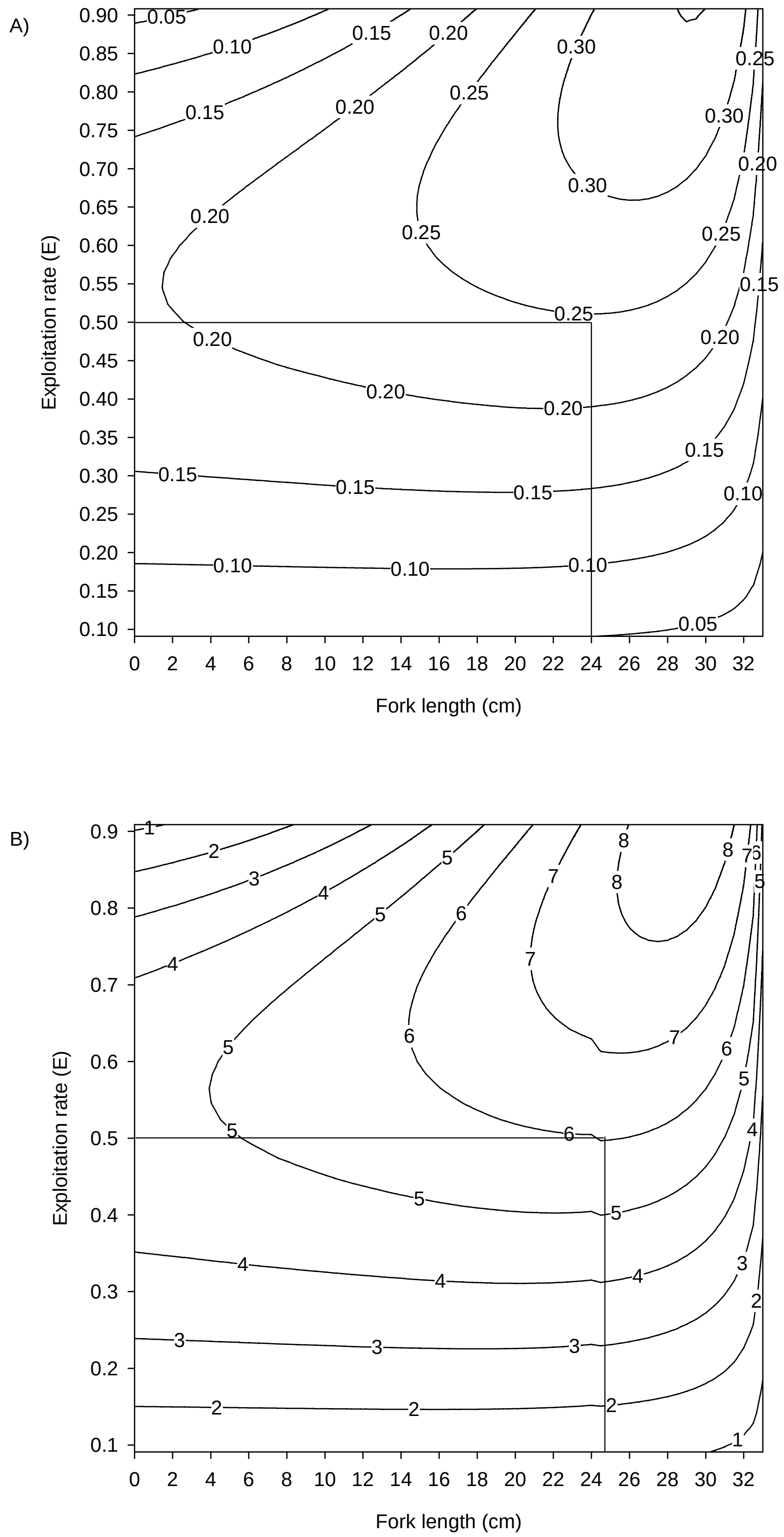


Figure 5.19. Yield and $ per recruit isopleths for blackspot pigfish. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

5.3.7. *Spawning potential ratio*

The SPR for blackspot pigfish at current levels of mortality is above the threshold level of 0.2 and indicates that at current levels of exploitation that blackspot pigfish should be producing sufficient eggs to sustain the population regardless of their size at first harvest (Fig. 5.20). The smallest blackspot pigfish in landings are ~ 20 cm and this size at first harvest corresponds to a SPR of ~ 0.43.

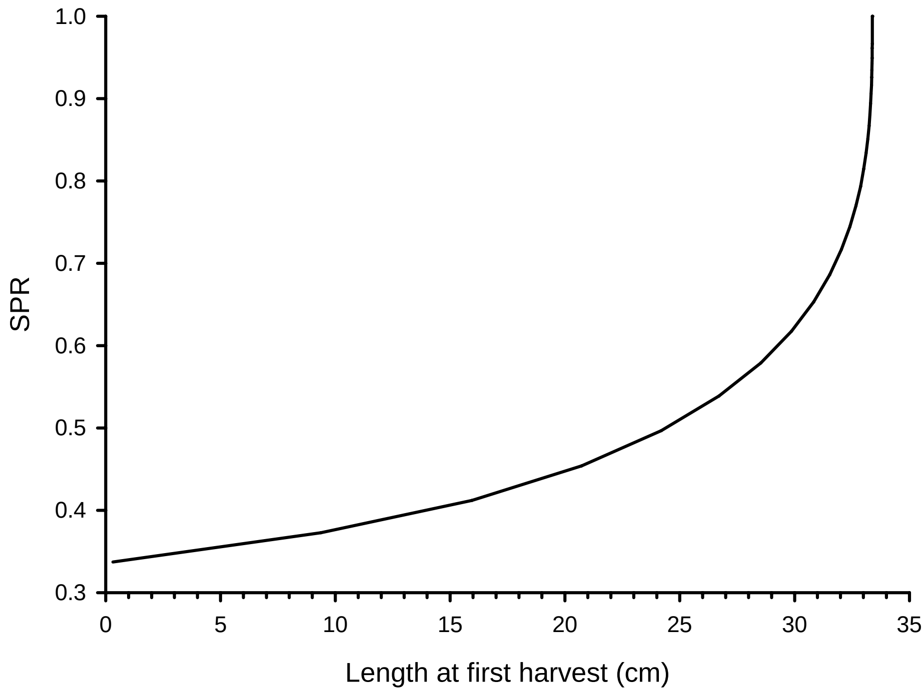


Figure 5.20. Spawning potential ratio for blackspot pigfish at current levels of exploitation for a range of sizes at first harvest.

5.3.8. *Information fact sheet*

Relevant material from this chapter was collated into an information fact sheet for blackspot pigfish (Fig. 5.21). Lengths were presented as total lengths.

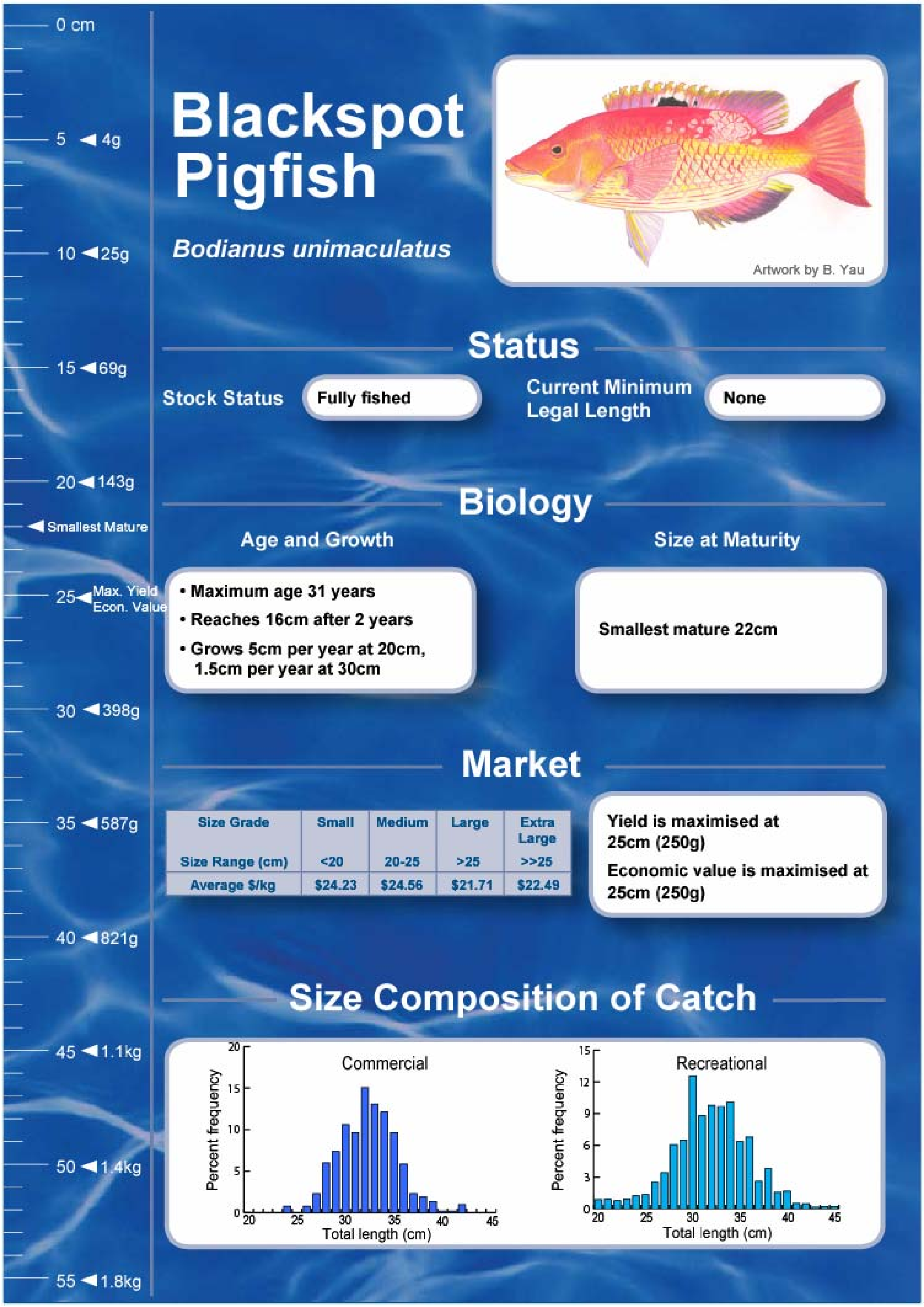


Figure 5.21. Information fact sheet for blackspot pigfish.

5.4. Discussion

The current NSW DPI assessment of blackspot pigfish as being FULLY FISHED is based on the information generated through the present study. Reasons for the assessment included the estimates of natural mortality being similar to fishing mortality, steady commercial catch rates and their protogynous hermaphroditism and extreme longevity making them vulnerable to overfishing.

The commercial and recreational fisheries in NSW appear to be harvesting blackspot pigfish in a sustainable manner at present. Total landings are relatively low and commercial catch rates have remained stable during the past few years. The fisheries land predominantly male fish and females above their size at maturity. There are many year classes represented in landings that result in a reasonably low estimate of total mortality based on catch curve analysis (Z = 0.2). Blackspot pigfish during this relatively short study were observed to display substantial longevity, with a maximum age of 31 years. The estimate of natural mortality based on maximum age was therefore quite low (M = 0.1 to 0.15) and fishing mortality was no greater than natural mortality. In addition, the SPR is well above the threshold level of 0.2.

However, despite the apparent sustainability of the stock under current levels of fishing pressure it is important that the stock be carefully monitored. Members of this genus are highly esteemed as food fish (Gomon & Randall 1978) and worldwide, fishing pressure has reduced many populations to critically low levels. Commercially, blackspot pigfish attain one of the highest prices per kg of all finfish (averaging > $24/kg) and there is therefore the potential for future specific targeting of this species. The rapidly increasing effort by recreational fishers is also likely to increase fishing pressure on this species. The age composition in landings showed evidence of variable recruitment, with relatively low numbers of fish aged 9, 14 and 19 years old. Extreme longevity may be an adaptation to reduce the risk of stock collapse through periods of poor environmental conditions for recruitment (Longhurst, 2002). As such, age-class truncation through fishing may be a threat to the long-term sustainability of blackspot pigfish and age-based monitoring of this species is recommended.

It is likely that the protogynous hermaphroditism of blackspot pigfish in combination with the selectivity of the fishing methods contribute to the sustainable harvesting of this species. Almost all commercially landed blackspot pigfish are caught in demersal fish traps and they are selected at ~ 25 cm FL in fish traps covered with 50 mm hexagonal wire mesh (Stewart & Ferrell, 2003). When escape panels of 50 x 75 mm mesh are introduced during 2007 it is predicted that blackspot pigfish will be selected at ~ 33 cm FL and that 65% of the commercial catch by weight will be lost. In addition, the hook selectivity of offshore recreational fishers may preclude the capture of small (< 20 cm) blackspot pigfish. This suggested selective harvesting of males, due to their larger sizes, may cause the dominant female to change sex and grow larger, ultimately becoming vulnerable to the fishing gears used. The recreational fishery is substantially larger than the commercial fishery, and will become proportionally even greater following the introduction of escape panels in fish traps. Fisheries for similar species have been severely depleted through fishing (Ault *et al.*, 2003) and it would be prudent to continue to monitor landings (particularly recreational) in terms of sizes, ages and sex ratios.

Blackspot pigfish are sexually dimorphic and conform to the general reproductive pattern of wrasses (family Labridae) in being monandric protogynous hermaphrodites (Robertson & Choat, 1973). Strong evidence for this is the predominance of males in the smaller size classes and females in the larger size classes, the presence of fish with colouration intermediate of that observed for females and males and the presence of male and female tissue in the gonads of these fish with intermediate colouration. Sex change in blackspot pigfish was observed to occur between 24 and 37 cm FL with 50% at 29 cm FL. It is reported that sex change in the genus Bodianus is related to social hierarchy. Harems of a single male and many females exist and the largest female changes to be male when the original male is removed (Hoffman, 1985). Male blackspot pigfish are larger than females which provides an insight into their reproductive strategy. Other members of the genus *Bodianus* that have larger males have paired spawning (*B. rufus* and *B. diplotaenia*), where a larger body-size for males is advantageous in terms of displaying aggressive dominance (Hoffman, 1985). It is hypothesized from this that blackspot pigfish have paired spawning. However, observations on blackspot pigfish social interactions are difficult because they occur in depths that preclude easy diving (> 50 m). Such observations may be achieved with the use of underwater video surveys.

Blackspot pigfish displayed an extended spawning period (March to August) with a peak during May and June. An autumn/winter spawning period is in contrast to the other labrid studied during the present study, the maori wrasse, which exhibited a summer/autumn spawning period (Chapter 6). Other temperate Australian labrids have spawning periods during winter/spring (blue groper *Achoerodus viridus*, Gillanders, 1995) and winter/summer (purple wrasse *Notolabrus fucicola*, Ewing *et al.* 2003). The reason for the autumn/winter spawning of blackspot pigfish is unknown, but may differ from the other species because they occur in much deeper waters.

The observed sex ratio in landings of blackspot pigfish was strongly biased towards males (~ 1.5:1). This ratio was likely to be driven by the selectivity of the fishing gears, rather than a reflection of the true sex ratio in the population. The sex ratios in populations of protogynous hermaphrodite labrids tend to be dominated by females (Ault *et al.*, 2003; Hoffman, 1985) and this is probably the case for blackspot pigfish. The predominance of males in commercial landings is almost certainly due to the selectivity of fish traps, with the majority of females being too small to be retained by the trap mesh (Stewart & Ferrell, 2001). The hook selectivity of recreational fishers in deeper offshore waters may also preclude the capture of smaller females.

Sectioned otoliths of blackspot pigfish were relatively easy to interpret and the marginal increment analysis showed a pattern that was consistent with annual periodicity of opaque zone formation. Opaque zones were formed during winter/spring but were mostly not scored as being completed until summer. No young (< three years old) fish were obtained and so growth up until ~ four years old was inferred from a size at hatching equivalent to other members of the genus and the fitted von Bertalanffy growth model. The model suggests that blackspot pigfish attain ~ 20 cm FL after three years, 30 cm FL after seven years and have very slow growth thereafter. The maximum age observed during this relatively short study (12 months sampling) was 31 years which is considered old within this genus.

6. BIOLOGY AND FISHERY FOR MAORI WRASSE

6.1. Introduction

The maori wrasse *Ophthalmolepis lineolatus* (Valenciennes, 1838) is a small endemic labrid commonly found on the temperate coastal rocky reefs of southern Australia, on both the east (Byron Bay, NSW to Wilson's Promontory, Vic.) and west (Houtman Abrolhos, WA to Kangaroo Island, SA) coasts (Hutchins & Swainston 1999). Maori wrasses are carnivorous and are more frequently found in reef habitats dominated by sponges than in kelp forest or urchin-grazed barrens (Curley *et al.*, 2002). Adult maori wrasses are also more abundant with increasing depth down to 20m where they may form loose aggregations, but can be found as deep as 60 m (Curley *et al.*, 2002; Kuiter, 1993).

The only commercial fishery in NSW which targets maori wrasse is the Ocean Trap and Line Fishery. Maori wrasse are mainly caught using baited handlines, but are also a valuable by-catch species caught when fish trapping. Maori wrasse are one of the most important species in landings of offshore recreational fishers in NSW and rank in the top 10 species by number (Steffe *et al.*, 1996). There are currently no management regulations aimed specifically at protecting maori wrasse; however a general bag limit of 20 fish per day applies to recreational fishers. The recreational catch in NSW is relatively large and is thought to be at least seven times greater than the commercial catch.

The most common reproductive pattern in the family Labridae is sequential protogynous hermaphroditism: the transformation of a functional female into a functional male (Robertson & Choat, 1974). Anecdotal information and personal observations suggest that maori wrasse is a protogynous hermaphrodite. Sexual dimorphism is marked with males and females differing distinctly in size and colour (pers. obs.). Spawning seasons for other temperate Australian protogynous labrid fishes which share the same reefs as the maori wrasse range from July – October for the blue groper *Achoerodus viridus* (Gillanders 1995), to August – January for the purple wrasse *Notolabrus fucicola* (Ewing *et al.*, 2003).

To date no basic biological information has been collected for maori wrasse in NSW waters, despite their importance to both commercial and recreational fisheries. This chapter aims to provide information on age, growth, longevity, reproduction and fishery landings that may be used to improve our knowledge and management of maori wrasse.

6.2. Materials and methods

Maori wrasses for examination of growth and reproduction were sampled from commercial fisher catches at the Sydney Fish Markets. A total of 234 maori wrasse were collected between January and December 2005 from between Yamba – Iluka (29º25'S, 153º20'E) and Eden (37º30'S, 150º00'E). The smallest maori wrasse sampled from commercial catches was 19.7 cm TL. Smaller fish used in analyses were provided by the collection of an additional 198 fish by the University of Newcastle (Jason Morton). These fish were collected on an *ad hoc* basis using handspears, hook and line, as well as from commercial catches. These additional fish were used in growth modelling, generation of an age length key, estimation of a commercial age structure, total mortality rate, and size-at-maturity. Fish were processed and analyses of growth, reproduction and fishery carried out as outlined in Chapter 2.

6.3. Results

6.3.1. Landings in NSW

6.3.1.1. Current exploitation status

Maori wrasse are not listed as being a primary or key secondary species of commercial importance in NSW, and so have not been assessed for exploitation status. Their status is, by default, UNDEFINED.

6.3.1.2. Trends in catch

Reported commercial landings of maori wrasse have been relatively low and variable since 1997/98 (Fig. 6.1). Catch rates by handlining since 1997/98 have closely followed trends in landings.

The best estimate of the recreational harvest of maori wrasse in NSW is that from offshore trailerboat fishers between 1993 and 1995 (Steffe *et al.*, 1996), and averaged more than 21 tonnes per year. Maori wrasse are one of the most important components of offshore recreational fishers' landings and ranked in the top 10 species by numbers during each year of the surveys. Maori wrasse were part of a species complex 'wrasse/tuskfish/gropers' during the National Recreational and Indigenous Fishing Survey (Henry & Lyle, 2003) and their specific harvest during the survey could not determined.

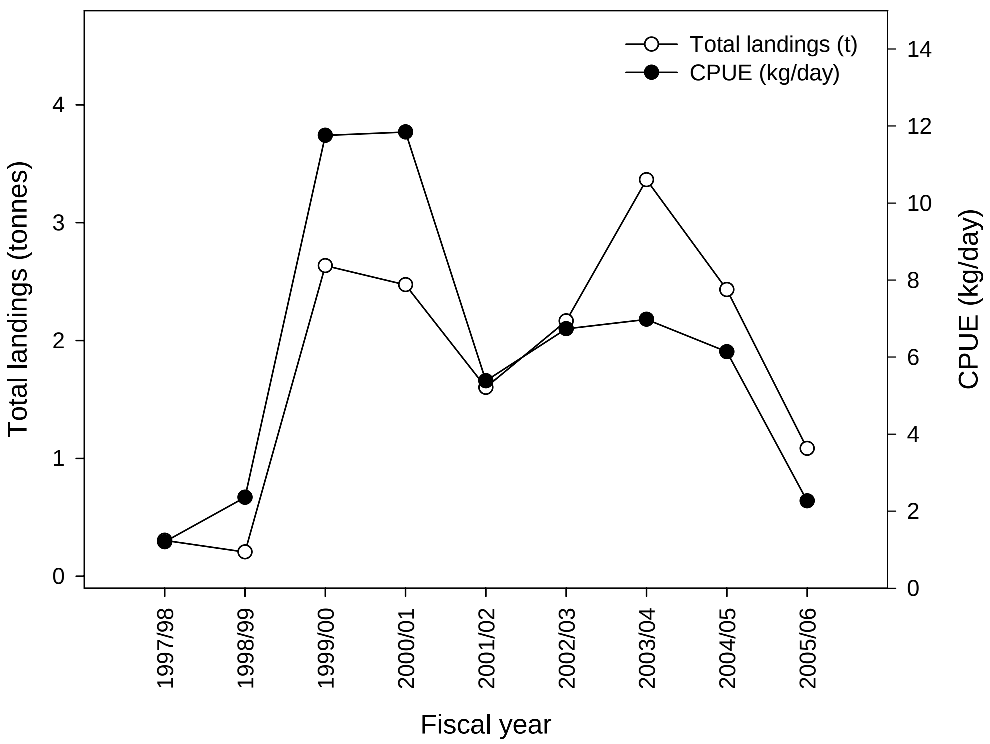


Figure 6.1. Reported commercial landings and catch rates (kg per day handlining) of maori wrasse in NSW. Source: NSW DPI Resource Assessment System.

6.3.1.3. Length measurements

Commercial landings

The sizes of maori wrasse captured by trap and line fishers were measured at the Sydney Fish Markets and regional co-ops during the study. A total of 1,403 maori wrasse were measured and ranged in size from 19 cm to 40 cm TL (Fig. 6.2). The majority (~ 94%) of the commercial trap and line catch of maori wrasse is comprised of fish between 25 and 35 cm TL.

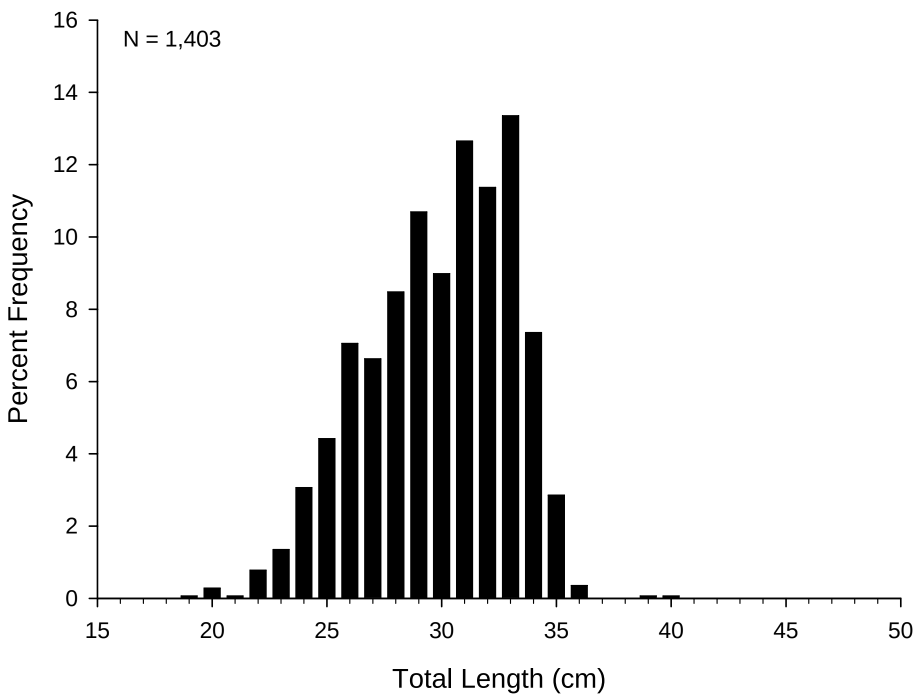


Figure 6.2. The lengths of maori wrasse landed by the NSW trap and line fishery during 2005/06.

Recreational landings

Maori wrasses landed by recreational fishers are, on average, similar in size to those landed by commercial fishers (Figs 6.3 & 6.4). More large (> 35 cm TL) fish are landed by trailerboat (~ 5%) and charterboat (~ 16%) fishers (cf 0.5% for commercial landings). The sizes of maori wrasse reported by charterboat fishers between 2001 and 2003 were similar to those landed by trailerboat fishers in 1993-95, but with more fish > 35 cm TL. Voluntary charterboat logbooks of discarded catch indicate that maori wrasse of all sizes captured are sometimes discarded and that fish as small as 15 cm TL are caught by line methods.

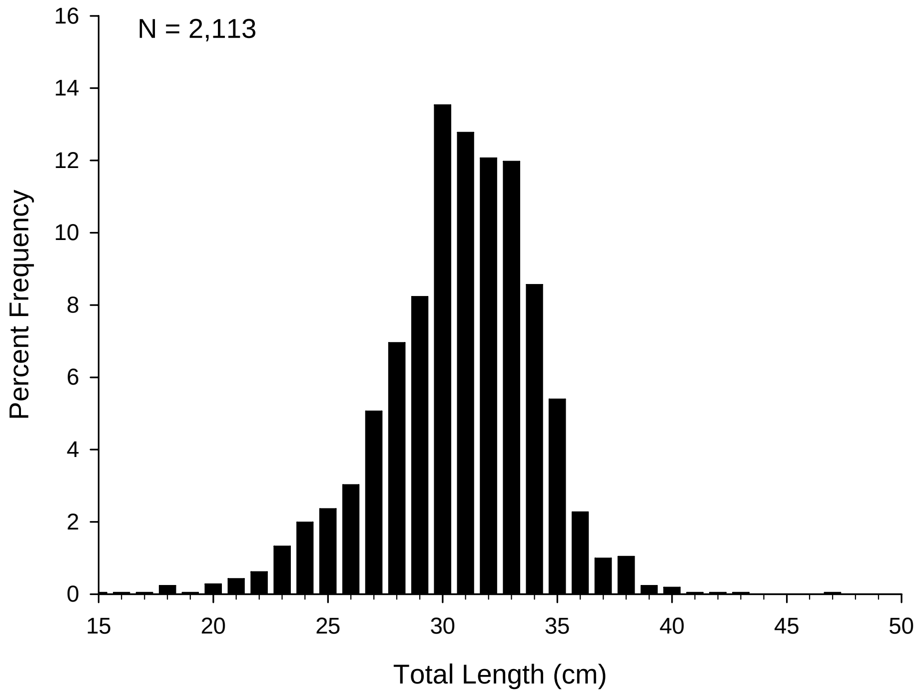


Figure 6.3. The lengths of maori wrasse landed by offshore trailerboat fishers during 1993/94 and 1994/95. Source: Steffe *et al.*, 1996.

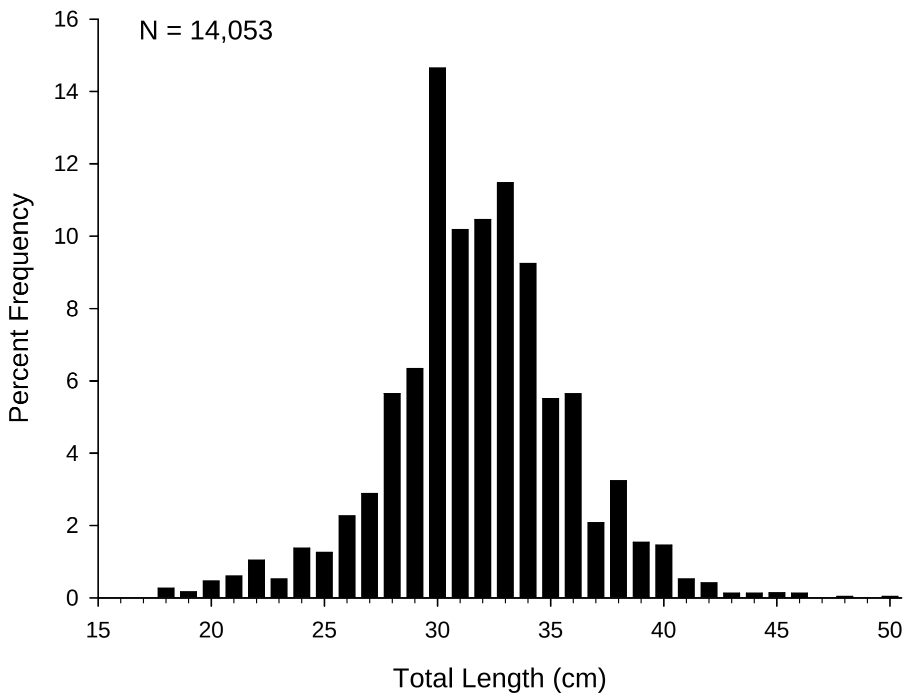


Figure 6.4. The lengths of maori wrasse measured by NSW charterboat operators 2001 to 2003.

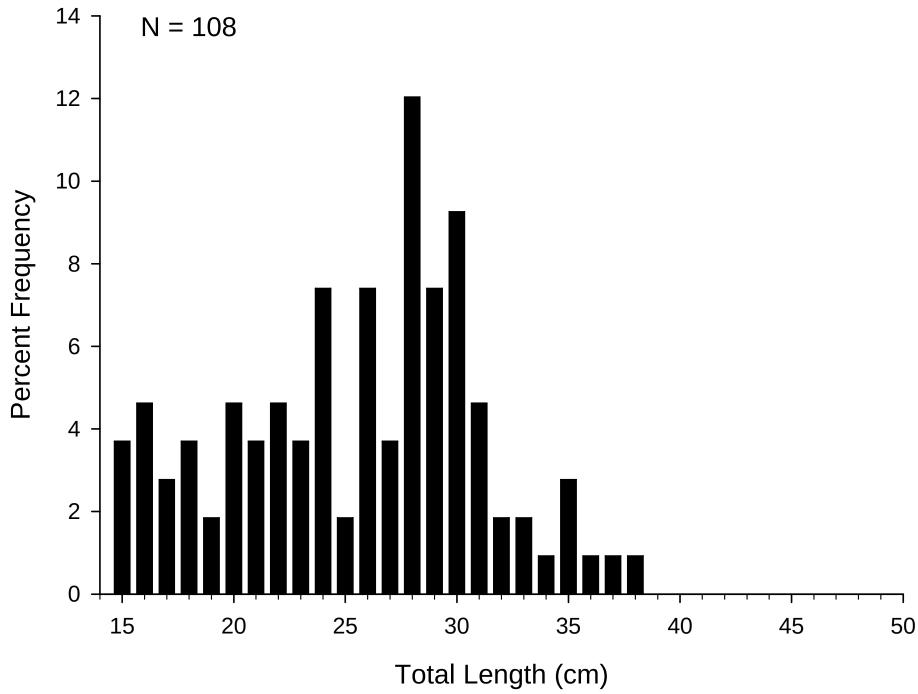


Figure 6.5. The lengths of discarded maori wrasse measured by volunteer NSW charterboat operators 2005/06.

6.3.2. Reproduction

6.3.2.1. Seasonality of spawning

Gonadosomatic indices

The peak spawning period indicated by elevated GSI values occurred between December and March for both male [max: Dec (0.23 ± 0.02%) and Jan (0.23 ± 0.05%)] and female (max: Mar 2.87 ± 0.20%) maori wrasse (Fig. 6.6). During this peak period, the ovaries and testes of maori wrasse increased in weight by approximately seven and five times their non-spawning weights, respectively.

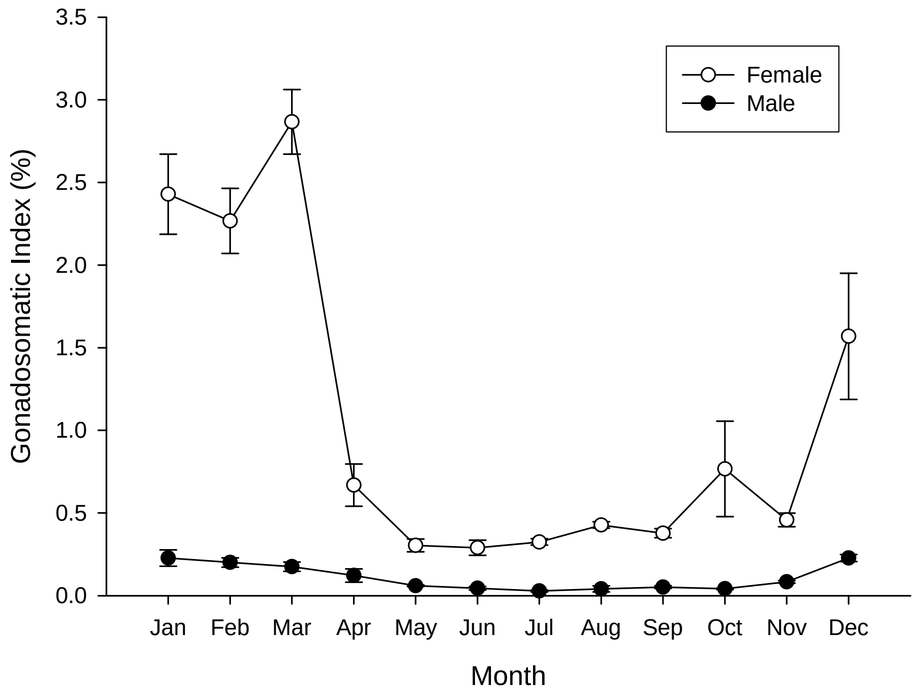


Figure 6.6. Gonadosomatic indices (mean GSI ± SE) for male and female maori wrasse.

Macroscopic gonad staging

The highest proportions of both female and male fish with reproductively active [stage 3 (ripe) and stage 4 (running ripe)] gonads occurred between December and March (Figs. 6.7). Between December and March, reproductively active testes made up 45 – 73% of testes sampled. Reproductively active ovaries made up 32 – 81% of ovaries sampled during the same period. Some female fish possessed reproductively active ovaries in April and October, at the finish and start of the spawning period respectively. Similarly, some “running ripe” (stage 4) testes occurred in male fish in April. “Spent” (stage 5) ovaries were present only in the months May (25%) and June (50%), after the cessation of spawning. Male fish with spent testes only occurred in January. For the remainder of the year, most ovaries and testes were estimated to be stage 2 (resting). Immature (stage 1) ovaries were present in fish first collected in October, and continued through to April. No immature fish were collected from May to September.

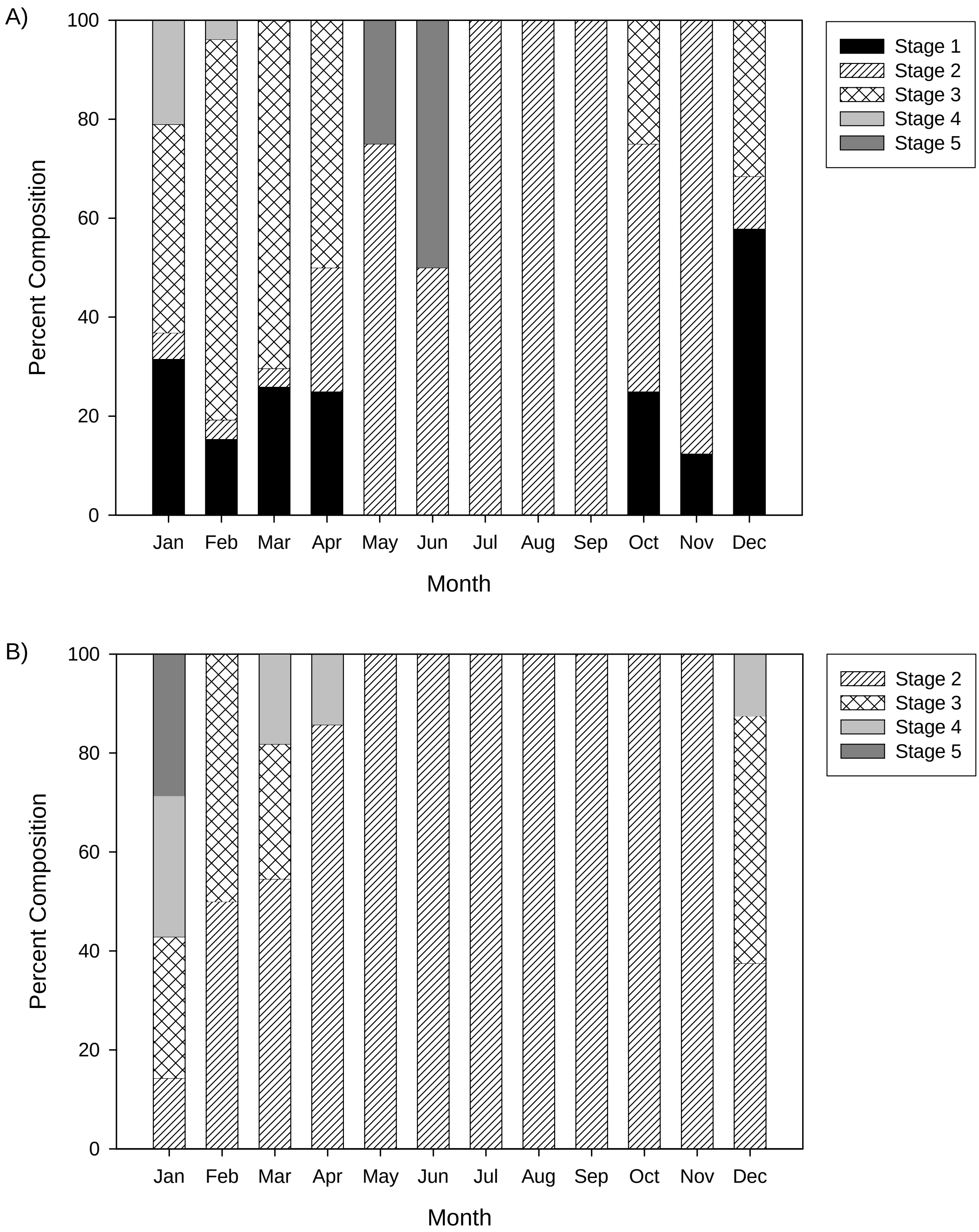


Figure 6.7. Monthly gonad stages for A) female and B) male maori wrasse.

6.3.2.2. Size at maturity

Maori wrasse first mature as females at an estimated size-at-50%-maturity of 18.86 ± 0.83 cm (Fig. 6.8). The smallest mature fish collected during the spawning season was 18.3 cm TL. All female fish collected during the spawning season greater than 19.0 cm were mature, except for a single immature female fish which was 30.0 cm. The smallest male fish collected during the project was 26.6 cm (Fig. 6.9). The estimated length at which 50% of females had changed to males was 29.8 ± 0.19 cm TL (range 27 – 34 cm TL; Fig. 6.9).

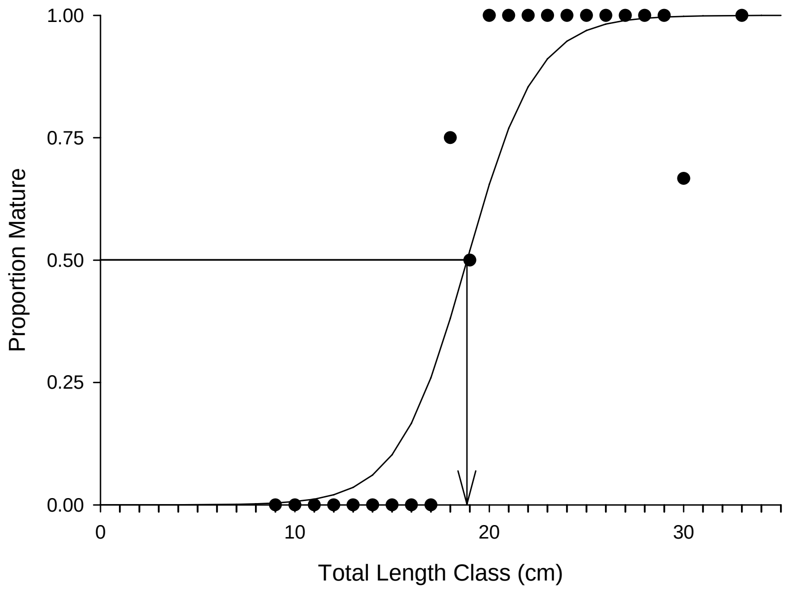


Figure 6.8. Reproductive maturity data with fitted logistic curve for female maori wrasse (*n* = 51). Arrow indicates size at 50% maturity.

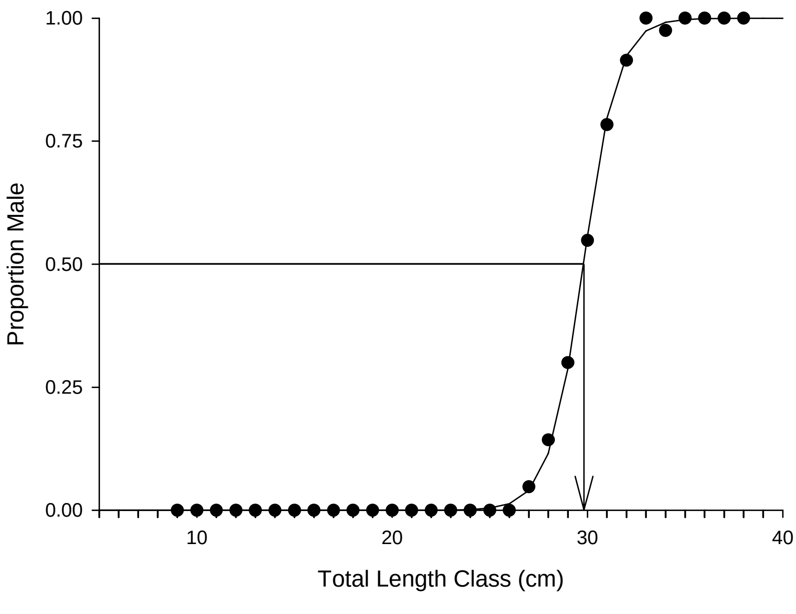


Figure 6.9. Size at sex change data with fitted logistic curve for maori wrasse (*n* = 413). Arrow indicates the size at which 50% of maori wrasse have changed sex from female to male.

6.3.2.3. Sex ratio

The number of male maori wrasse caught in commercial catches was significantly higher than the number of females ($\chi^2 = 66.125$, $p < 0.05$; Fig. 6.10). The sex ratio of males to females ranged from 0.2:1 in February to 5.5:1 in September. The overall sex ratio for male to females was 1.3:1. January, February and March were the only months when the sex ratio was biased towards females.

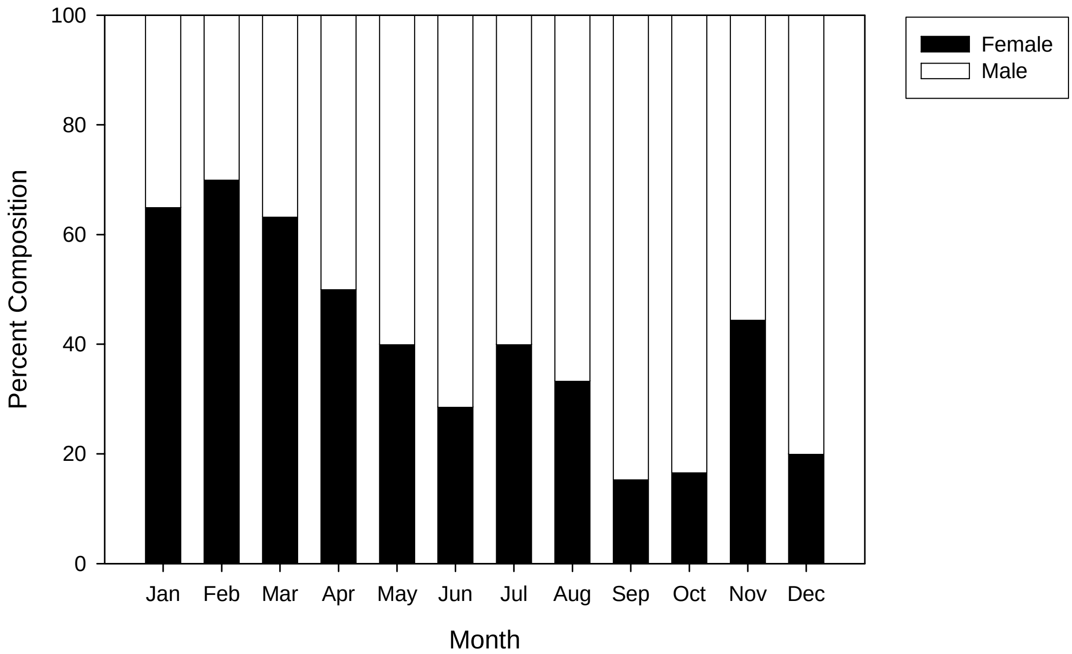


Figure 6.10. Monthly sex ratios for maori wrasse sampled from the Sydney Fish Markets (n = 224) during 2005.

6.3.3. *Age and growth*

6.3.3.1. Ageing procedure and validation

Appearance of maori wrasse otoliths

Sectioned maori wrasse otoliths were relatively simple to interpret, with opaque and translucent zones easily counted (Fig 6.11). The coefficient of variation, averaged across all age classes, was 0.07. The core was always a largely opaque region, followed by a translucent region and then a very distinct opaque band, which was scored as the first annulus.

Figure 6.11. Sectioned maori wrasse otolith viewed using reflected light. Ten annuli were counted in this section. Scale bar is 1 mm.

Marginal increment analyses

The monthly marginal increments for maori wrasse showed considerable variation each month (Fig. 6.12) but with a seasonal pattern of highest values in late spring-summer (October to January).

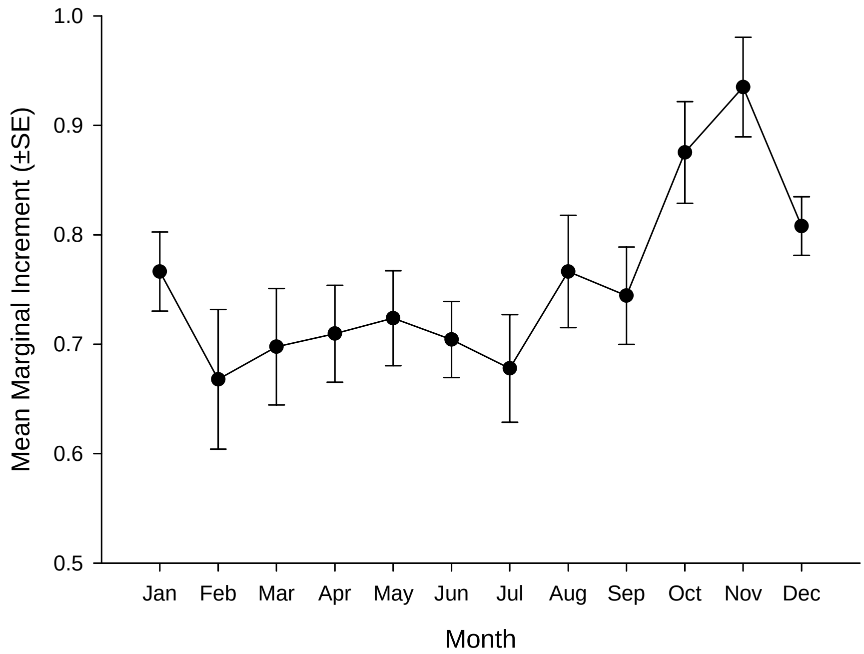


Figure 6.12. Mean (±SE) marginal increment values for maori wrasse (*n* = 188).

Edge analysis

The proportion of maori wrasse otoliths with opaque edges each month supports the marginal increment analyses and is consistent with annual periodicity of opaque zone formation. The highest proportion of otoliths having opaque edges occurred during February and March, while lower proportions were seen during the remainder of the year (Fig. 6.13).

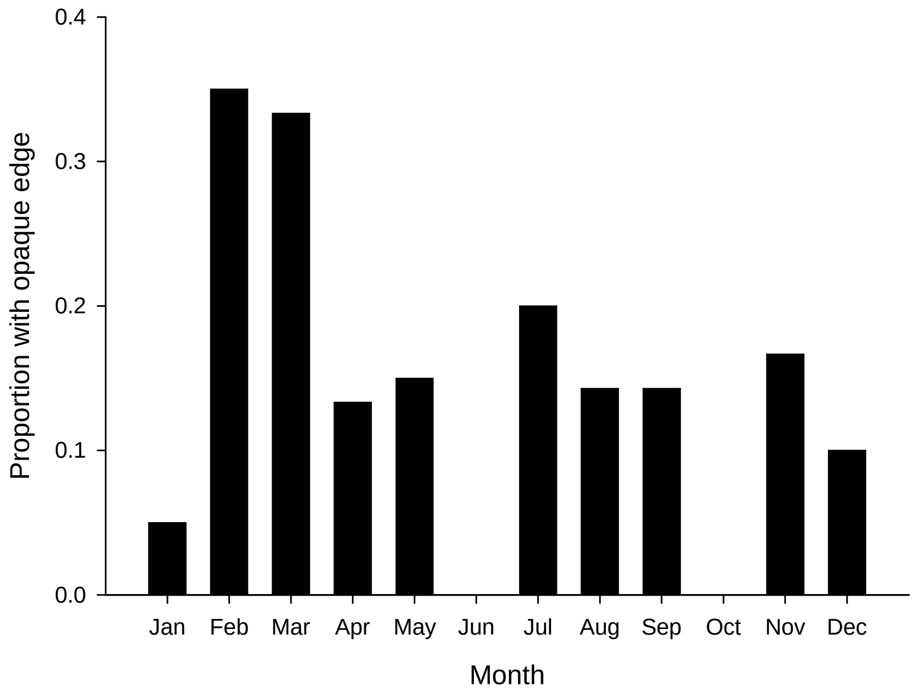


Figure 6.13. Monthly proportions of otoliths having opaque edges for maori wrasse (*n* = 224).

Development of ageing protocol

Opaque zones in otoliths were counted, and the fish placed into an age class according to opaque zone count only. The use of MI information for each otolith in assigning age class to maori wrasse was not attempted because of the considerable variation in the data. A universal birthday was set at 1st February, which was the middle of the GSI-defined spawning period (Dec-Mar; Fig. 6.6). The number of days from this universal birthday to the date of capture (as a proportion of a year) was then added to give the final age in years.

6.3.3.2. Growth model

The growth of male and female maori wrasse was not compared because they are protogynous hermaphrodites. The data were pooled and the von Bertalanffy growth model fitted (Fig. 6.14). Growth of maori wrasse appears to slow once sex change occurs (~ 30 cm). The oldest maori wrasse collected was a male estimated to be 13.4 years old (36.6 cm TL). The youngest male fish was 2.9 years old, but only 7.3 cm shorter (29.3 cm TL) than the oldest. The oldest female fish collected was estimated to be 9.4 years old (31.6 cm TL), however all other female fish collected (n = 204) were less than 7.5 years old.

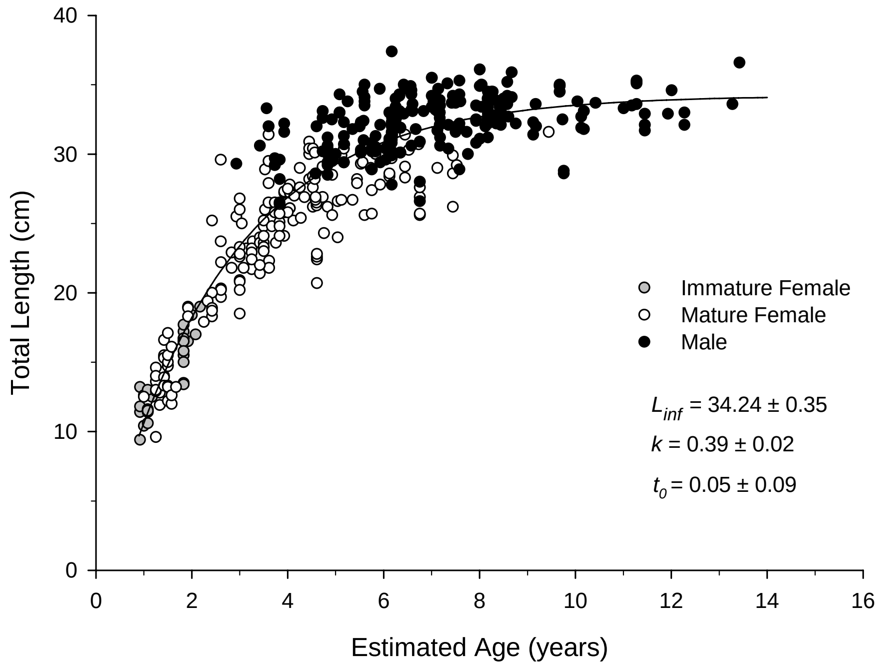


Figure 6.14. Size at age data with fitted von Bertalanffy growth curve for maori wrasse (n = 414).

6.3.3.3. Age composition of landed catch

The age-length key for maori wrasse (Table 6.1) was applied to the size composition data for commercial landings (Fig. 6.2) to obtain an estimate of age composition in commercial landings (Fig. 6.15). Approximately 95% of maori wrasse in commercial catches are 3 years old or older.

Table 6.1. Age-length key for maori wrasse sampled during 2006 (*n* = 418).

Total Length Class (cm)	**Age (years)**														
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Total**
9	1	1													2
10		2													2
11	2	4													6
12		9													9
13	1	1													11
14		6													6
15		8													8
16		7													7
17		3	2												5
18		2	4	1											7
19		1	3												4
20			3	3	1										7
21			1	4											5
22			2	6	3										11
23			1	11											12
24				7	1	1									9
25			2	7	4	2	2								17
26				7	1	3	2	1							23
27				3	6	4	2								15
28				2	7	2	4	2		2					19
29			2	4	8	8	5	3							30
30				1	1	14	12	4							41
31				2	1	4	12	5	2	2	2	1			31
32				2	3	5	8	6	14	3	1	3	1		46
33				1	1	5	7	12	8	1	4	3	1	1	44
34						4	7	4	8	2			1		26
35						1	1	3	3	1		3			12
36									1					1	2
37							1								1
n	4	53	20	61	55	53	63	40	36	11	7	10	3	2	418

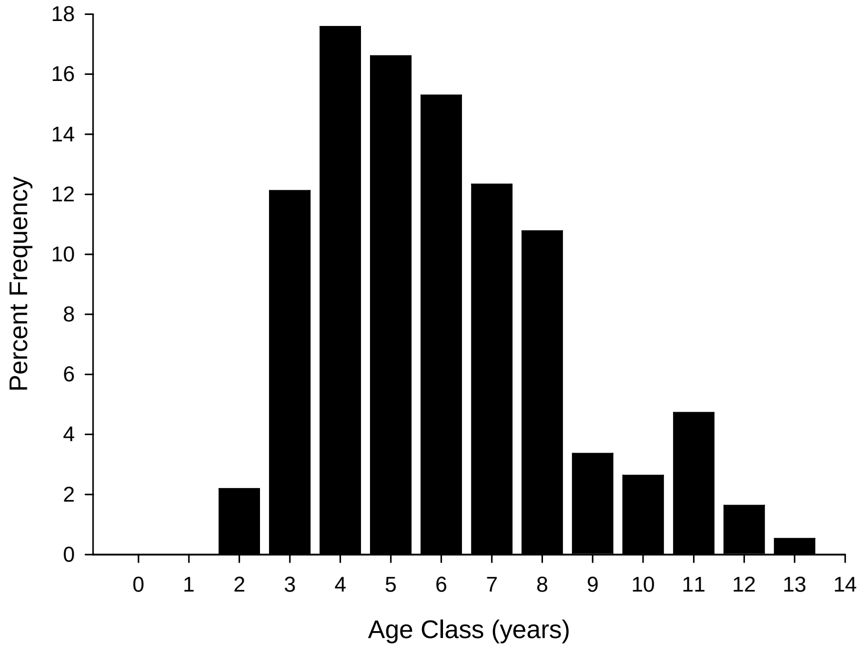


Figure 6.15. Age composition of maori wrasse in commercial landings.

6.3.4. Mortality estimates

Estimates of total mortality (Z) made from the slope of the descending limb of the catch curve for maori wrasse, fitted between ages 4 and 13, was 0.36 (Fig 6.16). Estimates of natural mortality (M) based on the method of Hoenig (1983) using a maximum age of 13 years ranged between 0.23 and 0.35 (based on 5% and 1% attaining T_{max} respectively). Estimates of fishing mortality (F), made by subtracting M from Z, therefore ranged from 0.01 to 0.13.

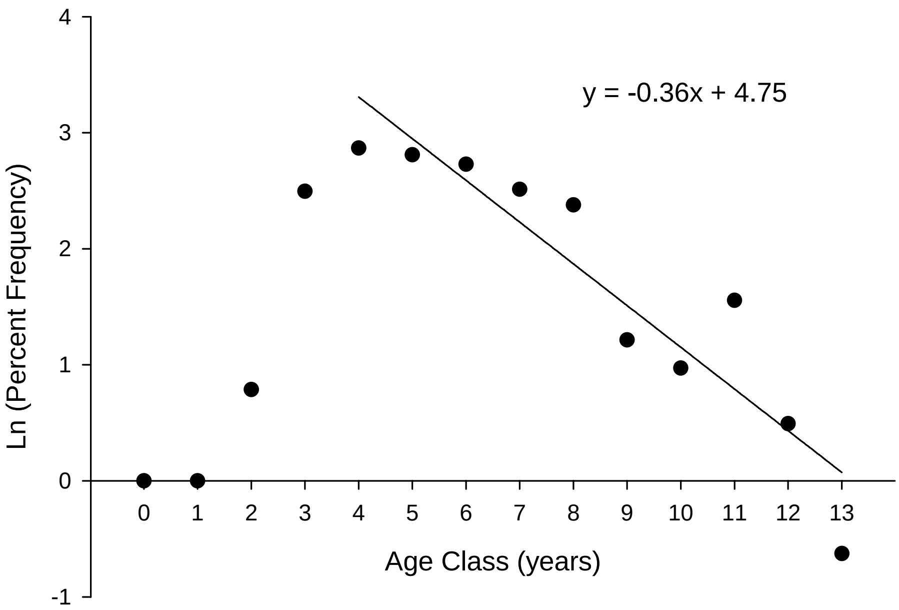


Figure 6.16. Catch curve for maori wrasse.

6.3.5. *Market price*

The Sydney Fish Markets do not apply a size grading schedule to maori wrasse; however many commercial fishers still grade their catches prior to selling based on relative sizes. Fish greater than 23 cm tended to be graded as “Large” and “Extra large”. Average prices for maori wrasse sold through the Sydney Fish Markets during 2003/04 and 2005/06 indicate that “Small” ($4.17/kg) and “Medium” ($4.61/kg) graded fish sold for substantially less than the “Large” ($7.12/kg) and “Extra-large’ ($7.45/kg) fish (Fig. 6.17).

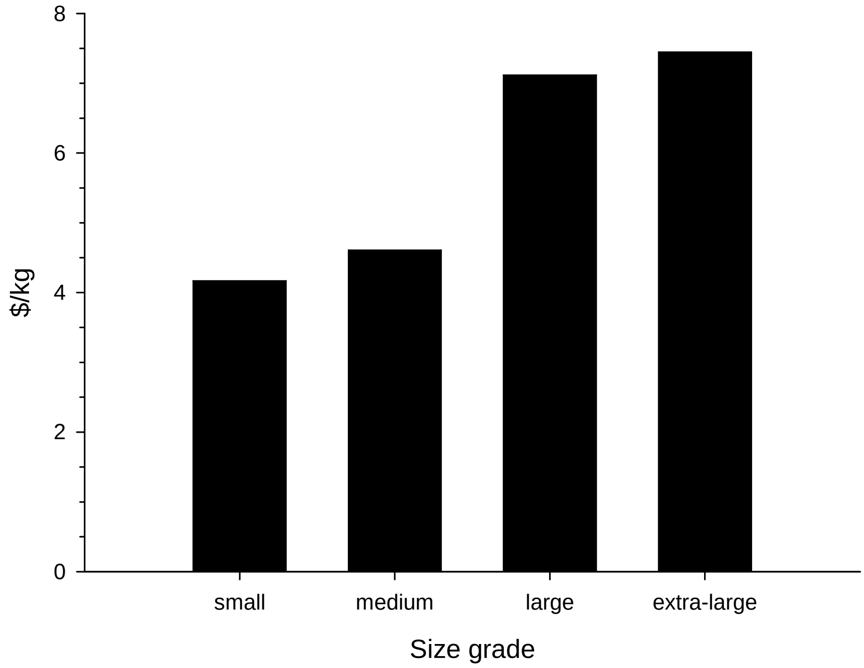


Figure 6.17. Average price information by size grade of maori wrasse.

6.3.6. *Per recruit analyses*

Per recruit analyses were done using the following parameters:

$L_\infty = 34.24$ cm
$K = 0.39$ yr^{-1}
$T_0 = 0.045$ yr
$Z = 0.36$
$M = 0.23$
$F = Z–M = 0.13$
$E = F/Z = 0.36$
$M/K = 0.59$

The market price and size grade information used were as described above. L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation that yield per recruit is maximised at 20 cm and that $ per recruit is maximised at 24 cm (Fig. 6.18).

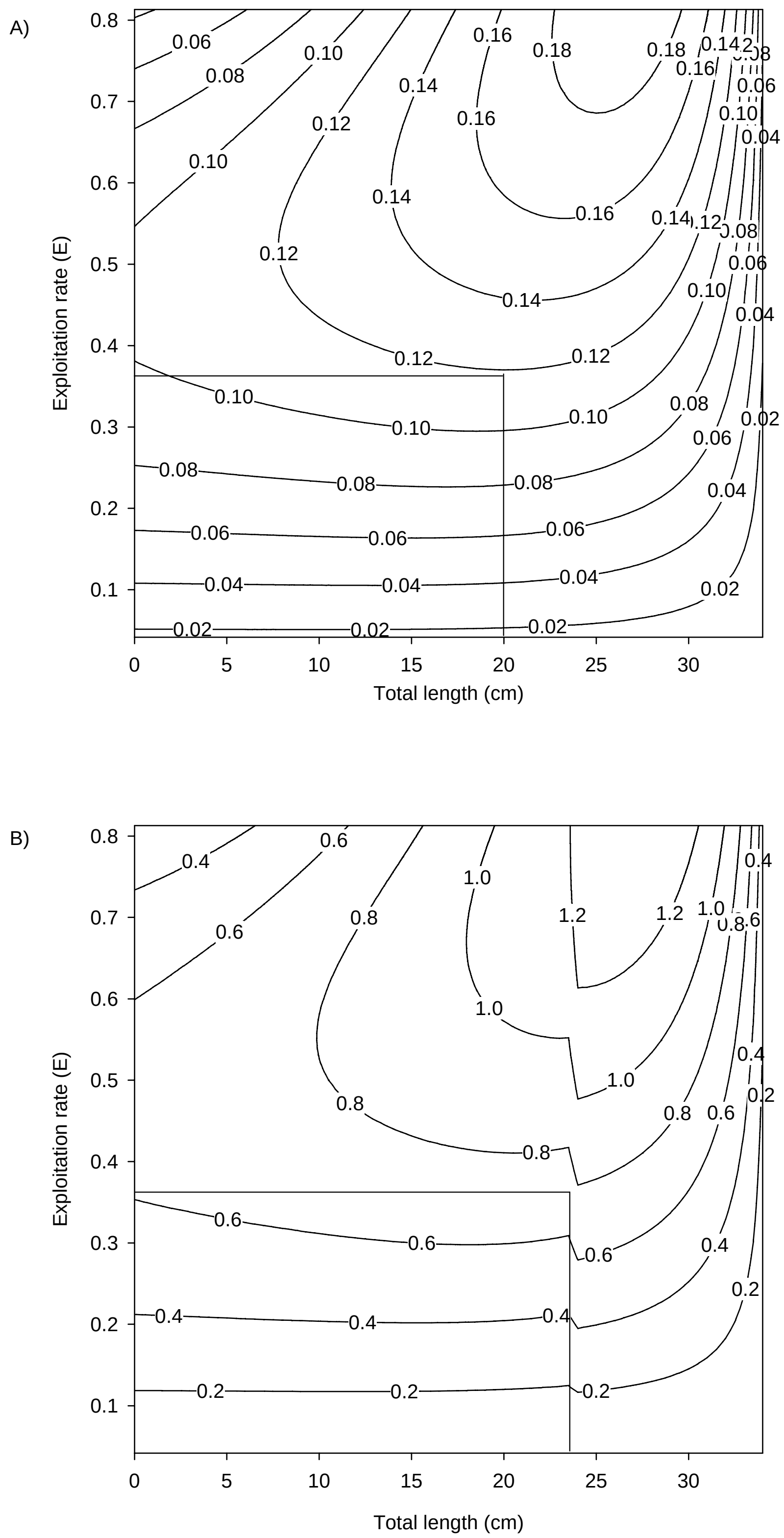


Figure 6.18. Yield and $ per recruit isopleths for maori wrasse. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

6.3.7. *Spawning potential ratio*

The SPR for maori wrasse at current levels of mortality is well above the threshold level of 0.2 and indicates that at current levels of exploitation that maori wrasse should be producing sufficient eggs to sustain the population regardless of their size at first harvest. The smallest maori wrasse in landings are ~ 20 cm and this size at first harvest corresponds to a SPR of ~ 0.6.

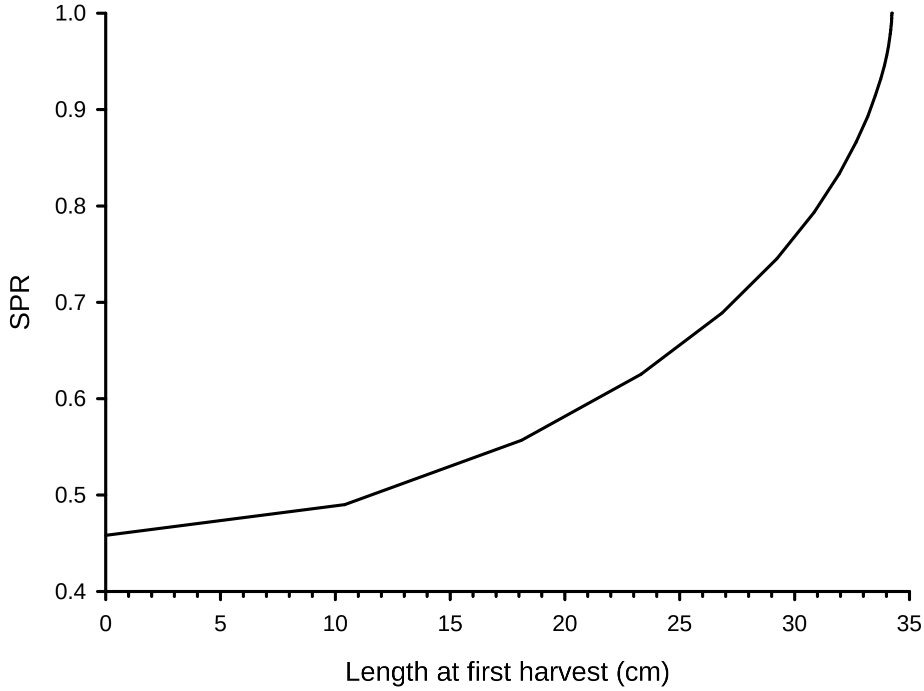


Figure 6.19. Spawning potential ratio for maori wrasse at current levels of exploitation for a range of sizes at first harvest.

