Sustainability of recreational fisheries for Murray Cod in the Murray Darling Basin

Wayne Fulton

State Government Victoria Department of Primary Industries

Australian Government Fisheries Research and Development Corporation

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NON-TECHNICAL SUMMARY

2006/053 Sustainability of recreational fisheries for Murray Cod in the Murray Darling Basin

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Objectives:

The objectives of the project as originally proposed were as follows:

1. Determine the rate of maturity with size and age, for Murray cod stocks in the Murray-Darling Basin.
2. Determine the levels of angler harvest within defined regions across the basin.
3. Determine the post release hooking survival of Murray cod under various hooking scenarios.
4. Investigate sensitivity of population structure and abundance to size at maturity, legal minimum length, fishing mortality (incl. release survival) etc.
5. Recommend management strategies in a risk-based framework for the sustainability of Murray cod fisheries across the Murray-Darling Basin.

Non Technical Summary:

The general objectives for this project were to collect critical information on specific aspects of the biology of Murray cod as well as details on the recreational fishery for this species. The most critical piece of biological information (size at maturity) was essential to determine whether the length limits that are the primary management tool for the recreational fishery, allowed Murray cod to reproduce at least once before they could be legally caught. The information on the fishery itself was collected by on-site creel survey; this was designed primarily to quantify the catch and harvest taken by recreational anglers and examine the methods used. A further component of the studies looked at the survival rate of fish that had been caught and released by anglers as this fishery has a very high rate of release of angled fish. Results from each of these studies were then incorporated into a population model developed for Murray cod. This model was then used to examine various management scenarios such as variation in legal minimum length (LML) and various levels of stocking to assess which combinations provided the best returns to anglers whilst at the same time ensuring that the fishery was sustainable into the future.

Preliminary studies were undertaken to trial methods and select the best options. Non-destructive methods were selected for the size at maturity work and sampling was undertaken during the period when most mature fish could be expected to show visible development. A random roving creel survey program that gave sufficient levels of reliability in the results was chosen and a survey area that covered more than 50% of Australian Murray cod fisheries was chosen. Assessment of the survival of released fish was undertaken in conjunction with a recreational angling club under normal angling conditions.

Size at maturity

The study confirmed that the present LML of 60 cm allows the vast majority of both male and female Murray cod to mature before they reach this length. There was some regional variation with fish in the Lower Murray River maturing at larger size than those in the central Murray and the northern Murray Darling Basin (MDB) (McIntyre River).

Angler catch and harvest

The creel study used a randomised creel survey design to sample recreational fishing catch and effort within six study-reaches; along the Murray River from Yarrawonga downstream to the South Australian border, and on the lower Goulburn, Ovens and Loddon Rivers. Three reaches were completed in each 9-month Murray cod season during 2006-07 and 2007-08. Anglers were interviewed during, or immediately after, their fishing activity by researchers patrolling the rivers in boats and four wheel drive vehicles. Each angler encountered was asked about their catch, the time they had spent fishing and a range of angler-behaviours and fishing-practices. Nearly 1,700 kilometres of river reaches were sampled and over 1,400 angler interviews were completed, giving a truly representative sample of fishing activity in the Murray cod fishery in the southern MDB.

Fishing effort and catch:

Anglers' responses were used to estimate that in the study reaches during these two fishing seasons, almost 1.4 million hours of fishing time was spent by all anglers in the fishery. This is equivalent to between 44 and 253 angler hours per hectare of river for this fishery. The total Murray cod catch within these study reaches was estimated at over 98,000 fish, of which just over 6,500 were harvested. When stream area is taken into account, the catch estimates for each river reach are equivalent to 2–12 Murray cod per hectare, with harvest rates observed of 0–1.4 Murray cod per hectare.

Release rate for Murray cod was around 90% overall, with most releases being compulsory as the fish were smaller than the LML. Voluntary release rates of 14–32% of fish larger than the minimum size limit were observed in the Goulburn and Murray Rivers.

Catch and harvest of by-catch species were also estimated where possible for golden perch, trout cod, silver perch, redfin and common carp. Anglers removed almost 60 tonnes of carp, an invasive pest species, from approximately 1,500 km of stream surveyed over the 18-month study. The catch of golden perch was markedly less than that of Murray cod and silver perch in most river reaches studied.

Catch of threatened species, such as trout cod and silver perch, was relatively high. Silver perch were caught in similar or greater abundance to carp in more than half the reaches. The estimated catch of trout cod in the Murray River, downstream of Yarrawonga weir, was substantial (over 12,000 fish in 350 km of stream).

Angler origins:

In total, 85% of anglers interviewed were Victorian residents. Along the Murray River (in NSW), 76–89% of anglers interviewed were also Victorians. During the 2007-08 Murray cod fishing season, 16% of those fishing in the Murray River from the SA border upstream to Tooleybuc, were residents of South Australia.

Fishing Licence ownership:

Overall, 72% of anglers interviewed were owners of a recreational fishing licence (RFL). Exemption from requiring a licence was claimed by 28%. In Victorian fisheries, such as the Loddon, Ovens and Goulburn Rivers, 22–37% of interviewees claimed they were exempt from RFL ownership. An important finding was that there were significant differences in Murray cod catch rates between RFL-exempt and non-exempt anglers, suggesting that the RFL-holders database would potentially offer a biased sampling-frame for future surveys.

Fishing methods:

Anglers fishing with two rods had significantly higher harvest-rates than those using a single-rod; however, using 3–5 rods achieved similar harvest rates to single-rod users. This suggests that harvest pressure will not be reduced by regulations restricting anglers from 5 to 2 rods, but that potentially, a further restriction to a single rod would achieve some reduction in harvest rate.

Bait fishing was consistently the most popular method for 52–97% of anglers across the reaches studied; 87% of all Murray cod caught by interviewees were caught on bait. The top three successful baits were cheese, shrimp and bardi grubs with 24%, 18% and 12% of Murray cod caught on these three baits, respectively. Lures (of all types) accounted for 13% of Murray cod caught.

Uptake of best-practice for released fish survival:

Angler's self-reported methods of landing and handling Murray cod, prior to release, were largely inconsistent with agreed best-practice (RecFish Australia). 'Hoisting' the fish out of the water suspended by the line and hook was common practice, and although 38% reported using a net, this included knotted-mesh nets (unknown incidence) along with knotless-mesh nets. Deep-hooked fish were generally 'unhooked', either by hand or using an instrument, contrary to the best-practice of cutting the line and leaving the hook in the fish.

Selectivity of fishing gear:

Lures were better at selecting larger fish; 21% of Murray cod caught on lures were larger than the present 60 cm LML, compared to 2% of those caught on cheese or shrimps. There was also an indication that anglers using large hooks caught fewer small Murray cod, but not enough anglers were observed using large hooks to make this conclusive.

There was evidence of a relationship between hook size, fish size and the likelihood of a fish being deep-hooked. A fish that is deep-hooked has a higher risk of significant injury and post-release mortality. Small Murray cod (<20 cm) have a low chance of being deep-hooked regardless of hook size. As fish size increases, the chance of deep-hooking increases for anglers using small hooks (hook size <2/0). All fish larger than the present LML of 60 cm that were caught on small hooks, were deep-hooked; whereas, none caught on hooks sized 5/0 and larger were deep-hooked.

Release Survival

The Donald Angling Club from north western Victoria assisted with capturing and holding Murray cod using their standard angling methods. Details of the methods used were recorded and angled fish were kept in floating cages and monitored for five days after hooking; overall, survival rates of 98% were observed. The implications of catch-and-release as a fishing mortality source were assessed by comparing our results to roving creel survey estimates of harvest from recreational fisheries. Estimated ratios of deaths from discard mortality to harvest indicated that, even with a mortality rate of only 2%, the high numbers of fish being released in this fishery means that this source of mortality could contribute as much or more to total fishing mortality as the actual harvest in some systems. Consequently, angler handling and release methods are critical for this fishery.

Population modelling

Harvest restrictions and stock enhancement are commonly proposed management responses for sustaining degraded fisheries, but comparisons of their relative effectiveness have seldom been considered prior to making policy choices. No previous modeling efforts have evaluated the effects of fisheries regulations or attempted to develop sustainable harvest policies for the Murray cod fishery. In this study, an age-structured model was constructed using known information as well as information collected during this study to evaluate the effects of LML and fishing mortality rates on Murray cod fisheries. Further additions were made to this model to look at the effect of stocking on Murray cod populations in association with various harvest restrictions.

Length Limit assessment

Murray cod fisheries can be managed sustainably, but the choice of harvest regulation is important. The current LML of 60 cm will protect Murray cod from overfishing as long as fishing mortality is less than about 20% of the stock per year. Higher levels of fishing mortality could be unsustainable. Higher LML regulations would protect stocks from overfishing, increase total angler catch and catches of trophy fish, but will lower harvest. Managers should recognize this trade off and identify the types of fisheries that anglers wish to have when setting regulations.

Stocking assessment

In most simulations, increasing minimum length limits were predicted to be more effective at preventing overfishing than increasing stocking rates, although the increased LMLs would result in reduced harvest (not catch) rates. In systems with good recruitment, stocking fewer large juveniles (e.g. 150 mm) was predicted to have a higher contribution than stocking many small juveniles (e.g. 50 mm). Benefits of stocking systems with existing natural recruitment were minimal.

Stocking was predicted to significantly increase total recruitment, population sustainability, and fishery metrics only in systems where natural reproduction had been greatly reduced via habitat loss, where fishing mortality was high, or both. If angler fishing effort increased with increased fish abundance from stocking efforts, fishing mortality was predicted to increase and reduce the benefits realized from stocking. The model also indicated that benefits from stock enhancement would be reduced if reproductive efficiency of hatchery-origin fish was compromised.

The simulations indicated that stock enhancement was a less effective method to improve fishery sustainability than measures designed to reduce fishing mortality (e.g. length limits).

OUTCOMES ACHIEVED TO DATE

This project provides information for fisheries managers that will ensure that Murray cod recreational harvest levels in the Murray-Darling Basin are not only sustainable but provide a margin for recovery. The work increases certainty for managers that the established management tools are appropriate; and to anglers that the Murray cod fisheries throughout the Murray-Darling Basin are sustainable into the future.

Outcome 1

- The levels of angler participation in a major part of the recreational Murray cod fishery in the Murray-Darling Basin have been accurately benchmarked.

Outcome 2

- The catch and harvest rates for a major part of the total recreational fishery have been benchmarked for future reference.
- Knowledge obtained on fishing methods has been combined with estimates of survival of released angler caught fish to provide an accurate measure of angling mortality in the fishery.
- The information has been used to inform population models for the fishery

Outcome 3

- Size at maturity assessments have confirmed the validity of the present LML regulations for the fishery.
- Information on size at maturity has also been used to inform population models for the fishery

Outcome 4

- Population models have been constructed and used to assess likely impacts of various management scenarios on the fishery.
- There is a sound body of information available for future reference.
- Fisheries managers have been informed of the results of the work and have been involved in setting priorities for further research.

Keywords: Murray cod *(Maccullochella peeli)*, recreational angling, angler harvest, sustainability, Murray-Darling Basin.

Acknowledgments

The original project concept was developed in consultation with staff at NSW Fisheries (Dean Gilligan), Queensland Fisheries (Mike Hutchison) and SARDI Aquatic Sciences (Qi Feng Ye). Fisheries Victoria has provided complimentary funding for the project through its Fisheries Research Branch and additional funding was also received through the Fisheries Victoria Fisheries Revenue Advisory Committee Grants Program. During the course of the project, a Visiting Scientist funding application was submitted to the Department of Primary Industries (DPI) Victoria by Neville Fowler and Wayne Fulton. This successful application led to Professor Mike Allen from University of Florida initially spending several weeks at Snobs Creek. A most beneficial collaboration subsequently developed from this also involving some of Prof. Allen's post-graduate students. Paul Brown and Kylie Hall from Fisheries Victoria have been most helpful in putting the final reports together. Further project specific acknowledgements are included in conjunction with each of the project elements.

FINAL REPORT

2006/053	**Sustainability of recreational fisheries for Murray Cod in the Murray Darling Basin**

Background

The Murray cod (*Maccullochella peeli*) is an icon species for recreational anglers in Australia. In recent years, concerns over the status of populations across the Murray-Darling Basin (MDB) have led to a number of reviews, workshops and surveys being undertaken to consider the status of cod populations.

Two key points emerge from these:

- The Native Fish Strategy (NFS) for the Murray-Darling Basin 2003-2013 considered that native fish numbers in the Basin are presently at 10% of pre-European settlement levels. The Strategy identified a return to 60% of these levels as a key objective.
- The status of Murray cod has been listed as vulnerable under the provisions of the *Environment Protection and Biodiversity Conversation Act 1999*.

Advice from the Threatened Species Scientific Committee convened to inform the Minister for the Environment and Heritage was, "*it is estimated that the size of the Murray cod population has declined substantially over the past 30 years (conservatively estimated to be at least 30%)* "(McKelleher 2005). A Draft Recovery Plan developed in response to this listing has highlighted a number of information gaps.

During 2000, the National Recreational and Indigenous Fishing Survey (NRIFS) collected data (via diary-assisted recall surveys) that estimated the whole-MDB, and individual state, catch statistics for Murray cod. This research indicated that 108,000 Murray cod (1,444 tonnes) were harvested, from a total catch of 483,000 Murray cod (i.e. 78% were released) (Henry and Lyle 2003). While the NRIFS represents benchmark data for broad geographic regions, some of its limitations are the lack of regionally (fishery) specific information for many regions, and the fact that it is already seven years old and measures a point in time largely before the severe drought in South-East Australia (2003–2010).

At present, there is considerable pressure to further limit the recreational fishery for this species through management tools such as bag and size limits, and access restrictions such as 'protected areas' (MDBC 2004a). For example, for the 2007-08 Murray cod season, New South Wales (NSW) recreational fishing legislation increased the legal minimum length (LML) from 50 to 55 cm total length. In the Murray cod fishing season 2008–09, both NSW and Victoria set the LML to 60 cm largely because of public and professional concern regarding size at maturity and population sustainability. Increased protection for large Murray cod was provided by a range of legislation in the states, prohibiting (in SA and QLD), or limiting (in Vic and NSW) the harvest of Murray cod larger than maximum size limits. From December 2009 legislation in South Australia provided a total moratorium on recreational fishing for Murray cod in South Australian waters. Detailed information is not available on size at maturity across the Basin. In addition, there is little accurate information on the impacts of angling on Murray cod populations.

In contrast to these concerns about sustainability, there are also strong anecdotal reports from anglers and researchers that Murray cod numbers are increasing (unpublished data presented at the Mildura NFS meeting 2007).

In anticipation of management needs, the FRDC project "Sustainability of recreational fisheries for Murray cod in the Murray Darling Basin" was established with four main project aims that can be summarised as:

1. Estimate size at maturity and how it varies across the MDB
2. Determine levels of catch, effort and harvest for individual river fisheries
3. Determine post-release mortality effects from fishery
4. Population modelling and management strategy evaluation.

The strategic challenge for this project is to provide information to fisheries managers that will ensure that recreational harvest levels are not only sustainable but provide a margin for recovery, in line with the NFS objective described above. The work should also increase certainty for managers that the established management tools are appropriate, and to anglers that the fisheries are sustainable into the future.

Need

Murray cod is Australia's highest profile freshwater fish species and there is a very high public expectation that fisheries for this species are managed sustainably. There is broad agreement that Murray cod numbers have declined considerably since European settlement and whilst the exact reasons may be varied, it is clear that continued recreational harvest is one identifiable factor that has the potential to hinder recovery. There is general uncertainty about a number of critical issues relating to the management of these recreational fisheries.

A number of information gaps have been identified in relation to the recreational fisheries for Murray cod as follows:

- There is some broad detail available on gross angler harvest, but there is no detailed information on catch related to individual rivers or basins.
- The LML of 50 cm is a critical issue as evidenced by the rapid decline in numbers of fish above this level. This also means that the survival of released fish is highly relevant.
- There is a lack of information on population structure and dynamics and, with particular reference to recreational fisheries management, there is uncertainty regarding size at maturity and whether this is constant across the MDB.

Current regulations may allow the removal of fish that are sexually immature. At low fishing pressure, this may be tolerable; however, at high fishing pressure, removing spawners before they mature may threaten a stock. The management of Murray cod populations requires that the LML chosen must be robust to both fisheries management and conservation requirements, but there has been no assessment to determine the appropriate LML for sustaining these fisheries.

The information from this project of the Murray cod size at maturity as well as angler harvest levels and hooking survival estimates will enable the impacts of recreational fishing on Murray cod populations to be determined via management scenario testing.

The need for this work was identified by Fisheries Victoria and they provided some advance funding in 2005-06 to facilitate assessment of methodologies and for the coordination of project development across the Basin (particularly between Fisheries Research in Victoria and NSW).

Objectives

The objectives of the project as originally proposed were as follows:

1. Determine the rate of maturity with size and age, for Murray cod stocks in the Murray-Darling Basin.
2. Determine the levels of angler harvest within defined regions across the basin.
3. Determine the post release hooking survival of Murray cod under various hooking scenarios.
4. Investigate sensitivity of population structure and abundance to size at maturity, legal minimum length, fishing mortality (incl. release survival) etc.
5. Recommend management strategies in a risk-based framework for the sustainability of Murray cod fisheries across the MDB.

Objectives 1-3 were the field work components of the project and they proceeded generally as planned. Part 4 involved the development of population models to assist in the scenario testing aspects of the project and this section was enhanced considerably through collaboration with Professor Mike Allen from University of Florida.

Chapter 1. General methods

This project was undertaken as a series of separate studies to fill particular knowledge gaps on Murray cod biology and fisheries.

These studies were preceded by a short scoping project designed to test certain survey methods in relation to the size at maturity work and to assist in the design of the creel survey program and the release survival assessment (Chapter 2). This preliminary work was funded by Fisheries Victoria prior to the FRDC project and reported internally to Fisheries Victoria. The original report to Fisheries Victoria contained a rationale for the wider project which subsequently formed part of the FRDC application. That rationale has been largely removed from the text where it duplicates the general focus of the background and need sections above. The remainder of the report provides the context for the methods that were used for the FRDC project.

The FRDC project has several distinct sections. Each of these sections requires its own methods, results and discussion before incorporation into a common outcome via the population model and management implications.

The basic field research components of this project consist of three essentially different elements, and as such these have been presented as stand alone chapters of this report (Chapters 3, 4 and 5). It would not be appropriate to combine the methods (or other) sections for the entire project into one section as this would make it more difficult to examine the work that has been done.

Following the field work, the modelling aspects proceeded in the same way (i.e. as separate processes). Professor Mike Allen from the School of Forests and Resource Conservation at the University of Florida was invited to spend time at Snobs Creek under DPI Victoria's Visiting Scientist program. Modelling of recreational fisheries was a particular skill set of Prof. Allen and he was subsequently invited to work on the Murray cod project.

With Fisheries Victoria staff, Prof. Allen and some of his post-graduate students constructed an age-structured population model using existing life history data (e.g. growth, mortality) as well as fishery parameters (size at maturity, discard mortality) collected during this project. This model was used to look at the implications of various management scenarios for the Murray cod fishery.

Further developments were made to the model to enable further evaluation of fisheries management scenarios such as stock enhancement as follows:

- Evaluate the potential for stock enhancement to improve fishery sustainability and angler catch metrics relative to minimum length limits.
- Explore effects of stocking rates and stocked fish sizes for producing fishery benefits.
- Evaluate the potential for negative impacts of stocking via density dependence and/or genetic changes in the stock.

From the modelling work described above, two papers were subsequently published and are presented as Chapters 6 and 7.

The reports/papers are each reproduced separately below with each section in turn relating primarily to one of the five objectives for the entire project:

- Chapter 3. Size at Maturity (FRDC Objective 1)

  Douglas, J, Brown, P, Allen, M, Gwinn, D, Hunt, T, Fulton, W. Assessment of variation in Murray cod length at maturity across the Murray Darling Basin.

- Chapter 4. Angler harvest (FRDC Objective 2)
  Brown, P. (2010). Sustainability of recreational fisheries for Murray cod: Creel Surveys on the Murray Goulburn, Ovens and Loddon rivers 2006–2008. Fisheries Revenue Allocation Committee, Melbourne.

- Chapter 5. Release Survival (FRDC Objective 3)
  Douglas, J., Brown, P., Hunt, T., Rogers, M., and Allen, M. (2010). Evaluating Relative Impacts of Recreational Fishing Harvest and Discard Mortality on Murray Cod (*Maccullochella peelii peelii*). *Fisheries Research* **106**, 18–21.
- Chapter 6. Population Modelling Age Structured Model - Length Limit Assessment (FRDC Objective 4)
  Allen, M S, Brown, P, Douglas, J, Fulton, W, Catalano, M. (2009). An assessment of recreational fishery harvest policies for Murray cod in southeast Australia. *Fisheries Research* **95**: 260-26.
- Chapter 7. Population Modelling Age Structured Model - Hatchery Component (FRDC Objective 5)
  Rogers, M W, Allen, M S, Brown, P, Hunt, T, Fulton, W, Ingram, B A. (2010). A simulation model to explore the relative value of stock enhancement versus harvest regulations for fishery sustainability. *Ecological Modelling* **221**: 919-926.
- Chapter 8. Management Implications
  This Chapter summarises the major findings from each of the papers as they relate to management of the MDB Murray cod fishery.

Chapter 2. Sustainability of Murray cod fisheries: Methodological pilot studies

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Introduction

In Victoria at the 2005 research priority meeting convened by the Victorian Fisheries Co-management Council, 'Sustainability of Murray cod fisheries' was given the highest priority in the recreational fisheries section. There are a number of other national and state documents that either directly or indirectly emphasise the need for information on the Murray cod fisheries. From a combination of these sources, a number of information gaps have been identified in relation to recreational fisheries:

- Whilst there is some broad detail on gross angler harvest from the national recreational and indigenous fishing survey, there is no detailed information on angler harvest related to individual rivers or basins (i.e. management units).
- There is a fundamental lack of information on population structure and dynamics and, with particular reference to recreational fisheries management, there is uncertainty regarding size at maturity and whether this is constant across the Basin.
- There is little accurate information on the impacts of angling on Murray cod populations. There are strong anecdotal reports from anglers that Murray cod numbers are increasing.

Angling Harvest and Released Fish Survival

Recreational angling is a popular activity in Australia. The national recreational and indigenous fishing survey (NRIFS) estimated over 3 million Australians fished more than 20 million days over a twelve-month period and caught over 107 million fish (Henry and Lyle 2003). This included over 483,000 Murray cod captured. Fishing regulations often set size or catch limits on the recreational catch and there are estimates that between 30% and 50% of the total recreational angling catch has to be released or discarded (Broadhurst *et al*. 2005). Henry and Lyle (2003) estimated that during the NRIFS, 77.6%, or nearly 375,000 of the Murray cod caught, were released for a retained harvest of 108,000. Ethical standards or regulations designed to protect fish stocks are only effective if there is high survival of the caught and released fish. Angling can injure or kill fish through handling stress or hook induced injury. Given such large numbers of fish angled, even a low mortality rate of the released fish equates to a considerable total of fish injured or killed through angling.

If recovery of native fish populations in the MDB proceeds as forecast (Anon, 2003), the question of ecological sustainability of this Murray cod fishery may hinge upon our knowledge of angler harvest levels, and our ability to control these, now and in the future. Although recent estimates of Murray cod effort, catch, and harvest are available, nationally, and on a state-by-state basis (Henry and Lyle 2003), fisheries managers across the MDB still lack quantitative estimates of recreational harvest for specific fisheries, management units, or catchments. Largely for species other than Murray cod, total-fishery estimates of catch, harvest and release have been completed recently for a range of Victorian fisheries using stratified random surveys (Creel surveys) (Douglas *et al.* 2002; Hall 2002; Douglas 2004; Douglas and Hall 2004; Brown and Gason 2007).

The Ovens, Goulburn and Loddon Rivers and the Broken Creek represent the main Victorian Murray cod river-fisheries in terms of angler participation. Large water storage impoundments such as Lake Eildon and Lake Eppalock also support Murray cod populations and developing fisheries. Such waters are considered outside the scope of this research for two reasons: firstly, they would add a level of complexity to any creel survey that is logistically undesirable; and secondly, as they are mainly managed by stocking.

Angling mortality can be caused by many factors, with anatomical location of hook wounds being an important component (Muoneke and Childress 1994). Many hooking mortality trials use wild fish and often have recreational anglers involved to collect fish. While this method certainly simulates what happens in 'normal' angling situations, the down side is that there is often considerable variation in the handling and transporting of fish to the holding cages. In these cases, mortality rate cannot be directly attributed to any particular angling action (like hook location) but instead only generalised. If the overall aim is to reach some understanding of the critical components of angling and how they relate to fish mortality, most of the variables have to be removed and individual components of the angling examined. Ultimately, to evaluate the likely release-survival rates of Murray cod in the fishery, three components are required:

1. An understanding of the distribution of anatomical location of hook wounds in the released component of the catch
2. A measure of the proportion of the catch that is released
3. An understanding of the likely survival effects from this range of hook-wound locations.

The first and second are obtainable by observation of anglers and their practices in the fishery. The third is best obtained from controlled experiments. Some form of angler-survey is important to gather information about the incidence of deep-hooking and fish release rate, while controlled experiments are required to obtain post-release fish survival probabilities.

Biological Rationale for Legal Minimum Length as a Management Tool

The size of maturity at first reproduction is a keystone variable in fisheries management. Legal minimum lengths (LML) are legislated and enforced in all states and territories of the MDB to manage recreational Murray cod fisheries. The biological principle underlying this tool is that the LML be set to allow most of the stock to attain maturity and reproduce, at least once, before they become vulnerable to fishing. Existing data on size-at-maturity for Murray cod shows a high level of regional variability (Gooley *et al.* 1995; Rowland 1998) and, current LMLs may not effectively serve their purpose.

The standard methods used to accurately determine the relationship between first-maturity and fish size involve sacrificing a large number of variously sized fish and dissecting-out the gonad for histological examination (Brown *et al.* 2005). Murray cod have a high perceived value in the community and destructive sampling on the required scale is deemed unacceptable. Fishery dependant sampling (i.e. by anglers) of fish that would be otherwise sacrificed is one option, and it may be appropriate to link this with angler surveys (i.e. creel surveys) mentioned in the previous section. Current LMLs would induce a size-bias into samples collected by anglers. There is a need for a non-destructive method of determining Murray cod maturity (in the field) within, and throughout, the size-range of mature development. Some standard hatchery methods of maturity estimation may be suitable for field-use (e.g. cannulation), but there is scope to investigate new maturation determination technologies.

A range of innovative methods for diagnosis of reproductive status have been used (usually) in large, valuable individuals of various fish species such as ultrasound in striped bass, halibut and sturgeon (Blythe *et al.* 1994; Martin-Robichaud and Rommens 2001; Jennings *et al.* 2005); oviduct endoscopy in sturgeon (Hernandez-Divers *et al.* 2004; Wildhaber *et al.* 2005) and surgical laparoscopy (Murray 2002). These techniques have shown potential and the present study evaluated them for practicality and accuracy on Murray cod.

Outcomes from this research include confidence in a viable non-destructive sampling tool or procedure to determine maturation status of live Murray cod. This gave us the ability to design a broad field study to determine relationship between fish size and first-maturity in wild Murray cod stocks; the long-term goal being to provide accurate advice with which to make biologically sound decisions on setting LML for Murray Cod that are robust to potential regional variation.

Objectives

1. Estimate likely precision and cost for Murray cod creel surveys in the Murray Darling basin
2. Develop and validate non-destructive methods for maturity estimation in Murray cod
3. Explore experimental approach to determining post-release survival for angled Murray cod.

Funding was provided by Fisheries Victoria to assist in developing the methodological approach to the broader research and to develop further research funding applications. This report describes these pilot studies.

Methods

Harvest Estimation

Estimated catch is the product of angling effort and catch rate. Such data are obtained through angler counts and interviews. The size of the MDB and the range of waterways create challenges to effective angler survey design, particularly to obtain acceptable precision within the available funding parameters. Recent random stratified creel surveys in Victoria were compared to ascertain any relationships among effort (number of sessions, total hours, and number of interviews) and the precision of the resulting catch estimates. A review of published reports showed that catch estimates and their standard error (SE) were available for several lake and river fisheries for several species (see Table 1). To standardise across surveys, the SE was expressed as a percentage of its catch estimate for each data point. Unfortunately, recent surveys and earlier surveys have some differences in the way that catch and effort estimates are calculated. Furthermore they were broadly arranged in two blocks: earlier surveys with lower effort and lower precision; and more recent work with higher effort and higher precision. While this arrangement increases the uncertainty in the comparability of the two groups of data-points, the whole data are broadly indicative of the relationship between increasing effort and increasing catch estimate precision. Theoretically, increasing sampling effort to collect more data will increase the precision of the estimate obtained, but with diminishing returns. A power curve that best describes the data was determined by least-squares fitting.

For a range of Victorian roving and access-point, random, stratified creel surveys, the ‘effort’ put into collecting the data can be described with the number of interview sessions, or the cumulative total time spent looking for interviews. This ‘total interview session duration’ is more useful as session time varies amongst the creels from 4–8 hours. The precision in the catch estimates can be standardised as a coefficient of variation that is the standard error of the estimate divided by the estimate itself, expressed as a percentage (%SE).

Maturity Estimation

1. Ultrasound examination

   Putatively immature Murray cod were obtained from an aquaculture facility near Mildura, and immature and mature Murray cod by electrofishing in the Goulburn River during April 2006. All fish were stored frozen until 17 April 2006 when they were rapidly defrosted in tepid water, and stored on ice until examination on 18 April 2006.

   An Aloka SSD500 ultrasound imager was used for examination of Murray cod using 2-probes: a 3.5 MHz linear array scanner (UST-934) and a 5.0 MHz linear array scanner (UST-935N-5). We were advised and assisted by Mr. Jonathan Daly (assistant curator) and Dr. Robert Jones (Veterinarian) from the Melbourne Aquarium.

2. Laparoscopic examination

   Further samples of Murray cod were obtained by electrofishing the Goulburn River in June 2006. Three putatively mature specimens were maintained in Snobs Creek aquaria for approximately 2 weeks prior to examination. Each fish was anaesthetised to stage III sedation and placed upside down on the operating table to be examined.

Adopting a standard hatchery procedure for determining reproductive status, a glass pipette was gently introduced to each gonoduct and a slight negative pressure applied in an effort to withdraw a sample of sperm or oocytes. A negative result (no sample) meant moving to the next stage of exploratory keyhole surgery.

The next stage used laparoscopy. A 10 mm incision was made in the skin just off the midline, half way between pelvic fin-tips and the vent, using a scalpel, and through muscle layers to the peritoneum, with blunt artery forceps. A surgical trochar (Karl Storz 10 mm Endoskope) was used to puncture the peritoneum and a 10 mm rigid laparoscope tube was introduced to view internally. To reduce adhesion of organs and assist the viewing process, the body cavity was inflated slightly with room air using either a 50 ml syringe (small fish) or a small battery pump (large fish) fitted to the gas-port on the trochar. Using the cold light-source fitted to the laparoscope, the internal organs, including the gonads, were visualised. Other veterinary surgical diagnostic instruments were comparatively trialled at this stage, including an otoscope, and a flexible endoscope. Each was introduced after the trochar was withdrawn. A diagnosis of gender and reproductive status (mature, immature) was made in each case.

After diagnosis, a little manipulation was required to release as much of the air as possible before closing the incision. The incision was closed with simple sutures (absorbable) in a single layer (skin and muscle) and the wound daubed with iodine solution. Finally the wound, sutures, and small adjacent de-scaled area were daubed with cyanoacrylate cement. The fish was then transferred to a recovery tank of fresh aerated water and monitored until normal swimming resumed. Each fish briefly assumed a 'tail-up' attitude (10–30 minutes) during early stages of recovery, presumably as a result of air-introduced to the body cavity.

During these procedures, we were advised and assisted by Terry Squires (Senior Technical Officer, DPI Animal Sciences, Developmental Biology, Werribee) and veterinarian Dr. Doug Norman.

Post-release Survival Experiments

The post-release survival work was undertaken at a commercially run aquaculture facility using grown-out hatchery produced Murray cod. The use of aquaculture facilities and domesticated fish for undertaking post-release survival trials has been used with success on other fish species (Butcher *et al.* 2006). The aim of this trial was to investigate the suitability of using the grow-out facility to undertake the study. A secondary aim was to investigate fish mortality attributed to hooking location. Murray cod are held at the facility in floating cages and fed a 20 mm pellet-based diet, delivered hourly 8 times a day during daylight. The aquaculture site offered several advantages for the purpose of a hooking mortality trial including:

- high availability of fish of a size just under the (then) legal minimum size of 500 mm total length
- domesticated fish that were familiar to crowded conditions
- a known mortality rate
- constant supervision and ease of checking for mortalities
- suitable infrastructure to undertake the trials (holding cages, nets etc).