6.3.8. *Information fact sheet*

Relevant material from this chapter was collated into an information fact sheet for maori wrasse (Fig. 6.20).

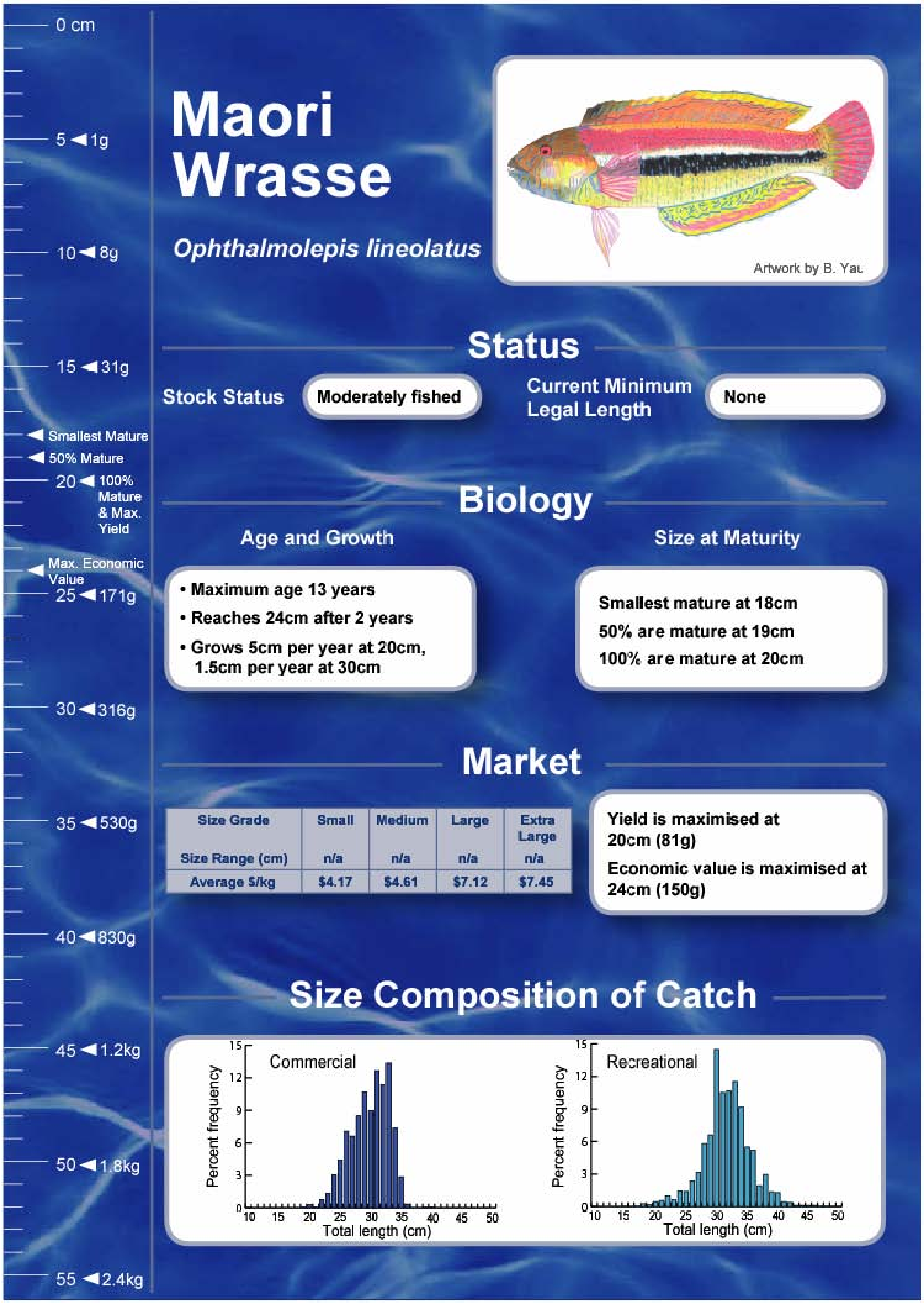


Figure 6.20. Information fact sheet for maori wrasse.

6.4. Discussion

Maori wrasse are not listed as being a primary or key secondary species of commercial importance in NSW, and so have not been formally assessed in terms of their resource status. Exploited species in NSW are prioritized for assessment by their relative importance to fisheries, and maori wrasse are relatively unimportant to most commercial fishers. However, maori wrasse are extremely important to recreational fishers and rank among the top 10 most common species in landings of offshore recreational fishers. The lack of a formal management strategy for recreational fishing in NSW is the reason why important species, such as maori wrasse, have not been identified as requiring formal assessment. Fortunately, the current project has provided sufficient information to recommend that maori wrasse be considered as being MODERATELY FISHED. This recommendation is based on the fact that the age composition in landings contains many older (> five years) fish, fishing mortality is estimated to be ~ half that of natural mortality, the selectivity of fishing gears and their protogynous hermaphroditism means that the fishery lands mainly males and females greater than their size at sexual maturity, the spawning potential ratio is well above threshold levels and the commercial harvest remains small.

The concern for maori wrasse is that they may become a more sought-after species as the availability of historically more desirable species declines. They already attain relatively high prices through the Sydney Fish Markets (averaging ~ $6.75/kg) and are therefore becoming more lucrative for some commercial fishers. Recreational fishing effort in general is increasing and maori wrasse are a substantial component of their landings. The major threat to the sustainability of maori wrasse may be from increased recreational fishing pressure which may lead to eventual age-class truncation. The effect of selectively harvesting the larger males on the social structure of maori wrasse is unknown, and being protogynous hermaphrodites may be a complicating factor. For example, removing the larger and older males may cause females to change sex at smaller sizes, ultimately potentially reducing the spawning potential through decreases in sperm and egg production (Morton, 2007). Nevertheless, now that this study has investigated, for the first time, the biology and fisheries for maori wrasse, it is hoped that resources for ongoing monitoring of landings can be found.

Maori wrasse are sexually dimorphic monandric protogynous hermaphrodites (Morton, 2007). This was confirmed during the present study because that there were no small or young males and they dominated the larger and older age classes. The spawning behaviour of maori wrasse has not been observed; however it may occur around sunset (Morton, 2007). Maori wrasse had a definite spawning season between December and March. A summer/autumn spawning period is in contrast to that for many other southern Australian labrids, which tend to breed during mid-winter to early summer. Morton (2007) also reported a summer/autumn spawning period for maori wrasse and hypothesized that such timing may be a strategy to reduce post-larval competition for food on reefs.

Maori wrasse first mature as females at an estimated size of ~ 19 cm, which equates to an age of ~ two years. Females matured over a narrow size range and, because there is little individual variation in size at age two (see Fig. 6.14), all females appear to mature at a similar age. However, sex change was observed to occur over a wide range of sizes (27 to 24 cm) and ages with the oldest female being 9+ years old. It is not known whether sex change in maori wrasse is governed by biological (size and age) or social (e.g., dominance and hierarchy) factors. Morton (2007) reported similar sizes at female maturity and sex change for maori wrasse and recommended that future manipulative studies, removing dominant males from populations, could be done to further investigate factors causing sex change.

Similar to blackspot pigfish (Chapter 5), the sex ratios in commercial landings of maori wrasse were biased towards males. However, typical of protogynous hermaphrodites, the sex ratio in the population of maori wrasse is substantially biased towards females at between 5 and 10:1 (Morton, 2007). The bias towards males observed during the present study was likely caused by trap and hook selectivity, with the smaller females being less vulnerable to capture. This is a prime example of why conclusions concerning population structure based on observed sex ratios in fishery landings should be cautious.

Sectioned otoliths of maori wrasse were relatively easy to interpret, with readily identifiable opaque zones. The ease of interpretation was reflected by a mean coefficient of variation of 0.07, a value well within those generally reported (Campana, 2001). Monthly patterns in marginal increments and opaque otolith edges were consistent with annual periodicity of opaque zone formation. Opaque zones appear to form during spring but may not be scored as being fully formed until late summer/autumn.

Maori wrasse grow quickly through the first few years, reaching sexual maturity at ~ 19 cm after ~ two years. Growth slows substantially at ~ 30 cm (the average length at which sex change occurs) and the maximum age observed was 13 years. A maximum age of 13 years is relatively young for temperate reef species off NSW (the 2nd shortest longevity of the 13 species reported on here, behind ocean leatherjackets). Other temperate wrasses (family Labridae) also have a much greater longevity, e.g., *Notolabrus fucicola* (20 years – Ewing *et al.*, 2003), *Achoerodus viridis* (35 years – Gillanders, 1995) and *Achoerodus gouldii* (50 years – Gillanders, 1999). However, Morton (2007) reported maximum ages of wrasses that co-exist with maori wrasse to be of similar longevity, e.g., *Notolabrus gymnogenis* (9+ years) and *Pictilabrus laticlavius* (4+ years). The relatively young maximum age for maori wrasse (and the other two labrids studied by Morton, 2007) may be a result of the life-history of these species, or alternatively a result of relatively short studies on fished populations. Maori wrasse are reported to attain 41 cm (Hutchins & Swainston, 1986), only slightly larger than the longest fish sampled of 37 cm, suggesting that maori wrasse do not have the potential for extreme longevity.

7. BIOLOGY AND FISHERY FOR RED ROCKCOD

7.1. Introduction

The red rockcod (*Scorpaena cardinalis*) is a member of the scorpionfish family Scorpaenidae, a large family containing about 350 species worldwide and occurring in all temperate and tropical seas (Gomon *et al.*, 1994). Scorpaenids are thought to have an important role in the benthic communities of rocky reefs (La Mesa *et al.*, 2005). The red rockcod is distributed along the east coast of Australia from southern Queensland (Noosa Head) to eastern Victoria and is also recorded from New Zealand (Hutchins and Swainston, 1986; Kuiter, 1993). The species inhabits shallow estuaries to deep offshore reefs and is common on coastal reefs of NSW. As with most scorpionfishes the red rockcod has a prominent head with spiny ridges, a large mouth and venomous dorsal fin spines. The species has cryptic and highly variable colouration, ranging from dull grey-brown to bright red. It is an ambush predator which feeds on small fish and crustaceans which it swallows whole (Russell, 1983).

Some members of the family Scorpaenidae support large fisheries, particularly the rockfishes (genus *Sebastes*). Members of the genus *Scorpaena*, whilst being commonly reported, are generally relatively minor components of commercial and recreational fisheries. Nevertheless, they are desirable targets because they are considered excellent to eat, many have bright red colouration and their hardiness after capture makes them ideal for the live fish trade. Species such as rascasse (*Scorpaena scrofa*) are integral ingredients in famous dishes such as bouillabaisse.

Red rockcod are currently taken in small numbers in the NSW ocean trap and line fishery. They are listed as being a secondary species in this fishery and the current harvest strategy is to ensure that the catch remains low and within historical levels. The catch of red rockcod by recreational fishers is thought to be at least three times bigger than the commercial catch. They are well represented in catches from offshore recreational fishing and ranked 22nd and 21st in abundance during surveys of offshore trailerboat fishers during 1993/94 and 1994/95 respectively (Steffe *et al.*, 1996).

Despite their widespread distribution and common occurrence in catches, there have been very few studies on the biology of the genus *Scorpaena*. Members of the genus are dioecious and reproductive modes include external fertilisation (with viviparity and ovoviviparity), spawning of eggs embedded in a large pelagic gelatinous matrix and spawning of individual pelagic eggs (Neira *et al.*, 1998). Scorpaenids appear to be variable in longevity, with some species being relatively long lived, up to 30 years (Ragonese *et al.*, 2003) while others only attain 4 – 5 years of age (La Mesa *et al.*, 2005).

To date no basic biological information has been collected for red rockcod anywhere, despite being well represented in landings of both commercial and recreational fishers. The aims of this chapter therefore, were to describe: (i) the growth and longevity; (ii) the spawning season and size/age-at-maturity, and; (iii) the fisheries for red rockcod in NSW.

7.2. Materials and methods

Red rockcod were sampled according to the methods described in Chapter 2.

7.3. Results

7.3.1. Landings in NSW

7.3.1.1. Current exploitation status

Red rockcod are not listed as a primary or key secondary species of commercial importance in NSW, and so have not been assessed for exploitation status. Their status is, by default, UNDEFINED.

7.3.1.2. Trends in catch

Reported commercial landings of red rockcod were highly variable between 1991/92 and 1996/97 with a minimum of 5t landed in 1993/94 and a maximum of 10t landed in 1996/97 (Fig. 7.1). Since 1996/97 landings have declined, but remained stable at ~ 5t/yr for the period 1998/99 to 2005/06. During the period of decline in landings, there was also a decline in catch rates for hand lining (1.6 kg/day in 1997/98 to 0.7 kg/day in 1999/00). In recent years, however, the catch rate has improved to 1.5 kg/day in 2005/06 and has remained stable at ~ 1.3 kg/day since 2000/01 (Fig. 7.1). Red rockcod are also retained as by-catch in the NSW lobster fishery; however the quantity landed is less than one tonne per year. The recreational harvest of red rockcod in NSW is likely to be considerably larger than the commercial harvest. The National Recreational and Indigenous Fishing Survey (Henry & Lyle, 2003) reported 95,416 scorpionfish/gurnard (which included ocean perch, red rockcod and gurnards) to be landed by recreational fishers in NSW. The best estimate of the recreational harvest in NSW is ~ 18 tonnes per year by offshore trailerboat fishers (Steffe *et al.*, 1996).

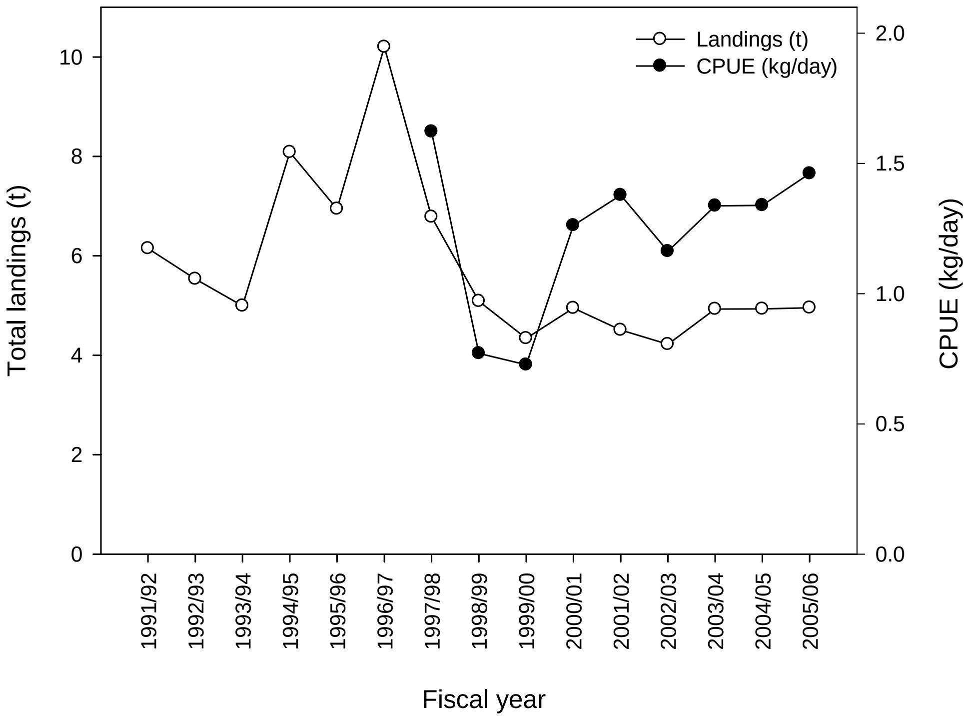


Figure 7.1. Reported commercial landings and catch rates (kg per day handlining) of red rockcod in NSW. Source: NSW DPI Resource Assessment System.

7.3.1.3. Length measurements

Commercial landings

The sizes of red rockcod captured by commercial trap and line fishers were measured at the Sydney Fish Markets and regional co-ops during the study. A total of 1,135 red rockcod were measured and ranged in size from 14 to 41 cm TL (Fig. 7.2). The majority (~ 67%) of the commercial trap and line catch of red rockcod is comprised of fish between 19 and 26 cm TL. The most commonly caught length classes of fish were 20 – 22 cm TL (34.8%). Relatively few fish (9.6%) larger than 30 cm TL were measured during 2005/06.

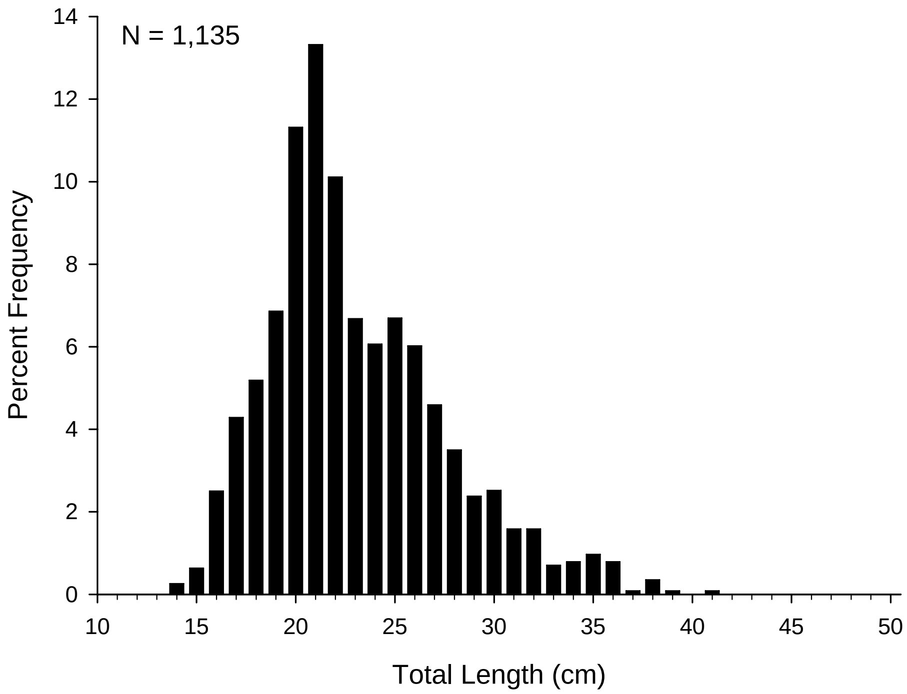


Figure 7.2. The lengths of red rockcod landed by the NSW trap and line fishery during 2005/06.

Recreational landings

The sizes of red rockcod landed by recreational fishers (Figs 7.3 & 7.4) were, on average, larger than those landed by commercial fishers. The bulk (~ 67%) of the trailerboat catch was comprised of fish between 23 and 31 cm TL. The majority (~ 72%) of charterboat caught red rockcod were even larger at 26 – 36 cm TL. The most commonly caught length classes of fish were 27 – 28 cm TL (19.3%) for trailerboats and 30 cm TL (11.0%) for charterboats. Many more large (> 30 cm TL) red rockcod are landed by trailerboat (~ 34%) and charterboat (~ 61%) fishers, compared with commercial fishers (9.6%). Very few fish smaller than 20 cm TL were landed by recreational fishers (5.7% trailerboat, 3.9% charterboat) compared with commercial landings (31.1%).

Red rockcod discarded by charterboat operators during 2005/06 were generally smaller than 26 cm TL (Fig. 7.5). Red rockcod as small as 11 cm TL were reported to be captured using line methods.

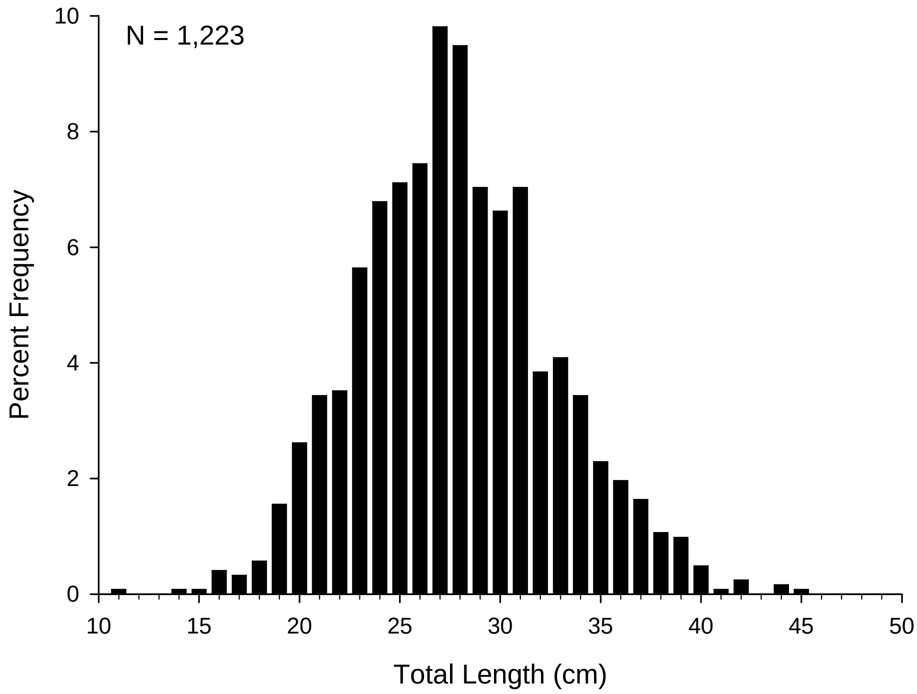


Figure 7.3. The lengths of red rockcod landed by offshore trailerboat fishers 1993/94 and 1994/95. Source: Steffe *et al.*, 1996.

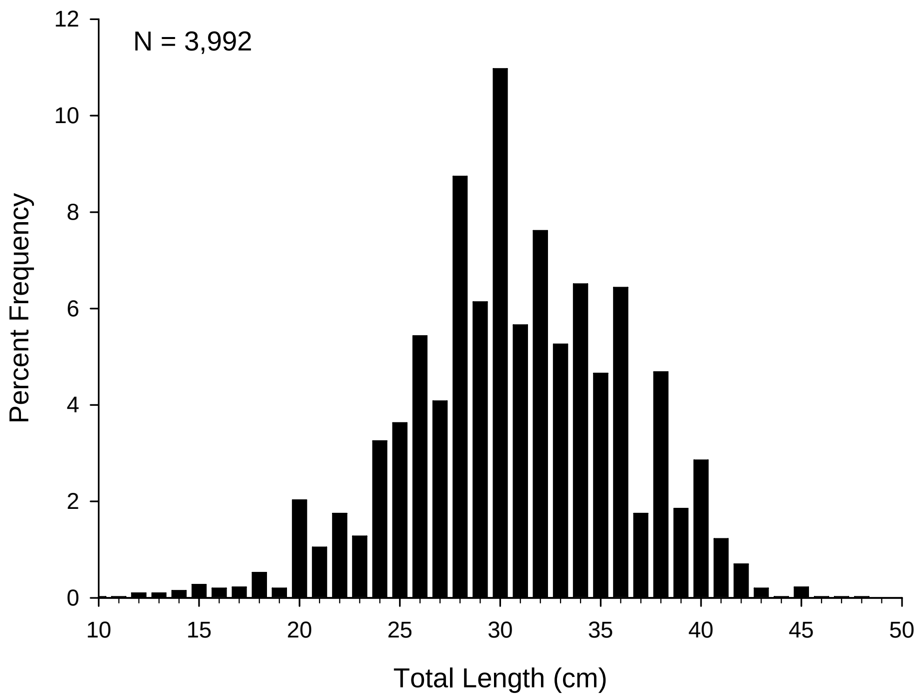


Figure 7.4. The lengths of red rockcod measured by NSW charterboat operators 2001 to 2003.

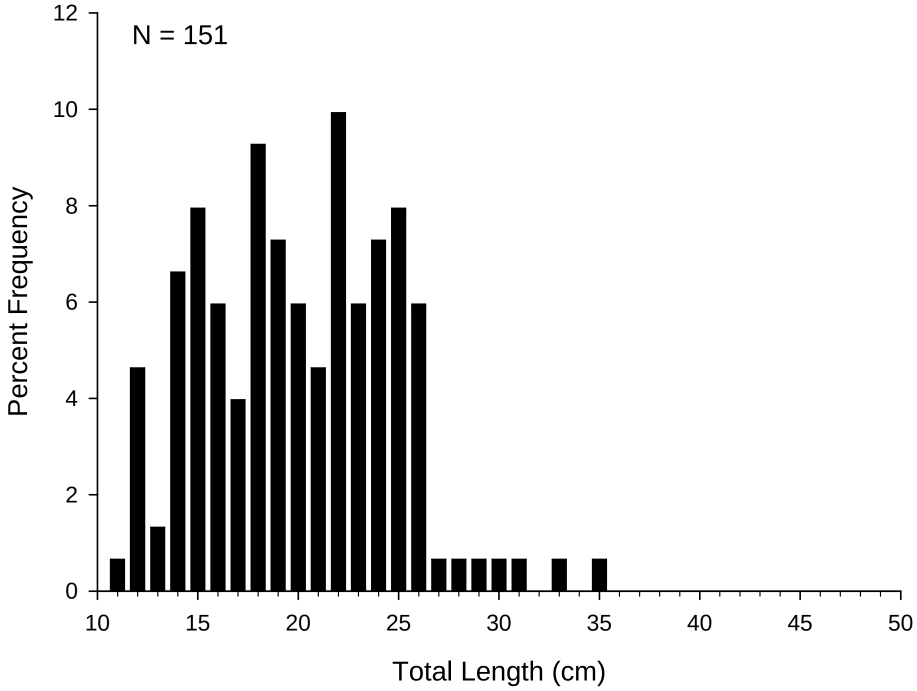


Figure 7.5. The lengths of discarded red rockcod measured by NSW charterboat operators 2005/06.

7.3.2. Reproduction

7.3.2.1. Seasonality of spawning

Gonadosomatic indices

Elevated levels of female GSIs were observed from December to April; however the major peak occurred during March (Fig. 7.6). During the peak spawning period (i.e., March), the ovaries of red rockcod were approximately six times their non-spawning weight. Male red rockcod did not have an obvious peak in GSI levels throughout the year, with the maximum value occurring in January (0.12 ± 0.04%), and slightly elevated levels discernable from January through to April (Fig. 7.6).

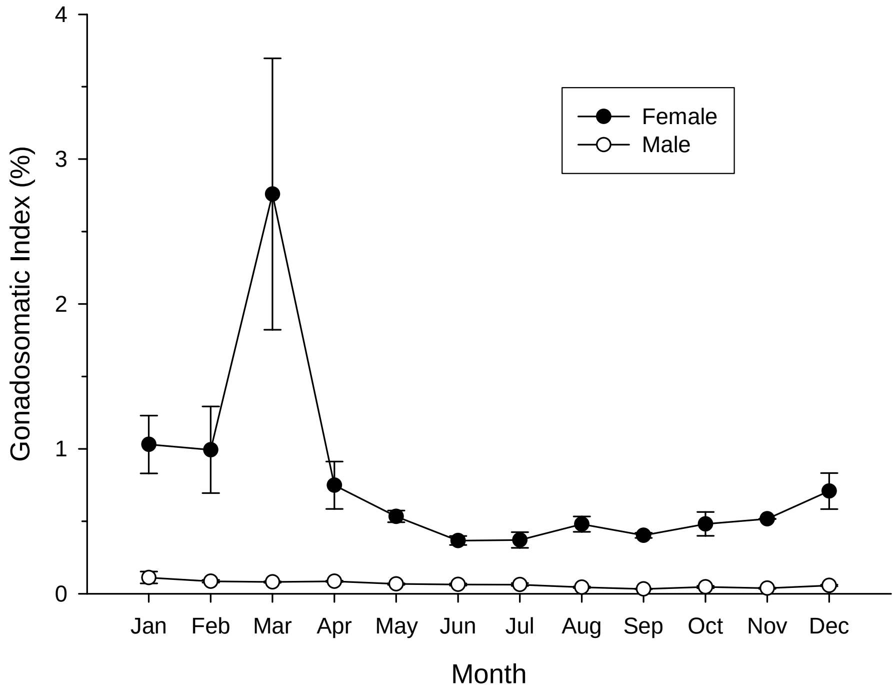


Figure 7.6. Gonadosomatic indices (mean GSI ± SE) for male and female red rockcod.

Macroscopic gonad staging

Female fish with reproductively active [stage 3 (ripe) and stage 5 (spent)] ovaries were observed between December and April (Fig. 7.7). The ovaries of all female fish sampled in March (*n* = 3) were estimated to be ripe (stage 3), and between 12.5 and 20% were ripe during the remaining spawning months (Dec, Jan, Feb, Apr). Spent female fish were observed only in February. Very few male fish with obviously reproductively active testes were sampled throughout the year: five in February and one in each of December and January (Fig. 7.7). During the remainder of the year, most ovaries and testes were estimated to be stage 2 (resting). All female red rockcod sampled in June were estimated to have immature (stage 1) ovaries. Female fish with stage 1 ovaries also occurred in February, May, July, September and November. Immature male fish were present in samples collected every month throughout the year.

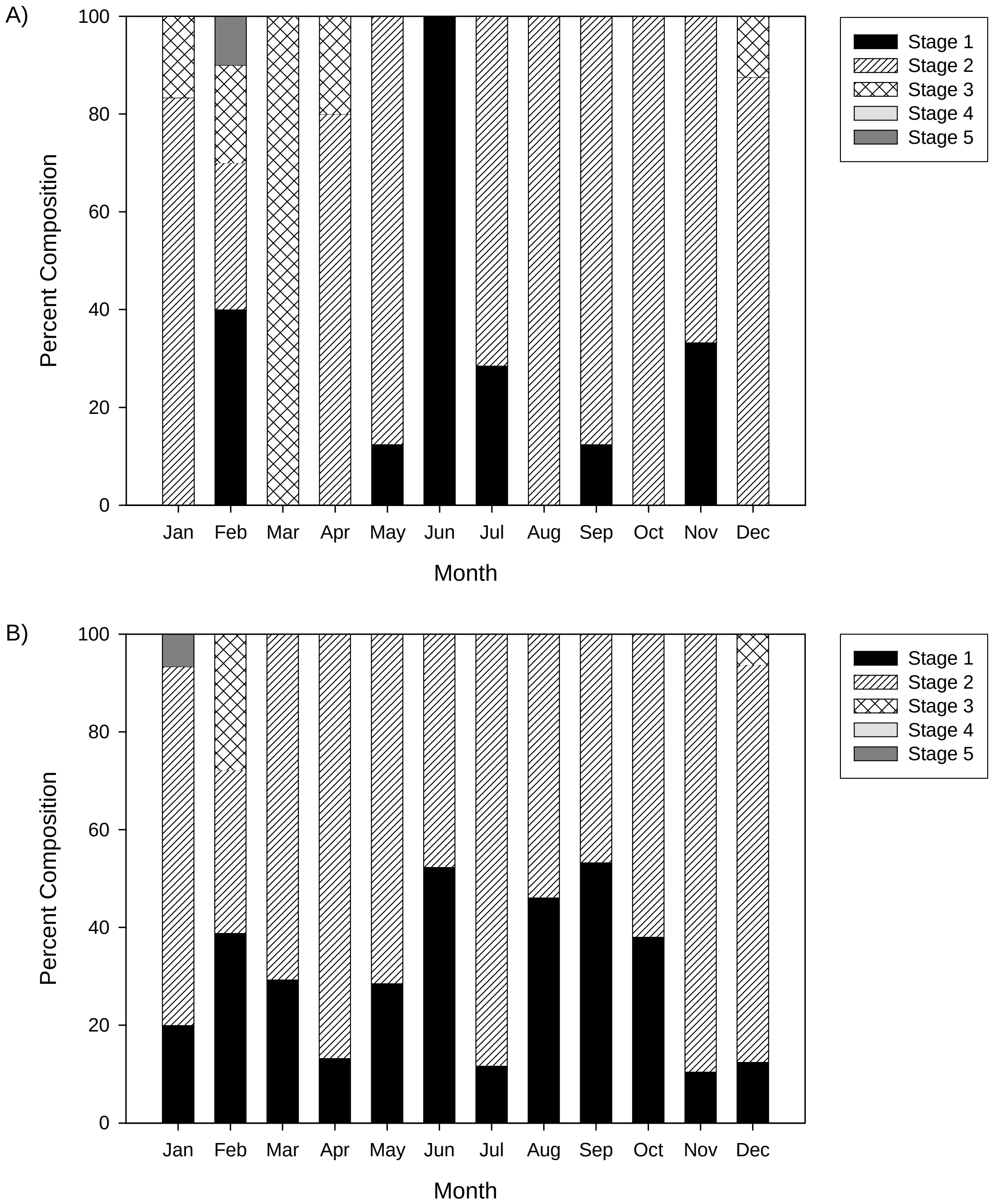


Figure 7.7. Monthly gonad stages of A) female and B) male red rockcod.

7.3.2.2. *Size at maturity*

Red rockcod females mature between 17 and 26 cm TL, with a fitted L_{50} value of 16.19 ± 1.77 cm TL (Fig. 7.8). Male red rockcod mature between 19 and 29 cm TL, with 50% mature at 24.30 ± 0.39 cm TL (Fig 7.8). The maturity curves and estimated sizes at 50% maturity were significantly different for male and female red rockcod (Wald's test, $p < 0.05$).

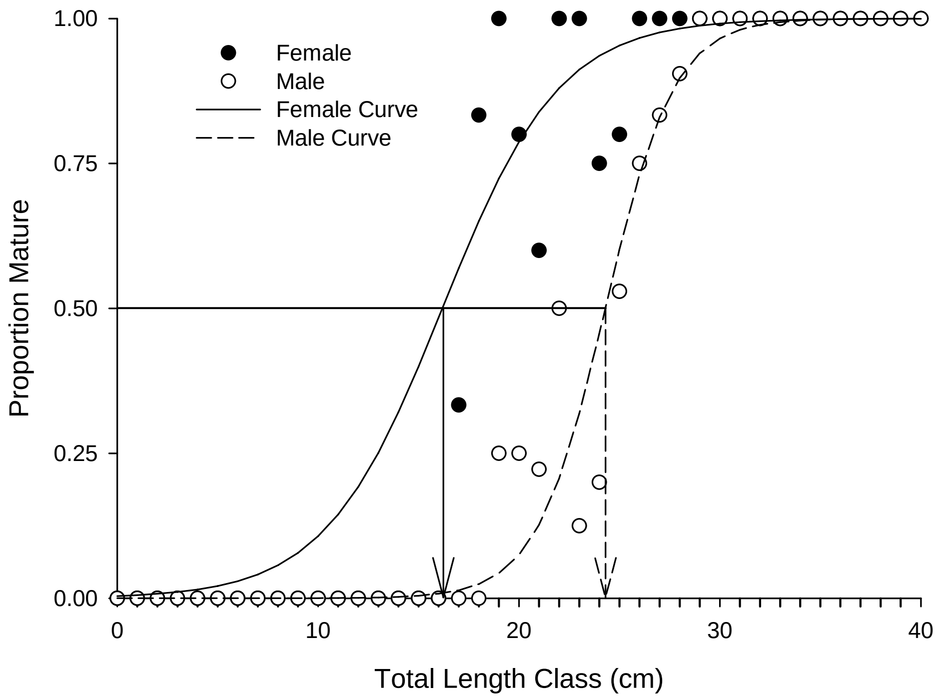


Figure 7.8. Reproductive maturity data with fitted logistic curve for male (*n* = 207) and female (*n* = 69) red rockcod. Arrows indicates sizes at 50% maturity.

7.3.2.3. Sex ratio

The number of male red rockcod caught in commercial catches was significantly higher than the number of females (χ^2 = 73.41, $p < 0.05$; Fig 7.9). The sex ratio was heavily biased towards males in every month sampled, ranging from 1.6:1 (male to female) in August, to 10.5:1 in October. The overall average sex ratio of males to females for all fish collected was 3.2:1.

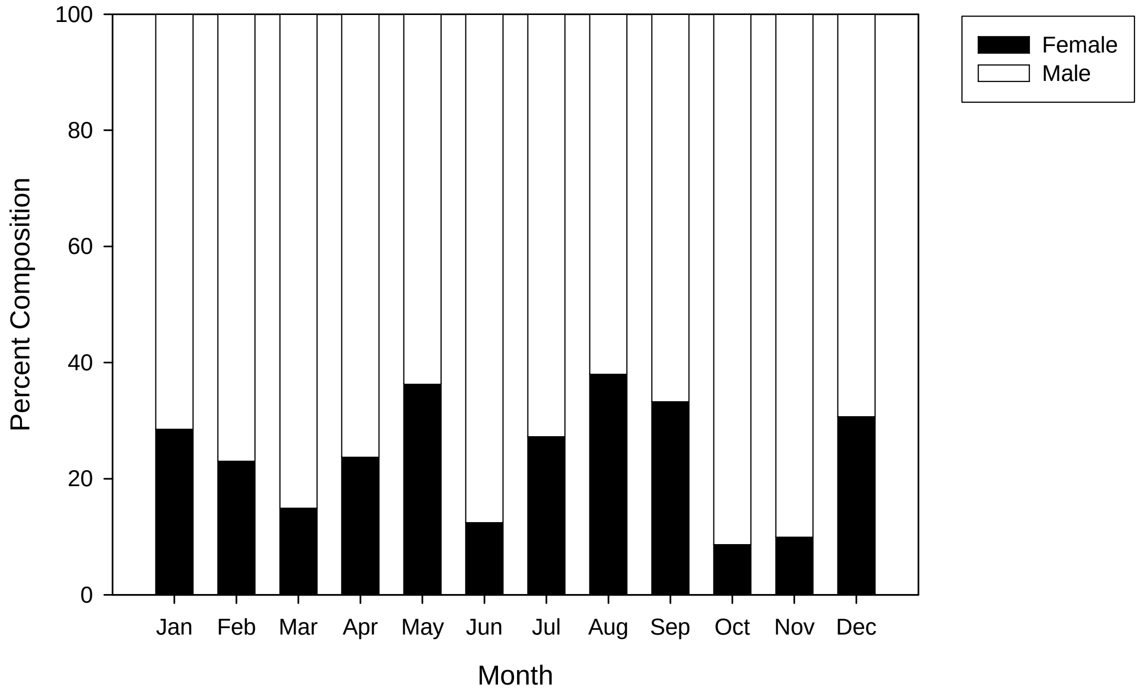


Figure 7.9. Monthly sex ratios for red rockcod sampled from the Sydney Fish Markets (n = 267) during 2005.

7.3.3. Age and growth

7.3.3.1. Ageing procedure and validation

Appearance of Red Rockcod Otoliths

Sectioned red rockcod otoliths were relatively easy to interpret. Opaque and translucent zones were easily discernable and counted (Fig. 7.10). The core was always a largely opaque region, followed by a translucent region and then a very distinct opaque band, which was scored as the first annulus (Fig. 7.10). Subsequent opaque zones became progressively finer and closer together the further out from the core they occurred. The maximum number of opaque zones counted was 32. The coefficient of variation (cv) averaged across all ages was 0.066.

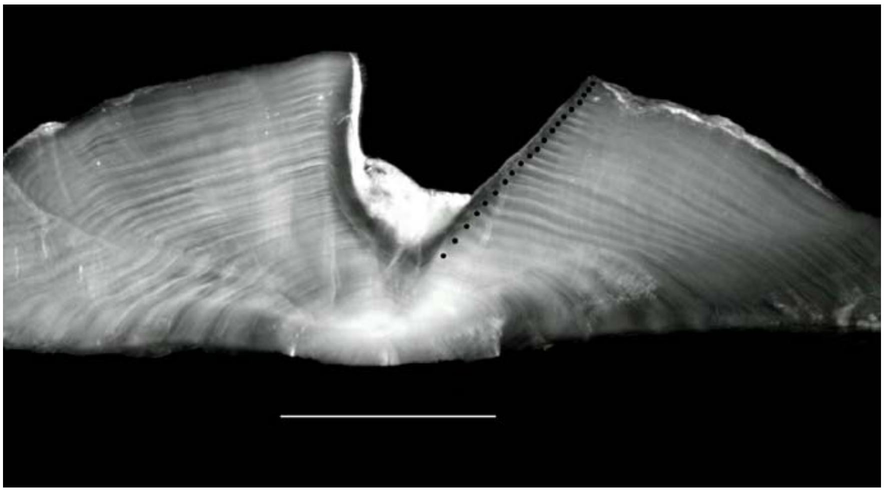


Figure 7.10. Sectioned red rockcod otolith viewed using reflected light (at 2x magnification). Twenty annuli were counted in this section. Scale bar is 1 mm.

Marginal increment analyses

The monthly marginal increments for red rockcod showed considerable variation each month (Fig 7.11) but with a seasonal pattern of highest values in summer (December to January) and lowest values in autumn (March to April).

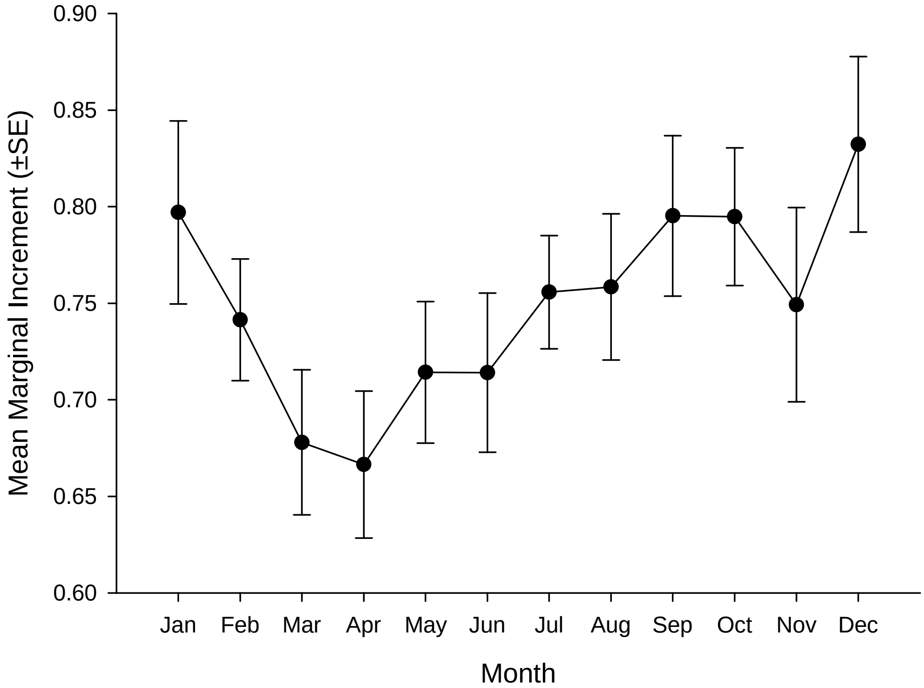


Figure 7.11. Mean (±SE) marginal increment values for red rockcod (n = 273).

Edge analysis

The proportion of red rockcod otoliths with opaque edges each month supports the marginal increment analyses and is consistent with annual periodicity of opaque zone formation (Fig. 7.12). The highest proportion of otoliths having opaque edges occurred during summer/autumn (December to April).

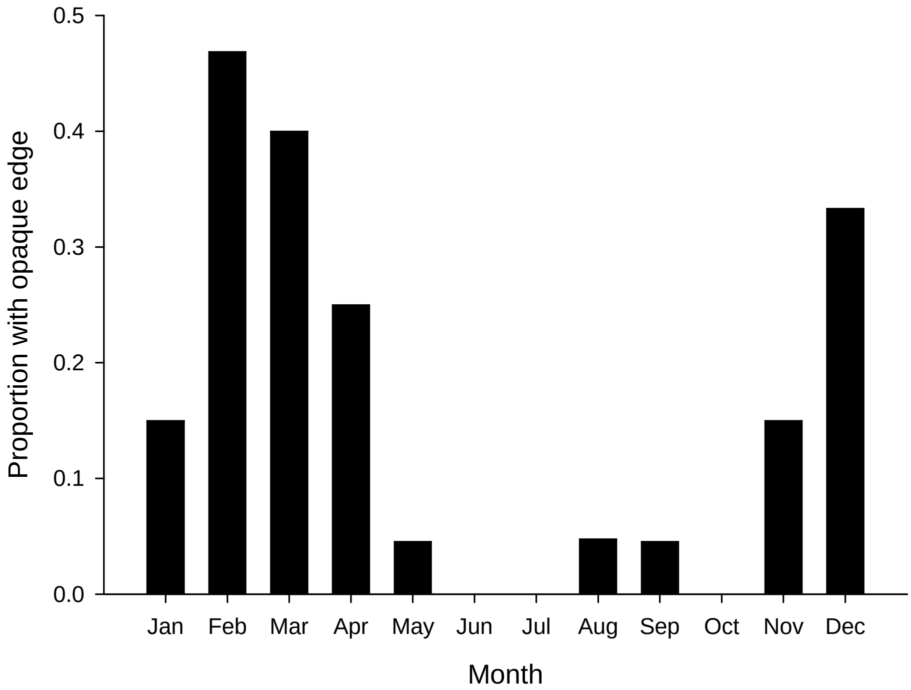


Figure 7.12. Monthly proportions of otoliths having opaque edges for red rockcod (*n* = 272).

Development of ageing protocol

Opaque zones in otoliths were counted, and the fish placed into an age class according to opaque zone count only. The use of marginal increment information for each otolith in assigning age classes to red rockcod was not attempted because of the considerable variation in the data (Fig. 7.11). A universal birthday was set at 15th March, which was the middle of the GSI-defined spawning period (Fig. 7.6). The number of days from this universal birthday to the date of capture (as a proportion of a year) was then added to give the final age in decimal years.

7.3.3.2. Growth model

The growth of male and female red rockcod was significantly different (ARSS $F_{(3, 259)} = 10.21$, $p < 0.001$). Males grew faster, lived longer and attained larger sizes than females (Table 7.1 & Fig. 7.13). Red rockcod grow slowly, attaining approximately 22 cm after five years and 26 cm after 10 years.

The oldest fish collected (32 years) was a male that measured 33.5 cm TL. The oldest female fish was estimated to be 23 years old and measured 21.8 cm TL. The two largest fish collected were males (40.5 and 39.9 cm TL) and both were estimated to be ~ 23 years old. The two largest female fish collected were 34.5 and 34.4 cm TL and were estimated to be ~ seven and 16 years old respectively.

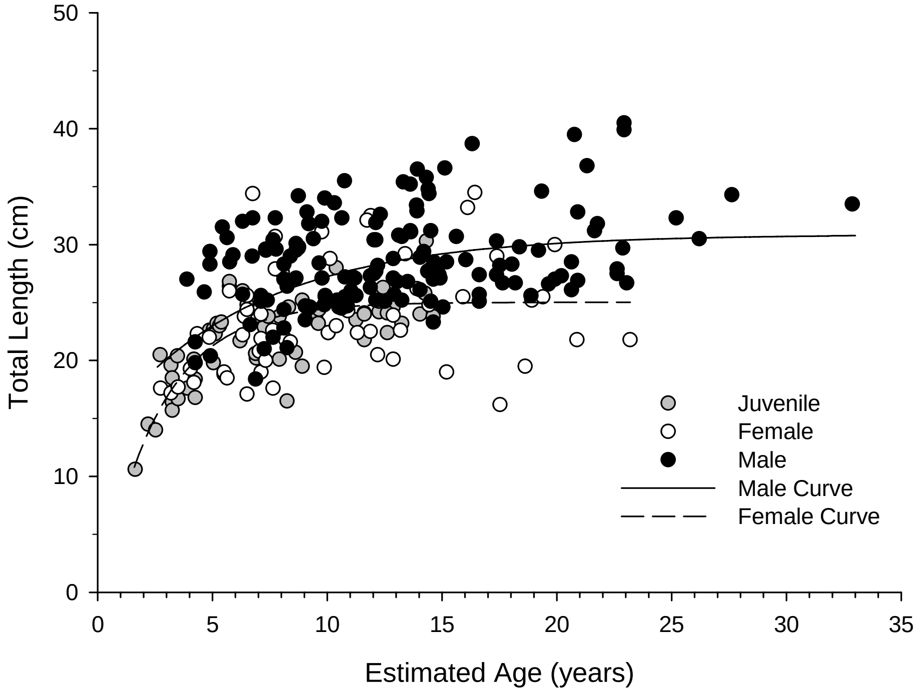


Figure 7.13. Size at age data with fitted von Bertalanffy growth curve for red rockcod (*n* = 275).

Table 7.1. von Bertalanffy growth function parameters (± SE) for red rockcod.

	Females	Males	Combined
L_∞ (cm)	25.14 (± 0.94)	31.17 (± 1.24)	28.98 (± 0.61)
k (yr^{-1})	0.36 (± 0.12)	0.14 (± 0.45)	0.25 (± 0.05)
t_0 (yr)	0.01 (± 0.98)	-4.69 (± 2.55)	-1.15 (± 0.92)

7.3.3.3. Age composition of landed catch

The age-length key for red rockcod (Table 7.2) was applied to the commercial size composition data (Fig. 7.2) to obtain an estimate of the age composition in commercial landings. The age composition is characterized by having many age classes, with more than 40% being greater than 10 years old.

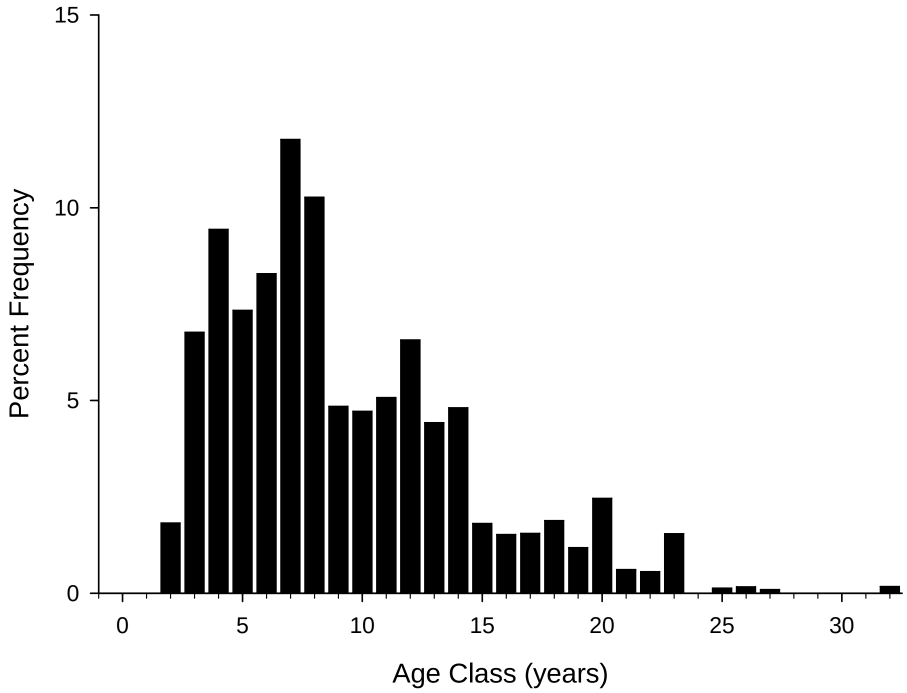


Figure 7.14. Age composition of red rockcod in commercial landings.

7.3.4. Mortality estimates

Estimates of total mortality (Z) made from the slope of the descending limb of the catch curve for red rockcod, fitted between ages 7 and 23, was 0.15 (Fig 7.15). Age 7 was the most abundant age class and was therefore chosen as being fully recruited to the fishery, while age 23 was chosen as the older limit because there were no 24 year old fish observed. Independent estimates of natural mortality (M) based on the method of Hoenig (1983), using a maximum age of 32, years ranged between 0.09 and 0.14. Estimates of fishing mortality (F), made by subtracting M from Z, therefore ranged from 0.01 to 0.06.

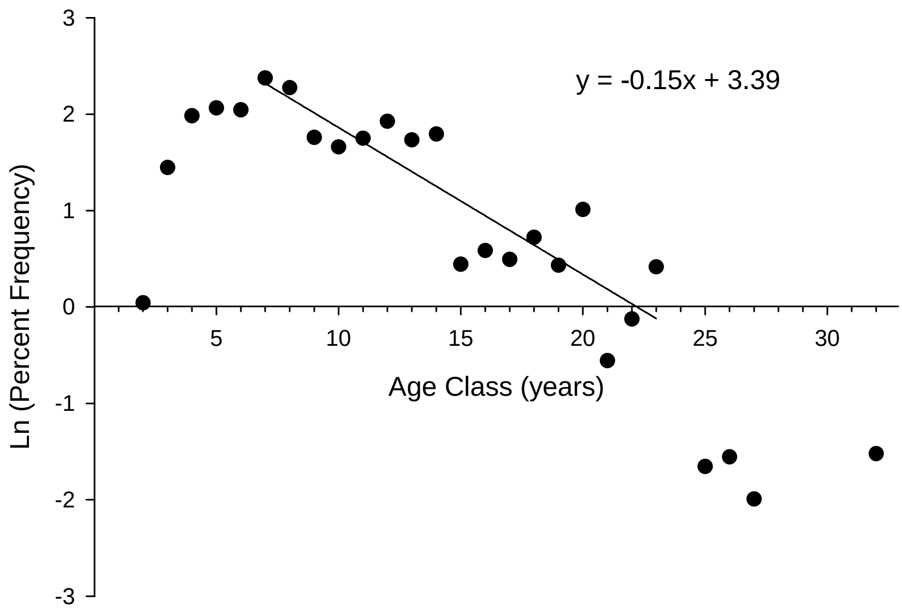


Figure 7.15. Catch curve for red rockcod.

Table 7.2. Age-length key for red rockcod sampled during 2005.

Fork length	Age (years)																																
class cm	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total
10-10.9		1																																1
11-11.9																																		0
12-12.9																																		0
13-13.9																																		0
14-14.9			2																															2
15-15.9				1																														1
16-16.9				2	1				1									1																5
17-17.9			1	4			1	1																										7
18-18.9				1	2	2	1																											6
19-19.9				1	2	2		1	1	1						1			1															10
20-20.9			1		2		2	3	1				2																					12
21-21.9					1		1	2	4			1												1										11
22-22.9					3	2	1	3	1		2	2	1	1																				16
23-23.9						3	2	2		3	1	1	1	1	2																			16
24-24.9					1		4	1	2	5	5	2	3	1	2	1																		27
25-25.9					1		2	4	1	2	3	1	4	1	2	1	2		2	1														27
26-26.9						3	1		1			2	1	3	1			1	1	1	2			1										18
27-27.9				1				1	3	1	1	3	3		6		1	1		1	1		2											25
28-28.9					1	1			1	1	2		2		3	1	1	1	1		1													16
29-29.9					1	1	1	3	4					1	1			1	1	1			1											16
30-30.9						1		3	1	1			2	2	1	1		1		1							1							15
31-31.9										2			1	2	1							2												9
32-32.9							2	1		2	1	2	1	1							1					1								12
33-33.9											1			1			1																1	4
34-34.9							1		1	1					2		1			1								1						8
35-35.9											1			2	1																			4
36-36.9														1		1						1												3
37-37.9																																		0
38-38.9																	1																	1
39-39.9																					1		1											2
40-40.9																							1											1
N	0	1	4	11	15	16	19	25	22	19	17	14	21	17	22	6	7	6	6	6	7	3	5	2	0	1	1	1	0	0	0	0	1	275

7.3.5. *Market price*

Red rockcod sold through the Sydney Fish Markets are graded according to the following schedule:

Small	< 20 cm
Medium	20 to 25 cm
Large	> 25 cm

Average prices for red rockcod sold through the Sydney Fish Markets during 2005/06 indicate that "Medium" ($10.26/kg) and "Large" fish ($9.94/kg) sold for slightly more than "Small" fish ($9.67/kg) (Fig. 7.16).

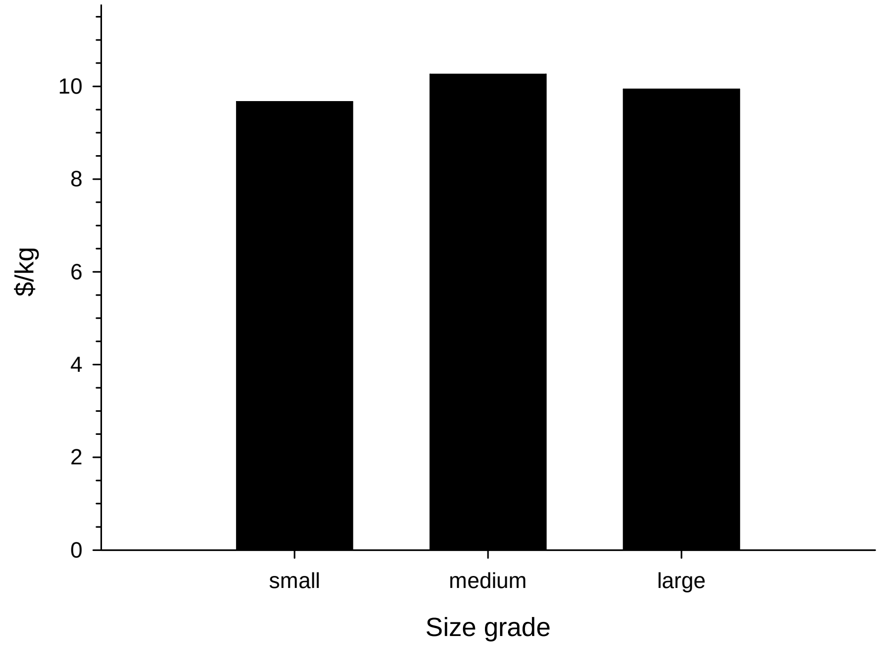


Figure 7.16. Average price information by size grade of red rockcod.

7.3.6. *Per recruit analyses*

Per recruit analyses were done using the following parameters:

L_∞ = 29.98 cm
K = 0.24 yr^{-1}
T_0 = -1.15 yr
Z = 0.15
M = 0.09
F = Z–M = 0.06
E = F/Z = 0.40
M/K = 0.38

The market price and size grade information used were as described above. L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation that yield per recruit is maximised at 18.5 cm TL and that $ per recruit is maximised at 20 cm TL (Fig. 7.17).

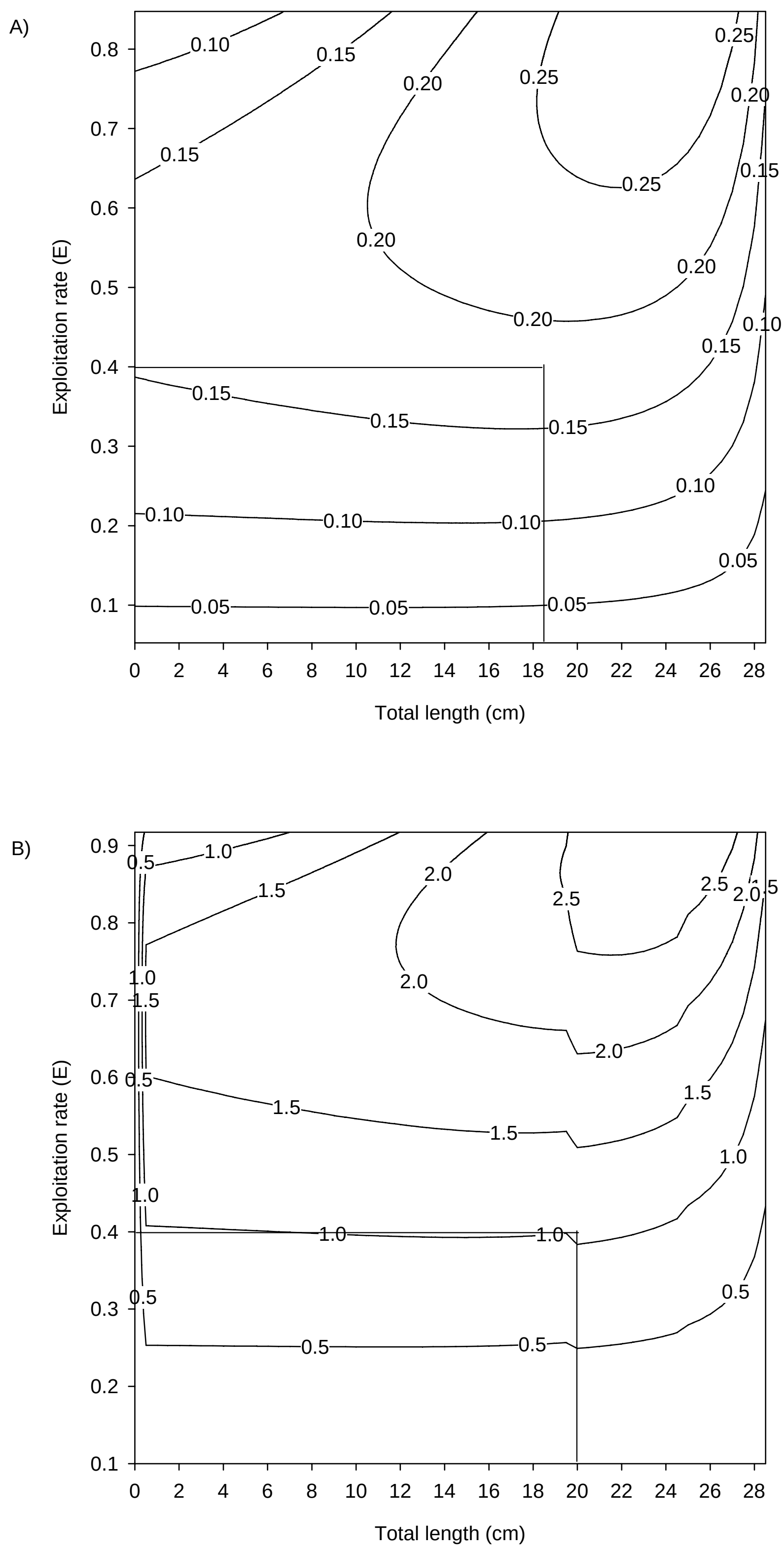


Figure 7.17. Yield and $ per recruit isopleths for red rockcod. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

7.3.7. Spawning potential ratio

The SPR for red rockcod at current levels of mortality is well above the threshold level of 0.2 and indicates that at current levels of exploitation that red rockcod should be producing sufficient eggs to sustain the population regardless of their size at first harvest. The smallest red rockcod in landings are ~ 15 cm and this size at first harvest corresponds to a SPR of ~ 0.51 (Fig. 7.18).

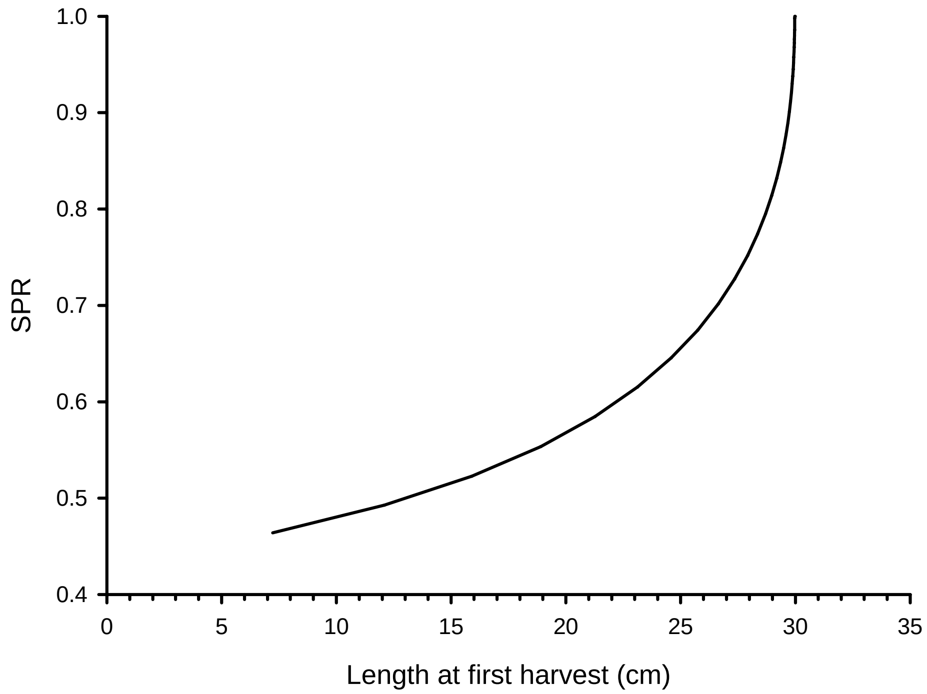


Figure 7.18. Spawning potential ratio for red rockcod at current levels of exploitation for a range of sizes at first harvest.

7.3.8. Information fact sheet

Relevant material from this chapter was collated into an information fact sheet for red rockcod (Fig. 7.19).

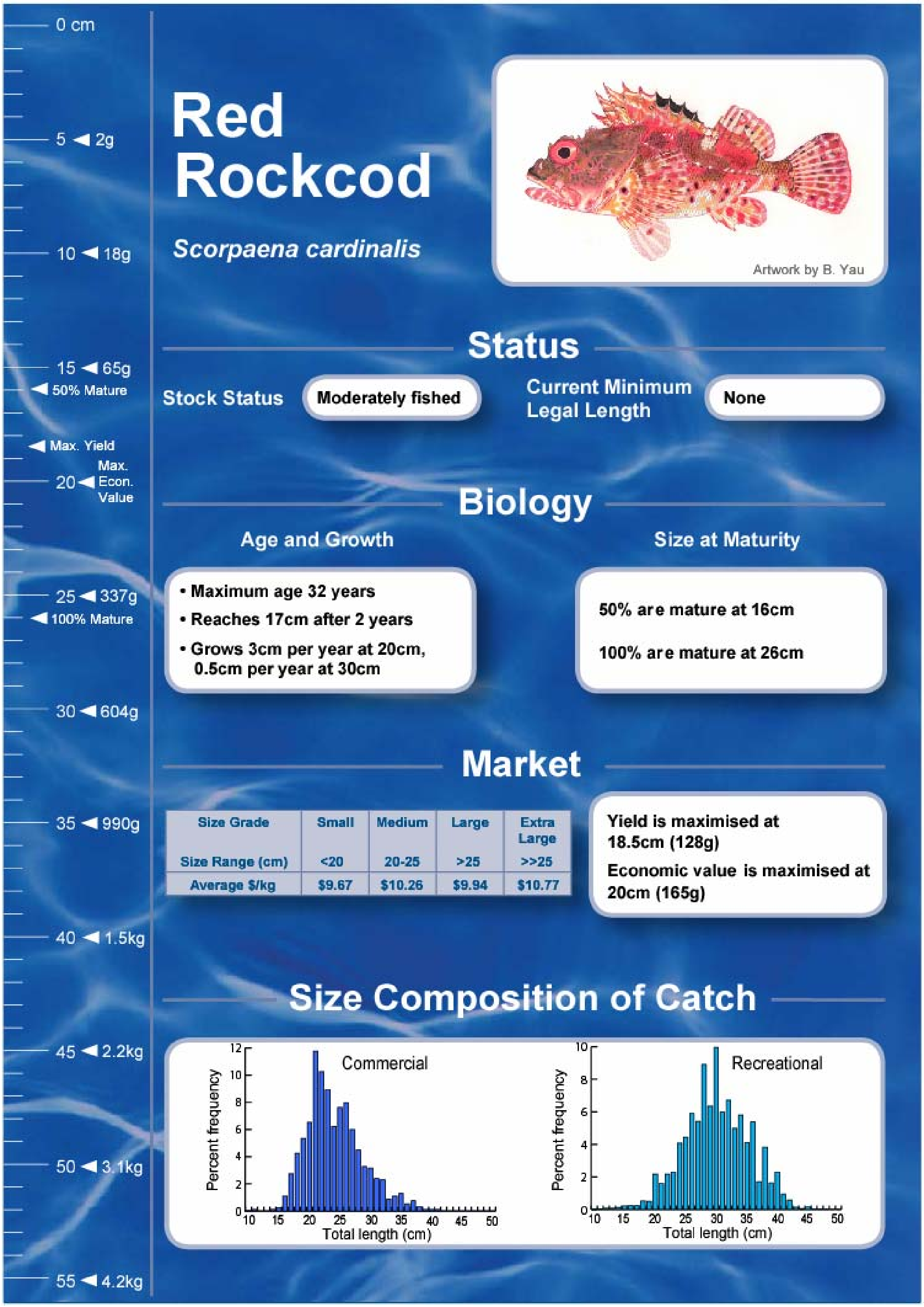


Figure 7.19. Information fact sheet for red rockcod.