Where possible the trials attempted to mimic what happens in a typical Murray cod angling situation in the 'wild'. Murray cod were angled from the holding cages using 'j' hooks (size 3/0) baited with either cheese or pellets. Fish were played for one minute then removed from the water with a landing net (Environet). The hook location was noted as either shallow (anterior to the level of the eye) or deep (posterior to the level of the eye) and the hook was removed by hand. Fish were measured on a wooden fish measuring board (to simulate an angler measuring the fish for legal size), then released into one of the holding cages. Fish were exposed to air for about two minutes in total.

Most hooking mortalities occur within 24 hours but can also manifest over the following few days. The use of initial (24 hour) plus delayed mortality (over several days) provides a more complete estimate of mortality (Muoneke and Childress 1994), so the fish in the holding cages were checked for mortalities daily for seven days after the hooking trial ended.

Results

Harvest Estimation

Analysis of the relationship between creel survey effort and the precision obtained in the resulting catch-estimates suggest that there is a relationship such that increasing effort results in increased precision (i.e. reduced %SE) (Table 1). This relationship is described well with a power curve shown in Figure 1. This curve suggests that %SE of around 5, 10, 15 or 20% can be obtained with about 440, 310, 250 or 215 hours of effort respectively for a given fishery. At the theoretical limits of this relationship, survey effort for 3,600 hours, representing constant interview sessions during all daylight hours in a given year would increase precision to near zero (0.1%SE), and any useful precision ceases (SE±100% of estimate) at around 100 hours per year.

While this total duration of creel effort may be useful as a guide, it is not absolute and it should be noted that the relationship would be modified by the stratification level and weighting of the various strata in a creel survey design. In a sense, this prediction assumes no stratification, or equal stratification and equal weighting of all strata for each survey in the data.

While the cost of conducting a roving creel or access-point creel survey is obviously related to the duration of interview effort employed, the differences in approach to staffing make comparisons difficult for the studies analysed here.

A recent comparative study of three methods of estimating catch and effort in the Port Philip Bay snapper fishery examined the cost of achieving a precision-target using roving, access-point (boat-ramp) and phone/diary surveys (Karina Ryan, Fisheries Victoria, pers. comm.). The latter is comparable to the approach taken in the recent NRIFS (Henry and Lyle 2003), and was chosen as the most appropriate for annual estimates of recreational catch, largely because of the low cost: precision ratio. The study also concluded that for medium-sized studies the cost of all three types was similar.

Off-site telephone surveys generally suffer from several disadvantages from relatively high risk of errors to responses to questions, through poor recall, lies, misinterpretation of questions, etc.. With a high-value and low-volume-of-catch species like Murray cod, recall levels are likely to be relatively good.

A key advantage of the on-site (roving) approach, where anglers are interviewed and their catch examined by scientists, is that data pertinent to other aspects of this program may be collected simultaneously. Examination of angler-harvested fish should result in additional size-at-maturity data, and accurate information on anatomical location of hook wounds being obtained.

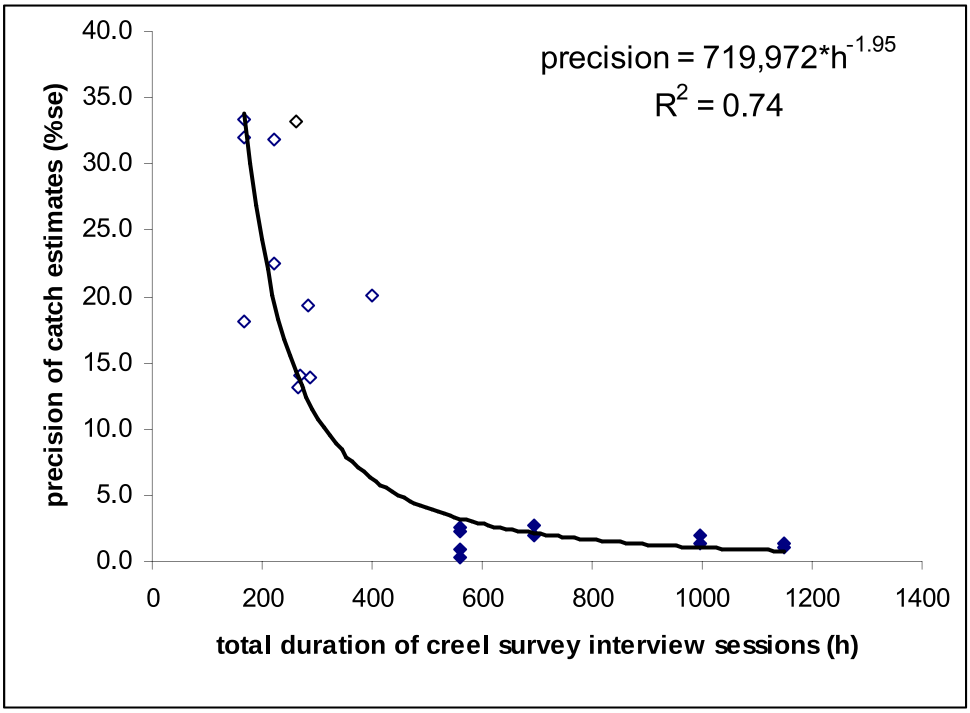

Figure 1: Relationship between precision of catch estimate and duration of interview sessions for a range of random, stratified creel surveys (roving and access-point) from Victoria. Clear symbols are from earlier surveys designed by D. Hume, DNRE; solid symbols are from surveys designed by DPI (details shown in Table 1).

Table 1: Examples of the catch estimates and the precision of these estimates from random, stratified creel surveys in Victoria in relation to the effort in collecting the data. BT =brown trout, RT = rainbow trout, GP=golden perch, MC=Murray cod. This data is also plotted in Figure 1.

Fishery	Source	Number of interview sessions	Total interview session duration (h)	Total Catch Estimate (Species)	Standard error (SE) of catch Estimates	SE as % of catch estimate
Goulburn River 2002–03	(Brown and Gason, 2007)	90	560	1,190 (BT)	26	2.2
				2,200 (RT)	55	2.5
Goulburn River 2003–04				527 (BT)	5	0.9
				3,165 (RT)	10	0.3
Lake Mokoan	(Hall, 2002)	139	695	51,762 (GP)	963	1.9
				750 (MC)	20	2.7
Lake Wendouree	(Douglas and Hall, 2004)	199	995	9,449 (RT)	134	1.4
				1,040 (BT)	21	2.0
Lake Dartmouth	(Douglas et al., 2002)	230	1,150	20,284 (BT)	223	1.1
				4,511 (RT)	57	1.3
Lake Toolondo	(Hume, 1991)	42	168	5,400 (RT)	1800	33.3
				250 (BT)	80	32.0
	(Overman and Heil, 1996)	100	400	1,502 (all)	301	20.0
Lake Purrumbete	(Eddy and Smith, 1994; 1996)	55	220	3,731 (all)	837	22.4
		71	284	3,059 (all)	589	19.3
	(Eddy, 1998)	72	288	9,682 (all)	1339	13.8
		66	264	9,249 (all)	1208	13.1
Lake Bullen Merri	(Eddy and Smith, 1994; 1995)	55	220	2,086 (all)	663	31.8
		65	260	545 (all)	181	33.2
Lake Murdeduke	(Eddy, 1998)	42	168	4,865 (all)	878	18.0
		67	268	8,627 (all)	1208	14.0

Maturity Estimation

Ultrasonography

Each fish (n=5) (Table 2) was examined using the ultrasound equipment, and where possible an estimate of reproductive condition was made. Following this, each specimen was dissected to reveal the true reproductive status. Both 5.0 mHz and 3.5 mHz probes were trialled. The best results were obtained with the higher frequency probe which gave better resolution of structural differentiation than the lower frequency probe. These resolution differences are consistent with other ultrasound trials on comparably sized fish. A higher frequency probe (7.5 mHz) was not available to trial but has been recommended for determining finer detail in Murray cod (Dane Newman, Deakin University, pers. comm.).

Table 2: Examination results of 5 fish using ultrasound equipment to estimate reproductive conditions.

Fish origin and size	Ultrasound examination	Dissection	Correct Diagnosis
Fish 1: Mildura Aquaculture (~400 mm TL)	No gonad structures obvious. Swimbladder and stomach identified putatively	Confirmed relative position of swimbladder and stomach. Noted that only thread-like gonads were present, undifferentiated, possibly female.	No diagnosis was attempted – trial for orientation only
Fish 2: Goulburn R. (530 mm TL) (Figure 2)	Stomach determined with hard object casting a shadow, swimbladder position determined, possible liver? No gonad obvious.	Ovaries present (4–5 cm in length by 2 cm in diameter. Stage II–III. Stomach contained Murray Crayfish remains which was responsible for the shadow observed by ultrasound	No
Fish 3: Goulburn R. (540 mm TL)	Stomach contains hard objects casts shadow. Swimbladder and relative position of putative gonads determined (as for Fish 1 and 2)	No gonad development present, undifferentiated threads. Fat bodies present possible mistaken as ovaries? Several yabbies found in gut (see fish 2)	No
Fish 4: Goulburn R. (430 mm TL)	Stomach, swimbladder landmarks noted. No gonad development	Gonads undifferentiated threads, possibly male?	Yes
Fish 5: Mildura Aquaculture (~380 mm TL)	Swimbladder but no gonad?	Masses of fat bodies, all organs swathed in fat. Gonads only undifferentiated threads	Yes

A successful diagnosis was difficult, and only achieved in half the examined specimens. In the two fish >50 cm TL, a false negative was obtained in Fish 2, and a false positive for Fish 3. The only successful diagnoses were in two fish <50 cm TL (Fish 4 and 5). Fish from the aquaculture facility were heavily fat-bound internally. These fat-bodies fill the space where gonad tissue would develop and in mature fish may lead to false detection. Whilst the wild-fish were less fat-bound, the actual boundaries of gonad tissue were hard to observe (in Fish 2), and it is likely that the presence of fat bodies immediately ventral to the swim bladder lead to the misdiagnosis of gonad tissue in Fish 3.

The presence of hard, crustacean exoskeletal material in the stomachs of 2 out of 3 wild fish was initially thought to be a problem as it obscured anything beyond the stomach. Ultrasound frequency cannot penetrate the crustacean exoskeleton and a 'shadow' is created on the image (see Figure 3). On further examination subsequent to dissection, leading to a better orientation of the image, the developing gonads of Fish 2 were visible in sections posterior to the stomach. In most specimens, stomach contents should not prevent the ultrasound imaging of the gonads.

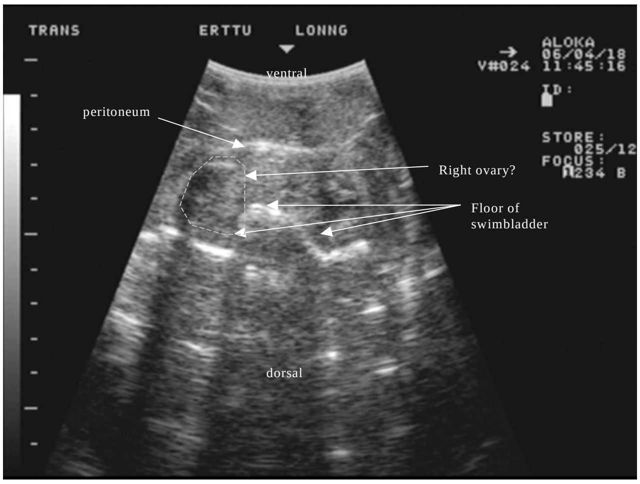

Figure 2: Ultrasound image sagittal section through Fish 2 at midpoint between anus and tips of pelvic fins. Section through ovary is illustrated with dashed line.

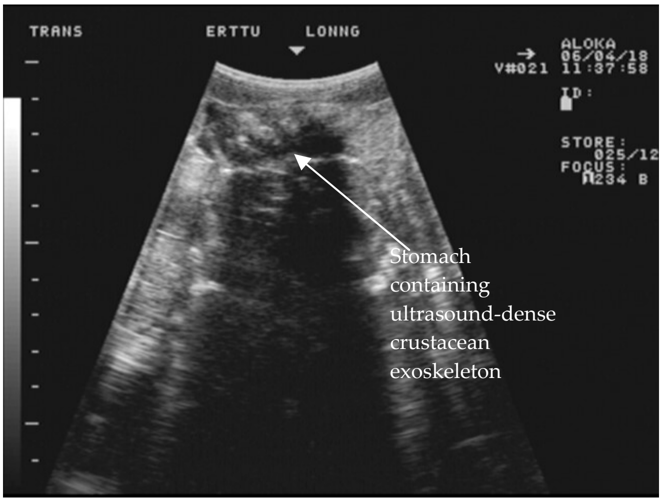

Figure 3: Ultrasound image sagittal section through Fish 2. Section more anterior to Figure 2, at midpoint of pelvic fins. Dark area in middle of image extending downwards is the 'shadow' from a hard crustacean exoskeleton within the stomach.

Laparoscopy

Three Murray cod (Fish 6, Fish 7, and Fish 8) were examined on 20 June 2006 at DPI laboratories, Snobs Creek.

Fish 6 (520 mm TL) the cannulation procedure of the gonoduct produced no result. For the laparoscopy, a decision was made *a priori* to euthanase this fish if a rapid diagnosis was not evident, so that examination under dissection could allow correct orientation of the instruments. On insertion, the laparoscope did reveal an uncertain diagnosis and no structures were immediately identified as gonad. No air inflation was used with this fish, and adhesion of the organs made orientation of the diagnostic image difficult. Euthanasia proceeded by doubling anaesthetic dose ~2 mg/litre. Dissection revealed gender as male, with undifferentiated testes immature or redeveloping (stage Ib (Rowland 1998) and stage 3–4 (Gooley *et al.* 1995). Once this dissected diagnosis was made, the fish was re-examined using the laparoscope. The correct orientation and path for the instrument was determined to identify the gonad relative to the swim bladder, an obvious 'landmark'.

For Fish 7 (650 mm TL) cannulation procedure of gonoduct again produced no sample. The laparoscope was inserted with air introduced via the trochar using a 50 ml syringe. This reduced adhesion of organs and made diagnosis easier. Using the 'landmarks' identified in Fish 6, the ovaries were rapidly identified. They were a large paired organ seemingly well developed as they occupied ~80–90% of the body cavity length. By varying the distance between laparoscope tip and the organ (~0–-10 mm) the image could be focussed through the ovarian membrane revealing a good view of the oocytes within. Oocytes appeared large (~2 mm) and yolky (yellowish), and were tightly packed the entire length of both ovaries. Diagnosis was maturing female, at stage III (Rowland 1998) or stage 4–5 (Gooley *et al*. 1995).

For Fish 8 (1100 mm TL cannulation with a glass pipette was again negative. Laparoscopy proceeded (Figure 4) with insufflation using an air-line via the trochar. The gonads were again easily identifiable and appeared as large (70–80% body cavity length) pale pinkish (left side) or whitish-pink (right side) paired organ. No oocytes were visible and this fish was diagnosed as mature, developing male stage III–IV, (Rowland 1998) or stage 5 (Gooley *et al.* 1995).

Fishes 7 and 8 recovered equilibrium within approximately 10 minutes, and within 30 minutes were both swimming normally "straight and level".

Figure 4: Inspecting the reproductive status of Murray cod via laparoscopy under anaesthesia.

Post-release hooking survival results

A total of 30 Murray cod were angled during the trial (mean total length 406 mm; maximum 440 mm; minimum 340 mm). All fish were shallow hooked. Although one intention of the study was to investigate both shallow and deep hooking, the fish could not be induced to swallow the baits, even when allowed considerable time after biting the bait. Only shallow hooking could be investigated. There was some variation in hooking location, but specific hook locations were not recorded. After seven days in the holding cage no mortalities were recorded and the trial was terminated.

Discussion

Estimation of recreational harvest of Murray cod

In balance, the added factors of being able to collect additional accurate data on hook placement, and sample the maturation status of angler-harvested cod provided by an on-site, roving creel survey outweigh the potential simplicity and cost-effectiveness of an off-site approach.

For any survey of the recreational harvest of Murray cod, the precision of the final estimate will vary proportionally with the cost of the survey. Cost will increase with increased effort employed (i.e. hours of on-site interview time, or number of diary-anglers telephoned). For purposes of benchmarking the harvest 'today' to compare with future harvest, the precision of the estimate must be low enough to allow statistical comparisons in the future. The NRIFS design worked to achieve precision targets of estimate ±20% SE. Many major fisheries stock assessment surveys (e.g. Great Australian Bight fisheries) use ±10% SE (Anne Gason, Fisheries Victoria, pers. comm.). The relationship between effort and precision in a range of Victorian freshwater creel surveys suggests that ±5–20% SE can be achieved with around 215–440 hours of interview effort annually per fishery.

Further discussion and consultation is necessary to finalise stratification structure in the design but typically, season, day-type and time would be included. The effort would be divided unequally amongst these strata depending upon weighting-factors, but that would leave each stratum with on average ~72–147 hours of interview effort, which equates to 18–37 shifts of four hours, or the equivalent.

Costs would ultimately also depend upon staffing mechanisms. There are advantages in having scientist staff trained in maturity staging or technical staff trained in sample acquisition conducting the interviews.

If interview sessions are randomised in both space (random start locations from the entire extent of the fishery) and time (random calendar days and times from the whole fishing-season), then the resulting estimates are valid for the whole fishery.

Recreational fisheries for Murray cod exist in widely varying geographic contexts across the MDB, and even throughout Victoria. They range in size from small non-navigable streams such as the Kiewa River, to large rivers with reaches navigable by small boat for 10s to 100s of kilometres such as the Ovens, Murray and Darling Rivers. The scale of these fishery-reaches has a bearing on the practical approach required to patrol it looking for anglers to interview. In geographic context, these fisheries also vary widely in location; they may be close to large population centres and have high visitation rates by anglers (e.g. Loddon River, Lake Mulwala, and Ovens River), or be much less accessible where anglers visit rarely (e.g. Lindsay River/Mullaroo Creek or upper Darling River tributaries). The location context effects the design of surveys and influences any stratification requirements. In order to get sufficient angler interviews, the creel-clerks may need to spend relatively more time in the fisheries with lower visitation-rates. The Murray cod creel survey would focus on the key fisheries in Victoria (or in the MDB). Stratification would start with 'fishery' and effectively partition the effort and results of the survey for each fishery of interest. Further stratification to consider could be 'seasonal' (i.e. summer/winter etc); 'type of day' (i.e. weekday/weekend etc); 'time of day' (i.e. morning, afternoon, evening etc).

Evaluation of methods for non destructive maturity estimation in Murray cod

Ultrasonography

Further experience in ultrasound use and image reading would improve the accuracy of maturity assessment and organ identification. Perhaps oocytes of mature fish in late vitellogenesis would be diagnosable. The resolution of images obtained with the 3.5 and 5 mHz probes seemed unlikely to reveal detail required to accurately judge oocyte size in maturing female Murray cod outside this period. Higher resolution may be obtained using higher frequency probes, although there is a trade-off in reduced ultrasonic penetration (Dane Newman, Deakin University, pers. comm.).

Results of our preliminary testing indicate that detecting the presence of mature gonads is reasonably accurate, but detecting the absence is less accurate. This may still be of practical use, as it would reduce the need for destructive sampling to only those fish where we cannot confidently confirm maturity.

The equipment used (Aloka SSD500) appeared to be reasonably portable, although it requires 240V input. It could be used on the river bank from the back of a vehicle, with a portable generator or voltage-inverter. Its ruggedness in such circumstances would have to be evaluated. This unit is available from international dealers for ~$11,000. Portability is an essential ingredient in field-based diagnostic equipment and although commercially available, a portable ultrasound unit is more expensive (e.g. Aloka SSD900 available from international suppliers pre-owned at $22,000). An assessment of both non-portable and portable units should be made before ultrasound is deemed an appropriate option as a non-lethal method of maturity assessment.

Laparoscopy
Of the equipment trialled, the straight laparoscopy telescope was easily the best. It was simple to use and the image quality was high (bright and sharp). The otoscope although simple, lacked similar brightness and the inability to use insufflation (i.e. gas-inflation), hampered its effectiveness. The flexible endoscope was too large and unwieldy and the image lacked brightness and resolution due to the properties of image transmission via fibre-optics.

The advantage of the laparoscope is in allowing direct observation and "what-you-see-is-what-you-get." Air insufflation was a definite advantage and, although veterinary texts recommend carbon-dioxide for its ease-of-absorption, air can be used satisfactorily (Murray 2002). Colouration of gonads during development is one key factor in determining status; the laparoscope allows correct colour visualisation. The laparoscope's ability to focus through the ovarian membrane and gauge the oocyte colouration and size distribution is another key factor in accurately assessing reproductive status.

The unit requires a 240V electrical supply to power the light-source for laparoscopy. With a current requirement of ~1 Amp, this should run satisfactorily via a 12V/240V inverter from vehicle or boat 12V batteries.

Post-release hooking survival

As no fish died during the trial, there is no mortality estimate from the study. If these rates are similar to the wild experience then shallow hooked cod may have a high survival rate if handled carefully. This preliminary hooking trial was not done in the wild so the results can only be applied to domestic fish. Some insight into shallow hooking mortality could be gained. Shallow hooking does not appear to result in high post release mortality.

Hooking mortality trials from fish sourced in the wild or from hatcheries generally list deep hooking as a factor in increased post-hooking mortality. Butcher *et al.* (2006) reported relatively high survival of hatchery sourced mulloway (95.8%) that were handled similarly to the Murray cod in our trial (i.e mouth hooked, the fish exposed to air, the hook removed and the fish monitored for seven days). Higher mortalities were reported from deep hooked mulloway. In studies of striped bass, Millard *et al.* (2000) noted that hook location was the only variable that significantly affected the survival of striped bass; specifically, gut hooked fish had a higher likelihood of dying than those hooked in the lip. This notion that deep hooking results in a higher post release mortality rate is reported in many hooking studies (Millard *et al.* 2000; Prince *et al.* 2002; Faragher 2004; Broadhurst *et al.* 2005; Butcher *et al.* 2006). It would, therefore, seem likely that the same would be true in Murray cod.

Despite the limited nature of this trial the results indicate that shallow hooked Murray cod, given limited handling and air exposure, have a high survival rate. Further trials are required to assess any impact from deep hooking or other aspects handling such as hook removal versus leaving hook in place.

The inability to get the Murray cod to swallow bait was a problem in our trials. In the current trial, the source cod were fed on the hour throughout the day with pellets via automatic feeders; there was also an abundance of 'natural' food present in and around the cages including small fish and shrimp. The caged fish appeared to feed on these natural food items as several of the angled fish had partially swallowed fish in their throats when landed. Murray cod may not have been hungry enough to swallow the baited hooks. Perhaps if the fish had been starved prior to the trial then the results may have been different. Different baits may have also changed the results. Although scrub worms baits were initially used in this trial, they were completely ignored by the fish.

There were several advantages in using domestic fish in the hooking trials. A key advantage was that any possible aggressive behavioural impacts of Murray cod in cages could be avoided as the fish are accustomed to being crowded and thus there was no requirement to hold the fish individually. The fish could all be exposed to the same treatment to minimise any handling induced effects and thus reduce many confounding variables. The size of the caged cod could be selected to be close to the legal minimum size limit for Murray cod in the wild and the fish used could be a reasonable representation of the size of fish that are caught and released in many Murray cod fisheries. There was a known (low) mortality rate of the caged cod prior to the trial starting as the fish were routinely monitored as part of the commercial operation.

Environmental conditions such as water and air temperature are important variables affecting the impact of stress and handling and variation in these components could influence results. Trials in the wild often take several days and potentially span natural changes in air and water temperature. In the present trial, the fish were all captured and held in the same conditions and the fish could be easily monitored for the duration of the trial. In the wild, such controlled conditions would be difficult to achieve and the collection of Murray cod time consuming. The variability of handling and the possible impacts of containing and holding wild fish were all avoided by using these reared Murray cod at the aquaculture facility.

The inability to obtain deep hooked fish prevented any analysis of deep-hooking mortality. The mortality associated with deep hooking should be addressed in further investigations on hooking mortality for Murray cod.

Conclusions

Harvest estimation

Roving creel surveys of up to four key recreational Murray cod fisheries in Victoria should be designed as interview sessions randomly sampled in space and time within each fishery. Up to 440 hours of interview effort per fishery should give a precision on the estimates of around 5%–20% SE. For each fishery, effort should be shared among up to three strata, weighted according to agreement by regional and local consultation.

Randomisation should be achieved spatially (by use of random start points and directions), and temporally (by sampling from all times and dates within the fishing-season) to allow estimates to represent the whole fishery.

Maturity estimation

Preliminary trials indicate that examination by laparoscopy is an appropriate field method for determining the maturity status of Murray cod without killing the fish to take histological samples. However, even with the best non-destructive techniques, complete diagnostic certainty is only likely with some individuals. This uncertainty is likely to be distributed unevenly, increasing for males and all Murray cod outside the pre-spawning (vitellogenesis) period and for Murray cod around the size-at-first-maturity. At these high-risk times or for individuals where a diagnosis has high uncertainty, it is essential that histological validation (after destructive sampling) be available as a technique. The diagnostic uncertainty can be minimised by sampling the majority of Murray cod between June and December, when the majority of mature females would be expected to be either developing in vitellogenesis, or newly spent. This timing to a certain extent rules out the use of angler caught Murray cod as this period falls largely within the closed season for angling.

To optimise accuracy while minimising destructive sampling, it is recommended that the following 6-point key be used to control the approach to sampling Murray cod to determine maturity.

Step	Action	Result
1.	Individually sedate each fish using approved anaesthetic. Weigh fish and measure total length	
2.	Can milt or eggs be expelled by gentle squeezing of the abdomen	yes => 5 no => 3
3.	Cannulate gonoduct with glass pipette. Can oocytes or sperm be withdrawn using slight negative pressure	yes => 5 no => 4
4.	Conduct laparoscopy procedure (see below). Can diagnosis of reproductive status confidently be made?	yes =>5 no => 6
5.	Close any incisions (if any)	recover fish from anaesthesia
6.	If fish cannot be sexed	euthanase fish and dissect gonads*.

Before proceeding from (4) to (6), the need to sacrifice a fish will be considered in relation to the population status at the collection site as well as its location and an assessment made of the extent to which the result that may be obtained is 'essential'. Note that all procedures described will be conducted under an approved animal care and ethics licence.

Release survival assessment

Pond trials do not provide a satisfactory surrogate for assessment of release survival of Murray cod from the wild fishery. The use of aquaculture reared fish do provide a source of 'control' fish for a field assessment.

The main problem for this assessment may be getting sufficient wild caught fish for statistical reliability of the results. Discussions will be initiated with anglers to assist with field trials.

Acknowledgments

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Chapter 3. Size at Maturity - Assessment of variation in Murray cod length at maturity across the Murray Darling Basin.

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Introduction

A common management tool for restricting the take of fish from a fishery is the use of legal minimum length (LML) regulations (Stewart 2008). The enforcement of LMLs is generally aimed to minimise recruitment overfishing by allowing the fish to contribute to the reproductive output of the stock before being vulnerable to harvest (Hill 1992; Winstanley 1992).

All fishery authorities in the Murray Darling Basin (MDB) impose angling regulations specific to Murray cod (Lintermans *et al.* 2005) and all are primarily based on LMLs (NSW, Victoria, Queensland angling regulations). Australian fishery regulations have traditionally been based on the state spatial scale rather than being related to a particular water, catchment or other geographic basis. Historically, the specific LMLs varied between the states, but recently there has been an alignment of Murray cod LMLs across the states (with the exception of SA). Victoria and New South Wales have increased the LML from 500 mm to 600 mm (TL) as it is in Queensland. South Australia essentially enforced a no take restriction on Murray cod in the 2009 calendar year.

The setting of LML regulations is ideally determined by sound knowledge of length at maturity. The length chosen for the management of fish populations must be robust enough to cater to both fisheries management and conservation requirements. The biological information pertaining to Murray cod size at maturity is not extensive, especially in relation to spatial variation; consequently, it is not known if the present restrictions are appropriate or if the fishery is sustainable under the restrictions. For example Nicol *et al.* (2005) indicated that the angling regulations in force at the time may not have been appropriate, at least at some specific locations, due to high angler pressure.

Size at maturity was examined by Rowland (1998b) using data from fish collected from the Edward, Wakool, Murray and Gwydir Rivers. He found that all females were mature at 590 mm and above, whilst the smallest mature female he found was 480 mm. He also found that all males above 585 mm were mature. Rowland (1998b) also examined some fish from Lake Mulwala and recorded immature females of 630 mm and 640 mm. In relation to spatial scale variation in Murray cod growth, Rowland (1998b) speculated that lower water temperatures may slow Murray cod growth in cooler southern waters and result in regional differences in size at maturity.

This present study aimed to determine the size at maturity of Murray cod from across the MDB and if it varied with location. The results will be used to verify the suitability of current state Murray cod LMLs, and be used in theoretical stock assessment models investigating the sustainability of the recreational Murray cod fishery within the MDB.

Methods

The length at maturity assessment was a field based program where wild Murray cod were captured, assessed for maturity then, where possible, returned to the water. As it was intended that a large number be assessed for maturity, it was essential that the assessment method be non-destructive where possible. Consequently, a number of methods were initially trialled to determine the most effective method (Chapter 2).

Diagnostic method trials

A number of non-destructive methods of estimating length at first maturation were reviewed and trialled including standard hatchery methods of cannulation, and innovative methods such as ultrasonography and laparoscopy. These methods were reviewed for accuracy, practicality and cost-effectiveness and details reported in Chapter 2.

Based on these trials, a procedure was devised for the maturation assessment and adopted for this investigation (Table 3).

Table 3: Assessment procedure.

Step	Action	Result	Comment
1.	Can milt or eggs be expelled by gentle squeezing of the abdomen	yes => 4 no => 2	Timing spring to early summer
2.	Cannulate gonoduct with glass pipette. Can oocytes or sperm be withdrawn using slight negative pressure	yes => 4 no => 3	
3.	Conduct laparoscopy procedure (see below). Can diagnosis of reproductive status confidently be made?	yes => 4 no => 5	
4.	Close any incisions (if any)	Recover fish from anaesthesia	Release fish alive close to place of capture
5.	If fish cannot be sexed	Euthanase fish and dissect gonads*.	

**Initial trials of this assessment procedure decision tree indicated that the need for the euthanasia option would be an exception.*

Sampling trips were generally undertaken in late spring to early summer prior to the Murray cod spawning season as mature fish would have obvious eggs or milt, and cannulation could be used as the primary method to sex and determine sexual maturity. This reduced the necessity to use the more invasive laparoscopic method. Captured fish could be given a light abdomen squeeze to express milt. If no milt, then the fish could be cannulated immediately after anaesthesia.

Description of diagnostic procedures used

Cannulation

This procedure involved inserting a 1 mm glass pipette into the gonoduct, via the genital papilla, for a distance of 2–3 cm. Eggs were withdrawn into the pipette after slight suction was applied.

Laparoscopy

When laparoscopic examination was required, each fish was sedated to surgical anaesthesia stage 3 and a 10 mm incision was made in the skin just off the ventral midline, half way between pelvic fin-tips and the vent. A scalpel was used to cut through the skin and blunt artery forceps used to push through muscle layers to the peritoneum. A surgical trochar (Karl Storz 10 mm Endoskope) was used to puncture the peritoneum allowing a 10 mm rigid laparoscope tube to be introduced to view inside. To reduce adhesion of organs and assist the viewing process, the body cavity was inflated slightly with air using either a 50 ml syringe (small fish) or a small battery pump (large fish) fitted to the gas-port on the trochar. Using the cold light-source fitted to the laparoscope, the internal organs, including the gonads could then be visualised. A diagnosis of gender and reproductive status (mature, immature) was made for each fish based on visual staging of the gonads (Rowland 1998b).

After diagnosis, a little manipulation was required to release as much of the air as possible before closing the incision. The incision was closed with simple sutures (absorbable) in a single layer (skin and muscle) and the wound daubed with iodine solution. Finally the wound, sutures, and small adjacent de-scaled area were daubed with cyanoacrylate cement. The fish was then transferred to a recovery tank of fresh aerated water and monitored. When normal swimming resumed the fish was released.

Field collection

Murray cod were captured from rivers of the Murray-Darling River system using boat-based electrofishing. Only riverine populations of Murray cod were sampled in this study. Electrofishing is the most appropriate method to sample Murray cod in rivers as it is a non-destructive sampling technique with high enough efficiencies to obtain suitable numbers of samples within a reasonable time frame.

All sampling and assessment of maturity was undertaken under appropriate animal care and ethics permits (NSW ACEC REF 07/05-Victorian DPI Fish AEC Oct06 0014).

Murray cod were collected from three zones representing the north, south and southwestern areas of the MDB (Figure 5). Zones were the “lower Murray”, which included the Murray River from Boundary Bend to the South Australian border; “McIntyre”, which included the McIntyre River from Boggabilla Weir to Goondiwindi Weir; and the “mid Murray”, which included the Murray River downstream of Yarrawonga to Echuca, the Ovens River downstream of Gapstead and the Loddon River at Bridgewater on Loddon. Some Murray cod were collected from central NSW but accurate maturity assessment could not be made on these fish and these data were not included in this analysis.

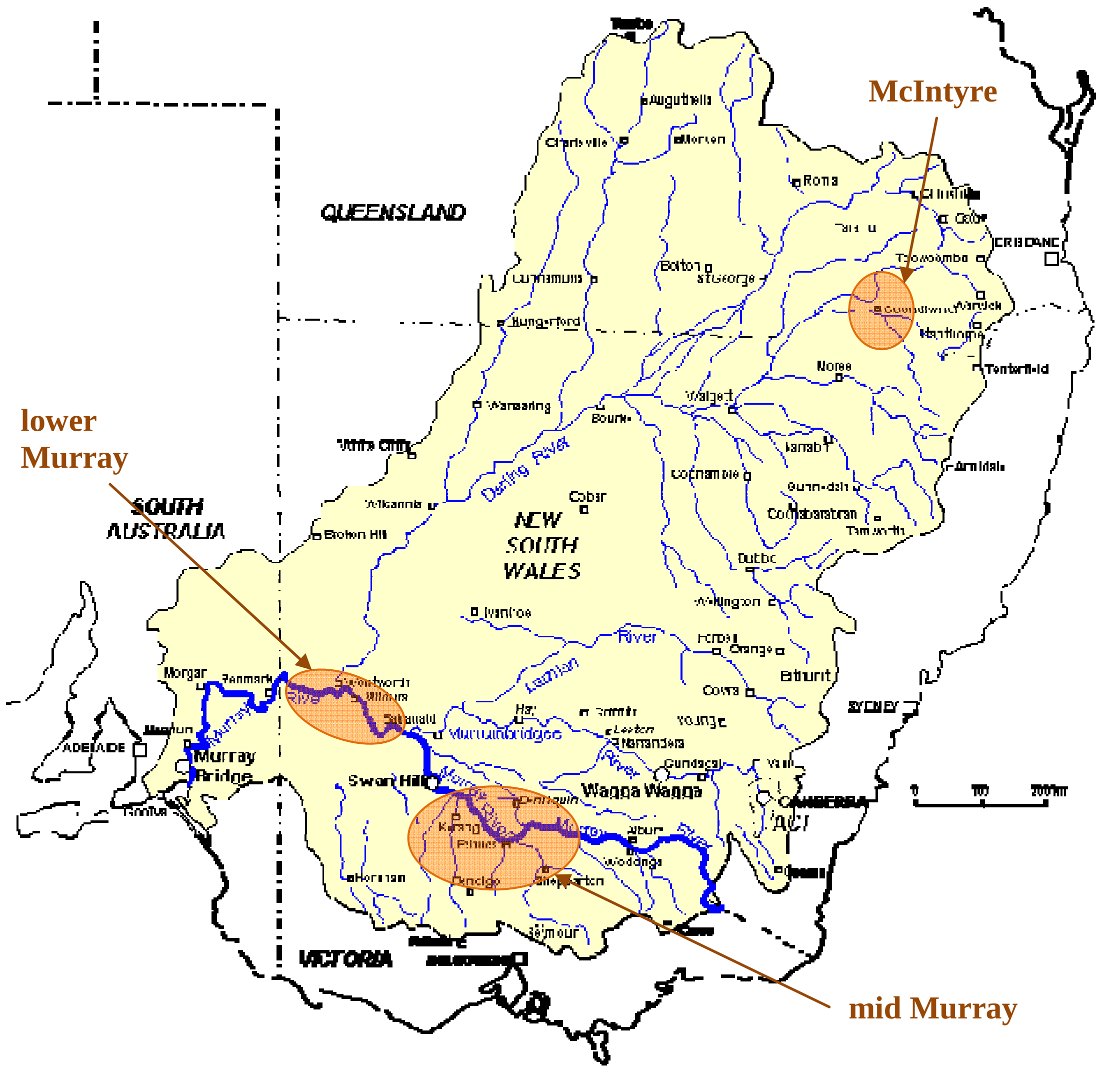

Figure 5: Location of zones within the MDB sampled for Murray cod length at maturity.

Analysis

The probability of Murray cod maturity (p) was estimated based on the total length (TL) of an individual using a logit model formulated as:

$$p = \frac{1}{1/e^{-(TL-Lmat)/sigma}} \qquad (1)$$

where *Lmat* is the length at which 50% of individuals are mature and *sigma* is the logistic shape parameter that describes the variance of the logistic distribution of *Lmat*. *Lmat* and *sigma* were iteratively solved for by maximizing a reduced binomial log likelihood formulated as:

$$LL = \sum_i \ln\left(p^k (1-p)^{(1-k)}\right) \qquad (2)$$

where p is the probability of maturity (equation 1) and $k = 1$ for fish that are mature and $k = 0$ for fish that are not mature. Confidence estimates were derived from the likelihood profiles using the POPTOOLS extension in Microsoft Excel. Potential differences in length at maturity (*Lmat*) and the rate of maturation (*sigma*) among regions of the MDB were evaluated by ranking various models with Akaikes Information Criterion (AIC) (Akaike 1973). AIC provides an objective way of determining which model, among a set of models, is the most parsimonious. Simplicity and parsimony is a concept based on Occam's razor, which suggests that the simplest explanation is probably the most likely and the model with the lowest AIC considered as the 'best' model. Models are compared based on the change in AIC scores (ΔAIC) relative to the lowest scored model. In this assessment it was considered that a ΔAIC < 3 indicates no difference between models, a ΔAIC < 7 indicates possible difference and a ΔAIC > 7 indicates significant differences between models (Hilborn and Mangel 1997).

Results

Summary of fish examined

A total of 389 Murray cod were assessed from the three zones: Lower Murray (n=125), McIntyre (n=104) and mid Murray (n=160). A summary of the numbers of males and females sexed is presented in Table 4.

Table 4: Summary of Murray cod collected and sexed from various zones within the MDB.

Sex	River			
	Lower Murray	McIntyre	Mid Murray	Total
females	31	34	29	94
male	31	24	33	88
Not sexed/immature	63	46	98	207
Total	125	104	160	389

Length frequency

The length frequency of fish collected from each of the three zones is presented in Figure 6.

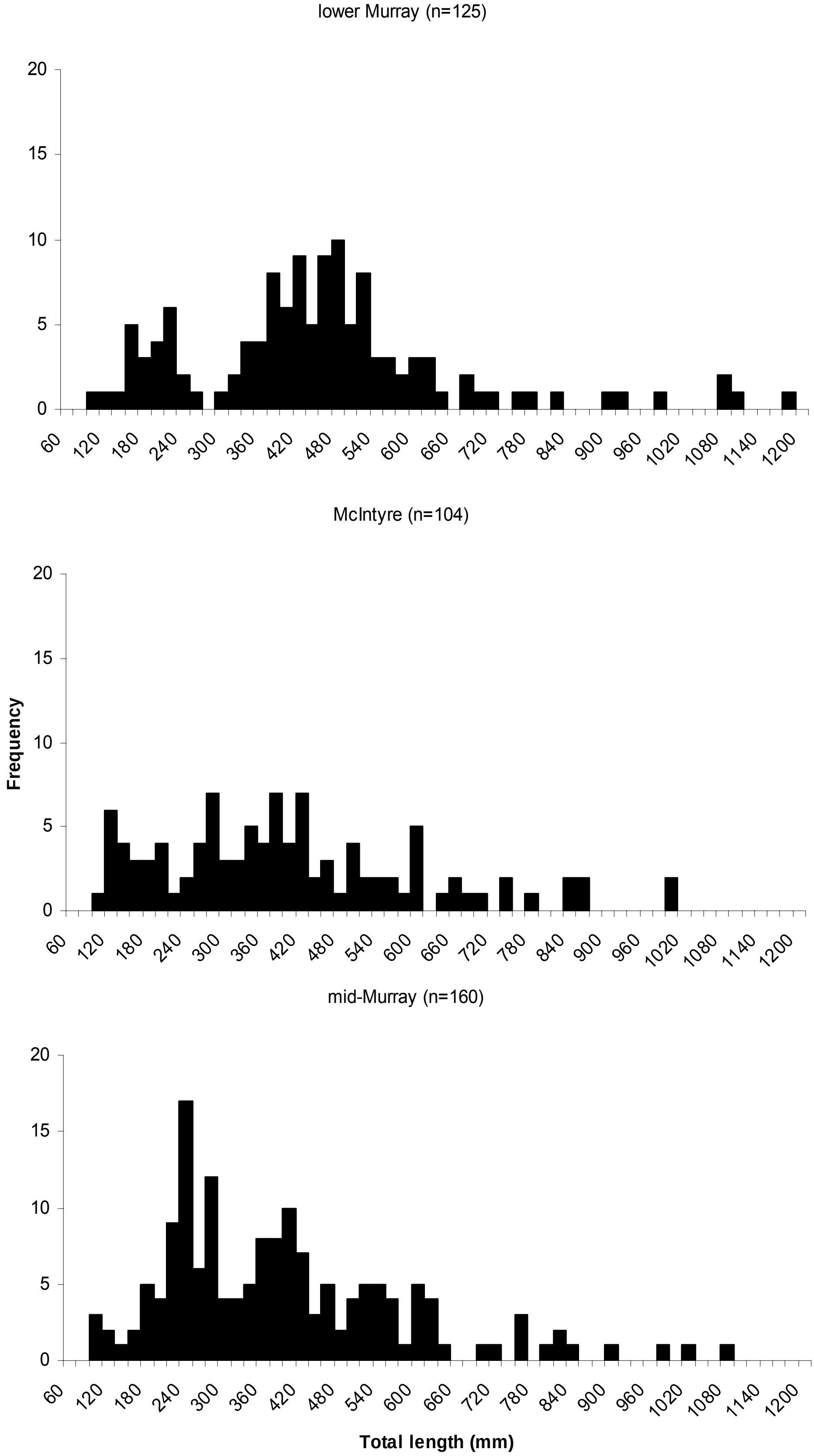

Figure 6: Murray cod total length frequency from fish sampled from the three zones.

Predicted length at maturity

For each zone sampled the predicted probability of maturity across the range of fish lengths sampled is given in Figure 7.

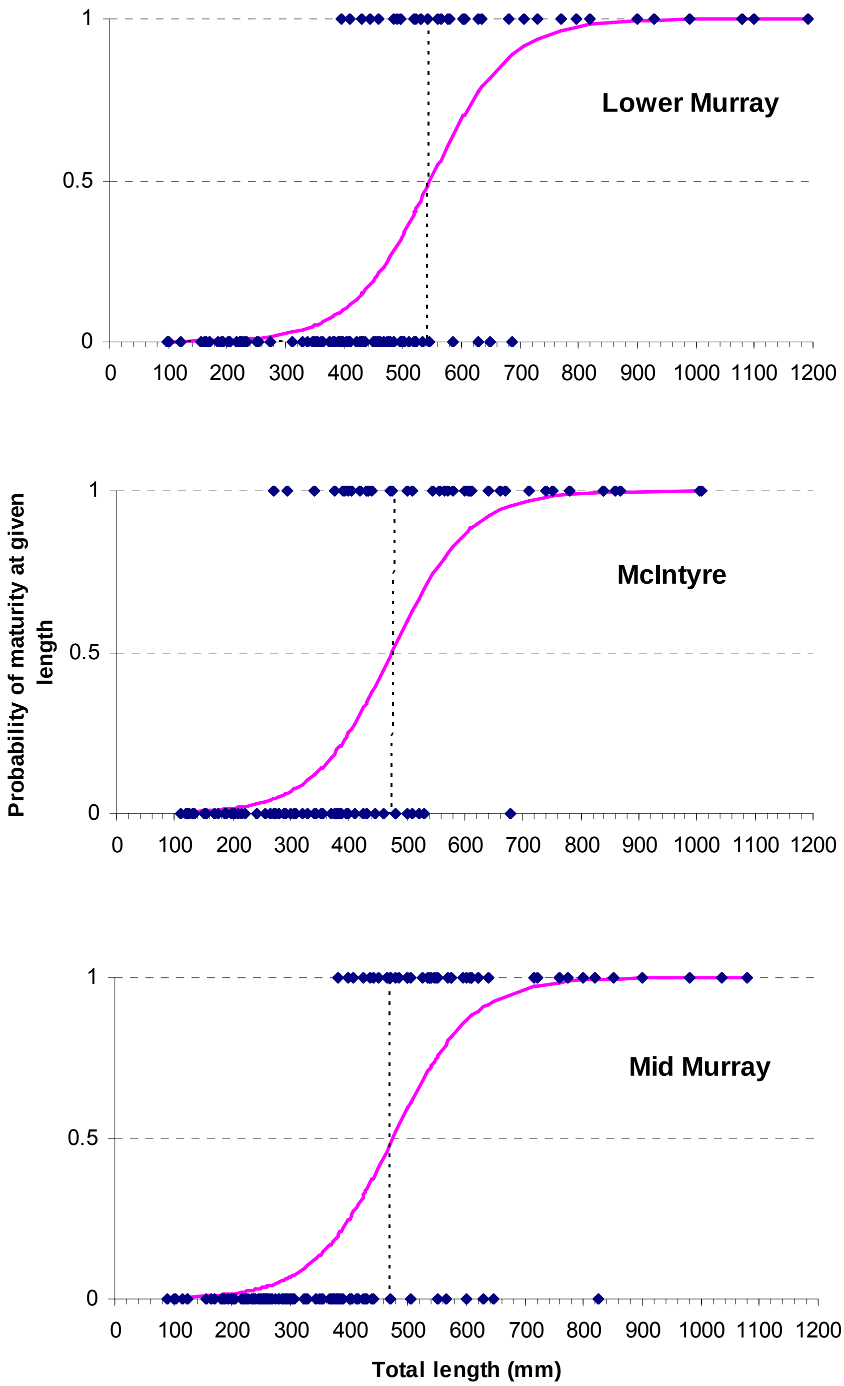

Figure 7: Predicted rate of change for Murray cod length at maturity from each of the three zones sampled derived from maximizing the reduced binomial log likelihood (curve). Diamonds are actual total length data from fish assessed as immature (0) or mature (1). Drop line indicates estimate of length where 50% of Murray cod are mature.

AIC analysis

An analysis of male and female length at maturity was undertaken to investigate if there were any differences between sexes (Table 5). The logit model gave similar estimates of male length at maturity (MLmat) and female length at maturity (FLmat) and rate of maturation for males (Msig) and females (Fsig) (Table 5). ΔAIC analysis was undertaken to compare all possible combinations of the multi-parameter model where both parameters in each sex can either be similar, or be allowed to vary. The model with the lowest number of parameters was chosen as the best model for the data. The ΔAIC was less than three for all models (Table 6), which indicated that no differences could be detected between models. It was inferred that there was no difference between male and female length at maturity.

The Logit model and AIC analysis was rerun for the study sites using the pooled male and female data. The Logit model gave similar estimates of length at maturity (Lmat) for the mid-Murray and McIntyre study sites, but a higher length at maturity (Lmat) for the lower-Murray study site (Table 7). As the 95% confidence intervals do not overlap, the difference in length at maturity was considered as significant

Table 5: Logit model estimates of length (mm, TL) at 50% maturity for males and female Murray cod. Flmat= female length at 50% maturity, Fsig=female shape parameter, Mlmat=male length at 50% maturity, Msig=male shape parameter.

Sex		
Females	Flmat	431
	Fsig	119
Males	Mlmat	431
	Msig	119

Table 6: AIC analysis of male and female Murray cod logit model estimates. Lmat= length at 50% maturity, Sigma=shape parameter, S=variable, .=constant, AIC=Akaike's Information Criterion, Δ AIC= Change in AIC.

Model	No. of Parameters	Log Likelihood	AIC	Δ AIC
Lmat(s)Sigma(s)	4	-94.11	196.23	2.26
Lmat(s)Sigma(.)	3	-94.20	194.40	0.41
Lmat(.)Sigma(s)	3	-94.51	195.03	1.06
Lmat(.)Sigma(.)	2	-94.98	193.97	0.00

Table 7: Logit model estimates of length (mm, TL) at maturity for Murray cod from different regions and 95% confidence limits.

Region	Length at maturity estimate		95% confidence estimates	
			Lower-	Upper-
Lower Murray	Lmat	547	513	586
	Sigma	67	55	84
McIntyre	Lmat	474	449	503
	Sigma	67	55	84
mid Murray	Lmat	474	449	503
	Sigma	67	55	84

Table 8 examines whether length at maturity and rate of maturation vary across the three regions. The results indicated the length at maturity varied, but the rate of maturity for all regions was constant.

The ΔAIC analyses of the study sites using the best supported model indicated that fish from the lower Murray has a significantly different length at maturity than fish from the mid Murray and were possibly different from fish in the McIntyre. The mid-Murray and McIntyre data could be described with one model, but a different model was required for the lower-Murray data (Table 9).

Table 8: AIC analysis of Murray cod logit model estimates for each study site (males and female data pooled). h=homogenous, .=constant.

Model	No. of Parameters	Log Likelihood	AIC	ΔAIC
Lmat(h)Sigma(h)	6	-129.61	271.22	3.13
Lmat(.)Sigma(h)	4	-134.62	277.23	9.14
Lmat(h)Sigma(.)	**4**	**-130.04**	**268.09**	**0.00**
Lmat(.)Sigma(.)	2	-136.52	277.04	8.95

Table 9: AIC analysis of Murray cod logit model estimates for each study site using the most supported model [Lmat(h) sigma(.)] Males and female data pooled.

Model	No. of Parameters	Log Likelihood	AIC	ΔAIC	Significance
Lmat(lm,.)Sigma(.)	**3**	**-131.13**	**268.26**	**0.00**	
Lmat(mc,.)Sigma(.)	3	-132.70	271.41	3.15	possible difference
Lmat(mm,.)Sigma(.)	3	-136.21	278.42	10.16	significant

Where lm =lower Murray; mc=McIntyre; mm=mid Murray

Discussion

Our results indicated that Murray cod in the McIntyre and mid-Murray study areas within the MDB became mature at a similar size; while Murray cod in the lower Murray matured at a larger size than fish at other locations.

Sexual maturity in fish may be age-dependant rather than dependant on size (Hill 1992; Rowland 1998b). If so, growth differences between cod in the lower Murray region and the other study areas could explain differences in size-at-maturity. In the wild, variation in Murray cod size at maturity was reported among lakes and rivers across the MDB by Rowland (1998b), who suggested that this was possibly due to colder water temperatures in the southern part of the Basin reducing growth rates. The MDB system covers about 13 degrees of latitude and climate ranges from sub-tropical in the north to temperate in the streams of the southern portion. If temperature was the main factor, some growth differences longitudinally would be expected to influence size at maturity between northern and southern study sites; this was not the case. Temperature is only one factor affecting growth rates of fish in the wild; others include habitat quality, food availability and population density.

While the reasons for the larger size at maturity in the Murray cod from the lower MDB are not known, one obvious difference between the various sampled areas is habitat. The fish in our study were all from riverine environments, so our results should be qualified as applying to riverine Murray cod. This is an important distinction because of the Murray cod growth rate variation observed between lakes and rivers (Rowland 1998a). The habitat between the lower Murray site and the other sites sampled is vastly different. The lower Murray sites were in a larger river relative to the other sites, and many of the fish were sampled from weir pools. The Murray weir pools have little flow and are similar in many respects to long lakes. The growth of Murray cod in these environments may be more aligned with Murray cod growth rates in impoundment rather than river fish. Murray cod were not aged in this study, so it is not known if there was any difference in age in the fish sampled.

The determination of Murray cod size at maturity in the present study provides information that can be used to:

- validate the legitimacy of current minimum size regulations pertaining to Murray cod
- support the setting of uniform Murray cod size-based regulations over large spatial scales
- give scientific support to current regulations
- allow the use of mathematical fishery models to forecast the outcomes of alternative regulation scenarios or future fishery trends.

It is important to validate the legitimacy of current minimum size regulations pertaining to Murray cod because inappropriate size limits may not lead to effective fishery management. Recently, the state-based regulators in Queensland, NSW and Victoria have aligned the state Murray cod LMLs across the MDB (DPI 2008). If these regulations were set with the specific purpose to allow fish to spawn before reaching a takeable size, then the present LML of 600 mm would seem appropriate for the majority (almost 90%) of Murray cod with the exception of the lower Murray River, where the figure is closer to 70%. Our data indicate that around 60% of Murray cod are mature at 500 mm across most of the MDB, whereas, in the lower Murray, around 30% are mature at 500 mm. This differs from Rowland (1998b) who reported all female Murray cod over 590 mm and all male Murray cod over 585 mm were mature.

The current Murray cod management arrangements pertaining to LMLs are uniform over large spatial scales. Confirmation that there is a similar size at maturity across rivers within a large region of the MDB supports the setting of basin-wide LMLs, or at least across a large-geographic scale. If the data had shown considerable variation in the size of Murray cod maturity across large spatial scales in rivers, then it may not have necessarily been appropriate to advocate a uniform Murray cod LML. Differences in LMLs between areas or states can be problematic from a fishery manager's perspective, particularly with contiguous states. Similar LMLs across areas or states are favoured by fisheries managers for reasons such as simplicity, ease of application and ease of enforcement (Winstanley 1992). However, it is important that such arrangements are also suitable from the biological perspective as specific size limit regulations may be required to cope with differences in management approaches, angling pressure or size and growth attributes applicable to different areas (Hancock 1990). Length at maturity can vary due to a range of demographic, genetic and environmental factors but is linked to growth rates. Growth rates in Murray cod can vary significantly. For example, Murray cod growth rates (as expressed by weight) can vary by a factor of 15 in same-age cohorts kept in identical conditions (Ingram *et al.* 2007).

The current LML (600 mm) regulations allow the removal of some fish that are sexually immature. At low fishing pressures, removing immature fish from a population may be tolerable. At high fishing pressure removing fish before they mature and spawn may threaten a stock.

There has been no assessment to determine the appropriate LML for sustaining the Murray cod fishery. Size limits have been used in Australian fisheries management for many years. In combination with gear restrictions and closed seasons, LML remain a fundamental element in contemporary fisheries management strategies including those directed for Murray cod (Winstanley 1992; Lintermans *et al.* 2005). Although sexual maturity in fish appears to be age dependant rather than size dependant (Hill 1992; Rowland 1998b), basing regulations on the age of a fish is not practical as it is much easier for an angler to measure a fish rather than age it (Hill 1992). Fish length is generally used as a surrogate of age and LMLs are employed as the management tool. The ability of such regulations to achieve success and produce the defined management objectives depends on a range of contemporary information. Such information includes detailed knowledge of fish population dynamics, characteristics of habitat, proximity to population centres, other fishing alternatives in the area, angler preferences, and enforcement limitations as well as predictions of alternative regulation scenarios and future trends using mathematical models (Carlson and Muth 1993; Van Den Avyle 1993). When this information is lacking, as it has been with Murray cod, the limits are often set more on an 'acceptable' size and some limited knowledge of when the fish first matured (Winstanley 1992) rather than being based on sound and accepted scientific principles and formal fishery assessment procedures (see Hancock 1990). On the global scale, the use of models to evaluate LMLs in recreational fishing management is widespread, but in Australia the use of models, particularly for freshwater angling species, is not common, probably because the required information is not available.

There are several limitations to our results that should be acknowledged. The expression of sperm from small Murray cod may not necessarily indicate that the fish were sexually mature. Sperm motility was not confirmed from any fish. It is also possible that although a fish may be sexually mature, it does not contribute to the breeding population due to behavioural or other constraints. Genetic typing of individuals bred under aquaculture conditions where cod spawn in earthen ponds at Snobs Creek, indicates that the larger males and smaller females were more successful in reproduction (Brett Ingram and Meagan Rourke, DPI Vic, pers. comm.). Although the spawning behaviour of Murray cod is not well known, it has been reported that Murray cod males select and prepare the spawning site and also engage in some degree of post-spawning parental care (Butler and Rowland 2009). If a size dependant factor is operating in Murray cod, then a small male cod may not be able to defend a spawning territory or attract and successfully court a female, and would not contribute to the breeding population.

A principal role of LML regulations is to limit recruitment overfishing where the adult population is fished so heavily that the number and size of the spawning population is reduced to the point where it does not have the reproductive capacity to replenish itself. For such purposes, size limits are set to allow fish to spawn before they are vulnerable to harvest. Not all reasons for applying a LML are biological as sometimes there is a sociological reason to maintain or promote quality of fishing (Noble and Jones 1993). The use of LMLs in recreational fishing is widespread but the success of the regulations depends on the suitability of the length to the fish stocks in question, compliance of recreational anglers to the regulations, and the level of illegal fishing (Winstanley 1992). Success of the regulations also depends on how well they assist in achieving any specific management goals. Murray cod fishing effort varies across the MDB (Brown 2010)and while there may be areas where angling pressure is high, it is unknown if current angling take is sufficient to impact on the overall fishery or at the local level.

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Chapter 4. Angler Harvest – Creel surveys on the Murray, Goulburn, Ovens and Loddon Rivers 2006–2008.

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Introduction

Murray cod is listed as vulnerable under the provisions of the *Environmental Protection and Biodiversity Conservation Act 1999*. Advice from the Threatened Species Scientific Committee convened to inform the Minister for the Environment and Heritage was, '*it is estimated that the size of the Murray cod population has declined substantially over the past 30 years (conservatively estimated to be at least 30%)*'. The advice also cited a range of types of habitat degradation held responsible for this decline (McKelleher 2005). A draft recovery plan has been developed in response to this listing.

The Native Fish Strategy (NFS) for the Murray Darling Basin (MDB) considers that overall, native fish numbers in the Basin are presently at 10% of pre-European settlement levels. The Strategy identifies a return to 60% of these levels as a key objective (MDBC 2004b).

For the 2007–08 Murray cod season, NSW recreational fishing legislation increased the LML from 50 to 55 cm (total length). In 2008–09, both NSW and Victoria set the LML to 60 cm, largely because of public and professional concern regarding size at maturity and population sustainability. Other recent legislation has increased the protection from harvest for large Murray cod, and provided a total moratorium on recreational fishing for Murray cod in South Australian waters.

The last work to quantify the recreational catch for Murray cod fisheries was from a national diary-assisted telephone survey in 2000 (Lyle *et al.* 2002; Henry and Lyle 2003). This survey relied on anglers' recollections of their fishing events recorded in a diary and relayed to researchers via a telephone-survey. Results pertained to the Australian Bureau of Statistics' statistical divisions and geographic areas, rather than particular rivers or individual waterways (Henry and Lyle 2003). Telephone and diary-based surveys are economical and widely used to sample fisheries for high-value, memorable species, in fisheries with diffuse angler-access; however, they can suffer from recall-bias of catch and/or effort especially from the more avid-anglers or where low-value, less memorable fish species are concerned (Pollock *et al.* 1994).

On-site surveys of anglers during or immediately following their fishing activity have been widely used in Victoria to estimate fishing-effort, catch and harvest for a range of inland fisheries (Hume 1991; Douglas *et al.* 2002; Brown and Gason 2007). Advantages of creel surveys include reduced recall (memory) bias, collection of site-specific information, and ability to examine harvested fish for measurement or collection of biological data, etc. (Pollock *et al.* 1994).

The National Recreational and Indigenous Fishing Survey (NRIFS) identified the large scale of the fishery, estimating that over 100,000 Murray cod were harvested across the MDB (Park *et al.* 2005). The national survey also identified that 77% of the overall catch was released, making this species a priority for more information on post-release survival and angler's behaviour leading up to release. Around the world there is increasing realisation that survival rates of fish released after capture by anglers can have a strong bearing on the sustainability of populations (Waters and Huntsman 1986; Muoneke and Childress 1994; Cooke and Philipp 2004).

The present study sets out to measure the impact of angling on Murray cod populations in fisheries popular with Victorian fishers during the 2006–07 and 2007–08 Murray cod seasons; namely the Murray River and the Goulburn, Ovens and Loddon Rivers. We identified these rivers as most important as Murray cod fisheries from the frequency of their use within the responses of anglers interviewed as part of the NRIFS (Lyle *et al*. 2002).

This report details the estimates of total catch, retained catch, and release-component of the recreational fishery, by season and river-reach, along with analyses of angler behaviour and how the fish were caught and handled prior to release.

Objectives

This chapter addresses the overarching FRDC objective (ii) – determine levels of angler harvest within defined regions of the basin; and supports FRDC objective (iii) – determine the post-release hooking survival of Murray cod under various hooking scenarios.

The objectives of this present study were to:

- Complete a stratified, random, survey of recreational fishers on important Murray cod fisheries for Victorian anglers.
- Provide whole-fishery estimates of the Murray cod catch, (retained and released components), fishing effort, and catch characteristics (including non-Murray cod by-catch).
- Describe and quantify fishing practices potentially important to the released survival rate for Murray cod.
- Provide estimates of recreational catch and retained catch that can be used in modelling simulations of a range of Murray cod management scenarios.

Methods

Study reaches

While the recreational fishery for Murray cod is managed on a state-by-state basis, for reasons of practicality we chose smaller river-reach scale units to survey. Throughout this report each of these survey reaches is referred to as a ‘fishery'. However, this is not meant to imply any preference for regional scale fisheries management.

Choice of study reach

Examination of the data from the NRIFS shows that during 1998–99, the Ovens, Goulburn and Loddon Rivers were the most important in Victoria for Murray cod anglers. These rivers were named as fishing locations by 34%, 17% and 15% of Victorian anglers, respectively. The angling effort in the same region accounted for 5.65% of the Australian catch (75% of the VIC catch). In NSW, the Murray River accounted for ~48% of the national effort and ~49% of the national catch, while the majority of anglers fishing the Murray River were Victorian residents.

During the first year (2006–07), three study reaches were chosen:

- Reach 1, Murray River from Yarrawonga downstream to Torrumbarry weir.
- Reach 2, Goulburn River from the Goulburn weir to the confluence with the Murray River upstream of Echuca.
- Reach 3, Ovens River from Myrtleford at the Great Alpine Road bridge downstream to the Pyke Street boat ramp (-36.037742° Lat., 146.175502° Long.) near its confluence with the Murray River.

During the second year, 2007–08, a further three study reaches were chosen:

- Reach 4, Murray River from Torrumbarry weir downstream to Tooleybuc Road bridge.
- Reach 5, Murray River from Tooleybuc Road bridge downstream to the South Australian border.
- Reach 6, Loddon River from Laanecoorie Reservoir downstream to the Boort-Pyramid Road.

In total 752 kilometres of three rivers in 2006–07, and 1,511 kilometres of two rivers in 2007–08, were covered by these surveys (Figure 8).

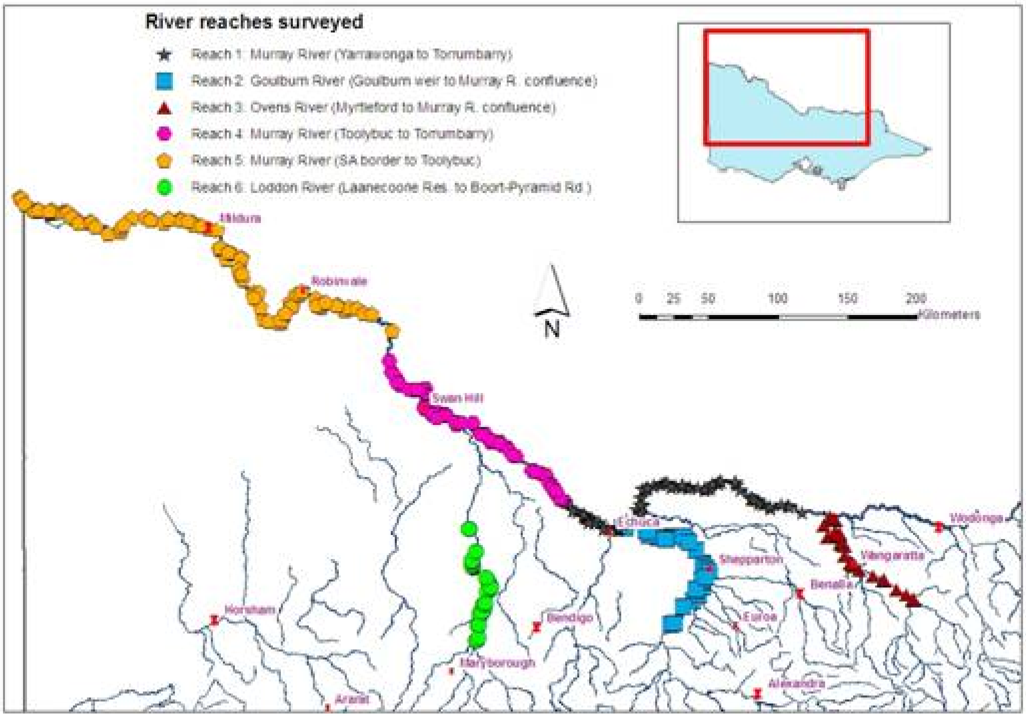

Figure 8: Showing the location and distribution of survey effort during the Murray cod creel surveys over two fishing seasons (2006–2008) along the River Murray and Goulburn, Ovens and Loddon Rivers. Each symbol represents the random location where daily survey effort started or ended.