7.4. Discussion

This is the first study to provide detailed information on the biology and fishery for red rockcod. Whilst red rockcod have not been formally assessed in terms of their resource status, there is sufficient information within this chapter to recommend their status as being MODERATELY FISHED. The age composition in landings contains many older fish (> 10 years) fish and the fitted catch curve provides a relatively low estimate of total mortality (Z = 0.15). This, combined with an estimated natural mortality of M = 0.09 (based on 5% attaining the observed maximum age of 32 years), suggests that fishing mortality is relatively low (F ≈ 0.06). Total landings are reasonably small and have been stable for the past eight years. Landings have declined since the mid 1990s, but catch rates have been overall increasing since 1999/00. Red rockcod mature at smaller sizes than those generally seen in landings and their SPR is well above threshold levels.

The concern for red rockcod is that they may become more sought-after as the availability of historically more desirable species declines. They already attain relatively high prices through the Sydney Fish Markets (averaging approximately $10/kg) and are therefore becoming more lucrative for fishers to target. Their flesh is firm, white and tasty and they are often referred to as 'poor mans lobster'. Their very slow growth rates and potential extreme longevity suggest that the population would be vulnerable to excessive exploitation. Monitoring of the lengths of red rockcod in landings (both recreational and commercial) would be prudent in order to monitor the stock. It is likely that age-class truncation due to excessive fishing is the greatest threat to the resilience of red rockcod and periodic ageing studies would be useful. The utility of management regulations like MLLs in controlling age-class truncation in a species that grows slowly and exhibits substantial variation in size-at-age is low. However, such regulations could be used to protect juveniles if fishers begin to land red rockcod at sizes smaller than they do at present.

The red rockcod fishery appears similar to other scorpaenid fisheries in other parts of the world in being an important, but relatively minor, component of commercial and recreational landings. As an example, the California scorpionfish (*Scorpaena guttata*) is a relatively minor, but well represented component of catches in the Californian charterboat fishery (ranked 15th), and is of similar importance commercially (Love *et al.*, 1987). The commercial fishery for California scorpionfish has exhibited large fluctuations in landings, driven by changes in fishing effort and environmental conditions. *Scorpaena scrofa* is an important component of the catch in the Mediterranean where they are captured by commercial and recreational fishers (Ordines *et al.*, 2005; Colloca *et al.*, 2004). Fisheries for other scorpaenids have received little examination. Their relatively minor importance to fisheries to date may be one reason why the biology of this genus has received little study.

Female red rockcod were estimated to mature between ~ 17 and 26 cm and males between 19 and 29 cm. The number of females sampled was relatively low and the maturity ogive did not fit the data well; the size at 50% maturity is therefore likely to be greater than 16.19 cm as predicted by the model. The data suggests that female red rockcod may mature after three to six years and that males mature after five to six years. Further analyses of age at maturity using observed ages, rather than estimating age from the growth model, should be done for red rockcod.

Red rockcod have a spawning season between December and April, but with most activity observed around February and March. Other scorpaenids have spawning periods of similar duration. *S. notata* have been reported to have a spawning season of ~ four months (July to October in the northern hemisphere) (Munoz *et al.*, 2005). *S. guttata* have a spawning season of ~ 4 months (May to August) in California (Love *et al.*, 1987). *S. guttata* also exhibit seasonal movement to spawning areas (Love *et al.*, 1987); however there is no evidence that red rockcod undergo such movements. Future tagging studies may help in understanding movement patterns of red rockcod.

The genus *Scorpaena* exhibits a range of spawning strategies, from basic oviparity (spawning eggs) to less primitive viviparity (giving birth to live young) (Munoz *et al.*, 2005). Fertilization is thought to be external. Some species (e.g., *S. guttata*) are thought to spawn at the surface (Love *et al.*, 1987), while others (e.g., *S. notata*) embed their eggs in a floating gelatinous matrix (Munoz *et al.*, 2002). The spawning strategy of the red rockcod is unknown, but hydrated eggs in ovaries showed no evidence of being within a gelatinous matrix.

Red rockcod are reported to attain 45 cm and 2.5 kg (Hutchins and Swainston, 1986), yet the maximum observed during the present study was 40.5 cm TL and weighed 1.4 kg. Red rockcod growth is slow, taking approximately five years to attain 22 cm and the oldest fish (32 years) was 33 cm TL. The method of estimating age used in the present study was by counting opaque zones in sectioned otoliths. Opaque zones were relatively easy to count which is reflected in a mean cv of 0.066, well within the range reported for many other species (Campana, 2001). A cv of 0.066 is considered acceptable for a species like red rockcod that can live for more than 30 years. These opaque zones were validated as being formed annually by marginal increment analysis. Monthly patterns in marginal increments and the proportions of otolith with opaque edges were consistent with one opaque zone being formed in the otoliths of red rockcod during spring/summer and generally being scored as complete by autumn.

Rizzo *et al.* (2003) also used sectioned otoliths to estimate age in *Scorpaena elongata* and reported an observed maximum age of 30 years. However, other studies on age of this genus have used whole otoliths (*Scorpaena maderensis* – La Mesa *et al.*, 2005, who reported a maximum age of five years), and sectioned anal pterygiophores (*Scorpaena guttata* – Love *et al.* 1987, who reported a maximum age of 21 years). La Mesa *et al.* (2005) reported a linear relationship between maximum length and longevity for scorpaenids. Our estimates of maximum size and age for red rock do not fit the linear relationship well; however they do grow larger and have greater longevity than most reported scorpaenids. Red rockcod males grow faster and attain greater ages than females. This is in contrast to the findings for two other scorpaenids (*S. maderensis* and *S. guttata*) where females were reported to grow faster and live longer than males (La Mesa *et al.*, 2005; Love *et al.*, 1987). The reason for this difference is unknown, but may be related to differences in life-history characteristics.

The sex ratio in landings of red rockcod during the present study was significantly skewed towards males (overall M:F ratio of 3.2:1). The bias towards males could be as a result of: (i) differences in average sizes resulting from males growing larger than females and therefore being more marketable, or; (ii) there being more males in the population. La Mesa *et al.* (2005) and Munoz *et al.* (2005) also reported males to be significantly more abundant in what were probably representative samples of *S. maderensis* and *S. notata* respectively. The reasons for these skewed sex ratios, and any advantages of having more males in the population, remain unknown.

8. BIOLOGY AND FISHERY FOR PEARL PERCH

8.1. Introduction

The pearl perch (*Glaucosoma scapulare*) is a member of the family Glaucosomatidae, a small family comprising four species of perch-like marine fishes which frequent submerged reefs, pinnacles and rough rocky bottom in moderately deep water throughout the Indo-Pacific (McKay, 1997). Pearl perch occur in small schools in the coastal waters of eastern Australia from Rockhampton in Queensland south to Port Jackson in New South Wales but are rarely caught south of Coffs Harbour (Hutchins and Swainston, 1986; McKay, 1997). They generally inhabit moderate depths up to 90 m on the continental shelf, close to reef or rough bottom, but may also move into shallow coastal water through the day (McKay, 1997). Pearl perch commonly grow to 35 – 40 cm but can reach a maximum length of 70 cm and weigh up to 7.3 kg.

Several species of glaucosomatid support significant commercial and recreational fisheries, particularly the West Australian dhufish (*G. hebraicum*) which is the most valuable commercial finfish in WA, and the northern pearl perch (*G beurgeri*) (Hesp *et al.*, 2002; Newman, 2002; Fletcher & Head, 2006). While pearl perch are considered an excellent eating fish and are exploited by both commercial and recreational fisheries in Queensland and NSW, they are rarely targeted specifically in NSW. In Queensland pearl perch is a primary target species of the southern rocky reef fishery, the second most frequently landed species in the fishery after snapper (*Pagrus auratus*) (Andersen, 2006). The retained annual catch for the commercial fishery in Queensland has increased from around 10 – 20 tonnes between 1989 and 2002, to 30 – 40 tonnes in 2003/04 and 65 tonnes in 2005 (Andersen, 2006). The combined recreational harvest of pearl perch fluctuates from about equal to well over double the commercial harvest. Queensland charter boat catches remained stable at ~ 10 tonnes between 1996 and 2000, but have since increased steadily to 25 tonnes in 2005. Estimates of the recreational catch of pearl perch in Qld made in 1999 and 2002 were 76 and 50 tonnes respectively, with a discard rate of about 40% (Andersen, 2006). Significant concerns have been raised over the long-term sustainability of rocky reef fish stocks in Queensland with increasing catches of both snapper and pearl perch as fishers shift from coral reef fisheries to rocky reef fisheries following recent management changes (Andersen, 2006). In NSW pearl perch are a secondary species caught almost exclusively in the Ocean Trap and Line (OTL) fishery. Current NSW landings are much lower than Queensland catches, fluctuating around 10 – 15 tonnes for the OTL fishery, with charter boat catches increasing steadily from 1.2 tonnes in 2000/01 to 7.2 tonnes in 2004/05.

Little biological information is available on pearl perch with the only published work that of McKay (1997) which, with the exception of taxonomy and distribution, contains only a small amount of information on the species. They are thought to be benthic feeders which may occasionally move up into the water column, and there is anecdotal evidence that they may be influenced by moon phase (McKay, 1997). An unpublished study (Sumpton, pers. comm.) aged pearl perch using whole sagittal otoliths and a maximum age of 14 years was estimated, with about 90% of the commercial harvest in Queensland aged between three and six years. The gonadosomatic index (GSI) was variable throughout the year but peaked in February, with histological sections of ovaries showing that most ripe females were sampled between October and March (Sumpton pers. comm.). Females began maturing (egg production) at a length of 25 – 30 cm (FL) and numbers of eggs produced increased with size to a maximum of 700,000 between 50 – 60 cm (FL) (Sumpton pers. comm.). Fecundity was considered to be low in comparison with other species which inhabit similar areas, e.g., snapper (*Pagrus auratus*) have a fecundity an order of magnitude higher, with an average length female (45 cm FL) producing around 3.5 million eggs

(Ferrell & Sumpton, 1997). The Queensland study collected few ripe females over an extended spawning period (Oct-Mar) suggesting that pearl perch may have a prolonged spawning period (Sumpton, pers. comm.).

To date, no basic biological information has been collected for pearl perch in NSW, despite their importance to both commercial and recreational fisheries. The aims of this chapter were to describe: (i) the growth and longevity; (ii) the spawning season and size/age-at-maturity, and; (iii) the fisheries for pearl perch in NSW.

8.2. Materials and methods

In addition to specimens obtained from commercial catches of pearl perch processed through the Sydney Fish Markets and other NSW co-ops, 14 small pearl perch between nine and 13 cm FL were obtained from the Coffs Harbour commercial prawn trawl fleet that occasionally catch small pearl perch as by-catch. Additional information on length frequency of small pearl perch was also obtained from catch data of the fisheries research vessel *Kapala* when undertaking exploratory prawn trawl surveys in northern NSW between 1990 and 1995. The gonadosomatic index was calculated as for other species in this study, however it was also calculated using a formula relating gonad weight and fork length ($(\text{Gonad Wt}/FL^3)*10^8$; Cayré & Laloë, 1986) in order to make comparisons to an unpublished study on Queensland pearl perch (Sumpton, pers. comm.).

Pearl perch have relatively large otoliths that, once sectioned, were difficult to interpret. Opaque and translucent zones were not easily discernable with zonation consisting of numerous narrow opaque and translucent bands. Opaque zones were marked along the dorsal margin of the sulcus; however both sides were used to count them. Otoliths were read and aged by two independent readers with no knowledge of fish size or the time of year they were captured. The first reader aged all otoliths twice and then a sub sample was read by the second reader and the two sets of counts compared. Where the two counts from reader one differed the final count was assigned based on a 3rd count done by both readers. In addition there were particular structural aspects of the otoliths which were also used to aid in identifying opaque zones. Unlike other species in this study, measurements were made to the outer-edge of opaque zones and not the middle. The inner structure of the otolith made it very difficult to identify the first “annular” mark. To help gain an understanding of this inner region, the otoliths of several small pearl perch (9 – 10 cm FL) were sectioned very finely (approximately 100 µm) in order to determine whether daily growth rings were present and if these could be used to help determine where the first annular mark is laid down.

Little biological information exists on pearl perch but a substantial amount of work has been done on closely related species, primarily the west Australian dhufish (*G. hebraicum*). Studies on the larval development of *G. hebraicum* indicate that larvae hatch at lengths of between 1.8 and 2.3 mm. Thus when fitting the von Bertalanffy curve to the growth data for pearl perch, t_0 was constrained to -0.025 since this gave a predicted length of 2.2 mm at age 0.

8.3. Results

8.3.1. Landings in NSW

8.3.1.1. Current exploitation status

With relatively small catches taken in NSW, the exploitation status of pearl perch is currently listed as UNDEFINED (2005/06). However, this project aims to provide adequate biological information to enable a classification of exploitation status for 2006/07. Catches in NSW and QLD appear to be increasing and pearl perch is a significant species in the recreational/charterboat fishery.

8.3.1.2. Trends in catch

Reported commercial landings of pearl perch have remained relatively stable during the last 10 years, fluctuating between maximum catches in 1992/93 and 1995/96 of around 17 tonnes, and minimum catches in 1991/92 and 2001/02 of around 9 tonnes (Fig. 8.1). Catch rates have also remained relatively stable since 1997/98 at around 1 – 2.5 kg/day for both line and trapping methods, although there has been an increase in line fishing catch rates in the last two years to more than three kg/day (Fig 8.1). There is little information on the current recreational harvest of pearl perch; however Steffe *et al.* (1996) reported substantial catches in 1993/94 (9.2 tonnes) and 1994/95 (3.6 tonnes) for recreational trailerboat fishers off the NSW coast. The retained catch of the charter boat fishery has increased steadily during the last five years from one tonne in 2000/01 to seven tonnes in 2004/05 (NSW DPI Resource Assessment System).

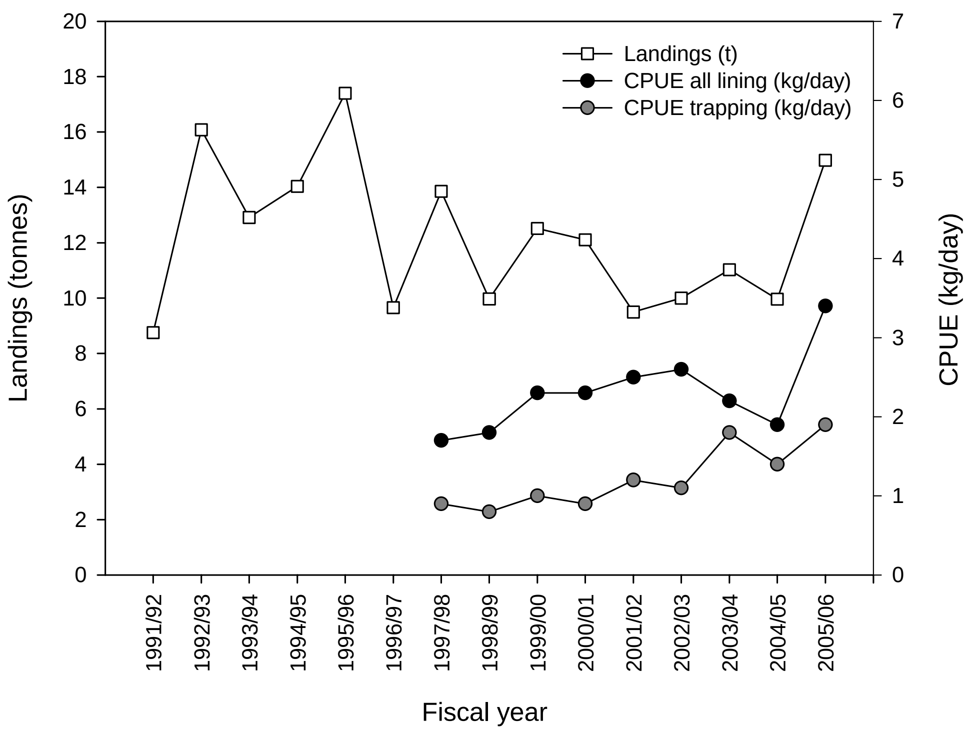


Figure 8.1. Reported commercial landings and catch rates (kg per day fish trapping/lining) of pearl perch in NSW. Source: NSW DPI Resource Assessment System.

8.3.1.3. Length measurements

Commercial landings

The sizes of pearl perch captured by trap and line fishers were measured at the Sydney Fish markets and regional co-ops during the study. A total of 1,185 pearl perch were measured and ranged between 17 and 62 cm FL (Fig. 8.2). The most abundant size classes taken by commercial fishers were ~ 28 to 38 cm FL (54% of catch) with an average of 34 cm FL (± 0.16 SE). A variable proportion of the pearl perch catch below 28 cm FL is probably discarded. Stewart and Ferrell (2003) report a self-imposed size limit among some fishers in the OTL fishery of 28 cm FL (similar to that for snapper) with a high discard rate of about 67% of total catch. However about 25% of the commercial catch sampled for this study was below 28 cm FL indicating that not all fishers follow this practice.

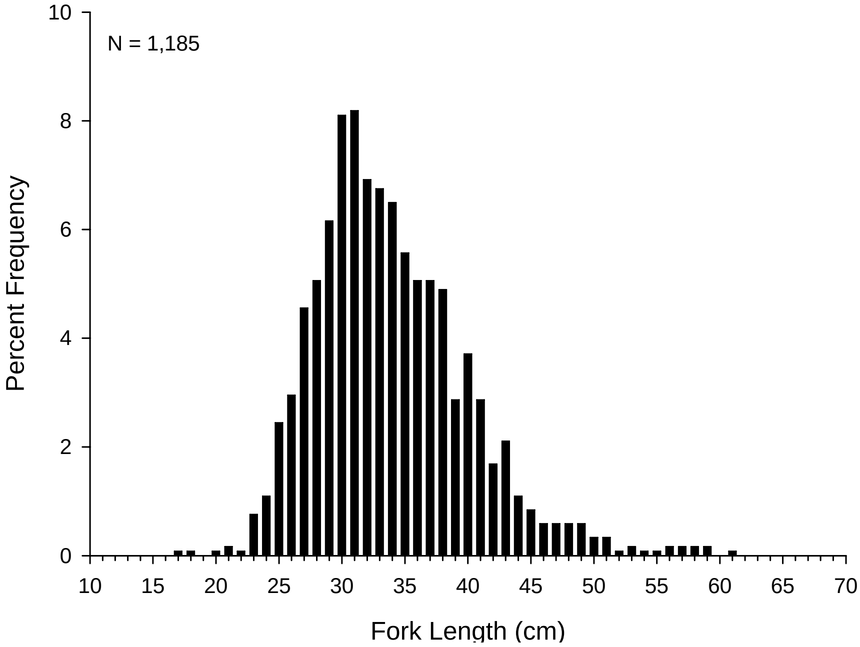


Figure 8.2. The lengths of pearl perch landed by the NSW Ocean Trap and Line Fishery during 2005/06.

Recreational landings

Pearl perch landed by recreational fishers are, on average, larger than those landed by commercial fishers, with the most abundant length classes being ~ 35 to 42 cm FL (Fig. 8.3) and an average length of 38.5 cm FL (± 0.69 SE).

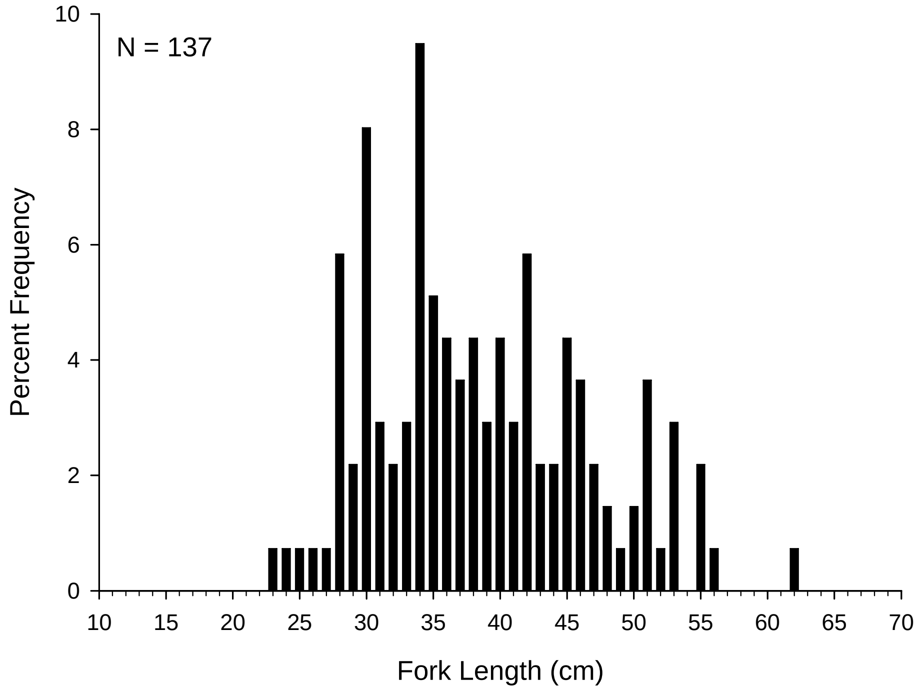


Figure 8.3. The lengths of pearl perch landed by offshore trailerboat fishers 1993/94 and 1994/95. Source: Steffe *et al.*, 1996.

The sizes of pearl perch reported by charter boat fishers during 2001 to 2003 (Fig. 8.4 & 8.5) were similar to those measured from trailer boat fishers in the mid-1990s (average 38.6 ± 0.07 cm FL) and suggests that the sizes of fish available to line fishers has not changed markedly between these survey periods. Weight of pearl perch retained by the charter boat fishery increased from 2000/01 to 2004/05 (period for which data is available) from around one tonne kept in 2000/01 to about seven tonnes kept in 2004/05. Charterboat log books show that pearl perch as small as 18 cm are caught (Fig. 8.5); however fish below about 25 cm are generally discarded.

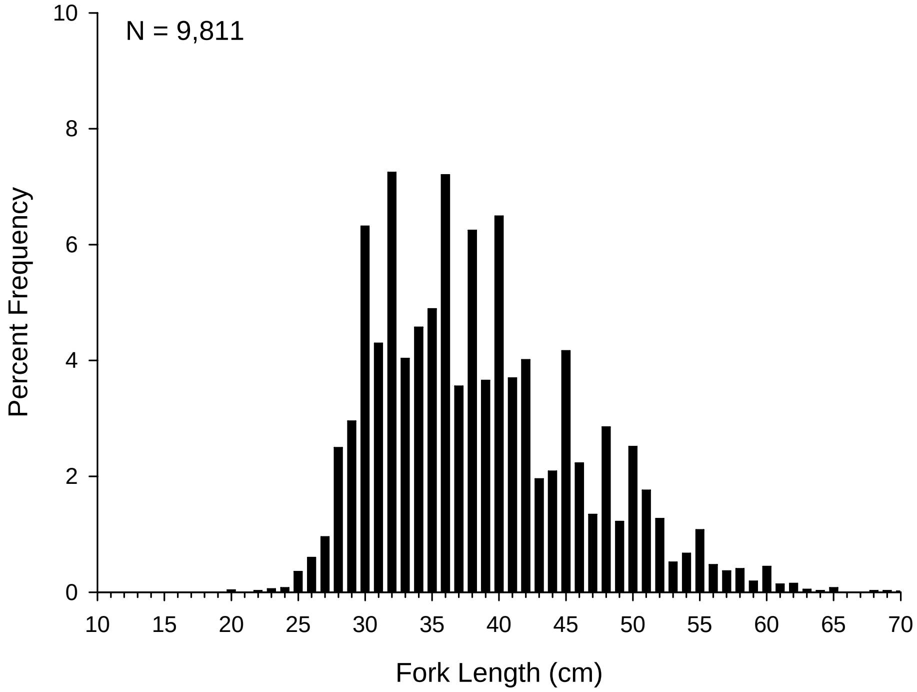


Figure 8.4. The lengths of retained pearl perch measured by NSW charterboat operators 2001 to 2003.

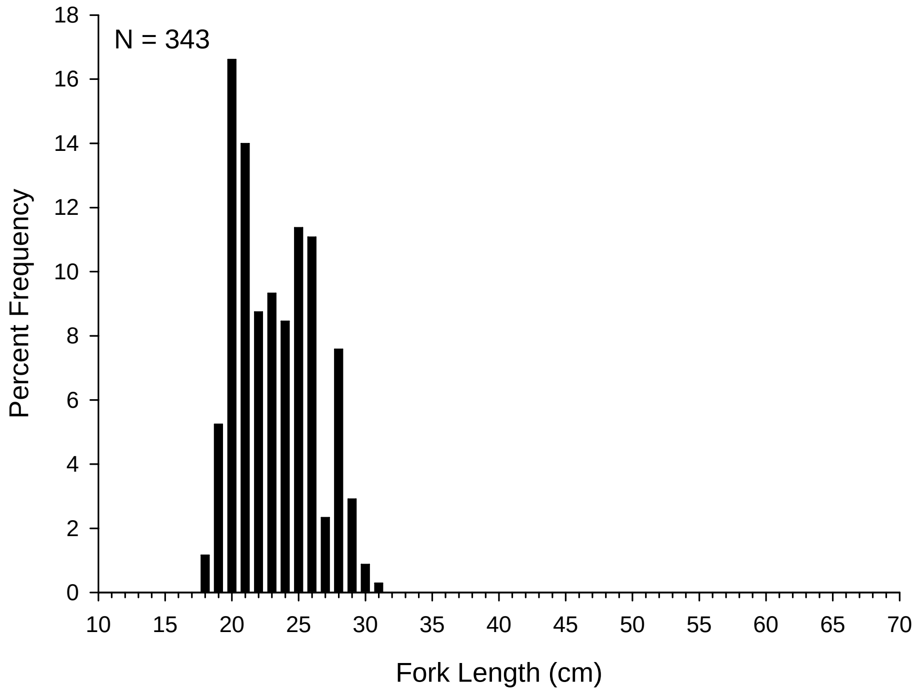


Figure 8.5. The lengths of discarded pearl perch measured by NSW charterboat operators 2001 to 2003.

8.3.2. Reproduction

A total of 172 fish had their gonads staged macroscopically, of these fish, 27 were juveniles and 145 were mature adults comprising 64 males and 81 females. For the purposes of this chapter fish with gonads at stage 2 of development were considered to be mature since most fish, including all females, failed to develop beyond this stage throughout the year. Complete gonad samples were only available for 132 mature fish (60 males and 72 females) and GSI could only be calculated for these fish.

8.3.2.1. Seasonality of spawning

Gonadosomatic indices

Most pearl perch collected throughout the year had gonads in the early stages of development with little clear indication of when spawning may occur. Female GSI values were similar throughout the year, but were highest between October and February (Fig. 8.6). Male GSI values were highest over a similar period (Dec to Feb). The male GSI value for September was based on a single specimen so it is not possible to say whether this reflects male GSI at this time of year. No data on reproductive state was available for mature females collected in May or July to September making it difficult to determine the spawning season in this species.

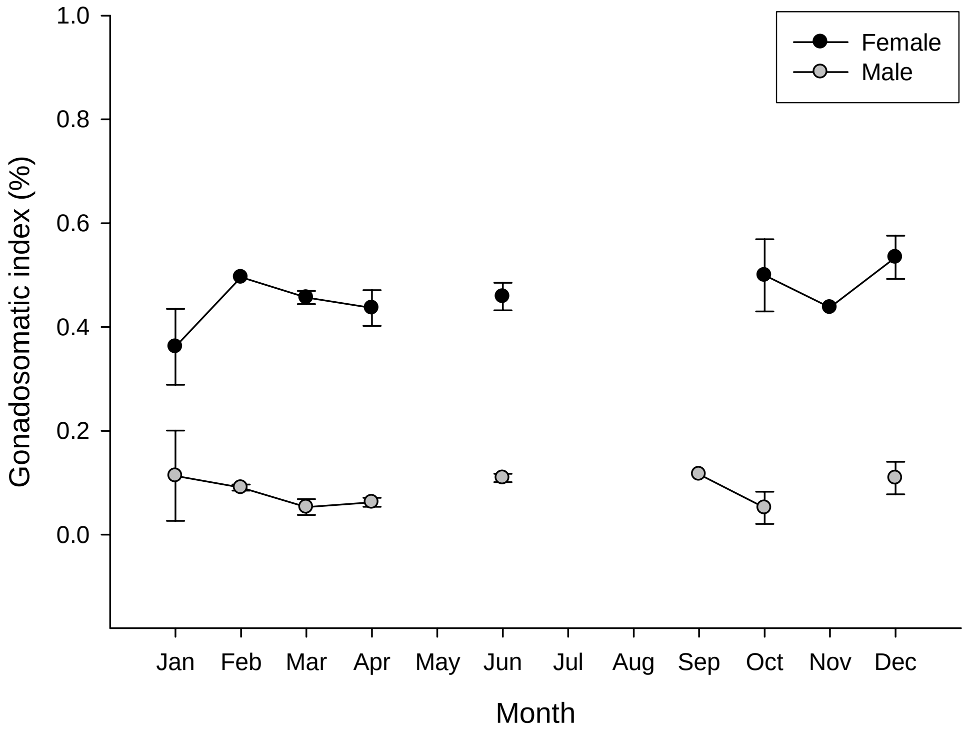


Figure 8.6. Gonadosomatic indices (mean GSI ± SE) for male (*n* = 60) and female (*n* = 72) pearl perch.

The values of GSI calculated using FL instead of fish weight were similar to those determined using body weight, with peaks in December and February but remaining at similar levels until June. The values of GSI calculated in this manner were substantially lower than those determined for pearl perch collected in southern Queensland during the summer period (Sumpton, pers. comm.) (Fig. 8.7).

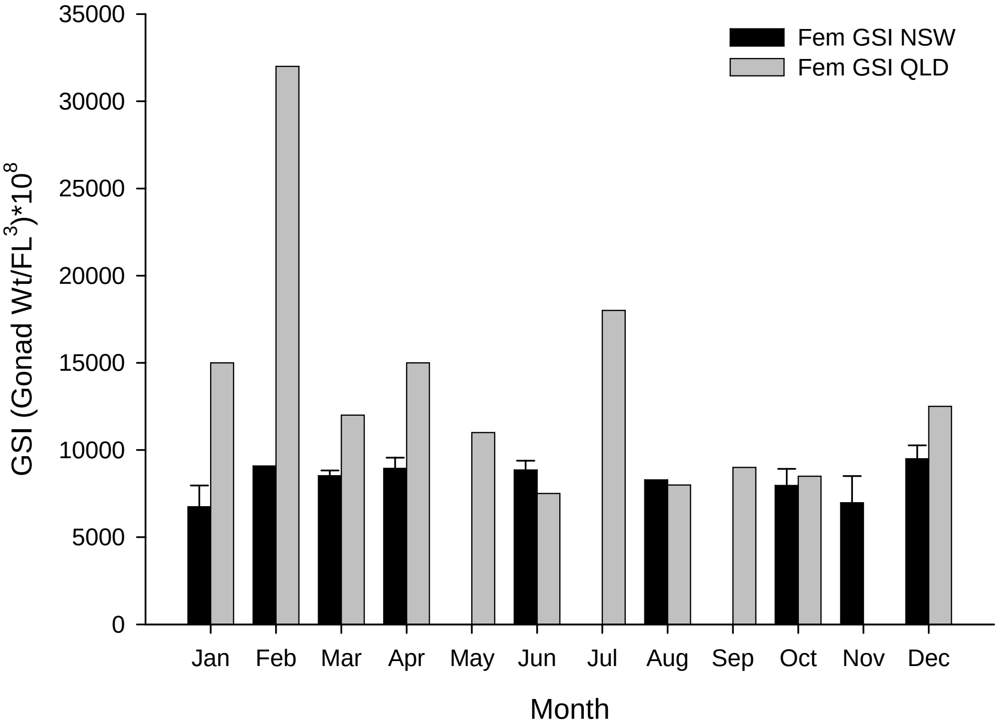


Figure 8.7. Mean female GSI (± SE) calculated using fork length compared with data from the southern Queensland population (Sumpton, pers. comm.). Gonad weight was not determined for female pearl perch collected during May or July to September in this study, and for only one female in February and August. Error estimates not available for Queensland GSI values.

Macroscopic gonad staging

Generally, there was little sign of reproductive activity at any time of the year in pearl perch from northern NSW. Mature female pearl perch remained in stage 2 of ovarian development (resting) throughout the year. A small number of immature females were collected in October with stage one ovaries. Male pearl perch showed a similar pattern with testes at stage 1 or 2 for most of the year, however males displayed some signs of reproductive activity with 10 – 30% of males collected between December and March having testes at stage 3 (Fig. 8.8). Immature (stage 1) testes were present in males collected from March to December, ranging from 17% in December to 56% in June. No male pearl perch were collected in July, August or November and all fish in May had been gutted prior to marketing with only one able to be sexed using remnant gonadal material (stage could not be determined).

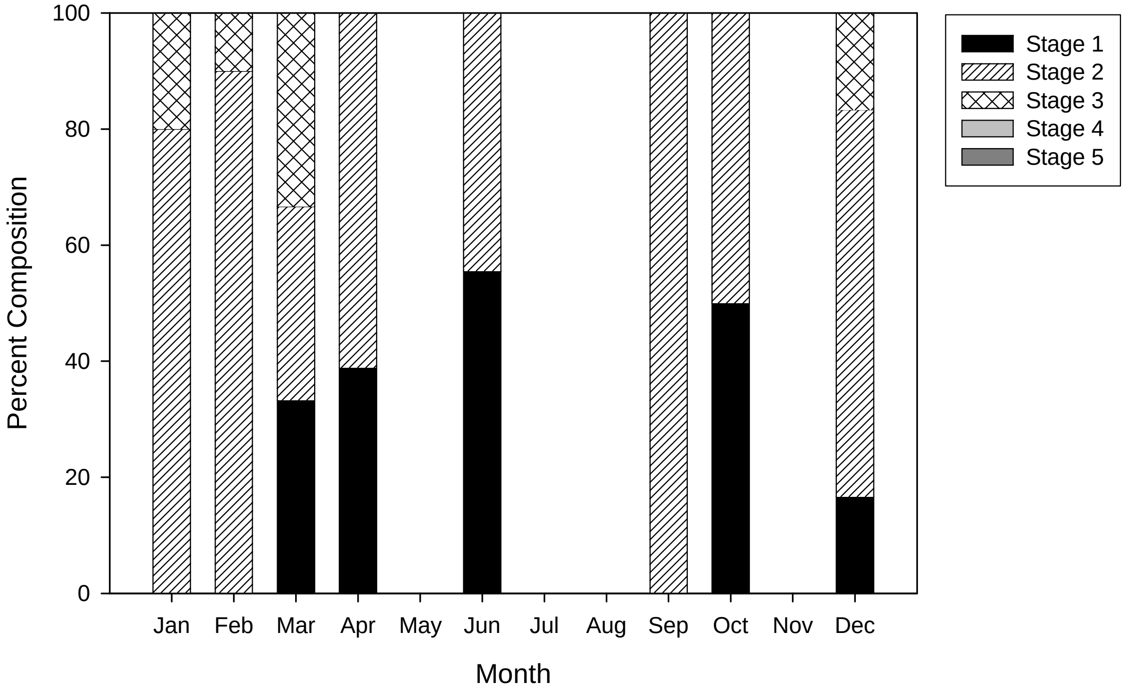


Figure 8.8. Monthly gonad stages for male pearl perch (n = 64).

8.3.2.2. Size at maturity

Pearl perch females mature between 21 and 25 cm FL, with 50% mature at 21.62 ± 0.75 cm FL (Fig 8.9). Male pearl perch mature between 25 and 35 cm FL, with 50% mature at 25.27 ± 1.76 cm FL. Because of the lack of development in female fish we used male maturity as the best estimate of maturity in pearl perch. This was similar to estimates of size at maturity for both female and male pearl perch from Queensland (Sumpton, pers. comm.).

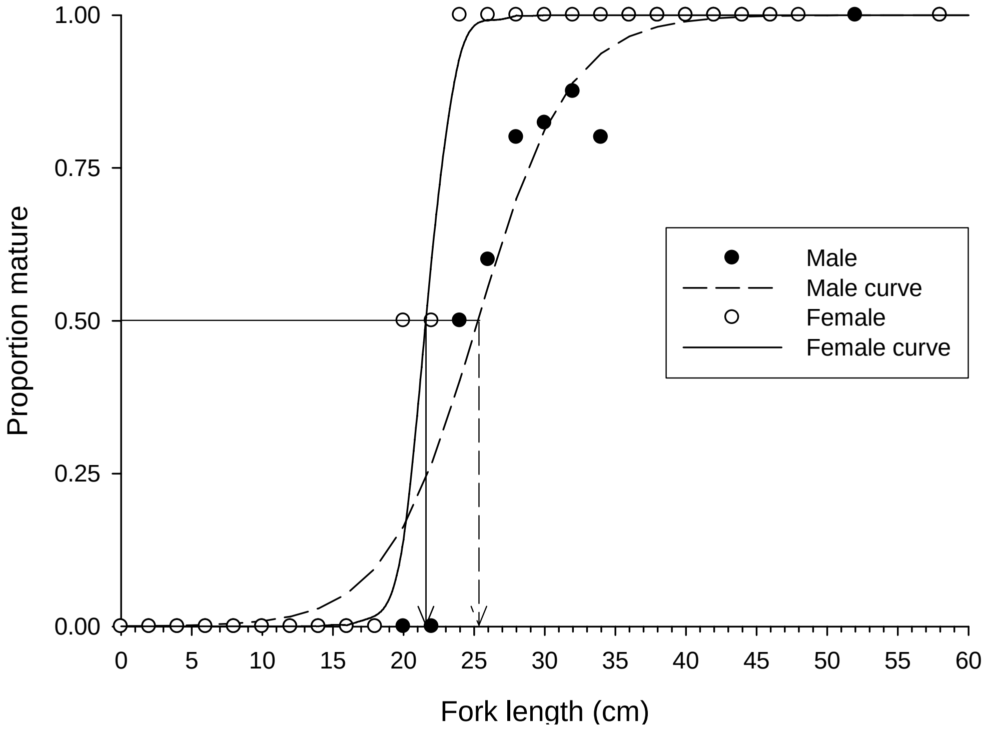


Figure 8.9. Reproductive maturity data with fitted logistic curves for pearl perch. The arrow indicates the size at 50% maturity.

8.3.2.3. Sex ratio

Of the 240 pearl perch sampled from commercial catches during this study, sex was able to be determined for 172, of which 27 were juveniles. The number of female pearl perch in the commercial catches was greater than the number of males (81 and 64 respectively), with an overall ratio of female to male fish of 1.27:1 which was significantly different to a 1:1 ratio ($\chi^2 = 23.14$, $p < 0.001$). Few specimens were collected in May, Jul-Sep and Nov (one to two fish only). For the remaining months sex ratio (female:male) ranged from 0.3:1 in February to 4:1 in October but, there was no obvious pattern in sex ratio (Fig. 8.10).

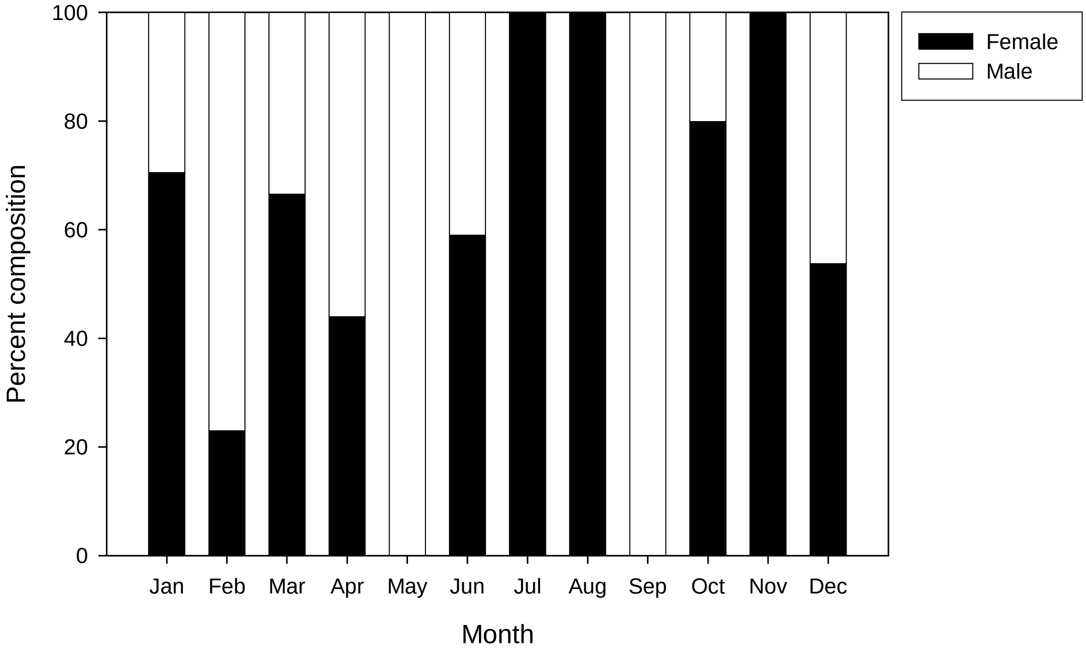


Figure 8.10. Ratios of male and female pearl perch in monthly samples. No males were collected in July, August or November, and no females were collected in May or September. (n = 145).

8.3.3. Age and growth

8.3.3.1. Ageing procedure and validation

Appearance of pearl perch otoliths

Pearl perch otoliths were relatively difficult to interpret due to the broad and diffuse nature of banding in the opaque zones and the subtle translucent marks between them (Figs. 8.11 & 8.12). The translucent regions were often more apparent on the narrow, ventral side of the sulcus and this proved to be the greatest aid in interpretation. Physical structures in the otoliths also aided in reading, including small indentations along the dorsal margin of the otolith corresponding to the translucent marks.

The otolith core was always a largely opaque region, but was followed by two to three translucent zones (the last being the most distinct) that were not considered as annuli because they were present in the otoliths of small fish (9 – 10 cm FL) that were thought to be approximately one year old (see below). Following this region there was usually a narrow opaque zone followed by a more definite translucent zone. This was counted as the first annulus since it was the first that could be easily identified on the ventral side of the sulcus, could be followed throughout the otolith section and corresponded to an indentation on the dorsal margin of the otolith. Subsequent opaque zones became progressively finer and closer together the further out from the core they occurred. The maximum number of opaque zones counted was 10.

Otolith sections from three small fish (9 – 12 cm FL) were used to validate our interpretation of the first annulus by counting daily growth rings. Once sectioned and polished down to a thickness of about 100 µm daily rings were observed in all three sections and were able to be counted along the dorsal margin of the sulcus except for the innermost portion of the core and the outermost edge. These counts ranged from 250 to 300 and, when daily rings that could not be observed were taken into account (assuming these were of similar width to those counted), these fish were about a year old (Figure 8.13). The distance from the core of these small otoliths to their edge was also similar to that measured from the core of larger otoliths to the first annular mark, thus confirming that the first annulus was being correctly interpreted in the sections of larger specimens.

Further evidence that 9 – 12 cm pearl perch were just under one year old was obtained from records of experimental prawn trawl surveys conducted by the FRV *Kapala* in northern NSW during the early to mid 1990s. These trawl surveys were done on prawn grounds about 1.4 nm east of the Clarence and Brunswick Rivers in depths of 30 – 45 m. Length frequency data indicate that pearl perch begin recruiting to the population at about 4 – 7 cm FL during the second quarter of the year (April to June)(Fig. 8.14), an observation which is consistent with a summer spawning period in Queensland (Sumpton, pers. comm.) and a larval period similar to other glaucosomatids of around 40 days (Pironet & Neira, 1998). These 0+ recruits grow throughout the year to attain a size of around 9 – 12 cm by the following Summer (Jan-Mar) and were the only cohort present in *Kapala* samples from this period. At this point they may move into the adult habitat (deep rocky reefs) and are no longer taken by prawn trawlers.

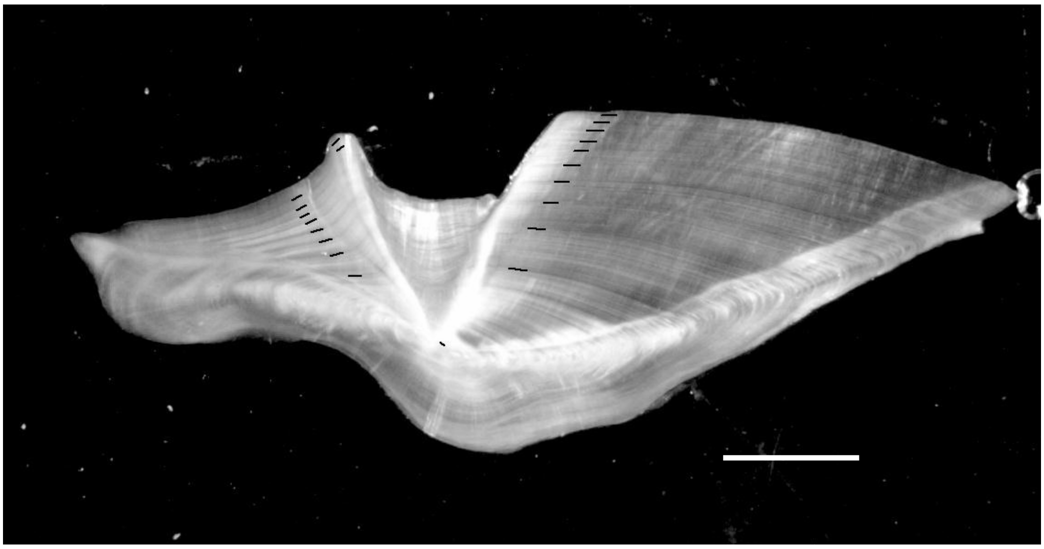


Figure 8.11. Pearl perch otolith with high readability: age 10 years. Scale bar is 2 mm.

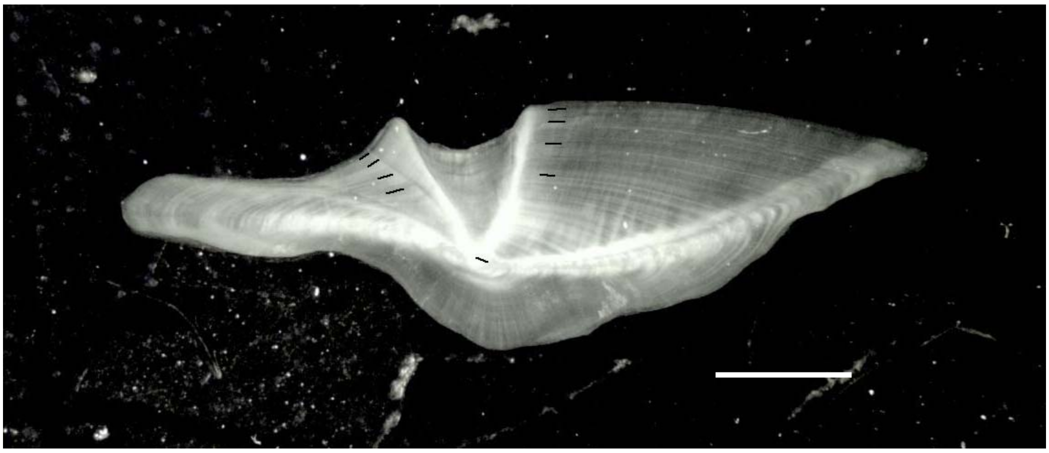


Figure 8.12. Pearl perch otolith with typical readability: age 4 years. Scale bar is 2 mm.

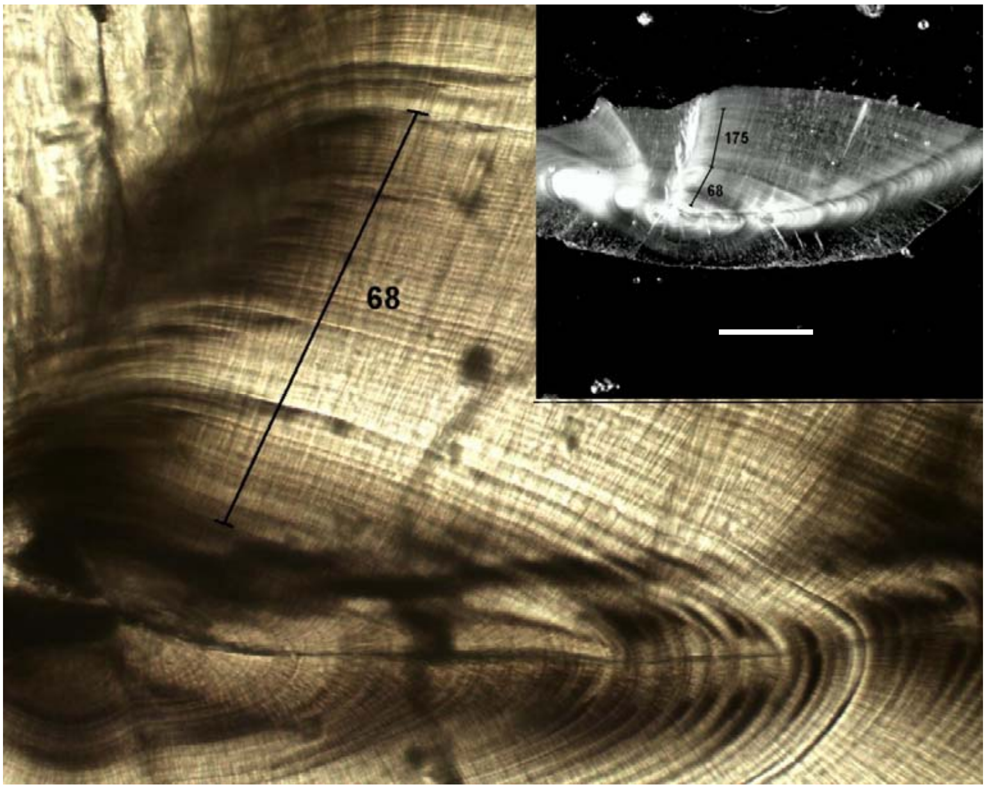


Figure 8.13. Pearl perch otolith from a 10.4 cm FL juvenile showing daily growth rings under transmitted light. Inset shows most of the section under reflected light. Scale bar is 1 mm.

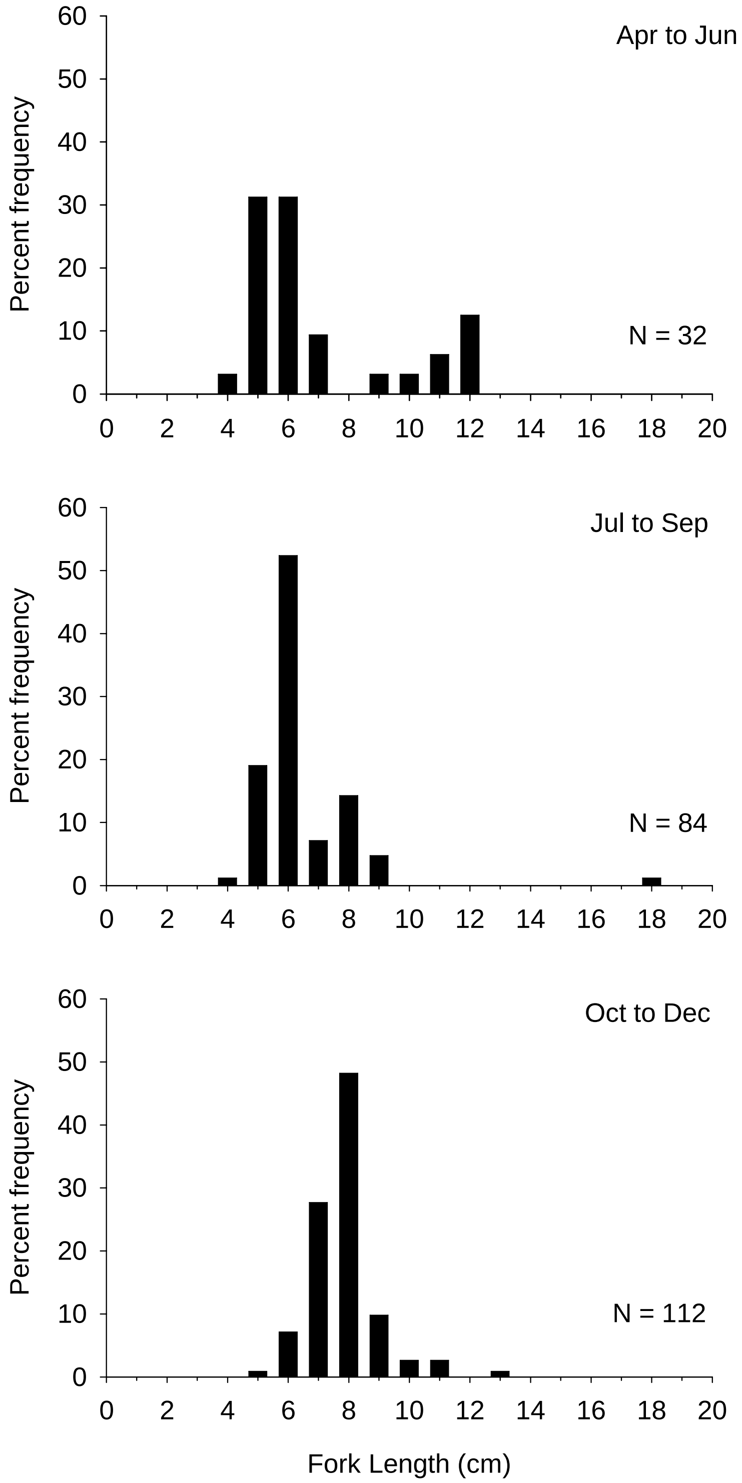


Figure 8.14. The length frequency of pearl perch captured by the FRV *Kapala* for each yearly quarter.

Marginal increment analyses

The monthly marginal increments for pearl perch showed considerable variation each month (Fig. 8.15). There was no obvious pattern that confirmed annual periodicity of opaque zone formation. However, this was thought to be due to the diffuse nature of the opaque zones and the difficulty in identifying opaque zones near the otolith edge. A pattern that was consistent with annual periodicity was identified when lines were drawn that separated otoliths that were thought to have had opaque zones scored near the otolith edge from those that did not.

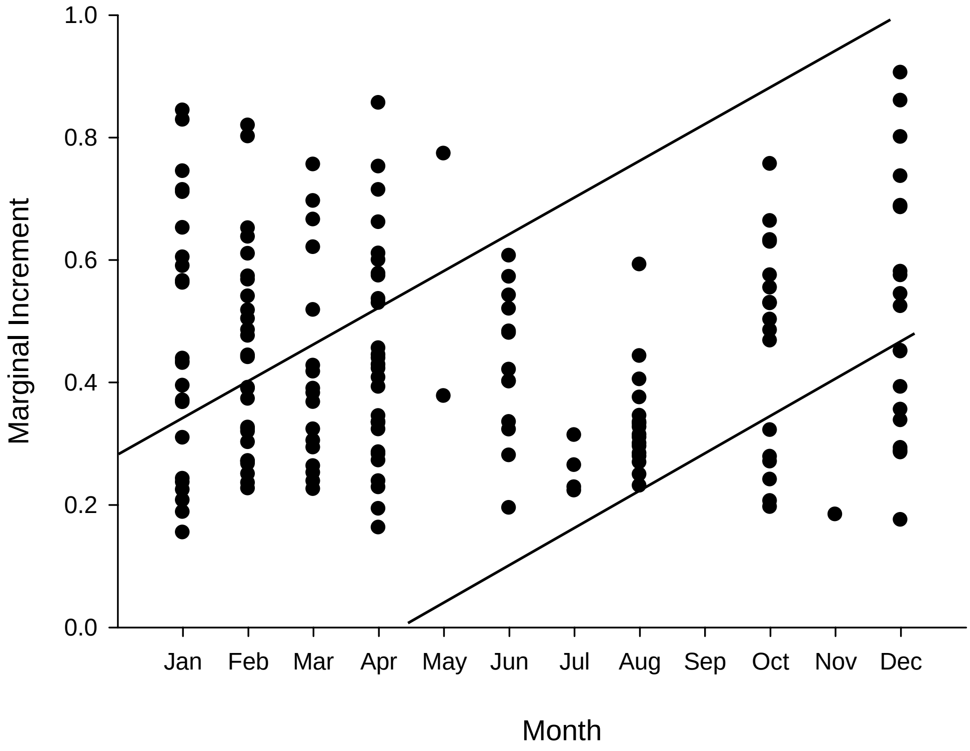


Figure 8.15. Marginal increment plot for pearl perch < 40 cm FL (*n* = 169).

Development of ageing protocol

Opaque zones in otoliths were counted, and the fish placed into an age class according to opaque zone count only. Assigning a birthdate for pearl perch from this study was difficult since no reproductively active female pearl perch were collected. However a universal birthday was set at 15th February, which was the middle of the period during which female GSI was highest (December to April) and the middle of the reproductive period for Queensland pearl perch (Sumpton pers. comm.). The number of days from this universal birthday to the date of capture (as a proportion of a year) was then added to give the final age in years.

The coefficient of variation between the first two counts of the first reader was 7.7% with 61% of otoliths assigned the same age and 34% differing by one. The coefficient of variation between the two readers for the sub-sample was 9.7%, with 63% of fish assigned the same age and 26% differing by one. In most cases the differences in age were related to variation in edge interpretation by the two readers i.e., whether a translucent zone was marked on the edge or not.

8.3.3.2. Growth model

The growth curves for male and female pearl perch were not significantly different (ARSS, $F_{(3, 121)} = 0.8785$, $p > 0.05$) and the data were therefore pooled for each sex and growth described by the von Bertalanffy parameters L_∞, K and t_0 (Fig. 8.16). Pearl perch grew slowly (K = 0.11), and reached (on average) 10.8 cm FL after 1 year, and 29.3 cm FL after 4 years. The two oldest fish collected had estimated ages of 9.15 and 10.3 years (61.4 and 61.6 cm FL respectively) but sex was not determined for these fish. Of fish that had their sex determined the oldest male and female were 9.6 years old (59.3 cm FL; 3rd oldest) and 7.3 years old (57.8 cm FL; 5th oldest) respectively.

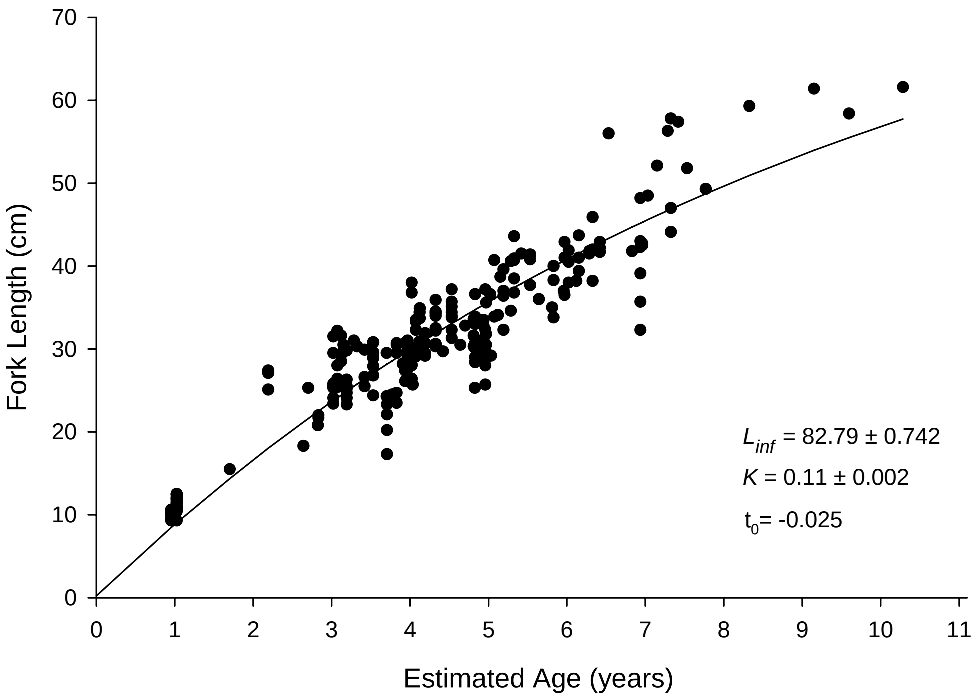


Figure 8.16. Size at age data with fitted von Bertalanffy growth curve for male and female pearl perch combined (n = 236).

8.3.3.3. Age composition of landed catch

The age composition of the commercial catch was estimated using the age-length key derived during the study (Table 8.1) and the length frequency data from Fig. 8.2. Pearl perch are fully recruited to the fishery at four years of age and the fishery is dominated by fish aged between three and six years old (> 90 % of catch) (Fig. 8.17).

Table 8.1. Age length key for pearl perch aged during this study.

Fork Length Class (cm)	Age											
	0	1	2	3	4	5	6	7	8	9	10	Total
9	5	1										6
10	5	3										8
11		6										6
12		5										5
13												0
14												0
15		1										1
16												0
17				1								1
18			1									1
19												0
20			1	1								2
21			1									1
22			1	1								2
23				4								4
24				7								7
25			2	7	3							12
26				6	2							8
27			2	4								6
28				6	5							11
29				10	11	1						22
30				8	14							22
31				4	6							10
32				1	7	1	1					10
33					9	2						11
34					7	2	1					10
35					4	1	1					6
36					2	5						7
37					2	3						5
38					1	3	3					7
39						1	2					3
40						6	1					7
41						3	6					9
42						1	6	1				8
43						1	2					3
44								1				1
45							1					1
46												0
47								1				1
48							1	1				2
49									1			1
50												0
51								1				1
52								1				1
53												0
54												0
55												0
56							1	1				2
57								2				2
58												0
59										1		1
60												0
61										1	1	2
62												0
n	10	16	8	60	73	30	26	9	1	2	1	236

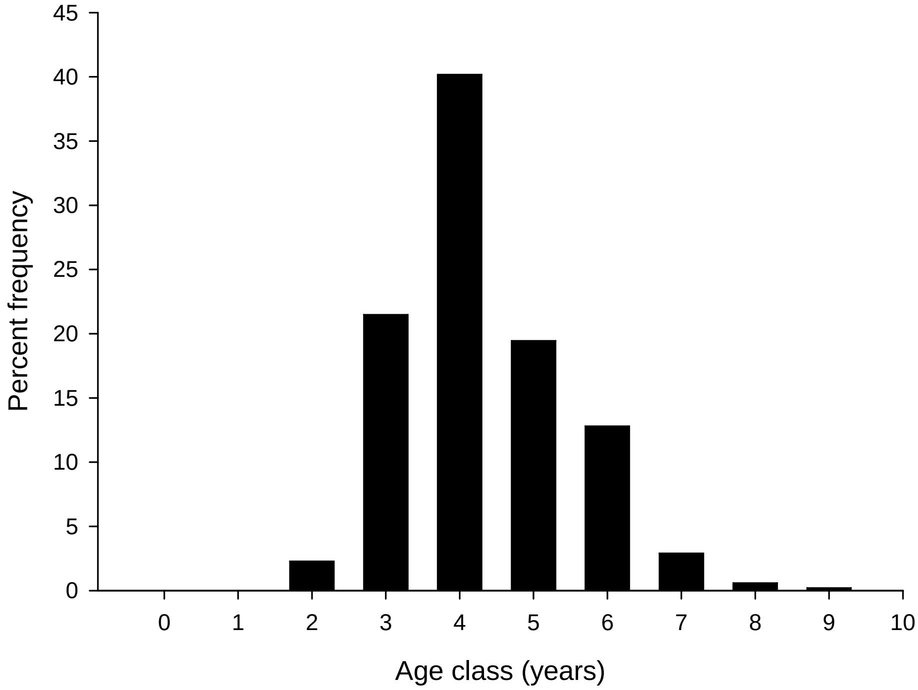


Figure 8.17. Age composition of pearl perch in commercial landings.

8.3.4. Mortality estimates

The estimate of total mortality (Z) made from the catch curve for pearl perch, fitted between ages four and 10, was 1.16 (Fig. 8.18). A second estimate was made between ages 4 and 7 because we sampled low numbers of fish aged between 8 and 10 (see Table 8.1) which may have biased the catch curve. This second estimate produced an estimate of Z = 0.83.

Figure 8.18. Catch curve for pearl perch.

An estimate of natural mortality was then made using the method of Hoenig (1983). Due to the short nature of the study and the fact that pearl perch are likely to attain greater ages than observed here, based on a reported maximum size of 70 cm (Hutchins & Swainston, 1986), a weight of up to 7.3 kg (McKay 1997) and age estimates of 14 years for pearl perch sampled in Queensland (Sumpton, pers. comm.), we applied the model that 5% of fish were likely to attain the maximum age observed in this study of 10 years, while 1% of fish attain 14 years. The best estimate of M was therefore 0.33 (ln(0.01)/14). This resulted in a fishing mortality of between ~ 0.50 and 0.83 depending on which estimate of Z is used.

In addition to M being estimated from the catch curve it was also estimated using the equation of Pauly (1980) relating mortality to the von Bertalanffy growth curve parameters L_{∞} & K, and mean water temperature. The mean surface water temperatures for Coffs Harbour (Lat. 30°S), where most fish were sampled, is 26°C and 20°C in summer and winter respectively. At a depth of 100 m the mean water temperature at Coffs Harbour is about 21°C with a minimum and maximum of 20 and 23°C respectively (http://www.marine.csiro.au/~dunn/cars2006). These temperatures produce estimates of M ranging between 0.28 (20°C) and 0.31 (26°C), with a mean of 0.30 (23°C).

8.3.5. *Market price*

Pearl perch sold through the Sydney Fish Markets are graded according to the following schedule:

Small	< 35 cm
Medium	35 to 40 cm
Large	40 to 45 cm

Average prices for pearl perch sold through the Sydney Fish Markets during 2005/06 indicate that larger fish attain higher prices per kg than the smaller size grades (Fig. 8.19). The “Large” grade of pearl perch received, on average, $8.43/kg.

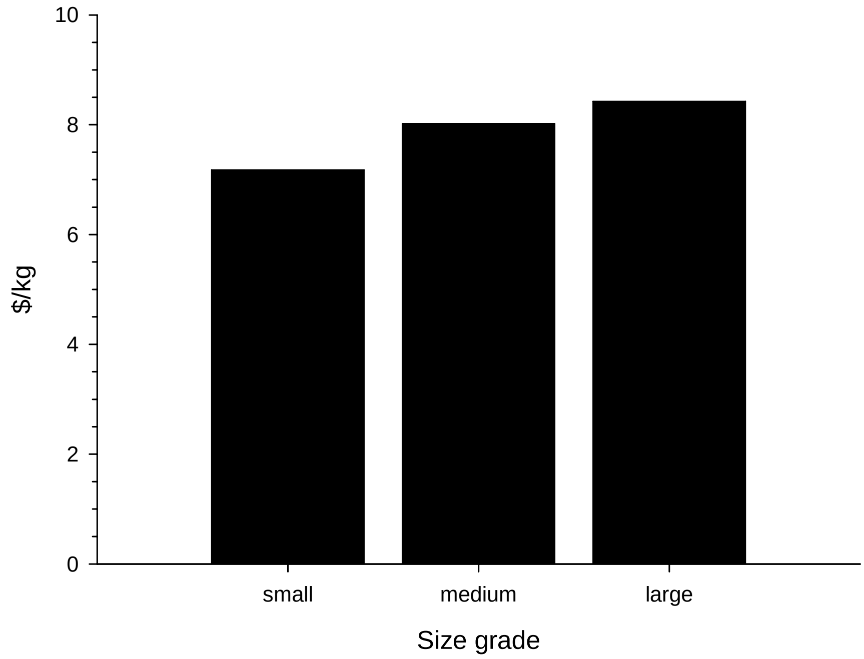


Figure 8.19. Average price information by size grade of pearl perch sold through the Sydney Fish Markets 2005/06.