Sampling Design

The design of the creel surveys was developed from a pre-survey questionnaire given to several Fisheries Officers and Murray cod anglers who were familiar with the fishery. The questionnaire was designed to gain some idea of the consistency of Murray cod fishing effort (and catch) throughout the season. Results from the pre-survey indicated that time-of-day, type-of-day, and time-of-year may influence the quantity of effort or the 'catchability' of the fish.

The concept of stratification (of survey effort) into categories of time and space within which catch rates may be expected to be similar, is to reduce the variability around the total estimates of catch or effort that are obtained (Pollock *et al.* 1994). For example, weekend-anglers in the afternoon may behave differently and have different catch-rate variability than those who fish during the week, say early in the morning. Statistically, it is better to consider these times as separate sample-strata for calculating variance and then combine the variances at a later stage. The most appropriate design for stratification of this survey was obtained by collecting opinions in a pre-creel survey (see below). The statistically random design of the survey makes it likely that this sub-sample of catch rates and angler behaviours within the fishery truly represents the whole fishery. The statistical randomisation determines when the creel clerk is on the river collecting data, and not anyone's preconceived opinions about the best, or worst, times to do it.

A pilot study (Chapter 2), and meta-analysis of the relationship between survey-effort and the precision of estimates obtained, suggested that estimates of fishing effort and catch should be made with adequate precision (5–20% of the estimate) with around 40–50 interview-shifts for a study reach (Brown, Douglas and Tucker, unpublished data 2006).

Shifts were selected at random with unequal probability from a sampling of all available dates and times within the Murray cod fishing season (1 December–30 August). Sampling effort was distributed across the three strata with unequal probability weightings based on the responses received in the pre-survey. A stratification design was chosen to split the 2006-07 fishing season into two parts: the busy summer period (December–February), and the less frequented autumn winter period (March–August). This was subsequently modified during the 2007-08 fishing season so that the summer period included March. There was a greater intensity of survey effort during the summer periods in both 2006–07 and 2007–08 fishing seasons. We also differentiated weekends and public holidays for more intense survey effort than ordinary weekdays, and in summer on Reach 1, scheduled more early and late interview-sessions than mid-day sessions.

The Murray River between Yarrawonga weir and the South Australian border (Reaches 1, 4 and 5) is continuously navigable by small boat; many anglers fish from boats, so a boat-patrol was selected as the most appropriate method of sampling anglers in these reaches of the Murray River fishery. The Ovens River (Reach 3), Goulburn River (Reach 4) and the Loddon River (Reach 6) are each only partially-navigable by small boat; most anglers fish from the river banks. Public access is available to a high proportion of these smaller rivers via adjacent public land with vehicle access. The Ovens, Goulburn and Loddon Rivers were patrolled by 4x4 vehicle with anglers encountered along the way interviewed as they fished. The minority of anglers who fished from a boat in Reaches 3, 4 and 6 were interviewed either by hailing them from the bank, or by intercepting them after they had finished fishing.

For each individual sampling session, the starting location was allocated as a randomly selected map square from the set of all map squares in the VICROADS country street directory that contained the river-reach being surveyed (RACV 2000). The patrol direction (upstream or downstream) was also chosen at random.

Sampling the catch and effort of anglers occurred throughout three time periods: 06:00–11:00h (early), 11:00–16:00h (midday) and 16:00–21:00h (late). Creel clerks patrolled during these periods and asked questions relating to fishing activity. Questions relating to the anglers' history of fishing within each fishery were also asked.

Spatial registry of sampling effort: Searched-area method

Due to the large-scale (100s of kilometres) of the study reaches, the project staff could only sample a portion of the entire study reach during each interview session. This portion varied depending upon river conditions. An accurate system was developed to measure the portion searched which enable the fishing effort and catch rates to be estimated per unit area (Ha). The most-upstream and most-downstream locations of the reach that was searched for anglers during each interview session, and the locations of each angler interview, were recorded by the project staff on a hand-held global positioning system (GPS). After the fishing season had finished, the river-distance searched during each session was calculated using a geographic information system (ArcView, ESRI) from the measured distance along the river. An estimate of mean stream-width was made by randomly sampling observable width on aerial photographs (DPI/DSE Image Web Server). An estimate of river-area searched during each interview session was made by multiplying mean stream-width by river-distance searched. Similarly to a standard creel survey approach, the assumption behind these calculations is that the fishing effort and catch rate for that area searched is representative of the whole study reach at that time; our modification allows the searched-area to vary depending on conditions encountered on the day.

Angler Interviews

Survey and questionnaire was based on previous surveys (Douglas *et al.* 2002; Douglas and Hall 2004; Douglas 2005; Brown and Gason 2007; Stoessel 2008). The interviews collected information on catch and effort, demographics, previous catch history and fishing practices from all anglers encountered during or immediately after their fishing activity.

Anglers were asked about their catch and effort during the interview-shift:

- How long they had fished for, or to estimate how long they would be fishing, during the interview session?
- How many, and what species of fish they had caught, and how many and what species they had released after capture, and what was the reason for releasing these fish?
- What was their main method (i.e. bait or lure)?
- How many rods did they use?
- Did they mainly fish from the bank or a boat?
- How many set-lines had they used (question used during season 2006–07 only)?

Anglers were also asked about their avidity: "How frequently had they fished within this fishery?"

As a surrogate measure of angler avidity (i.e. expertise and eagerness to fish / affinity with the fishery) we used a self estimated experience measure. Each angler classified themselves according to a scale of frequency-of-use (i.e. occasional, regular, or active), where 'occasional' was an angler who fished less than once-per-month, 'regular' was one who fished at least once-per-month and 'active' was at least once-per-week).

To explain the demographics of anglers, the place of residence (i.e. post-code) of each angler was also requested.

To examine the relationship between anglers actively fishing and the population sample obtainable from recreational angling licence databases, anglers were also asked if they held, or were exempt from holding, a recreational fishing licence.

Anglers were also asked about their history of fishing for Murray cod in the present fishery (e.g. Murray, Goulburn, Ovens or Loddon Rivers depending upon place of interview):

- Had they fished previously during the present season?
- If so, could they recall the duration of their last trip, and how many Murray cod they caught during that trip? How many were kept (i.e. harvested).
- Each angler was then asked to recall how many other Murray cod in total (excluding those already discussed) they had captured so far this season, and how many trips they had made to fish there to that date.

For any anglers that reported catching a Murray cod during the interview session, a final series of questions was asked to gather detailed information about each individual capture:

- What was the measured length (self-reported) where this was available?
- Was it harvested or released?
- What bait or lure was used?
- What hook-size and type?
- How was the fish landed?
- What was the anatomical location of the hook-wound?
- Was the hook removed? If so, how?
- Were any injuries noted on the fish?

Statistical Analyses

Creel Calculation Methods for Catch and Effort Estimates

Catch and effort calculations were based on previous methods adapted to allow for the spatial component of the fishery (Brown and Gason 2007). The present study estimated catch rates per hectare of the portion of the study reach covered by the interviewers at each interview session. Calculations were all performed within a MSAccess database with five main queries:

- The first query collates all the effort, numbers of each species caught and released, and a catch and harvest rate for each species for each interview for the area searched during that interview session
- The second query calculates the sums and variance for catch and effort data for each interview session
- The third query groups these sums and variances with the relevant numbers of interview sessions and their weighting factors for all strata in the survey-design. Weighting factors are simply the number of possible occurrences of that stratum within the season (e.g. the number of weekday mornings during the summer part of the season)
- The fourth query expands the summed catch and effort data to estimate these for the whole season and reach surveyed using the number of sessions and weighting factors, and known reach dimensions
- The fifth query calculates the standard errors of each estimate based on the variances.

Hypothesis testing

Catch rate data contains many zeros and comparisons of catch-rates using ANOVA required that the data be transformed prior to analysis to meet the assumptions about the normality of the data. This was achieved with fourth root transformation.

Results

Survey Effort

Throughout the 2006–07 Murray cod season, 651 anglers were interviewed on Reaches 1, 2 and 3 (Table 10). Responses of interviewed anglers to questions about their fishing effort lead to estimated total effort for these fisheries of over 1.1 million hours. Effort for each study reach and effort density (h/Ha) are shown to enable comparisons.

During the 2007–08 Murray cod season, 807 anglers were interviewed on reach 4, 5 and 6 (Table 10). The corresponding estimate of total effort for these fisheries was over 787,400 hours.

Table 10: Summary of interview totals, reach dimensions and estimated angler effort (h) and density of effort (h/Ha) for each survey reach.

Study reach	Survey Location	Number of interviews	Reach length (km)	Average stream width (m)	Reach area (Ha)	Angler effort (h)	Angler effort density (h/Ha)
2006–07							
1	Murray River (Yarrawonga to Torrumbarry)	498	356	101	3596	494026	137
2	Goulburn River	73	244	50	1220	68 107	56
3	Ovens River	80	152	50	760	33 462	44
	subtotal	651				595 595	
2007–08							
4	Murray River (Torrumbarry to Tooleybuc)	163	226	72	1627	237 616	146
5	Murray River (Tooleybuc to SA)	541	612	134	8201	474 825	58
6	Loddon River	103	106	28	297	75 044	252
	subtotal	807				787 485	

Catch and Fishing Effort

During the designated interview sessions, anglers that were interviewed in 2006–07 caught six species of fish including:

- four native species
  - Murray cod (n=178)
  - trout cod (*Maccullochella macquariensis*) (n=49)
  - golden perch (*Macquaria ambigua*) (n=16)
  - silver perch (*Bidyanus bidyanus*) (n=73)
- two non-native species
  - redfin (*Perca fluviatilis*) (n=3)
  - common carp (*Cyprinus carpio*) (n=103).

In 2007–08, anglers that were interviewed caught five species of fish including:

- three native species,
  - Murray cod (n=222)
  - golden perch (n=205)
  - silver perch (n=253)
- two non-native species
  - redfin (n=4)
  - common carp (n=137).

Trout cod and silver perch are protected by legislation in Victoria and New South Wales, meaning that anglers are legally obliged to return all fish caught. Despite this, occasional harvest of silver perch (n=1 in 2006–07, and n=14 in 2007–08) was admitted by anglers being interviewed, allowing a first estimate of the illegal harvest of this protected species. No illegal take of trout cod was reported or observed.

Common carp are classed as 'noxious species' in Victoria and NSW; it is illegal to return captured fish alive to the water. Despite this, a few carp were returned reducing their potential harvest below 100% of the catch.

Overall, 70% of fish caught by interviewed anglers were released each year. Release rates for species were as follows for 2006–07 and 2007–08, respectively: Murray cod (89%, 90%), trout cod (100%, none caught[1]), golden perch (31%, 66%), silver perch (99%, 95%), redfin (33%, 25%) and common carp (12%, 0%).

The harvested or retained component of the catch by interviewed anglers in 2006-07 was: Murray cod (n=20), golden perch (n=11), silver perch (n=1), redfin (n=2) and common carp (n=91). Retained catch from interviewed anglers during 2007-08 was: Murray cod (n=23), golden perch (n=69), silver perch (n=14), redfin (n=3) and common carp (n=137).

Recorded fishing effort, numbers of all fish species caught and numbers retained during the interview sessions were expanded mathematically using the method described above to estimate total fish caught and retained by all anglers fishing the whole study reaches over each whole season. Estimates of total effort, and for each species the catch and retained-catch and their standard errors for season 2006–07and 2007–08 are given in Table 11 and Table 12.

Table 11: Estimates of total effort, catch and harvest (retained catch) and standard errors of the estimates by species, from the recreational fisheries along the study reaches of the Murray (Reach 1), Goulburn (Reach 2) and Ovens Rivers (Reach 3), 1 December 2006—31 August 2007. SE= standard error, ne=not estimable, empty cells indicate no fish were caught by interviewed anglers.

	Survey Location	Reach 1		Reach 2		Reach 3	
		Estimate	SE	Estimate	SE	Estimate	SE
Angler Effort (h)		494,026	5,490	68,107	866	33,462	1,175
Murray cod	Catch	35,100	2,185	3,959	255	1,174	197
	Harvest	3,181	1,359	238	85	0	0
Golden perch	Catch	2,058	351	1,221	ne	408	85
	Harvest	1,806	351	598	ne	120	42
Trout cod	Catch	12,935	802				
	Harvest	0	0				
Silver perch	Catch	15,690	1,545	5,405	711		
	Harvest	133	163	0	0		
Redfin	Catch	526				120	
	Harvest	526				0	
Common carp	Catch	17,764	2,618	385	ne	2,021	146
	Harvest	17,018	2,726	275	ne	562	62

[1] Areas surveyed in 2007–08 season were outside the known present-range of the trout cod

Table 12: Estimates of total effort, catch and harvest (retained catch) and standard errors of the estimates by species, from the recreational fisheries along the study reaches of the Murray (reach 4 & 5), Loddon Rivers (reach 6), 1 December 2007—31 August 2008. SE= standard error, ne=not estimable, empty cells indicate no fish were caught by interviewed anglers.

	Survey Location	Reach 4		Reach 5		Reach 6	
		Estimate	SE	Estimate	SE	Estimate	SE
Angler Effort (h)		237,616	39,454	474,825	4,917	75,044	2,503
Murray cod	Catch	19,654	2,170	38,132	2,596	551	409
	Harvest	796	478	1,897	997	418	408
Golden perch	Catch	9,518	387	34,009	4,002	788	92
	Harvest	796	478	12,871	2,445	589	92
Silver perch	Catch	32,231	3,997	36,659	2,525		
	Harvest	2,869	2,235	221	133		
Redfin	Catch			367	ne	169	ne
	Harvest			367	ne	36	ne
Common carp	Catch	4,879	548	28,913	1,427	8,213	3,993
	Harvest	4,879	548	28,913	1,427	8,213	3,993

Density of fishing-effort and catch

The spatial dimensions of each study reach were used to calculate an approximate area in hectares for the fisheries. The total estimates are divided by this area to produce overall mean estimates of the density of fishing-effort, catch and retained-catch per hectare (Table 13).

Each of the fisheries experienced different densities of fishing-effort, with the mid-Murray River (Reach 3 - Torrumbarry to Tooleybuc) and Loddon River (Reach 6) the most heavily fished at 146 h/Ha and 253 h/Ha, respectively. The most lightly fished reaches were the Ovens River (Reach 3) and Murray River (Reach 5 - Tooleybuc to SA) at 44 h/Ha and 58 h/Ha, respectively.

Coefficients of variation (CV) for fishing-effort estimates were generally less than 5% of the estimates, although CV for effort on Reach 4 was high at 17% of its estimated effort. CV for the catch estimates was higher but still generally low (4–11%), with the CV for catch on Reach 6 of 74% indicating high variability in the catches for this reach. Estimates of harvest were associated with much higher CV ranging from 36% to 98% of estimated harvest.

Angler Avidity

The null hypothesis tested was that 'Murray cod catch rate and harvest rate do not differ among avidity groups'. The number of anglers identifying their level of avidity for the fishery is shown in Table 14. Although the more experienced anglers (regular and active) had the highest catch and harvest rates for Murray cod (Figure 9), the variability in catch (and harvest) rates was high and there were no significant differences amongst any avidity groups. The null hypothesis was accepted for total catch-rate (ANOVA, F=2.39, p=0.09, df=2), and for harvest rate (ANOVA, F=1.35, p=0.26, df=2).

Angler Demographics

Anglers who supplied their home post-code (n=1438) were distributed across 306 post-code districts in five states (Table 15). Anglers from Victorian households represented 84% of respondents interviewed on the Murray River (Reaches 1, 4 & 5) and 93% on the Goulburn, Ovens and Loddon Rivers. South Australian residents were predominantly interviewed fishing the Murray (Reach 5) near the border with South Australia (n=87) during the 2007–08 season.

Table 13: Estimated density of effort, catch and harvest (retained catch) per hectare by species, for the recreational fisheries along the study reaches of the Murray (Reach 1), Goulburn and Ovens rivers (Reaches 2 & 3) during 1 December 2006–31 August 2007; and the Murray (Reaches 4 & 5) and Loddon (Reach 6) rivers during 1 December 2007–31 August 2008. Blank cells indicate these species were not caught by the anglers interviewed in the specified reach.

		Reach 1 Murray R.	Reach 2 Goulburn R.	Reach 3 Ovens R.	Reach 4 Murray R.	Reach 5 Murray R.	Reach 6 Loddon R.
Angler Effort (h/Ha)		137	56	44	146	58	253
Murray cod	catch/Ha	9.8	3.2	1.5	12.08	4.65	1.86
	harvest/Ha	0.9	0.2	0	0.49	0.23	1.41
Golden perch	catch/Ha	0.6	1.0	0.5	5.85	4.15	2.65
	harvest/Ha	0.5	0.5	0.2	0.49	1.57	1.98
Trout cod	catch/Ha	3.6		0			
	harvest/Ha	0		0			
Silver perch	catch/Ha	4.4	4.4		19.81	4.47	
	harvest/Ha	0	0		1.76	0.03	
Redfin	catch/Ha	0.1		0.16		0.04	0.57
	harvest/Ha	0.1		0		0.04	0.12
Common carp	catch/Ha	4.9	0.3	2.66	3.00	3.53	27.67
	harvest/Ha	4.73	0.23	1.64	3.00	3.53	27.67

Table 14: Number of anglers self-classifying their avidity for the fishery in which they were interviewed as 'occasional' (<1 x month), 'regular' (≥1 x month >1 x week) and 'active' (≤1 x week).

Survey reach	Occasional '<monthly'	Regular '≥ monthly'	Active '≤weekly'
Reach 1 - Murray River (Yarrawonga to Torrumbarry)	218	157	109
Reach 2 - Lower Goulburn River	35	24	13
Reach 3 - Lower Ovens River	56	18	5
Reach 4 - Murray River (Toolybuc to Torrumbarry)	75	38	50
Reach 5 - Murray River (SA to Toolybuc)	331	90	119
Reach 6 - Loddon River	41	28	34
Totals	756	355	330

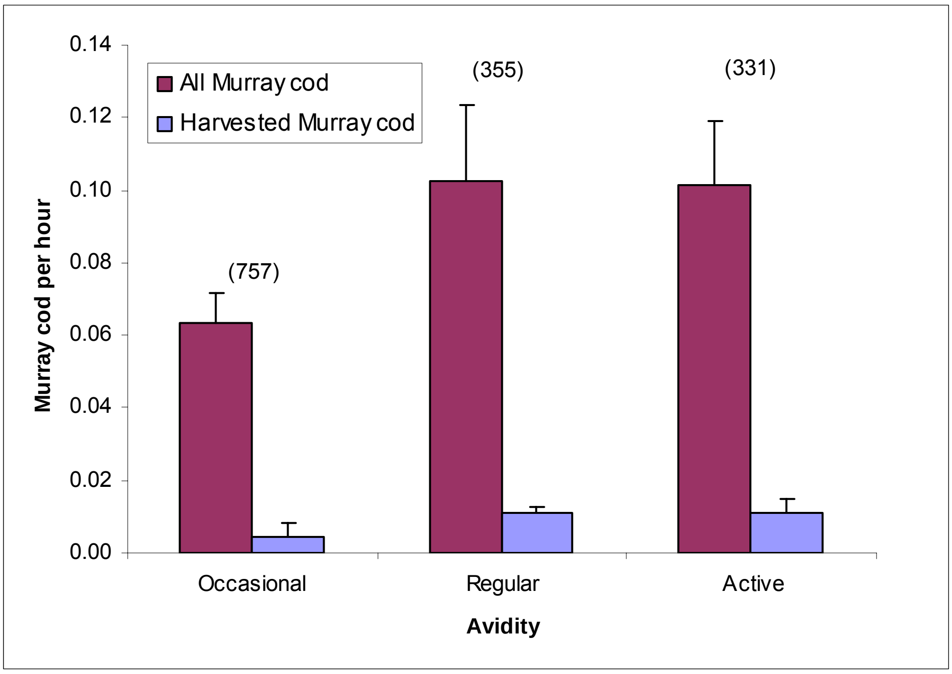

Figure 9: Mean (±SE) catch rates and harvest rates for Murray cod by anglers who self assessed their participation in the fishery as 'occasional' (less than once per month), 'regular' (at least once per month), or 'active' (at least once per week). No significant differences among groups. Sample sizes are in parentheses.

Table 15. Percentage distribution of the state of residence of anglers interviewed during creel surveys

Survey reach	VIC	NSW	SA	QLD	WA
Reach 1 - Murray River	89%	10%		1%	
Reach 2 - Lower Goulburn River	98%	2%			
Reach 3 - Lower Ovens River	82%	17%		1%	
Reach 4 - Murray River	96%	4%	<1%		
Reach 5 - Murray River	76%	7%	16%		1%
Reach 6 - Loddon River	97%	2%		1%	
Total	85%	8%	6%	1%	

Recreational Fishing Licence Ownership

Approximately 72% of all anglers interviewed responded that they had a recreational fishing licence (RFL) relevant for the water they were fishing (i.e. a NSW RFL for the Murray River, or a Victorian RFL for the Ovens, Goulburn or Loddon Rivers). The remainder claimed to belong to one of the exempt categories and did not require an RFL (Table 16). There was little variation in these proportion across the six reaches studied. The overall distribution across the four exempt categories is shown in Figure 10. Only 2 anglers interviewed said that they were not exempt but did not have a RFL. The proportion of anglers that had a RFL varied from 63% on the Ovens River to 78% on the Goulburn River. Murray cod catch rates of anglers exempt from requiring an RFL were significantly lower than those of anglers requiring an RFL (ANOVA, F=13.3, p=0.0003, df=1) (Figure 11).

Table 16: The percentage of angler interviewees that responded that they "did require", or "were exempt from the requirement of", a Recreational Fishing Licence for either NSW waters (Reaches 1, 4 & 5) or Victorian waters (Reaches 2, 3 and 6). (Six anglers did not respond to this question).

Recreational Fishing licence ownership	Combined Total	Reach 1 Murray R.	Reach 2 Goulburn R.	Reach 3 Ovens R.	Reach 4 Murray R.	Reach 5 Murray R.	Reach 6 Loddon R.
Yes	72% (1040)	74% (367)	78% (56)	63% (51)	70% (114)	71% (377)	69% (75)
No (exempt)	28% (410)	26% (128)	22% (16)	37% (30)	30% (48)	29% (155)	31% (33)
No (illegal)	0.4% (2)	0.4% (2)					

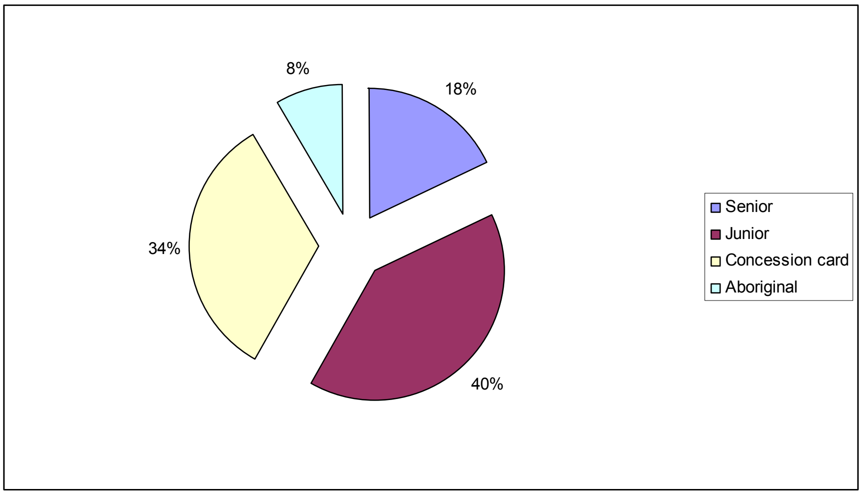

Figure 10: The proportional distribution of those that responded that they were exempt from requiring an RFL (n=410), by exemption category.

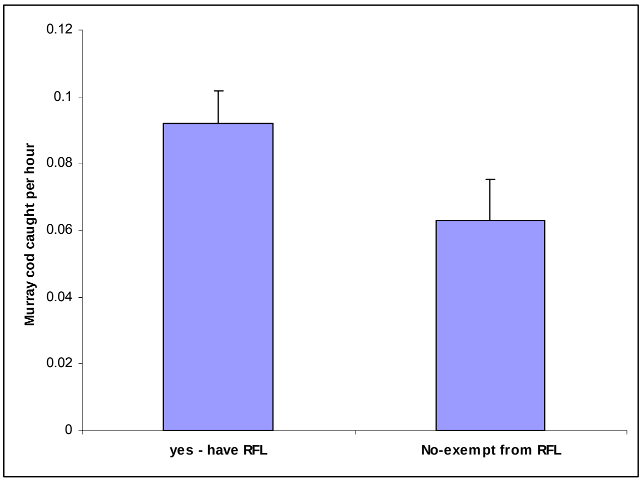

Figure 11: Average Murray cod catch rates (error bars = 1SE) for anglers who held an RFL compared to those who were exempt from holding an RFL. ANOVA shows significant difference (F=13.3, p=0.0003, df=1).

Angling Method Characteristics

Boat vs Bank

In the Murray River (Reaches 1, 4 & 5), most anglers (n=1168) that were interviewed identified a main fishing platform (i.e. boat or bank), the remainder (n=23) did not respond. Of those anglers who responded, 68% fished mainly from a boat compared to only 32% bank-fishing. On the Goulburn, Ovens and Loddon Rivers (Reaches 2, 3 & 6) the pattern was reversed, with 244 anglers identifying one main fishing platform; 36% fishing from a boat while 64% fished mainly from the bank. In both the Murray River (df=1, F=33.7, p<0.001) and the Victorian tributaries (df=1, F=6.5, p=0.01) catch rates for Murray cod were significantly higher for anglers who used a boat as their main fishing platform (Figure 12).

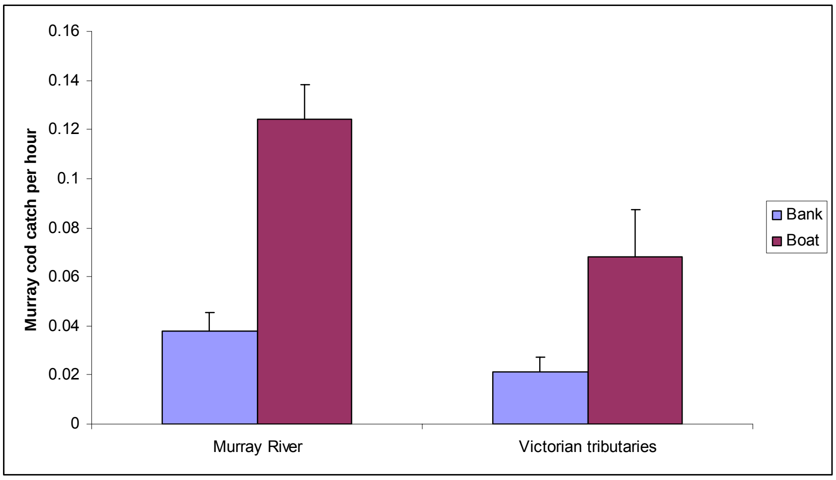

Figure 12: Average Murray cod catch rates (±SE) for anglers fishing mainly from a boat or from the bank. For the Murray River (Reaches 1, 4 & 5) (n=1168) and the Victorian tributaries (Reaches 2, 3 &6) (n=244) catch rates were higher for boat-fishing anglers (Murray River, F=33.7, p<0.001; Victorian tributaries, F=6.5, p=0.01).

Do more lines increase catch?

Set-lines vs rods

Limited analysis was possible on the use of set-lines as these 'unattended lines' are illegal in Victoria and were only a legal method in part (~60%) of the Murray River (Reach 1) studied in 2006–07. By 2007–08, set-lines were illegal throughout NSW. Of the anglers asked "if /how many setlines they had in the river", 19 out of the 500 who responded (<5%) acknowledged that they were fishing with set-lines. Eleven anglers had 4 set-lines each, the remainder claimed from 1 to 3 set-lines, giving a total of 57 set-lines. The use of set-lines made no statistical difference to anglers' catch rates for Murray cod. The average catch rate of Murray cod for anglers with up to 4 set-lines was 0.15 Murray cod per hour compared with the rate of 0.11 Murray cod per hour for anglers with no set-lines (Figure 13). Only seven Murray cod were reported caught on set-lines and measured (15–58 cm) so a comparative analysis of the size structure of the catch on set-lines vs. rods was not performed.

Multiple rods

Over both fishing seasons and all surveyed reaches, the responses from 1,438 anglers who were asked, 'how many rods are you fishing with?' indicated that 815 (57%) were using a single rod, 587 (41%) were using two rods, 36 (3%) were using from 3–5 rods. On the Victorian tributaries, (the Ovens, Goulburn and Loddon Rivers) the pattern was similar with 43%, 53%, and 4% using 1, 2 or 3–5 rods, respectively. The harvest rate (retained catch of Murray cod per hour) was significantly higher for anglers using two rods compared to those using a single rod (ANOVA, F=16.1, p<0.001, df=1) (Figure 14). The use of multiple rods did not make anglers any better at catching Murray cod overall. The Murray cod catch rate of anglers fishing with 1 to 5 rods was not significantly different (ANOVA, F=1.34, p=0.25, df=4), and there was no difference in Murray cod catch rate (released and retained catch) between anglers using a single or two rods (Figure 14).

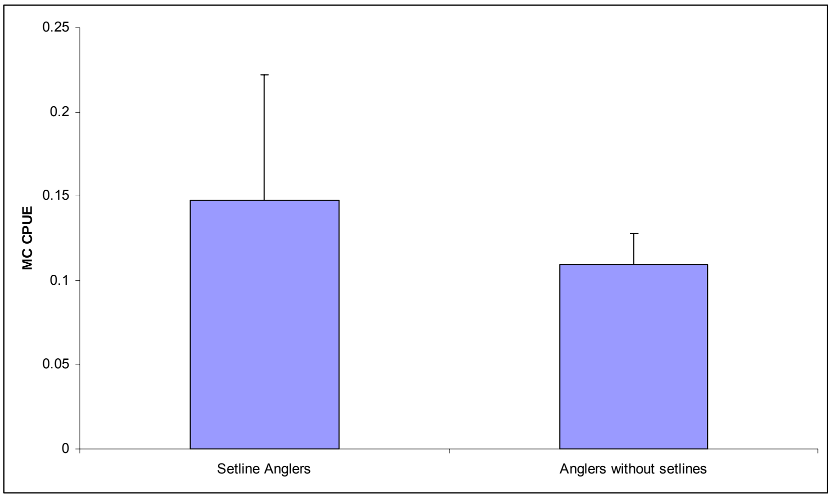

Figure 13: Average Murray cod catch rate (error bars= 1SE) of all anglers interviewed in Reach 1, in 2006–07, that used at least one setline (n=19; compared with those not using any setlines (n=474). Although CPUE was higher for setline anglers a two sample T-test assuming unequal variance shows that this difference was not significant.

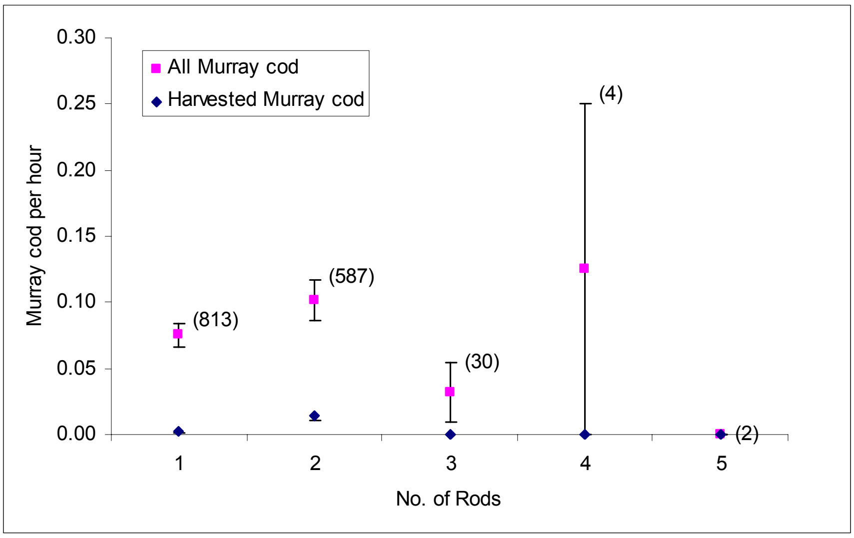

Figure 14: Mean catch rate (±SE) of all Murray cod (squares) and harvested Murray cod (diamonds) for anglers using from one to five rods. Harvest rate of anglers with two rods was significantly higher than those using one rod. Number of interviews in parentheses. No significant differences between catch rates for all Murray cod.

Baits and Lures

Most anglers interviewed identified either 'bait', 'lure' or 'bait and lure' as their main method (n=1455). In all study reaches, bait was consistently the most popular, with 52% to 97% of anglers choosing this as their main method. The overall proportions for all reaches pooled were 80% bait, 13% lure and 7% bait and lure fishing. The proportional distribution varied according to angler avidity. While bait was the most popular for all avidity classes, 27% of the more avid (active) anglers choosing lure fishing as their main method while 10% and 7% of less avid (regular) and (occasional) anglers chose lure fishing (Figure 15). Regular and occasional anglers showed similar preference for bait fishing (83%). Active anglers were also more specialised focussing on a single method, with fewer choosing the bait and lure option (4%) in comparison with 7% and 9% of regular and occasional anglers.

Baits accounted for 87% (n=288) of all Murray cod caught by interviewed anglers who specified the bait or lure used (Figure 16). The remainder (13%) were caught on lures, including hard-bodied lures (8%) and spinner baits (3%). Successful baits for Murray cod included artificial baits such as cheese (24%) and chicken (1%), and natural baits such as shrimp (*Macrobrachium australiense*) (18%), bardi grubs (*Abantiades marcidus*) (12%) yabbies (*Cherax destructor*) (8%), worms (8%), mussels (*Velesunio* spp.) (1%) and assorted cocktails or multiple-combinations of the above (5%).

The proportions of the catch retained or released were not distributed evenly across the main bait types; this seems likely to be due to the apparent size-selection of Murray cod caught on some baits and lures. Lures caught more larger fish and less smaller ones: Murray cod caught using cheese tended to be small (Figure 17). Two-percent of the Murray cod caught on cheese and shrimps, and 21% of the Murray cod caught on lures were larger than the present LML (60 cm TL).

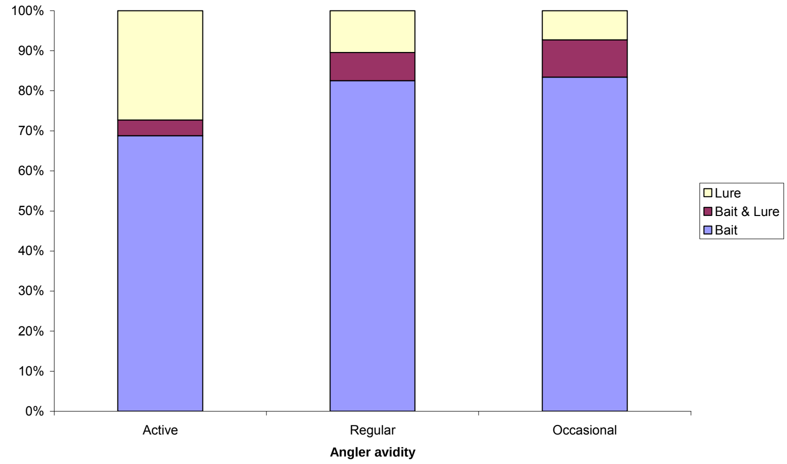

Figure 15: Proportional distribution (%) of main fishing method by angler avidity classification. Active anglers fish at least once per week, regular anglers fish at least once per month, occasional anglers fish less than once per month. N=1,455 anglers interviewed.

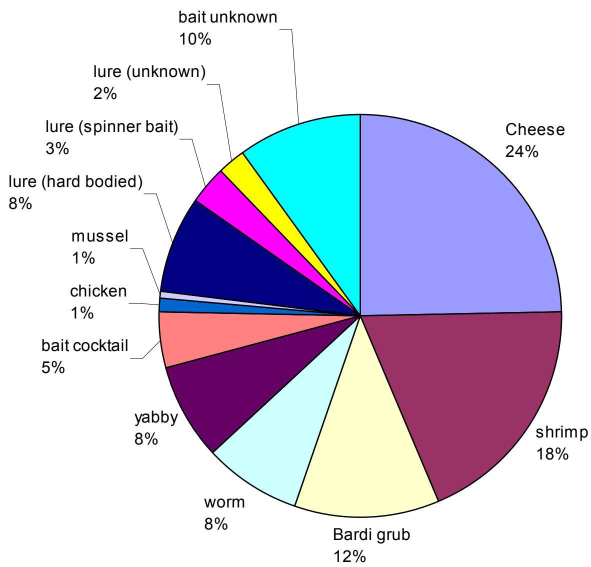

Figure 16: The percentage distribution of baits and lures that were used during successful Murray cod captures (n= 331).

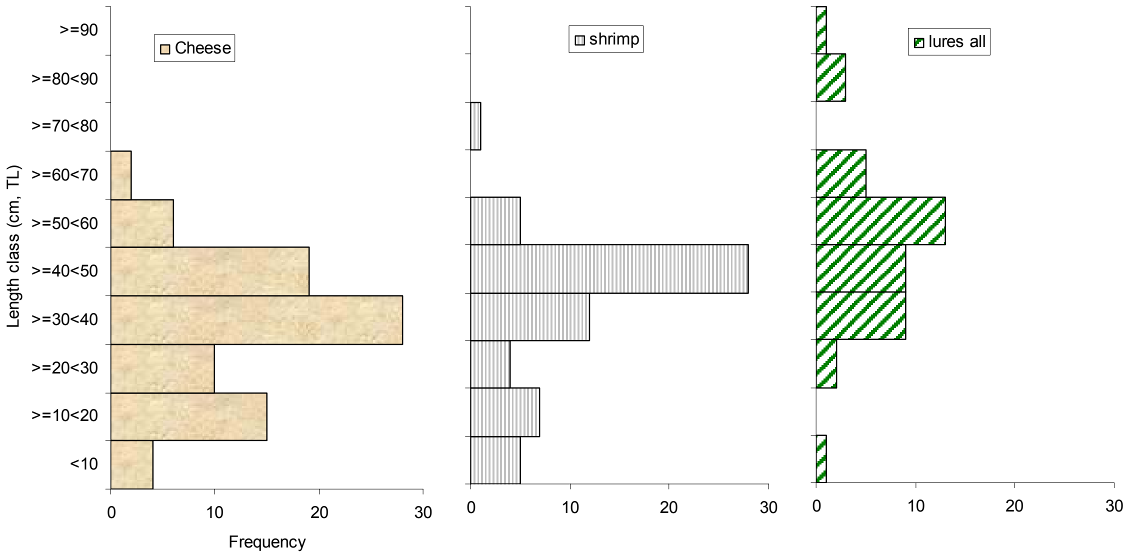

Figure 17: Length distributions of Murray cod (n=189) caught on the two most popular baits, and of all those caught on lures.

Use of Hooks

Hook size - Cod size

Anglers catching Murray cod were asked to identify the hook size (from a standard chart) and hook type used (single or multi hook). Lure fishers generally used multi-hooks (mainly trebles) but some single hooked lures were recorded (e.g. spinner baits). Multiple hooks accounted for 11% of the Murray cod caught.

Bait fishers used a variety of sizes of single hook from the small size-6 up to large size-7/0. Most Murray cod were caught on sizes 1/0 to 4/0 single hooks. Larger single hooks (5/0 to 7/0) caught proportionally more fish larger than a LML of 60 cm than smaller hooks (<=4/0), but the sample size for fish caught on larger hooks is small (n=9). Given the small number of large fish measured, and the scarcity of large hooks used, there was no strong relationship between size of hook and size of Murray cod caught (Table 17).

Table 17: Proportion of Murray cod caught on single-hooks and measured during the creel survey. n=sample size. Small hooks were up to 4/0 size; large hooks were size 5/0 or larger. LML =60 cm, total length.

	small hooks (n=274)	large hooks (n=9)
<LML	97%	89%
>LML	3%	11%

Hook size and hook-wound location

Anglers were asked to recall the hook-wound location (deep, shallow or external) for each Murray cod caught. The proportions of fish deep-hooked using multiple-hooks (i.e. lures) and single hooks (i.e. mainly bait) were similar at 24% and 29%, respectively. Overall, 77 (29%) Murray cod caught on single-hooks during the creel surveys were deep-hooked out of 270 (where a hook location and type was recorded), giving an overall probability of deep-hooking of 29%. The probability of deep-hooking varied with respect to hook-size and fish size. The proportion of deep-hook wounds is expressed as the probability of a fish being deep-hooked and is presented by hook-size and fish length in Figure 18. When small-sized hooks were used (size ≤1/0), the probability of deep-hooking Murray cod was low with small fish, but increased markedly with the size of the fish. Fish below the LML of 60 cm could have an almost even chance (p=0.5) of being deep-hooked. Using hooks size 5/0 and larger, the probability of deep-hooking fish remains low (p<0.15) independently of fish-size.

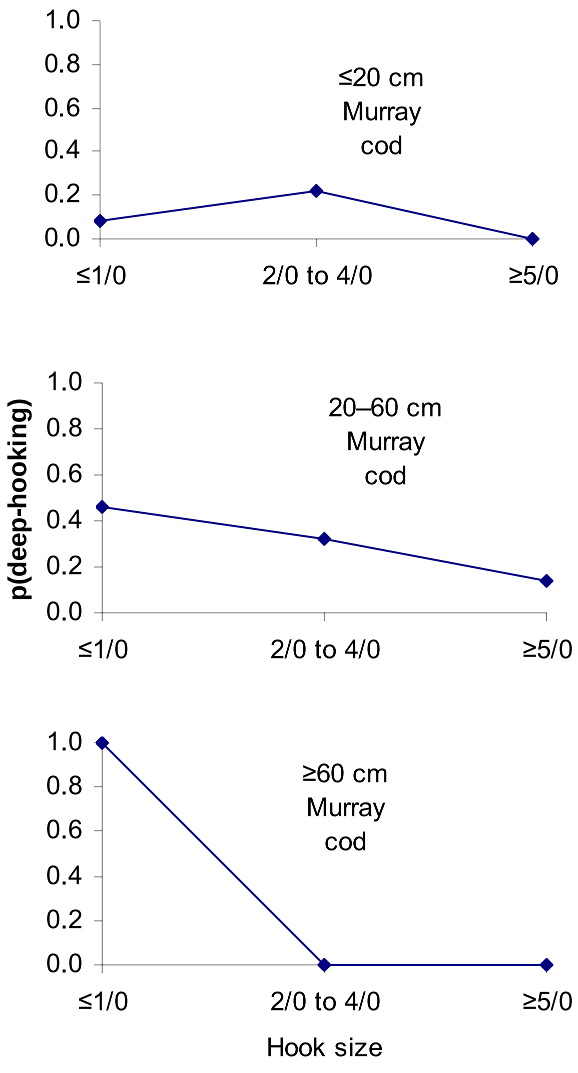

Figure 18: The probability of Murray cod being deep-hooked, for fish caught using single hook (n=269 fish of known length), with respect to three fish length-classes and three hook size-classes.

Landing and Handling

Anglers were asked to describe how they landed each Murray cod captured during the creel-interview sessions and how they unhooked the fish. They were also asked if any injuries were obvious on the fish (e.g. bleeding, eye damage). The method of landing (removing the fish from the water) was recorded for 359 captured Murray cod. Overall, 50% were landed 'by hand' although as the survey developed it became clear that this included those who had lifted the fish out of the water suspended by the line in addition to those who had used their hands to cradle and lift the fish out of the water. The next most common landing method was to use a net (38%). Only 5% were landed with a 'jaw gripper', a device which secures the fish by clamping over the jaw before the fish is lifted from the water. Few fish were beached (6%) although this was relatively more common with bank fishers for obvious reasons. The remainder, 1% were unhooked in the water.

The method of unhooking was provided for 359 Murray cod captures where the fish was subsequently released. Fish that were released were generally unhooked, either by hand (70%) or by using an 'instrument', generally pliers or forceps (23%). For the remainder (7%) the hook was left within the fish. Of the Murray cod that were deep-hooked (n=87), 34% were unhooked by hand, 38% unhooked by instrument, and 28% left retaining the hook.

Anglers reported no observed injuries (other than the hook wound itself) for 91% of all Murray cod caught and subsequently released (n=348). Injuries were reported for 3% of these fish, with anglers not recording an answer for a further 6% (they often said "I don't know, I didn't look"). Deep-hooked fish had no more injuries reported than the remainder.

Observed Murray cod size distribution in catch

Of the Murray cod caught and measured (n=309), 132 were captured where a 50 cm LML was legislated (during 2006–07 season, or during the 2007–08 season on the Loddon River); and 177 were captured where a 55 cm LML was legislated (during the 2007–08 season from the Murray) (Figure 19). Most Murray cod lengths recorded came from along the Murray River fishery where the majority of interviews were obtained (Figure 20). There is a notable variation in the size-structure of the catches from individual reaches. Catches from the lower Murray River reach (Reach 5) contained larger fish 70 to 92 cm in length than those present in catches from reach 1 and 4. Across both fishing seasons, 77% of Murray cod measured by anglers were smaller than an applicable 50 cm LML; 93% were smaller than an applicable 55 cm LML. The total release-rate is generally high (Table 18); this is due to the majority of fish caught being smaller than the LML.

Total and voluntary release rates are highly variable across the range of fisheries studied. For data pooled across all fisheries, under a 50 cm LML, the voluntary release rate (i.e. the proportion of legally-harvestable fish released by anglers voluntarily) was 30% whereas during 2007–08 under a 55 cm LML, the voluntary release-rate was 25%.

Given the variable LML legislated across the duration and geographic extent of this study, a meaningful examination of trends in catches of Murray cod larger than LML is difficult. To allow a consistent comparisons of a LML 'indicator' for future evaluation, the total percentage caught in each study reach larger than 60 cm is included in Table 18. Sixty centimetres is the new LML for Victoria and NSW in 2009, making these states consistent with Queensland legislation. This indicator was highest in the Loddon River (16.7%) and lowest in the Ovens and Goulburn Rivers (0.0%).

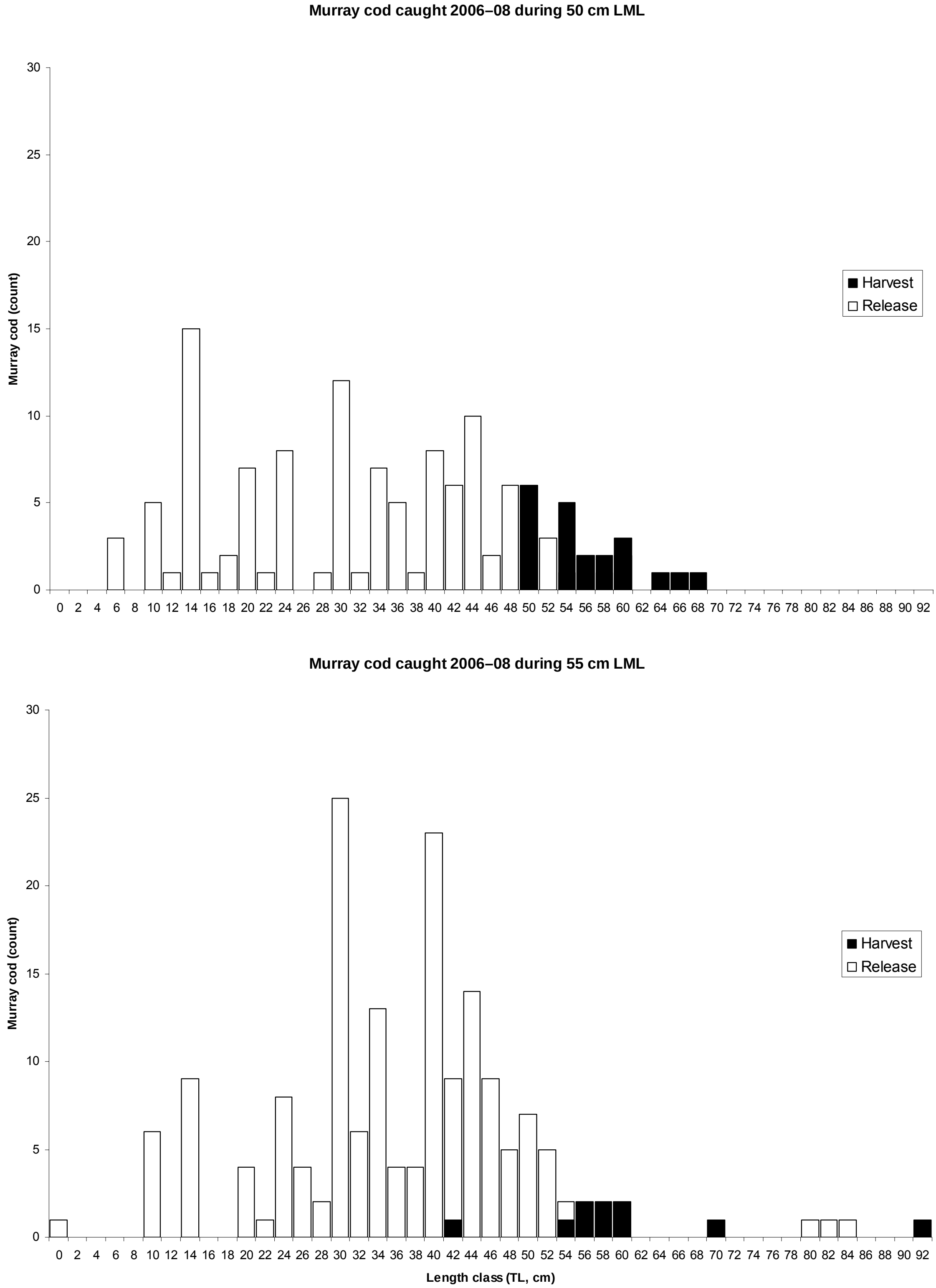

Figure 19: Frequency counts of lengths of Murray cod measured by anglers that were interviewed on the Murray River and Victorian tributaries 2006–08 under a 50 cm LML (n=132) (upper panel) and a 55 cm LML (n=177) (lower panel). Fish that were harvested (solid bars) and released (open bars) are shown separately.

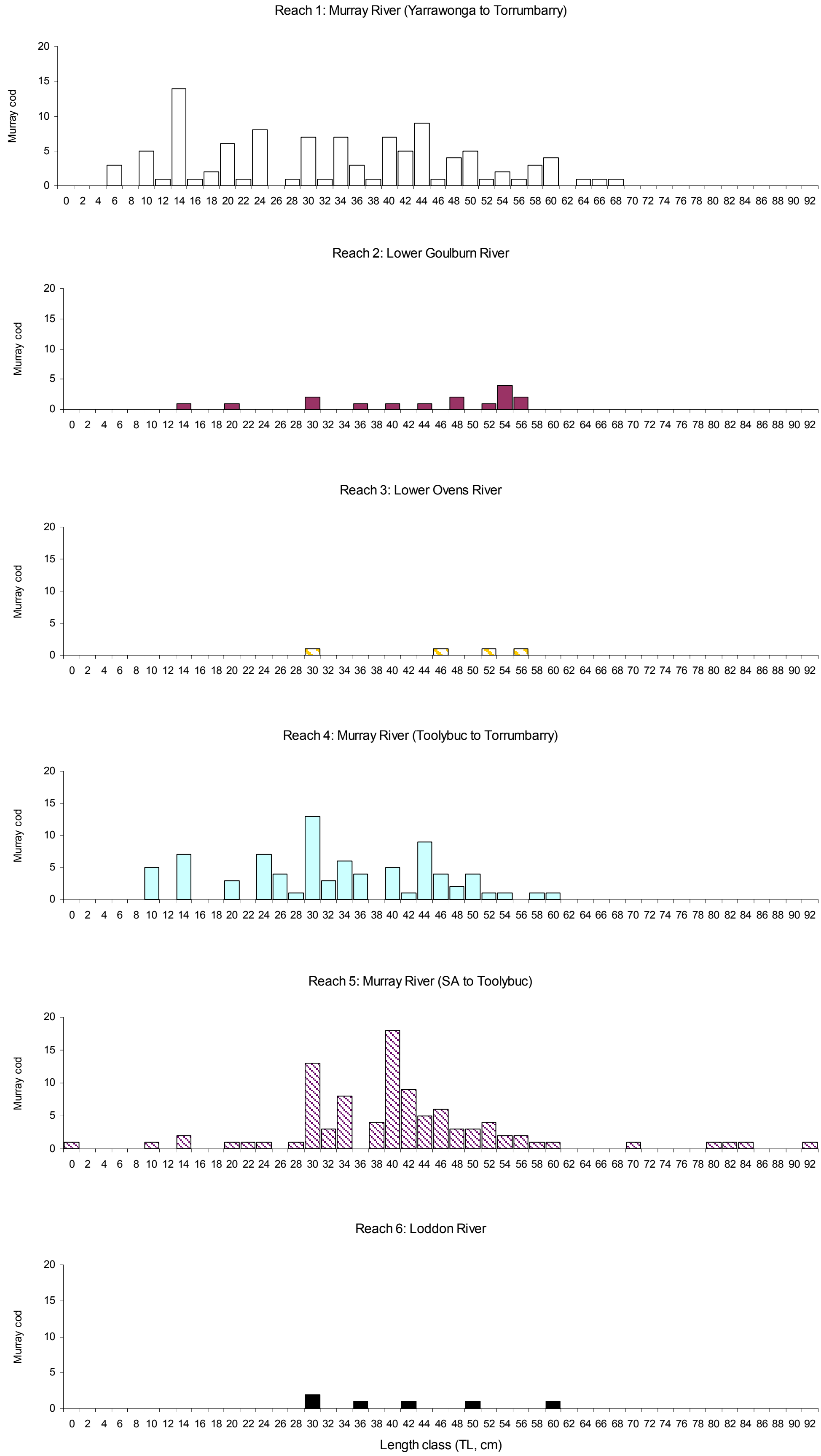

Figure 20: Frequency count of lengths of Murray cod measured by anglers 2006–08 in six study reaches.

Table 18: Catch and release statistics for the individual study reaches under the two legal minimum lengths (LML) that were legislated during the study. During 2006–07, a 50 cm LML applied in all waters. In NSW waters this was raised to 55 cm in 2007-08. Total release rate is the percentage of the total catch that was released by anglers. Voluntary release rate is the percentage of Murray cod ≥ the LML that were released by anglers. As of March 2009, Vic, NSW and Qld now all have a 60 cm LML and the percentage of Murray cod caught ≥ 60cm is included as a 'benchmark' to assess future changes in size-distribution.

Study reach	LML applied (cm)	Total release rate (%)	Voluntary release rate (%)	Total caught >60cm (%)
Lower Goulburn River	50	63	14	0.0
Lower Ovens River	50	100	na[2]	na
Loddon River	50	67	0	16.7
Murray River (Yarrawonga to Torrumbarry)	50	88	32	6.6
Murray River (Toolybuc to Torrumbarry)	55	95	0	1.2
Murray River (SA to Toolybuc)	55	91	30	6.3

Recalled catch rate: Comparison of 'last trip' with present data collected at interview

Anglers that had fished in the fishery prior to the present interview were asked to recall their last trip to that fishery. The timing of the last trip varied from 'earlier that day' (i.e. before the interview shift started) to possibly 'months ago.' Anglers were asked to estimate how many hours they fished, how many Murray cod they captured, and how many they harvested. Catch rates and harvest rates (Murray cod per hour) were calculated for each response and compared to those given for the present trip during interview.

The correlation between catch rates on the previous trip with present catch rates was statistically significant (n=747, c=0.22) with a significant linear regression of $CPUE_{(present\ trip)}$ on $CPUE_{(last\ trip)}$ (F=6.5, d.f.=1, p=0.01), suggesting that the general trend was for angler catch rates to be consistent. The previous trip recalled data had lower frequency of zero catch-rates and higher frequency of non-zero catch rates than the present trip data (Figure 21). This recall bias inflated the reported average catch rate by over 400% and the harvest rate by over 150% for recalled previous trips (Figure 22).

[2] 1 fish >LML caught and released, sample size too small

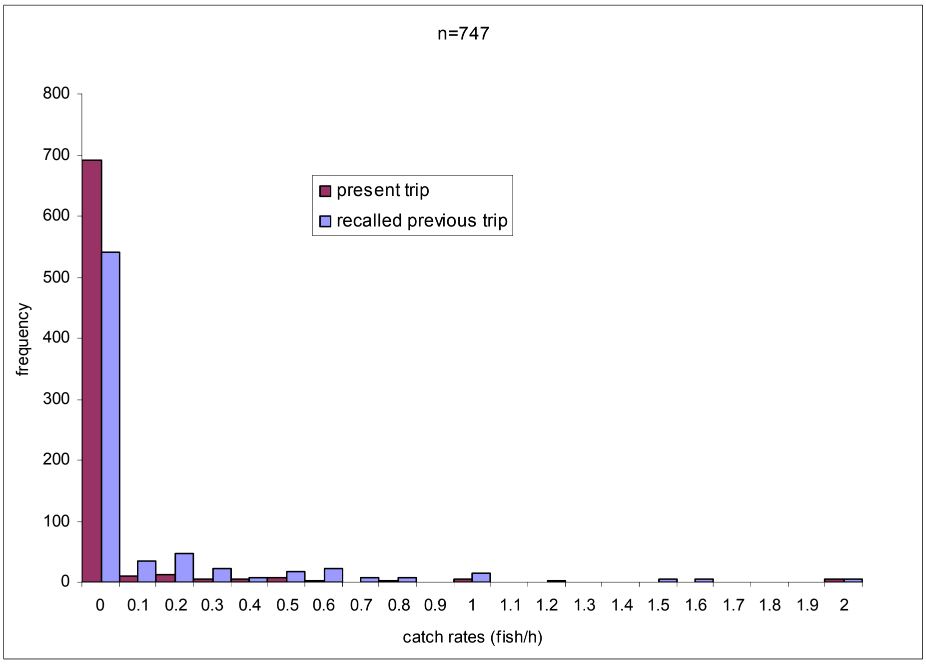

Figure 21: Frequency distribution of Murray cod catch rates (fish/h) for recalled previous trip and present trip. NB recalled previous trip catch rates data is truncated at 2.0 for comparative-clarity, maximum values included 4.1 fish/h.

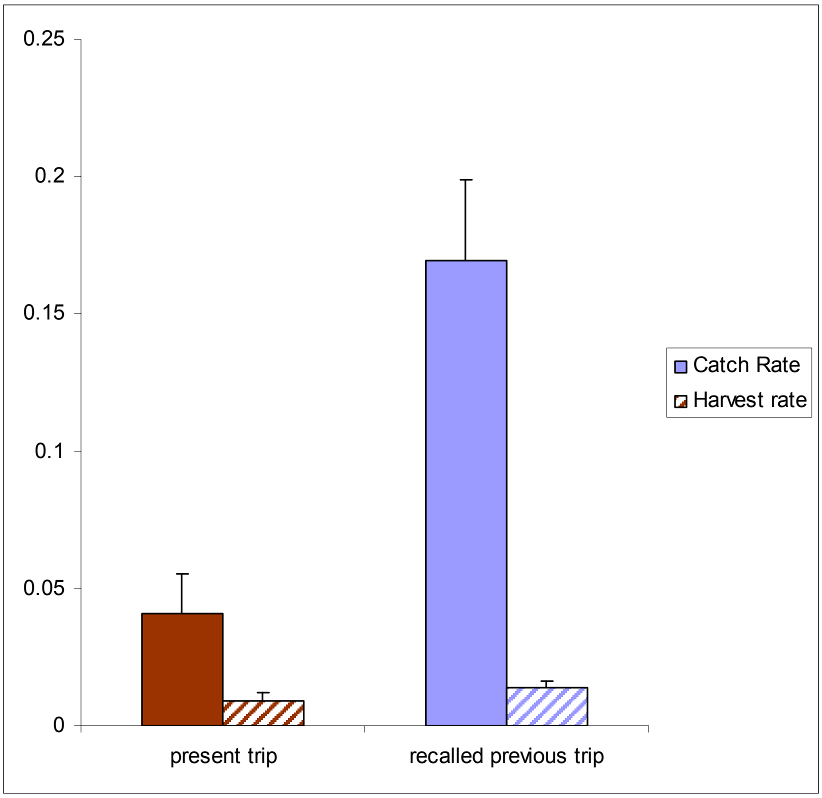

Figure 22: Comparison of Murray cod average catch rates and harvest rates (fish/h) collected during face-to-face interview for present trip, and their recalled previous trip for a random sample of 747 anglers fishing in the River Murray, and Goulburn, Ovens and Loddon Rivers.

Discussion

Angler harvest

The present study completes two years of angler surveys in Murray cod fisheries that are important for Victorian recreational fishers. It provides estimates of the total quantity of fishing effort, and catch that are attributable to reach-specific areas on the Murray River, Goulburn River, Ovens River and Loddon River (Tables 11, 12 and 13). These are the first catch data for these fisheries since they were included within the national diary-assisted phone survey conducted in 2000 about the fishing events of the 1998 and 1999 Murray cod seasons (Henry and Lyle 2003; Park *et al.* 2004).

In addition to total fishery statistics on catch and retained-catch (i.e. harvest), the present study shows that in a 9-month open season, a hypothetical 'representative hectare' of river yields from 2 to 12 Murray cod as a recreational catch, with less than two (0–1.4) Murray cod retained. Presenting such catch data on a 'per-area' basis facilitates comparison with population-density estimates that can be made in measured areas using typical fisheries-science methods such as mark-and-recapture experiments, and depletion methods. Through such comparisons of recreational catch and population density it is possible to address questions of fishery sustainability, particularly when such figures are used in predictive mathematical models of the population and its fishery (see Chapters 6 and 7, this study).

The statistically random sampling in both time and space used in this research means that the resulting estimates of catch and effort are representative of the whole fishery on these river reaches during the period of study. The sampling design also ensured that the comprehensive dataset of observations of angler-behaviour reflected an unbiased analysis of how the fishery is conducted.

The Murray Darling Basin Commission's Native Fish Strategy has a target to rebuild native fish stocks (including Murray cod) from 10% (in 2003) to 60% of pre-settlement abundance over 50 years (MDBC 2004b). As such, the present estimates of catch for Murray cod and a range of other species, together with fishing-effort in the fishery, will form a useful fishery-dependant benchmark for assessment of the future level of recovery.

Some Methodological Considerations – Constraints and Limitations

Precision: Repeatability for future comparisons

The coefficient of variation (CV) is an accepted statistical standard method for measuring the *precision*, or repeatability of an estimate (Pollock *et al.* 1994). In the present study, CV for fishing effort and catch are low, indicating relatively precise estimates have been obtained. The precision of effort and catch estimates in the present study are comparable with those in NRIFS (Henry and Lyle 2003). The National survey reported less precision in some of its harvest estimates (28% for Vic, and 59% for SA) (Henry and Lyle 2003), and that pattern is also repeated here in this study.

The target for precision (10-30%) was far exceeded in most cases for effort and catch estimates in most fisheries, although precision of harvest estimates was poor probably due to the relatively low harvest rates estimated for most fisheries.

Accuracy of Estimates: Range checking with existing data

Many creel surveys in other Victorian fisheries have estimated the total effort within a fishery in angler-hours or an equivalent unit (Douglas and Hall 2004; Brown and Gason 2007). Few if any, published studies have used an equivalent of the 'searched-area' method described in the present study. With a basic sharing of the estimated effort across the water-area of other fisheries it is possible to look comparably at the annual effort estimates available for a range of large Australian recreational fisheries tabulated in Bucher (2006) (Table 19). The present study's estimates of the density of fishing effort (44–253 angler-hours/Ha) are comparable with those of large to moderate sized east-coast estuaries.

If we assume that annual effort varies little during the first and second years of the present study, then we can combine our estimates spanning two separate years in none-overlapping locations and conclude that, together, our six survey-reaches are equivalent to the annual effort for the same geographic area. The combined total effort in the present study was 1.9

Table 19: A comparison of effort, area, effort per hectare for a range of Australian east-coast estuarine, multi-species, recreational fisheries tabulated after Bucher (2006).

Estuary	Water Area (Ha)	Annual Effort (angler-hours)	Effort density Angler-hours/hectare	Source
Lake Macquarie	125500	970480	77	Steffe and Chapman (2003)
Clarence River	8924	709395	80	Steffe et al. (1996)
Port Jackson	4967	836950	169	Henry (1984)
Manning River	2335	144892	62	Bucher (2006)
Richmond River	1907	390240	205	Steffe et al. (1996)
Tweed River	1792	557413	311	Steffe et al. (1996)
Brunswick River	222	127200	573	Steffe et al. (1996)
Wooli River	190	60963	321	Steffe et al. (1996)
Sandon River	141	16602	118	Steffe et al. (1996)
Mooball Creek	40	28538	713	Steffe et al. (1996)

million angler-hours. This seems broadly consistent with the NRIFS in 2000–01 (Henry and Lyle 2003), that provided estimates of the fishing effort from 12 months spanning the 1998 and 1999 Murray cod fishing season by state. For Victoria and NSW, respectively, 2.3 million hours and 3.8 million hours of line fishing (all species) was estimated for 'rivers' (6.1 million hours for both states). Our present estimate is equivalent to slightly less than a third of all the fishing effort expended in 'rivers' in NSW and Victoria during the NRIFS (Henry and Lyle 2003). It should be noted that the NRIFS estimate included areas outside the range of Murray cod.

Catch and harvest estimates from the present study from a small proportion of the MDB are broadly comparable with the MDB estimates overall (Henry and Lyle 2003; Park *et al.* 2004). Total catch estimates for Murray cod in 2006–08 from the present study of around 54% of the length of the Murray fishery (1,074 km out of 1,986 km of River Murray up to Yarrawonga) plus 502 km of three Victorian tributaries, are equivalent of around 22% of that estimated for the whole MDB in 1998–99. For the retained component of the catch, total harvest estimates in the present study are only equivalent to approximately 8% of the harvest estimated for the MDB in 1998–99. As a proportion of the total catch, the present estimate of harvest was much smaller (just over three times) what it was estimated to be in 1998–99 (Park *et al.* 2004). This could be due to the total release rates in the present study being generally higher than previously observed. The present day 'climate' of higher LMLs may have contributed to this, making it harder for anglers to catch a legally-harvestable fish. The lack of data on length structure of the catch in 1998–99 makes further analysis of this a moot point, and highlights the importance of collecting data on catch length-structure into the future.