8.3.6. *Per recruit analyses*

Per recruit analyses were done using market price information and size grades as described above, and the following parameters:

L_∞ = 82.8 cm
K = 0.114 yr^{-1}
T_0 = -0.025 yr
Z = 1.16
M = 0.33
F = Z-M = 0.83
E = F/Z = 0.72
M/K = 2.89

Where L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation, yield per recruit is maximised at ~ 37 cm FL (~ 39 cm TL) and $ per recruit is maximised at ~ 41 cm FL (~ 43 cm TL) (Fig. 8.20). YPR as a function of fishing mortality at different sizes at first harvest show that under the current size at first harvest of approximately 25 cm FL that pearl perch are growth overfished (Fig 8.21).

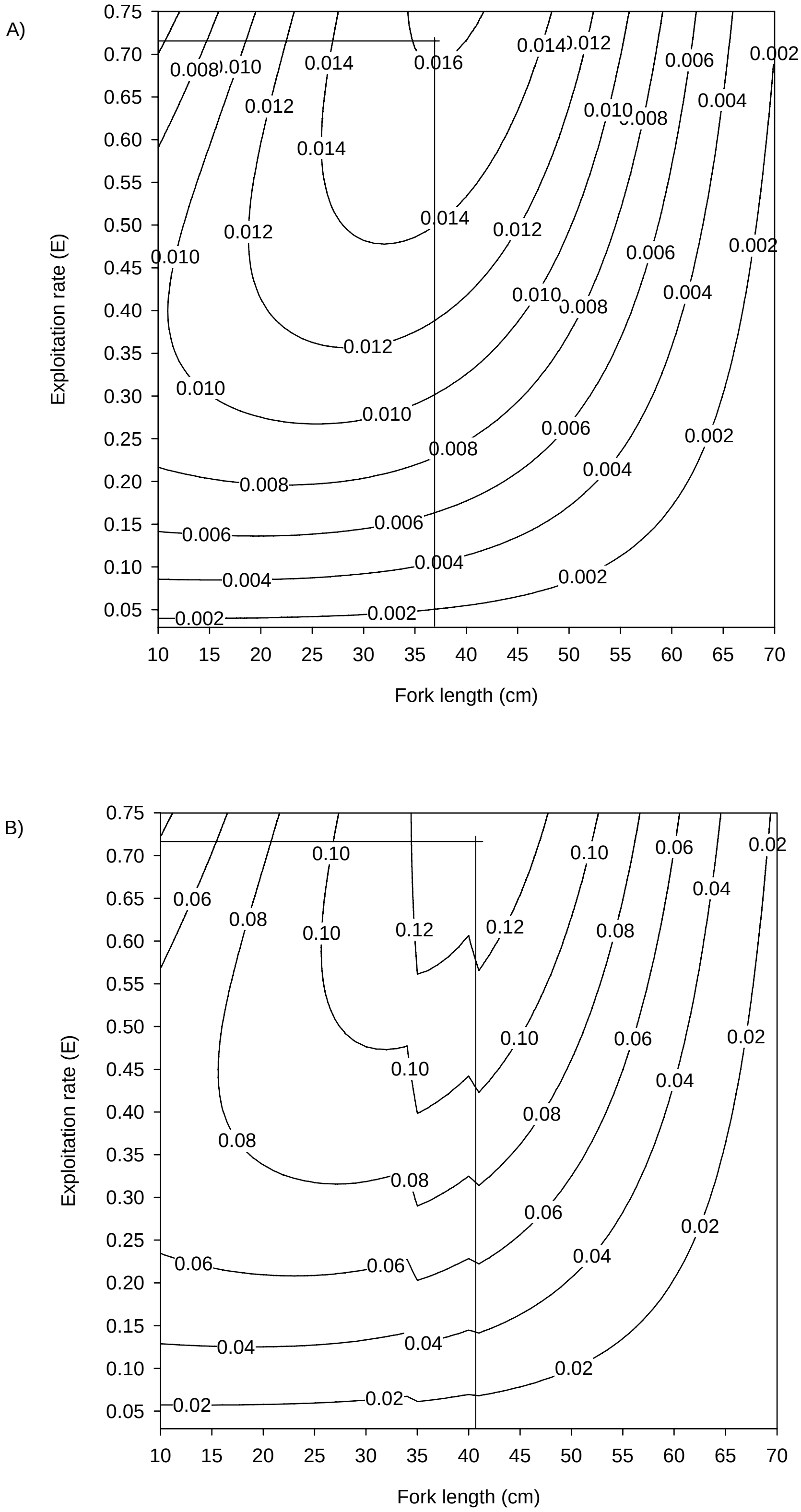


Figure 8.20. Yield and $ per recruit isopleths for pearl perch. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

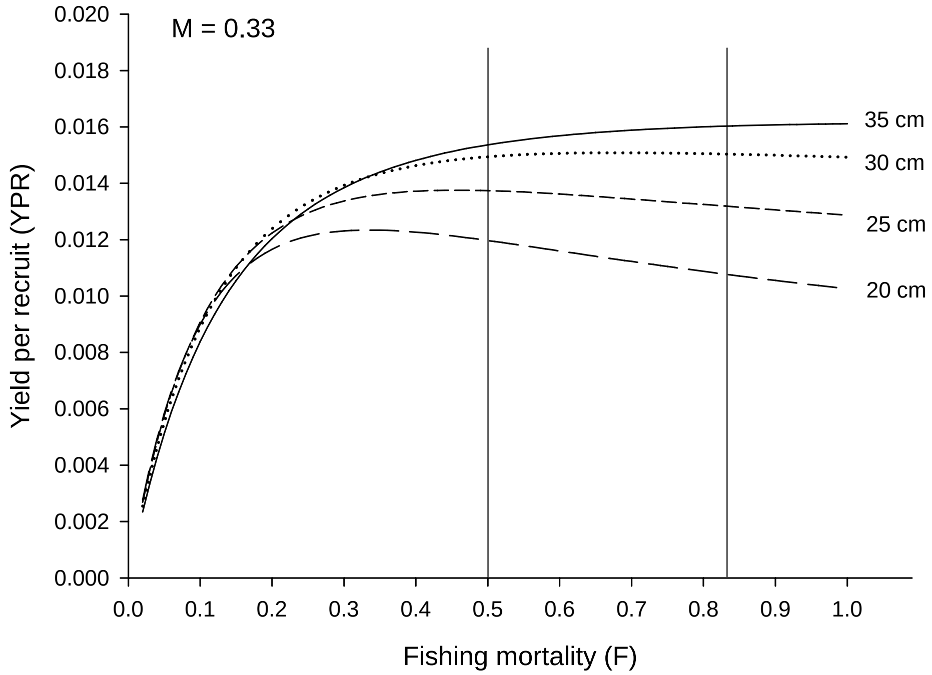


Figure 8.21. YPR plotted against fishing mortality for different sizes (FL) at first capture, and a natural mortality rate of M = 0.33. The vertical lines represent estimates of current fishing mortality.

8.3.7. *Spawning potential ratio*

The smallest pearl perch in landings are ~ 25 cm FL and this size at first harvest corresponds to a SPR of ~ 0.21, close to the threshold level of 0.2 (Fig. 8.22). Therefore first harvesting pearl perch at ~ 25 cm FL, under current levels of exploitation, may be putting the species at risk of recruitment overfishing. A proposal to implement a MLL of 30 cm TL (~ 29 cm FL) should increase the SPR above the threshold level.

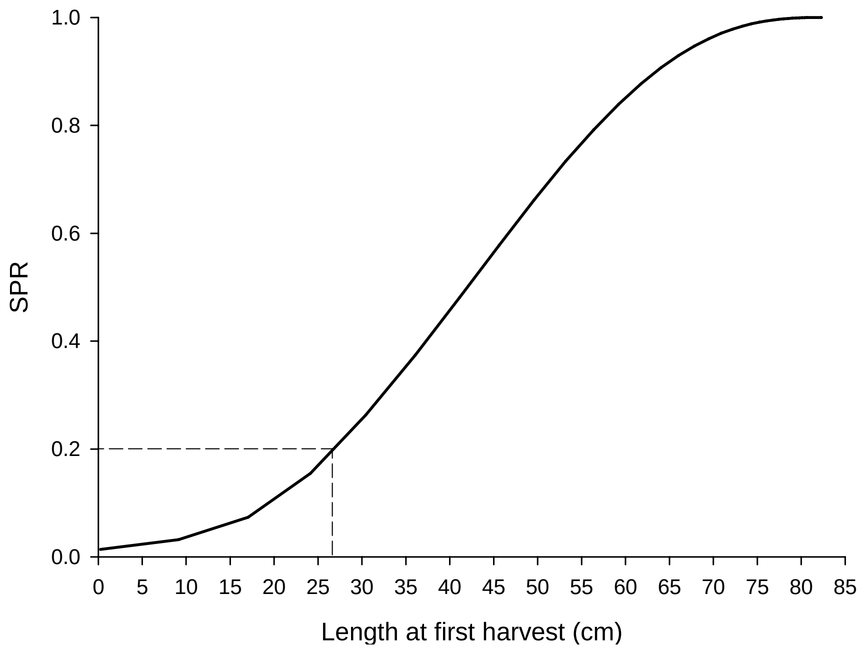


Figure 8.22. Spawning potential ratio (SPR) for pearl perch at current levels of exploitation for a range of sizes at first harvest. The dashed lines indicate the length at first harvest at the threshold level of 0.2.

8.3.8. *Information fact sheet*

Relevant material from this chapter was collated into an information fact sheet for pearl perch (Fig. 8.23). The information was presented as total lengths.

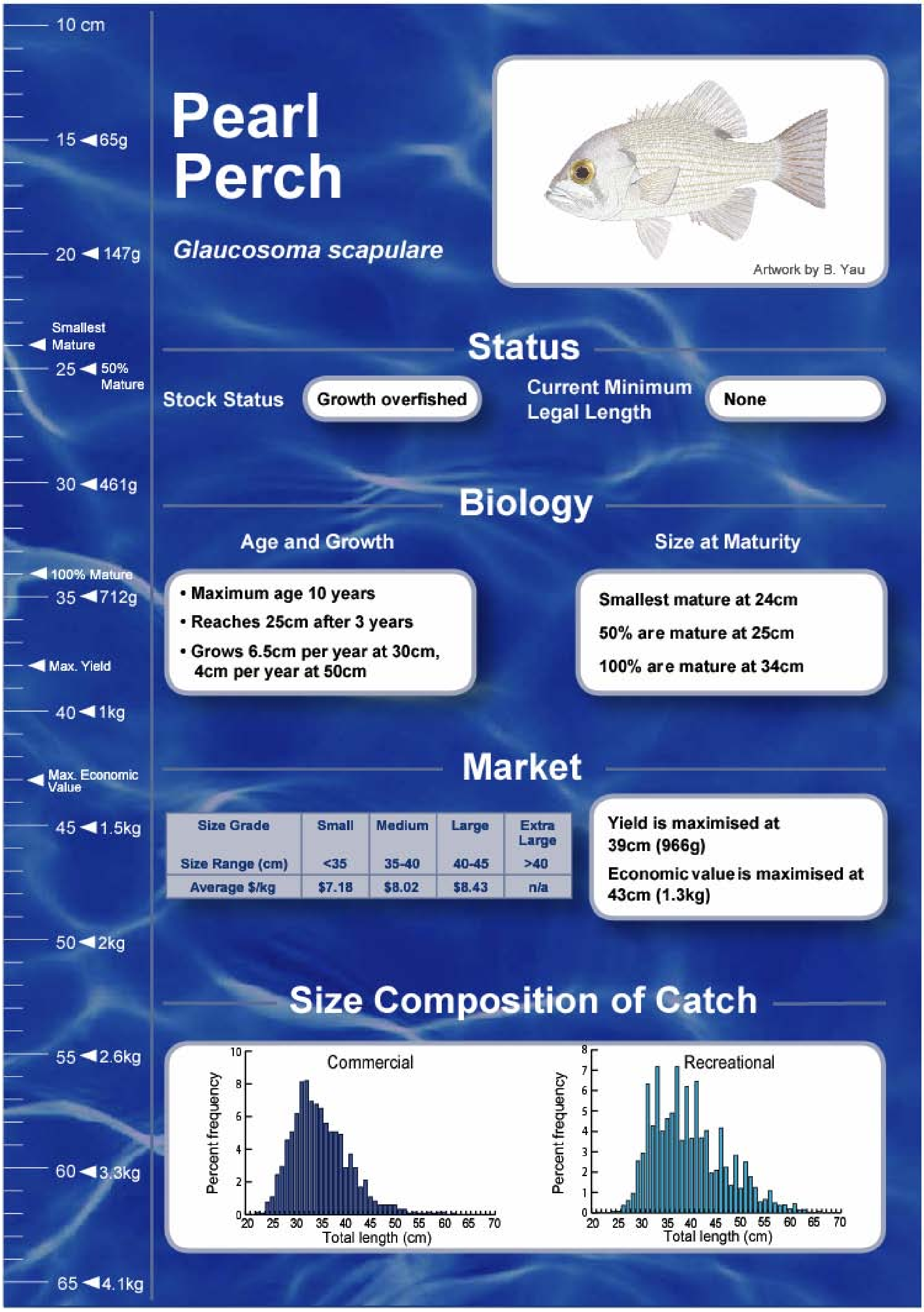


Figure 8.23. Information fact sheet for pearl perch.

8.4. Discussion

This study has provided the first detailed examination of the biology and fishery for pearl perch. The distribution of pearl perch into northern NSW represents the southernmost extent of this species range (Rockhampton QLD to Coffs Harbour NSW) although there is anecdotal evidence that they are being taken with increasing frequency further to the south (pers. obs.). The somewhat limited distribution of pearl perch in NSW has meant that relatively low numbers are caught in the northern region of NSW by commercial operators in the ocean trap and line fishery, and by offshore recreational line and spear fishers. Estimates of recreational catches from the early 1990s (Steffe *et al.*, 1996) and current information of charter boat catches indicate that the combined recreational harvest of pearl perch is at least equal to, if not greater than, the current commercial harvest. Although it is prized as a food fish these low catch rates have meant that the only management options currently in place for this species is a recreational bag limit of five fish.

Pearl perch is relatively heavily fished in southern Queensland with a fishing mortality (F) about three times natural mortality (M). A MLL of 30 cm TL for pearl perch was introduced in the Queensland commercial and recreational sectors in 1993 which saw a reduction in the instantaneous rate of mortality (Z) from about 1.51 to 1.15 (Sumpton, pers. comm.). Taking a maximum age of 14 years (Sumpton, pers. comm.) and a corresponding M of 0.33, these changes in MLL would have reduced F from about 1.18 to 0.82. Following these changes CPUE dropped in 1994 before increasing to an all time high in 1995 and 1996. This could be attributed to an increase in YPR resulting from growth of the previously exploited sub-30 cm size class fish (Sumpton, pers. comm.). With concern expressed about the long term sustainability of rocky reef stocks the MLL was further increased in 2002 for both pearl perch and snapper to 35 cm TL and possession limits decreased to five fish for each of these species. There is currently no information available on how this most recent increase in MLL for pearl perch has affected fishing mortality of pearl perch in the Queensland rocky reef fishery.

Although the fishery for pearl perch in NSW is much smaller than that in Queensland, the structure of the fishery is similar. The commercial catch is comprised mostly of fish between 25 and 40 cm FL representing 85% of fish landed. The lengths of pearl perch landed by the recreational sector are greater than the commercial sector with most fish between 30 and 45 cm FL (70%) or greater. Based on the age length key developed in this study the general size range of the commercial catch encompassed fish with ages of two to seven years; however three and four year old fish dominate the catch (~ 65%).

Both commercial and recreational catches in NSW have a substantial proportion of fish below 30 cm FL, about 25% of the commercial catch and 12% of the recreational catch. With 50% maturity not attained until around 25 cm FL this implies that both fisheries are taking some fish that have not matured. Fishers in the OTL fishery often discard small pearl perch (Stewart & Ferrell 2003), and the charter boat fishery frequently discards fish less than 30 cm TL. The closely related dhufish (*G. hebraicum*) is highly susceptible to barotrauma with related injuries increasing in frequency and severity with depth of capture, and post capture mortality ranging from 50% at 30 – 44 m to 80% at 45 – 59 m. (St John & Syers 2005). Rates of discard mortality are unknown for pearl perch; however the observation that CPUE increased to its highest levels after the 30 cm MLL was introduced in Queensland, and the suggestion that this allowed the sub-30 cm size class time for additional growth thus increasing YPR (Sumpton, pers. comm.), suggests that discard mortality may not be excessively high. There is a clear need for further research into the discard mortality rates of pearl perch.

Estimates of total mortality derived from the commercial catch curve are relatively high for pearl perch (Z = 1.16) and result in an estimate of fishing mortality (F = 0.83) more than twice natural mortality (M = 0.33). The value of M can have a significant impact on analyses based around mortality rates so two methods of estimating M were used, both provide similar values (0.33 and 0.30). Although fish are not fully recruited to the fishery until they reach the 4+ age class, the 3+ age class also contributes a significant proportion of the commercial catch (about 20%). At this age fish are between 18 and 30 cm FL and as such may well have not reached maturity. This study and data from Queensland indicates that while pearl perch may begin to mature at around 20 cm they are not fully mature until at least 35 cm FL. Rates of mortality derived from data on Queensland pearl perch samples are very similar to those from this study. The total rate of mortality (Z) in the Queensland fishery was 1.51 prior to the introduction of a MLL and then dropped to 1.15 following the application of a MLL of 30 cm (TL) in 1995. These rates of mortality prior to the introduction of a MLL suggest that fishing pressure in Queensland was greater than it currently is in NSW (1.16) because natural mortality (M) was calculated from the maximum age observed in Queensland pearl perch and was thus the same for both sets of data. The observed drop in Z following the introduction of a 30 cm TL MLL indicates that introducing a similar MLL in NSW may also help in reducing fishing mortality.

Growth in pearl perch appears to be moderately fast, but seems to lack the very rapid growth phase during the first few years of life typical of many temperate reef associated species. However this may be the result of sampling a low number of fish in the 1 – 2 year age groups. Pearl perch less than about 12 cm FL were available as by-catch from prawn trawlers but once fish attain this size they are no longer taken by trawlers, as indicated by the length frequency data from the *Kapala* prawn trawl surveys. Conversely, very few fish obtained from the trap and line fishery were less than about 23 cm FL which suggest that fish smaller than this are discarded or that they are not captured by the fishing methods used.

Per recruit analyses indicate that the yield per recruit for pearl perch at current levels of exploitation is maximised at 37 cm FL (~ 39 cm TL). Pearl perch are a relatively highly priced fish and their value sold through the Sydney Fish Markets varies only slightly with size grade, with “Large” fish fetching ~ 14% more per kg than “Small” fish. The $ per recruit analysis shows the influence of the relatively higher prices per kg attained by “Large” fish with a maximum $ per recruit being attained at ~ 41 cm FL (~ 43 cm TL). Conclusions from these per recruit analyses are that: (i) current yield per recruit could be increased by decreasing fishing mortality; and (ii) increases in both YPR and $PR could be achieved by increasing the size/age at first capture. Both of these conclusions are clearly shown in the plot of YPR against fishing mortality for different sizes at first capture. Given that some commercial fishers already observe a minimum size when harvesting pearl perch and the fact that recreational fishers generally discard small fish, the introduction of a MLL may be an astute management option. In addition to increasing YPR, a substantial increase in egg production and therefore SPR is also likely to result from an increase in size at capture.

The results of this study show only low levels of reproductive activity in pearl perch from northern NSW. For female pearl perch collected in Queensland GSI peaks in summer and, while variable throughout the year, histological sections of ovaries showed that most ripe females were sampled between October and March (Sumpton, pers. comm.). The commercial catch of pearl perch in NSW sampled for this study was greatest over this period, with over 70% of fish collected between December and April. Despite this sampling there was little sign of reproductive activity in any of the 82 mature female pearl perch collected. The GSI for females was almost constant throughout the year and ovarian development did not progress beyond stage 2. Comparing female GSI from this study with data available for pearl perch sampled in Queensland shows that GSI levels attained through the summer months, were substantially lower than that reported in the Queensland study. Male GSI was also relatively constant throughout the year but, as with females, reached its highest levels in summer (December/January). However unlike females, males appear to attain a slightly higher level of maturity with a small number of mature testes (10% of all mature males) reaching stage 3 of development between December to March. Fecundity was not determined in this study, however fish collected in Queensland have a relatively low fecundity compared to similar species such as snapper (Sumpton, pers. comm.).

Coffs Harbour (northern NSW) where most of the samples for this study were collected is close to the southern most distribution of pearl perch in Australia. Given that data on pearl perch collected in Queensland suggest that spawning occurs in summer it is possible that environmental conditions in northern NSW are not suitable for reproduction in pearl perch. The two main environmental cues for reproduction in fishes are photoperiod and temperature (Bye 1990) and while photoperiod is not appreciably different across the distributional range of pearl perch, temperature does vary substantially.

The estimate of the size at maturity for female pearl perch in NSW was smaller than those calculated for male and female pearl perch collected in Queensland, 25 and 30 cm FL respectively (Sumpton, pers. comm.). The smallest female thought to be mature in our study was 19 cm FL and the logistic curve estimated a 50% maturity at 22 cm FL and 100% maturity by 23 cm. In contrast, the first mature male pearl perch collected was 20 cm FL with 50% maturity reached at a little over 25 cm, and 100% maturity at 34 cm FL. These low estimates for female size at maturity may be at least partly the result of classifying females with stage 2 ovaries as mature. Typically these fish would be considered to be juveniles developing for their first spawning, or mature fish at a resting stage following reproduction, and would not be considered to be mature at stage 2 during the spawning season. However because no females were collected that had ovaries beyond this level of development it was decided to classify these fish as mature, since the alternative would be to classify all female fish as immature. For the purposes of applying maturity estimates to pearl perch from NSW waters the male estimate was used since males showed slightly greater reproductive development and the estimate was similar to maturity estimates for fish from Queensland.

Ageing pearl perch was relatively difficult given the diffuse nature of the opaque zones in the otolith. The marginal increment data was inconclusive regarding the annual periodicity of opaque zone formation however the analysis of daily rings and length frequency data from the *Kapala* prawn trawls increased certainty in identifying the first "annual" mark. Subsequent opaque zones and the translucent breaks between them could then be marked with certainty.

Two other glaucosomatids are exploited by fisheries in Australia. In Western Australia the dhufish (*G. hebraicum*) is the most commercially valuable fin fish in the state (~ 250 tonnes a year), and is highly sought by the recreational sector (Hesp *et al.*, 2001). The dhufish occupies similar habitat to pearl perch but attains a greater length and age (up to 112 cm and 41 years). Current management options for dhufish include a MLL of 50 cm which, with the species reaching 50% maturity by ~ 31 cm, allows 6 – 7 years of spawning before the MLL is reached (Hesp *et al.*, 2001). However dhufish that are released after capture experience high rates of mortality if caught at depths greater than 30 m suggesting that the use of a MLL may be of only limited value in managing this species (Hesp *et al.*, 2001; St John & Syers, 2005). Fishing mortality was estimated to be about half of total mortality and with strong anecdotal evidence of increased fishing effort and declining numbers of dhufish on inshore fishing grounds Hesp *et al.* (2001) urged caution in the management of this fishery.

The northern pearl perch (*G. buergeri*) is distributed along the north coast of Western Australia at depths of 80 – 150 m and is associated with hard substratum and epibenthic communities (Newman, 2002). Around 55 tonnes is caught annually, primarily by the northern trawl fishery but also as an incidental catch in the trap and line fishery (Newman, 2002; Fletcher & Head, 2006). Newman (2002) studied age and growth of northern pearl perch from catches between 1997 and 1999 and found that they reached a maximum age of 26 years and were slow growing, reaching a maximum size of 55 cm. The stock over this period was considered to be relatively unfished and so total instantaneous mortality (Z = 0.14) was considered to be an accurate estimate of natural mortality (Newman 2002). Fish were fully recruited to the fishery by age two (12 – 22 cm TL) and although size at maturity was not determined Newman (2002) suggested that the species was highly vulnerable to capture by the trawl fishery and susceptible to overfishing.

The exploitation status of pearl perch is currently UNDEFINED however the results of this study suggest that they may be GROWTH OVERFISHED. Fishing mortality may be very high at around 2.5 times natural mortality. The fishery depends heavily on relatively young fish, three and four year olds for a species that has a maximum age of 14, with fish greater than six years old rarely taken. There is no information on the size of fish landed by the NSW fishery other than that collected during this study, but over the two years during which data were collected (2005 and 2006) there was little variation in the length and age of fish harvested.

The introduction of a MLL for pearl perch seems to be a prudent management option given the results of this study. Spawning potential ratio, YPR and $PR can be increased by increasing the size at first capture to around 30 cm FL. Reducing fishing mortality would also increase YPR. Post release mortality in pearl perch is not known and if high, as it is in related species, may reduce the effectiveness of a MLL. However the limited data showing a decrease in F with increases in YPR following the introduction of a MLL for pearl perch in Queensland suggests that the overall benefit of a MLL may outweigh any negative effects due to discard mortality. In addition to a MLL the proposed introduction of 50 x 75 mm welded mesh ‘escape panels’ in fish traps in NSW may also help to reduce catch of pearl perch below a length of 24 cm FL (unpublished data). These two measures are likely to achieve a significant decrease in fishing mortality with minimal impact on current fishing activities.

9. BIOLOGY AND FISHERY FOR OCEAN LEATHERJACKET

9.1. Introduction

The ocean leatherjacket *Nelusetta ayraudi* (Quoy and Gaimard, 1824) is a large monocanthid found in deeper offshore waters of southern Australia from southern Queensland on the east coast to North West Cape in Western Australia (Hutchins & Swainston, 1999). Although adults are found up to a depth of 350 m, juveniles seasonally school in estuaries and coastal embayments. Ocean leatherjacket have a long head and slender body (unlike most monocanthids), and are the only leatherjacket in southern Australian waters to commonly reach a size of 70 cm (Gomon *et al.*, 1994). The male is deeper bodied and has a grey colouration, while females and juveniles are yellow/brown and have horizontal stripes.

A study by Lindholm (1984) of demersal fishes of the Great Australian Bight collected adult ocean leatherjackets near the sea floor at all depths across the continental shelf, with fish size increasing with depth. They were often caught in groups of similar sized fish, suggesting that they are a schooling species that probably school in size classes. Unlike most monacanthids the species appears to be carnivorous (Lindstrom, 1984), with the diet of fish collected in the Great Australian Bight consisting of fish (23%), salps (19%), gastropods (14%) and crustaceans (13%).

Ocean leatherjackets are an important commercial and recreational species in NSW. The recreational catch is thought to be lower than the commercial catch but is still substantial. The Ocean Trap and Line Fishery lands ~ 80% of the total commercial catch using demersal fish traps. The ocean trawl fishery accounts for the majority of the remaining 20% of the total catch. Historically the species supported high catch rates in the early years (1918-23) of the south east Australian (primarily NSW) trawl fishery, after which catch rates declined (1937-42) before the species virtually disappeared from catches in later years (1952-57) (Klaer, 2001).

Until recently there had been no studies on the biology or fishery for ocean leatherjackets in NSW. The species has been studied in South Australia (S.A.) (Grove-Jones & Burnell, 1991); however that fishery is very different from the one in NSW. Estimates of reproduction in S.A. are likely to differ from those in NSW and estimates of age by counting bands in vertebrae less accurate than those derived from sectioned otoliths. Ocean leatherjackets have been the subject of a recent project that aimed to describe their fishery and biology in NSW (M. Miller, unpublished data). The aim of this chapter was to collate and re-analyse available information for ocean leatherjackets that could be used to assist in determining the best size at which they should be harvested.

9.2. Materials and methods

The information on age, growth and reproduction provided in this chapter has been sourced from Mr Marcus Miller who is studying ocean leatherjackets as the topic for his MSc thesis at the University of Wollongong. The use of his data is gratefully acknowledged. The remainder of fishery landings information were gathered during the present study and analyses were done as described in Chapter 2.

9.3. Results

9.3.1. Landings in NSW

9.3.1.1. Current exploitation status

Ocean leatherjacket are listed as being FULLY FISHED in NSW (2005/06). They were previously listed as UNDEFINED for 2003/04 and MODERATELY FISHED for 2004/05. The assessment of FULLY FISHED was made now that more biological and fishery information for NSW has been obtained.

9.3.1.2. Trends in catch

Ocean leatherjackets are reported by commercial fishers as both ‘leatherjackets, chinaman’ and ‘leatherjackets, unspecified’. The majority of ‘leatherjackets, unspecified’ are ocean leatherjackets (M. Miller, pers. comm.) and the trends in landings are for both chinaman and unspecified leatherjackets (Fig. 9.1). Landings increased substantially in 2001/02 and CPUE has continued to increase since that time. Historically, landings during the 1950s were generally more than 500 tonnes per year and peaked at ~ 900 tonnes during the early 1950s.

The most recent estimate of the recreational harvest of leatherjackets in NSW was ~ 108 tonnes between April 2000 and March 2001 (Henry & Lyle, 2003). This estimate may have been an underestimate because it assumed an average weight of 0.28 kg per fish retained. The average size in recreational landings is ~ 37 cm and ~ 500 g. Using an average weight of 500 g per fish results in an estimated recreational take of ~ 190 t during 2000/01.

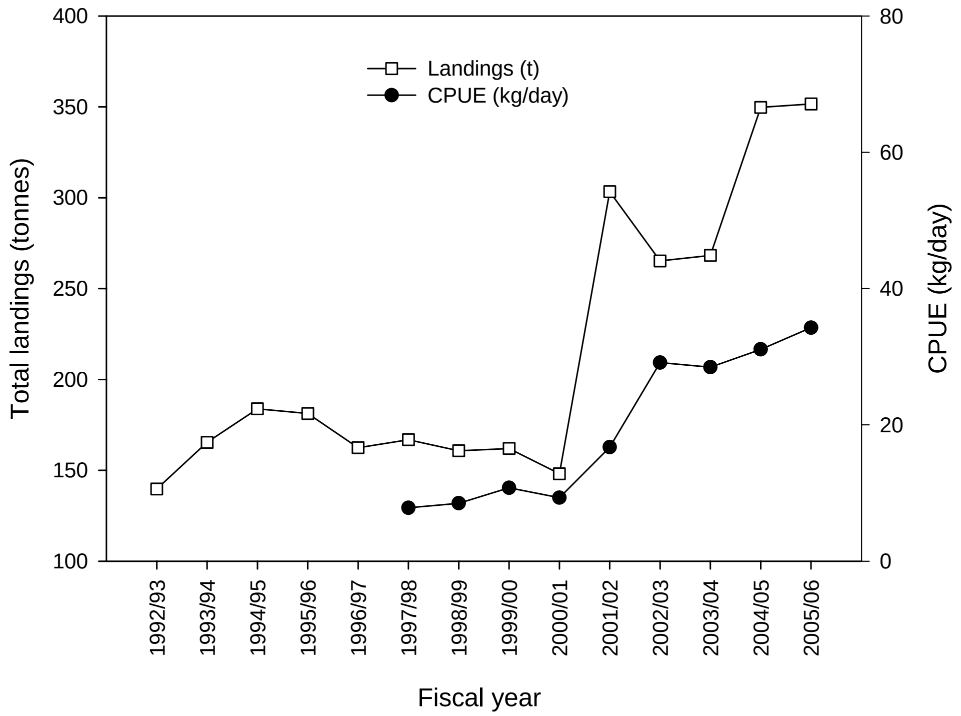


Figure 9.1. Reported commercial landings and catch rates (kg per day fish trapping) of ‘ocean’ and ‘unspecified’ leatherjackets combined in NSW. Source: NSW DPI Resource Assessment System.

9.3.1.3. Length measurements

Commercial landings

The sizes of ocean leatherjackets landed by fish trappers were measured at the Sydney Fish Markets during 2005. A total of 3,791 fish were measured and generally ranged between 25 and 50 cm (Figure 9.2). Data from a previous FRDC funded project indicated that ocean leatherjackets caught by fish trapping are rarely discarded (Stewart & Ferrell, 2001). This same study also reported that the size at 50% retention for ocean leatherjackets in fish traps covered with 50 mm hexagonal mesh was ~ 25 cm.

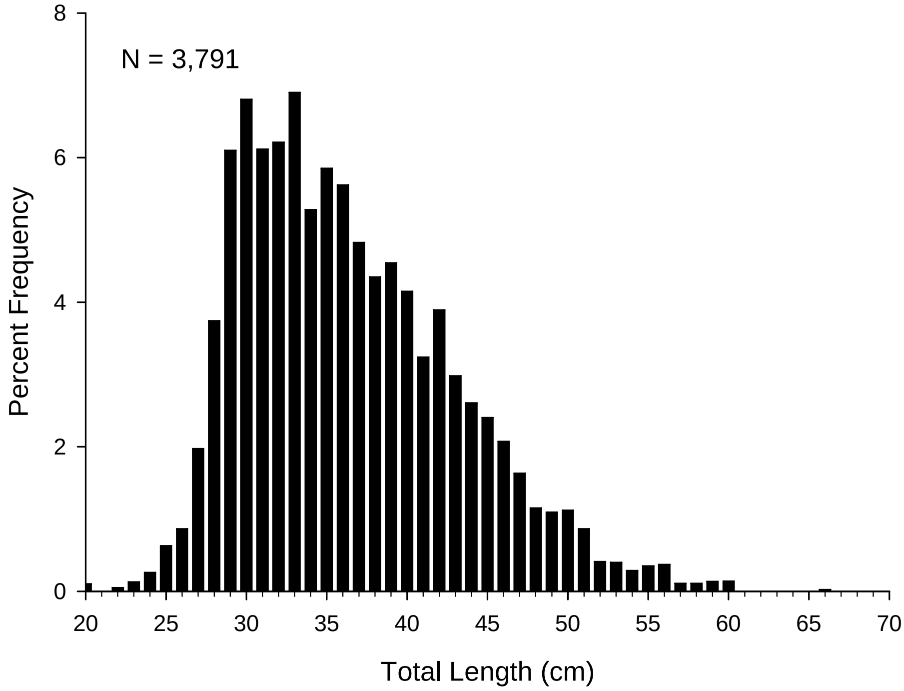


Figure 9.2. The lengths of ocean leatherjackets landed by commercial fishers and sold through the Sydney Fish Markets during 2005.

Recreational landings

Ocean leatherjackets measured during the early 1990s from trailerboat fishers (*n* = 405) were generally similar to those reported by charterboat fishers during 2001 to 2003 (*n* = 25,786) and therefore the data were pooled (Fig. 9.3). The sizes of ocean leatherjackets landed by recreational fishers were similar to those landed by commercial fishers, but with proportionally more fish < 30 cm. Peaks at 5 cm intervals suggest that many charterboat fishers are approximating lengths. Approximately 40% of ocean leatherjackets caught by recreational anglers in NSW were reported to be discarded during the National Recreational and Indigenous Fishing Survey (Henry & Lyle, 2003).

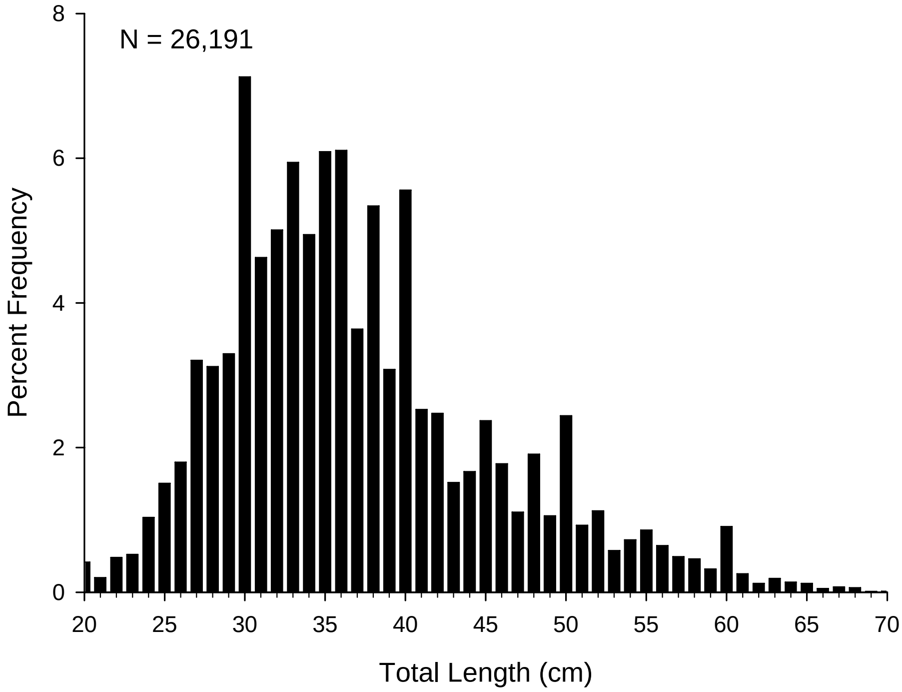


Figure 9.3. The lengths of ocean leatherjackets landed by offshore trailerboat and charterboat fishers.

9.3.2. Reproduction

9.3.2.1. Seasonality of spawning

Ocean leatherjackets spawn during winter, with peak activity being observed during August (M. Miller, unpublished data). There is evidence that ocean leatherjackets have limited spawning on the south coast of NSW, with relatively low gonadosomatic indices compared to those sampled further north (Forster). In addition, only very small amounts of ocean leatherjacket roe from the south coast have been consigned for sale through the Sydney Fish Markets when compared to the north coast.

9.3.2.2. Size at maturity

Assessment of maturity using macroscopic staging of gonads showed no differences in the sizes at 50% maturity for male and female ocean leatherjackets (M. Miller, unpublished data). Fifty percent of ocean leatherjackets were found to be mature at ~ 35 cm and 100% at 40 cm. Ocean leatherjackets are therefore likely to spawn during their second or third winters.

9.3.3. Age and growth

The age of ocean leatherjackets in NSW has been estimated by counting annually formed opaque zones in sectioned otoliths (M. Miller, unpublished data). The results showed that ocean leatherjackets grow quickly, attaining ~ 30 cm after two years. A von Bertalanffy growth model was fitted to size-at-age data and produced the following growth function parameters: L_∞ = 88.5 cm, K = 0.16 $yr^{-1}$and t_0 = -0.57 yr.

Miller (unpublished data) reported a maximum age of nearly six years and a maximum size of ~ 65 cm. Ocean leatherjackets are reported to attain 1 m (Hutchins, 1980) though a maximum length of 71 cm has been recorded by Hutchins and Swainston (1986). It is therefore likely that ocean leatherjackets may live longer and grow larger than observed during Millers MSc.

Ocean leatherjackets are fully recruited to the fishery by age two. The fishery during 2003/04 was dominated (> 80%) by fish aged two and three years (M. Miller, unpublished data).

9.3.4. Mortality estimates

The estimate of total mortality (Z) for ocean leatherjackets in NSW based on catch curve analysis is 1.1. M is estimated to range between 0.8 (based on 1% attaining T_{max} of six years) and 0.5 (based on 5% attaining T_{max}).

The estimates of mortality applied in the present study were: Z = 1.1, M = 0.5 and F = 0.6.

9.3.5. *Market price*

Ocean leatherjackets sold through the Sydney Fish Markets are generally done so as "Gutted and Headed" (GH) and are graded according to the following schedule (Table 9.1):

Table 9.1. Size grade schedule for ocean leatherjackets sold through the Sydney Fish Markets. Fish are graded as being "gutted and headed" (GH) and have been converted to total lengths based on the GH length being 68% of the total length (unpublished data).

Size grade	**GH length**	**Total length**
Small	< 23 cm	< 38 cm
Medium	23 to 25 cm	38 to 42 cm
Large and Extra Large	> 25 cm	> 42 cm

Average prices for ocean leatherjackets sold through the Sydney Fish Markets during 2005/06 indicate that "Large" and "Extra Large" sized fish attained a greater price per kg than the "Medium" and "Small" size grades (Fig. 9.4). The average price for "Extra Large" fish was $3.95/kg.

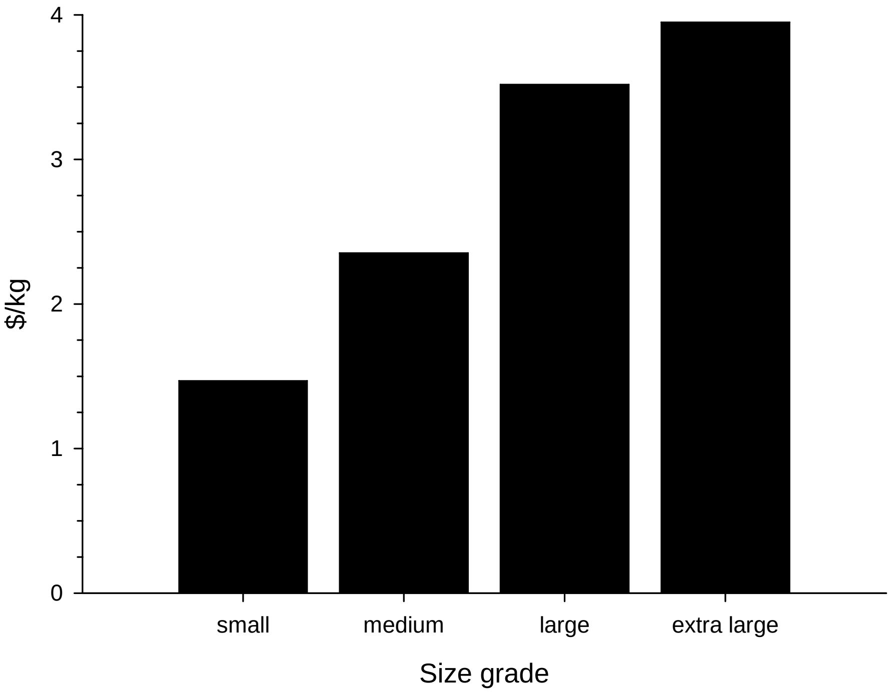


Figure 9.4. Average price information by size grade of ocean leatherjackets sold through the Sydney Fish Markets 2005/06.

9.3.6. *Per recruit analyses*

Per recruit analyses were done using the following parameters:

$L_\infty = 88.5$ cm
$K = 0.16$ yr^{-1}
$T_0 = -0.57$ yr
$M = 0.5$
$Z = 1.1$
$F = Z\text{-}M = 0.6$
$E = F/Z = 0.55$
$M/K = 3.13$

with market price information and size grades as described above. Where L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation that yield per recruit is maximised at 35 cm and that $ per recruit is maximised at 42 cm (Fig. 9.5).

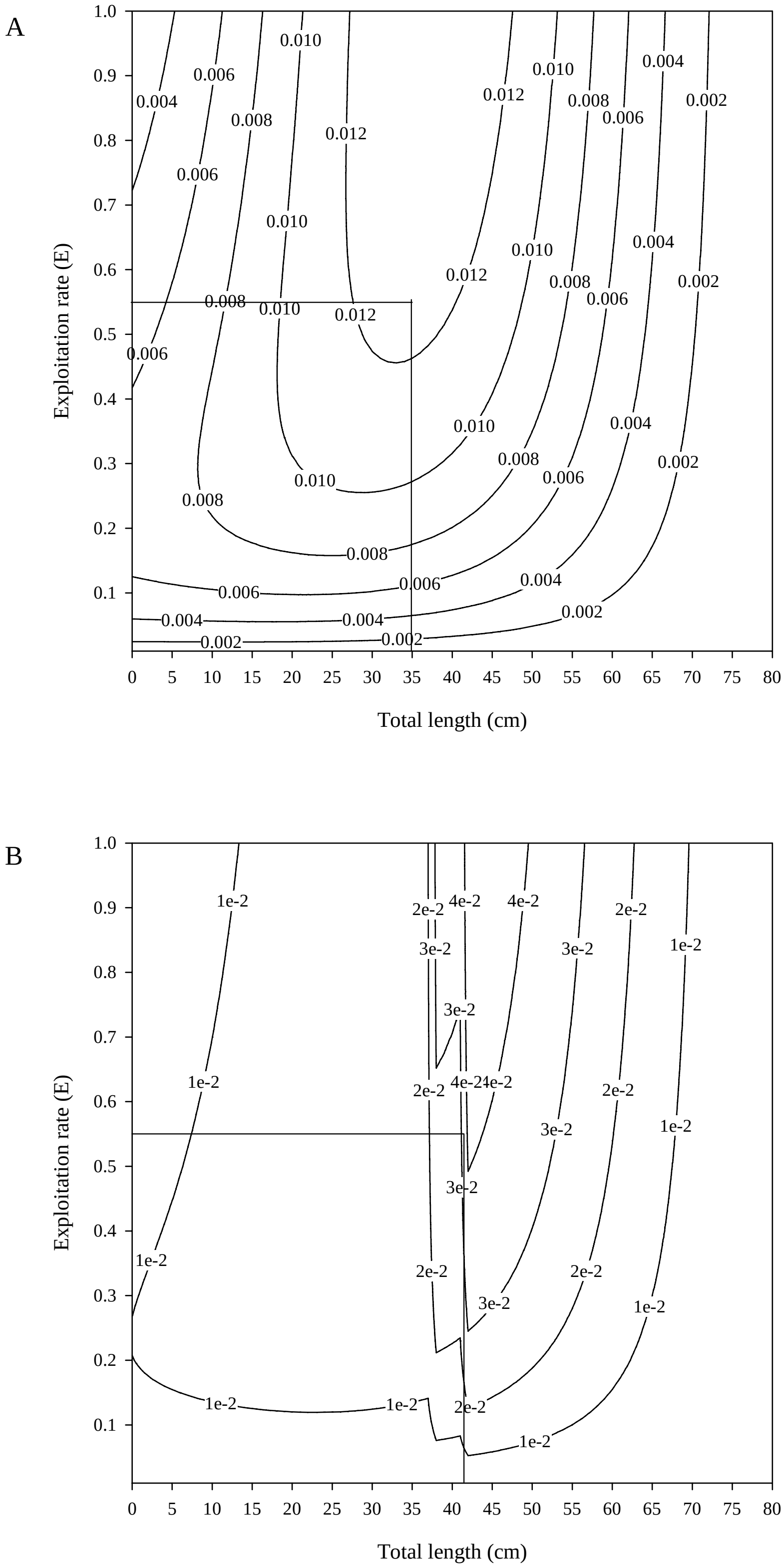


Figure 9.5. Yield and $ per recruit isopleths for ocean leatherjacket. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

9.3.7. *Spawning potential ratio*

Few ocean leatherjackets in landings are < 25 cm and this size at first harvest corresponds to a SPR of ~ 0.21 (Fig. 9.6). However, ocean leatherjackets are generally not retained at less than 30 cm and this size at first harvest corresponds to a SPR of ~ 0.38.

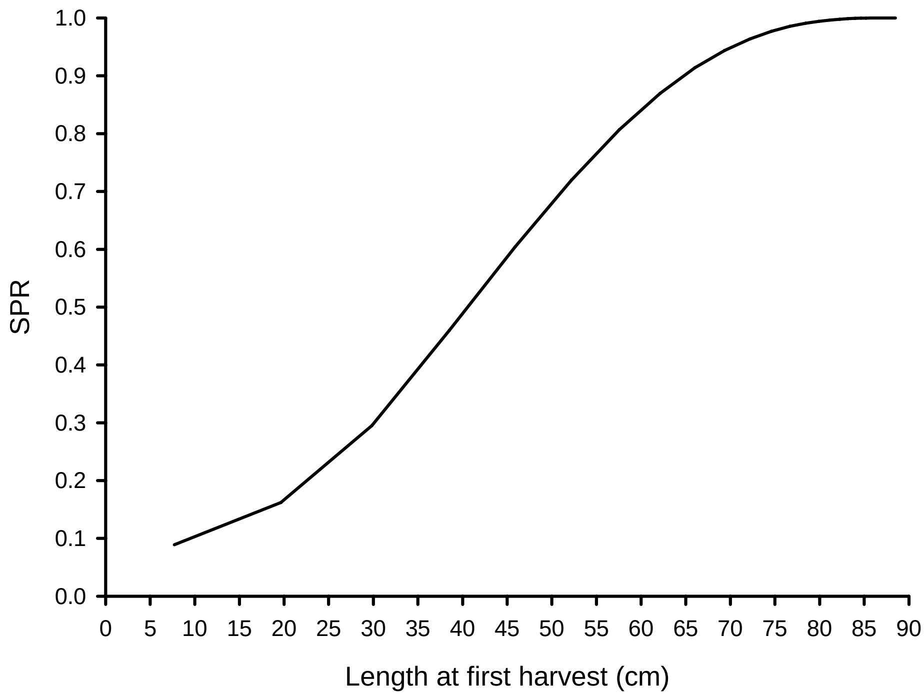


Figure 9.6. Spawning potential ratio for ocean leatherjacket at current levels of exploitation for a range of sizes at first harvest.

9.3.8. *Information fact sheet*

Relevant material from this chapter was collated into an information fact sheet for ocean leatherjackets (Fig. 9.7).

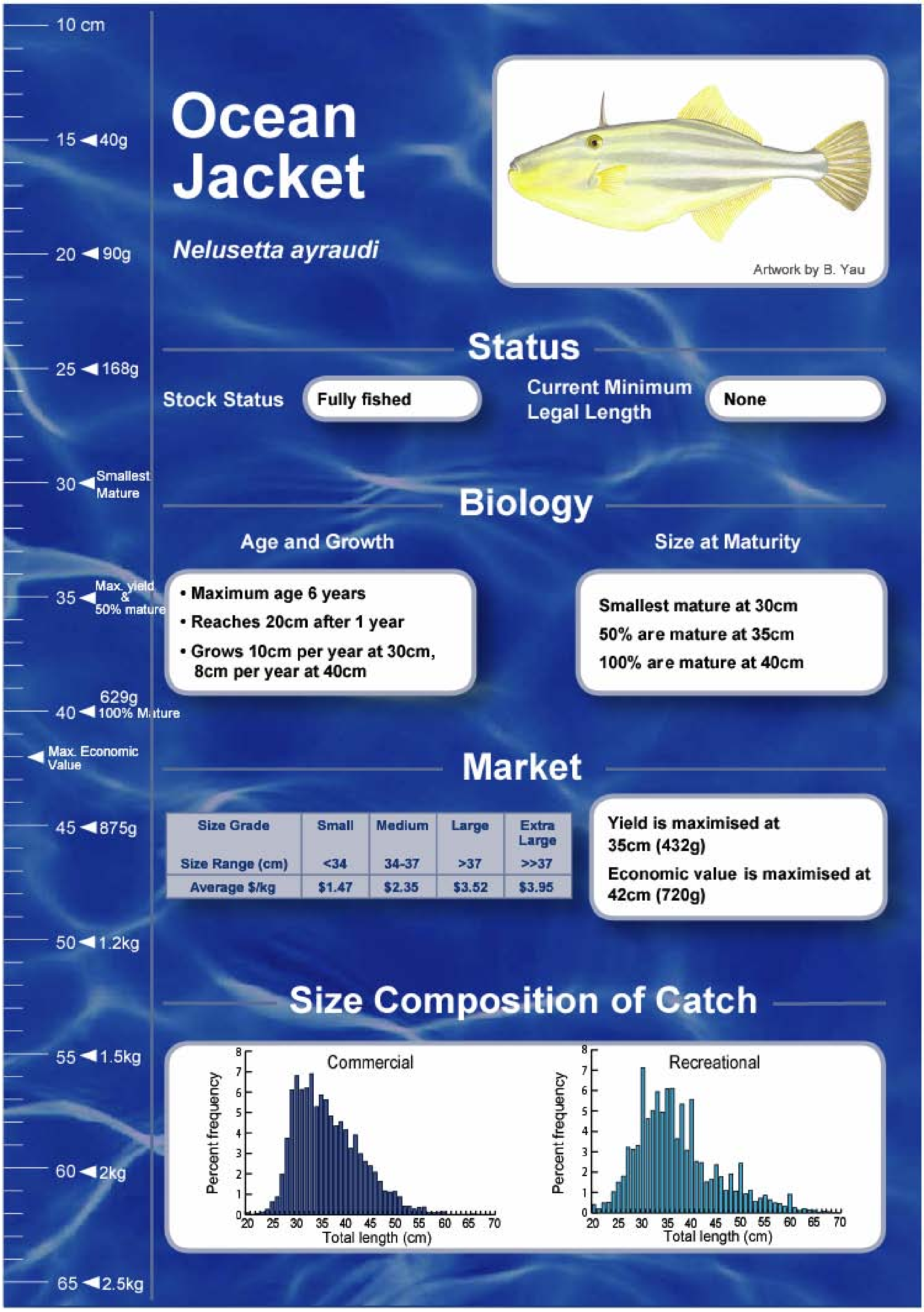


Figure 9.7. Information fact sheet for ocean leatherjackets.

9.4. Discussion

The status of ocean leatherjackets as FULLY FISHED (2005/06) is as a result of the estimate of F being approximately equal to M. In addition, historical catch information suggests that the ocean leatherjacket stock was previously fished down during the 1920s when they were heavily targeted by steam trawlers and again during the 1950s as a result of trawling and a developing trap fishery. These factors indicate that although current landings and CPUE are increasing, that ocean leatherjackets are vulnerable to overfishing and that major increases in fishing mortality may cause stock declines.

Ocean leatherjackets have become increasingly important to recreational and commercial fishers in NSW. Commercial and charterboat landings have been increasing steadily since 2000/01. Ocean leatherjackets have become a mainstay of many charterboat trips.

The sizes of ocean leatherjackets landed by commercial and recreational fishers in NSW indicate that much of the catch is of juvenile sized fish (< 35 cm). The selectivity of ocean leatherjackets caught in commercial fish traps covered in 50 mm hexagonal wire mesh is relatively knife-edge at ~ 25 cm (Stewart & Ferrell, 2001). However, escape panels of 50 x 75 mm welded mesh are to be made compulsory in fish traps in NSW by late 2007 and these traps will select ocean leatherjackets at ~ 35 cm (their size at sexual maturity).

Market price information shows that ocean leatherjackets graded as “small’ (< 38 cm) fetch considerably lower prices than larger grades. Anecdotal information indicates that commercial trawl fishers discard large quantities of small ocean leatherjackets due to a lack of marketability. The increase in value per kg with increasing fish size has resulted in an optimal $ per recruit being at a slightly larger size than that which optimizes yield per recruit.

The information presented here may assist managers when considering whether a MLL is an appropriate management tool for ocean leatherjackets. There are currently no problems with the level of harvest in NSW and the introduction of escape panels in fish traps will select ocean leatherjackets at both their size at maturity and at a size that will optimize yield. As a consequence, a MLL may not be required in this fishery. Conversely, both recreational and trawl fishers catch substantial quantities of small ocean leatherjackets and a MLL may help in protecting these small fish. There are currently no estimates of discard mortality for ocean leatherjackets; however discard mortality is likely to be high as ocean leatherjackets suffer from barotrauma-related injuries from relatively shallow (< 30 m) depths and may be damaged during trawls (pers. obs.).

10. BIOLOGY AND FISHERY FOR YELLOWFIN BREAM

10.1. Introduction

Yellowfin bream (*Acanthopagrus australis*) of the family Sparidae are endemic to eastern Australia. They are distributed from approximately Townsville in Queensland south to the Gippsland Lakes in Victoria (www.fishbase.org) and are thought to comprise the one stock. Yellowfin bream are most abundant in estuaries but also inhabit inshore reefs and waters adjacent to ocean beaches and rocky headlands. They are a demersal fish and associate with a variety of substrata, from sand and mud to rocky reef and river beds. They feed on a wide variety of foods including molluscs, crustaceans, worms, fish and ascidians.

Yellowfin bream are one of the most popular targets for recreational fishers and are also very important to commercial fishers. The recreational harvest is thought to be at least twice the commercial harvest in NSW. The bulk of the commercial harvest is from the Estuary General Fishery and is caught using mesh nets. The Ocean Trap and Line Fishery takes < 10% of the commercial catch, mainly using demersal fish traps.

Yellowfin bream have been studied extensively, yet there are limitations to the usefulness of the available information for management of bream fisheries in NSW. The most comprehensive work on their biology (age, growth and reproduction) was done in Moreton Bay, Queensland (Pollock, 1982) and as such may not be accurate for the species in NSW. In addition, much of the work done in NSW has been restricted to fish greater than the minimum legal length (25 cm TL) and as a result growth and maturity models are limited because of age-class truncation in samples (Gray *et al.*, 2000). This chapter collates and re-analyses available information for yellowfin bream and presents it in a manner that may be used when considering the optimum size at which they should be harvested in NSW.

10.2. Materials and methods

Biological and fishery information for yellowfin bream was sourced from previous studies. Age, growth and reproductive information was largely sourced from Pollock (1982) who studied yellowfin bream in Moreton Bay, Queensland. Sexual maturity and fishery information was sourced from NSW studies (SPCC, 1981; Steffe *et al.*, 1996; Gray *et al.*, 2000; Scandol & Forrest 2001; Stewart & Ferrell, 2001). Analyses of mortality rates, market prices and yield and $ per recruit were as described in the Chapter 2.

10.3. Results

10.3.1. Landings in NSW

10.3.1.1. Current exploitation status

Yellowfin bream are currently listed as being FULLY FISHED in NSW (2005/06). This assessment is based on a long history of stability in the lengths and CPUE in commercial landings. However, it is recognised that the recreational fishery is considerably larger than the commercial fishery and that further increases in fishing effort are not desirable.

10.3.1.2. Trends in catch

Reported commercial landings of bream (yellowfin and black combined) have declined since the mid 1990s, but have been relatively stable at ~ 360 tonnes per year since that time (Fig. 10.1). Two indices of relative abundance, commercial catch rates using both traps and mesh nets, have increased during the past few years. The most recent estimate of the recreational harvest in NSW (yellowfin and black bream combined) was ~ 729 tonnes between April 2000 and March 2001 (Henry & Lyle, 2003). This estimate may be an under-estimate because it used an average retained weight of 350 g. The most reliable data on the lengths of retained recreationally caught bream (see Fig. 10.3) indicates an average size of ~ 25 cm FL that corresponds to an average retained weight of 380 g. Using this average weight provides an estimate of ~ 771 tonnes of bream retained by recreational fishers per year.

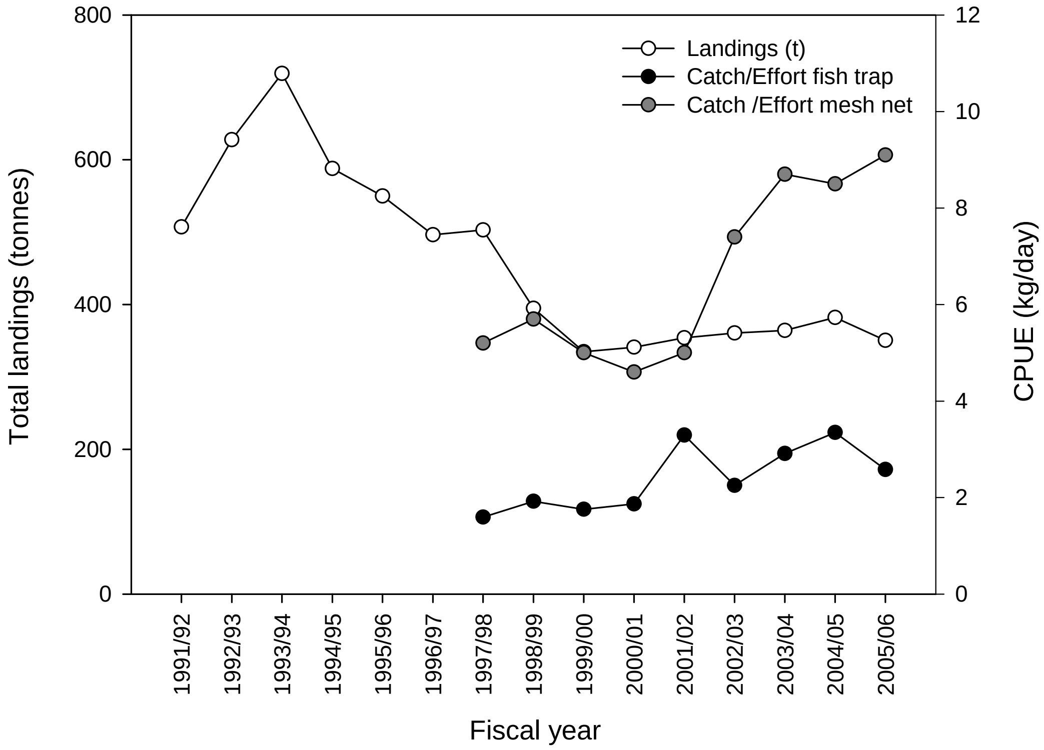


Figure 10.1. Reported commercial landings and catch rates of yellowfin bream (kg per day trapping and per day mesh net) in NSW. Source: NSW DPI Resource Assessment System.

10.3.1.3. Length measurements

Commercial landings

The sizes of bream landed by commercial fishers have remained relatively stable since the 1960s (RAS unpublished data). The lengths of bream landed by commercial trap fishers during 1999/00 (Fig. 10.2) show a steady decline in numbers for each length class after being fully recruited to the fishery at the MLL of 25 cm TL (~ 23 cm FL). Commercial trap fishers discard ~ 19% of bream they catch because they are smaller than the MLL of 25 cm TL (Stewart & Ferrell, 2003).

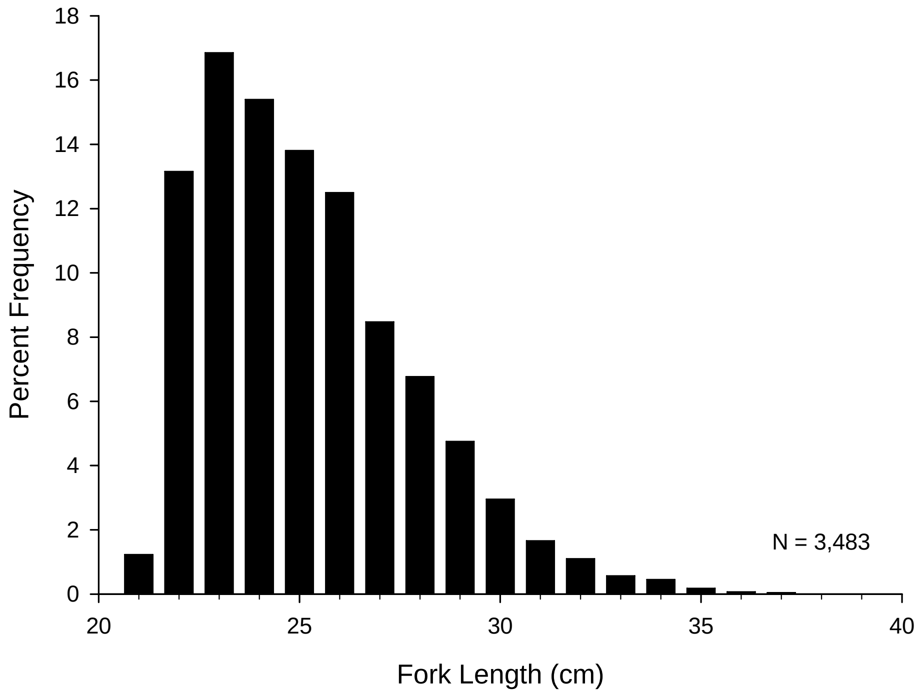


Figure 10.2. The lengths of yellowfin bream landed by commercial fishers 1999/00. Source: Stewart & Ferrell, 2003.

Recreational landings

The lengths of bream landed by recreational fishers are, on average, larger than those landed by commercial fishers (Figs 10.3 & 10.4). The most abundant length class landed by trailerboat fishers during the early 1990s was 24 cm FL. The sizes of bream reportedly retained by charterboat fishers are larger, with a peak at 27 cm FL (Fig. 10.4). Given the stability in the sizes of bream in commercial landings and the similar shapes of the trailerboat and charterboat bream length distributions, with the charterboat lengths being shifted by ~ 3 cm larger, the majority of charterboat measurements may have been of TL rather than FL. Recreational fishers discard ~ 65% of all bream they catch (Henry & Lyle, 2003). Mortality of these discarded bream is difficult to quantify; however Broadhurst *et al.* (2005) reported a mortality rate of ~ 17% in the shallow waters of Botany Bay. The numbers of bream used by Broadhurst *et al.* (2005) was probably too few (42 experimental fish and 28 control fish) to draw any firm conclusions; however mortality may be significant and warrants further study.

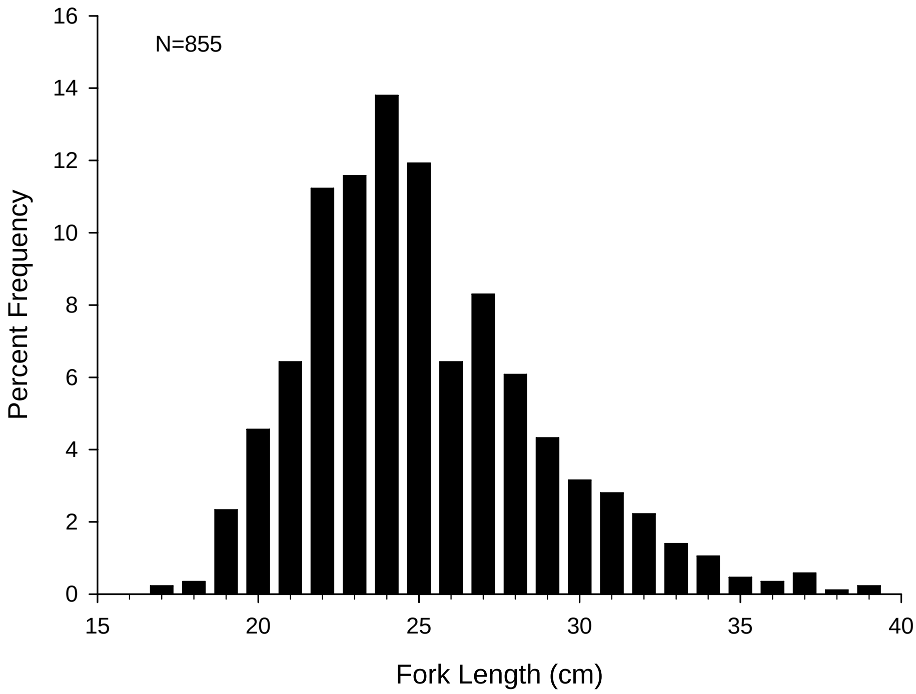


Figure 10.3. The lengths of yellowfin bream landed by offshore trailerboat fishers 1993/94 and 1994/95. Source: Steffe *et al.*, 1996.