Surveying a widespread fishery with diffuse access

The innovative use of hand-held GPS (global positioning system) to track survey-effort enabled replicate spatial sub-sampling of angling activity on large study-reaches (100s kms). Previous on-site, roving creel surveys have required the 'whole area of interest' to be patrolled to develop 'daily' estimates of average catch and effort for the fishery, as described by Robson (1991). The 'standard' assumption is that the average catch and effort at those times surveyed is representative of all the similar times in the season and is weighted-up accordingly. The present study modifies these calculations such that average catch and effort are calculated for a variable spatial-sample of the fishery, as well as a temporal one.

The extra assumption here is that average catch and effort in our spatial-sample is representative of the rest of the study-reach at that time, and this is again weighted-up accordingly. Both of these assumptions can be tested by examining the temporal and spatial variation in catch-rates from interviews; however, this analysis is yet to be completed.

The 'big dry'
For large parts of southern and eastern Australia, dry conditions have now persisted since October 1996. For some areas, the accumulated total rainfall deficit over this period now exceeds a full year's normal rain. For the MDB, the present study took place in the sixth year of lower than average rainfall totals (Australian Bureau of Meteorology, Special Statement No. 14. Issued 1 November 2007 by the National Climate Centre).

The Ovens River is an unregulated stream. The catchment has no water-storage capacity and the summer of 2006–07 saw several months with zero-flows downstream of Everton and Wangaratta. This extreme dry period for the MDB was also accompanied by high temperatures, causing higher evaporation rates that exacerbated the low rainfall. The present study should not be considered as representative of a typical year for the Ovens River. Rather, it is an example of the recreational fishery that occurred during an extreme period of drought-stress on the river and its natural resources.

Angler Recall Bias
All of the data collected at interview were of recalled-events. The catch data recalled for a short period of up to five hours during the interview (the maximum length of an interview session), are regarded in the present study as un-biased and as *real-time* data on catch and effort.

If anglers recalled perfectly the number of fish and the time-spent-fishing, the frequency distribution of recalled-catch rates should be no different to the distribution of catch-rates at interview. The data showed that anglers tended to under-report zero catch rates, and over-report non-zero catch rates such that the overall recalled catch-rate was vastly inflated compared to the rate estimated for the interview session. Whether this is deliberate or simply indicative of failing memory is immaterial.

Based on angler avidity data reported, it would seem that the skill and experience varies widely among the anglers in these fisheries as it does in many others (Douglas 2005; Brown and Gason 2007). Catch rates of anglers during the interview session were correlated with catch rates during their last recalled trip. That is, anglers with high catch rates during interview tended to also have high catch rates on previously recalled trips; conversely those with low catch rates 'now' tended to have low catch rates 'last time'. So the assumption that angler's skill-levels in the fishery remain stable on a timescale relevant to their recollections seems valid.

Recalled catch rates are an unreliable indicator of actual catch rate even for Murray cod which may be considered a 'high-value, memorable' species. Other studies have shown that bias in recalling participation levels (i.e. effort) is common, and frequently varies with avidity of the anglers, with more avid anglers overestimating their participation in the fishery (Connelly and Brown 1995). This is of concern for the designers of any off-site angler surveys designed to estimate catch, effort or catch-rate. Previous research has used comparisons of diary vs. mail-back surveys to show that duration of recall is correlated with overestimation of effort (Tarrant *et al.* 1993; Connelly and Brown 1995). Few have evaluated recall bias using real-time data and previous-trip data from on-site surveys. Anglers' exaggeration of catch rates is a well-known phenomenon both anecdotally and in research publications (Sullivan 2003). The present study shows that for Murray cod fisheries, unless catch and effort is recorded by anglers during, or immediately after fishing activity, recalled catch rates will be overestimated. The use of diaries to assist accuracy of recall is probably beneficial, but unless the diaries are completed during fishing trips, they are likely to lead to biased over-estimates of catch rate, catch or underestimates of effort.

The present study did not record the duration of the recall period for each interview, but such data would be useful to determine the period over which anglers recollections of catch and effort can be used and with what level of bias. Further comparisons of self-reported catch rate from interviews, with actual-catch rates of trusted 'research anglers' may also be warranted to assess the minimum level of bias attainable at interview in the fishery.

Released Murray Cod: some considerations and implications

The contemporary angling literature is full of articles by anglers promoting (mainly) lure fishing and more often than not, advocating the voluntary release of Murray cod (Ainsworth 2008; Mackenzie 2008; Clark 2009). Fishing tournaments across the MDB are almost exclusively run as 'live-release' events[3]. An observer would perhaps assume that catch-and-release plays a big role in the effects of fishing on Murray cod stocks. Our data shows that while a large proportion of the catch is released, the majority are released because they are smaller than the LML. Amongst those larger fish that are legally harvestable, the voluntary release rate is still modest (<32%). It is perhaps important to note from this that the ethical choice of anglers to release fish (i.e. voluntary release) is only having a modest effect in reducing fishing mortality. Trends in other fisheries, e.g. largemouth bass in the USA (Allen *et al.* 2008), suggest that voluntary release rate may increase through changing socio-ethical behaviours and reducing pressures to provide food through recreational fishing. Increases in voluntary release rate have the capacity to reduce overall mortality rate, but also reduce the power of length-based limits to achieve increased sustainability (Allen *et al.* 2008). While increased ethical behaviour of anglers towards voluntary release is likely to reduce overall fishing mortality, such increases may be balanced by legislating for increased LML which exposes a smaller proportion of the size-structure in the population to the choice of release or harvest. This balance may, in turn, be influenced by increases to LML that allow more Murray cod in the population to grow to a size when the ethical choice must be made. The complexity of the processes and possible outcomes of just two of the parameters involved in Murray cod population biology and management (e.g. release rate and LML) is an illustration of why well constructed population models are invaluable to evaluate possible management decisions (Allen *et al.* 2009).

The Murray cod population models presently available (Todd *et al.* 2005; Allen *et al.* 2009) (also see Chapter 6 and 7, this study) are simulation models based on our biological understanding of the species. These models are 'tuned' to reflect limited observations about length frequency in the population (Todd *et al.* 2005; Allen *et al.* 2009) and recreational catch and harvest (Allen *et al.* 2009). Quantitative observations of catch and harvest are important to provide checks on the suitability of model simulations. Our understanding of Murray cod biology and ecology is conceptually advanced (Lintermans and Phillips 2005; Rowland 2005), yet the present understanding of the quantitative relationships between recruitment of Murray cod and environmental factors (for example flows and habitat complexity) is rudimentary and insufficient to build accurate predictive models of Murray cod abundance. Repeating observations of catch and effort like those in the present study, will eventually enable the fitting of more traditional predictive models of population abundance with which to recommend and evaluate management decisions. Some things are difficult, like determining the nature of the environmental drivers for Murray cod production, and estimating how many Murray cod are in a population. Some things are easier, like estimating the amount of effort in the fishery and the level and nature of the catch and harvest. The former are useful to know but harder to manage; the latter are also useful, perhaps easier to achieve and more directly amenable to control by fisheries management policy.

Murray cod were the most abundant species caught in all three study reaches. The Murray cod fisheries predominantly comprise immature fish that are smaller than the relevant LML (50, 55 or 60 cm). Across all fisheries surveyed, around 60–100% of the observed Murray cod catch was returned. Measurement of the survival rate of these released fish has begun (Hall *et al.* 2008; Douglas *et al.* 2010), and this work is likely to play a significant role in determining the level of sustainability of the present fishery.

The high observed release rate (c.f. harvest rate) suggests that post-release survival rate may be important to overall mortality rate, and that the mandatory release of fish smaller than the LML may contribute the most to this component of mortality. Post-release survival of large

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[3] E.g. See http://www.codclassic.com.au/html/other_competitions.html, lists: "2008 Engel X-Mass Fish-A-Rama, 2009 Golden $$, 2009 Lowrance Da$h 4 Ca$h, 2009 His & Hers Partners Classic" as live release tournaments

numbers of small, immature fish has long been recognised as highly valuable to the sustainability of fish populations (Waters and Huntsman 1986; Allen *et al.* 2008). A similar high release rate (77%) was observed for Murray cod from the whole MDB during the 1998 and part of the 1999 fishing seasons (Henry and Lyle 2003; Park *et al.* 2004) although that survey gave no indication of the reasons for release.

Understanding factors influencing post-release survival is important in fisheries with high release rates. These factors can include bait type (artificial vs. natural), hook-type (number, size and style), hook-wound location and fish size and fish handling behaviour (Muoneke and Childress 1994; Infofish 2007).

Most Murray cod were shallow-hooked within the mouth, or outside the mouth. This may be due to the tendency for hooks to be set during the 'smash-and-grab' nature of the bite. While Murray cod biting gently are encountered, a violent bite and immediate hook-set is the norm. Most of the literature on post-released survival of angler-caught fish suggests that hook placement is a key factor influencing survival (Muoneke and Childress 1994). Survival is generally good for shallow hooked individuals in many fish species (Muoneke and Childress 1994). Experimentally determined survival rates for both shallow and deep-hooked fish (Douglas *et al.* 2010) could be applied within Murray cod population models by using the finding that 71% and 29% of fish caught in the fishery are shallow-hooked and deep-hooked, respectively.

Bait used on single hooks is by far the most popular and successful method used in the recreational Murray cod fishery along the Murray River and its Victorian tributaries. Baits such as cheese and shrimp are popular and yet they tend to select relatively small Murray cod compared to lures. Most lures used were ~6–15 cm in size (reconstructed from the hook-sizes recorded). This is consistent with the diet study of Ebner (2006) who showed that in the gut contents of large Murray cod (i.e. >50 cm, and sampled by anglers), fish and decapod-crustaceans up to 15 cm long were the norm.

The use of small to medium sized hooks is popular, yet in this fishery they increase the risk of deep-hooking for many Murray cod caught. The reason for the popularity of small hooks is unknown. Anglers may choose to fish with small hooks because:

- There is a need to match hook-size to a preferred small bait size (e.g. live shrimp, *Macrobrachium* sp.)
- They are targeting other species (e.g. golden perch) or have a perception that smaller hooks increase the likelihood of a by-catch of other species while also allowing Murray cod to be 'targeted'
- The relative abundance of small Murray cod is known and anglers wish to catch them, even though they must release them.

It may be useful to consider the question: Do large hooks limit the by-catch of small fish? While we observed a slightly greater proportion of fish >LML caught on large hooks, so few anglers chose to fish with large single hooks that there was little confidence in the data to support the idea that big hooks select big fish. Murray cod have mouths with a large gape relative to their body size; a 60 cm Murray cod has a gape of ~8 cm (Ebner 2006), easily accommodating hooks of size 10/0 and larger. Yet the most popular hook sizes in the fishery were small (<5/0). In other fisheries, small hooks have been shown to be effective and less damaging in species such as carp (Rapp *et al.* 2008), and tropical reef fish (Mapleston *et al.* 2008). The diet of Murray cod >50 cm is mainly large fish and crustaceans (Ebner 2006). Given these dietary preferences, selection of bait by size should be expected for Murray cod; larger baits should lead to capture of fewer Murray cod that are smaller than the LML. Large baits would generally require large hooks and there could be a trade-off between large hooks minimising deep-hooking, and small hooks causing reduced damage. Experimental evaluation of this trade-off may be warranted before one or the other is advocated.

Uptake of 'best practice' for released-fish survival

The National Strategy for the Survival of Released Line Caught Fish[4] is an initiative of the Fisheries Research and Development Corporation in conjunction with the Australian National Sportfishing Association and Recfish Australia. The strategy aims to increase the survival rates of released line caught fish and improve anglers' understanding of the benefits of doing so. The National Strategy promotes best practice for releasing fish. Strategies include:

- minimising hook damage by using circle hooks
- using a larger hook size than normal to reduce the chances of gut hooking and catching undersized fish
- using fish friendly equipment such as long-nosed pliers to remove hooks from shallow-hooked fish
- cutting the line outside the mouth for deep-hooked fish
- using knotless landing nets and fish-grips to land fish.

Compliance of anglers with the current best practice for handling and release of fish is low in the Murray cod fishery along the Murray River and its Victorian tributaries. Just over a third of Murray cod were landed with a net; this included knotted as well as knotless mesh. Knotted mesh nets have been shown to be more harmful to fish than the knot-less kind (Barthel *et al.* 2003). The majority were landed 'by hand', which included lifting small fish out of the water by the rod and line. Jaw clamping 'fish-grip' devices were uncommon and only 1% of the recorded Murray cod captures were released after being unhooked in the water. Two-thirds of the fish that were deep-hooked were likely to be unhooked by hand, or using an instrument, rather than the best-practice of leaving the hook and cutting the line close to the jaw.

Fisheries and conservation agencies and representatives of the recreational fishing industry may need to do more to advocate and promote 'best practice' behaviours amongst anglers in the Murray cod fishery.

By-catch of Fish Species other than Murray Cod

Although the survey primarily sought information about the Murray cod fishery, catch data were collected for all species. Carp are not a preferred target species of most recreational anglers, and yet we estimate that anglers removed over 74 tonnes (conservatively assuming each carp had an average weight >=1 kg) in the 1,074 km of the Murray River and 502 km of the Victorian tributaries studied over two 9-months fishing seasons.

The catch of other important recreational species such as golden perch was estimated, although the fishery was significantly smaller than that for Murray cod. Golden perch were most abundant in Reach 5 (Murray adjacent to SA border) and in the Ovens River (where catches of cod were relatively small).

Threatened species, such as trout cod and silver perch, were also relatively abundant in the catch and were present in similar numbers to pest fish species such as common carp. Anglers reported catching trout cod in the Murray River downstream as far as Cape Horn near the mouth of the Goulburn River (35.074 S, 144.853 S) which is significantly further downstream than previously reported (McKinnon 1993). Records of bycatch could be used to monitor vulnerable species such as trout cod and silver perch.

Flow-on effects of South Australian moratorium on fishing for Murray cod – assessing the shifting fishing-effort

In December 2008, coincidently at the end of data collection in the present study, the South Australian government announced a moratorium on fishing for Murray cod. Residents of SA wishing to fish for Murray cod are likely to shift their attention to the NSW waters of the Murray River in nearby south-western NSW and north-western Victorian waterways. This shifting fishing effort will increase pressure on the resource of these streams.

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[4] (http://www.info-fish.net/releasefish/econtent.asp?lang=1&id=82)

The present study has 'benchmarked' the catch and fishing effort on a large reach of Murray River adjacent to the SA border (Reach 6) during the season prior to the moratorium, and documented the proportion of fishers that were SA residents. This data puts management agencies in the position to gauge the effects of this *de facto* 'protected area' on neighbouring stocks. Potential positive effects on the NSW or Victorian side of the border may include increased catches and shifts in size-structure of catches through recruitment and migration of Murray cod from the protected area in SA.

Potential negative effects (on sustainability-indicators) may include increased fishing effort and localised depletion.

Conclusions

- The use of a stratified, random, roving creel survey was effective at sampling Murray cod catch, retained-catch and fishing-effort in large river reaches within the MDB system. In two fishing seasons, 2006–08, nearly 1,700 km of river reaches in the southern MDB were sampled and over 1,400 angler interviews were completed. Representative data were collected from anglers about their catch, the time they had spent fishing and a range of angler-behaviours and fishing-practices.
- Most (85%) of anglers interviewed were Victorian residents. Along three reaches of the Murray River (in NSW) 76–89% of anglers interviewed were Victorians, confirming previous findings that the NSW waters of the Murray River are extremely important to fishers who are Victorian residents.
- Reduction in the number of rods per angler to two may have had little effect in removing any fishing 'pressure' from Murray cod stocks. Anglers using one to five rods showed no difference in catch rates for Murray cod, but anglers with two rods harvested (i.e. retained) Murray cod at a greater rate than those with a single rod.
- Analysis of a subset of the interviews in 2006–07 on a study reach where set-lines were legal fishing gear, showed only a slightly higher (non-significant increase) catch rate for anglers using set-lines. It is acknowledged that this research project was unable to measure the effect of the removal of large numbers of set-lines that were legal in much of the fishery prior to this study.
- At the level at which angler avidity[5] was measured (three categories) there was no statistical difference in Murray cod catch or harvest rates. Avid anglers (e.g. 'active' and 'regular') caught Murray cod at slightly higher, but statistically similar, rates to 'occasional' anglers. It seems likely that segmentation of anglers in the Murray cod fishery by their avidity may require more categories in order to see the expected trend of increased catch-rates with avidity.
- Although catches varied from reach-to-reach, and at a finer scale within reaches, the study shows that an 'average hectare' of river yields from 2 to 13 Murray cod as a recreational catch per season, and less than two (0–1.4) Murray cod are harvested per hectare.
- Bait used on single-hooks is by far the most popular and successful method used in the recreational Murray cod fishery along the Murray River and its Victorian tributaries. Cheese, shrimps and bardi grubs were the three most popular successful baits for Murray cod. In total these three baits accounted for 54% of the catch. Lures accounted for 13% of the Murray cod catch. Lure-caught Murray cod included proportionally more fish larger than the LML than fish caught on bait.
- Bait fishing anglers should use large hooks (> 5/0)
    - Most Murray cod were caught on relatively small hooks (relative to the gape of the fish) from size 1/0 to 4/0. Few anglers fished with hooks sized 5/0 or larger.

[5] Avidity – meaning, 'experience with and knowledge of the fishery'

- o A third of Murray cod caught were deep-hooked. The probability of deep-hooking varied with fish-size and hook-size. Using large hooks (5/0 and larger) may give the bait-fishing angler the best chance of only shallow-hooking a Murray cod. As hook-size decreases and fish-size increases, the chance of deep-hooking reaches a maximum. Due to the species' voracity and large mouth gape-size, large hooks do not just catch large Murray cod, but any small cod caught when using a large hook are less likely to be deep-hooked.
- o Differential survival rates of some fish species by hook-size indicate that this should be experimentally investigated for Murray cod to determine if there is a trade-off with large hooks causing low survival when they are ingested deeply.

- Voluntary release rate (of fish larger than LML) is only moderate (14–32%) and to-date only contributes moderately to the sustainability of this fishery. The high overall release rate observed (70%), is mainly compulsory-release due to fish being smaller than the LML.
- Given the likely importance of the survival of small Murray cod in the sustainability of this fishery, more should be done by all stakeholders to try and achieve practice-change to maximise survival of released fish. The uptake of 'best-practice' for released Murray cod survival in this fishery is presently poor. Use of nets or jaw-grippers to land fish is low. Hooks were most often removed from deep-hooked fish, instead of the recommended 'cutting the line close to the jaw and leaving the hook in the fish'.

Recommendations

- Periodic repetition of some or all of these surveys is recommended to establish a time-series of data on the recreational fishery. These data could be used to evaluate future management decisions, through the use of such data in quantitative Murray cod population models (Allen *et al.* 2009 and see also chapter 6 and 7, this study) and in adaptive management approach as advocated in recent Murray cod management workshops (Nicol *et al.* 2005).
- To accompany these recreational fishery data, estimates of population-density (fish or kg per hectare) should be made from representative sites around the MDB to enable evaluation of the sustainability of the recreational fishery. Recreational fishery data collected as catch-density and harvest-density estimates(fish or kg per hectare), such as in this study, are directly comparable with estimates of population density.
- Increased and more effective efforts must be made to advocate 'best-practice' for improved released fish survival targeting anglers fishing for Murray cod. The present study acts as a bench-mark to evaluate levels of practice change achieved in the future.
- Experimental examination of the potential trade-off between increasing damage from using large hooks and of large-hooks reducing the incidence of deep-hooking, warrants investigation. Until this is complete, the recommendations made to anglers should be to 'use large hooks for Murray cod to reduce the number of small fish being deep-hooked and increase your chances of catching one large enough to harvest.'
- Effects of the South Australian moratorium on Murray cod fishing (commenced 2009) may have ramifications for cross-border fisheries (e.g. increasing effort). The present work is suitable as a benchmark for SA residents fishing NSW and Victorian waters. The SA moratorium may serve as a de facto 'protected area' for Murray cod and presents opportunities to study effects on adjoining fisheries, to increase understanding of potential role of protected areas in the sustainable management of Murray cod stocks.
- Further analysis of existing angler interview data at finer spatial scales than presented here may enable increased knowledge of the relationship between catch and effort, and ease-of-access for anglers informing public access managers about the level of Murray-cod protection/exploitation that caused by management of angler-access.

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Chapter 5. Release survival - Evaluating relative impacts of recreational fishing harvest and discard mortality on Murray cod (*Maccullochella peelii peelii*)

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Abstract

Murray cod (*Maccullochella peelii peelii)* support popular recreational fisheries in Australia. Catch-and-release of Murray cod is common due to regulations and a developing trend of voluntary angler release of harvestable fish, but no previous studies have investigated discard mortality of released fish. We estimated discard mortality by measuring post-angling survival of angler-caught wild Murray cod. Angled fish were monitored for five days after hooking; overall survival rates of 98% were observed. We explored implications of catch-and-release on mortality by comparing our results to roving creel survey estimates of harvest from six fisheries. We applied the maximum likelihood mortality estimate and upper 95% confidence interval to creel survey estimates of the number of Murray cod that were released in the fishery to estimate the total deaths resulting from catch-and-release activity. The deaths resulting from the high number of catch-and-release fish could contribute as much or more to fishing mortality as total harvest in some systems. Future Murray cod research should aim to estimate annual exploitation rates to determine the population-level impacts of fishing mortality, and thus allow effects of hooking and harvest mortality to be considered in future regulation decisions.

Key Words: post-release, mortality, Murray River, discard, Murray cod.

Introduction

The total impact of recreational fishing on a population includes both harvested fish and fish that die after release by anglers. The use of size and catch limit regulations to manage fisheries along with the promotion of catch-and-release activities are based on the assumption that released fish have high survival (Pollock and Pine 2007). The intention of regulations may be undermined if a large percentage of released fish die due to the angling process (e.g. hooking, handling) (Conron *et al.* 2004; Waters and Huntsman 1986). Evaluating impacts of discard mortality can inform the need for alternative regulations to limit fishing mortality.

Recreational Murray cod (*Maccullochella peelii peelii)* fisheries exist throughout the Murray-Darling Basin (MDB) of southeastern Australia. Murray cod fisheries are regulated using legal minimum lengths (LML), bag limits, and closed seasons, which require release of fish that are too small, in excess of harvest limits, or caught out of season. There is also a developing social trend for voluntary catch-and-release of Murray cod (Park *et al.* 2005; Van Der Walt *et al.* 2005). The number of Murray cod caught and released is probably increasing through time as a result of increasingly restrictive regulations and changing angler attitudes, as seen in many recreational fisheries (e.g. largemouth bass *Micropterus salmoides*; Myers *et al.* 2008).

Mortality due to catch-and-release can undermine the value of fisheries management practices (e.g. length and size limits) and impact fishery sustainability. Even low discard mortality rates can contribute to fishing mortality when large numbers of fish are caught and released, with severe implications for long-lived fishes or low productivity populations (Coggins *et al.* 2007). Discard mortality in Murray cod could be very important to the choice of sustainable harvest strategies because they are long-lived (i.e. maximum age up to 48 years, Anderson *et al.* 1992). Henry and Lyle (2003) estimated that about 78% of angled Murray cod were released in the year 2000; with 110,000 being harvested, but over three times this number (375,000) being released. This ratio of released fish to harvested fish is high compared with other Australian species that are estimated to have release-rates of between 30% and 60% of the total recreational angling catch (Henry and Lyle 2003). Allen *et al.* (2008) evaluated sustainable harvest policies for Murray cod with an age-structured population model and showed that Murray cod populations were highly sensitive to fishing mortality because of their low natural mortality and longevity. Murray cod have been identified as being potentially susceptible to high levels of discard mortality (McLeay *et al.* 2002), but post-discard mortality rates for the Murray cod recreational fishery have not been published.

Discard mortality has been determined for many recreational fish species worldwide (Muoneke and Childress 1994) and rates range widely from 0% to 95% (Bartholomew and Bohnsack 2005). With this variation in mind, no generic or average rate is acceptable, and estimation of discard mortality is required on a case by case basis. The implications of discard mortality relative to harvest should also be expected to vary across fisheries and both could be important to understanding fishing mortality in some systems. Our objective was to estimate discard mortality in a field experiment and then evaluate the potential impacts of discard mortality relative to angler harvest on Murray cod fisheries.

Material and methods

Catch and Release Mortality Estimates

Two experimental angling trials were undertaken on the Murray River downstream of Boundary Bend, Victoria (Figure 23). Trial one was undertaken in February 2008 at a water temperature of 27 °C. Trial two was undertaken in April 2009 at a water temperature of 13 °C. The trials enlisted recreational anglers to fish over two days between 7.00 am and 9.00 pm along a 6.5 km reach of the river. The anglers used their preferred Murray cod fishing gear and methods and were instructed not to alter how they would typically fish for, land or handle any angled Murray cod. After capture, angled fish were released into a secure water filled drum tethered to the nearest in-stream woody habitat. Wild Murray cod can exhibit aggressive behaviour when housed together and this may lead to injury or mortality (Ingram *et al.* 2005). The placement of each fish into individual drums removed interactions between fish and served as our study replicates. The 120 litre plastic "Brute ®" drums (Rubbermaid Commercial Products) had their sealable lids drilled with six (44 mm) holes to allow water transfer. This style of drum is consistent with other freshwater discard mortality studies (Hall *et al.* 2008). The fish were monitored daily for five days after capture.

Thirty Murray cod were obtained from a commercial aquaculture facility (Thurla Farm) near Redcliffs in north-west Victoria and used as controls in each trial. We chose to use aquaculture produced fish as controls to minimize stresses that can be introduced when capturing wild fish and result in pre-confinement effects. Control fish were weighed and measured prior to loading, and transported to the study site via an oxygenated commercial fish transport trailer. The trips took about two hours including processing, loading and transport of the control fish to the study site. At the study site, water temperature between the transporter and the river was equalised and the fish were transported via 100 litre open fish bin in a small boat across the river and placed into individual holding drums tethered in the river in the same manner as described for the angled fish. Control fish were held in the drums for five days. Most deaths in previous discard mortality studies occur over 24 hours, but can manifest over periods of days (Muoneke and Childress 1994). Five days was considered an appropriate length of time to investigate mortality from hooking while limiting effects of captivity. Fish were checked daily for mortality by slightly inverting the submerged drum and allowing water to flow out of the lid holes. Once sufficient water was drained, the fish could be visually observed through the lid holes and the drum re-immersed. Mortality was defined as failure to maintain equilibrium with no opercula movement. At the completion of the trials each fish was removed from the drums, visually inspected for any damage and then released. All control fish were returned to the commercial farm.

Applying Post-Release Survival Estimates to the Recreational Fishery

Estimates of catch (C) and harvest (retained catch, H) with 95% confidence intervals, were made using a randomised, stratified, roving creel survey of six reaches of the southern MDB during the 2006–07 and 2007–08 Murray cod fishing seasons (Brown 2010, Chapter 4). The six reaches covered 2,263 km of the Murray, Ovens, Goulburn and Loddon Rivers (Figure 23). The released component of the catch (R) was calculated as R=C-H for each reach.

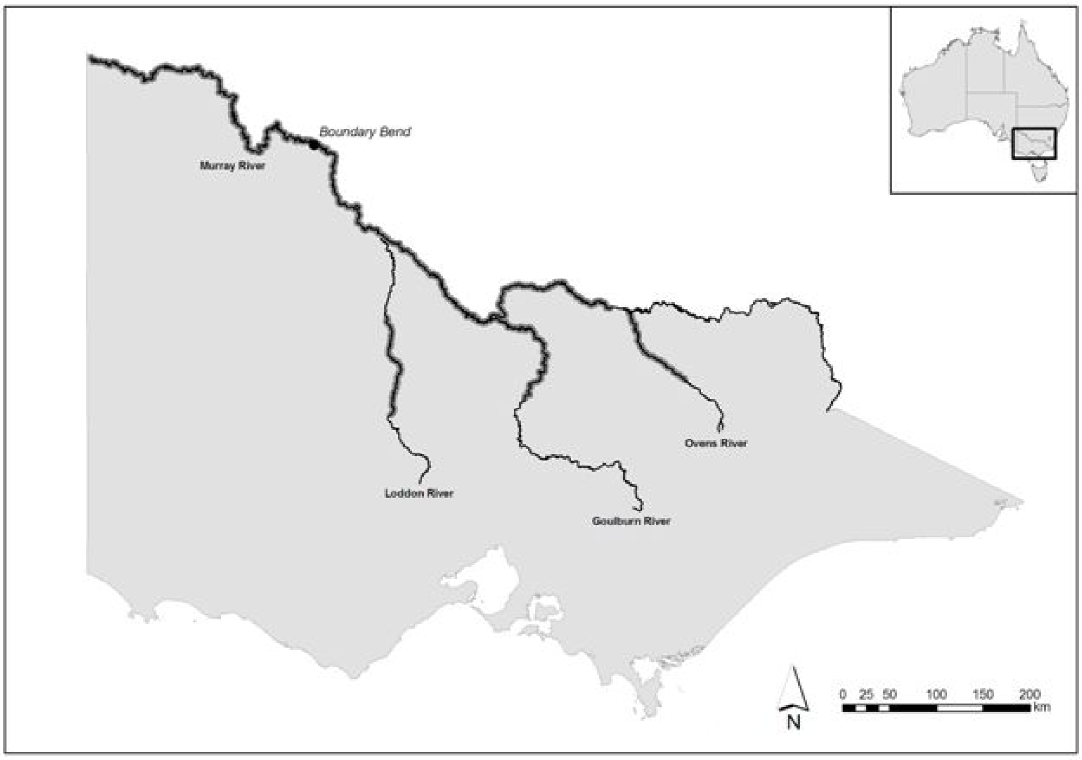

Figure 23: Location of two experimental angling trials and creel survey reaches in Victoria, Australia. Experimental angling trials were undertaken near Boundary Bend on the Murray River. Creel surveys were undertaken along Murray, Ovens, Goulburn and Loddon Rivers indicated by shading.

Calculation

We calculated the maximum likelihood estimate of the finite discard mortality rate D and used the binomial form of the likelihood ratio test to determine approximate 95% confidence interval for D by finding the value of D such that the log-likelihood L[N,d|D]-L[N,d|MLED]=1.92 (Hilborn and Mangel 1997), where N is the total number of fish, d is the number of fish that died, and MLED is the maximum likelihood estimate of D.

The predicted numbers of fish deaths due to catch-and-release via recreational fishing (M_D) in each of the creel survey study reaches was obtained by applying the estimated discard mortality rate (D) from the experimental trials to creel survey estimates of R. We also evaluated the maximum expected influence of discard mortality by using the upper confidence interval of D and the upper confidence limit of R to generate an upper confidence limit (i.e. a worst case) on the estimate of fish deaths due to discard mortality in the fishery.

Results

Catch and Release Mortality Estimates

Discard mortality rate (D) was low with maximum likelihood estimates of less than 3% in both trials (Table 20). The lack of differences in D between trials provided evidence that D was not strongly influence by water temperature for the conditions we evaluated. The maximum likelihood estimate of mortality for control fish was 10% and 0% for Trials 1 and 2, indicating that the control fish had similar mortality to treatment fish. The confidence intervals in treatment trials overlapped substantially, and they were combined for further analyses. The maximum likelihood estimate of D from both trials was 1.9% and the upper and lower 95% confidence intervals were 8.9% and 0%, respectively (Figure 24). The maximum likelihood estimate and upper 95% confidence limit were used to project how many Murray cod would have died from the released component of recreational catches in the six fisheries studied, under the assumption that released fish are caught on a single occasion per year (Table 21).

The ratio of the predicted number of dead discard to harvest provided a measure of the relative importance of catch-and-release mortality to directed harvest mortality. Our estimates of MD/H ratios ranged from 1% to 45% across these fisheries. Applying upper confidence intervals of our discard mortality estimate indicated that catch and release mortality could be as high as 114% of harvest at some locations (Table 21). Discard deaths could be a large component of fishing mortality and exceed harvest in some cases.

Table 20: Results of two experimental trials to estimate catch and release mortality (D) over five days post-capture for Murray Cod. Lower 95% CI of D =zero mortality.

		Trial 1	Trial 2	Combined
Catch & Release Treatment	Sample size (N)	67	36	103
	No. mortalities (d)	1	1	2
	D (%)	1.5	2.8	1.9
	Upper 95% C.I. (%)	10.6	18.9	8.9
Control	Sample size (N)	30	30	60
	No. mortalities (d)	3	0	3
	D (%)	10	0	5
	Upper 95% C.I. (%)	28.8	13.8	17.8

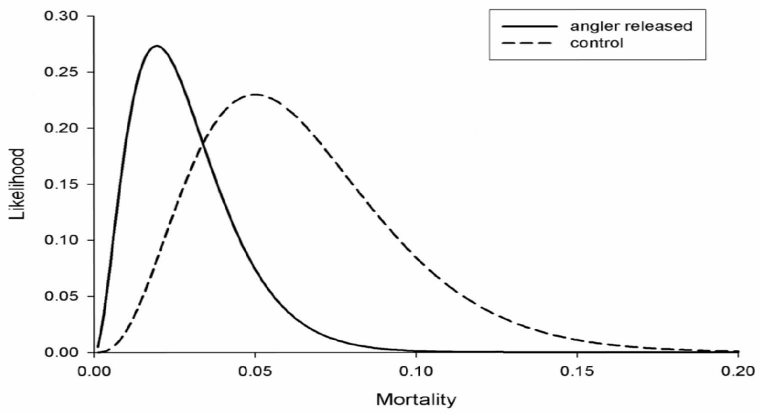

Figure 24: Maximum likelihood mortality estimates for angler-released and control fish from two combined trials.

Table 21: Comparison of estimated Murray cod mortalities from recreational fishing harvest (H) and discard (MD) in six study-reaches of the southern Murray-Darling River system. Worst case estimates for discard mortality were constructed from the upper 95% confidence interval for the finite mortality rate (experiment) and the upper 95% confidence estimate for fish released by anglers (creel survey).

Study reach	Location	Year	Catch (C) [upper 95% CI]	Release (R) [upper 95% CI]	Harvest (H) [upper 95% CI]	Estimated Discard mortality (MD) [upper 95% CI]	MD/H (%) [upper 95% CI]
1	Murray River (Yarrawonga to Torrumbarry)	2006–07	35,100 [39,383]	31,919 [33,538]	3,181 [5,845]	613 [2985]	19 [51]
2	Goulburn River	2006–07	3,959 [4,459]	3,721 [4,054]	238 [405]	71 [361]	30 [89]
3	Ovens River	2006–07	1,174 [1,560]	1,174 [1,560]	0	23 [139]	
4	Murray River (Torrumbarry to Tooleybuc)	2007–08	19,654 [23,907]	18,858 [22,174]	796 [1,733]	362 [1974]	45 [114]
5	Murray River (Tooleybuc to SA)	2007–08	38,132 [43,220]	36,235 [36,369]	1,897 [3,851]	696 [3504]	37 [91]
6	Loddon River	2007–08	551 [1,353]	133 [135]	418 [1,218]	3 [12]	1 [1]

Discussion

Harvest regulations and angler attitudes have become increasingly important to recreational fisheries management (Muoneke and Childress 1994) along with recognizing that their unexpected effects can increase fishing mortality (Coggins *et al.* 2007). Our experimental results indicated that Murray cod have a low discard mortality rate. High release rates found in the fishery suggested that discard mortality can be important if catches affected a large fraction of the population. Combining discard mortality experiments with creel survey data showed that the importance of discard deaths could be considerable or potentially exceed harvests in some river reaches. This is new information and indicates the potential for population-level impacts of catch-and-release fishing for Murray cod.

Our study provided the first non-tournament discard mortality estimate for common Murray cod fishing practices. Hall *et al.* (2008) reported 15% mortality on Murray cod caught in a catch-and-release fishing tournament. Hall *et al.* (2008) cited handling factors such as excessive air-exposure and inadequate live-wells as contributing factors to tournament mortality. Post-hooking mortalities from freshwater catch and release angling tournaments over a range of species were significantly higher than general angling mortality estimates for fish caught and immediately released (Bartholomew and Bohnsack 2005; Wilde 1998). Our study estimated mortality following general Murray cod recreational angling practices with immediate catch and release and did not represent tournament conditions.

A challenge to quantifying hook and release effects is the ability to adequately isolate treatment effects by using a control group. Pollock and Pine (2007) recommended that control fish should always be used for short-term containment studies and capture mortality should optimally equal zero. In our study, and in most other discard mortality studies, it is not possible to catch wild control fish in a manner that does not exert mortality risks, albeit different ones to those of the angled treatment-fish (e.g. electrofishing). Of the potential mortality outcomes for treatment versus control groups (e.g. high versus low, both groups high, etc.), similarly low mortality estimates for both groups suggested that both endured the pre-confinement and confinement process with few deaths. Similarly, low mortality rates also eliminated the possibility of definitively separating angling effects. Our results provided confidence that the discard mortality rate (i.e. from a single capture per individual) due to angling would not exceed that observed in our experiments that included both treatment (i.e. angling) plus confinement. In a sense, the control group became less important in terms of interpreting the results, once discard mortality was low for both groups.

Our estimates of discard mortality and 95% confidence limits were low, and included zero. The risk of ignoring discard mortality cannot be elucidated without annual exploitation estimates. Coggins *et al.* (2007) showed that a discard rate exceeding 5% for long-lived, low productive species could preclude fishery sustainability if the population exploitation rate was high. If fishing mortality from harvest is relatively high, such as some conditions simulated by Allen *et al.* (2008), it would indicate that discard deaths identified here could add an increasing stressor to managing Murray cod. Our estimate of the importance of catch-and-release indicated that it could exceed harvest in extreme cases. We also suggest that our implications for catch-and-release fishing are likely conservative in some cases. For example, we only considered a single catch-and-release episode to calculate the discard mortality during a fishing season, whereas fish could be subjected to multiple captures per year depending on the level of fishing effort. Nelson (2002) and Pollock and Pine (2007) warned that low mortality per angling capture event could result in substantial population impacts if effort and release rates are high.

Conclusions

Our study provided a discard mortality rate of 2% for recreationally caught Murray cod in the southern Murray Darling Basin. Despite low discard mortality estimates, incorporating creel survey data showed that discard deaths could be at least as important to consider in stock assessments as death due to directed harvest. Estimates of fishing mortality would identify whether discard mortality has significant importance for sustaining Murray cod fisheries with implications for setting regulations.

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Chapter 6. Age Structured Model – Length Limit Assessment - An assessment of recreational fishery harvest policies for Murray cod in Southeast Australia.

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Abstract

Murray cod (*Maccullochella peelii peelii)* is one of the world's largest freshwater fish and supports popular fisheries in southeast Australia, but no previous modeling efforts have evaluated the effects of fisheries regulations or attempted to develop sustainable harvest policies. We compiled existing population metrics and constructed an age-structured model to evaluate the effects of legal minimum length limits (LML) and fishing mortality rates on Murray cod fisheries. The model incorporated a Beverton and Holt stock recruit curve, age-specific survivorship and vulnerability schedules, and discard (catch-and-release) mortality for fish caught and released. Output metrics included yield (kg), Spawning Potential Ratio (SPR), total angler catch, total harvest, and the proportion of angler trips that would be influenced by each regulation based on recent creel survey data. The model suggested that annual exploitation (*U)* should be held to less than 0.15 under the current LML of 500 mm total length to achieve an SPR > 0.3, a target usually considered to prevent recruitment overfishing. Exploitation rates at or exceeding 0.3 would cause SPR values to drop below typical management targets unless the LML was set at or above 700 mm. Regulations that protected Murray cod from overfishing created higher angler catches and higher catch of trophy fish, but at a cost of reducing the proportion of angler trips resulting in a harvested

fish. Expressing model output on a per-angler trip basis may help fishery managers explain regulation trade offs to anglers.

Keywords: stock assessment, modelling, fishing regulations, Murray cod *Maccullochella peelii peelii*

Introduction

The Murray cod (*Maccullochella peelii peelii)* is found in the extensive Murray Darling Basin (MDB) of southeastern Australia. As one of the world's largest freshwater fish with maximum size exceeding 100 kg, Murray cod support popular recreational fisheries in Australian states including New South Wales, Victoria, South Australia, and Queensland. Although recreational Murray cod fisheries are regulated with a range of size limits, bag limits, and closed seasons (Lintermans *et al.* 2005), no previous efforts have evaluated the influence of fishing on Murray cod populations or evaluated optimal harvest strategies. We compiled available life history parameters for Murray cod and constructed an age-structured population model to evaluate the effects of harvest policies for recreational fisheries.

Murray cod has undergone a range of fisheries over the past two centuries. Commercial fisheries began as early as the mid-1800s, and records indicate that commercial catches and catch per licensed boat decreased substantially from the 1940s to the early 1980s (Rowland 1989). The commercial fishery declined due to low harvests by the mid-1960s, and New South Wales closed commercial harvest for Murray cod in 2001 (Rowland 2005). Recreational fishing for Murray cod has been popular for decades, but the extent of recreational effort and harvest is not well documented through time. A national survey of recreational fishing estimated annual harvest of about 110,000 Murray cod in 2001 with about 375,000 fish released by anglers (Henry and Lyle 2003). Thus, Murray cod support important recreational fisheries today, and there is a need for an assessment evaluating potential impacts of a range of harvest policies on angling quality and sustainability. We compiled existing life history (e.g. growth, mortality) and fishery parameters (minimum size limits, discard mortality) for Murray cod and incorporated these parameters into an age-structured population model to evaluate harvest policies including legal minimum length limits (LML) and fishing mortality rates.

Methods

We constructed an age-structured simulation model similar to Walters and Martell (2004, chapter 3) and Allen *et al.* (2008). The model employed survival schedules, fecundity schedules and a Botsford formulation of a Beverton-Holt stock-recruitment function to predict equilibrium recruitment and age specific abundance under a variety of fishing mortality rates and harvest regulation scenarios. Survival schedules incorporated natural, harvest and discard mortalities. Harvest was driven by a stated exploitation rate and length-based vulnerabilities which included simulated LML. Fecundity was specified as a function of fish weight and the collective fecundity for a given year was reduced by all mortality sources. The model included ages 1 to 40 and was constructed in Excel®.

Equilibrium recruitment was calculated using a Botsford modification of a Beverton-Holt stock-recruitment function (Botsford and Wickham 1979; Botsford 1981a, 1981b) as described by Walters and Martell (2004). This simple formulation predicts equilibrium recruitment as a function of the fishing mortality rate. The model predicted the equilibrium age-1 recruits (R_{eq}) of an exploited population and is summarized in Walters and Martel (2004) as:

$$R_{eq} = R_0 \frac{CR - \frac{\Phi_0}{\Phi_f}}{CR - 1} \quad \textbf{(1)}$$

where R_0 is the number of age-1 recruits of the unfished population at equilibrium and CR is the Goodyear compensation ratio (Goodyear 1980), defined as the ratio of the recruits per spawner at very low population abundance (i.e. at the origin of the stock recruit curve) relative to the recruits per spawner in the unfished equilibrium condition. The parameter R_0 is the virgin age-1 recruitment and was simply a scaling parameter that did not influence most model predictions, except for the angler catch predictions described below. The model also included the option for stochastic recruitment variability using lognormally distributed deviate with mean of 1 and error (σ_R) around the equilibrium stock recruitment prediction R_{eq}.

Age-specific fecundity was estimated as a quadratic function of fish weight (Rowland 1998):

$$f_a = \beta_0 + \beta_1 w_a + \beta_2 w_a^{\;2} \tag{2}$$

where w_a is the mean weight-at-age, β_0 is the y- intercept, and β_1 and β_2 are fecundity-weight coefficients. To account for the cumulative affects of fishing on the reproductive capacity of the population, we used the incidence functions for the unfished (Φ_0) and fished egg production per recruit (Φ_f) as per Walters and Martell (2004). These incidence functions were calculated as:

$$\Phi_0 = \sum_a f_a l_a \tag{3}$$

$$\Phi_f = \sum_a f_a l_{fa} \tag{4}$$

where f_a represents age-specific fecundity, and l_a and l_{fa} are the survivorship schedules of the unfished and fished state, respectively. The value of (f_a) was set to zero if age was less then age at maturity (A_{mat}), resulting in a knife-edge fecundity with age relationship.

The model used survivorship curves to calculate the survivors per recruit to each age. Survivorship to age *a* in the absence of fishing was found as:

$$l_a = S_a l_{a-1} \tag{5}$$

where S_a is the age specific finite annual natural survival rate (i.e. e^{-M}). Discard mortality of fish caught and released by anglers is an important consideration in recreational fisheries where length limits can cause large numbers of fish to be released (Coggins *et al.* 2007). Our survivorship schedules in the fished condition incorporated natural mortality, harvest, and discard mortality as:

$$l_{fa} = l_{fa-1} S_a \left(1 - UV'_{a-1}\right)\left(1 - \left(U_o V_{a-1} - UV'_{a-1}\right)D\right) \tag{6}$$

where l_{fa} is the survivorship in fished condition, U is the finite annual exploitation rate, U_0 is the finite rate of capture by anglers, V_a and V'_a are age specific vulnerabilities to harvest and capture, and D is the discard (catch and release) mortality rate. The first term $U \times V'_{a-1}$ describes deaths due to harvest, and the last term $(U_o \times V_{a-1} - U \times V'_{a-1}) \times D$ models deaths due to discard mortality for fish caught below the LML and those that are legal to harvest but are voluntarily released by anglers. Thus, the model included deaths due to discard mortality for both fish protected from harvest and those that were voluntarily released by anglers. Age specific abundance (N_a) was estimated as the product of the number of age-1 recruits (R_{eq}) and the age specific survivorship schedule.

The model used length specific differences in natural and fishing mortality. We estimated the annual natural survival rate S_a as per Lorenzen (2000):

$$S_a = e^{-M\left(\frac{TL_r}{TL_a}\right)^c} \tag{7}$$

where M is the instantaneous natural mortality rate at TL_r, TL_a is the mean total length at age, TL_r is a reference length, and c is the allometric exponent modifying the relationship between natural mortality and length. Mean total length at age, L_a, was calculated from the von Bertalanffy growth model. Values of TL_r were set at the median age (age 20 in the model, corresponding to total length of 1,068 mm total length, Table 21).

Table 22: Parameters used in the simulation model.

Parameter		Value
Natural Mortality		
M	instantaneous adult natural mortality (yr^{-1})	0.108
S_a	annual natural survival	0.47 to 0.91
c	natural mortality exponent	0.9
TL_r	reference length for natural mortality	1,068
Fishing Mortality		
U	annual harvest exploitation rate	0.05 to 0.4
U_0	annual capture rate	0.06 to 0.44
D	discard mortality rate	0.05[6]
Vulnerability		
L_{low}	lower length at 50% capture vulnerability (mm)	300
SD_{low}	standard deviation of 50% capture vulnerability	30
L_{high}	upper length at 50% capture vulnerability (mm)	1,100
SD_{high}	standard deviation of 50% capture vulnerability	110
LML	length at 50% harvest vulnerability (mm)	400 to 800
SD_{LML}	standard deviation of 50% harvest vulnerability	$0.1 \times LML$
Growth		
L_∞	asymptotic length (mm)	1,202
K	metabolic coefficient (yr^{-1})	0.108
t_0	time at zero length (yr)	0
Length-Weight		
a	length-weight coefficient (mm to grams)	0.000036
b	length-weight exponent	2.91
Recruitment		
R_0	average annual unfished recruitment	100,000
CR	Goodyear compensation ratio	30
β_0	fecundity-weight intercept	-389
β_1	fecundity-weight coefficient	5,344
β_2	fecundity-weight coefficient	-69.5
A_{mat}	age at maturity (yrs)	5

[6] Based on the completed work in Chapter 4, this may be an overestimate, an experimental estimate of short-term discard mortality of 2% was made for normal fishing conditions. However, 5% still stands as a reasonable approximation given the potential for longer-term effects than were measurable under experimental conditions; and potential for a higher discard mortality component from tournament-style angling (See Chapter 4 for further discussion).

We specified the proportion of fish vulnerable to capture and harvest (V_a *and* V'_a, respectively) using a dome-shaped double logistic model:

$$V_a = \frac{1}{(1+e^{-\frac{(TL-L_{low})}{SD_{low}}})} - \frac{1}{(1+e^{-\frac{(TL-L_{high})}{SD_{high}}})} \qquad (8)$$

where V_a is the vulnerability schedule (either V_a or V'_a), *TL* is the mean total length at age *a*, L_{low} is the lower total length at 50% vulnerability to capture, SD_{low} is the standard deviation of the logistic distribution for L_{low}, L_{high} is the upper total length at 50% vulnerability to capture, and SD_{high} is the standard deviation for L_{high}. The left term models increasing vulnerability to harvest with length, and the right term can be used to simulate declining vulnerability with fish length, either as a harvest window or in cases where fish vulnerability to fishing may decline for large fish. Values of SD_{low} and SD_{high} specify the steepness of each side of the curve, and were set at 10% of the respective length at 50% vulnerability. When calculating harvest vulnerability (V'_a), we substituted a LML and standard deviation for the LML (SD_{LML}) for L_{low} and SD_{low} in equation 8.

To evaluate the performance of various harvest regulations, we simulated a range of exploitation rates (0.05 to 0.4) and LML (400 to 800 mm). Model output metrics included yield (kg), total angler catch (fish harvested and released), total harvest (number of fish), the number of trophy fish (total length ≥ 1,000 mm) in the population, and the Spawning Potential Ratio (SPR). We used the SPR to evaluate the extent to which fishing mortality can reduce reproductive output of Murray cod:

$$SPR = \frac{\Phi_f}{\Phi_0} \qquad (9)$$

where Φ_f and Φ_0 are defined in equations 3 and 4. The SPR measures the lifetime fecundity per recruit for a given level of fishing mortality and is a commonly used reference to assess fisheries sustainability (Goodyear 1993). Recruitment overfishing is generally prevented by maintaining an SPR ≥ 0.4 (Mace 1994). Target SPR values vary with stock productivity, with lower SPR required for sustaining highly-productive stocks (Clark 2002).

We used the model to evaluate effects of varying LML on angler catches. All simulations began with 100,000 fish recruiting to age-1 in the unfished condition (R_0), which resulted in model-predicted harvest that was similar to the estimated angler harvest from a recent creel survey from the middle Murray River (Brown 2008, Chapter 4). This stratified random creel survey was conducted in the river section from the Yarrawonga weir to the Torrumbarry weir in 2006 and 2007 (Brown 2008, Chapter 4). The creel survey results were used to measure the proportion of angler trips that caught 0, 1, 2, etc. Murray cod per trip, and the proportion of trips that harvested 0, 1, 2, etc. fish (i.e. ≥ 500 mm) in 2006–2007. We tuned R_o in equation 1 so that the model produced similar harvest estimates to the creel survey from this section of the river under the current LML (500 mm). For each alternate LML considered in the model, we estimated the probability of capturing 0, 1, 2 fish, etc. using a Poisson probability density function:

$$P_n = \frac{e^{-\lambda}\lambda^n}{n!} \qquad (10)$$

where P_n is the probability of capturing *n* Murray cod per angler trip given a mean catch per angler trip (λ). We calculated λ for each LML and metric by dividing the model-predicted catch by the estimated number of angler trips per year from the creel survey (196,299 4.5-hour angler trips; Brown 2008). The model predicted the proportion of trips with Murray cod catch (i.e. all fish sizes), harvest (i.e. catch of legal-sized fish), and catch of trophy fish (*TL* ≥ 1,000 mm) under each simulated LML. The exploitation rate for Murray cod was not known, and we conducted this analysis using an assumed annual harvest exploitation rate of 0.15 as a hypothesized moderate level of fishing mortality.

We specified a *CR* of 30 for Murray cod, which is similar to a wide range of relatively long-lived predators from meta-analyses of Myers *et al.* (1999) and Goodwin *et al.* (2006). This value suggests relatively high compensation for fishing, which is typical of long-lived predators that utilize a wide range of prey types throughout their ontogeny.

Murray cod size at 50% maturity was preliminarily estimated as 519 mm during recent surveys of Victoria Department of Primary Industries (VicDPI) staff in the MDB (J. Douglas, DPI, pers. comm., Chapter 3). This value is similar to previous work from Rowland (1998), which showed that fish were about 50% mature at length groups between 500 mm and 550 mm. We specified the age at 50% maturity (A_{mat}) at age 5, which corresponded to a model-predicted total length of 502 mm and a weight at 50% maturity of 2.6 kg and approximated estimates from VicDPI and Rowland (1998).

The von Bertalanffy growth curve used for all simulations is shown in Figure 25. We used growth parameters for Murray cod from Anderson *et al.* (1992). This curve used asymptotic length (L_∞) and metabolic parameter (K) values from Anderson *et al.* (1992), which included a sample of 290 fish with a maximum age of 36, including fish from the middle Murray River.

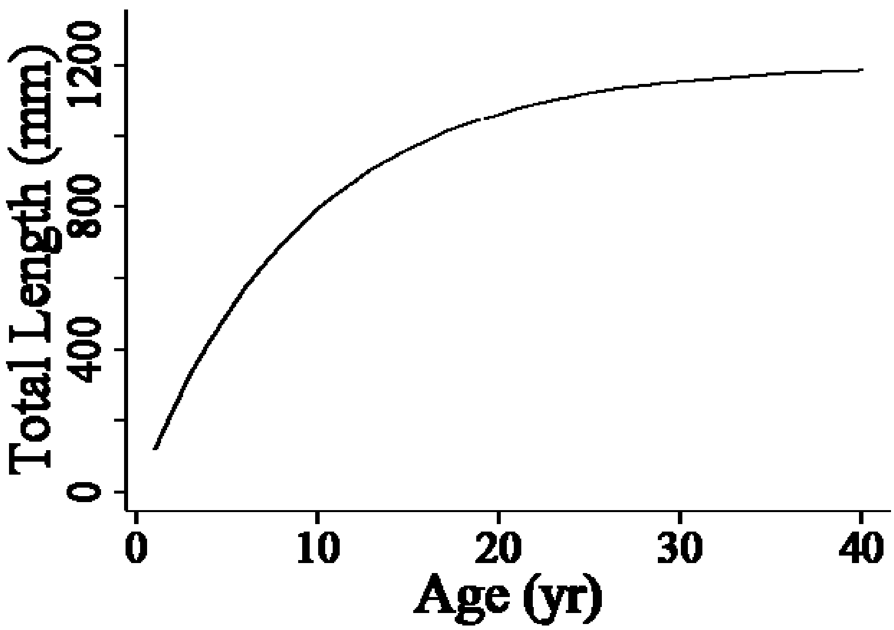

Figure 25: Relationship between mean total length (mm) and age for all simulations. Values of the growth curve are from Anderson *et al.* 1992.

We fixed the time at zero length (t_0) at zero for all simulations. The value of K was 0.108, which we used as a surrogate for the natural mortality rate (M). Setting M equal to K provided similar estimates of M to methods based on maximum age (e.g. Hoenig 1983; Pauly 1980) and is frequently used in modelling efforts (Walters and Martell 2004). We used a value of 0.9 for c in the Lorenzen natural survival curve from equation 7. The resulting age-specific changes in natural survival are shown in Figure 26. To predict fish weight from length, we used estimates of the a and b parameters from Anderson *et al.* (1992) for the weight-length relationship (Table 22).

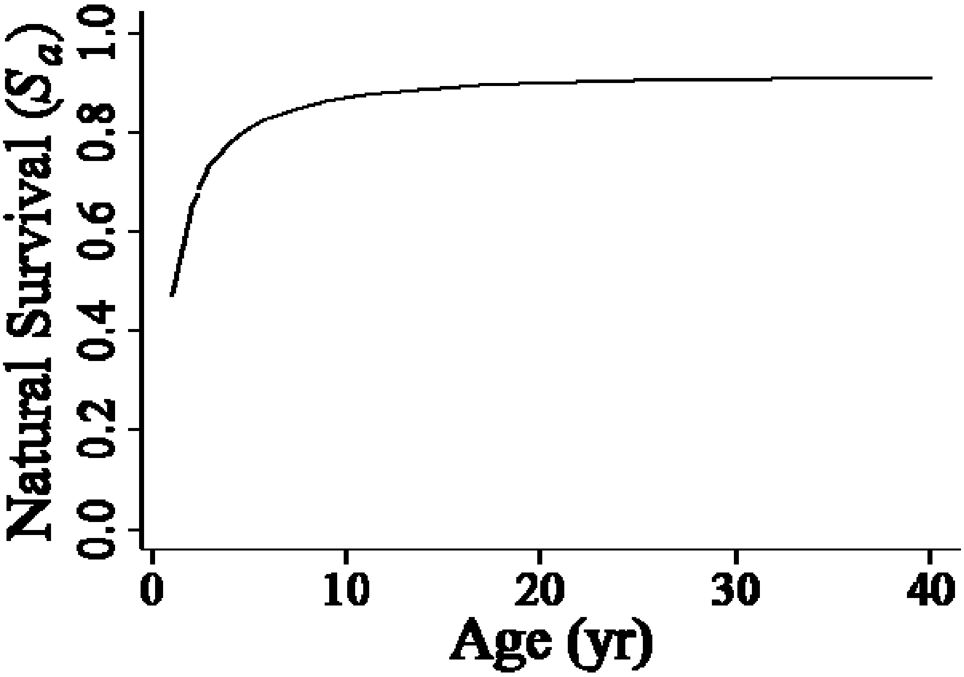

Figure 26: Relationship between annual natural survival and age used in the population model.

Discard mortality of fish released was set at 5% for all simulations[7]. This discard mortality rate is relatively low but supported by recent estimates from VicDPI researchers (J. Douglas, unpublished data). We assumed that anglers voluntarily released 15% of the fish that were legal to harvest, based on recent creel surveys in the Goulburn River (Brown 2008). Thus, U_o was set as $U_o = U + (U \times 0.15)$ for all simulations.

The fish total length at 50% vulnerability to angling was set at 300 mm (Table 22), because fish less than 200 mm are rare in the recreational catch (Brown 2008). We suspected that vulnerability to angling declined for large fish. Dome shaped vulnerability curves are common for recreational line fisheries, even for relatively small fish (e.g. Miranda and Dorr 2000, Newby *et al.* 2000). Most Murray cod anglers use lures and natural baits that are no larger than 100-200 mm, and large-gaped fish predators readily consume prey up to 30% of their total length (Scharf *et al*. 2000). This would infer that a 1,000 mm Murray cod would consume prey up to 300 mm, and few fishing lures used by anglers are this large. We used a dome-shaped capture vulnerability for angling in the model (Table 22). The dome-shaped curve used for capture vulnerability and an example 500 mm LML are shown in Figure 29. These parameters define that in the model, fish are vulnerable to capture for 2-3 years prior to harvest under this LML, and vulnerability to fishing declines gradually after age 10 (Figure 27).

[7] Based on the completed work in Chapter 4, this may be an overestimate, an experimental estimate of short-term discard mortality of 2% was made for normal fishing conditions. However, 5% still stands as a reasonable approximation given the potential for longer-term effects than were measurable under experimental conditions; and potential for a higher discard mortality component from tournament-style angling (See Chapter 4 for further discussion).

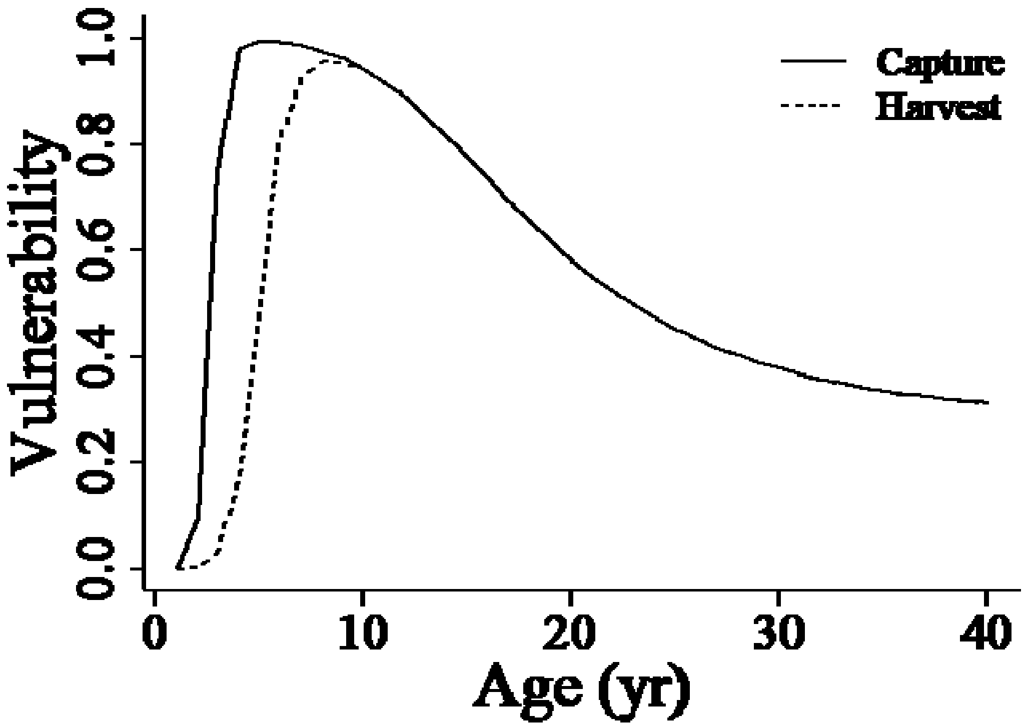

Figure 27: Age-specific vulnerability to capture (solid line) and harvest (dashed line) under a 500 mm legal minimum length.

We conducted two types of sensitivity analyses to evaluate the response of spawning potential ratio (SPR) and yield to perturbations in *M*, *D*, L_{low}, L_{high}, L_{∞}, *K*, *CR*, A_{mat}, TL_r, and *c*. The first analysis evaluated the elasticity of SPR and yield to relatively small changes in each parameter. Elasticity represents the proportional response of a function to a proportional change in a parameter value and is useful for estimating the relative influence of parameters on a model when the parameters are measured on different scales (Caswell 2002). We calculated elasticity as the proportional change in SPR and yield resulting from a 5% increase in each parameter value. Elasticity analysis shows the relative influence of parameters in the neighbourhood of their baseline value but does not reveal the influence of large errors in parameters. The second sensitivity analysis evaluated how large amounts of uncertainty in model parameters would influence our predictions by plotting SPR and yield across a wide range of values for each parameter.

Results

The model-predicted SPR values were less than 0.3 at exploitation rates exceeding 0.3 when the LML was less than 700 mm (Figure 28). Fishing mortalities that would achieve an SPR of 0.3 or higher ranged from 0.1 to 0.3, and the LML to obtain an SPR > 0.3 increased with fishing mortality (Figure 28). Walters and Martell (2004) indicated that sustainable levels of exploitation (U_{msy}) are typically about $0.8 \times M$, which in this case would be a *U* of about 0.1. However, the level of U_{msy} will vary with the *CR* for a given fish population, whereas our static SPR management target is invariant to the *CR*. A *U* of 0.1 was predicted to give SPR values exceeding 0.3 for all LML considered (Figure 28). Our study suggested that U must be held to less than 0.15 under the current LML of 500 mm to achieve an SPR > 0.3. Similarly, exploitation rates at or exceeding 0.3 would cause SPR values to drop below typical management targets unless the LML was set at 700 mm or higher.

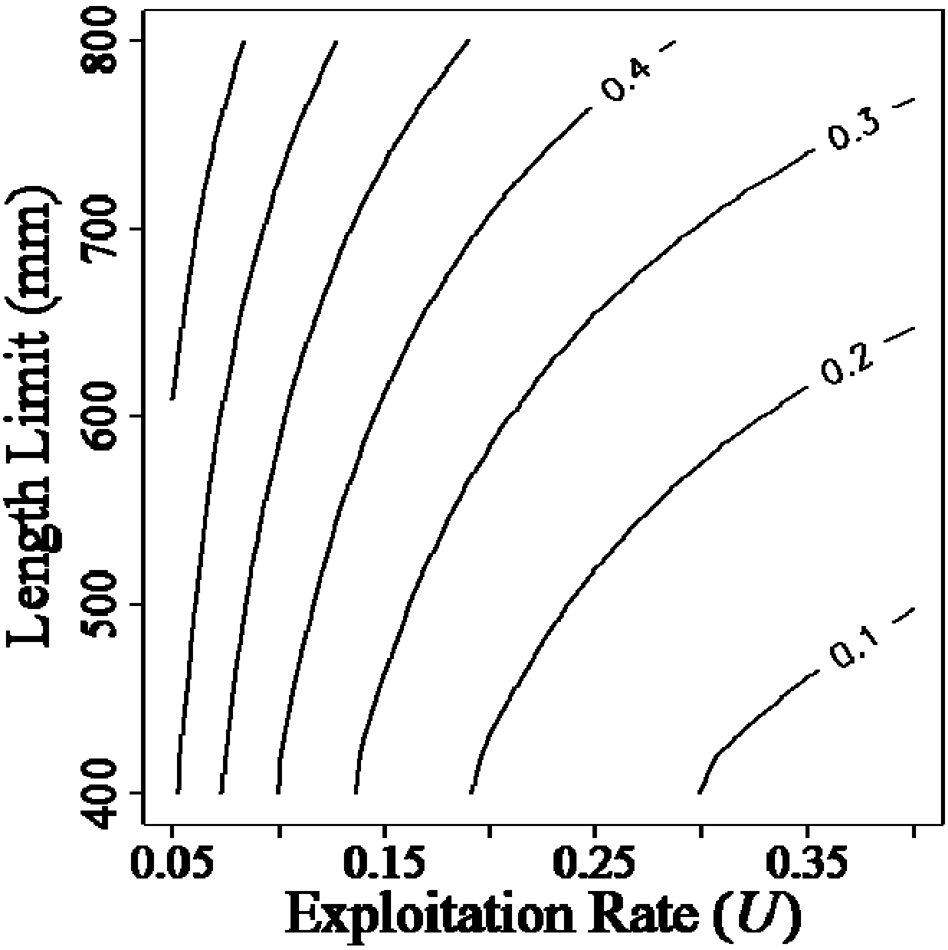

Figure 28: Isopleths of the Spawning Potential Ratio (SPR) on harvest exploitation rate (U, x axis) and legal minimum length (mm, y axis). Values of SPR below 0.3 are usually indicative of recruitment overfishing.