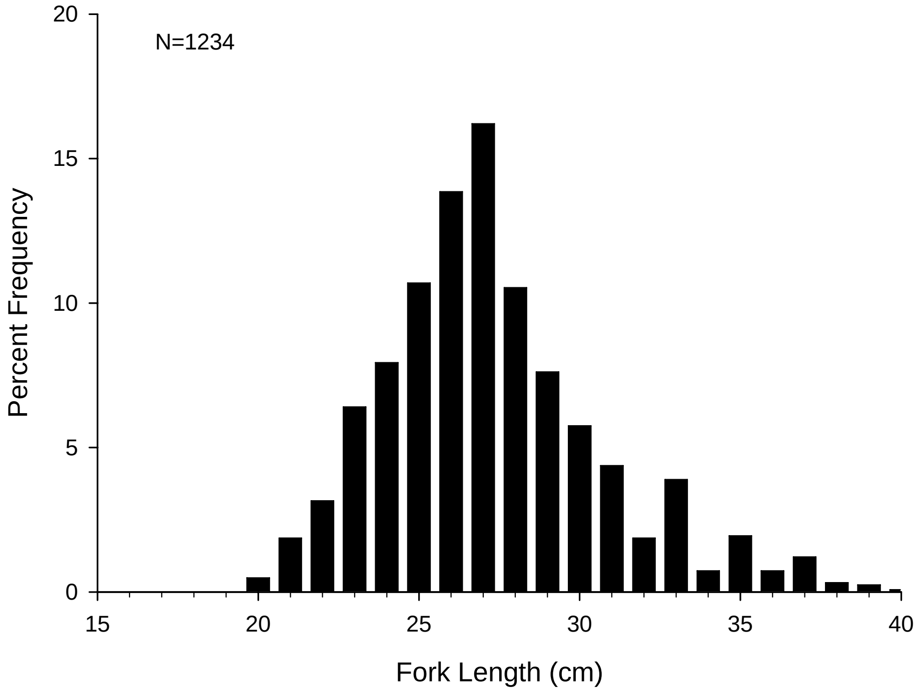


Figure 10.4. The lengths of bream measured by NSW charterboat operators 2001 to 2003.

10.3.2. *Reproduction*

The timing of spawning of yellowfin bream varies along the east coast of Australia. They have been reported to spawn from winter/summer in southern NSW (SPCC, 1981) to July/August in southern Queensland (Pollock, 1982). There is a pre-spawning run of fish from estuaries to the ocean usually between April and July (Gray *et al.*, 2000). Yellowfin bream are thought to spawn in the coastal zone along beaches and near estuary mouths.

Sexual maturity for 50% of females is attained at ~ 24 cm FL (~ 27 cm TL) (SPCC, 1981). This size is reached after between 2 and 10 years (Gray *et al.*, 2000). Males mature at slightly smaller sizes (~ 21 cm FL).

10.3.3. *Age and growth*

Age and growth of yellowfin bream have been studied using sectioned otoliths (Gray *et al.*, 2000), as well as tagging and length frequency analysis (Pollock, 1982). Growth is rapid for juveniles (~ 20 cm FL after 1 year), but slows (up to 1 cm/year) after reaching sexual maturity. There is large variation in size-at-age. The largest yellowfin bream recorded from NSW was 56 cm TL (4.5 kg), although specimens greater than 40 cm are rare (Gray *et al.*, 2000). The oldest yellowfin bream observed to date was 22 years (Gray *et al.*, 2000). The best available von Bertalanffy growth function parameters are from Pollock (1982): L_∞ = 29.5 cm, K = 0.51 yr^{-1} and t_0 = -0.32 years. The fishery for yellowfin bream in NSW is dominated by fish aged between two and 10 years old (Gray *et al.*, 2000).

10.3.4. *Mortality estimates*

An estimate of total mortality (Z) is available from age-based catch curves (Scandol & Forrest, 2001). The best estimate is Z = 0.4. M is estimated to range between 0.21 (based on 1% attaining T_{max}) and 0.14 (based on 5% attaining T_{max}).

The estimates of mortality applied in the present study were: Z = 0.4, M = 0.14 and F = 0.26.

10.3.5. *Market price*

Bream sold through the Sydney Fish Markets are graded according to the following schedule:

Small	25 to 30 cm
Medium	30 to 35 cm
Large	35 to 45 cm
Extra large	> 45 cm

Average prices for bream sold through the Sydney Fish Markets during 2005/06 indicate that the "Large" and "Extra large" size grades attain greater prices (> 10/kg) than the smaller grades (Fig. 10.5).

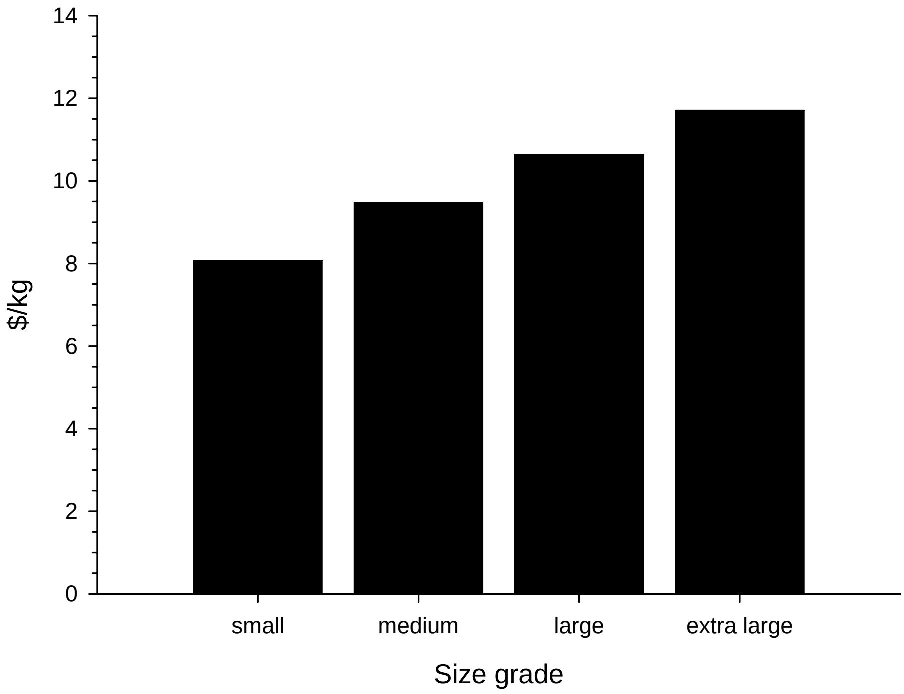


Figure 10.5. Average price information by size grade of bream sold through the Sydney Fish Markets 2005/06.

10.3.6. Per recruit analyses

Per recruit analyses were done using the following parameters:

L_∞ = 29.5 cm
K = 0.51 yr^{-1}
T_0 = -0.32 yr
M = 0.14
Z = 0.40
E = F/Z = 0.65
M/K = 0.275

with market price information and size grades as described above. Where L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation that yield and $ per recruit are maximised at 23.5 cm FL (~ 27 cm TL) (Fig. 10.6).

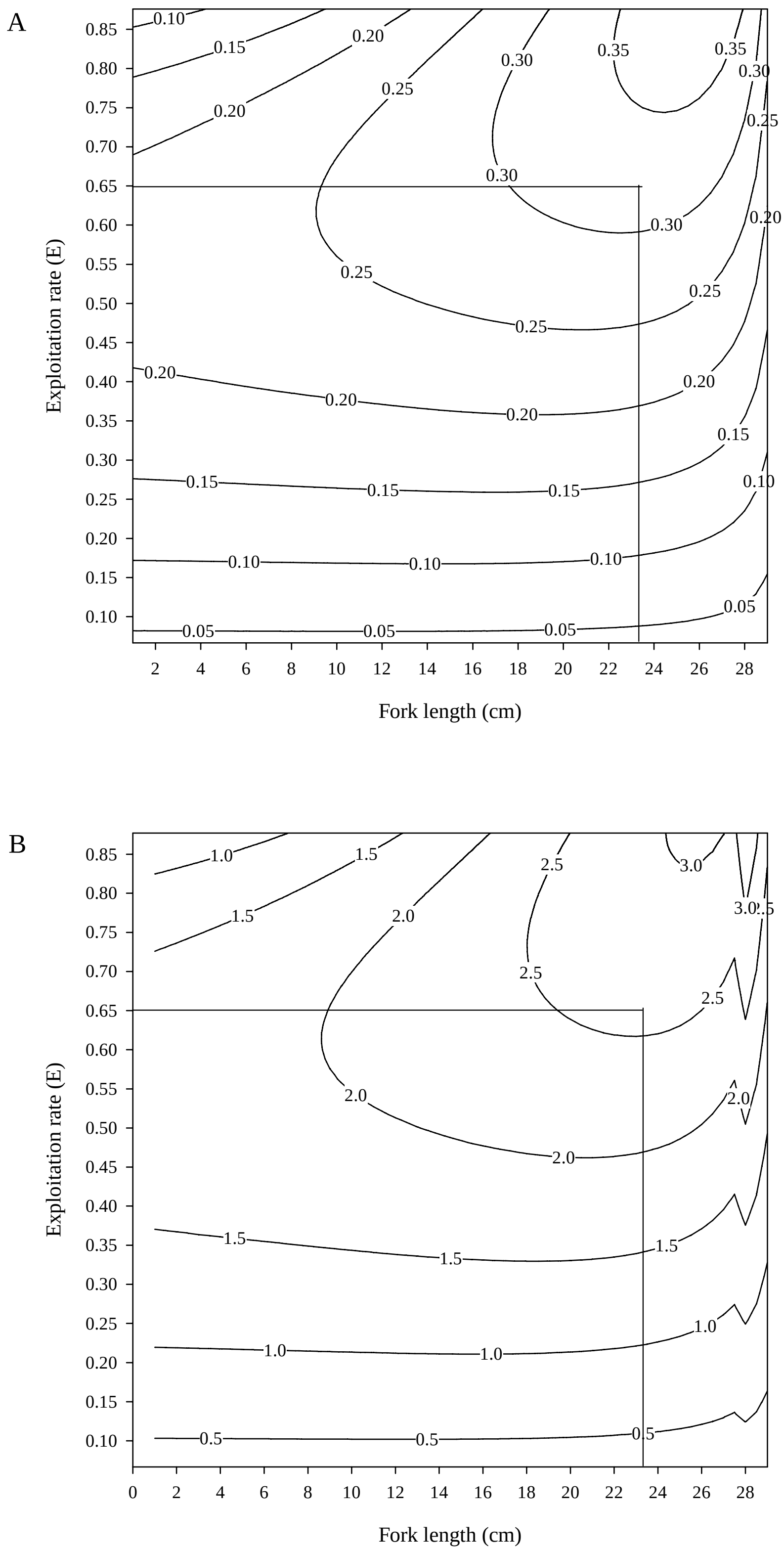


Figure 10.6. Yield and $ per recruit isopleths for yellowfin bream. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

10.3.7. Spawning potential ratio

The SPR for yellowfin bream at current levels of mortality is ~ 0.31, above the threshold level of 0.2 (Fig. 10.7). The SPR level indicates that at current levels of exploitation yellowfin bream should be producing sufficient eggs to sustain the population.

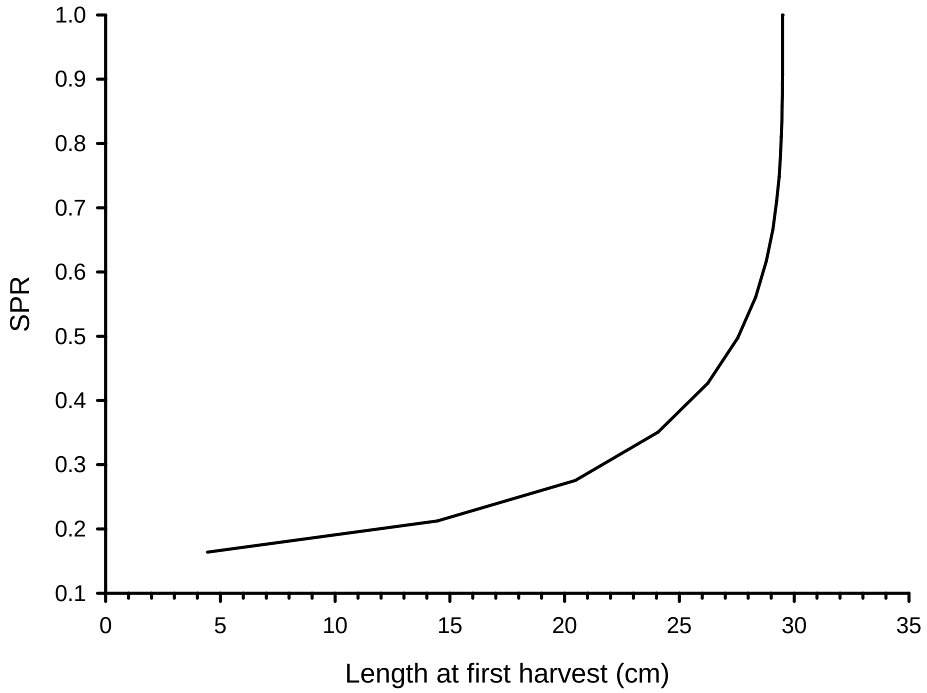


Figure 10.7. Spawning potential ratio for yellowfin bream at current levels of exploitation for a range of sizes at first harvest.

10.3.8. Information fact sheet

Relevant material from this chapter was collated into an information fact sheet for yellowfin bream (Fig. 10.8). The information was presented as total lengths.

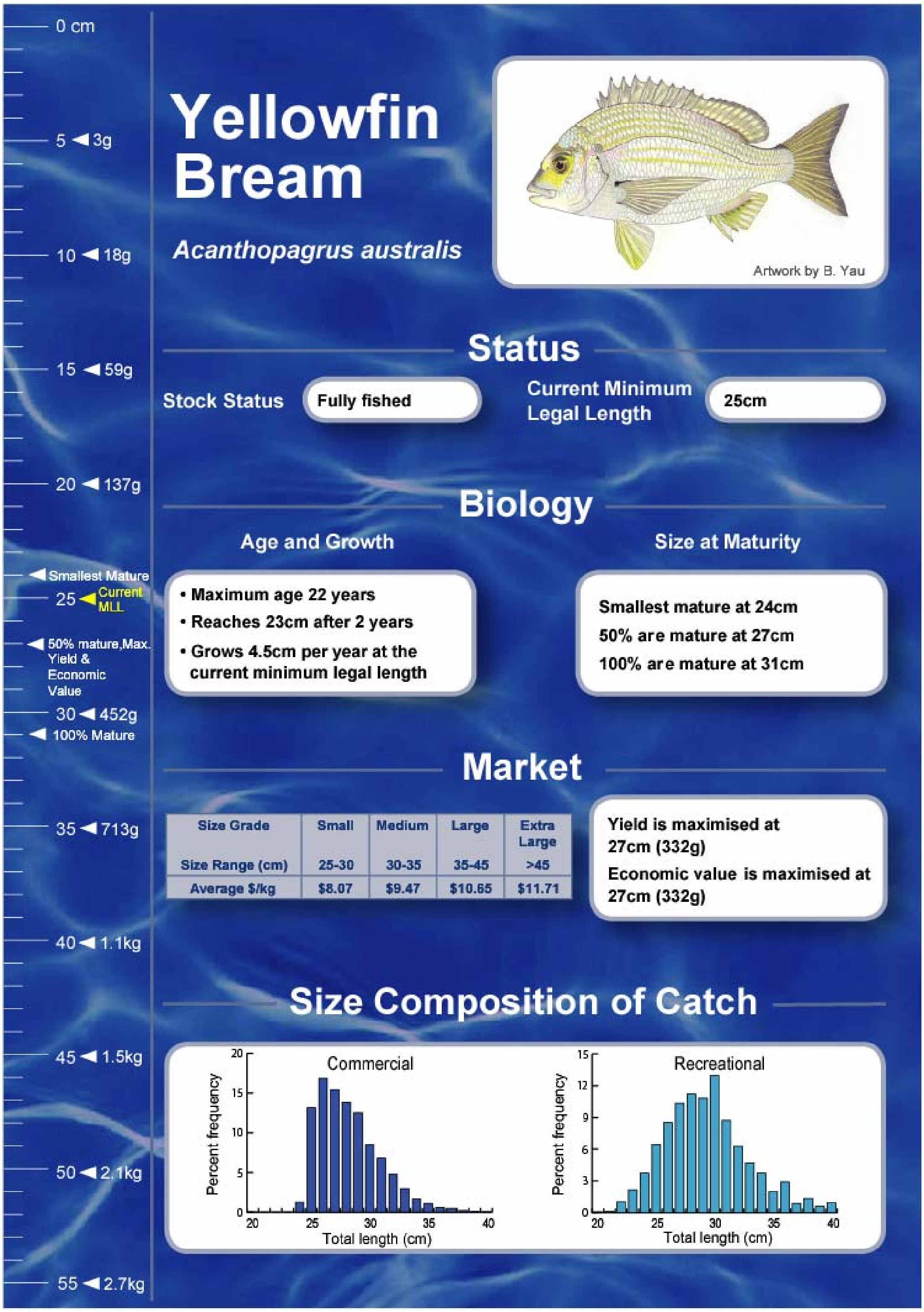


Figure 10.8. Information fact sheet for yellowfin bream.

10.4. Discussion

The status of yellowfin bream in NSW as FULLY FISHED is reasonable given the long-term stability in the sizes and ages of commercially landed fish and catch rates. The fact that the recreational take is at least twice the commercial take in NSW, in addition to ~ 65% of bream being caught and released with potentially high mortality rates, strongly suggests that the recreational fishery requires careful monitoring. Future resource assessments should incorporate more information from the recreational sector.

The information on sizes at sexual maturity for yellowfin bream needs improving. The best available information is that from the early 1980s in Botany Bay; however the maturity curves were fitted by eye and no raw data is provided. There is anecdotal evidence that bream from the Clarence River in northern NSW mature at very small sizes (< 15 cm), but this is yet to be confirmed. Given the importance of yellowfin bream to commercial and recreational fisheries in NSW, and the relative importance of the size at sexual maturity in management arrangements, there is a need for more refined estimates to be made.

Several aspects of the biology of yellowfin bream in relation to the current MLL of 25 cm TL may have contributed to the apparent healthy nature of the stock at high levels of exploitation. Bream display rapid early growth rates and can mature after only two years. Fifty percent of females are reported to mature sexually at ~ 27 cm TL (SPCC, 1981); however more than 25% of bream are given the opportunity to spawn at least once prior to entering the fishery. Analysis of growth and mortality rates with market price information indicates that both yield and value per recruit are optimized at only slightly greater sizes than the current MLL.

The information presented in this chapter suggests that there are no stock problems and that the current MLL is slightly too small to optimise the management objectives of: (i) protecting juveniles and; (ii) optimising commercial yield and economic return. Options for managers to consider with associated optimum sizes at first capture are presented in Chapter 16.

11. BIOLOGY AND FISHERY FOR KINGFISH

11.1. Introduction

Yellowtail kingfish (*Seriola lalandi*) of the family Carangidae are distributed throughout temperate waters of the Pacific and Indian Oceans. In Australian waters they are distributed from southern Queensland to central Western Australia, including the east coast of Tasmania, and around Lord Howe and Norfolk Islands. They are a pelagic and demersal species that usually form schools near rocky shores, reefs, offshore islands and sometimes in estuaries. They are found commonly to depths of 50 m although have been recorded to 300 m. Schools of small juveniles are found in offshore waters, often near or beyond the continental shelf where they associate with drifting objects. The diet of kingfish consists mainly of small fish, squid and crustaceans.

Kingfish is an important commercial and recreational species in NSW. The recreational harvest is thought to be increasing and is probably larger than the commercial harvest. The Ocean Trap and Line Fishery lands about 99% of the total commercial catch using line methods. A 60 cm MLL was imposed for kingfish in NSW waters in 1990, and kingfish traps were banned in 1996.

Yellowtail kingfish have been the subject of previously FRDC funded projects that have provided much of the information presented here. FRDC project 95/128 (Gillanders *et al.*, 1996) examined methods for ageing kingfish and provided information on reproduction, while FRDC project 97/126 (Stewart *et al.*, 2001) provided an assessment of age, growth and the fishery for kingfish in NSW. The aim of this chapter was to collate and re-analyse available information for kingfish that could be used to assist in determining the best size at first harvest.

11.2. Materials and methods

Information was sourced from two previous FRDC projects (Gillanders *et al.*, 1996; Stewart *et al.*, 2001). Market price information was obtained and analyses were done according to the methods described in Chapter 2.

11.3. Results

11.3.1. Landings in NSW

11.3.1.1. Current exploitation status

Yellowtail kingfish are listed as being GROWTH OVERFISHED in NSW (2005/06). This assessment was based largely on the findings from Stewart *et al.* (2001) based on estimates of mortality and yield per recruit analyses.

11.3.1.2. Trends in catch

Reported commercial landings of kingfish have declined from ~ 400 tonnes per year during the early 1990s to ~ 120 tonnes during 2005/06 (Fig. 11.1). CPUE shows a similar trend to total landings and has increased since 1997/98 (when it became possible to assign days using a particular method to the catch of a species). The overall decline in total landings can largely be attributed to reduced commercial fishing effort. The most recent estimate of the recreational harvest in NSW was ~ 180 tonnes between April 2000 and March 2001 (Henry & Lyle, 2003). This estimate may have been an underestimate because it assumed an average weight of 2 kg per fish retained. A 60 cm TL kingfish weighs ~ 1.8 kg and the average size landed by recreational fishers is ~ 2.5 kg (from Steffe *et al.*, 1996). Using an average of 2.5 kg per fish results in an estimated recreational take of ~ 225 tonnes in 2000/01.

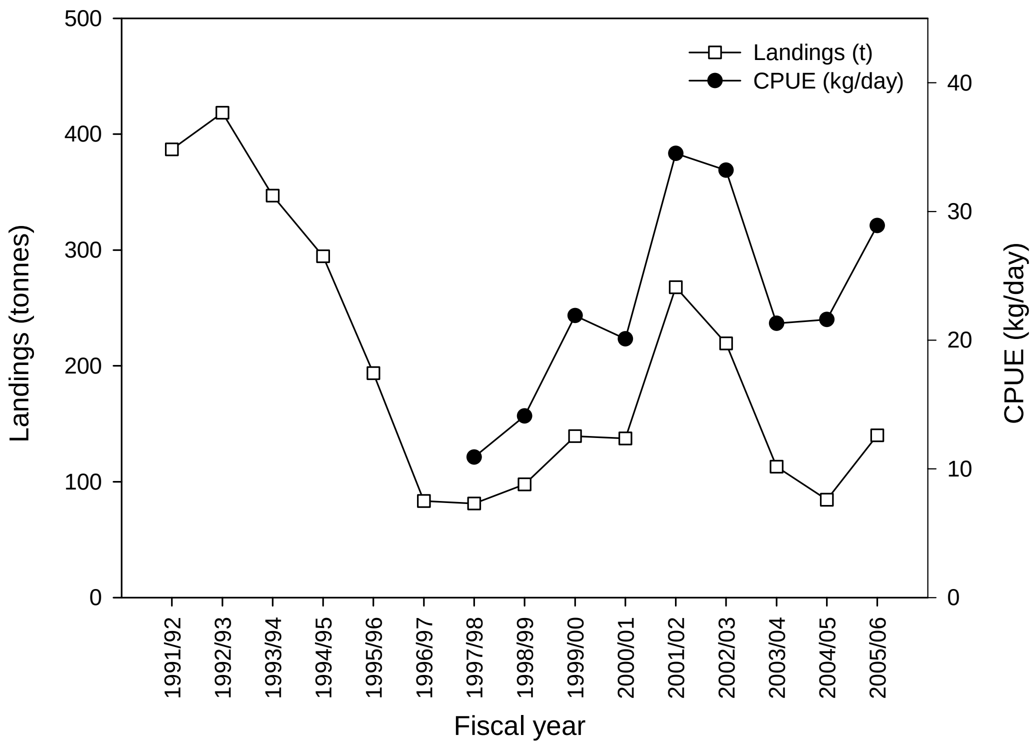


Figure 11.1. Reported commercial landings and catch rates of kingfish (kg per day line fishing) in NSW. Source: NSW DPI Resource Assessment System.

11.3.1.3. *Length measurements*

Commercial landings

The sizes of kingfish landed by commercial fishers during 1998 to 2000 were generally close to the MLL of ~ 52.5 cm FL (60 cm TL). Approximately 60% of landed fish were within 10 cm of this MLL (Fig. 11.2). There is some evidence that the average size has increased during recent years; however the data is yet to be fully examined (NSW DPI unpublished data). Substantial numbers of kingfish are known to be captured and released because they are smaller than the MLL (Stewart *et al.*, 2001).

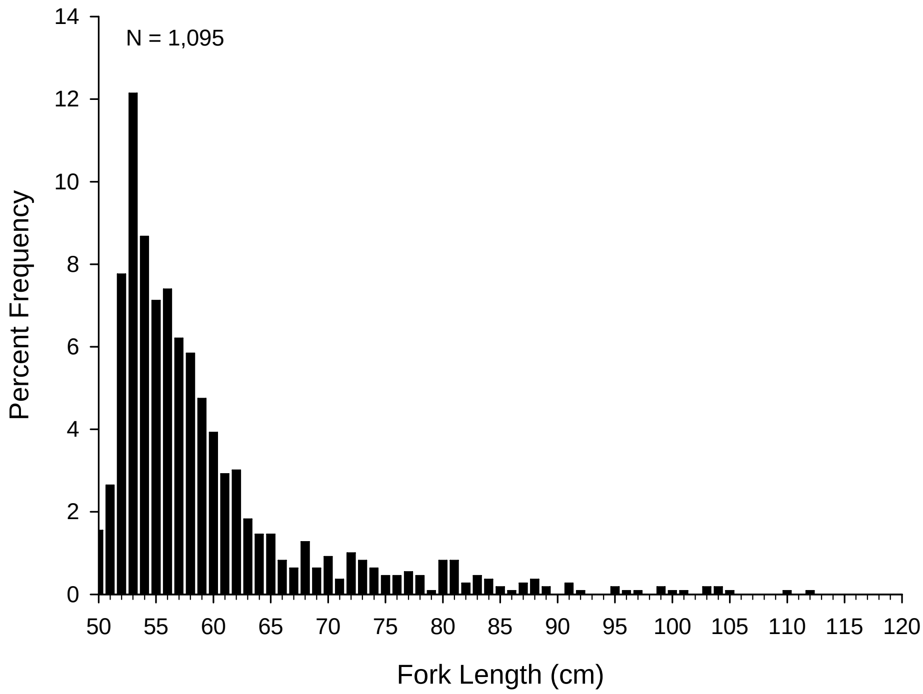


Figure 11.2. The lengths of kingfish landed by commercial fishers 1998 to 2000. Source: Stewart *et al.* (2001).

Recreational landings

Kingfish landed by recreational trailerboat fishers during 1993/94 and 1994/95 (Fig. 11.3) were of similar sizes to those landed by commercial fishers, although there was a higher proportion of fish smaller than the MLL of ~ 52 cm FL (60 cm TL). In contrast, the sizes of kingfish reportedly retained by charterboat fishers are larger, with relatively few fish smaller than 60 cm FL (Fig. 11.4). It is apparent that many of these kingfish measurements may have been of TL, and peaks in the distribution at 5 cm intervals suggest that many lengths were not measured accurately. There exists little information on discarding of kingfish by recreational fishers; however given that kingfish are caught by hook and line by both commercial and recreational fishers, discarding is likely to be similar to that reported for commercial fishers. There is an added potential for recreational fishers to release kingfish greater than the MLL because of personal catch and release practices.

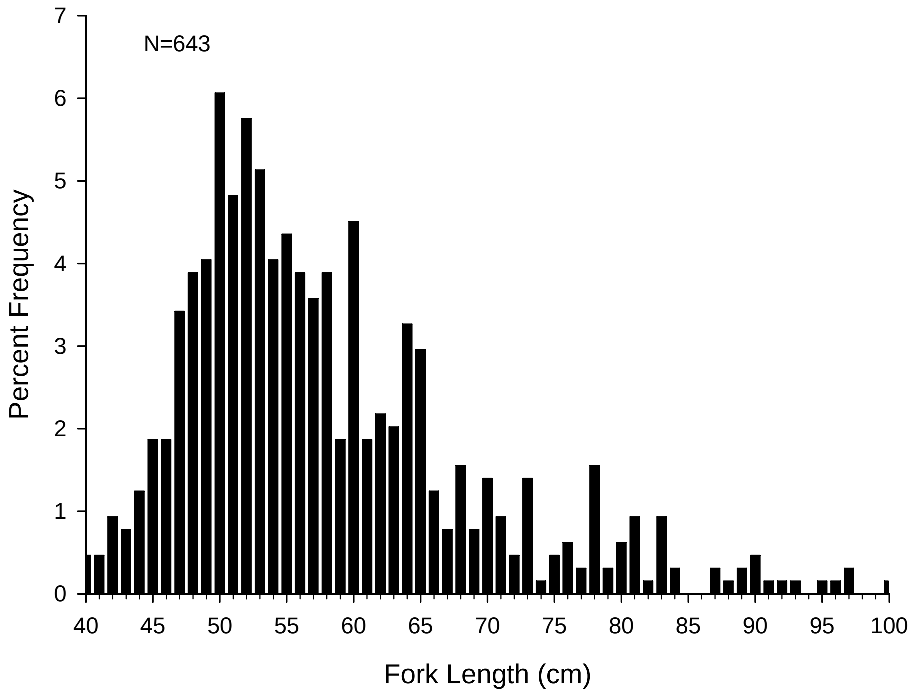


Figure 11.3. The lengths of kingfish landed by offshore trailerboat fishers 1993/94 and 1994/95. Source: Steffe *et al.*, 1996.

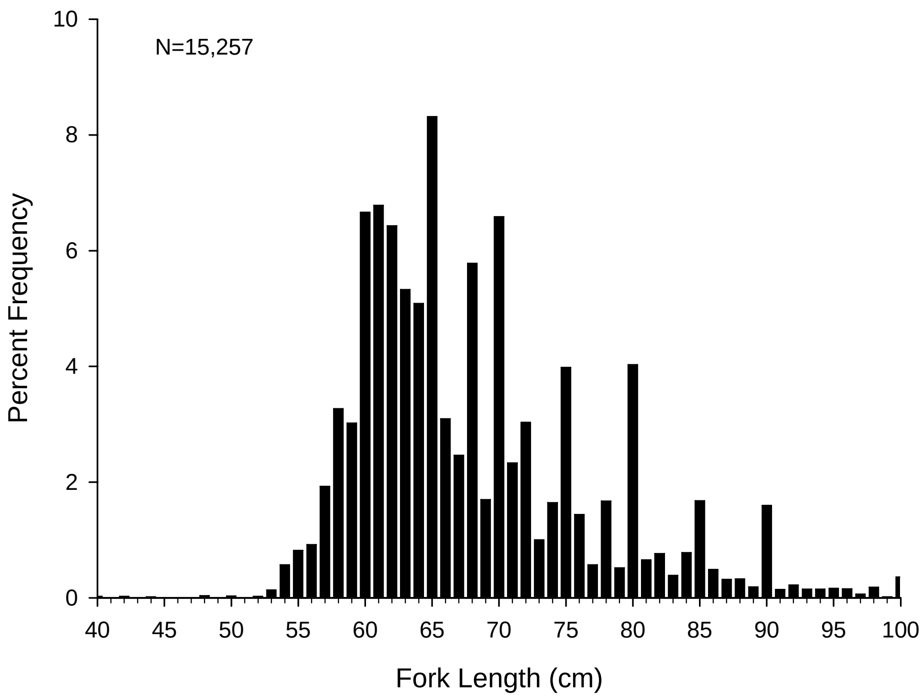


Figure 11.4. The lengths of kingfish measured by NSW charterboat operators 2001 to 2003.

11.3.2. Reproduction

Kingfish are reported to spawn off the NSW coast during summer (Gillanders *et al.*, 1999). Sexual maturity for 50% of females is attained at 83 cm FL (~ 95 cm TL, Gillanders *et al.*, 1999). The smallest mature female observed was 70 cm FL (~ 80 cm TL). Males mature at smaller sizes, with 50% being mature at ~ 55 cm TL.

11.3.3. Age and growth

Kingfish grow rapidly and attain the MLL of 60 cm TL after ~ two years (Stewart *et al.*, 2004). There is no difference in growth rates between sexes and kingfish have a maximum recorded age of 21 years. The von Bertalanffy growth function parameters from Stewart *et al.* (2004) are: L_{∞} = 184 cm, K = 0.054 yr^{-1} and t_0 = -4.4 years.

The fishery for kingfish in NSW is dominated by two and three year old fish, with ~ 90% of landings being less than seven years old.

11.3.4. Mortality estimates

Estimates of mortality rates for kingfish have been sourced from Stewart *et al.* (2004) and Gillanders *et al.* (2001). Estimates of Z based on catch curve analyses range between 0.43 and 0.79. M is estimated to range between be 0.2 (based on 1% attaining T_{max}) and 0.14 (based on 5% attaining T_{max}). Gillanders *et al.* (2001) estimated M to be ~ 0.12 based on the rate of decay of tag returns.

The estimates of mortality applied in the present study were: Z = 0.43, M = 0.2 and F = 0.23.

11.3.5. Market price

Kingfish sold through the Sydney Fish Markets are graded according to the following schedule:

Small	60 to 74 cm
Medium	74 to 90 cm
Large	90 cm to 15 kg
Extra large	> 15 kg

Average prices for kingfish sold through the Sydney Fish markets during 2005/06 indicate that "Small" and "Medium" sized fish attain a greater price per kg than the larger size grades (Fig. 11.5). The average price for "Small" fish was $7.83/kg.

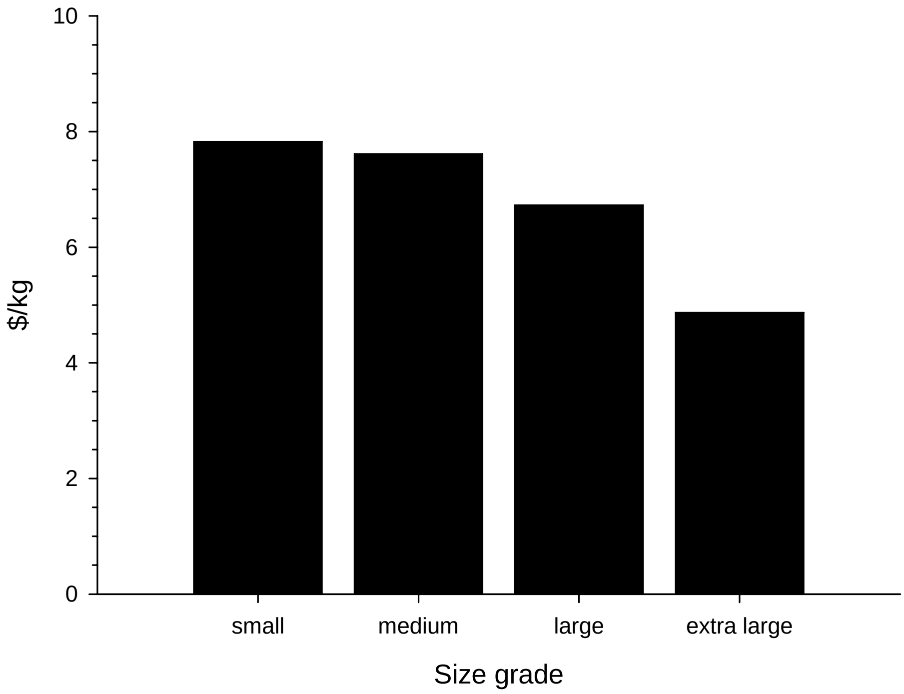


Figure 11.5. Average price information by size grade of kingfish sold through the Sydney Fish Markets 2005/06.

11.3.6. Per recruit analyses

Per recruit analyses were done using the following parameters:

L_∞ = 184 cm
K = 0.054 yr^{-1}
T_0 = -4.4 yr
M = 0.2
Z = 0.43
F = Z-M = 0.23
E = F/Z = 0.54
M/K = 3.7

with market price information and size grades as described above. Where L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation yield per recruit is maximised at 65 cm FL (~ 74 cm TL) and that $ per recruit is maximised at 64.5 cm FL (~ 74 cm TL) (Fig. 11.6). It should be noted that if lower values of M are used (a more precautionary approach), then the optimum sizes at harvest increase substantially.

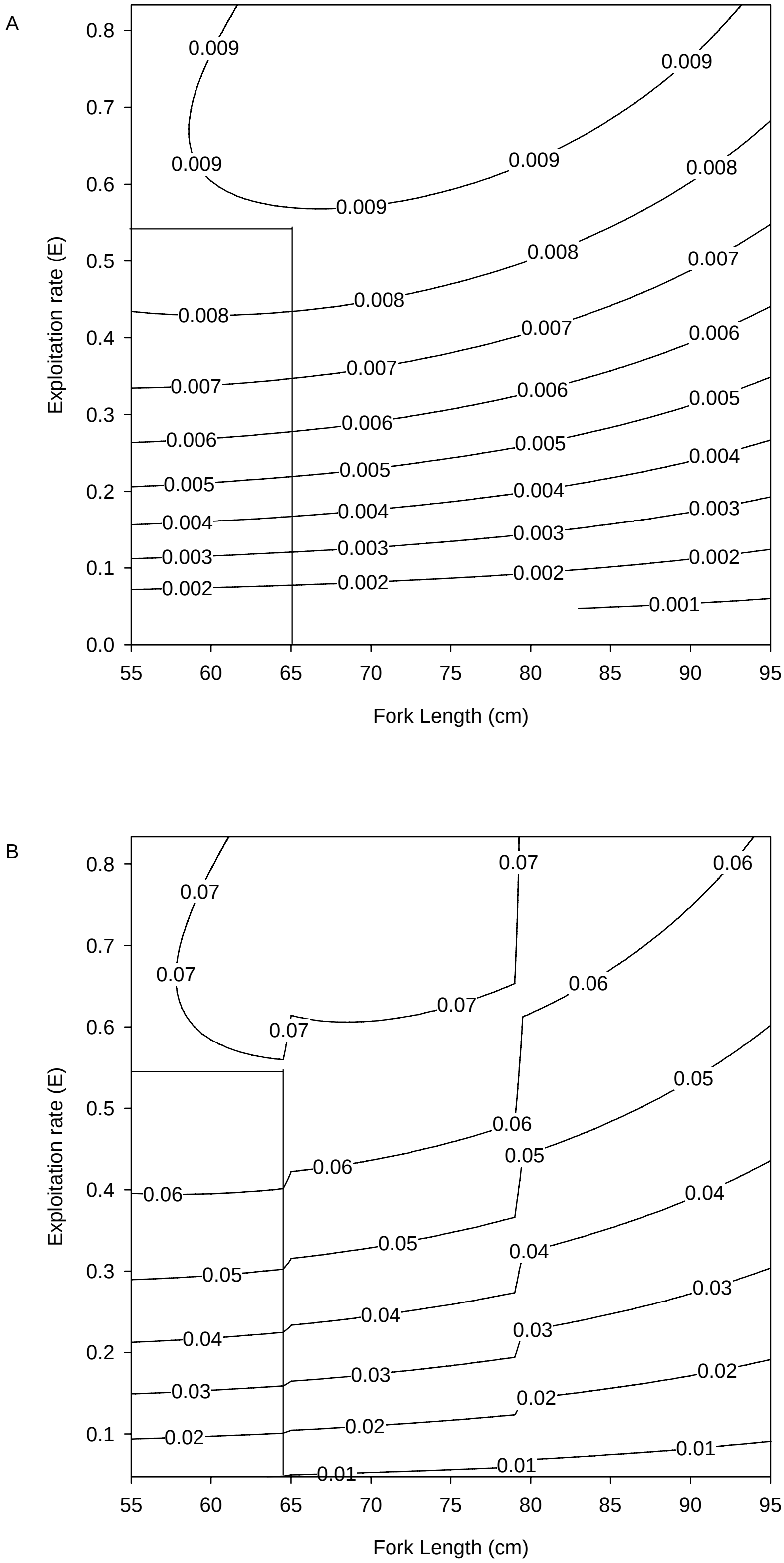


Figure 11.6. Yield and $ per recruit isopleths for kingfish. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

11.3.7. Spawning potential ratio

The SPR for kingfish at current levels of exploitation is ~ 0.11, well below the threshold level of 0.2. Using a less precautionary estimate of M = 0.14 (based on 5% at T_{max}) produces a SPR of ~ 0.05. As such kingfish may be at risk of recruitment failure under present management arrangements. The threshold SPR level of 0.2 could be attained by increasing the MLL to at least 67 cm FL (~ 76 cm TL) (Fig. 11.7).

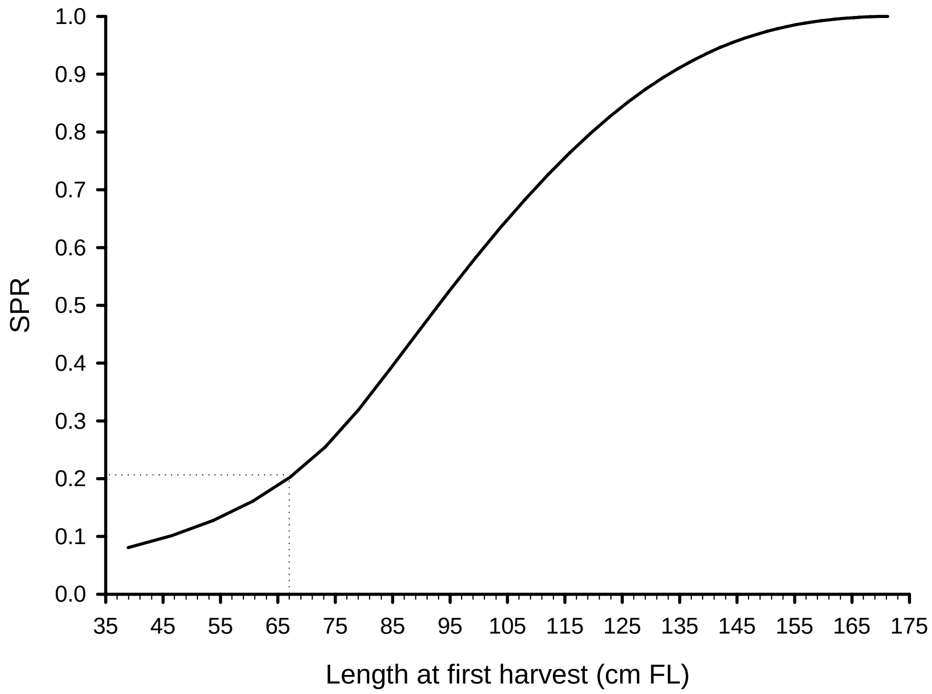


Figure 11.7. Spawning potential ratio for kingfish at current levels of exploitation for a range of sizes at first harvest. The dotted lines indicate the length at first harvest that corresponds to the threshold level of SPR under current levels of exploitation.

11.3.8. *Information fact sheet*

Relevant material from this chapter was collated into an information fact sheet for kingfish (Fig. 11.8). The information was presented as total lengths.

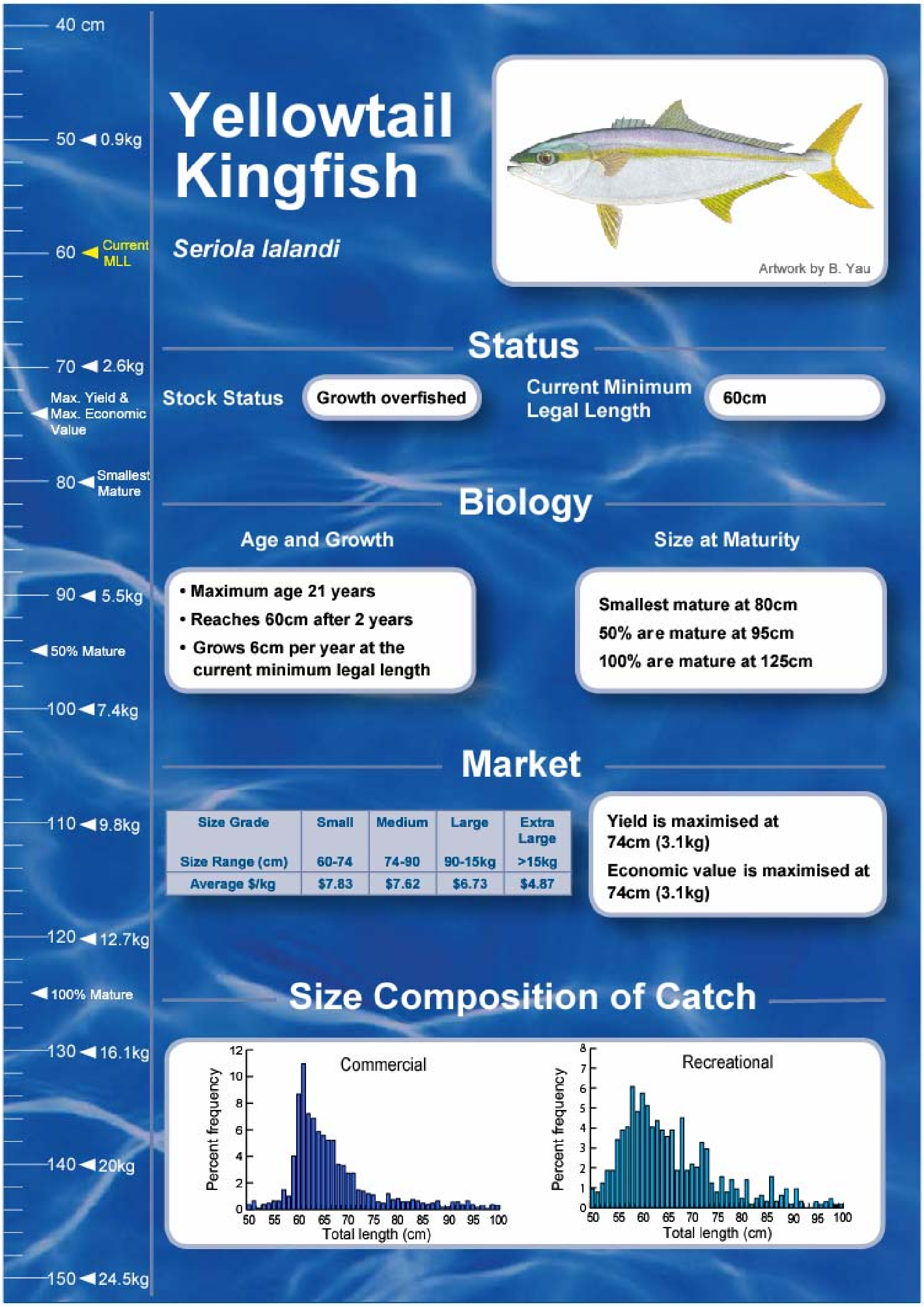


Figure 11.8. Information fact sheet for yellowtail kingfish.

11.4. Discussion

The status of kingfish in NSW as GROWTH OVERFISHED is as a result of yield per recruit analyses. The estimate of M used here (M = 0.2) was at the higher end of the range of expected values, yet the yield per recruit analysis still indicated that increases in yield could be achieved by increasing the size at first capture. The SPR analyses suggest that under current management arrangements and existing levels of exploitation that yellowtail kingfish may be unable to produce sufficient eggs to maintain their population. This is the first time that the reproductive capacity of yellowtail kingfish has been examined in NSW and the results may warrant moving them into the OVERFISHED status category. Other factors that suggest yellowtail kingfish are being exploited unsustainably are that fishing mortality is greater than natural mortality and the majority of fish are being harvested before they attain sexual maturity.

Countering these areas of concern is the fact that landings remain apparently healthy. Commercial catch rates have been generally increasing since 1997/98 and anecdotally the recreational fishery has been good in recent years. In addition, the length composition in landings has remained relatively constant through time; however most fish are caught within 10 cm of the MLL so substantial changes in length distributions due to overfishing would not be expected.

The recreational catch of kingfish in NSW is currently substantially bigger than the commercial harvest and as such it is important that the problems with monitoring the recreational catch using charterboat logbooks are remedied. More detailed assessments, incorporating commercial and recreational landings information, may be required. In addition, the only age-length key for yellowtail kingfish was produced in the late 1990s and it may be timely to update the available size-at-age data.

As a consequence of kingfish maturing at sizes substantially bigger than the current MLL (~ 95 cm vs 60 cm TL), the stated objective of using a MLL in NSW to protect juveniles achieves little. The data presented indicates that increasing the MLL in NSW is likely to result in increases in both yield and reproduction. Losses of fish available to both commercial and recreational fisheries would occur by increasing the MLL; however their fast growth rates and relatively low level of natural mortality suggest that any losses would be short term.

It seems likely that the stock of yellowtail kingfish in NSW is being exploited at a level that is putting its sustainability at risk, and further management measures are required in order to reduce that risk. Fisheries managers are encouraged to state meaningful objectives of their management regulations, particularly with respect to MLLs. Options for managers to consider with associated optimum sizes at first capture are presented in Chapter 16. Note that the analyses concerning MLLs were done using the trailerboat length information as being representative of the recreational fishery. This was because the charterboat logbook data were considered unreliable.

12. BIOLOGY AND FISHERY FOR MULLOWAY

12.1. Introduction

Mulloway (*Argyrosomus japonicus*) of the family Sciaenidae are distributed throughout coastal and estuarine waters of the Pacific and Indian oceans. In Australia, mulloway are found along the south of the continent between ~ Shark bay in W.A. and Brisbane in Qld (www.fishbase.org). Juveniles are found exclusively in inshore waters while adults are mainly inshore and generally in waters less than 100m deep.

In NSW, mulloway are an iconic and valuable commercial and recreational species. The recreational catch is thought to be between five and 10 times the current commercial catch. The Ocean Trap and Line Fishery historically landed ~ 40% of the commercial catch but currently lands ~ 25% of the catch. Most of the Ocean Trap and Line catch is taken by handlining. In 2005/06 ~ 67% of the catch was reported in the Estuary General Fishery. There is a MLL of 45 cm for mulloway in NSW.

Mulloway have been the subject of two recent FRDC funded projects (2002/004 Farmer *et al.*, 2005, and 2001/027 Silberschneider & Gray, 2005). Most information for the present study was obtained from Silberschneider & Gray (2005).

12.2. Materials and methods

Most information in this chapter was sourced from FRDC project 2001/027 and the NSW DPI Resource Assessment Unit. Market price information was obtained and analyses were done according to the methods described in Chapter 2.

12.3. Results

12.3.1. Landings in NSW

12.3.1.1. Current exploitation status

Mulloway are listed as being OVERFISHED in NSW (2005/06). This assessment is based on: (i) the age composition in landings; (ii) declines in catches and catch rates; and (iii) a spawning potential ratio below the recommended threshold.

12.3.1.2. Trends in catch

Reported commercial landings of mulloway have declined from ~ 250 tonnes per year during the early 1970s to ~ 60 tonnes during 2005/06 (Fig. 12.1). CPUE shows a similar decreasing trend through time. The offshore handline component of the fishery tends to target aggregations of fish during the spawning season and a decline in catch rates in this sector may reflect a decline in abundance of spawning fish. The most recent estimate of the recreational harvest in NSW was ~ 270 tonnes between April 2000 and March 2001 (Henry & Lyle, 2003). This estimate may have been an underestimate because it assumed an average weight of 2 kg per fish retained. The average size of mulloway observed in recreational catches by Steffe *et al.* (1996) was ~ 80 cm (~ 4.5 kg), which when applied to the numbers caught results in an estimate of ~ 600 tonnes by recreational fishers in NSW. However, this calculation may provide an over-estimate because Steffe's study did not include estuarine-caught mulloway that may be, on average, smaller than those caught offshore.

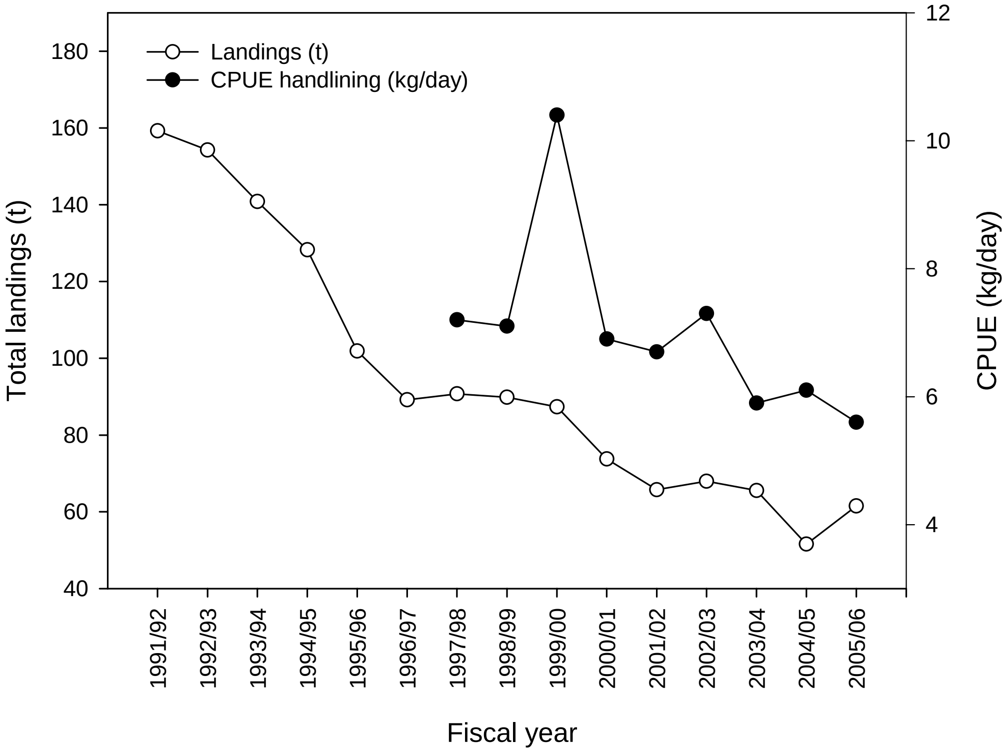


Figure 12.1. Reported commercial landings and catch rates (kg per day handlining) of mulloway in NSW. Source: NSW DPI Resource Assessment System.

12.3.1.3. Length measurements

Commercial landings

The sizes of mulloway landed by commercial fishers between 2003 and 2005 were generally close to the MLL of 45 cm (Fig. 12.2). More than 80% of the catch was of fish within 15 cm of the MLL. Overall, the sizes of mulloway reported from the estuarine sector were similar to those reported from the ocean sector; however the ocean sector did report a greater proportion of large (> 70 cm) individuals. Discarding of mulloway smaller than the MLL has not been quantified but is thought to be substantial.

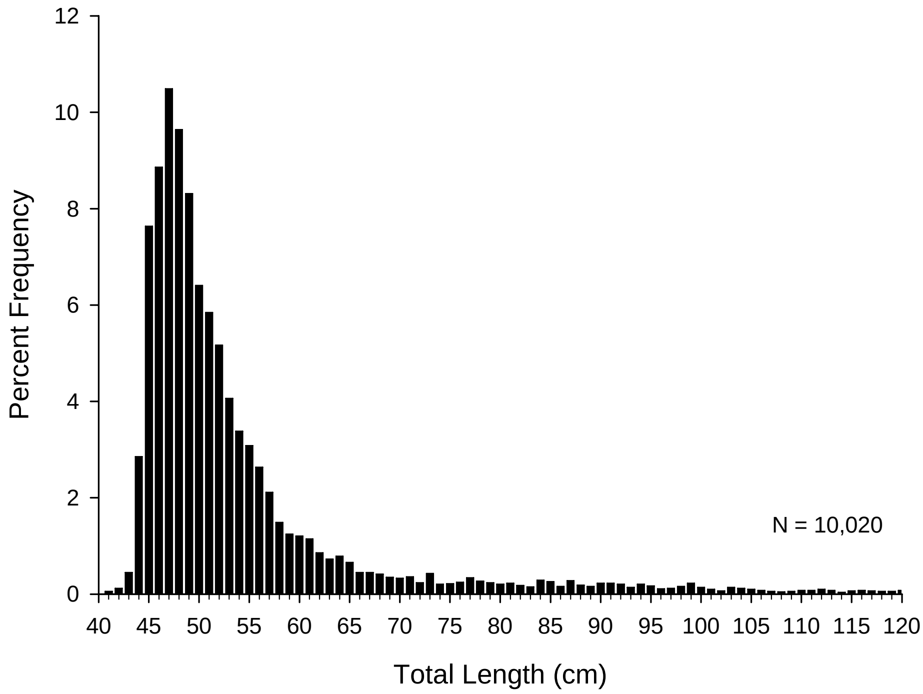


Figure 12.2. The lengths of mulloway landed by commercial fishers 2003 to 2005. Source: Silberschneider & Gray, 2005.

Recreational landings

The sizes of mulloway landed by offshore trailerboat fishers in NSW during the early 1990s were, on average, considerably larger than those landed by the commercial fishery in recent years (Fig. 12.3). This may have been a result of smaller mulloway being more common in estuaries and not as available to offshore trailerboat fishers. The sizes of mulloway reported by charterboat fishers are similar to those from trailerboat fishers (Fig. 12.4). This similarity in sizes, in contrast with the poor agreement for most other species in this report, may be because mulloway do not have forked tails and so the same body measurements were made in each sector. Nevertheless, major peaks at 5 and 10 cm intervals in the charterboat data suggest that the lengths of many fish are being estimated.

Approximately 25% of all mulloway captured by recreational fishers in NSW are released (Henry & Lyle, 2003). There is little useful published information on the mortality of released line-caught mulloway. Studies that have attempted to quantify mortality have been done so in aquaria using extremely small mulloway from hatcheries and have reported relatively high survival rates.

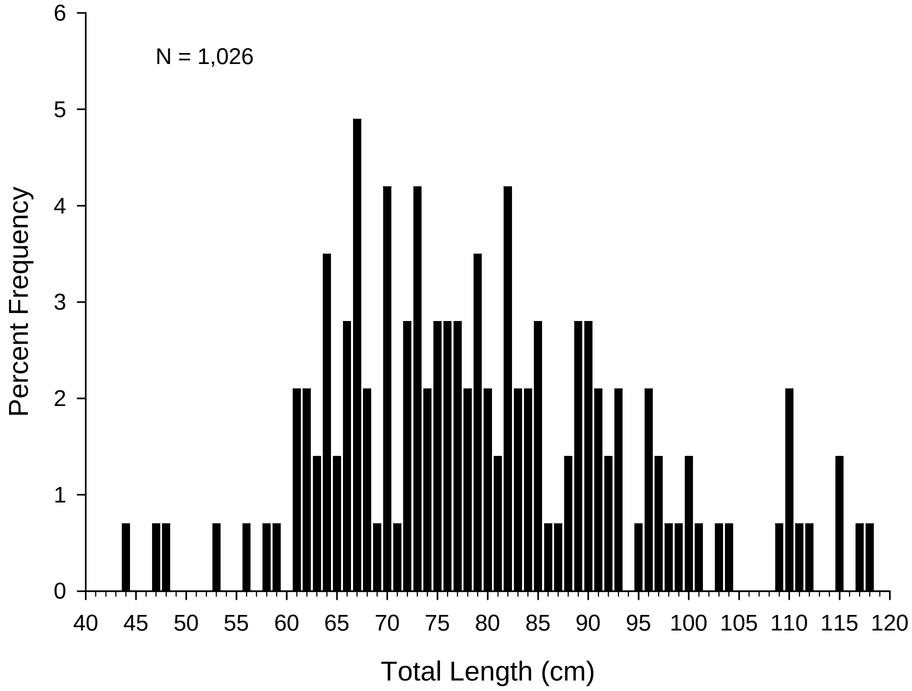


Figure 12.3. The lengths of mulloway landed by offshore trailerboat fishers 1993/94 and 1994/95. Source: Steffe *et al.*, 1996.

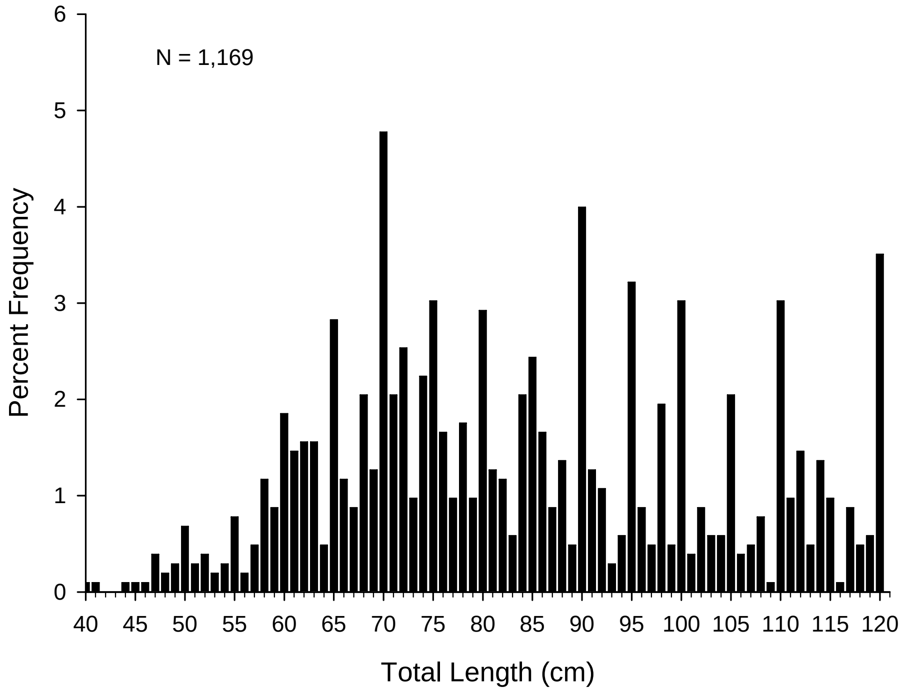


Figure 12.4. The lengths of mulloway measured by NSW charterboat operators 2001 to 2003.

12.3.2. *Reproduction*

Information on the reproductive biology of mulloway is from Silberschneider & Gray (2005). Spawning is thought to occur in estuaries and the ocean, mainly between November and March. The size at 50% sexual maturity for mulloway in NSW is ~ 68 cm for females and 51 cm for males. These estimates are considered to be robust, as fish collected for determination of sexual maturity were done so during the spawning period. Both sexes are estimated to mature after two to three years.

12.3.3. *Age and growth*

Mulloway in NSW have been aged using sectioned otoliths and the information presented here is from Silberschneider & Gray (2005). Mulloway grow quickly and attain, on average, ~ 45 cm after one year and ~ 95 cm after five years. Mulloway in South Africa have been reported to attain > 180 cm and > 75 kg. They have been reported to live for at least 42 years. The maximum age reported by Silberschneider & Gray (2005) during a two year study was 24 years. Growth of mulloway in NSW is described by the von Bertalanffy growth function parameters: L_∞ = 131.7 cm, K = 0.20yr^{-1} and t_0 = -0.55 years.

The commercial fishery for mulloway in NSW is dominated (98%) by fish aged between two and five years old. There are very few older fish in landings, despite the potential for mulloway to live for more than 40 years.

12.3.4. *Mortality estimates*

Mortality estimates are from Silberschneider & Gray (2005). Total mortality (Z) was estimated from catch curve analysis (ages two to 15 years) as being 0.45. Natural mortality was estimated to range between 0.2 and 0.13 based on 1% and 5% of fish attaining the maximum age of 24 years.

The estimates of mortality applied in the present study were: Z = 0.45, M = 0.13 and F = 0.32.

12.3.5. *Market price*

Mulloway sold through the Sydney Fish Markets are graded according to the following schedule:

Small	45 to 50 cm
Medium	50 to 70 cm
Large and Extra large	> 70 cm

Average prices for mulloway sold through the Sydney Fish Markets during 2005/06 indicate that price did not change substantially with size grade; however the smaller grades did attain slightly higher average prices than the larger grades (Fig. 12.5).

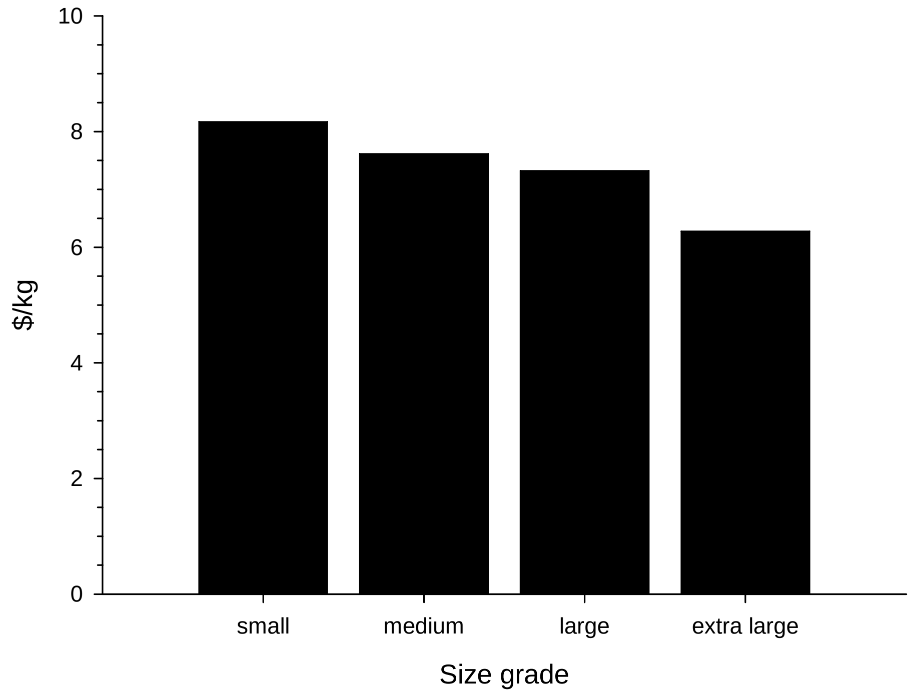


Figure 12.5. Average price information by size grade of mulloway sold through the Sydney Fish Markets 2005/06.

12.3.6. Per recruit analyses

Per recruit analyses were done using the following parameters:

L_∞ = 131.7 cm
K = 0.20 yr^{-1}
T_0 = -0.55 yr
M = 0.13
Z = 0.45
F = Z-M = 0.32
E = F/Z = 0.711
M/K = 0.65

with market price information and size grades as described above. Where L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation that yield and $ per recruit are maximised at ~ 96 cm (Fig. 12.6).

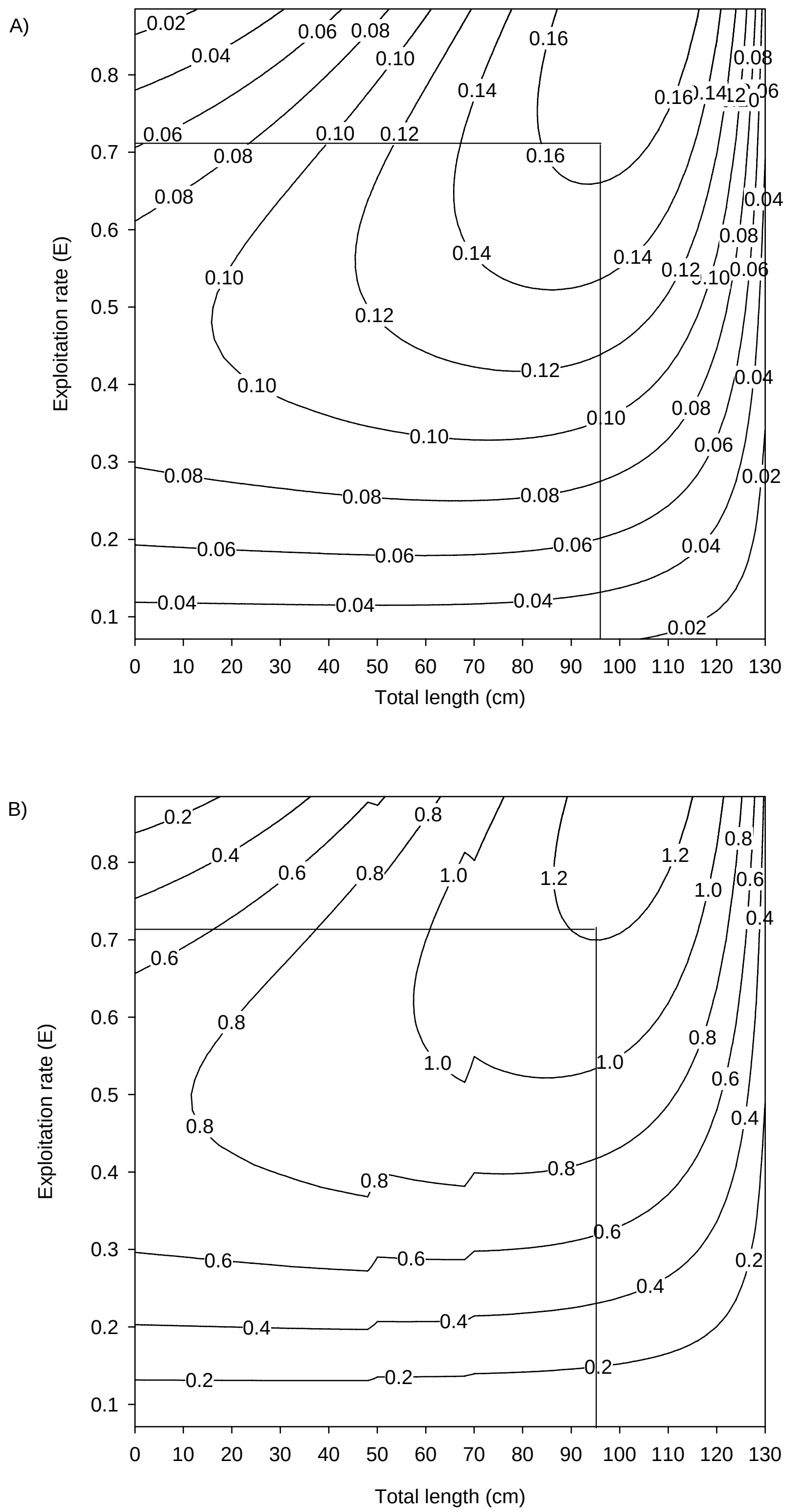


Figure 12.6. Yield and $ per recruit isopleths for mulloway. Lines indicate the current level of exploitation rate and corresponding lengths at which they are maximised.

12.3.7. Spawning potential ratio

The SPR for mulloway at current levels of mortality is 0.11, well below the threshold level of 0.2 (Fig. 12.7). The SPR is affected by the value of natural mortality; however even when using the less conservative estimate of M = 0.2 (based on 1% attaining T_{max}) the SPR is ~ 0.23. The SPR level indicates that at current levels of exploitation and with a MLL of 45 cm that mulloway are at risk of recruitment failure. The threshold SPR level of 0.2 could be attained by increasing the MLL to at least 68 cm.

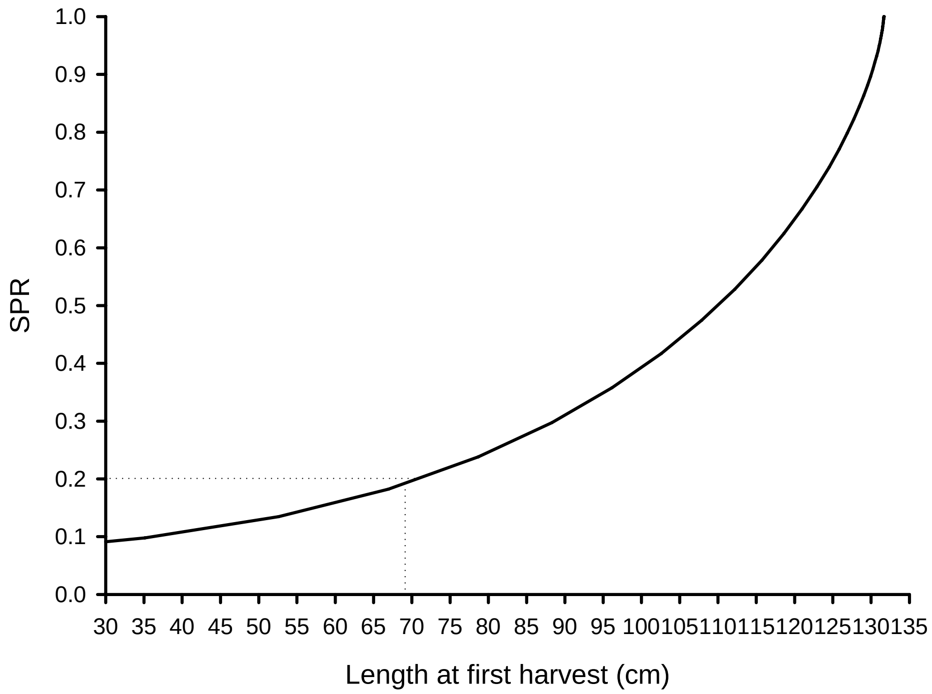


Figure 12.7. Spawning potential ratio for mulloway at current levels of exploitation for a range of sizes at first harvest. The dotted lines indicate the threshold level for sustainability at current levels of exploitation.

12.3.8. *Information fact sheet*

Relevant material from this chapter was collated into an information fact sheet for mulloway (Fig. 12.8).

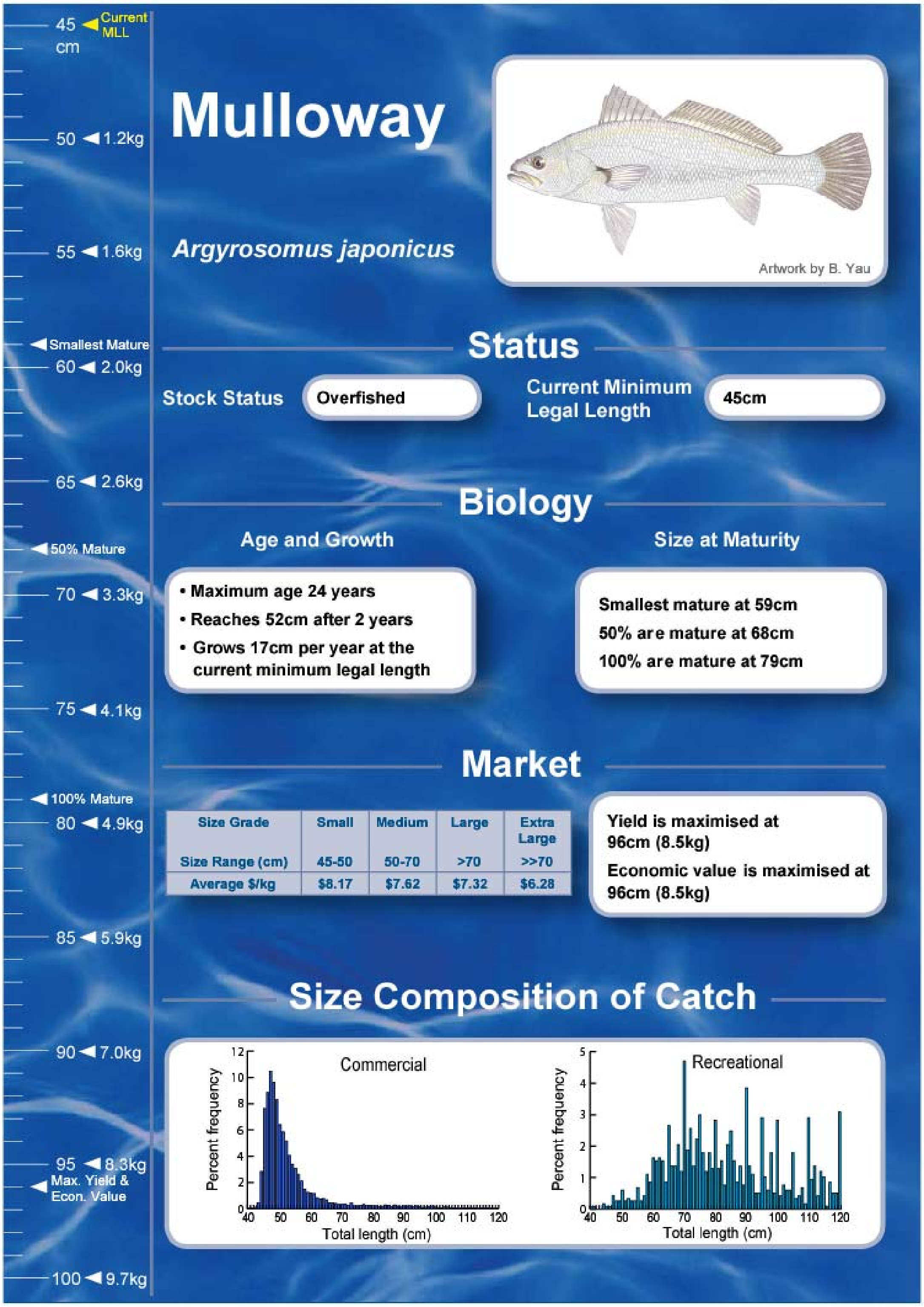


Figure 12.8. Information fact sheet for mulloway.

12.4. Discussion

The status of mulloway in NSW as OVERFISHED is in recognition that the stock may be in a severely depleted state. Mulloway were assessed as being overfished following the recently completed FRDC funded project (Silberschneider & Gray, 2005). The authors identified several areas of concern. Mulloway are substantially growth overfished, but there are also concerns that they may already be recruitment overfished. Long-term declines in landings and CPUE for the offshore handline fishery (that tends to target spawning aggregations during summer), the near absence of older (> five years) fish in landings, and a spawning potential ratio that may be 10% of virgin levels all suggest that the spawning stock is currently very low.

Revised estimates of the recreational harvest of mulloway in NSW (based on the average size of fish in landings) indicate that the recreational harvest may be up to 10 times the commercial harvest. This is important when considering how best to monitor the health of the stock when using landings information. It should also assist when considering how to increase protection for mulloway and the impacts that any further regulations may have on different stakeholder groups.

The majority of available information on the sizes of mulloway retained by recreational fishers in NSW comes from fishers fishing in offshore waters (e.g., offshore trailerboat fishers (Steffe *et al.* 1996) and charterboat logbooks). Small mulloway inhabit estuaries and move into offshore coastal waters after ~ two years. The recreational catch of small mulloway in estuaries has not been monitored, and as a consequence the overall size frequency distribution for mulloway is not particularly useful for management. As an example, current information suggests that most recreationally caught mulloway are greater than 60 cm long (see Figs. 12.3 & 12.4) and that therefore the MLL could be increased to 60 cm with almost no negative impacts on recreational fishers. This is unlikely to be the case for recreational fishers in estuaries.

As a consequence of being listed as OVERFISHED, NSW DPI is in the process of developing a recovery program for mulloway. One management change that has been discussed is increasing the MLL for mulloway in NSW. The current MLL of 45 cm is substantially smaller than the estimated size at maturity of ~ 70 cm and therefore does little to protect juveniles. In addition, mulloway will remain as being growth overfished while the size at recruitment to the fishery remains small. The problem for fisheries managers is that increasing the MLL of mulloway to a biologically and economically sensible size may be unpopular with some fishers. This may especially be the case for commercial estuarine fishers whose catch is mostly of juvenile fish < 70 cm long. In fact, a proposal to increase the MLL of mulloway in 2006 from 45 to 50 cm was ultimately rejected by NSW DPI management because of the negative impact it would have on commercial estuarine fishers. In the absence of alternative mechanisms to protect mulloway this decision is difficult to understand. There is a lot of evidence that mulloway require increased protection as both juveniles and spawning adults, and increasing the MLL is a tool that should be considered to help in achieving this.

The information presented here and in Chapter 16 should assist managers when considering long-term benefits versus short-term losses at varying MLLs for mulloway. The framework for setting appropriate sizes at first harvest in chapter 16 should assist fisheries managers in setting effective management objectives and in understanding how they may be achieved through using MLLs.

13. BIOLOGY AND FISHERY FOR SNAPPER

13.1. Introduction

Snapper (*Pagrus auratus*) of the family Sparidae are distributed throughout the Indo-Pacific including New Zealand, the Philippines, Indonesia, China, Japan and Taiwan. In Australia snapper are common in coastal and deep offshore waters (< 200 m) of Australia's southern half from Hinchinbrook Island (Qld) to the central coast of Western Australia (WA), and occasionally on the north coast of Tasmania (Tasmania).

In NSW, snapper are an iconic species which are excellent to eat, grow to large sizes, provide good sport and have an attractive appearance. These qualities have resulted in snapper being heavily targeted by commercial and recreational fishers. In NSW and Queensland snapper are listed as being growth-overfished and there is increasing evidence that the stock is over-exploited (Allen *et al.*, 2006). The MLL for snapper in NSW was increased from 28 cm TL to 30 cm TL in July 2001. A further increase to 32 cm is planned but to date has not occurred. Almost all (97%) commercially landed snapper in NSW are caught in the Ocean Trap and Line Fishery with the majority being caught in fish traps.

Snapper have been the subject of previously FRDC funded research and much of the information on growth and maturity in this chapter was sourced from FRDC project 93/074 (Ferrell & Sumpton, 1997).

13.2. Materials and methods

Information was gathered from various sources. Data on maximum age and size at sexual maturity was from Ferrell & Sumpton (1996). Growth was modelled using the von Bertalanffy growth function and composite size-at-age information. The size-at-age information for commercially landed snapper was from Ferrell & Sumpton (1996) while information for small snapper was from cohort analysis and size-at-age data from the NSW Fisheries Deepwater Ocean Outfall Monitoring project. Fork lengths were converted to total lengths using the relationship from Western Australia (Moran & Burton, 1990).

13.3. Results

13.3.1. Landings in NSW

13.3.1.1. Current exploitation status

Snapper are listed as being GROWTH OVERFISHED in NSW (2005/06). This assessment is based largely on yield per recruit analyses (Ferrell & Sumpton, 1997).

13.3.1.2. Trends in catch

Reported commercial landings of snapper in NSW have declined since the early 1990s (Fig. 13.1). This decline has been associated with a decline in the number of commercial snapper fishers. CPUE has increased steadily since the MLL was increased from 28 cm to 30 cm TL in July 2001. The most recent estimate of the recreational harvest in NSW was ~ 117 tonnes between April 2000 and March 2001 (Henry & Lyle, 2003). This estimate may have been an under-estimate because it assumed an average weight of 0.35 kg per fish. The most reliable information on the sizes of snapper retained by recreational fishers is from Steffe *et al.* (1996) and shows an average length of ~ 31 cm FL (see Fig. 13.3) which corresponds to an average weight of 0.67 kg per fish (using the length/weight relationship from Moran & Burton, 1990). Using an average weight of 0.67 results in an estimated recreational take of ~ 224 tonnes per year, similar to the NSW commercial catch (prior to the increase in MLL in 2001). Steffe *et al.* (1996) estimated the snapper catch by offshore recreational trailerboat fishers in NSW to be ~ 184 tonnes during 1993/94 and ~ 188 tonnes during 1994/95.

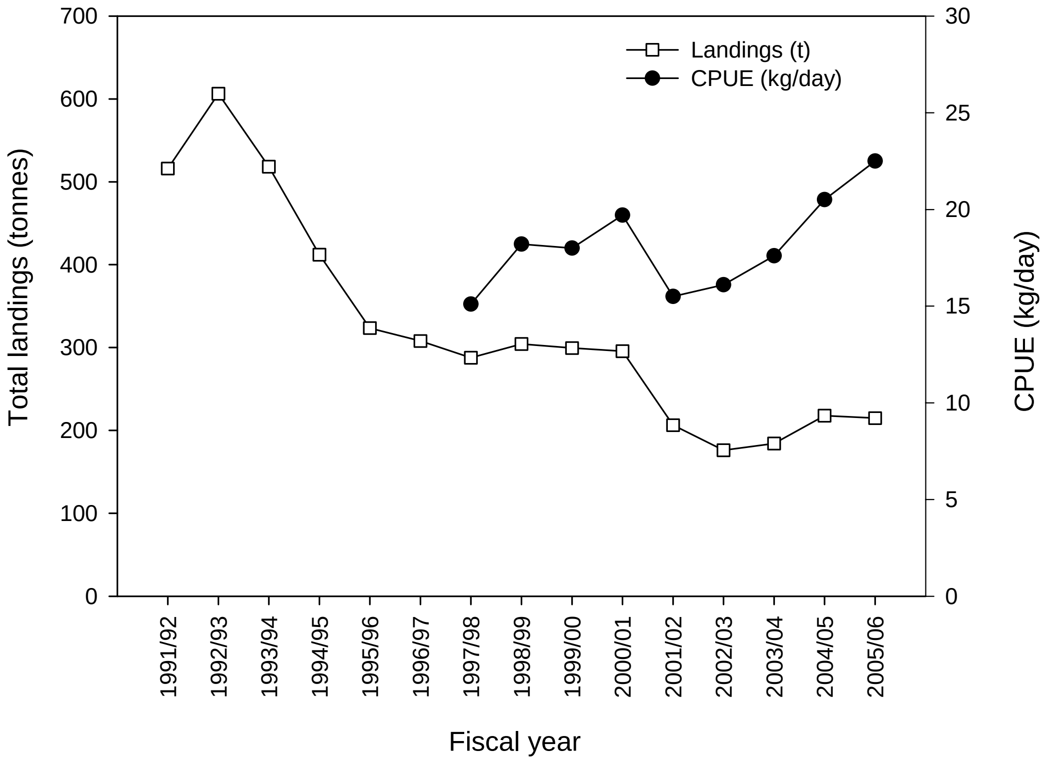


Figure 13.1. Reported commercial landings and catch rates (kg per day fish trapping) of snapper in NSW. Source: NSW DPI Resource Assessment System.

13.3.1.3. Length measurements

Commercial landings

The sizes of snapper landed by commercial fishers have been stable since the early 1990s, with the exception being an increase in size of the smallest fish by two cm as a result of the increase in MLL in 2001. The majority of the catch (70%) is within the first five cm of the current MLL of 30 cm TL (~ 25 cm FL) Fig. 13.2. Commercial trap fishers are thought to discard ~ 50% of all snapper they catch because they are smaller than the MLL (based on data from Stewart & Ferrell, 2003).

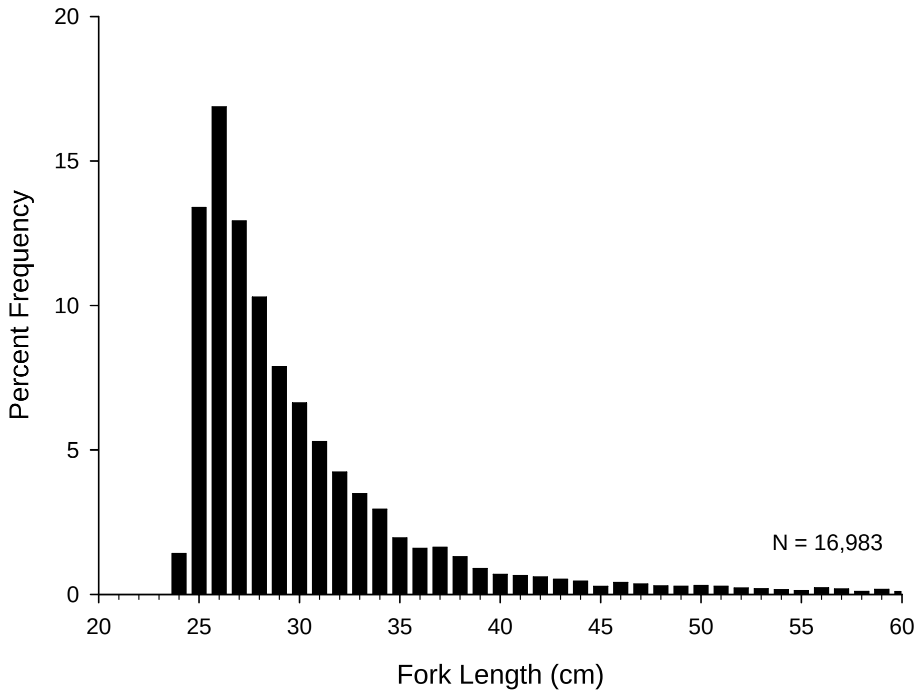


Figure 13.2. The lengths of snapper landed by commercial fishers in NSW during 2005/06. Source: NSW DPI Resource Assessment System.

Recreational landings

The sizes of snapper landed by trailerboat fishers in NSW during the early 1990s are similar to those landed by commercial fishers when a 2 cm increase in MLL is accounted for (Fig. 13.3). The sizes of snapper reported by charterboat fishers since 2001 are considerably larger, on average, than those landed by trailerboat and commercial fishers (Fig. 13.4). Varying peaks in abundance with such a large sample size (> 65,000 fish) and also at 30 cm suggests that many of the measurements were: (i) estimated, and; (ii) total lengths.

Approximately 66% of recreationally caught snapper are released (Henry & Lyle, 2003). There is little useful information on the survival of recreationally caught and released snapper; however Broadhurst *et al.* (2005) reported a discard mortality rate of > 30% in the shallow waters (< 6 m deep) of Botany Bay, Australia.

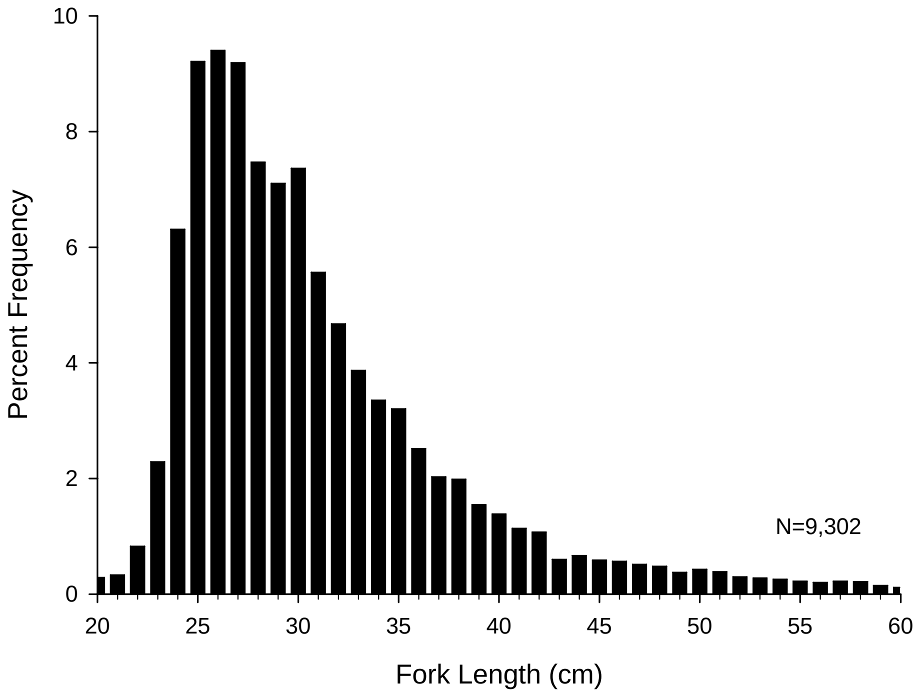


Figure 13.3. The lengths of snapper landed by offshore trailerboat fishers 1993/94 and 1994/95. Source: Steffe *et al.*, 1996.

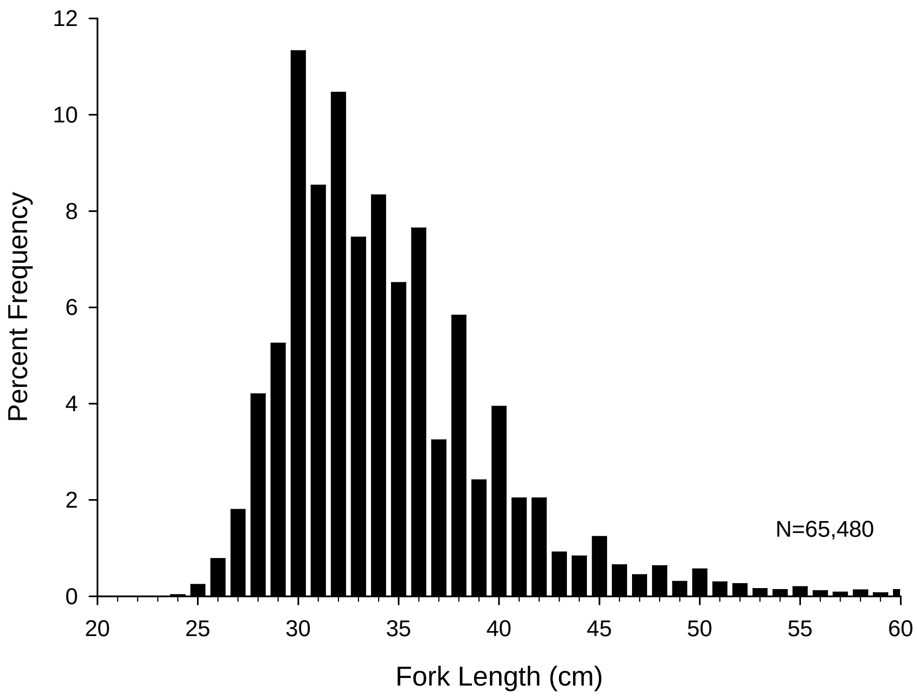


Figure 13.4. The lengths of snapper measured by NSW charterboat operators 2001 to 2003.

13.3.2. Reproduction

Snapper off the east coast of Australia are reported to spawn during winter/spring (Ferrell & Sumpton, 1997); however the peak times almost certainly vary with latitude.

Size at sexual maturity has not been well documented along the east coast of Australia. The best estimate is from snapper in Queensland (Ferrell & Sumpton, 1997) who did not sample fish during the spawning period specifically to estimate size at maturity. The best estimate available is that 50% are mature at 22 cm FL (~ 25 cm TL) and two years of age. All fish are mature by 33 cm FL and five years old.

13.3.3. Age and growth

13.3.3.1. Ageing procedure and validation

Age and growth of snapper has been estimated using sectioned otoliths (Ferrell & Sumpton, 1997). Snapper grow quickly as juveniles and attain ~ 30 cm FL after ~ 3 years. There is considerable variation in size-at-age. Snapper can grow to weigh ~ 16 kg, and in NSW have been observed to attain 40 years of age. Growth of snapper in NSW is best estimated using a combination of size-at-age information from commercially landed fish (Ferrell & Sumpton, 1997) with that from fish smaller than the MLL and juvenile cohort analysis (NSW DPI unpublished data). The resulting 'best' description of growth is provided by the von Bertalanffy growth function parameters: L_∞ = 57.4 cm, K = 0.138 yr^{-1} and t_0 = -2.2 years.

The fishery for snapper in NSW since the increase in MLL to 30 cm TL in 2001 has been dominated by fish aged three and four years old, with more than 90% of the fishery consisting of fish aged less than six years old (NSW DPI unpublished data).

13.3.4. Mortality estimates

Total mortality (Z) was estimated as the average of Z values from catch curves for 1999/00 to 2003/04 between ages three and 19. The average estimate of Z was 0.47. M is estimated to range between 0.08 and 0.12 based on whether 5% or 1% of snapper attain the observed maximum age of 40 years.

The estimates of mortality applied in the present study were: Z = 0.47, M = 0.12 and F = 0.35.

13.3.5. Market price

Snapper sold through the Sydney Fish Markets are graded according to the following schedule:

Small	< 34 cm
Medium	34 to 48 cm
Large	48 to 55 cm
Extra large	> 55 cm

Average prices for snapper sold through the Sydney Fish Markets during 2005/06 indicate that the "Small" and "Medium" size grades attained slightly higher prices per kg than the larger size grades (Fig. 13.5). The "Small" grade of snapper received, on average, > $10/kg.

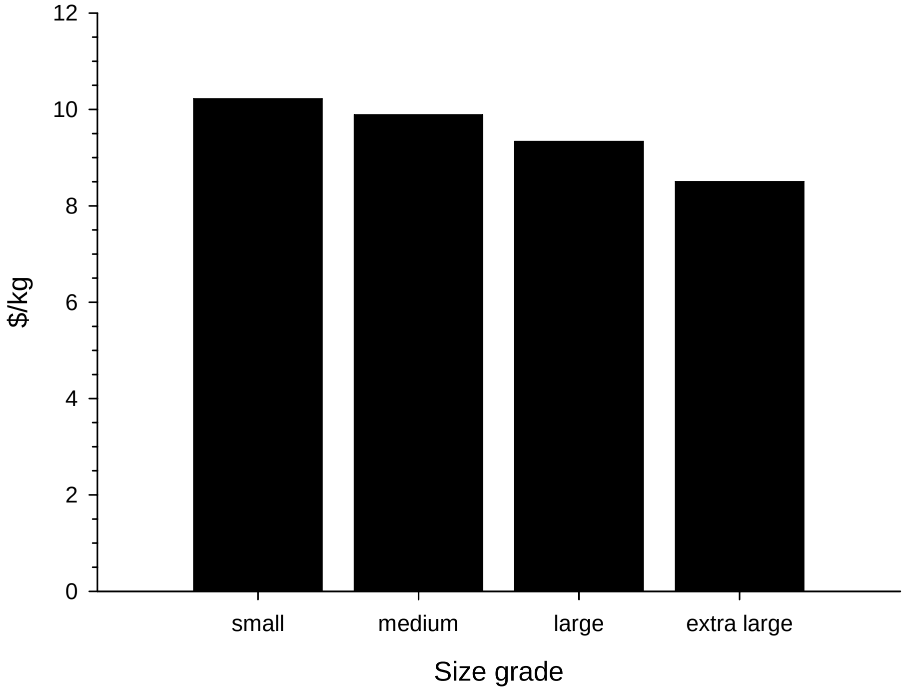


Figure 13.5. Average price information by size grade of snapper sold through the Sydney Fish Markets 2005/06.

13.3.6. Per recruit analyses

Per recruit analyses were done using the following parameters:

L_∞ = 57.4 cm
K = 0.138 yr^{-1}
T_0 = -2.2 yr
M = 0.12
Z = 0.47
F = Z-M = 0.35
E = F/Z = 0.75
M/K = 0.87

with market price information and size grades as described above. Where L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation that yield and $ per recruit are maximised at ~ 40 cm FL (~ 47 cm TL) (Fig. 13.6).

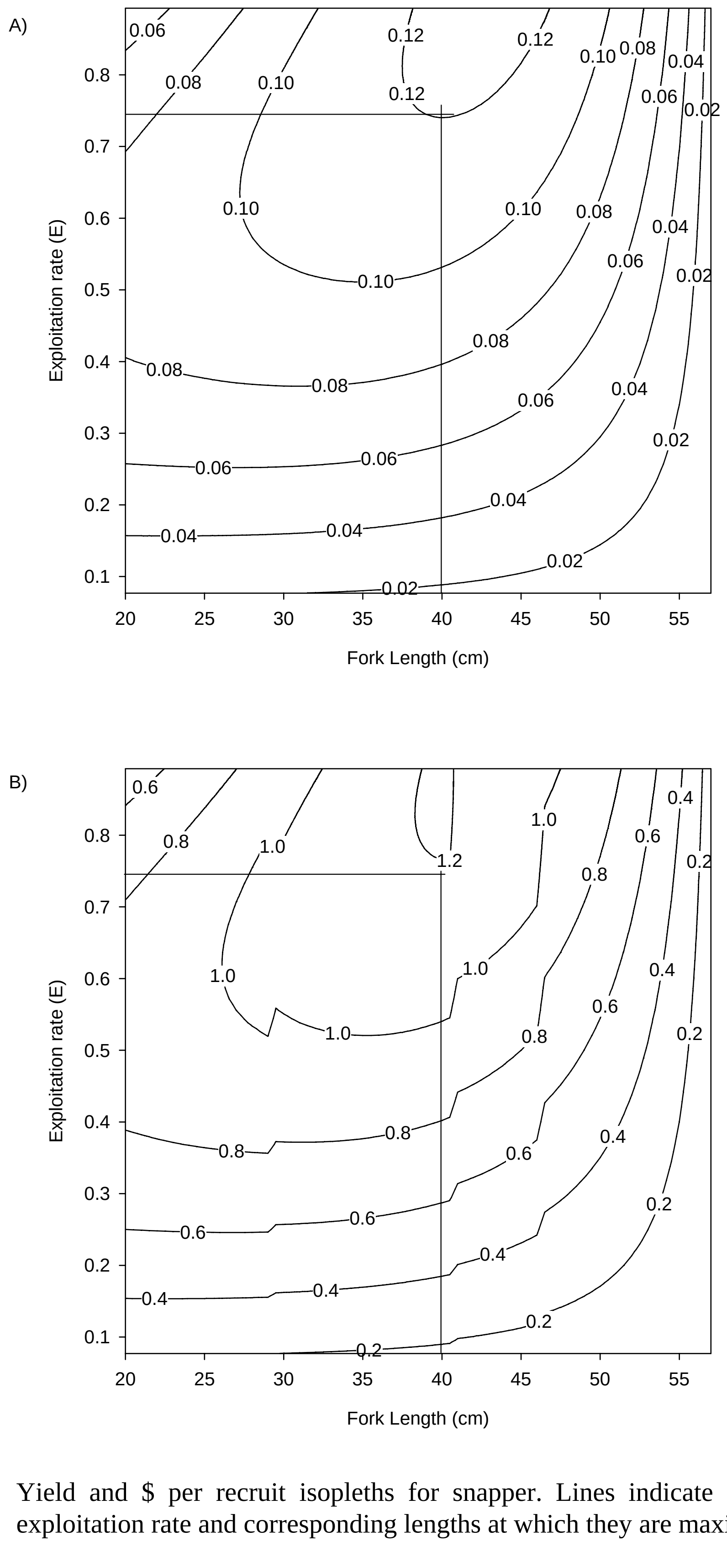


Figure 13.6. Yield and $ per recruit isopleths for snapper. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

13.3.7. Spawning potential ratio

The SPR for snapper at current levels of mortality and a MLL of 25 cm FL is ~ 0.12 (Fig. 13.7). This is lower than the desired level of 0.2; however the SPR for snapper is quite sensitive to estimates of M. Using M = 0.2 rather than 0.12 produces a SPR of ~ 27%. Nevertheless, the most likely situation is that the SPR for snapper is below the threshold level at the current level of exploitation. A MLL of at least 30 cm FL is needed to attain the threshold level of SPR = 0.2.

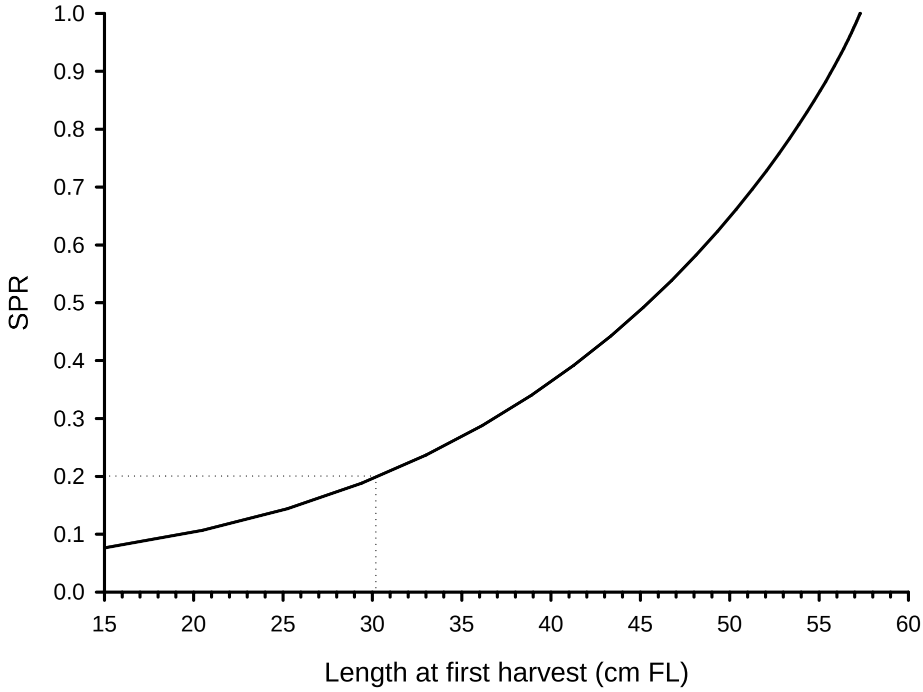
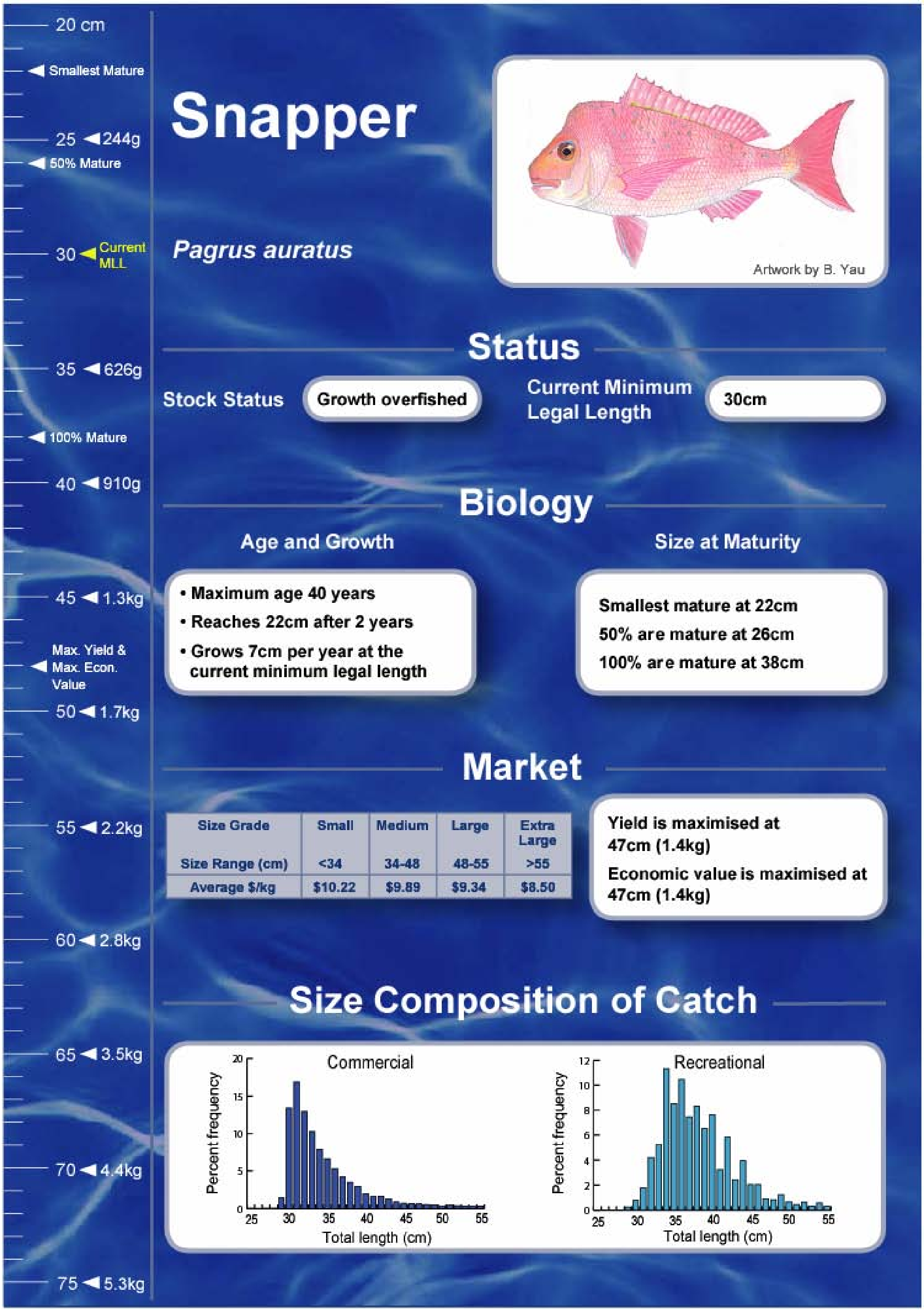


Figure 13.7. Spawning potential ratio for snapper at current levels of exploitation for a range of sizes at first harvest. The dotted lines indicate the threshold level for sustainability at current levels of exploitation.

13.3.8. *Information fact sheet*

Relevant material from this chapter was collated into an information fact sheet for snapper (Fig. 13.8). The information was presented as total lengths.



Size Grade	Small	Medium	Large	Extra Large
Size Range (cm)	<34	34-48	48-55	>55
Average $/kg	$10.22	$9.89	$9.34	$8.50

Figure 13.8. Information fact sheet for snapper.

13.4. Discussion

The status of snapper in NSW as GROWTH OVERFISHED is based on yield per recruit analyses. The debate about the appropriateness of the current MLL of 30 cm TL is ongoing in NSW, with commercial fishers arguing that further increases would harm their businesses. There is strong evidence that the initial increase in MLL from 28 to 30 cm TL has been successful. There have been increases in CPUE along the entire coast following the 1st year after the change and there has been a higher proportion of 'medium' sized fish (aged five to six years) in landings (NSW DPI unpublished report). Nevertheless, managers need to consider both short and longer-term impacts on fishers of further increases.

The size and age frequency distributions of landed snapper are indicative of a stock that is heavily fished. Much (70%) of the catch is within 5 cm of the MLL and the fishery is based on fish aged two to four years old. The SPR analysis indicates that under current levels of exploitation that snapper may be at risk of being unable to sustain their population. Using a less precautionary value of M = 0.2 in the analysis produces a SPR greater than the threshold level of 0.2, but still below the threshold preferred by many of 0.3. The results indicate that increasing the MLL for snapper would result in increases in egg production, would spread the fishery across more age classes (and hence reduce the risk of collapse following poor recruitment episodes) and would address growth overfishing by increasing the yield per recruit.

A lot of snapper are caught and released by commercial and recreational fishers and the mortality of these released fish requires further assessment. Impacts of any further increases in MLL may be confounded by the overall size gradient of small to large fish from shallow to deep waters, with increased discard mortality due to barotrauma.

It is apparent that better information on the reproductive biology of snapper in NSW is needed. The only estimate of size at maturity comes from Queensland and using data which was not specifically collected in order to estimate size at maturity. Information from other states suggests that snapper mature at considerably larger sizes than estimated in Queensland (e.g., 41 cm in Western Australia). Size at maturity is an important factor to consider when setting MLLs and should be a priority for NSW DPI fisheries biology research.

The per recruit analyses indicate that yield and $ per recruit are optimised at ~ 47 cm TL, substantially larger than the current MLL of 30 cm TL and larger than the bulk of commercial and recreational landings. The per recruit analyses were sensitive to estimates of M, with yield being optimized at ~ 37 cm TL if using M = 0.2. Natural mortality is very difficult to estimate and almost certainly varies with age. Recent work done on snapper in Western Australia estimated that M for juvenile snapper may be as high as 2.58 (92% per year) (Wakefield *et al.*, 2007). Our 'best' estimate of M = 0.12 may be reasonable for the entire snapper population but almost certainly under-estimates M for juveniles. Further investigations incorporating differing values of M for different age classes for snapper in per recruit analyses would be useful.

14. BIOLOGY AND FISHERY FOR SWEEP

14.1. Introduction

Sweep (*Scorpis lineolatus*) of the family Scorpididae, are distributed along the coasts of south-eastern Australia and the North Island of new Zealand. In Australia, sweep are most abundant in NSW waters, but also occur in southern Queensland, Victoria and Tasmania. Sweep are a schooling, planktivorous fish that are often observed in mid-water schools feeding above rocky reefs. Adults and juveniles are associated with coastal and estuarine reefs.

The following extract is from Stewart & Hughes (2005). "Silver sweep are commonly captured by both commercial and recreational fishers in NSW. They are a relatively low-value commercial species and, while aggregations are occasionally targeted, are generally considered as a secondary species in the fish trap (60% of the catch) and purse-seine (40% of the catch) fisheries. Approximately 75% of the total commercial catch is taken in the central region of NSW (32°S to 35°S). The recreational fishery is coastal and lands a similar tonnage to the commercial sector (Henry and Lyle, 2003). Silver sweep are generally not highly prized by anglers, but because they grow to a reasonable size, provide good sport and are of a fair eating quality are a welcome catch. They are an important species to recreational fishers and ranked in the top 10 most abundant species caught by offshore trailerboat fishers between 1993/94 and 1994/95 (Steffe *et al.*, 1996). There are currently few regulations that specifically control the harvest of silver sweep. There is a recreational bag-limit of 20 silver sweep per person, but no minimum legal size restriction."

Until recently very little was known of the biology or fisheries for sweep. A previous FRDC funded study (project No. 98/138, Stewart & Ferrell, 2001) documented the sizes retained in demersal fish traps. Stewart & Hughes (2005) described age, growth, reproduction and the NSW fishery for sweep. This chapter collates and presents information from these previous studies in a form that may be useful when assessing an appropriate size at first harvest for sweep.

14.2. Materials and methods

All biological and commercial fishery data for sweep was sourced from Stewart & Ferrell (2001) and Stewart & Hughes (2005). Information from the recreational sector was obtained from Steffe *et al.* (1996) and the NSW DPI charterboat logbook program. All other analyses were as described in Chapter 2.

14.3. Results

14.3.1. *Landings in NSW*

14.3.1.1. Current exploitation status

Sweep are currently listed as being FULLY FISHED in NSW (2005/06). This assessment was based on the extreme longevity identified for this species and evidence of localized depletion where they were targeted by purse-seine vessels. It is recognized that sweep in NSW may not be heavily exploited in some areas and that the stock as a whole may be moderately fished. However, evidence of localized depletion suggests that the stock may not be able to sustain any longer-term increases in fishing effort.

14.3.1.2. Trends in catch

Reported commercial landings of sweep have declined considerably since 1997/98, from ~ 140 tonnes per year to ~ 40 tonnes per year since 2000/01 (Fig. 14.1). This decline in commercial landings was associated with a similarly steep decline in CPUE for purse seining. The CPUE for fish trapping has remained relatively constant and has increased slightly during the past few years. This pattern is reflected by the relative contribution of each fishery to the total NSW commercial landings. The ocean hauling fishery (i.e., purse-seine) landed ~ 60% of the catch during 1999/00 and this has declined steadily through time and is currently (2005/06) only ~ 10% of the total catch. This suggests that the rapid decline in total landings was as a result of localized depletion of sweep on the inshore grounds regularly worked by purse-seine vessels. The most recent estimate of the recreational harvest of sweep in NSW was ~ 93,000 individuals between April 2000 and March 2001 (Henry & Lyle, 2003). Applying the average weight of sweep landed by trailerboat fishers (see Fig. 14.3) of ~ 0.6/kg indicates an approximate annual harvest of 55 tonnes – similar to the commercial harvest.

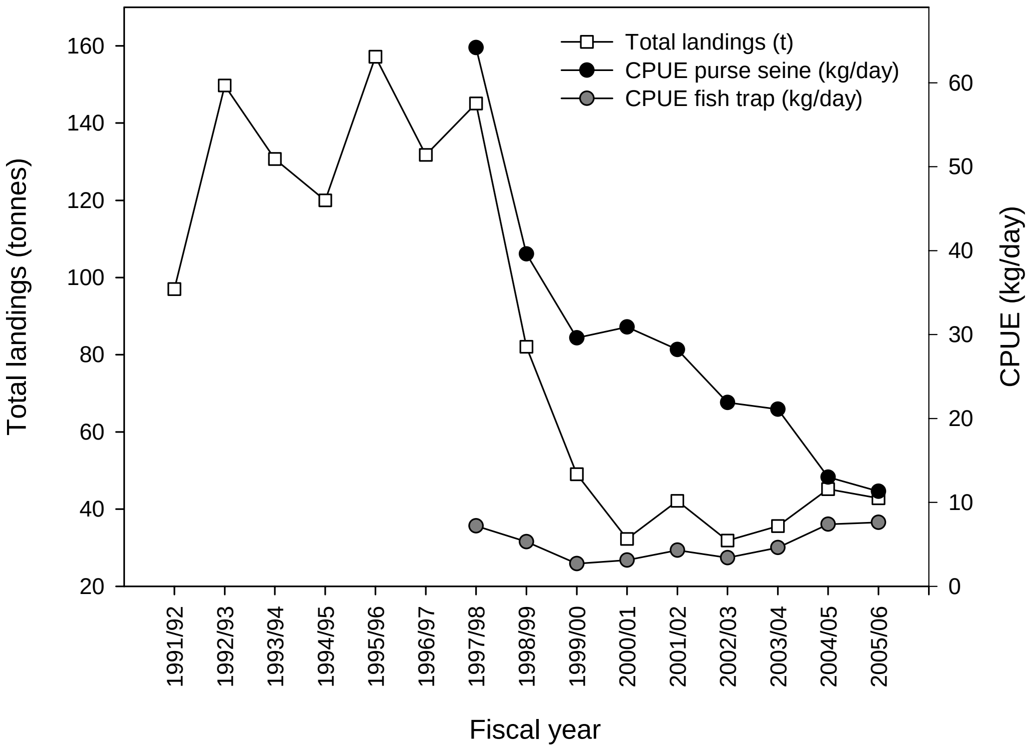


Figure 14.1. Reported commercial landings and catch rates (kg per day fish trapping and kg per day purse-seining) of sweep in NSW. Source: NSW DPI Resource Assessment System.

14.3.1.3. Length measurements

Commercial landings

The lengths of sweep landed by commercial fish trap and purse-seine fishers are similar and were pooled. Likewise, the sizes of sweep landed since 2002 have not changed markedly and were also pooled. The majority of sweep landed by commercial fishers range between 20 and 30 cm FL (Fig. 14.2). There is no MLL for sweep in NSW, yet commercial fish trappers sometimes discard small (< 20 cm) sweep, and larger individuals when only a few are caught, due to poor marketability (Stewart & Ferrell, 2001). Survival rates of discarded sweep are unknown; however observations that sweep are vulnerable to barotrauma and often float when released suggests that it may be low.

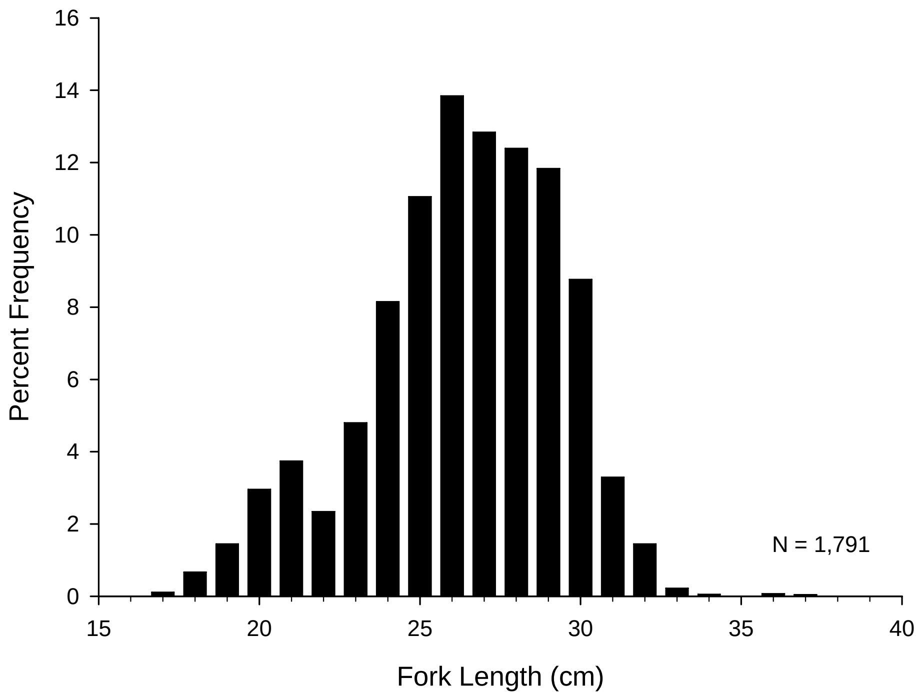


Figure 14.2. The lengths of sweep landed by commercial fishers 2002 to 2006. Source: Stewart & Hughes (2005) and NSW DPI Resource Assessment System.

Recreational landings

The lengths of sweep landed by offshore trailerboat fishers were similar to those landed by commercial fishers (Fig. 14.3). Charterboat operators report catching sweep that are, on average, larger than those captured by trailerboat fishers. Like all the charterboat logbook information presented in this report, the data for sweep should be viewed with caution. It is likely that estimating lengths and measuring total lengths has confounded the data to the extent that charterboat operators often report sweep larger than their maximum recorded size (~ 37 cm TL and 31.3 cm FL). Recreational fishers report releasing ~ 45% of all sweep caught (Henry & Lyle, 2003).

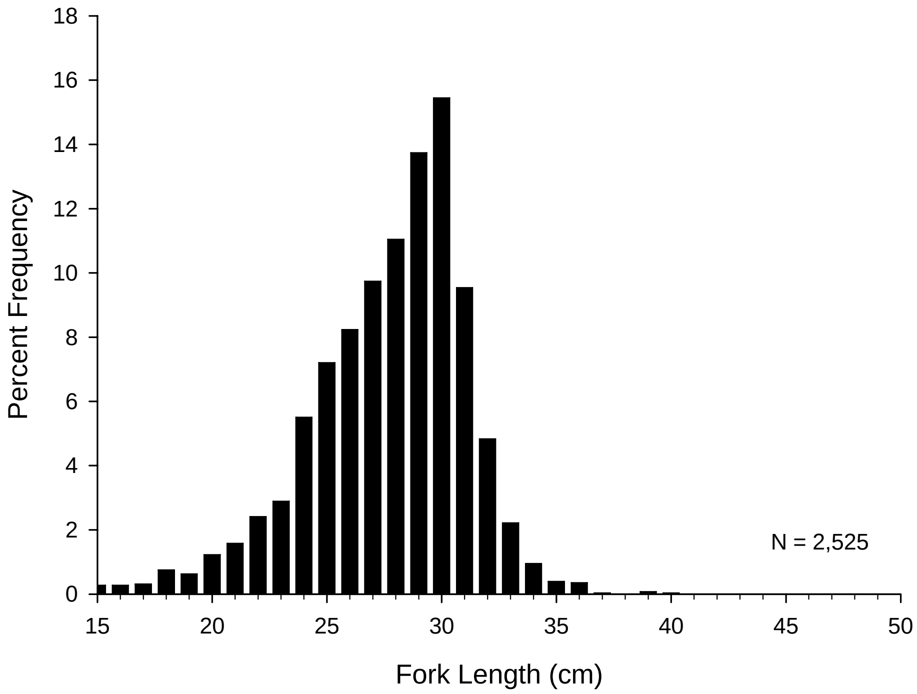


Figure 14.3. The lengths of sweep landed by offshore trailerboat fishers 1993/94 and 1994/95. Source: Steffe *et al.*, 1996.

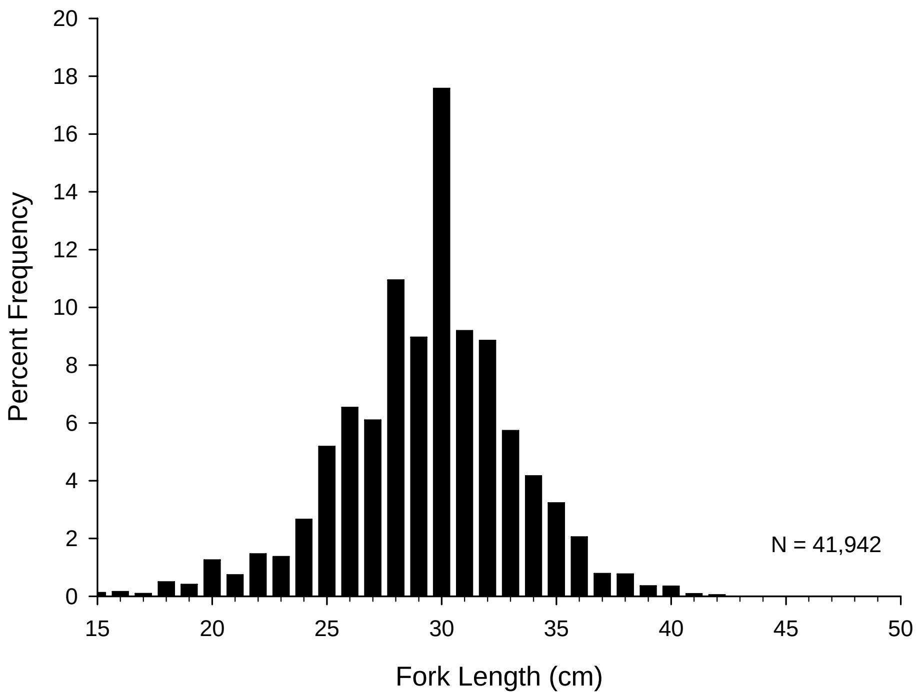


Figure 14.4. The lengths of sweep measured by NSW charterboat operators 2001 to 2003.

14.3.2. Reproduction

Information on reproduction in sweep is from Stewart & Hughes (2005). Sweep have a distinct winter spawning season off the NSW coast with peak activity observed between May and August. There were significantly more females than males in commercial landings during their study (female:male ratio ~ 1.5:1). The size at 50% sexual maturity was 17.2 cm FL (~ 23 cm TL) and at an age of ~ two to three years old.

14.3.3. Age and growth

14.3.3.1. Ageing procedure and validation

Estimates of age and growth for sweep have been made by counting validated annual opaque zones in sectioned otoliths (Stewart & Hughes, 2005). Sweep exhibit extreme longevity with an observed maximum age of 54 years. Growth is rapid during the first few years before reaching sexual maturity, after which growth slows dramatically. There is no difference in growth rates between the sexes and there is considerable variation in size-at-age.

Growth was best described by the four parameter model described in Schnute (1981). However, for the analyses used in the present study the von Bertalanffy growth model was fitted to the size-at-age data. The von Bertalanffy growth function was best described by the following parameters: L_∞ = 26.32 cm, K = 0.47 yr^{-1} and t_0 = -0.47 years. Sweep appear fully recruited to the fishery by age three and the fishery is based on many year classes. Approximately 50% of the catch is of fish aged > 15 years old and more than 20% is of fish aged > 30 years old.

14.3.4. Mortality estimates

Estimates of mortality rates were sourced from Stewart & Hughes (2005) and were based on catch curve analyses and maximum age. The estimates of mortality applied in the present study were: Z = 0.05, M = 0.04, F = 0.01.

14.3.5. Market price

Sweep sold through the Sydney Fish Markets are graded according to the following schedule:

Small	< 25 cm
Medium	25 to 30 cm
Large and Extra large	> 30 cm

Average prices for sweep sold through the Sydney Fish Markets during 2005/06 indicate that the larger size grades attain greater prices than the smaller grades (Fig. 14.5).

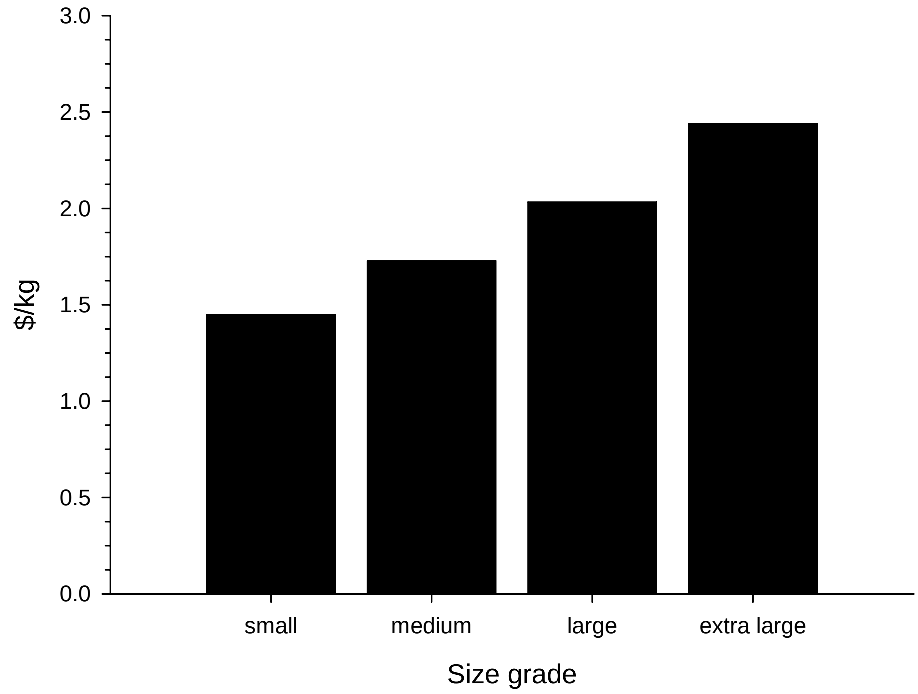


Figure 14.5. Average price information by size grade of sweep sold through the Sydney Fish markets 2005/06.

14.3.6. Per recruit analyses

Per recruit analyses were done using the following parameters:

L_∞ = 26.32 cm
K = 0.47 yr^{-1}
T_0 = -0.47 yr
M = 0.04
Z = 0.05
F = Z-M = 0.01
E = F/Z = 0.2
M/K = 0.085

with market price information and size grades as described above. Where L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation that yield per recruit is optimized at 15 cm FL (~ 18 cm TL) and that $ per recruit is optimized at 25.5 cm FL (~ 30 cm TL) (Fig. 14.6).

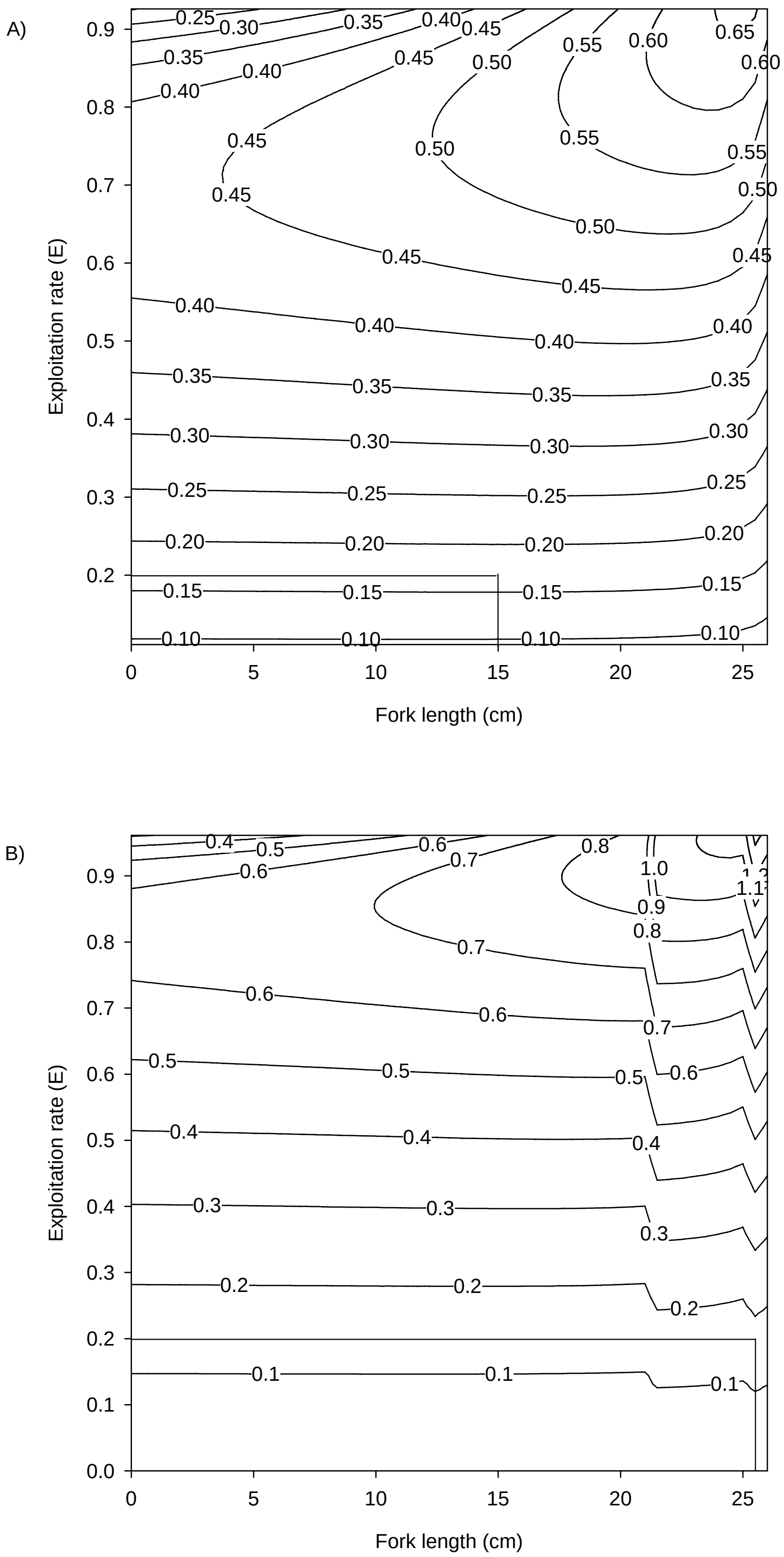


Figure 14.6. Yield and $ per recruit isopleths for sweep. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

14.3.7. Spawning potential ratio

The SPR for sweep at current levels of mortality is well above the threshold level of 0.2 and indicates that at current levels of exploitation that sweep should be producing sufficient eggs to sustain the population regardless of their size at first harvest. The smallest sweep in landings are ~ 20 cm FL and this size at first harvest corresponds to a SPR of ~ 0.86 (Fig. 14.7).

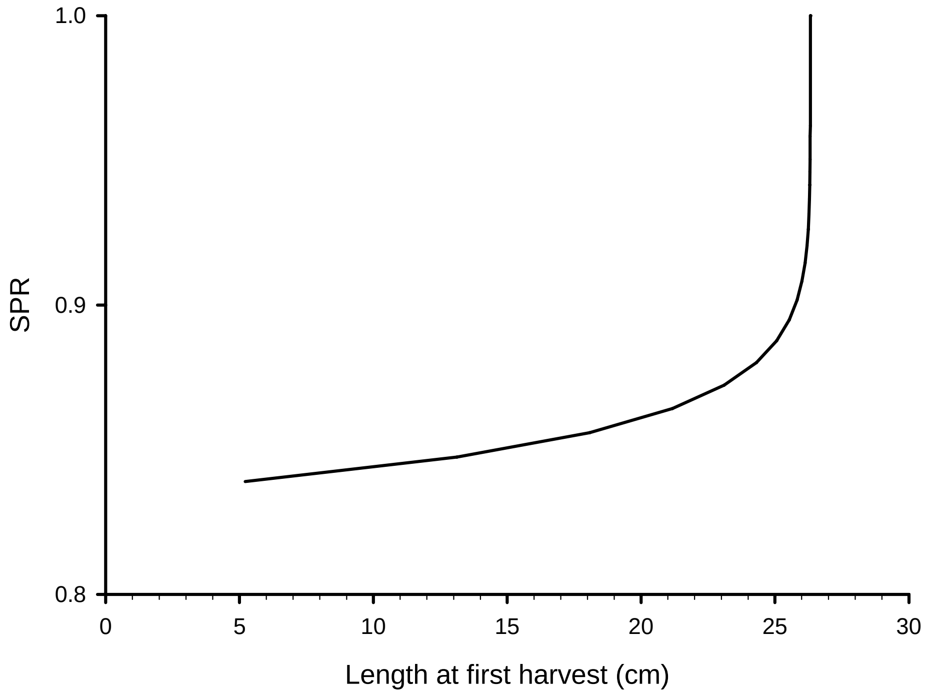


Figure 14.7. Spawning potential ratio for sweep at current levels of exploitation for a range of sizes at first harvest.

14.3.8. *Information fact sheet*

Relevant material from this chapter was collated into an information fact sheet for sweep (Fig. 14.8). The information was presented as total lengths.

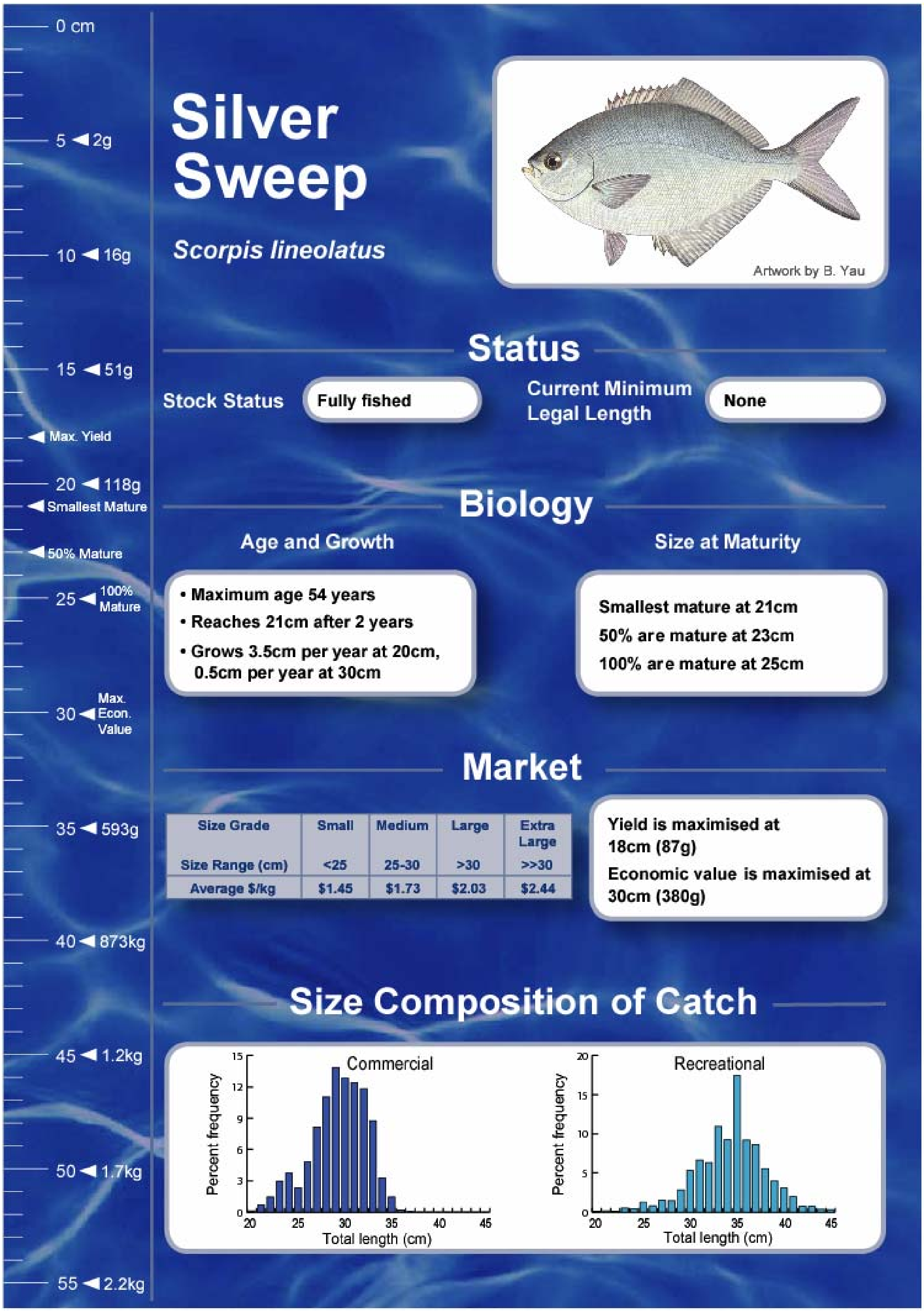


Figure 14.8. Information fact sheet for sweep.

14.4. Discussion

The status of sweep in NSW as being FULLY FISHED is a precautionary assessment based on evidence of extreme longevity and localized depletion after only a few years of targeted fishing. Nevertheless, the estimates of mortality are indicative of a stock that is being lightly exploited. There is currently no MLL for sweep in NSW and the information presented in this chapter may be useful to managers if it is decided that such a management tool is required. Stewart & Hughes (2005) identified age-class truncation due to fishing as the greatest risk to the sustainability of the stock in NSW and discussed the difficulties in using a MLL to reduce the risk. The very large variation in size-at-age for sweep means that any MLL designed to minimize age-class truncation would need to be set at a size that would make a large proportion of the stock unavailable to fishers. In addition, MLLs are only effective if discard mortality is low and anecdotal information suggests that sweep are vulnerable to barotrauma and that discard mortality may be large.

15. BIOLOGY AND FISHERY FOR SILVER TREVALLY

15.1. Introduction

Silver trevally (*Pseudocaranx dentex*) of the family Carangidae are distributed throughout coastal and estuarine waters of Australia's southern half, from southern Qld to WA (North West Cape). Silver trevally are also found in schools throughout the warm temperate waters of the Atlantic, Indian and Pacific Oceans (including Lord Howe Island, Norfolk Island and New Zealand). Juvenile silver trevally inhabit estuaries, bays and shallow continental shelf waters, while adults form schools in offshore waters.

Silver trevally are an important component of commercial and recreational landings in NSW. The recreational harvest is thought to be less than the commercial harvest; however the commercial harvest is thought to be declining. The bulk (~ 70%) of NSW commercial landings are caught by fish trawling, with the Ocean Trap and Line fishery landing the majority of the rest of the catch. Trap and line caught silver trevally tend to be in better condition, and receive greater market prices, than trawl caught fish. Silver trevally in NSW currently have no MLL. There has been a proposal to implement a MLL of 30 cm TL since 2000, however this has not occurred to date.

The biology and fisheries for silver trevally in Australia have been studied extensively (e.g., FRDC projects 97/125 Rowling & Raines 2000; 2002/004 Farmer *et al.*, 2005), yet there is continued debate in NSW about appropriate management arrangements, especially the implementation of a MLL. This chapter collates and re-analyses available information for silver trevally in NSW and presents it in a manner that may be used when considering the best size at which they should be harvested.

15.2. Materials and methods

Biological and fishery information for silver trevally was largely sourced from the previous FRDC study "Description of the biology and an assessment of the fishery for Silver Trevally *Pseudocaranx dentex* off New South Wales." Project No. 97/125, Rowling & Raines, 2000. Information from the demersal trap fishery was sourced from the FRDC project "Mesh selectivity in the NSW demersal trap fishery" Project No. 98/138, Stewart & Ferrell, 2001. Information on the recreational fishery was sourced from Steffe *et al.* (1996) and the NSW DPI Resource Assessment Unit. Analyses of mortality rates, market prices, optimum yield and $ per recruit and spawning potential ratio were as described in Chapter 2.

15.3. Results

15.3.1. Landings in NSW

15.3.1.1. Current exploitation status

Silver trevally are currently listed as being GROWTH OVERFISHED in NSW (2005/06). This assessment has not changed since the publication of the report from FRDC project 97/125 in 2000. There is a long history of decline in commercial landings and the average sizes of fish being landed. These declines, in association with yield per recruit analyses, indicate that the stock of silver trevally has been depleted and that the species is growth overfished.

15.3.1.2. Trends in catch

Reported commercial landings of silver trevally have declined since the early 1990s; however two indices of CPUE (kg per day fish trawling and kg per day fish trapping) have remained relatively constant since 1997/98 (Fig. 15.1). Commercial landings have declined steadily since the mid 1980s when landings peaked at ~ 1400 tonnes in 1984/85. The recreational harvest of silver trevally in NSW was estimated to be ~ 87 tonnes between April 2000 and March 2001, using an estimated average weight of 0.35 kg per fish (Henry & Lyle, 2003). This was likely a large under-estimate of the recreational harvest because the average size of silver trevally landed by trailerboat fishers is reported to be ~ 33 cm FL (see Fig. 15.3). This size equates to an average weight of ~ 0.7 kg (from the length weight relationship in Steffe *et al.*, 1996). Using an average weight of 0.7 kg per fish produces an estimated annual recreational harvest of ~ 175 tonnes.

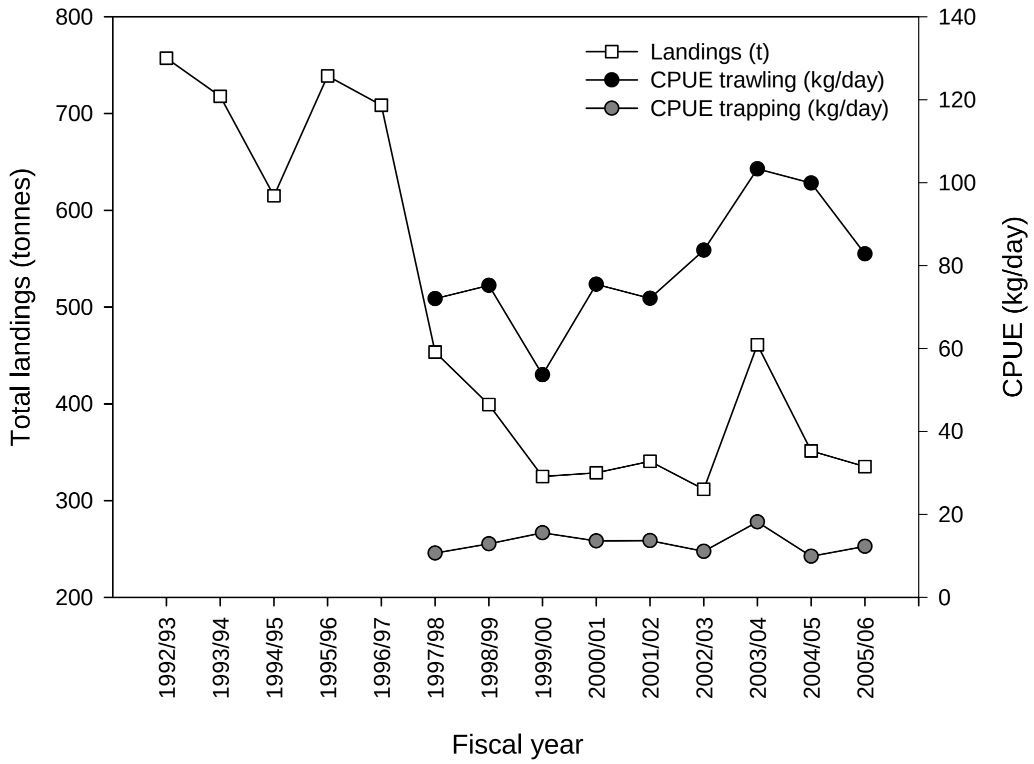


Figure 15.1. Reported commercial landings and catch rates (kg per day fish trapping and trawling) of silver trevally in NSW. Source: NSW DPI Resource Assessment System.

15.3.1.3. Length measurements

Commercial landings

The sizes of silver trevally landed by commercial fishers were similar each year between 1998 and 2006 and the data were therefore pooled (Fig. 15.2). There are relatively few fish greater than 35 cm FL in landings. Commercial trap fishers are reported to discard very few silver trevally (Stewart & Ferrell, 2001).

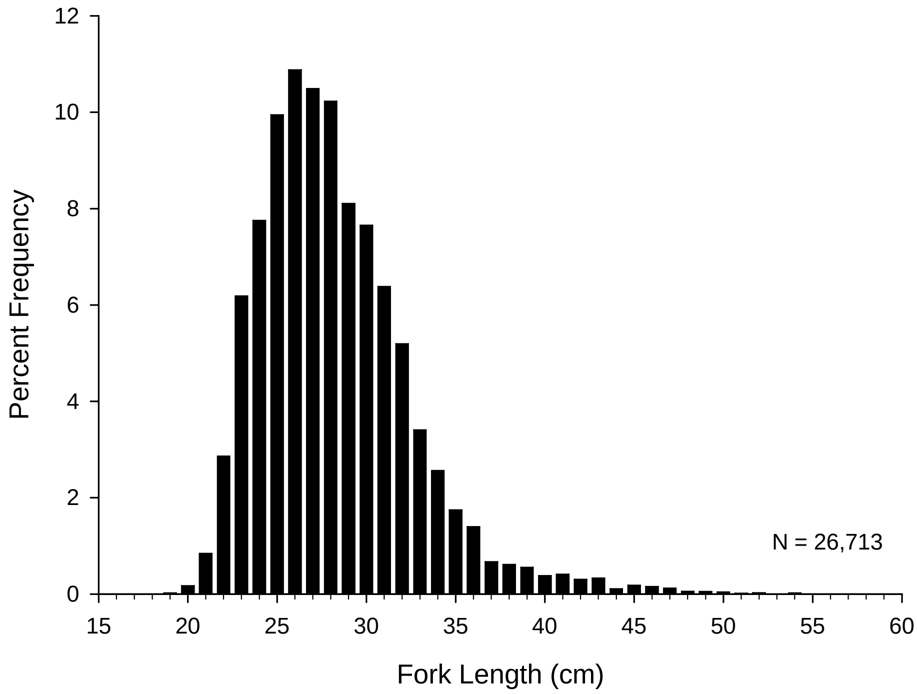


Figure 15.2. The lengths of silver trevally landed by commercial fishers in NSW 1998 to 2006. Source: NSW DPI Resource Assessment System.

Recreational landings

The lengths of silver trevally landed by recreational fishers are, on average, larger than those landed by commercial fishers (Figs 15.3 & 15.4). Trailerboat fishers report a greater proportion of large (> 40 cm FL) fish in landings, with a peak at ~ 30 to 31 cm FL. Charterboat fishers report silver trevally that are, on average, slightly longer than those reported by trailerboat fishers. However, the problems of charterboat operators estimating lengths and measuring total lengths means that the reliability of this information is low. Recreational fishers release ~ 30% of all silver trevally they catch (Henry & Lyle, 2003). Broadhurst *et al.* (2005) estimated a discard mortality rate of ~ 17% for silver trevally caught and released by recreational anglers.

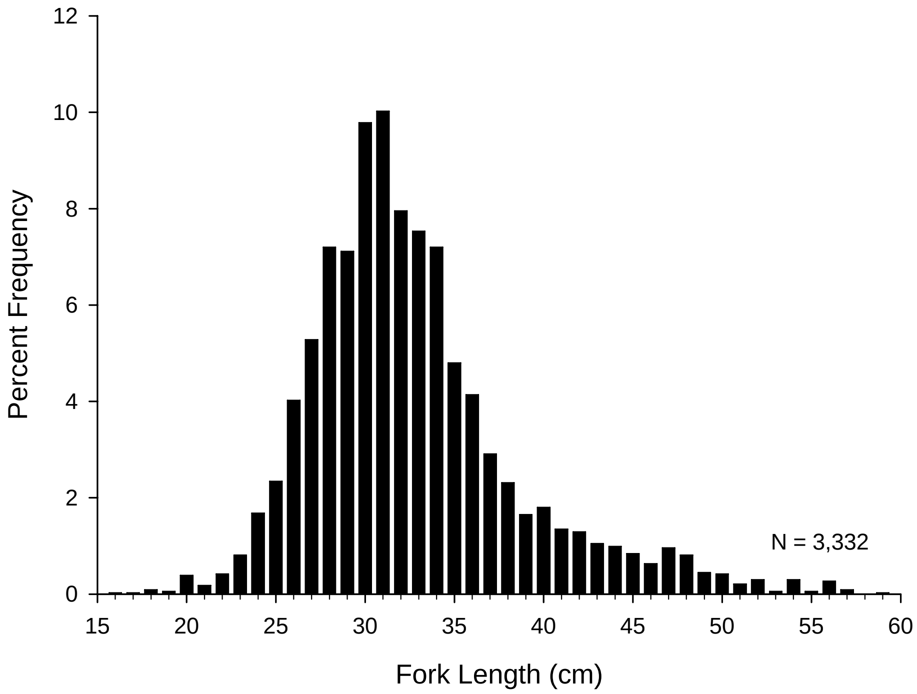


Figure 15.3. The lengths of silver trevally landed by offshore trailerboat fishers 1993/94 and 1994/95. Source: Steffe *et al.*, 1996.

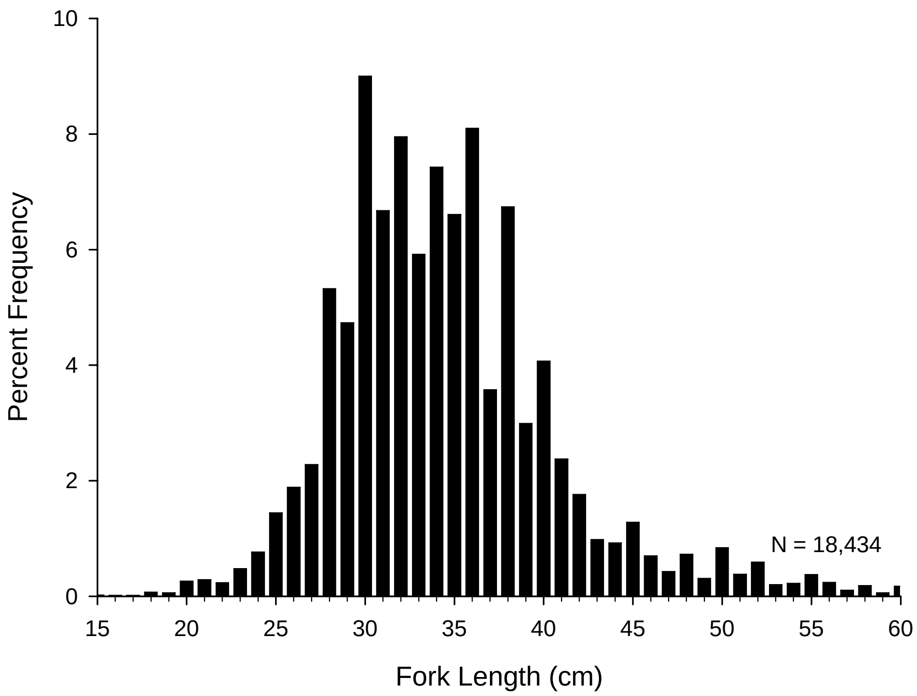


Figure 15.4. The lengths of silver trevally measured by NSW charterboat operators 2001 to 2003.

15.3.2. Reproduction

Silver trevally in NSW have an extended spawning period from September to March (Rowling & Raines, 2000). The size at 50% sexual maturity for females is ~ 19 cm FL (~ 20 cm TL) and at 100% is ~ 24 cm FL (~ 26 cm TL). Female silver trevally have moderate fecundity (50,000 to 200,000 eggs).

15.3.3. Age and growth

Estimates of age of silver trevally have been made by counting annuli in sectioned otoliths (Rowling & Raines, 2000). They reported silver trevally to be a relatively slow growing, long-lived species. Maturity is attained at between one and four years of age. In NSW, silver trevally have been reported to attain 65 cm, approximately four kg and a maximum age of 30 years. The best available von Bertalanffy growth function parameters are from Rowling & Raines (2000): L_∞ = 63.16 cm, K = 0.05 yr^{-1} and t_0 = -6.47 years. The fishery for silver trevally in NSW is dominated by fish aged between two and 10 years (Rowling & Raines, 2000). Silver trevally were fully recruited to the trap fishery by age four.

15.3.4. Mortality estimates

Total mortality (Z) was estimated by Rowling & Raines (2000) using catch curves between the ages of 7 and 16 years. The best estimate of Z was 0.4. M was estimated to range between 0.15 and 0.1 (based on 1% and 5% of the T_{max} (30 years) respectively). The estimates of mortality used in the present study were: Z = 0.4, M = 0.15 and F = 0.25.

15.3.5. Market price

Silver trevally sold through the Sydney Fish markets are graded according to the following schedule:

Small	25 to 30 cm
Medium	30 to 36 cm
Large	36 to 40 cm
Extra large	> 40 cm

Average prices for silver trevally sold through the Sydney Fish Markets during 2005/06 indicate that the price increased with increasing size grade (Fig. 15.5). The “Extra large” size grade attained, on average, three times the price of fish graded as “Small”.

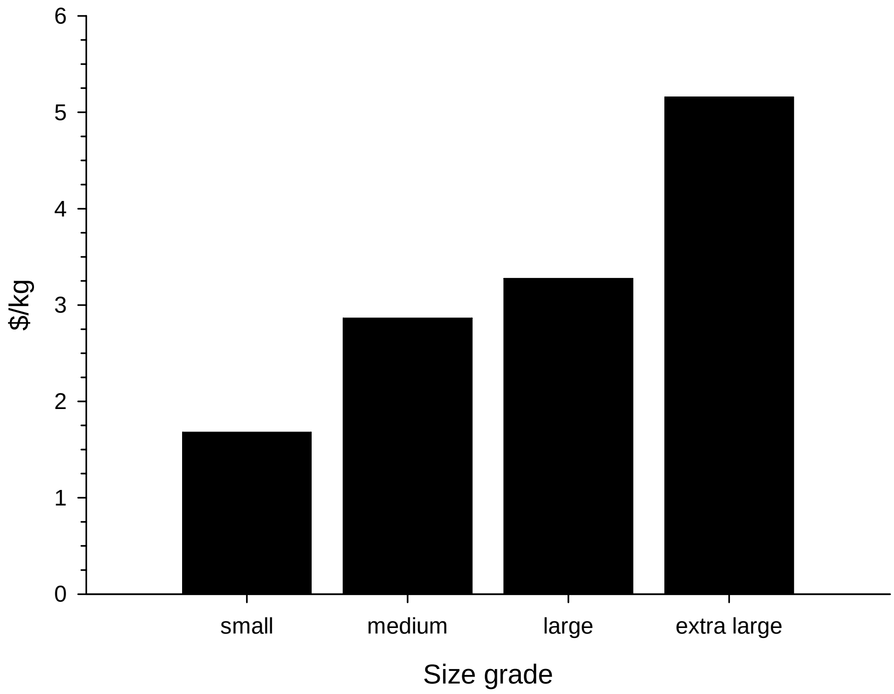


Figure 15.5. Average price information by size grade of silver trevally sold through the Sydney Fish Markets 2005/06.

15.3.6. Per recruit analyses

Per recruit analyses were done using the following parameters:

L_∞ = 63.16 cm
K = 0.05 yr^{-1}
T_0 = -6.47 yr
M = 0.15
Z = 0.40
F = Z-M = 0.25
E = F/Z = 0.625
M/K = 3.0

with market price information and size grades as described above. Where L_∞, K and T_0 are von Bertalanffy growth parameters, M is natural mortality rate, Z is total mortality rate and E is exploitation rate.

The results indicate that at present levels of exploitation that yield per recruit is optimized at ~ 26.5 cm FL (~ 29 cm TL) and that $ per recruit is optimized at ~ 36 cm FL (~ 41 cm TL) (Fig. 15.6).

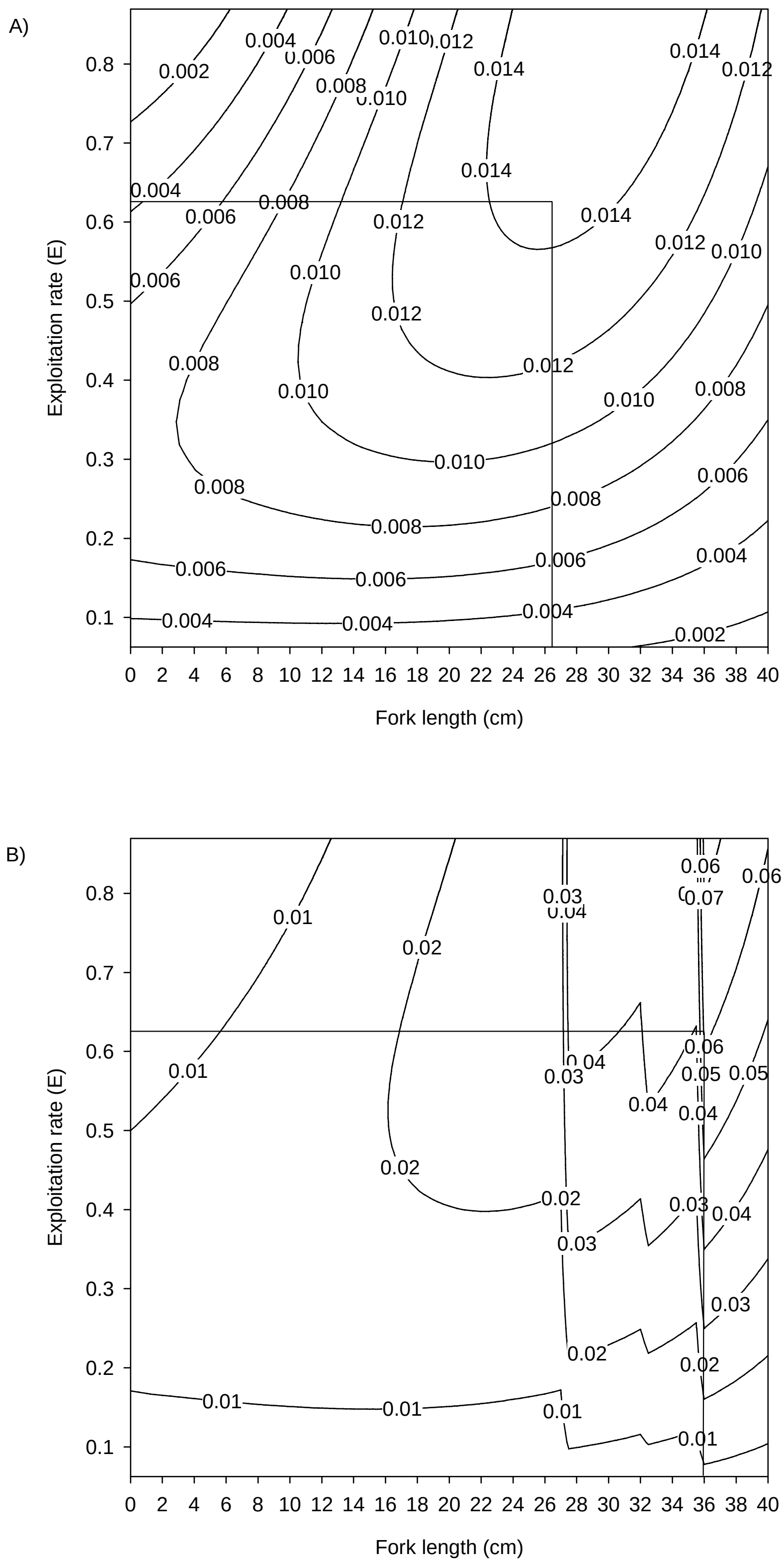


Figure 15.6. Yield and $ per recruit isopleths for silver trevally. Lines indicate current levels of exploitation rate and corresponding lengths at which they are maximised.

15.3.7. Spawning potential ratio

The smallest silver trevally in landings are ~ 20 cm and this size at first harvest corresponds to a SPR of ~ 0.23, above the threshold level of 0.2 (Fig. 15.7). The majority of silver trevally in landings are > 25 cm FL and this size at first harvest corresponds to a SPR of ~ 0.33. The proposed MLL for silver trevally of 30 cm TL (~ 27 cm FL) would, under current levels of exploitation, correspond to a SPR of ~ 0.38.

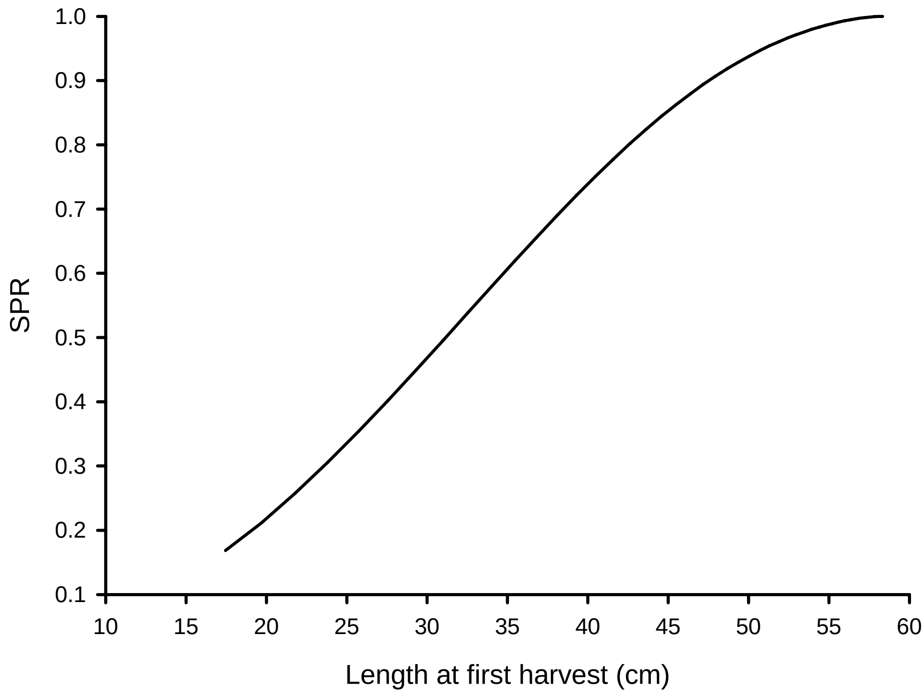


Figure 15.7. Spawning potential ratio for silver trevally at current levels of exploitation for a range of sizes at first harvest.

15.3.8. *Information fact sheet*

Relevant material from this chapter was collated into an information fact sheet for silver trevally (Fig. 15.8). The information was presented as total lengths.

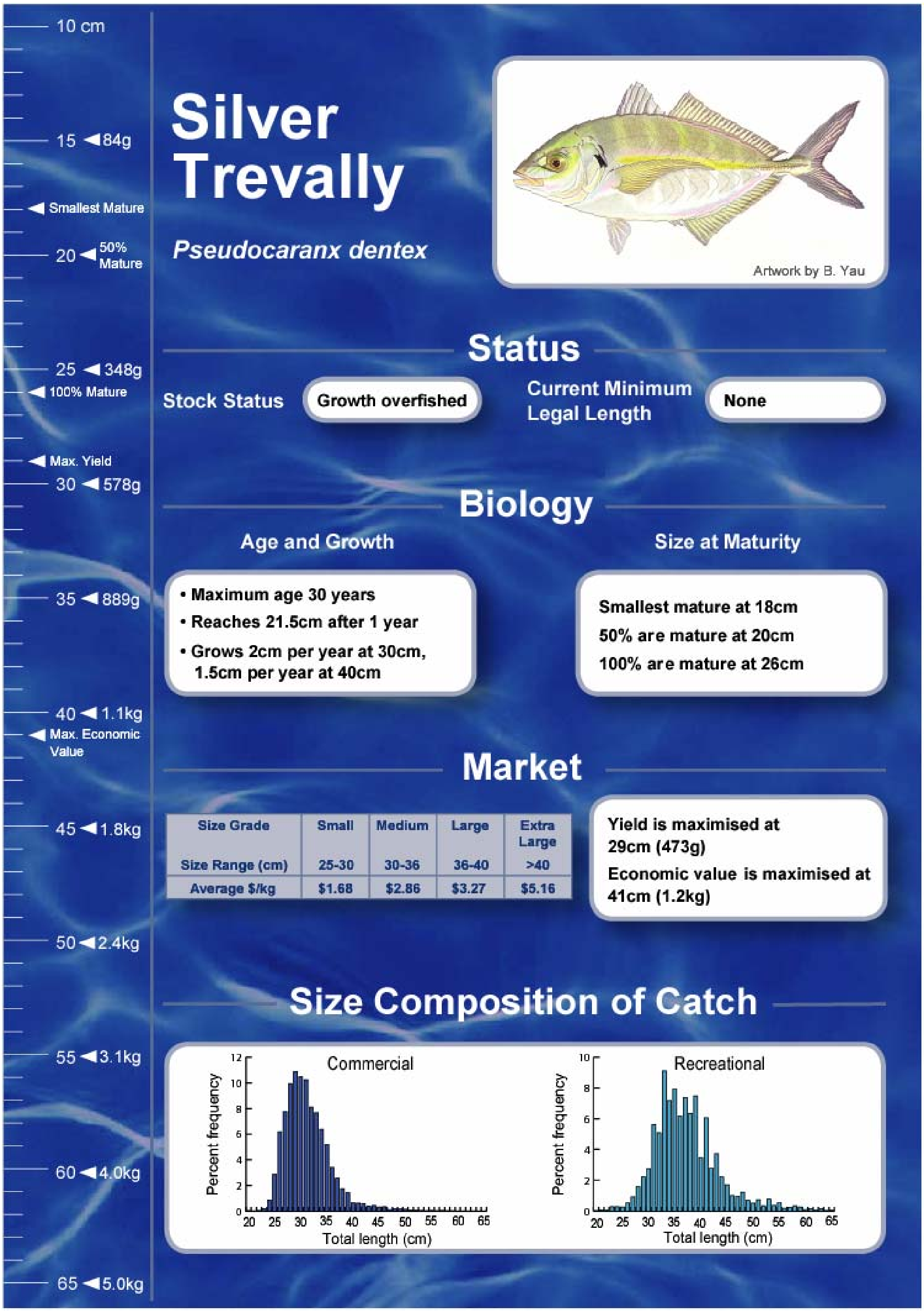


Figure 15.8. Information fact sheet for silver trevally.

15.4. Discussion

The status of silver trevally in NSW as GROWTH OVERFISHED is based on the observed long-term declines in landings and fish size as well as yield per recruit analyses (Rowling & Raines, 2000). The per recruit analyses done in the present chapter are similar to those done by Rowling & Raines (2000) and indicate that silver trevally should be harvested later in life than at present in order to optimize yield and $ per recruit. Based on the information presented the case to introduce a MLL of 30 cm TL for silver trevally in NSW is very strong. The proposal to do this was introduced in 2000 and to date no MLL has been implemented. The stock has shown no signs of recovery since the 2000 report.

The proposal of 30 cm TL as a MLL would protect juveniles, take advantage of fast early growth, increase the yield per recruit, optimise economic return, increase egg production and would have little impact on recreational landings. There would be some initial impact on commercial landings, mainly by the trawl fishery. Options for managers to consider when setting an appropriate size at harvest for silver trevally are presented in Chapter 16.

16. A FRAMEWORK FOR DETERMINING SIZES AT FIRST HARVEST

16.1. Introduction

The ultimate objective of this research was to develop a framework to assist managers when setting minimum sizes at first harvest. Such minimum sizes at harvest may be restricted through gear selectivity or, more commonly, through minimum legal lengths (MLLs). Minimum sizes at harvest are referred to as MLLs in the present chapter. Currently there are no formal policies for setting MLLs in NSW (or elsewhere in Australia), and fisheries management agencies justify the use of MLLs for a range of reasons. Generally justification revolves around protecting juvenile fish. For example, the NSW DPI website states that “Setting a minimum size limit is a management tool regularly used to ensure that most of the fish in the population are able to grow to breeding size and spawn at least once before they are caught”. A recent consultation paper distributed by the Queensland Department of Primary Industries and Fisheries states “size limits are typically based on biological research into each species’ reproductive cycles, to allow fish to contribute to the population before they are taken”. Similarly, the recently completed commercial Ocean Trap and Line Fishery Management Strategy (FMS) in NSW states under management response 2.1 (e) that NSW DPI will “Review and where appropriate implement minimum legal lengths for the primary and key secondary species to give a high probability that at least 50% of the fish of each particular species landed have reached reproductive maturity (unless alternative strategies apply to individual species)”. The earlier commercial fishery FMSs in NSW (since 2003) stated similar objectives. These examples of justification for using MLLs are laudable and defensible; however in practice MLLs appear to be rarely set at levels that achieve these goals. Analysis of the review done for the Director of NSW Fisheries in 2003 (Levitt, 2003) showed that of the 18 species with MLLs for which there also existed information on sexual maturity, only three (sand whiting, snapper and black bream) were found to mature, on average, at sizes smaller than their MLL. This may be reduced to two once improved estimates of the size at sexual maturity of snapper are made.

The observation that MLLs are clearly not set using the “50% mature rule” indicates that factors other than size at maturity are being considered more important by decision makers. Although the setting of MLLs is predominantly justified on biological and ecological grounds, the decision making process is plainly influenced by social and/or political factors. There is evidence here (above) that decision makers (fisheries managers and politicians) see short-term unpopularity as consequences of increases to MLLs as outweighing longer-term benefits of sustainability of fisheries. Such value judgements are to be expected; however decision makers should have a framework available which allows longer-term benefits to be easily weighed against the short-term costs. In addition, the existing justification for setting MLLs is clearly too narrow and should be expanded to include other factors.

The objective of this chapter is to describe a framework that can help managers throughout the process of setting MLLs.

16.2. The framework

This framework is designed to assist decision makers by:

(i) Improving transparency as to why minimum legal lengths (MLLs) are being introduced or changed for each species;

(ii) Integrating scientific understanding of reproduction, growth and mortality as well as consideration of socio-economic factors;

(iii) Encouraging recognition of the objective information available, and;

(iv) Documenting trade-offs between analytically optimal solutions (from scientific information on biology and fisheries) and short-term socio-economic impacts.

The framework is based upon multi-criteria decision analysis (MCDA) that has been used in natural resource decision making (Wenstop & Seip, 2001). This approach can incorporate qualitative and quantitative information and has recently been used within NSW DPI to prioritise observer programs for commercial fisheries.

The first and most important step is to identify the problem faced by the decision makers. In the case of setting MLLs, the problem being considered is what size will best achieve the objectives of the management action. This can only be assessed once the objectives of having a MLL are stated and these are pre-requisite of this framework. Managers should be encouraged to state objectives that can be readily assessed rather than broad qualitative statements listed in corporate plans and vision statements. For example, the NSW DPI FMSs have separated 'visions' from 'goals', 'objectives' and 'management responses' (Fig. 16.1).

Figure 16.1. Management model for NSW commercial fisheries management.

This model should assist managers in understanding why a management action (such as a MLL) is being used. Specific to the NSW Ocean Trap and Line Fishery and MLLs the FMS model works as follows:

The ‘vision’ is “a profitable fishery that provides the community with fresh local seafood and carries out fishing in an ecologically sustainable manner”; the ‘goal’ is to “maintain stocks of primary and key secondary species harvested by the OTLF at sustainable levels”; the ‘objective’ is to “prevent overfishing of the stocks of primary and key secondary species by ocean trap and line fishers”; and the ‘management response’ is to “Review and where appropriate implement minimum legal lengths for the primary and key secondary species to give a high probability that at least 50% of the fish of each particular species landed have reached reproductive maturity (unless alternative strategies apply to individual species)”.

The framework described in the present chapter is designed to assist managers in assessing how successfully their management actions achieve the broader fishery objectives and goals.

Unfortunately, such well defined and documented visions, goals and management responses do not exist for the recreational fishery in NSW. Recreational fishery managers should develop a similar model if they are to benefit from using the framework suggested here.

Some common management objectives, and those to be used in this example framework, are to:

(i) Ensure that fish have the opportunity to spawn at least once before being recruited to the fishery.

(ii) Ensure sufficient reproduction to maintain stocks.

(iii) Maximise the yield (on a weight per recruit basis) from the resource.

(iv) Maximise value.

(v) Address growth overfishing.

In addition, managers may wish to add objectives to be assessed during implementation of any change in MLL, such as:

(vi) Minimise immediate losses to commercial fishers.

(vii) Minimise immediate losses to recreational fishers.

16.2.1. *Multi-criteria decision analysis (MCDA)*

The MCDA approach as being used here can be divided into two distinct parts: (a) factual investigation of feasible options – the search for measures and attributes to describe the relative success of those options in achieving the original objectives, and converting attributes to rankable utilities, and; (b) valuation – where measures are given relative weights and sensitivity analyses done on this impact on the total utility measure.

The MCDA framework uses a progression of steps that are outlined below and in Table 16.1.

1. *Identification of the options*

Options to be considered in this model are simply the different sizes (lengths) of each species. Lengths used here are whole centimetres (cm), however they could easily be used in any size class desired (i.e., two or five cm classes).

2. *Defining measures and attributes to compare those options*

Measures used in this model address individual objectives and indicate how well each option (length of fish) satisfies each objective. Note that these measures do not account for discard mortality and its potential impact on achieving each objective. As an example, for the objective "to ensure that fish have the opportunity to spawn at least once before being recruited to the fishery" the measure to be used is "the proportion of immature females that are protected at each option (length)". The attributes are the "values" associated with each measure for each option (e.g., a maturity ogive indicates the proportion of immature fish at any length and ranges from 0 to 1).

3. *Converting the values of attributes to utilities*

Measures are converted to utilities using a utility function. Utilities range from 0 to 1, 0 being the least value of an option and 1 being the greatest value. Examples of these utility functions are provided for rubberlip morwong (Fig. 16.2). The utility functions for the objectives to "ensure sufficient reproduction to maintain stocks" and "address growth overfishing" are not shown because they are not relevant to rubberlip morwong at current levels of exploitation.

4. *Combining all the utility measures for an option*

Each management objective is given a relative weighting of importance and these must sum to 1. Initially all management objectives can be given equal weight prior to examining the sensitivity of the outputs to changes in relative weightings. The values of each utility for each objective are then summed for each option. The result indicates which option (length) produces the maximum utility measure and is therefore the length that is optimal for achieving the combined objectives.

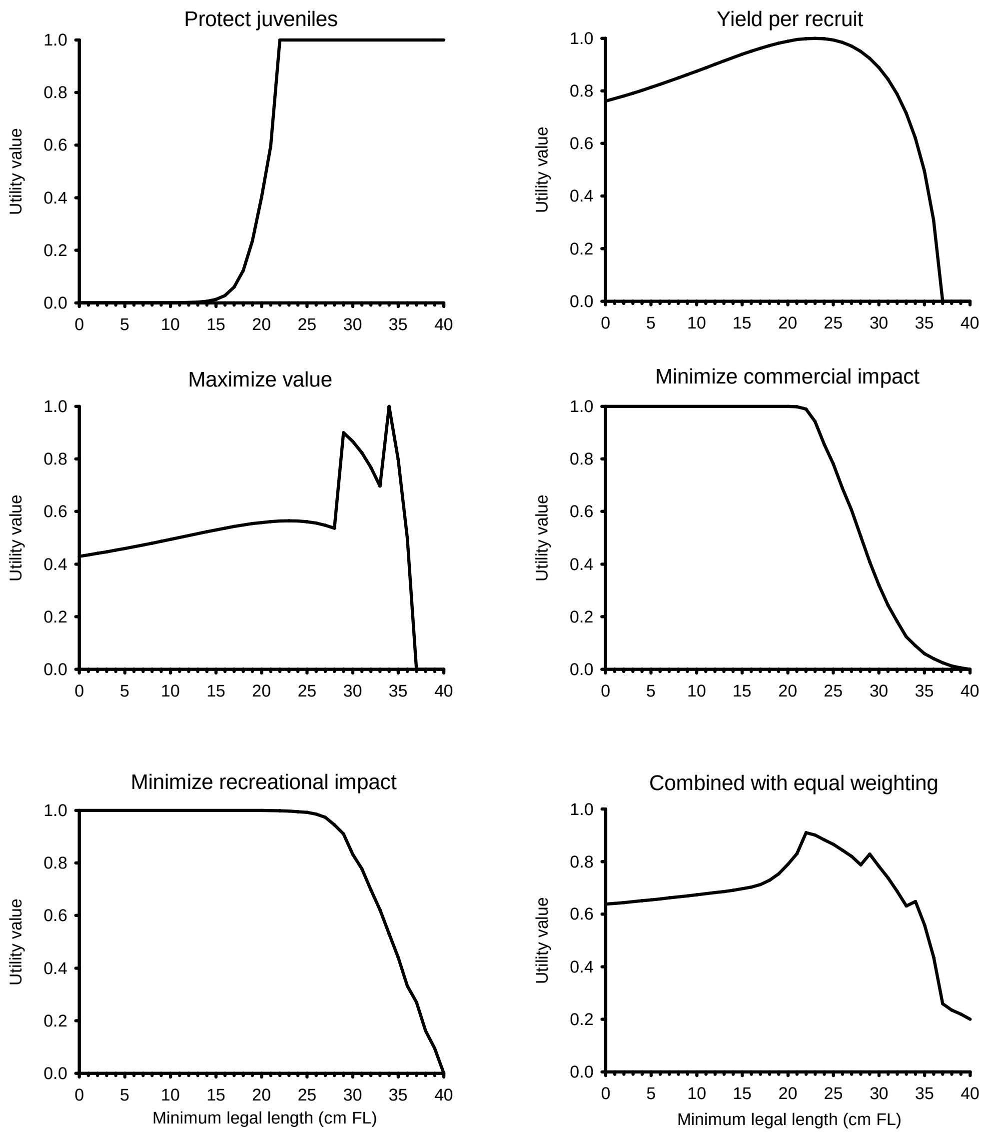


Figure 16.2. Utility functions for six management objectives for rubberlip morwong.

Table 16.1. Management objectives, measures, attributes and utilities used in this example.

Objective	Measure and attribute	Utility
Ensure that fish have the opportunity to spawn at least once before being recruited to the fishery.	Proportion of immature females protected at each size. The attribute ranges from 0 to 1.	In this case the utility value equals the attribute value until the threshold of 0.75, after which the utility value = 1.
Ensure sufficient reproduction to maintain stocks.	Spawning potential ratio at each size. The attribute is a ratio from 0 to 1.	The utility is knife-edged at 0.2 (the threshold level for sustainability). Values < 0.2 = 0 and values ≥ 0.2 = 1.
Maximise the yield from the resource.	Yield per recruit analyses requiring information on growth rates and mortality estimates at current MLL. The attribute is a yield per recruit value (in grams) for each size.	The size to maximise YPR is set at 1 and all other sizes are ranked as proportions of this value.
Maximise value.	Value is defined as dollars per recruit for commercial landings because it is readily available. The attribute is a dollar per recruit value for each size.	The size to maximise $PR is set at 1 and all other sizes are ranked as proportions of this value.
Address growth overfishing.	Growth overfishing may be addressed by reducing fishing mortality and/or increasing the size at harvest. Yield per recruit analyses indicate an optimal size to maximise yield and are used again here, however the utility function is different to above.	(YPR at option size – YPR current)/(Optimum YPR – YPR current). Negative values default to zero. Once an optio*n* = 1, then all sizes greater than this default to 1, because although YPR is then decreasing growth overfishing has been addressed.
Minimise immediate impact on commercial landings by numbers.	Proportion of landed catch below option size. The attribute ranges from 0 to 1.	1 minus cumulative frequency for each size in landings.
Minimise immediate impact on recreational landings by numbers.	Proportion of landed catch below option size. The attribute ranges from 0 to 1.	1 minus cumulative frequency for each size in landings.

16.2.1.1. An example using rubberlip morwong

A detailed description is provided for rubberlip morwong to illustrate application of the framework. The seven potential management objectives are treated separately and the measures, attributes and utilities associated with each objective explained. The utilities for all objectives are then combined to produce an ‘optimal’ length at first harvest. Sensitivity analyses of different weighting for different management objectives are also presented. Only option lengths to 40 cm FL are shown for ease of presentation here.

- **Management objective 1:** Ensure that fish have the opportunity to spawn at least once before being recruited to the fishery.

Measure and attribute: The **measure** used to assess how well each proposed MLL (in 1 cm increments) satisfies the management objective is the proportion of immature females that would be protected at that option length. The **attribute** (or value) that describes this **measure** is the maturity ogive for rubberlip morwong (Fig. 3.7). The maturity ogive describes the proportion of immature rubberlip morwong at each length (Table 16.2). Therefore, the attributes associated with each length range from 0 (being zero protection for juveniles) to 1 (being maximum protection for juveniles).

Utility value: Utility values must range between 0 and 1. The shape of a maturity ogive means that the size class at 100% maturity is generally over-estimated (see Fig. 3.7). To avoid the utility value not attaining the maximum of 1 until unrealistically large sizes, the utility value is set equal to the attribute value until it reaches 0.75, after which the utility value equals 1. This is akin to having a management target of protecting at least 75% of juveniles – an improvement on the “50% mature rule” applied historically. Note that if the management target was to protect 50% of juveniles, then the utility function could be altered accordingly.

- **Management objective 2:** Ensure sufficient reproduction to maintain stocks.

Measure and attribute: The **measure** used to assess how well each proposed MLL (in 1 cm increments) satisfies the management objective is the spawning potential ratio (SPR) which results from first harvesting fish at each option length. The **attribute** is the value of the SPR analysis at current levels of exploitation for each length (Fig. 3.17).

Utility value: The threshold level of SPR has been set at 0.2 and the **utility** values are calculated as being 0 if < 0.2 and 1 if ≥ 0.2. Rubberlip morwong are a poor example for this management objective because all option lengths had a utility value of 1, i.e., the SPR was > 0.2 for all sizes at first harvest under the current level of exploitation.

Table 16.2. Rubberlip morwong attributes and utility values for the management objective "to ensure that fish have the opportunity to spawn at least once before being recruited to the fishery".

Option	**Attribute**	**Utility**	**Option**	**Attribute**	**Utility**
FL	Maturity ogive	Value	FL	Maturity ogive	Value
0	0.00	0.00	21	0.60	0.60
1	0.00	0.00	22	0.76	1.00
2	0.00	0.00	23	0.88	1.00
3	0.00	0.00	24	0.94	1.00
4	0.00	0.00	25	0.97	1.00
5	0.00	0.00	26	0.99	1.00
6	0.00	0.00	27	0.99	1.00
7	0.00	0.00	28	1.00	1.00
8	0.00	0.00	29	1.00	1.00
9	0.00	0.00	30	1.00	1.00
10	0.00	0.00	31	1.00	1.00
11	0.00	0.00	32	1.00	1.00
12	0.00	0.00	33	1.00	1.00
13	0.00	0.00	34	1.00	1.00
14	0.01	0.01	35	1.00	1.00
15	0.01	0.01	36	1.00	1.00
16	0.03	0.03	37	1.00	1.00
17	0.06	0.06	38	1.00	1.00
18	0.12	0.12	39	1.00	1.00
19	0.23	0.23	40	1.00	1.00
20	0.40	0.40			

- **Management objective 3:** Maximise the yield from the resource.

Measure and attribute: The **measure** used to assess how well each proposed MLL (in 1 cm increments) satisfies the management objective is the yield per recruit from harvesting fish at each option length. The **attribute** is the value of the yield per recruit analysis (in grams) at current levels of exploitation for each length (Fig. 3.15A).

Utility value: Utility values must range between 0 and 1, and in this case the length at which yield per recruit is maximised is set at 1. The utilities for all other lengths are ranked as a proportion of the maximum yield per recruit value. The results show that yield per recruit is maximised at ~ 22 to 24 cm FL (Table 16.3).

Table 16.3. Rubberlip morwong attributes and utility values for the management objective "to maximise the yield from the resource". YPR is yield per recruit. The lengths with optimum utility values are shaded.

Option	Attribute	Utility	Option	Attribute	Utility
FL	YPR (g)	Value	FL	YPR (g)	Value
0	0.11	0.76	21	0.14	0.99
1	0.11	0.77	22	0.14	1.00
2	0.11	0.78	23	0.14	1.00
3	0.11	0.79	24	0.14	1.00
4	0.11	0.80	25	0.14	0.99
5	0.11	0.81	26	0.14	0.98
6	0.11	0.82	27	0.13	0.97
7	0.12	0.84	28	0.13	0.95
8	0.12	0.85	29	0.13	0.92
9	0.12	0.86	30	0.12	0.89
10	0.12	0.87	31	0.12	0.84
11	0.12	0.89	32	0.11	0.79
12	0.12	0.90	33	0.10	0.71
13	0.13	0.91	34	0.09	0.62
14	0.13	0.93	35	0.07	0.50
15	0.13	0.94	36	0.04	0.31
16	0.13	0.95	37	0.00	0.00
17	0.13	0.96	38	0.00	0.00
18	0.13	0.97	39	0.00	0.00
19	0.14	0.98	40	0.00	0.00
20	0.14	0.99			

- **Management objective 4:** Maximise value.

Measure and attribute: The **measure** used to assess how well each proposed MLL (in 1 cm increments) satisfies the management objective is the commercial $ per recruit from harvesting fish at each option length. The **attribute** is the value of the $ per recruit analysis (in $s) at current levels of exploitation for each length (Fig. 3.15b).

Utility value: Utility values must range between 0 and 1, and in this case the length at which value is maximised is set at 1. The utilities for all other lengths are ranked as a proportion of the maximum $ per recruit value. The results show that value is maximised at ~ 34 cm FL (Table 16.4), larger than the YPR because of the considerably higher market prices for extra large rubberlip morwong (see Fig. 3.14).

Table 16.4. Rubberlip morwong attributes and utility values for the management objective "to maximise value". $PR is $ per recruit. The lengths with optimum utility values are shaded.

Option	Attribute	Utility	Option	Attribute	Utility
FL	$PR ($)	Value	FL	$PR ($)	Value
0	0.16	0.43	21	0.21	0.56
1	0.16	0.43	22	0.21	0.56
2	0.17	0.44	23	0.21	0.56
3	0.17	0.45	24	0.21	0.56
4	0.17	0.45	25	0.21	0.56
5	0.17	0.46	26	0.21	0.56
6	0.18	0.47	27	0.21	0.55
7	0.18	0.47	28	0.20	0.54
8	0.18	0.48	29	0.34	0.90
9	0.18	0.49	30	0.33	0.87
10	0.19	0.49	31	0.31	0.82
11	0.19	0.50	32	0.29	0.77
12	0.19	0.51	33	0.26	0.70
13	0.19	0.52	34	0.38	1.00
14	0.20	0.52	35	0.30	0.80
15	0.20	0.53	36	0.19	0.50
16	0.20	0.54	37	0.00	0.00
17	0.20	0.54	38	0.00	0.00
18	0.21	0.55	39	0.00	0.00
19	0.21	0.55	40	0.00	0.00
20	0.21	0.56			

- **Management objective 5:** Address growth overfishing.

Measure and attribute: The **measure** used to assess how well each proposed MLL (in 1 cm increments) addresses growth overfishing is the yield per recruit from harvesting fish at each size. The **attribute** is the value of the yield per recruit analysis (in grams) at current levels of exploitation for each length (Fig. 3.15A). Note that this management objective is only relevant to species that have been assessed as being growth overfished and that rubberlip morwong are not growth overfished.

Utility value: Whilst the measure and attributes used for this management objective are the same as those used for the management objective "to maximise the yield from the resource", the utility function is different. The calculation of the utility value recognizes that the management objective here is to improve on the current situation. Utility values for each option are calculated as:

$$\frac{\text{YPR at option length} - \text{YPR at current levels}}{\text{maximum YPR} - \text{YPR at current levels}}$$

The current level is set at the current MLL (~ 23 cm FL). Negative values default to 0 (because there is no improvement) and all option lengths greater than that which has a utility value of 1 default to 1, because although the YPR values are declining the issue of growth overfishing has been addressed. Note that rubberlip morwong are not considered to be growth overfished (see

Chapter 3) and that yield per recruit is maximized at the current MLL of 23 cm. As a consequence utility values for rubberlip morwong are equal to zero at all sizes. More relevant examples for this management objective are in Appendix 3.

- **Management objective 6:** Minimise immediate impact on commercial landings.

Measure and attribute: The **measure** used to assess to what degree each proposed MLL (in 1 cm increments) would impact on current commercial landings (by numbers of fish) is the proportion of the landed catch that is currently smaller than each option length. The **attribute** for each option length is the cumulative frequency at that length of the proportion of fish in landings (see Fig. 3.2). The attribute ranges from 0 (smaller than any landed rubberlip morwong) to 1 (the largest rubberlip morwong in landings) (Table 16.5).

Utility value: The management objective here is to minimise any impact, so the desired **utility** value is 1 minus the attribute value. The results indicate that any increases in MLL would have some impact on commercial landings, and that an increase to 30 cm FL would result in a reduction of 67% of the number of fish retained (Table 16.5).

Table 16.5. Rubberlip morwong attributes and utility values for the management objective "to minimise short-term impact on commercial landings".

Option	**Attribute**	**Utility**	**Option**	**Attribute**	**Utility**
FL	cum freq	Value	FL	cum freq	Value
0	0.00	1.00	21	0.00	1.00
1	0.00	1.00	22	0.01	0.99
2	0.00	1.00	23	0.06	0.94
3	0.00	1.00	24	0.14	0.86
4	0.00	1.00	25	0.22	0.78
5	0.00	1.00	26	0.31	0.69
6	0.00	1.00	27	0.39	0.61
7	0.00	1.00	28	0.49	0.51
8	0.00	1.00	29	0.58	0.41
9	0.00	1.00	30	0.67	0.32
10	0.00	1.00	31	0.74	0.24
11	0.00	1.00	32	0.80	0.18
12	0.00	1.00	33	0.86	0.12
13	0.00	1.00	34	0.90	0.09
14	0.00	1.00	35	0.93	0.06
15	0.00	1.00	36	0.94	0.04
16	0.00	1.00	37	0.96	0.02
17	0.00	1.00	38	0.97	0.01
18	0.00	1.00	39	0.98	0.01
19	0.00	1.00	40	0.98	0.00
20	0.00	1.00			

- **Management objective 7:** Minimise immediate impact on recreational landings.

Measure and attribute: The **measure**, **attribute** and **utility** function for this management objective are similar to those for the previous objective for commercial landings. The **measure** used to assess to what degree each proposed MLL (in 1 cm increments) would impact on current recreational landings (by numbers of fish) is the proportion of the landed catch that is currently smaller than each option length. The **attribute** for each option length is the cumulative frequency at that length of the proportion of fish in landings (see Fig. 3.16). The attribute ranges from 0 (smaller than any landed rubberlip morwong) to 1 (the largest rubberlip morwong in landings) (Table 16.6).

Utility value: The management objective here is to minimise any impact, so the desired **utility** value is 1 minus the attribute value. The results show that because recreational fishers land, on average, larger rubberlip morwong than commercial fishers, that any increases in MLL will have a smaller impact on recreational than commercial fishers.

Table 16.6. Rubberlip morwong attributes and utility values for the management objective "to minimise short-term impact on commercial landings".

Option	**Attribute**	**Utility**	**Option**	**Attribute**	**Utility**
FL	cum freq	Value	FL	cum freq	Value
0	0.00	1.00	21	0.00	1.00
1	0.00	1.00	22	0.00	1.00
2	0.00	1.00	23	0.00	1.00
3	0.00	1.00	24	0.00	1.00
4	0.00	1.00	25	0.01	0.99
5	0.00	1.00	26	0.01	0.99
6	0.00	1.00	27	0.02	0.97
7	0.00	1.00	28	0.04	0.94
8	0.00	1.00	29	0.07	0.91
9	0.00	1.00	30	0.13	0.83
10	0.00	1.00	31	0.17	0.78
11	0.00	1.00	32	0.24	0.70
12	0.00	1.00	33	0.29	0.62
13	0.00	1.00	34	0.37	0.53
14	0.00	1.00	35	0.44	0.44
15	0.00	1.00	36	0.52	0.33
16	0.00	1.00	37	0.57	0.27
17	0.00	1.00	38	0.65	0.16
18	0.00	1.00	39	0.71	0.09
19	0.00	1.00	40	0.78	0.00
20	0.00	1.00			

Identifying the 'best' option length using combined utility measures

Once the utility values have been calculated for each option length and for each management objective they are combined to determine the 'best', or most highly ranked, option length. The combined utility value for each option length is the weighted sum of all utility values for that option length. The sum of management objective weightings must equal 1. The weighting given to each management objective is subjective and will probably affect the 'best' option length considerably. Sensitivity analysis to changes in weighting should be undertaken.

The first example using rubberlip morwong combines all utility values using equal weighting for each of the seven management objectives. The result shows that the 'best' option length for all management objectives is 22 cm FL (Table 16.7). This approach is also useful because it not only indicates the overall 'best' option length, but shows 'trade-offs' between management objectives by the relative attainment of each management objective at this 'best' length. Table 16.7 shows that while 22 cm is the 'best' overall length, that the management objective of maximising value has not been achieved at this length because the utility value is 0.56 of the maximum.

The next step is to examine the effects of different weightings for each management objective. Management objectives can be ignored by simply giving them zero weighting. Table 16.8 shows that if ignoring the impact on commercial and recreational landings and giving equal weighting to the other five management objectives the 'best' option length is 29 cm FL.

The results indicate that including the management objectives to minimise the impacts on landings of commercial and recreational fishers tend to produce smaller 'best' option lengths. This is an important consideration because the inclusion of these objectives generally results in lower levels of success in achieving the original management objectives of implementing a MLL (i.e., the reasons why MLLs are considered are not actually related to minimising the impacts on landings).

Table 16.7. Combined utility measures for all management objectives for rubberlip morwong. Note that all management objectives have equal weighting. The length with the 'best' option length is shaded and the 'best' option lengths for each management objective are in bold.

Objective	**Protect juveniles**	**Maintain stock**	**Max. yield**	**Max. value**	**Address growth overfishing**	**Min. commercial impact**	**Min. recreational impact**	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option FL (cm)	Utility Value	Utility Value	Utility Value	Utility Value	Utility Value	Utility Value	Utility Value	Utility Sum
0	0.00	1.00	0.76	0.43	0.00	1.00	1.00	0.5986
1	0.00	1.00	0.77	0.43	0.00	1.00	1.00	0.6007
2	0.00	1.00	0.78	0.44	0.00	1.00	1.00	0.6030
3	0.00	1.00	0.79	0.45	0.00	1.00	1.00	0.6053
4	0.00	1.00	0.80	0.45	0.00	1.00	1.00	0.6078
5	0.00	1.00	0.81	0.46	0.00	1.00	1.00	0.6103
6	0.00	1.00	0.82	0.47	0.00	1.00	1.00	0.6129
7	0.00	1.00	0.84	0.47	0.00	1.00	1.00	0.6156
8	0.00	1.00	0.85	0.48	0.00	1.00	1.00	0.6184
9	0.00	1.00	0.86	0.49	0.00	1.00	1.00	0.6212
10	0.00	1.00	0.87	0.49	0.00	1.00	1.00	0.6241
11	0.00	1.00	0.89	0.50	0.00	1.00	1.00	0.6271
12	0.00	1.00	0.90	0.51	0.00	1.00	1.00	0.6301
13	0.00	1.00	0.91	0.52	0.00	1.00	1.00	0.6332
14	0.01	1.00	0.93	0.52	0.00	1.00	1.00	0.6365
15	0.01	1.00	0.94	0.53	0.00	1.00	1.00	0.6403
16	0.03	1.00	0.95	0.54	0.00	1.00	1.00	0.6451
17	0.06	1.00	0.96	0.54	0.00	1.00	1.00	0.6521
18	0.12	1.00	0.97	0.55	0.00	1.00	1.00	0.6633
19	0.23	1.00	0.98	0.55	0.00	1.00	1.00	0.6814
20	0.40	1.00	0.99	0.56	0.00	1.00	1.00	0.7071
21	0.60	1.00	0.99	0.56	0.00	1.00	1.00	0.7359
22	1.00	1.00	1.00	0.56	0.00	0.99	1.00	0.7930
23	1.00	1.00	1.00	0.56	0.00	0.94	1.00	0.7863
24	1.00	1.00	1.00	0.56	0.00	0.86	1.00	0.7733
25	1.00	1.00	0.99	0.56	0.00	0.78	0.99	0.7610
26	1.00	1.00	0.98	0.56	0.00	0.69	0.99	0.7449
27	1.00	1.00	0.97	0.55	0.00	0.61	0.97	0.7282
28	1.00	1.00	0.95	0.54	0.00	0.51	0.94	0.7055
29	1.00	1.00	0.92	0.90	0.00	0.41	0.91	0.7345
30	1.00	1.00	0.89	0.87	0.00	0.32	0.83	0.7011
31	1.00	1.00	0.84	0.82	0.00	0.24	0.78	0.6698
32	1.00	1.00	0.79	0.77	0.00	0.18	0.70	0.6336
33	1.00	1.00	0.71	0.70	0.00	0.12	0.62	0.5938
34	1.00	1.00	0.62	1.00	0.00	0.09	0.53	0.6059
35	1.00	1.00	0.50	0.80	0.00	0.06	0.44	0.5417
36	1.00	1.00	0.31	0.50	0.00	0.04	0.33	0.4542
37	1.00	1.00	0.00	0.00	0.00	0.02	0.27	0.3279
38	1.00	1.00	0.00	0.00	0.00	0.01	0.16	0.3106
39	1.00	1.00	0.00	0.00	0.00	0.01	0.09	0.2999
40	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.2857

Table 16.8. Combined utility measures for rubberlip morwong with zero weighting for the impacts on commercial and recreational landings. The length with the 'best' option length is shaded and the 'best' option lengths for each management objective are in bold.

Objective	**Protect juveniles**	**Maintain stock**	**Max. yield**	**Max. value**	**Address growth overfishing**	**Min. commercial impact**	**Min. recreational impact**	
Weighting	0.20	0.20	0.20	0.20	0.20	0	0	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
0	0.00	1.00	0.76	0.43	0.00	1.00	1.00	0.4380
1	0.00	1.00	0.77	0.43	0.00	1.00	1.00	0.4410
2	0.00	1.00	0.78	0.44	0.00	1.00	1.00	0.4442
3	0.00	1.00	0.79	0.45	0.00	1.00	1.00	0.4475
4	0.00	1.00	0.80	0.45	0.00	1.00	1.00	0.4509
5	0.00	1.00	0.81	0.46	0.00	1.00	1.00	0.4544
6	0.00	1.00	0.82	0.47	0.00	1.00	1.00	0.4581
7	0.00	1.00	0.84	0.47	0.00	1.00	1.00	0.4619
8	0.00	1.00	0.85	0.48	0.00	1.00	1.00	0.4658
9	0.00	1.00	0.86	0.49	0.00	1.00	1.00	0.4697
10	0.00	1.00	0.87	0.49	0.00	1.00	1.00	0.4738
11	0.00	1.00	0.89	0.50	0.00	1.00	1.00	0.4779
12	0.00	1.00	0.90	0.51	0.00	1.00	1.00	0.4821
13	0.00	1.00	0.91	0.52	0.00	1.00	1.00	0.4864
14	0.01	1.00	0.93	0.52	0.00	1.00	1.00	0.4911
15	0.01	1.00	0.94	0.53	0.00	1.00	1.00	0.4964
16	0.03	1.00	0.95	0.54	0.00	1.00	1.00	0.5031
17	0.06	1.00	0.96	0.54	0.00	1.00	1.00	0.5129
18	0.12	1.00	0.97	0.55	0.00	1.00	1.00	0.5287
19	0.23	1.00	0.98	0.55	0.00	1.00	1.00	0.5540
20	0.40	1.00	0.99	0.56	0.00	1.00	1.00	0.5900
21	0.60	1.00	0.99	0.56	0.00	1.00	1.00	0.6307
22	1.00	1.00	1.00	0.56	0.00	0.99	1.00	0.7125
23	1.00	1.00	1.00	0.56	0.00	0.94	1.00	0.7129
24	1.00	1.00	1.00	0.56	0.00	0.86	1.00	0.7124
25	1.00	1.00	0.99	0.56	0.00	0.78	0.99	0.7108
26	1.00	1.00	0.98	0.56	0.00	0.69	0.99	0.7079
27	1.00	1.00	0.97	0.55	0.00	0.61	0.97	0.7035
28	1.00	1.00	0.95	0.54	0.00	0.51	0.94	0.6974
29	1.00	1.00	0.92	0.90	0.00	0.41	0.91	0.7648
30	1.00	1.00	0.89	0.87	0.00	0.32	0.83	0.7511
31	1.00	1.00	0.84	0.82	0.00	0.24	0.78	0.7335
32	1.00	1.00	0.79	0.77	0.00	0.18	0.70	0.7110
33	1.00	1.00	0.71	0.70	0.00	0.12	0.62	0.6823
34	1.00	1.00	0.62	1.00	0.00	0.09	0.53	0.7242
35	1.00	1.00	0.50	0.80	0.00	0.06	0.44	0.6585
36	1.00	1.00	0.31	0.50	0.00	0.04	0.33	0.5614
37	1.00	1.00	0.00	0.00	0.00	0.02	0.27	0.4000
38	1.00	1.00	0.00	0.00	0.00	0.01	0.16	0.4000
39	1.00	1.00	0.00	0.00	0.00	0.01	0.09	0.4000
40	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.4000

The immediate impacts on commercial and recreational landings resulting from increases in MLLs will be short-term because of longer-term benefits such as increases in yield and stock size. Therefore the sensitivity analyses of differing weightings for management objectives below (Table 16.9) have been done by excluding and including these objectives.

Table 16.9. Example of sensitivity analyses of differing weightings for management objectives for rubberlip morwong.

	Ignoring impacts on landings	**Including impacts on landings**
Objective weightings	"Best" FL (cm)	"Best" FL (cm)
All objectives equal	29	22
Protect juveniles only	> 21	22
Maintain stock only	any	> 19
Max. yield only	23	21
Max. value only	34	21
Address growth overfishing only	any	> 19
Protect juveniles x 2, others equal	29	22
Maintain stock x 2, others equal	29	22
Max. yield x 2, others equal	29	22
Max. value x 2, others equal	29	22

16.3. Recommended sizes at first harvest

It is not in the scope of this study to tell fisheries managers how to manage their fisheries; rather it is to provide the available information objectively to managers and stakeholders. Note that the seven management objectives used here may be logical and commonly stated, but have only been presented for demonstration purposes. The true reasons for management objectives concerning MLLs may not be obvious to scientists, who are mainly concerned with biological and sustainability issues. Nevertheless, the available information for each species studied has been collated and detailed MCDA tables, which include all seven demonstration management objectives, are provided in Appendix 3.

One objective of the present study was "To recommend appropriate sizes at harvest for primary species shared by the commercial trap and recreational fisheries in NSW". To satisfy this objective the MCDA tables in Appendix 3 were used, giving equal weighting to the management objectives related to biology and stock sustainability (i.e., to protect juveniles and maintain the stock). The objective to address growth overfishing was also included for those species that have been assessed as being growth overfished (note that we have assessed pearl perch as being growth overfished in contrast to the NSW DPI 2005/06 assessment of undefined). Calculations were done using FLs; however these were converted to TLs to be consistent with the way MLLs are set in NSW. Finally, recommended MLLs were rounded to the nearest five cm to make them easier for stakeholders to memorize (Table 16.10).

Table 16.10. Recommended appropriate sizes at first harvest for selected species shared by the commercial trap and line and recreational fisheries in NSW. * denotes that protecting juveniles was not considered. † denotes growth overfishing was not addressed.

Species	Status	Current MLL		Recommended MLL		
		FL	TL	FL	TL	MLL
Rubberlip morwong	Fully fished	23.5	28	22	26.5	**25**
Tarwhine	Fully fished	18	20	21	24	**25**
Blackspot pigfish	Fully fished	None	None	22	22	**20**
Maori wrasse	Moderately fished	None	None	21	21	**20**
Red rockcod	Moderately fished	None	None	20	20	**20**
Pearl perch	Growth overfished	None	None	36	37.5	**35**
Ocean leatherjacket	Fully fished	None	None	37	37	**35**
Yellowfin bream	Fully fished	23	25	25	28	**30**
Yellowtail kingfish	Growth overfished	52.5	60	89	101	**100**
*Yellowtail kingfish	Growth overfished	52.5	60	68	78	**80**
Mulloway	Overfished	45	45	94	94	**95**
†Mulloway	Overfished	45	45	72	72	**70**
Snapper	Growth overfished	25	30	40	47	**45**
†Snapper	Growth overfished	25	30	30	35	**35**
Sweep	Fully fished	None	None	19	23	**25**
Silver trevally	Growth overfished	None	None	26	29	**30**

16.4. Recommended MLLs for species across fisheries

The third stated objective of this project was "Where appropriate to recommend minimum legal lengths for species across all fisheries". The background to this objective was from a previous FRDC funded study (98/138) into the mesh selectivity of demersal fish traps in NSW (Stewart & Ferrell, 2001). That study concluded that the selectivity of the mesh used in fish traps in NSW was inappropriate and that escape panels of larger mesh should be used to allow small fish to escape. That study was successful in having 50 x 75 mm mesh incorporated into fish traps in NSW. The NSW trap fishery is a multi-species one and no one-sized mesh is perfect for every species. One option for the demersal trap fishery is to do away with regulated MLLs and to control the sizes at first harvest by changing the selectivity of the gear. Such an approach would immediately remove issues to do with by-catch and discard mortality. Multi-species yield per recruit and SPR analyses may indicate an optimum sized escape panel mesh for the trap fishery if managers decide to examine such an approach. Similar to the compromises that must be reached when dealing with conflicting management objectives when assessing MLLs, compromises would be required between a mesh size that harvested some species at too small a size and some species at too large a size.

Table 16.11 details the sizes at first harvest that would be achieved by implementing the recommended MLLs for recreational fishers and using only gear selectivity to control the sizes of fish retained in commercial fish traps. Selectivity in two escape panel mesh sizes is documented and sizes have been rounded to the nearest 5 cm TL.

Table 16.11. Options for controlling the sizes at first harvest using MLLs for recreational fishers and gear selectivity for demersal trap fishers. Sizes have been rounded to the nearest 5 cm total length.

	Recreational MLL (cm)	50x75 trap mesh selectivity (cm)	50x87 trap mesh selectivity (cm)
Rubberlip morwong	25	25	30
Tarwhine	25	25	unknown
Blackspot pigfish	20	35	40
Maori wrasse	20	lose all	lose all
Red rockcod	20	unknown	unknown
Pearl perch	35	unknown	unknown
Ocean leatherjacket	35	35	40
Yellowfin bream	30	25	30
Snapper	35	25	30
Sweep	25	Retain all	25
Silver trevally	30	25	30

16.5. Discussion

The MCDA framework presented here is for the benefit of fisheries management agencies when deciding on appropriate sizes at first harvest. It is important to note that in order for this framework to work effectively the biological and fishery data that it requires must be robust. Unreliable information will undermine confidence in the framework outputs and managers may feel uncomfortable in implementing changes based on such information. The framework cannot produce unequivocal solutions, but does provide an objective way for managers to examine the available information and to assess how well they can achieve their management objectives. Importantly, the framework also provides a transparent mechanism for stakeholders to understand why such management decisions are made. The problem for managers remains that when multiple objectives are being considered there will seldom be unambiguous and optimal solutions for all objectives. Compromises are therefore required, and the relative weightings given to measures in the MCDA framework allows for such compromises to be examined transparently. The relative weightings given to different measures are subjective and will likely vary depending on individual or stakeholder preferences. This is why sensitivity analyses should be done to examine what impact differences in weighting may have on the 'best' MLL (Table 16.9). The example using rubberlip morwong is interesting because for most combinations of different weightings examined the optimal solution (ignoring immediate impacts on fisheries) was 29 cm FL (Table 16.9). Such a result provides additional confidence in what may be appropriate.

The inclusion of management objectives that aim to minimize immediate losses from any increases in MLLs may be counter-productive when deciding at what size a species should first be harvested. Such management objectives are not the reasons behind wanting to limit the size at first harvest and their inclusion in the MCDA framework results in smaller optimal MLLs (Table 16.9). Rather, once a decision has been made on what an appropriate MLL should be, these extra management objectives may be used to help managers in achieving the desired MLL in a manner that minimises immediate losses to fishers. (Note that if managers are to make informed decisions on immediate impacts of management changes they require reliable information on what is being harvested by each fishery. In NSW there is no reliable current information on the sizes of fish landed by the recreational fishery.) Implementing a series of staged increases in MLL through time is one way of achieving a desired outcome whilst minimizing short-term losses. Any staged increases must be associated with clearly defined timeframes and a commitment to achieve the desired MLL if such an approach is to succeed. Such a staged approach was attempted for snapper in NSW when a decision was made to increase the MLL from 28 to 32 cm TL. The MLL was increased to 30 cm in 2001, yet the next staged increase has not happened to date (mid 2007) despite evidence that the initial increase has had positive results. While the way in which management changes are implemented is not the focus of the present study, such examples of poorly implemented management changes serve to demonstrate ways in which future changes in MLLs can be better handled and improve perception of the management agency. It is accepted that public consultation can be complex and that ultimately decisions will always be made at the political level. However, in order to achieve a high level of public approval such consultation and decision making should be done in a timely fashion (see review of the current NSW review at the end of this chapter). Taking too long to implement management changes can be embarrassing to the government and damages the credibility of the management organization.

Note that following using this framework to determine the 'best' size at which a species should first be harvested, an assessment must be made of whether a MLL is an appropriate management tool. For example, if discard mortality rates are large, then any benefits from harvesting fish at larger sizes will be negated and in such instances alternative management tools should be considered (e.g., changes to gear selectivity). This decision is an important one and has ramifications for the management philosophy in NSW that commercial and recreational fisheries should have complementary MLLs. For example, if discard mortality rates for silver trevally caught by trawling are high then a MLL may not be a sensible management tool in the trawl fishery. Rather, a more sensible way of controlling the size at first capture would be to modify the selectivity of the trawl nets used. However, if discard mortality rates of recreationally caught silver trevally are low (and some preliminary work suggests that it may be, Broadhurst *et al.*, 2005), then a MLL for recreational fishers would be a sensible management tool.

The recommended appropriate sizes at first harvest in Table 16.10 are made as a required objective of the project; however we reiterate that it is outside of the scope of this study to tell managers how to manage their fisheries. These recommendations have been made based solely on the grounds of biology and sustainability. The MCDA framework resulted in optimal sizes at first harvest that were larger than the current management limits for all species except for rubberlip morwong. These analyses are based on sustainability issues at current levels of exploitation and provide evidence that current management limits may be inappropriate for many species.

Based on the sizes of fish currently retained (see species chapters and information fact sheets), the recommended MLLs for rubberlip morwong, blackspot pigfish, maori wrasse, red rockcod and sweep would have negligible immediate impacts on commercial and recreational landings. As such there may be an argument to maintain the current management arrangements for these species. Alternatively, it may be prudent to implement the recommended MLLs to prevent future increases in harvesting of small fish and to demonstrate pro-active management. In contrast, increases in the MLLs for tarwhine, pearl perch, ocean leatherjacket, yellowfin bream, yellowtail kingfish, mulloway, snapper and silver trevally would result in significant immediate losses to harvesters. Predicted future increases in stock sizes as a consequence of increasing the size at first harvest should negate these immediate losses; however staged increases in MLLs could be made if managers consider immediate impacts to be too great.

The MCDA analyses for yellowtail kingfish and mulloway show how the framework may also benefit managers by giving them the option of making post hoc justifications as to why MLLs are being implemented. The 'best' size at which to first harvest yellowtail kingfish so as to protect juveniles, sustain the stock and address growth overfishing is 100 cm TL. A 100 cm TL yellowtail kingfish is a very large fish (~ nine kg) and such a large MLL would be considered unsuitable for the NSW commercial or recreational fisheries. However, the MCDA framework showed that by not including the management objective "to protect juveniles" that the optimal MLL was reduced to 80 cm. Such a limit would be defensible based on the management objectives to maintain the stock and address growth overfishing. Likewise for mulloway, the MCDA indicated that they should have a MLL at a very large size (95 cm). However, by limiting the management objectives to those that protect juveniles and maintain the stock, the optimal MLL is reduced to 70 cm – a much more acceptable size to fishers.

The index of sustainability used in the MCDA, the spawning potential ratio (SPR) is a proxy for the ability of a population to spawn sufficient eggs to ensure adequate recruitment. The threshold level of 0.2 set for the analyses is based on the general life-history of the species being studied, and is not conservative. A more conservative threshold level that has been recommended is 0.3 (Mace & Sissenwine, 1993). If the management objective is to ensure adequate reproduction to maintain stocks, the SPR is probably a more useful measure than that of protecting juveniles (see Table 16.1). This is because the SPR includes information on the size at maturity as well as the exponentially increasing numbers of eggs produced as fish grow. The SPR levels in each species' chapter and the SPR utility values in Appendix 3 show that the majority of species are being exploited at a level that should allow sufficient reproduction. However, the SPR levels for yellowtail kingfish, mulloway and snapper are below the threshold level of 0.2 (~ 0.11, 0.11, 0.12 in each case) indicating that under current harvesting arrangements (e.g., size at first harvest and exploitation rate) that these species may be at high risk of recruitment failure. The SPR for pearl perch is at the threshold level and it would be prudent to try and increase it to safer levels. Increasing the size at first harvest for these species would have the effect of reducing overall fishing mortality (assuming discard mortality to be small) and of increasing the reproductive capacity to sustainable levels. It is strongly recommended that managers consider increasing the MLL to the recommended levels for these four species to ensure their sustainability.

The third stated objective of this project was "Where appropriate to recommend minimum legal lengths for species across all fisheries". It is not appropriate to recommend MLLs across fisheries; however we have documented options for managers should they wish to control the sizes at first harvest through gear selectivity, rather than MLLs, in the commercial trap fishery. Such an approach has merit because it immediately removes problems involving by-catch and discard mortality. Table 16.11 shows that removing all regulated MLLs in the trap fishery while using 50 x 75 mm or 50 x 87 mm escape panel mesh would produce comparable restrictions to those recommended for the recreational fishery for some species. Equality could be achieved between fisheries by changing the recreational MLL to the selection size in commercial gears where appropriate from a sustainability perspective. The predicted loss of all maori wrasse from the trap fishery as a result of this management option would be a small issue given their minor contribution to earnings from fish traps. Such a minor loss would be far outweighed by the benefits of not having any by-catch issues. Multi-species yield per recruit and SPR analyses should be done if managers wish to pursue this management approach.

Current NSW DPI Review of MLLs

This report does not criticize the process of the current fishing bag and size limit review in NSW; however short-comings are identified so that future reviews can continuously improve. The recent bag and size limit review in NSW was originally well conducted in both a transparent and informative manner. An excellent discussion paper was widely distributed in July 2005, which detailed proposed changes in MLLs and some rationale behind their implementation. Background information was provided with the options for each species; however the discussion paper lacked information on species-specific management objectives and how well each option addressed those objectives. It is likely that this short-coming precluded educated assessment and comments from the majority of stakeholders. Information fact sheets similar to those included in each species' chapter with MCDA management objectives and summaries may improve future consultation.

Public submissions were collated and support from the peak recreational and commercial fishing industry bodies assessed. Unfortunately, despite the transparency evident throughout most of the review, the final decisions on changes to MLLs were made without publicly available justifications. Final recommendations were made to the government minister in mid 2006 and the changes have only just been announced (August, 2007). The very slow process (greater than two years between when the discussion paper was released and changes were announced) has been unfortunate because an unnecessary air of conspiracy has now soured the process and the government has been widely criticized. The MCDA framework presented in this report may assist in improving transparency and in educating the peak industry bodies as to why management changes are being proposed.

It is concluded that future reviews could be improved by: (i) stating management objectives for each species and how well each option for a MLL satisfies those objectives; (ii) providing more detailed information on each species; (iii) greater transparency and justification in the final decision making process, and; (iv) more timely dissemination of results to stakeholders.

Summary

- Management require a well defined series of visions, goals, objectives and management responses. Desired management objectives of limiting the size at first harvest must be stated and this is pre-requisite for the MCDA framework to succeed.
- The MCDA framework requires reliable, current information on the fisheries and biology of species to be considered.
- Assigning relative weightings to different management measures will affect the optimal solutions and sensitivity analyses should be done.
- Rounding optimal solutions to 5 cm increments may be prudent.
- Once appropriate sizes at first harvest are decided, consultation with stakeholders and implementation of management changes should be done in a timely manner.
- Disparate MLLs and/or management controls should be considered for different fisheries.

17. OUTCOMES AND RECOMMENDATIONS

17.1. Benefits

This study has provided important new information on the biology and fisheries for several significant coastal fish species in NSW. This information will directly lead to improved assessment and management of the commercial and recreational fisheries in NSW. Information on species that span state jurisdictions (e.g., tarwhine, pigfish, pearl perch, kingfish, mulloway and snapper) will benefit other state fisheries management agencies. Development of the multi-criteria decision analysis (MCDA) framework for deciding on appropriate sizes at first harvest has the potential to benefit fisheries management agencies around the world.

17.2. Further Development

The project has highlighted the need for accurate, current and local information on biology and fisheries in order to manage them in an informed an effective manner. Such information is lacking for many exploited species and is requisite for the MCDA framework to be used successfully. An outcome from the present study has been identifying the relatively poor information that is available for current recreational fishing. Available information on the lengths of fish landed by recreational fishers in NSW is more than 12 years old (Steffe *et al.*, 1996), the catch and effort data is more than 7 years old (Henry & Lyle, 2003), and the charterboat information is generally unreliable. Given the need for reliable information from the recreational and charterboat fishing sectors for the MCDA framework to operate successfully, appropriate resources should be allocated to improving our knowledge of their activities.

Much of the new information reported for exploited coastal species will be written and published in the international scientific literature in order to increase the exposure of the projects outcomes to the international scientific community.

17.3. Planned Outcomes

The planned outcomes of this project were:

(i) A formal protocol for determining appropriate minimum legal lengths based on biological, economic and social factors.

Achieved. The multi-criteria decision analysis (MCDA) framework described in Chapter 16 satisfies this planned outcome. The framework successfully demonstrates how biological, economic and social factors can be used in an objective and transparent manner when determining appropriate sizes at first harvest for fish. The resulting sizes at first harvest may be controlled through regulated minimum legal lengths, or gear selectivity.

(ii) Provide information that contributes to an understanding of stock-status for important species harvested by both the NSW Ocean Trap and Line and the recreational fisheries.

Achieved. The project has provided new information for 13 important species harvested in commercial and recreational coastal fisheries in NSW. Analyses of trends in landings, catch per unit of effort, the proportion of the catch taken by each fishing sector, mortality estimates, yields per recruit and spawning potential ratios all contribute to an improved understanding of stock status. The 2007 NSW DPI annual resource assessment workshop incorporated much of the information presented in this report. As a direct result of this project the resource assessment status for five species (rubberlip morwong, tarwhine, blackspot pigfish, maori wrasse and red rockcod) were improved from level 4 assessments (being undefined) to level 3 assessments. The assessment for pearl perch should also be improved for 2006/07 based on the findings in this study. The spawning potential ratio analyses may be incorporated into future assessments because they provide indices concerning the ability of populations to replenish themselves at current levels of exploitation.

(iii) Information on the biology and fisheries for these species (including growth rates, reproductive biology and the sizes and ages in landings).

Achieved. This project has provided the first information available on the biology and fisheries for rubberlip morwong, tarwhine, blackspot pigfish, maori wrasse, red rockcod and pearl perch in NSW. It has also collated and re-analysed existing information for another seven important exploited species. The new information on age, growth, sexual maturity, spawning seasons, mortality estimates and fishery landings will be invaluable for assessment and management of these species. The information will also be important for further research on these, and similar, species worldwide.

17.4. Conclusions

The objectives of this project were focussed on providing new information on the biology and fisheries for species that are exploited by coastal commercial and recreational fishers in NSW. This information was to be used for demonstration purposes in developing a framework that has great potential to improve the way in which fisheries managers determine appropriate sizes at first harvest, generally through implementing MLLs.

The results have provided a more thorough understanding of the fisheries for, and exploitation status of, exploited coastal species in NSW. In summary, these coastal species are being heavily exploited with five of the 13 species being assessed as overfished, six as being fully fished and two as being moderately fished. The proportion of the catch taken by recreational fishers is increasing and many species are now predominantly harvested by this sector. There is little doubt that increased recreational fishing pressure is a major contributing factor in the decline of many important coastal species. The species studied can be characterised as being generally long-lived (> 15 years and ranging up to > 50 years for sweep), and maturing sexually at relatively small sizes and young ages (two to three years old). Despite their potential longevity, landings of species that have a long history of exploitation are characterised by being dominated by a few young age classes. These observations result in relatively high estimates of total mortality (from age-based catch curves) and low estimates of natural mortality (based on maximum age). However, for those species that have historically been considered a by-catch for commercial and recreational fishers (e.g., blackspot pigfish, red rockcod, maori wrasse and sweep), the age composition in landings are generally characteristic of species that have received lower fishing pressure (the fisheries are based on many year classes and there are relatively large numbers of older fish in landings). One concern is that the importance of these species to fishers has the potential to increase substantially as the abundance of traditionally more highly-prized species diminishes. If their sizes at first harvest are not set at levels that ensure the sustainability of stocks, then they too have the potential to become severely depleted in the future.

The relative increases in catch and effort by the recreational and charterboat fisheries highlights the importance of incorporating landings from these sectors into fishery assessments. Monitoring recreational landings is difficult and expensive; however it is required for informed management. The most recent information available for use during the present study was by Steffe *et al.* (1996) who provided high quality information on the landed catch from offshore trailerboat fishers during 1993 – 1995. This information is currently more than 12 years old and may not reflect current landings. Unfortunately, we have demonstrated that the self-reported logbook information on the lengths of fish caught by charterboat fishers in NSW as a requirement of their licences is of very poor quality. There has clearly been little attempt at quality control and the information provided is an ugly mix of different length measurements (fork lengths and total lengths) and rough estimates. It is hoped that the present study has demonstrated the importance of accurate information from this sector in allowing sensible management of this fishery. A major recommendation from this report is that the managers responsible for the charterboat logbook program in NSW rectify the problems identified as a priority.

We have demonstrated that local biological information is required for assessment and management of local fisheries. Basic life-history traits such as age, growth, longevity, sizes and ages at sexual maturity and reproductive seasons are shown to vary substantially between populations of the same species in other states (e.g., tarwhine, pearl perch, ocean leatherjackets, bream, mulloway, snapper and silver trevally). As such, each population may respond differently to exploitation and management based on non-local biological parameters is high risk.

It is hoped that the multi-criteria decision analysis (MCDA) framework provided is adopted by fishery managers when considering appropriate sizes at first harvest. The framework is a major improvement on existing arrangements because it: (i) requires objectives of management to be stated; (ii) can integrate all available information; (iii) documents trade-offs between conflicting objectives and stakeholders, and; (iv) encourages transparent decision making. The framework also indicates areas where information is lacking for informed management and can therefore identify areas for future research and monitoring.

The recommended sizes at first harvest made in the present study were determined using the MCDA framework with only biological and sustainability management objectives. Recommended MLLs were greater than the current regulations for all species except for rubberlip morwong, providing evidence that current management arrangements may be inappropriate. This is likely a reflection of the failure of fisheries management to abide by their oft-proclaimed goal of ensuring sufficient reproduction by applying the ‘50% maturity rule’ when setting MLLs. We believe that the spawning potential ratio (SPR) is a more useful tool for assessing the ability of a population to reproduce sufficiently and encourage its use in the MCDA framework.

Finally, once appropriate sizes at first harvest are determined managers must decide whether they are controlled through regulated MLLs or gear selectivity. Issues such as discard mortality are vitally important to such decisions. It may also be useful for managers to consider disparate management arrangements for controlling the sizes at first harvest for different fisheries. The demersal trap fishery in NSW may be an ideal fishery whereby minimum sizes at first harvest could be controlled through gear selectivity in place of regulated MLLs. The result would immediately solve by-catch and discard mortality issues in the fishery and commensurate sizes at first harvest in the recreational fishery could be implemented through MLLs. Consideration of different sizes at first harvest for different fishing sectors may also be useful.

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19. APPENDICES

19.1. Appendix 1 – Intellectual property

No patentable inventions or processes were developed as part of this work. The work presented in this report remains the intellectual property of the authors, and they should be acknowledged when citing this work.

19.2. Appendix 2 – Staff

Staff directly employed on this project were:

Dr John Stewart – Research Scientist
Mr Julian Hughes – Fisheries Technician
Mr Matthew Lockett – Fisheries Technician
Mr Glen Cuthbert – Casual Assistant
Mr Glen Campbell – Casual Assistant

19.3. Appendix 3 – Multi-criteria decision analysis tables

Multi-Criteria Decision Analysis Tables have been prepared for the 13 species analysed in this report. The tables include all seven demonstration management objectives described in Chapter 16.

Table 19.1. Combined utility measures for all management objectives for rubberlip morwong. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective are in bold. Data is from Chapter 3.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreational impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
2	0.00	**1.00**	0.78	0.08	0.00	**1.00**	**1.00**	0.5511
3	0.00	**1.00**	0.79	0.08	0.00	**1.00**	**1.00**	0.5528
4	0.00	**1.00**	0.80	0.08	0.00	**1.00**	**1.00**	0.5547
5	0.00	**1.00**	0.81	0.08	0.00	**1.00**	**1.00**	0.5566
6	0.00	**1.00**	0.82	0.08	0.00	**1.00**	**1.00**	0.5586
7	0.00	**1.00**	0.84	0.09	0.00	**1.00**	**1.00**	0.5606
8	0.00	**1.00**	0.85	0.09	0.00	**1.00**	**1.00**	0.5627
9	0.00	**1.00**	0.86	0.09	0.00	**1.00**	**1.00**	0.5648
10	0.00	**1.00**	0.87	0.09	0.00	**1.00**	**1.00**	0.5670
11	0.00	**1.00**	0.89	0.10	0.00	**1.00**	**1.00**	0.5693
12	0.00	**1.00**	0.90	0.10	0.00	**1.00**	**1.00**	0.5716
13	0.00	**1.00**	0.91	0.10	0.00	**1.00**	**1.00**	0.5740
14	0.01	**1.00**	0.93	0.10	0.00	**1.00**	**1.00**	0.5767
15	0.01	**1.00**	0.94	0.18	0.00	**1.00**	**1.00**	0.5909
16	0.03	**1.00**	0.95	0.19	0.00	**1.00**	**1.00**	0.5954
17	0.06	**1.00**	0.96	0.19	0.00	**1.00**	**1.00**	0.6022
18	0.12	**1.00**	0.97	0.20	0.00	**1.00**	**1.00**	0.6132
19	0.23	**1.00**	0.98	0.20	0.00	**1.00**	**1.00**	0.6311
20	0.40	**1.00**	0.99	0.34	0.00	**1.00**	**1.00**	0.6758
21	0.60	**1.00**	0.99	0.35	0.00	**1.00**	**1.00**	0.7049
22	**1.00**	**1.00**	**1.00**	0.35	0.00	0.99	**1.00**	0.7624
23	**1.00**	**1.00**	**1.00**	0.44	0.00	0.94	**1.00**	0.7679
24	**1.00**	**1.00**	**1.00**	0.52	0.00	0.86	**1.00**	0.7671
25	**1.00**	**1.00**	0.99	0.60	0.00	0.78	0.99	0.7673
26	**1.00**	**1.00**	0.98	0.69	0.00	0.69	0.99	0.7637
27	**1.00**	**1.00**	0.97	0.77	0.00	0.61	0.97	0.7594
28	**1.00**	**1.00**	0.95	0.84	0.00	0.51	0.94	0.7486
29	**1.00**	**1.00**	0.92	0.90	0.00	0.41	0.91	0.7348
30	**1.00**	**1.00**	0.89	0.95	0.00	0.32	0.83	0.7135
31	**1.00**	**1.00**	0.84	0.99	0.00	0.24	0.78	0.6934
32	**1.00**	**1.00**	0.79	**1.00**	0.00	0.18	0.70	0.6668
33	**1.00**	**1.00**	0.71	0.98	0.00	0.12	0.62	0.6343
34	**1.00**	**1.00**	0.62	0.91	0.00	0.09	0.53	0.5937
35	**1.00**	**1.00**	0.50	0.78	0.00	0.06	0.44	0.5391
36	**1.00**	**1.00**	0.31	0.51	0.00	0.04	0.33	0.4555
37	**1.00**	**1.00**	0.00	0.00	0.00	0.02	0.27	0.3279
38	**1.00**	**1.00**	0.00	0.00	0.00	0.01	0.16	0.3106
39	**1.00**	**1.00**	0.00	0.00	0.00	0.01	0.09	0.2999
40	**1.00**	**1.00**	0.00	0.00	0.00	0.00	0.00	0.2857

Table 19.2. Combined utility measures for all management objectives for tarwhine. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 4.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreational impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
0	0.00	0.00	0.60	0.00	0.00	**1.00**	**1.00**	0.3716
1	0.00	0.00	0.62	0.00	0.00	**1.00**	**1.00**	0.3740
2	0.00	0.00	0.64	0.00	0.00	**1.00**	**1.00**	0.3766
3	0.00	0.00	0.66	0.00	0.00	**1.00**	**1.00**	0.3794
4	0.00	0.00	0.68	0.00	0.00	**1.00**	**1.00**	0.3823
5	0.00	0.00	0.70	0.00	0.00	**1.00**	**1.00**	0.3855
6	0.00	0.00	0.72	0.00	0.00	**1.00**	**1.00**	0.3888
7	0.00	0.00	0.75	0.00	0.00	**1.00**	**1.00**	0.3922
8	0.00	0.00	0.77	0.00	0.00	**1.00**	**1.00**	0.3959
9	0.00	0.00	0.80	0.00	0.00	**1.00**	**1.00**	0.3996
10	0.00	0.00	0.82	0.00	0.00	**1.00**	**1.00**	0.4034
11	0.00	0.00	0.85	0.00	0.00	**1.00**	**1.00**	0.4072
12	0.00	**1.00**	0.88	0.00	0.00	**1.00**	**1.00**	0.5539
13	0.00	**1.00**	0.90	0.00	0.00	**1.00**	**1.00**	0.5577
14	0.00	**1.00**	0.93	0.00	0.00	**1.00**	**1.00**	0.5613
15	0.00	**1.00**	0.95	0.00	0.00	**1.00**	**1.00**	0.5649
16	0.01	**1.00**	0.97	0.00	0.00	**1.00**	**1.00**	0.5686
17	0.03	**1.00**	0.99	0.00	0.00	0.86	**1.00**	0.5547
18	0.10	**1.00**	**1.00**	0.83	0.77	0.64	**1.00**	0.7628
19	0.27	**1.00**	**1.00**	0.83	**1.00**	0.49	0.99	0.7984
20	0.55	**1.00**	0.99	0.83	**1.00**	0.38	0.98	0.8188
21	**1.00**	**1.00**	0.97	0.81	**1.00**	0.29	0.97	0.8635
22	**1.00**	**1.00**	0.94	**1.00**	**1.00**	0.22	0.94	0.8702
23	**1.00**	**1.00**	0.88	0.93	**1.00**	0.15	0.89	0.8359
24	**1.00**	**1.00**	0.78	0.83	**1.00**	0.09	0.78	0.7825
25	**1.00**	**1.00**	0.61	0.65	**1.00**	0.06	0.67	0.7124
26	**1.00**	**1.00**	0.22	0.24	**1.00**	0.04	0.50	0.5713

Table 19.3. Combined utility measures for all management objectives for blackspot pigfish. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 5.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreational impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
0	0.00	**1.00**	0.69	0.00	0.00	**1.00**	**1.00**	0.3838
1	0.00	**1.00**	0.70	0.00	0.00	**1.00**	**1.00**	0.3852
2	0.00	**1.00**	0.71	0.00	0.00	**1.00**	**1.00**	0.3867
3	0.00	**1.00**	0.72	0.00	0.00	**1.00**	**1.00**	0.3882
4	0.00	**1.00**	0.73	0.00	0.00	**1.00**	**1.00**	0.3898
5	0.00	**1.00**	0.74	0.00	0.00	**1.00**	**1.00**	0.3915
6	0.00	**1.00**	0.75	0.00	0.00	**1.00**	**1.00**	0.3933
7	0.00	**1.00**	0.77	0.00	0.00	**1.00**	**1.00**	0.3951
8	0.00	**1.00**	0.78	0.00	0.00	**1.00**	**1.00**	0.3970
9	0.00	**1.00**	0.79	0.00	0.00	**1.00**	**1.00**	0.3989
10	0.00	**1.00**	0.81	0.00	0.00	**1.00**	**1.00**	0.4009
11	0.00	**1.00**	0.82	0.00	0.00	**1.00**	**1.00**	0.4030
12	0.00	**1.00**	0.84	0.00	0.00	**1.00**	**1.00**	0.4051
13	0.00	**1.00**	0.85	0.00	0.00	**1.00**	**1.00**	0.4073
14	0.00	**1.00**	0.87	0.00	0.00	**1.00**	**1.00**	0.4095
15	0.00	**1.00**	0.88	0.00	0.00	**1.00**	**1.00**	0.4117
16	0.00	**1.00**	0.90	0.00	0.13	**1.00**	**1.00**	0.5756
17	0.00	**1.00**	0.91	0.00	0.26	**1.00**	**1.00**	0.5964
18	0.00	**1.00**	0.93	0.00	0.39	**1.00**	**1.00**	0.6165
19	0.00	**1.00**	0.94	0.00	0.51	**1.00**	0.99	0.6357
20	0.00	**1.00**	0.96	0.00	0.63	**1.00**	0.98	0.6531
21	0.00	**1.00**	0.97	0.00	0.74	**1.00**	0.98	0.6691
22	**1.00**	**1.00**	0.98	0.97	0.83	**1.00**	0.97	0.9636
23	**1.00**	**1.00**	0.99	0.98	0.91	**1.00**	0.96	0.9762
24	**1.00**	**1.00**	**1.00**	0.98	0.97	0.99	0.95	0.9835
25	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.96	0.93	0.9854
26	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.91	0.91	0.9731
27	**1.00**	**1.00**	0.99	0.99	**1.00**	0.83	0.87	0.9560
28	**1.00**	**1.00**	0.98	0.98	**1.00**	0.72	0.81	0.9282
29	**1.00**	**1.00**	0.96	0.96	**1.00**	0.63	0.75	0.8981
30	**1.00**	**1.00**	0.92	0.92	**1.00**	0.47	0.63	0.8478
31	**1.00**	**1.00**	0.86	0.86	**1.00**	0.34	0.54	0.7989
32	**1.00**	**1.00**	0.75	0.75	**1.00**	0.22	0.44	0.7379
33	**1.00**	**1.00**	0.53	0.47	**1.00**	0.13	0.35	0.6381

Table 19.4. Combined utility measures for all management objectives for maori wrasse. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 6.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreational impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
0	0.00	**1.00**	0.83	0.00	0.00	**1.00**	**1.00**	0.5475
1	0.00	**1.00**	0.84	0.00	0.00	**1.00**	**1.00**	0.5487
2	0.00	**1.00**	0.85	0.00	0.00	**1.00**	**1.00**	0.5499
3	0.00	**1.00**	0.86	0.00	0.00	**1.00**	**1.00**	0.5512
4	0.00	**1.00**	0.87	0.00	0.00	**1.00**	**1.00**	0.5526
5	0.00	**1.00**	0.88	0.00	0.00	**1.00**	**1.00**	0.5540
6	0.00	**1.00**	0.89	0.00	0.00	**1.00**	**1.00**	0.5554
7	0.00	**1.00**	0.90	0.00	0.00	**1.00**	**1.00**	0.5569
8	0.00	**1.00**	0.91	0.00	0.00	**1.00**	**1.00**	0.5586
9	0.00	**1.00**	0.92	0.00	0.00	**1.00**	**1.00**	0.5603
10	0.01	**1.00**	0.93	0.00	0.00	**1.00**	**1.00**	0.5622
11	0.01	**1.00**	0.94	0.00	0.00	**1.00**	**1.00**	0.5644
12	0.02	**1.00**	0.95	0.00	0.00	**1.00**	**1.00**	0.5671
13	0.04	**1.00**	0.96	0.00	0.00	**1.00**	**1.00**	0.5706
14	0.06	**1.00**	0.97	0.00	0.00	**1.00**	**1.00**	0.5756
15	0.10	**1.00**	0.98	0.00	0.27	**1.00**	**1.00**	0.6211
16	0.17	**1.00**	0.98	0.00	0.51	**1.00**	**1.00**	0.6656
17	0.26	**1.00**	0.99	0.00	0.71	**1.00**	**1.00**	0.7088
18	0.38	**1.00**	**1.00**	0.00	0.87	**1.00**	**1.00**	0.7488
19	0.52	**1.00**	**1.00**	0.00	0.97	**1.00**	**1.00**	0.7830
20	0.65	**1.00**	**1.00**	0.92	**1.00**	**1.00**	0.99	0.9370
21	**1.00**	**1.00**	**1.00**	0.92	**1.00**	**1.00**	0.99	0.9849
22	**1.00**	**1.00**	0.99	0.91	**1.00**	0.99	0.98	0.9811
23	**1.00**	**1.00**	0.99	0.90	**1.00**	0.97	0.97	0.9760
24	**1.00**	**1.00**	0.97	**1.00**	**1.00**	0.94	0.95	0.9816
25	**1.00**	**1.00**	0.96	0.98	**1.00**	0.90	0.94	0.9681
26	**1.00**	**1.00**	0.93	0.96	**1.00**	0.83	0.92	0.9477
27	**1.00**	**1.00**	0.90	0.93	**1.00**	0.76	0.88	0.9247
28	**1.00**	**1.00**	0.86	0.88	**1.00**	0.68	0.83	0.8927
29	**1.00**	**1.00**	0.81	0.83	**1.00**	0.57	0.76	0.8533
30	**1.00**	**1.00**	0.75	0.77	**1.00**	0.48	0.62	0.8012
31	**1.00**	**1.00**	0.66	0.68	**1.00**	0.35	0.51	0.7443
32	**1.00**	**1.00**	0.56	0.57	**1.00**	0.24	0.40	0.6818
33	**1.00**	**1.00**	0.41	0.42	**1.00**	0.11	0.29	0.6035
34	**1.00**	**1.00**	0.16	0.17	**1.00**	0.03	0.20	0.5081

Table 19.5. Combined utility measures for all management objectives for red rockcod. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 7.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreational impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
0	0.00	**1.00**	0.85	0.00	0.00	**1.00**	**1.00**	0.5503
1	0.01	**1.00**	0.86	0.00	0.00	**1.00**	**1.00**	0.5516
2	0.01	**1.00**	0.86	0.00	0.00	**1.00**	**1.00**	0.5531
3	0.01	**1.00**	0.87	0.00	0.06	**1.00**	**1.00**	0.5634
4	0.02	**1.00**	0.88	0.00	0.13	**1.00**	**1.00**	0.5744
5	0.02	**1.00**	0.89	0.00	0.19	**1.00**	**1.00**	0.5861
6	0.03	**1.00**	0.90	0.00	0.26	**1.00**	**1.00**	0.5985
7	0.04	**1.00**	0.91	0.00	0.33	**1.00**	**1.00**	0.6116
8	0.06	**1.00**	0.92	0.00	0.40	**1.00**	**1.00**	0.6256
9	0.08	**1.00**	0.93	0.00	0.48	**1.00**	**1.00**	0.6406
10	0.11	**1.00**	0.94	0.00	0.55	**1.00**	**1.00**	0.6567
11	0.15	**1.00**	0.95	0.00	0.62	**1.00**	**1.00**	0.6739
12	0.20	**1.00**	0.96	0.00	0.70	**1.00**	**1.00**	0.6922
13	0.26	**1.00**	0.97	0.00	0.77	**1.00**	**1.00**	0.7117
14	0.33	**1.00**	0.98	0.92	0.83	**1.00**	**1.00**	0.8634
15	0.41	**1.00**	0.98	0.93	0.89	0.99	0.99	0.8839
16	0.49	**1.00**	0.99	0.94	0.94	0.97	0.99	0.9009
17	0.58	**1.00**	**1.00**	0.94	0.97	0.92	0.99	0.9134
18	0.66	**1.00**	**1.00**	0.94	**1.00**	0.87	0.98	0.9209
19	0.74	**1.00**	**1.00**	0.95	**1.00**	0.80	0.98	0.9215
20	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.69	0.96	0.9490
21	**1.00**	**1.00**	0.99	0.99	**1.00**	0.56	0.94	0.9256
22	**1.00**	**1.00**	0.98	0.98	**1.00**	0.46	0.92	0.9045
23	**1.00**	**1.00**	0.96	0.96	**1.00**	0.39	0.90	0.8860
24	**1.00**	**1.00**	0.93	0.93	**1.00**	0.33	0.86	0.8632
25	**1.00**	**1.00**	0.89	0.86	**1.00**	0.26	0.81	0.8312
26	**1.00**	**1.00**	0.83	0.80	**1.00**	0.20	0.75	0.7971
27	**1.00**	**1.00**	0.73	0.71	**1.00**	0.15	0.70	0.7571
28	**1.00**	**1.00**	0.58	0.57	**1.00**	0.12	0.61	0.6970

Table 19.6. Combined utility measures for all management objectives for pearl perch. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 8.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreational impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
15	0.00	0.00	0.53	0.46	0.00	**1.00**	**1.00**	0.4274
16	0.06	0.00	0.56	0.49	0.00	**1.00**	**1.00**	0.4449
17	0.08	0.00	0.59	0.52	0.00	**1.00**	**1.00**	0.4565
18	0.10	0.00	0.63	0.55	0.00	**1.00**	**1.00**	0.4681
19	0.13	0.00	0.66	0.58	0.00	**1.00**	**1.00**	0.4812
20	0.17	0.00	0.69	0.61	0.00	**1.00**	**1.00**	0.4954
21	0.22	0.00	0.72	0.64	0.00	**1.00**	**1.00**	0.5111
22	0.27	0.00	0.76	0.66	0.00	**1.00**	**1.00**	0.5261
23	0.34	0.00	0.78	0.69	0.00	0.99	0.99	0.5426
24	0.41	0.00	0.81	0.71	0.00	0.98	0.99	0.5577
25	0.48	**1.00**	0.84	0.74	0.00	0.96	0.98	0.7140
26	0.56	**1.00**	0.87	0.76	0.16	0.93	0.97	0.7487
27	0.64	**1.00**	0.89	0.78	0.31	0.89	0.96	0.7810
28	0.70	**1.00**	0.91	0.80	0.44	0.83	0.91	0.7980
29	**1.00**	**1.00**	0.93	0.82	0.56	0.77	0.88	0.8519
30	**1.00**	**1.00**	0.95	0.83	0.67	0.69	0.80	0.8484
31	**1.00**	**1.00**	0.96	0.84	0.77	0.60	0.77	0.8500
32	**1.00**	**1.00**	0.98	0.86	0.85	0.52	0.75	0.8503
33	**1.00**	**1.00**	0.99	0.86	0.91	0.47	0.72	0.8505
34	**1.00**	**1.00**	0.99	0.87	0.96	0.40	0.63	0.8350
35	**1.00**	**1.00**	**1.00**	0.98	0.99	0.34	0.58	0.8396
36	**1.00**	**1.00**	**1.00**	0.98	**1.00**	0.29	0.53	0.8295
37	**1.00**	**1.00**	**1.00**	0.98	**1.00**	0.24	0.50	0.8165
38	**1.00**	**1.00**	**1.00**	0.98	**1.00**	0.19	0.45	0.8024
39	**1.00**	**1.00**	0.99	0.97	**1.00**	0.16	0.42	0.7919
40	**1.00**	**1.00**	0.98	0.96	**1.00**	0.13	0.38	0.7787
41	**1.00**	**1.00**	0.97	**1.00**	**1.00**	0.10	0.35	0.7747
42	**1.00**	**1.00**	0.96	0.99	**1.00**	0.08	0.29	0.7593
43	**1.00**	**1.00**	0.94	0.97	**1.00**	0.06	0.27	0.7489
44	**1.00**	**1.00**	0.92	0.95	**1.00**	0.05	0.25	0.7383
45	**1.00**	**1.00**	0.90	0.93	**1.00**	0.04	0.20	0.7246
46	**1.00**	**1.00**	0.88	0.90	**1.00**	0.03	0.17	0.7118
47	**1.00**	**1.00**	0.85	0.88	**1.00**	0.03	0.15	0.7005
48	**1.00**	**1.00**	0.82	0.85	**1.00**	0.02	0.13	0.6896
49	**1.00**	**1.00**	0.79	0.82	**1.00**	0.02	0.12	0.6794
50	**1.00**	**1.00**	0.76	0.79	**1.00**	0.01	0.11	0.6678

Table 19.7. Combined utility measures for all management objectives for ocean leatherjacket. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 9.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreational impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
20	0.00	1.00	0.61	0.36	0.00	1.00	1.00	0.5665
21	0.00	1.00	0.84	0.37	0.12	1.00	0.99	0.6167
22	0.00	1.00	0.86	0.38	0.23	1.00	0.99	0.6364
23	0.00	1.00	0.88	0.39	0.34	1.00	0.98	0.6549
24	0.00	1.00	0.90	0.40	0.44	0.99	0.97	0.6714
25	0.00	1.00	0.91	0.40	0.53	0.99	0.96	0.6855
26	0.00	1.00	0.93	0.41	0.62	0.98	0.94	0.6976
27	0.00	1.00	0.94	0.42	0.70	0.96	0.91	0.7047
28	0.00	1.00	0.96	0.42	0.77	0.92	0.88	0.7080
29	0.01	1.00	0.97	0.43	0.83	0.86	0.84	0.7065
30	0.02	1.00	0.98	0.43	0.89	0.79	0.77	0.6976
31	0.04	1.00	0.99	0.44	0.93	0.73	0.73	0.6931
32	0.08	1.00	0.99	0.44	0.96	0.67	0.68	0.6891
33	0.16	1.00	1.00	0.44	0.99	0.60	0.62	0.6861
34	0.29	1.00	1.00	0.44	1.00	0.55	0.57	0.6923
35	0.47	1.00	1.00	0.44	1.00	0.49	0.51	0.7007
36	0.65	1.00	1.00	0.44	1.00	0.43	0.45	0.7099
37	1.00	1.00	0.99	0.44	1.00	0.38	0.41	0.7468
38	1.00	1.00	0.99	0.70	1.00	0.34	0.36	0.7691
39	1.00	1.00	0.98	0.69	1.00	0.30	0.32	0.7564
40	1.00	1.00	0.97	0.69	1.00	0.25	0.27	0.7401
41	1.00	1.00	0.96	0.68	1.00	0.22	0.24	0.7290
42	1.00	1.00	0.95	1.00	1.00	0.18	0.22	0.7641
43	1.00	1.00	0.93	0.98	1.00	0.15	0.20	0.7531
44	1.00	1.00	0.91	0.97	1.00	0.13	0.19	0.7420
45	1.00	1.00	0.89	0.95	1.00	0.10	0.16	0.7295
46	1.00	1.00	0.87	0.92	1.00	0.08	0.15	0.7180
47	1.00	1.00	0.85	0.90	1.00	0.07	0.13	0.7075
48	1.00	1.00	0.83	0.87	1.00	0.05	0.12	0.6961
49	1.00	1.00	0.80	0.85	1.00	0.04	0.11	0.6857
50	1.00	1.00	0.78	0.82	1.00	0.03	0.08	0.6728

Table 19.8. Combined utility measures for all management objectives for yellowfin bream. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 10.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreational impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
15	0.00	**1.00**	0.89	0.00	0.00	**1.00**	**1.00**	0.5550
16	0.00	**1.00**	0.90	0.00	0.00	**1.00**	**1.00**	0.5578
17	0.00	**1.00**	0.92	0.00	0.00	**1.00**	**1.00**	0.5603
18	0.00	**1.00**	0.94	0.00	0.00	**1.00**	**1.00**	0.5627
19	0.00	**1.00**	0.96	0.00	0.00	**1.00**	0.99	0.5636
20	0.00	**1.00**	0.97	0.00	0.00	**1.00**	0.97	0.5627
21	0.05	**1.00**	0.99	0.00	0.00	0.99	0.93	0.5646
22	0.10	**1.00**	**1.00**	0.00	0.00	0.86	0.86	0.5451
23	0.25	**1.00**	**1.00**	**1.00**	**1.00**	0.69	0.78	0.8166
24	0.50	**1.00**	**1.00**	**1.00**	**1.00**	0.53	0.68	0.8151
25	**1.00**	**1.00**	0.99	0.99	**1.00**	0.40	0.56	0.8478
26	**1.00**	**1.00**	0.96	0.96	**1.00**	0.27	0.46	0.8077
27	**1.00**	**1.00**	0.92	0.92	**1.00**	0.19	0.33	0.7643
28	**1.00**	**1.00**	0.84	0.98	**1.00**	0.12	0.24	0.7389
29	**1.00**	**1.00**	0.65	0.76	**1.00**	0.07	0.18	0.6644
30	**1.00**	**1.00**	0.00	0.00	**1.00**	0.04	0.13	0.4528
31	**1.00**	**1.00**	0.00	0.00	**1.00**	0.02	0.09	0.4451
32	**1.00**	**1.00**	0.00	0.00	**1.00**	0.01	0.07	0.4407
33	**1.00**	**1.00**	0.00	0.00	**1.00**	0.01	0.04	0.4357
34	**1.00**	**1.00**	0.00	0.00	**1.00**	0.00	0.03	0.4339
35	**1.00**	**1.00**	0.00	0.00	**1.00**	0.00	0.02	0.4317
36	**1.00**	**1.00**	0.00	0.00	**1.00**	0.00	0.01	0.4308
37	**1.00**	**1.00**	0.00	0.00	**1.00**	0.00	0.01	0.4293
38	**1.00**	**1.00**	0.00	0.00	**1.00**	0.00	0.00	0.4290
39	**1.00**	**1.00**	0.00	0.00	**1.00**	0.00	0.00	0.4286
40	**1.00**	**1.00**	0.00	0.00	**1.00**	0.00	0.00	0.4286

Table 19.9. Combined utility measures for all management objectives for yellowtail kingfish. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 11. Note also that only trailerboat length data was used for the recreational fishery because the charterboat data was considered to be of unacceptably poor quality.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreational impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
50	0.00	0.00	0.94	0.00	0.00	**1.00**	**1.00**	0.4201
51	0.00	0.00	0.95	0.00	0.00	0.97	0.95	0.4102
52	0.00	0.00	0.95	0.96	0.00	0.89	0.89	0.5277
53	0.00	0.00	0.96	0.96	0.14	0.77	0.83	0.5245
54	0.00	0.00	0.97	0.97	0.27	0.68	0.79	0.5264
55	0.00	0.00	0.97	0.97	0.40	0.61	0.74	0.5285
56	0.00	0.00	0.98	0.98	0.51	0.54	0.70	0.5293
57	0.01	0.00	0.98	0.98	0.61	0.47	0.66	0.5305
58	0.01	0.00	0.99	0.99	0.70	0.41	0.62	0.5302
59	0.01	0.00	0.99	0.99	0.77	0.36	0.60	0.5328
60	0.01	0.00	0.99	0.99	0.84	0.32	0.55	0.5308
61	0.01	0.00	**1.00**	**1.00**	0.90	0.29	0.53	0.5326
62	0.01	0.00	**1.00**	**1.00**	0.94	0.26	0.51	0.5321
63	0.02	0.00	**1.00**	**1.00**	0.97	0.25	0.49	0.5318
64	0.02	0.00	**1.00**	**1.00**	0.99	0.23	0.46	0.5284
65	0.03	0.00	**1.00**	0.97	**1.00**	0.22	0.42	0.5199
66	0.03	0.00	**1.00**	0.97	**1.00**	0.21	0.41	0.5176
67	0.04	0.00	**1.00**	0.97	**1.00**	0.20	0.40	0.5162
68	0.05	**1.00**	**1.00**	0.97	**1.00**	0.19	0.39	0.6557
69	0.06	**1.00**	**1.00**	0.97	**1.00**	0.18	0.38	0.6545
70	0.07	**1.00**	0.99	0.97	**1.00**	0.17	0.36	0.6520
71	0.08	**1.00**	0.99	0.97	**1.00**	0.17	0.35	0.6512
72	0.10	**1.00**	0.99	0.96	**1.00**	0.16	0.35	0.6504
73	0.12	**1.00**	0.98	0.96	**1.00**	0.15	0.33	0.6487
74	0.14	**1.00**	0.98	0.95	**1.00**	0.14	0.33	0.6495
75	0.16	**1.00**	0.97	0.95	**1.00**	0.14	0.33	0.6504
76	0.19	**1.00**	0.97	0.94	**1.00**	0.13	0.32	0.6514
77	0.23	**1.00**	0.96	0.94	**1.00**	0.13	0.32	0.6532
78	0.26	**1.00**	0.96	0.93	**1.00**	0.12	0.30	0.6537
79	0.30	**1.00**	0.95	0.82	**1.00**	0.12	0.30	0.6416
80	0.35	**1.00**	0.94	0.81	**1.00**	0.12	0.29	0.6438
81	0.40	**1.00**	0.93	0.80	**1.00**	0.11	0.28	0.6459
82	0.45	**1.00**	0.93	0.80	**1.00**	0.10	0.28	0.6502
83	0.50	**1.00**	0.92	0.79	**1.00**	0.10	0.27	0.6531
84	0.55	**1.00**	0.91	0.78	**1.00**	0.10	0.26	0.6570
85	0.60	**1.00**	0.90	0.77	**1.00**	0.09	0.26	0.6614
86	0.65	**1.00**	0.89	0.76	**1.00**	0.09	0.26	0.6657
87	0.70	**1.00**	0.88	0.76	**1.00**	0.09	0.26	0.6688
88	0.74	**1.00**	0.87	0.75	**1.00**	0.09	0.26	0.6714
89	**1.00**	**1.00**	0.86	0.74	**1.00**	0.08	0.26	0.7049
90	**1.00**	**1.00**	0.84	0.73	**1.00**	0.08	0.25	0.7011

Table 19.10. Combined utility measures for all management objectives for mulloway. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 12.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreational impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
40	0.00	0.00	0.61	0.00	0.00	**1.00**	**1.00**	0.3729
41	0.00	0.00	0.62	0.00	0.00	**1.00**	**1.00**	0.3743
42	0.00	0.00	0.62	0.00	0.00	**1.00**	**1.00**	0.3741
43	0.00	0.00	0.63	0.00	0.00	0.99	**1.00**	0.3735
44	0.00	0.00	0.64	0.00	0.00	0.97	**1.00**	0.3681
45	0.00	0.00	0.65	0.72	0.00	0.89	**1.00**	0.4501
46	0.00	0.00	0.66	0.73	0.02	0.80	0.99	0.4304
47	0.00	0.00	0.67	0.74	0.05	0.70	0.99	0.4084
48	0.00	0.00	0.68	0.75	0.07	0.60	0.99	0.3862
49	0.01	0.00	0.68	0.76	0.10	0.52	0.99	0.3688
50	0.01	0.00	0.69	0.77	0.12	0.45	0.98	0.3556
51	0.01	0.00	0.70	0.73	0.15	0.39	0.98	0.3390
52	0.01	0.00	0.71	0.74	0.17	0.34	0.97	0.3306
53	0.02	0.00	0.72	0.75	0.20	0.30	0.97	0.3268
54	0.02	0.00	0.73	0.76	0.23	0.27	0.97	0.3255
55	0.03	0.00	0.74	0.77	0.25	0.24	0.96	0.3235
56	0.04	0.00	0.75	0.78	0.28	0.21	0.96	0.3238
57	0.05	0.00	0.76	0.79	0.30	0.19	0.95	0.3252
58	0.06	0.00	0.76	0.80	0.33	0.17	0.94	0.3280
59	0.08	0.00	0.77	0.80	0.35	0.16	0.93	0.3316
60	0.10	0.00	0.78	0.81	0.38	0.15	0.92	0.3389
61	0.13	0.00	0.79	0.82	0.40	0.14	0.90	0.3456
62	0.17	0.00	0.80	0.83	0.43	0.13	0.89	0.3550
63	0.21	**1.00**	0.81	0.84	0.45	0.12	0.87	0.3642
64	0.26	**1.00**	0.82	0.85	0.48	0.11	0.86	0.3758
65	0.31	**1.00**	0.83	0.86	0.50	0.11	0.84	0.3885
66	0.37	**1.00**	0.83	0.87	0.53	0.10	0.82	0.4010
67	0.44	**1.00**	0.84	0.88	0.55	0.10	0.81	0.5585
68	0.51	**1.00**	0.85	0.89	0.58	0.09	0.79	0.5734
69	0.58	**1.00**	0.86	0.89	0.60	0.09	0.78	0.5869
70	0.64	**1.00**	0.87	0.90	0.62	0.09	0.73	0.6015
71	0.70	**1.00**	0.88	0.88	0.65	0.08	0.71	0.6110
72	**1.00**	**1.00**	0.88	0.88	0.67	0.08	0.69	0.6559
73	**1.00**	**1.00**	0.89	0.89	0.69	0.08	0.67	0.6610
74	**1.00**	**1.00**	0.90	0.90	0.71	0.08	0.65	0.6664
75	**1.00**	**1.00**	0.91	0.91	0.73	0.07	0.62	0.6704
76	**1.00**	**1.00**	0.91	0.91	0.76	0.07	0.60	0.6744

Table 9.10. Continued

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreationa l impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
77	**1.00**	**1.00**	0.92	0.92	0.78	0.07	0.59	0.6796
78	**1.00**	**1.00**	0.93	0.93	0.80	0.06	0.57	0.6835
79	**1.00**	**1.00**	0.94	0.94	0.81	0.06	0.56	0.6874
80	**1.00**	**1.00**	0.94	0.94	0.83	0.06	0.53	0.6900
81	**1.00**	**1.00**	0.95	0.95	0.85	0.06	0.52	0.6954
82	**1.00**	**1.00**	0.95	0.95	0.87	0.06	0.50	0.6980
83	**1.00**	**1.00**	0.96	0.96	0.88	0.05	0.49	0.7006
84	**1.00**	**1.00**	0.96	0.96	0.90	0.05	0.47	0.7031
85	**1.00**	**1.00**	0.97	0.97	0.91	0.05	0.45	0.7070
86	**1.00**	**1.00**	0.97	0.97	0.93	0.05	0.43	0.7096
87	**1.00**	**1.00**	0.98	0.98	0.94	0.04	0.43	0.7121
88	**1.00**	**1.00**	0.98	0.98	0.95	0.04	0.41	0.7132
89	**1.00**	**1.00**	0.99	0.99	0.96	0.04	0.40	0.7173
90	**1.00**	**1.00**	0.99	0.99	0.97	0.04	0.37	0.7184
91	**1.00**	**1.00**	0.99	0.99	0.98	0.00	0.00	0.7086
92	**1.00**	**1.00**	**1.00**	**1.00**	0.99	0.00	0.00	0.7129
93	**1.00**	**1.00**	**1.00**	**1.00**	0.99	0.00	0.00	0.7129
94	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.00	0.00	0.7143
95	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.00	0.00	0.7143
96	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.00	0.00	0.7143
97	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.00	0.00	0.7143
98	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.00	0.00	0.7143
99	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.00	0.00	0.7143
100	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.00	0.00	0.7143

Table 19.11. Combined utility measures for all management objectives for snapper. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 13.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreationa l impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
15	0.00	0.00	0.49	0.51	0.00	1.00	1.00	0.4288
16	0.00	0.00	0.51	0.54	0.00	1.00	1.00	0.4350
17	0.00	0.00	0.54	0.56	0.00	1.00	1.00	0.4428
18	0.00	0.00	0.56	0.58	0.00	1.00	1.00	0.4493
19	0.10	0.00	0.59	0.61	0.00	1.00	1.00	0.4715
20	0.33	0.00	0.61	0.64	0.00	1.00	0.99	0.5095
21	0.40	0.00	0.64	0.66	0.00	1.00	0.99	0.5275
22	0.50	0.00	0.66	0.69	0.00	0.99	0.99	0.5470
23	0.55	0.00	0.69	0.72	0.00	0.99	0.99	0.5623
24	0.60	0.00	0.71	0.74	0.00	0.98	0.99	0.5746
25	0.60	0.00	0.74	0.77	0.00	0.85	0.99	0.5641
26	1.00	0.00	0.76	0.80	0.09	0.68	0.98	0.6150
27	1.00	0.00	0.79	0.82	0.19	0.55	0.97	0.6173
28	1.00	0.00	0.81	0.85	0.29	0.45	0.92	0.6166
29	1.00	0.00	0.84	0.87	0.38	0.37	0.87	0.6187
30	1.00	1.00	0.86	0.89	0.47	0.30	0.76	0.7549
31	1.00	1.00	0.88	0.92	0.55	0.25	0.67	0.7524
32	1.00	1.00	0.90	0.94	0.63	0.21	0.57	0.7497
33	1.00	1.00	0.92	0.96	0.71	0.17	0.49	0.7497
34	1.00	1.00	0.94	0.94	0.78	0.14	0.41	0.7449
35	1.00	1.00	0.95	0.96	0.84	0.12	0.35	0.7457
36	1.00	1.00	0.97	0.97	0.89	0.11	0.27	0.7447
37	1.00	1.00	0.98	0.98	0.93	0.09	0.24	0.7463
38	1.00	1.00	0.99	0.99	0.97	0.08	0.18	0.7446
39	1.00	1.00	0.99	1.00	0.99	0.07	0.15	0.7425
40	1.00	1.00	1.00	1.00	1.00	0.06	0.11	0.7386
41	1.00	1.00	0.99	1.00	1.00	0.05	0.09	0.7327
42	1.00	1.00	0.99	0.99	1.00	0.05	0.07	0.7291
43	1.00	1.00	0.98	0.98	1.00	0.04	0.06	0.7234
44	1.00	1.00	0.96	0.97	1.00	0.04	0.06	0.7185
45	1.00	1.00	0.95	0.95	1.00	0.03	0.04	0.7101
46	1.00	1.00	0.92	0.93	1.00	0.03	0.04	0.7023
47	1.00	1.00	0.89	0.90	1.00	0.03	0.03	0.6922
48	1.00	1.00	0.85	0.81	1.00	0.02	0.03	0.6730
49	1.00	1.00	0.81	0.77	1.00	0.02	0.02	0.6599
50	1.00	1.00	0.76	0.72	1.00	0.02	0.02	0.6458

Table 19.12. Combined utility measures for all management objectives for sweep. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 14. Note also that only trailerboat length data was used for the recreational fishery because the charterboat data was considered to be of unacceptably poor quality.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreationa l impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
10	0.00	**1.00**	**1.00**	0.93	0.00	**1.00**	**1.00**	0.7033
11	0.00	**1.00**	**1.00**	0.93	0.31	**1.00**	0.99	0.7477
12	0.00	**1.00**	**1.00**	0.93	0.59	**1.00**	0.99	0.7870
13	0.01	**1.00**	**1.00**	0.93	0.81	**1.00**	0.98	0.8183
14	0.02	**1.00**	**1.00**	0.93	0.96	**1.00**	0.98	0.8405
15	0.07	**1.00**	**1.00**	0.93	**1.00**	**1.00**	0.97	0.8514
16	0.19	**1.00**	**1.00**	0.93	**1.00**	**1.00**	0.95	0.8664
17	0.43	**1.00**	**1.00**	0.93	**1.00**	**1.00**	0.93	0.8972
18	0.71	**1.00**	**1.00**	0.92	**1.00**	0.99	0.90	0.9317
19	**1.00**	**1.00**	**1.00**	0.92	**1.00**	0.98	0.84	0.9629
20	**1.00**	**1.00**	0.99	0.92	**1.00**	0.95	0.77	0.9471
21	**1.00**	**1.00**	0.99	0.91	**1.00**	0.91	0.69	0.9286
22	**1.00**	**1.00**	0.98	0.90	**1.00**	0.89	0.59	0.9086
23	**1.00**	**1.00**	0.97	0.89	**1.00**	0.84	0.48	0.8829
24	**1.00**	**1.00**	0.95	0.87	**1.00**	0.76	0.34	0.8457
25	**1.00**	**1.00**	0.91	**1.00**	**1.00**	0.65	0.19	0.8214
26	**1.00**	**1.00**	0.82	0.90	**1.00**	0.51	0.09	0.7600
27	**1.00**	**1.00**	0.82	0.90	**1.00**	0.38	0.04	0.7343
28	**1.00**	**1.00**	0.82	0.90	**1.00**	0.26	0.02	0.7143
29	**1.00**	**1.00**	0.82	0.90	**1.00**	0.14	0.01	0.6957
30	**1.00**	**1.00**	0.82	0.90	**1.00**	0.05	0.01	0.6829
31	**1.00**	**1.00**	0.82	0.90	**1.00**	0.02	0.00	0.6771
32	**1.00**	**1.00**	0.82	0.90	**1.00**	0.00	0.00	0.6743
33	**1.00**	**1.00**	0.82	0.90	**1.00**	0.00	0.00	0.6743
34	**1.00**	**1.00**	0.82	0.90	**1.00**	0.00	0.00	0.6743
35	**1.00**	**1.00**	0.82	0.90	**1.00**	0.00	0.00	0.6743

Table 19.13. Combined utility measures for all management objectives for silver trevally. Note that all management objectives have equal weighting. The length with the overall 'best' option length is shaded and the 'best' option lengths for each management objective in bold. Data is from Chapter 15.

Management objective	Protect juveniles	Maintain stock	Max. yield	Max. value	Address growth overfishing	Min. commercial impact	Min. recreational impact	
Weighting	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1
Option	Utility	Utility	Utility	Utility	Utility	Utility	Utility	Utility
FL (cm)	Value	Value	Value	Value	Value	Value	Value	Sum
15	0.00	0.00	0.76	0.38	0.00	**1.00**	**1.00**	0.4476
16	0.00	0.00	0.79	0.39	0.00	**1.00**	**1.00**	0.4552
17	0.15	0.00	0.83	0.41	0.00	**1.00**	**1.00**	0.4837
18	0.30	0.00	0.86	0.43	0.00	**1.00**	**1.00**	0.5118
19	0.50	0.00	0.89	0.44	0.00	**1.00**	**1.00**	0.5465
20	0.65	**1.00**	0.91	0.45	0.00	**1.00**	**1.00**	0.7157
21	**1.00**	**1.00**	0.94	0.46	0.27	0.99	0.99	0.8071
22	**1.00**	**1.00**	0.96	0.47	0.50	0.96	0.99	0.8400
23	**1.00**	**1.00**	0.97	0.48	0.69	0.90	0.98	0.8600
24	**1.00**	**1.00**	0.99	0.49	0.84	0.82	0.98	0.8743
25	**1.00**	**1.00**	**1.00**	0.49	0.94	0.72	0.96	0.8729
26	**1.00**	**1.00**	**1.00**	0.49	**1.00**	0.61	0.94	0.8629
27	**1.00**	**1.00**	**1.00**	0.50	**1.00**	0.51	0.91	0.8457
28	**1.00**	**1.00**	**1.00**	0.49	**1.00**	0.41	0.85	0.8214
29	**1.00**	**1.00**	0.99	0.49	**1.00**	0.32	0.80	0.8000
30	**1.00**	**1.00**	0.98	0.82	**1.00**	0.25	0.71	0.8229
31	**1.00**	**1.00**	0.96	0.81	**1.00**	0.18	0.64	0.7986
32	**1.00**	**1.00**	0.94	0.79	**1.00**	0.13	0.56	0.7743
33	**1.00**	**1.00**	0.91	0.77	**1.00**	0.10	0.50	0.7543
34	**1.00**	**1.00**	0.89	0.75	**1.00**	0.07	0.43	0.7343
35	**1.00**	**1.00**	0.86	0.72	**1.00**	0.06	0.36	0.7143
36	**1.00**	**1.00**	0.82	0.79	**1.00**	0.04	0.29	0.7057
37	**1.00**	**1.00**	0.78	0.76	**1.00**	0.03	0.25	0.6886
38	**1.00**	**1.00**	0.74	0.72	**1.00**	0.03	0.19	0.6686
39	**1.00**	**1.00**	0.70	0.68	**1.00**	0.02	0.16	0.6514
40	**1.00**	**1.00**	0.66	**1.00**	**1.00**	0.02	0.13	0.6871
41	**1.00**	**1.00**	0.61	0.93	**1.00**	0.01	0.10	0.6643
42	**1.00**	**1.00**	0.57	0.86	**1.00**	0.01	0.09	0.6471
43	**1.00**	**1.00**	0.52	0.79	**1.00**	0.01	0.08	0.6286
44	**1.00**	**1.00**	0.47	0.72	**1.00**	0.01	0.07	0.6100
45	**1.00**	**1.00**	0.43	0.65	**1.00**	0.01	0.06	0.5929
46	**1.00**	**1.00**	0.38	0.58	**1.00**	0.00	0.05	0.5729
47	**1.00**	**1.00**	0.33	0.51	**1.00**	0.00	0.04	0.5543
48	**1.00**	**1.00**	0.29	0.44	**1.00**	0.00	0.04	0.5386
49	**1.00**	**1.00**	0.25	0.38	**1.00**	0.00	0.03	0.5229
50	**1.00**	**1.00**	0.21	0.32	**1.00**	0.00	0.03	0.5086

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