The yield isopleths showed highest yields at relatively high exploitation rates combined with high LML (Figure 29). The model predicted maximum yield (56.7 kg) occurred at a *U* of 0.26 and LML of 689 mm (Figure 29). Yield was predicted to be near the maximum if *U* was greater than 0.15 and the LML exceeded 600 mm. Losses in yield would be required to maintain an SPR greater than 0.35. To illustrate this trade-off, consider that an SPR of 0.45 would be obtained at a *U* of 0.1 and LML of 500 mm (Figure 28), which would be considered a safe harvest policy. Under this management scenario, the fishery would attain only 85% of the maximum yield (Figure 29). Such management trade-offs may be necessary to reduce the risk of recruitment overfishing.

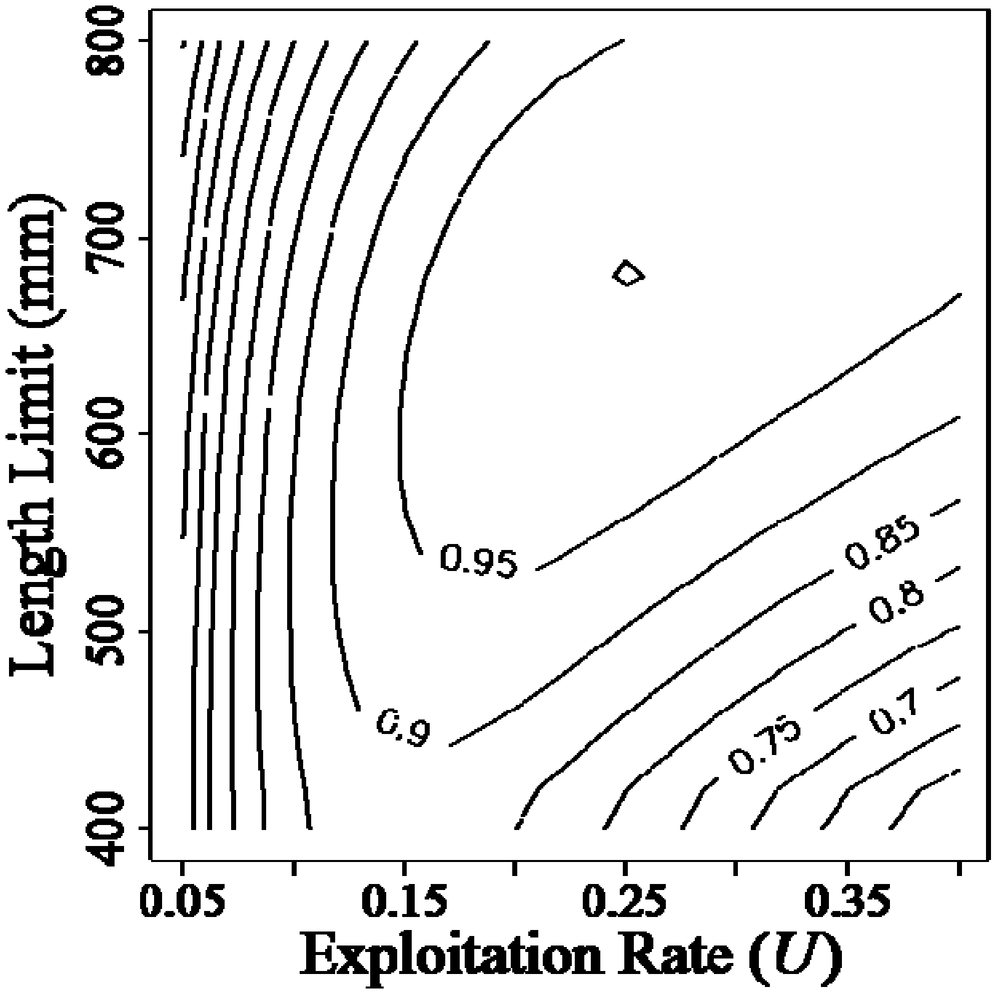

Figure 29: Yield (kg) isopleths plotted on harvest exploitation rate (U, x axis) and legal minimum length (mm, y axis). Isopleths represent the proportion of MSY.

We tuned R_0 in equation 1 to 100,000 fish, which produced similar total harvest values to the creel survey data (Table 23). The model produced estimates of total catch that were substantially lower than the field estimates from Brown (2008), and thus the equilibrium model predicted fewer undersized fish relative to the creel survey data. Our equilibrium model predictions under constant recruitment, U=0.15, and a 500 mm LML found that four out of ten angler caught fish would be harvestable (i.e. ≥ 500 mm), whereas the creel survey data showed that only one out of ten fish caught actually exceeded 500 mm (Table 23).

Table 23: Comparison of creel survey data from Brown (2008) to model-predicted values of the proportion of angler trips with catch of 0, 1, and 2 fish per trip for fish harvested (≥ 500 mm) and total catch (all Murray cod). The value of λ is the catch/196,299 trips for harvested fish and all fish from Brown (2008) and the model-predicted values.

	Brown (2008)		**Model Predictions**	
	Harvest	**Total Catch**	**Harvest**	**Total Catch**
Number of Fish	7,450	75,825	7,873	17,911
λ	0.038	0.386	0.040	0.091
Catch/trip				
0	0.96	0.68	0.96	0.91
1	0.04	0.26	0.04	0.08
2	<0.01	0.05	<0.01	<0.01

We explored this discrepancy using a wide range of model parameters including the stochastic recruitment function. We used a wide range of vulnerability parameters and fishing mortality rates to explore conditions where the model would replicate the high catch of small fish relative to fish over 500 mm seen in the creel survey data, but none produced only a 10% occurrence of harvestable fish in angler catches. We explored the lognormally distributed stochastic recruitment component to equation 1, and found that an error (σ_R) of 0.8 around average annual age-1 abundance could cause catch of harvested fish to represent only 10% of the total catch in years following above average recruitment.

The equilibrium simulations predicted that angler catch, harvest, and catch of trophy fish was influenced by the LML for Murray cod (Figure 30). The probability of landing a Murray cod (of any size) increased as the length limit increased (Figure 30A). For example, our model predicted that an increase in the LML from 500 to 700 mm would result in a 16% increase in the probability of landing a Murray cod. This translated to a predicted increase in the number of successful trips (i.e. trips with at least one fish landed) from one out of twelve trips to one out of ten. This was due to increased fish abundance resulting from increased recruitment and protection of adult fish by the higher LML. If maximizing angler catch were a priority for Murray cod fisheries then a large LML would be optimal. The probability of harvesting a Murray cod declined with increasing LML (Figure 30B) due to losses of fish via natural mortality before they grow past the legal length. An increase in the LML from 500 to 700 mm would decrease the trip harvest success rate by 37% from one in twenty six trips to one in forty two. Our model predicted that the probability of landing a trophy-sized Murray cod increased by 60% with an increase in the LML from 500 to 700 mm (Figure 30C), which corresponds to an increase in the trip success rate from one out of 222 trips to one out of 138 trips. These analyses demonstrate the trade offs associated with various LML, because regulations that provide high numbers of fish harvested (e.g. 400 to 500 mm LML) also result in a higher risk of overfishing (Figure 28), lower overall angler catch rates, and lower occurrence of trophy fish due to higher exploitation (Figure 30).

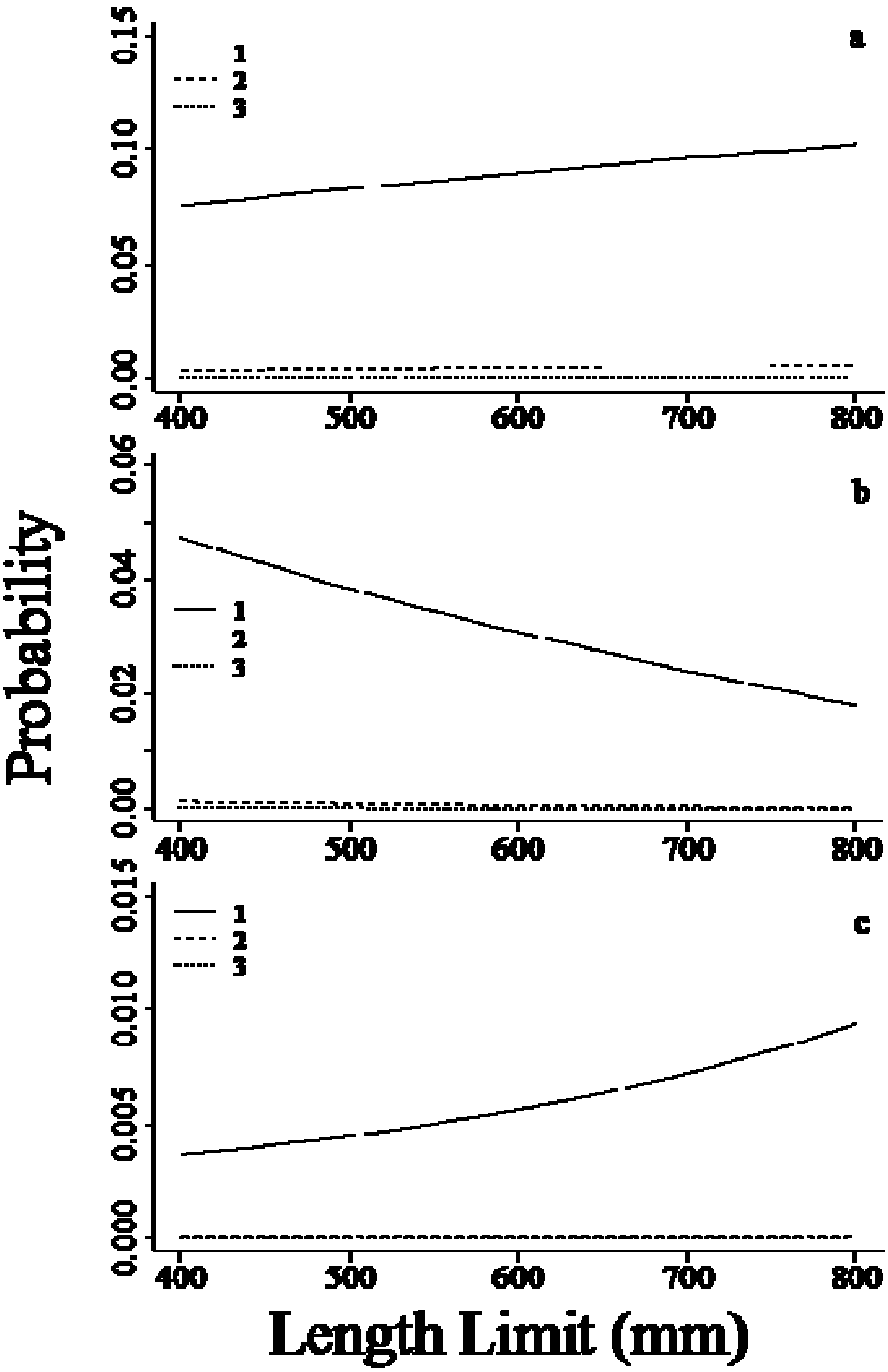

Figure 30: Probability of capturing one (solid line), two (dashed line), or three (dotted line) Murray cod of: Panel A any size; Panel B legal-size (TL > LML) and Panel C trophy-size (TL > 1,000 mm;) per angler trip across a range of legal minimum length at a harvest exploitation rate (U) of 0.15.

Elasticity analysis showed that the model overall was most sensitive to changes in natural mortality and growth parameters (Table 24). The *SPR* was most sensitive to natural mortality parameters *M* (instantaneous natural mortality) and TL_r (mortality reference length) followed by L_{high} (maximum vulnerable length). Equilibrium yield was very sensitive to changes in growth parameters (L_∞ and *K*) and mortality parameters (*M*, TL_r, and *c*). *SPR* and yield were robust to perturbations in discard mortality (*D*) and the length at first capture (L_{low}).

Plots of SPR and yield across a wide range of parameter values indicated that most parameters had a nearly linear affect over the parameter ranges examined, with the exception of *M*, *K* and *CR* (Figure 31a-h and Figure 32a-i). Linear relationships suggest that elasticity estimates are valid across a wide range of parameter uncertainty. However, nonlinear trends for *M*, *K* and *CR* suggest that the influence of the parameter on yield and SPR depends on the assumed parameter value. For example, *K* had a stronger influence (steeper slope) on SPR at low *K* values than at high *K* values (Figure 31f). Similarly, *M* had a stronger influence on yield at low *M* values than high (Figure 32). Yield was relatively insensitive to changes in *CR* when *CR* was greater than 10, but was highly sensitive when *CR* was less than 10 (Figure 32d).

Table 24: Elasticity of Spawning Potential Ratio (SPR) and yield to changes in ten of the model parameters. Elasticity was calculated as the proportional change in SPR and yield resulting from a 5% increase in the parameter value. For example, yield decreased by 240% with a 5% increase in M.

	Elasticity	
Parameter	**SPR**	**Yield**
M	0.68	-2.40
D	-0.02	-0.03
Llow	0.13	0.03
Lhigh	-0.55	0.32
L∞	-0.36	4.86
K	-0.23	3.31
CR		0.06
Amat	-0.35	-0.03
TLr	0.61	-2.17
c	0.11	-2.81

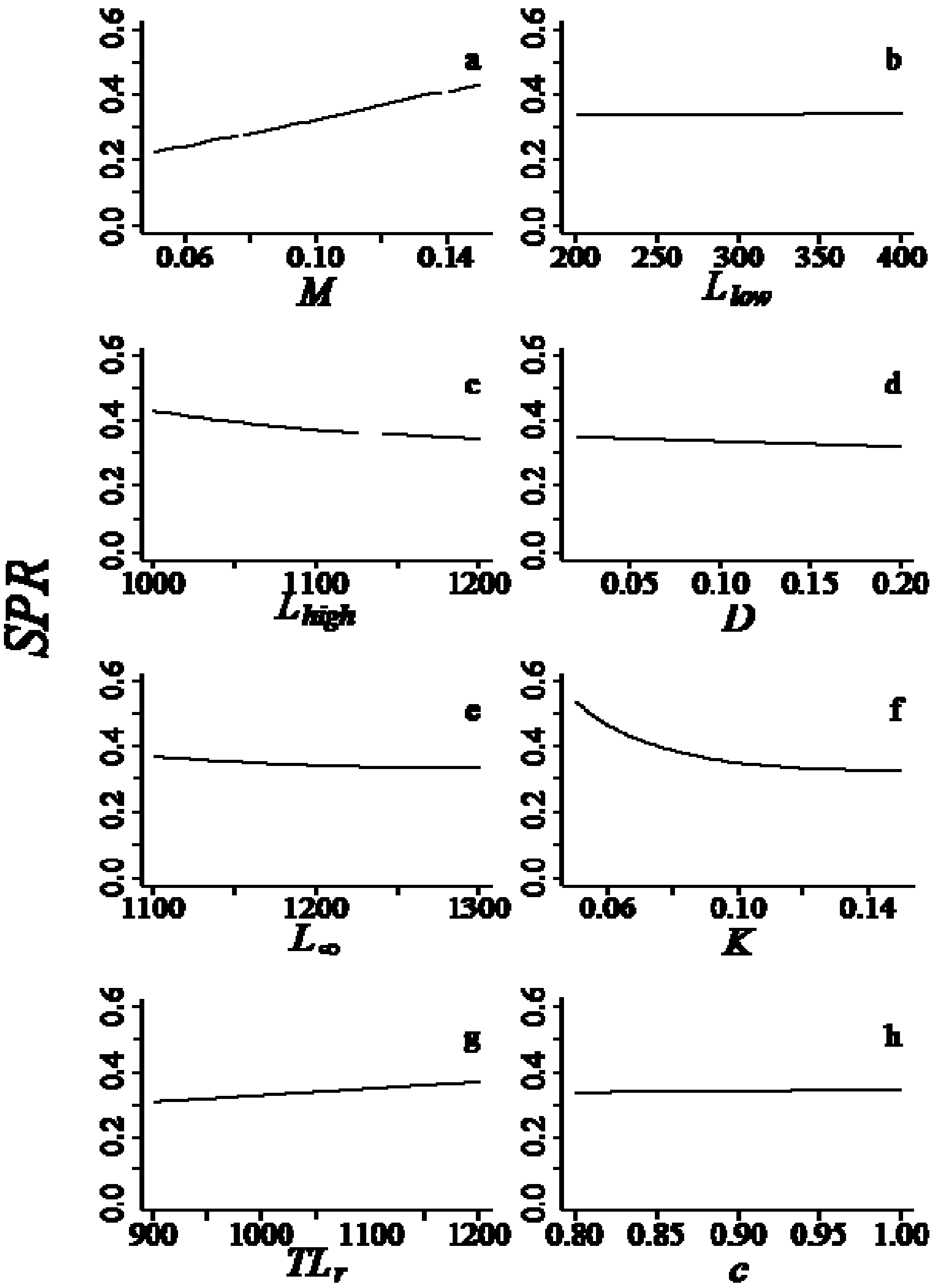

Figure 31: Sensitivity analyses showing equilibrium SPR as a function of varying eight model parameters.

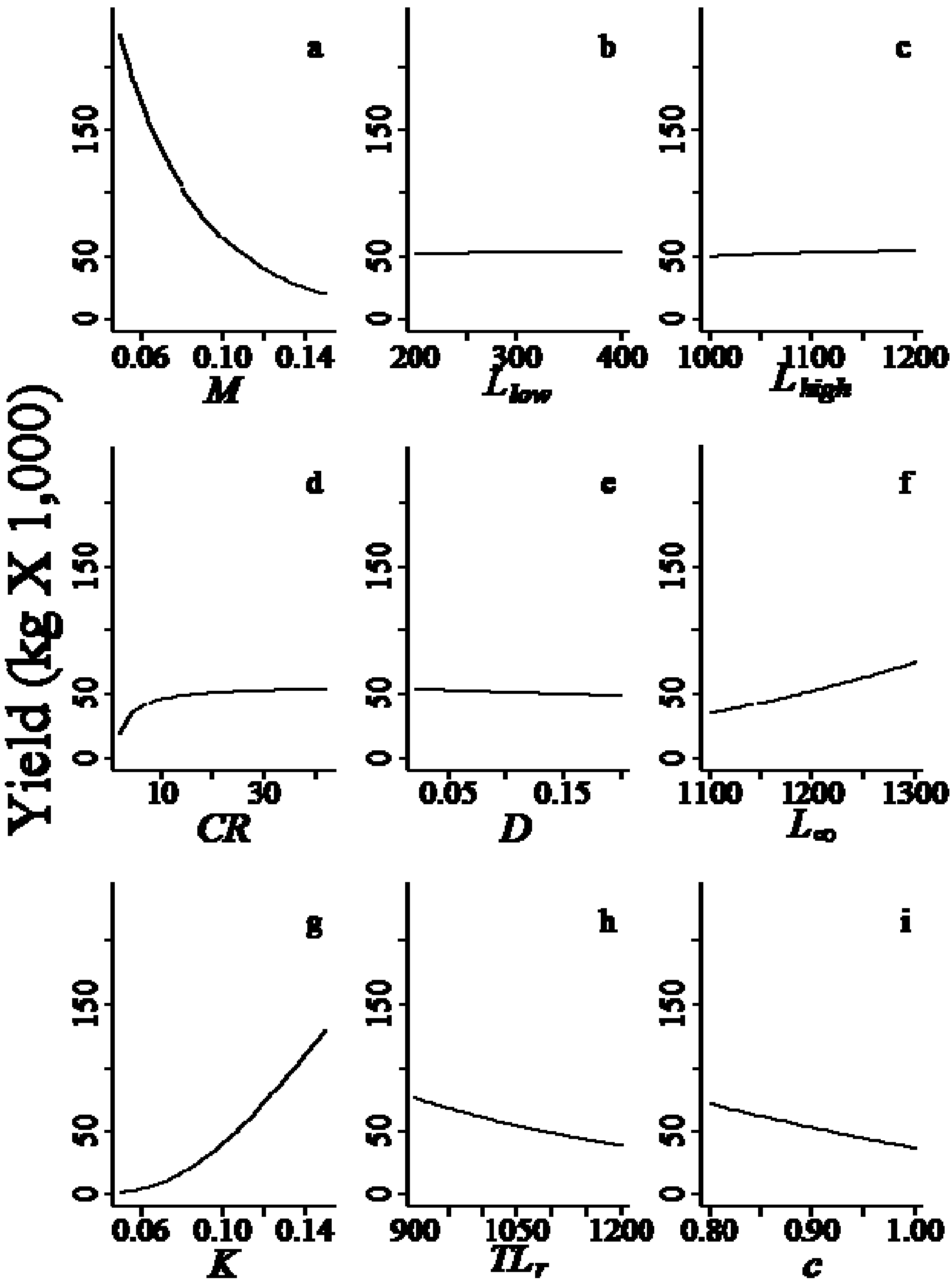

Figure 32: Sensitivity analyses showing equilibrium yield (kg X 1,000) as a function of varying nine model parameters.

Discussion

Our results infer that annual exploitation rates should not exceed about 0.3 for Murray cod fisheries unless the LML was 700 mm or higher. There are no previously published estimates of fishing mortality for Murray cod. Recent tagging experiments have indicated that annual exploitation could exceed 0.3 for fish in the 600–750 mm size for Murray cod in the Middle Murray River (C. Todd, Arthur Rylah Institute for Environmental Research, pers. comm.). Values of SPR below 35% are typically considered at risk of recruitment overfishing (Mace 1994; Clark 2002), and thus our results suggest that exploitation rates of 0.3 would put Murray cod stocks at risk of recruitment overfishing regardless of the LML. Future research should include estimates of fishing mortality, preferably using a variable reward system correcting for angler non-reporting (e.g. Pine *et al.* 2003), telemetry methods (e.g. Hightower *et al.* 2001), or estimates of fish harvest from creel surveys divided by estimates of fish population size. Such estimates would substantially enhance resource managers' ability to improve Murray cod fisheries, and results of this study could be used to set management plans when fishing mortality is better described.

We used equilibrium analysis that is useful for predicting long-term average responses to changes in LML, but may not predict fishery characteristics in the short term if recruitment is highly variable. Our equilibrium model predictions showed substantially less young fish in the population than creel survey data, and the model indicated that variable recruitment could have caused the observed trend. Rowland (2005) noted that Murray cod recruitment in the MDB appeared to increase in the late 1990s and early 2000s. Koster *et al.* (2004) also found increased electrofishing catches of Murray cod in the Goulburn River in 2003 and 2004 relative to previous sampling efforts in the early 1980s. These indicators suggested that recruitment of Murray cod increased over the last 5-10 years. The coefficient of variation around annual recruitment of 80% has been found for other freshwater predators (Allen and Pine 2000). The national recreational fishing survey in 2001 found that about 30% of total angler catch was harvested (Henry and Lyle 2003), which is closer to our equilibrium predictions from the model (40%). Higher than average recruitment in recent years is a probable explanation for the discrepancy between our model and the recent creel survey data.

Stocking of Murray cod has increased exponentially beginning in the early 1980s, with over one million juvenile Murray cod stocked in VIC and NSW waters by 2002 (Lintermans *et al.* 2005). The contribution of stocked fish to wild Murray cod populations is not known, and higher recruitment in recent years could result from natural production, stocked fish, or both. Future studies should evaluate the effects of stocked Murray cod on total recruitment to the population and the production of wild fish progeny.

Low angler and electrofishing catches of fish over 500 mm (Koster *et al.* 2004; Brown 2008) in the Murray and Goulburn Rivers may indicate that fishing mortality has altered Murray cod size structure and thus SPR. The creel survey data showed that only 4% of angler trips resulted in the harvest of a Murray cod with a 500 mm LML in place (Brown 2008). Truncation of the age/size structure from fishing mortality could have caused the low number of harvested fish. Recent reports of higher recruitment would indicate that recruitment overfishing is not currently occurring. Additionally, if larger Murray cod are not vulnerable to fishing gear and/or sampling gear, then the low occurrence of large fish in creels and sampling gear could reflect fish vulnerability rather than fishing mortality. Our model used a dome-shaped vulnerability schedule to include the hypothesis that fish vulnerability declines with size. The true vulnerability schedule is not known. The relatively large sensitivity of SPR to the L_{high} parameters suggests that understanding the shape of the vulnerability curve is important because the vulnerability function becomes more sigmoidal and less dome-shaped as L_{high} increases. This amplifies the need for size-specific estimates of fishing mortality for Murray cod.

We assumed a 5% discard mortality which was similar to recent work based on common recreational angling practices (VicDPI, unpublished data), but measuring discard mortality under a range of fishery conditions will be important in the future. High discard mortality substantially alters the effects of fishing on yield and SPR, with length limits showing little value when discard mortality reaches or exceeds 0.1 for long-lived species like the Murray cod (Coggins *et al.* 2007). Thus, measures of discard mortality under a range of fishing methods will be important when evaluating potential harvest regulations for Murray cod fisheries. However, our sensitivity analysis showed that SPR and yield were relatively insensitive to variation in discard mortality.

Our model predicted the proportion of angler trips that would be influenced by each hypothesized regulation, which could make regulation choices more interpretable to fisheries managers and anglers. Model outputs common to commercial fisheries stock assessments such as yield or SPR are often vaguely useful in recreational fisheries where anglers evaluate trade offs relative to their personal fishing outcomes. Anglers frequently consider the opportunity to catch large, trophy sized Murray cod an important component of fisheries (Rowland 2005). Our model output put regulation comparisons on a per-angler trip basis, which may help fishery managers explain regulation trade offs. For example, our analysis showed that increasing the LML from 500 to 700 mm would increase the proportion of trips where anglers would catch a Murray cod and catch a trophy Murray cod, but decrease the probability they would be able to harvest a fish. Such analyses may help anglers understand the trade offs associated with a range of regulation options. Variable recruitment can mask effects of regulation changes, and realized changes in angler catches may vary substantially from model predictions if recruitment vulnerability is high (Allen and Pine 2000). We found evidence of this when comparing the equilibrium model predictions to creel survey data, suggesting that inter-annual variability in recruitment could mask effects of regulation changes.

We assumed that fishing effort would remain similar after each hypothesized regulation change, but shifts in angler effort are an important consideration in open-access recreational fisheries (Cox *et al.* 2003). Lowering bag limits has caused fishing effort reductions for walleye *Sander vitreus* fisheries in North America (Beard *et al.* 2003; Fayram and Schmalz 2006). Alternately, some recreational fisheries remain extremely popular with very stringent size limits in place (Chen *et al.* 2003). Fishing effort responses to changes in regulations will likely vary with the value anglers place on harvesting fish relative to higher catch rates of fish they must release. Future studies could evaluate model predictions of angler catch by evaluating how fishing effort would change after regulations were enacted (e.g. Beard *et al.* 2003; Cox *et al.* 2003; Fayram and Schmalz 2006), which would be useful for managing open-access recreational fisheries (Cox *et al.* 2003).

Conclusion

The current regulations for Murray cod in Victoria and New South Wales includes a seasonal closure during September through November (spawning period), a 500 mm LML, and only one fish larger than 750 mm (Victoria) or 1,000 mm (NSW) can be taken per angler daily. The restriction on upper-sized fish is not expected to influence fishing mortality because of the low occurrence of fish exceeding these sizes both in the field (Brown 2008) and based on our model predictions. The LML and seasonal closure represent the major regulations of fishing mortality. Both NSW and Victoria will raise the LML to 600 mm in 2009, but our model predicts only modest increases in SPR, yield, catch, and catch of trophy-sized fish based on this 100 mm increase in the LML. Additionally, the model predicted that LML of 700 to 800 mm have the potential to increase yield, total angler catch (number of fish), and the number of trophy fish for Murray cod fisheries, particularly if U exceeds 0.2. Only total harvest (number of fish) was predicted to decline by increasing the LML to 700 mm. Our results indicated that higher LML should be considered by fisheries managers, pending estimates of the fishing mortality rate for a range of Murray cod stocks.

Acknowledgments

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Chapter 7. Age Structured Model – A simulation model to explore the relative value of stock enhancement versus harvest regulations for fishery sustainability.

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Abstract

Harvest restrictions and stock enhancement are commonly proposed management responses for sustaining degraded fisheries, but comparisons of their relative effectiveness have seldom been considered prior to making policy choices. We built a population model that incorporated both size-dependent harvest restrictions and stock enhancement contributions to explore trade-offs between legal minimum length (LML) and stock enhancement for improving population sustainability and fishery metrics (e.g. catch). We used a Murray cod (*Maccullochella peelii peelii)* population as a test case, and the model incorporated density-dependent recruitment processes for both hatchery and wild fish. We estimated the spawning potential ratio (SPR) and fishery metrics (e.g. angler catch) across a range of LML and stocking rates. Model estimates showed that increased LML were much more effective than stock enhancement for increasing SPR and angler catches in exploited populations, but length limits resulted in reduced harvest. Stocking was predicted to significantly increase total recruitment, population sustainability, and fishery metrics only in systems where natural reproduction had been greatly reduced via habitat loss, fishing mortality was high, or both. If angler fishing effort increased with increased fish abundance from stocking efforts, fishing mortality was predicted to increase and reduce the benefits realized from stocking. The model also indicated that benefits from stock enhancement would be reduced if reproductive efficiency of hatchery-origin fish was compromised. The simulations indicated that stock enhancement was a less effective method to improve fishery sustainability than measures designed to reduce fishing mortality (e.g. length limits).

Introduction

Sustainability of open-access recreational fisheries is an increasing concern in both freshwater and marine systems. There is growing evidence of overfishing from recreational fishing across broad spatial and temporal scales (Post *et al*. 2002; Cooke and Cowx 2004). Limiting angler effort to reduce overfishing in public resource fisheries is difficult. Resource managers have often adopted aggressive management strategies such as stringent length limits and bag limits (e.g. walleye *Sander vitreus* in Wisconsin, Beard *et al*. 2003), and increased use of closed areas and seasons after contentious debates. Stock enhancement programs are often favoured by angler groups for restoration and sustainability of fisheries that have undergone overfishing and/or loss in habitat quantity and quality (Grimes 1998; Molony *et al.* 2003; Lorenzen 2005).

Despite positive intentions of stock enhancement programs, substantial evidence shows that stock enhancement can be ineffective or cause harm to the fisheries which are targeted for improvement. Hilborn and Eggers (2000) showed that one of the world's largest hatchery operations (i.e. pink salmon *Oncorhynchus gorbuscha* stocking in Prince William Sound) resulted in replacement of wild stocks rather than additive effects to natural recruitment. Lorenzen (2005) gave an overview of the potential benefits and pitfalls of stock enhancement and showed that stocking large, recruited fish can substantially increase fishery yields, whereas stocking maladapted hatchery fish can cause substantial negative impacts via introgression with native fish and reduce population abundance. Hilborn (1999) commented that responsible use of hatcheries in management should focus on (1) testable objectives for the hatchery programs including a plan for evaluation of those objectives, (2) measures of survival of stocked fish via tagging programs and monitoring, and (3) an assessment of whether the hatchery program produces a net augmentation to the wild stock. Leber (2002) also called for thorough evaluation and hypothesis testing in stock enhancement before production-level operations begin. Public and private institutions stock billions of fish worldwide annually, but the relative role of stock enhancement compared to other tools for sustaining fisheries (e.g. harvest restrictions) has seldom been evaluated.

The purpose of this study was to use simulation modelling to evaluate the role of stock enhancement relative to other common management strategies for sustaining and improving recreational fisheries. We used Murray cod (*Maccullochella peelii peelii)*, a large freshwater predator in Australia, as a test case for this evaluation. Murray cod are long-lived (likely exceeding 50 years) and late maturing (ages 4-5) species (Lintermans *et al.* 2005). Murray cod spawn on hard substrates and exhibit a short period of male nest guarding, whereafter, larvae free drift downstream for 5-7 days (Humphries *et al.* 2002; Lintermans *et al.* 2005). Murray cod populations have undergone large population declines over the past century, likely due to a combination of overfishing, introduction of exotic species, and habitat alterations (Lintermans *et al.* 2005; Rowland 2005). Murray cod have been managed with a combination of closed seasons, length limits, bag limits, and stock enhancement in the MDB (Lintermans *et al.* 2005). Murray cod fisheries are an excellent example for evaluating the value of stock enhancement relative to other management tools. Our objectives were to: 1) evaluate the potential for stock enhancement to improve fishery sustainability and angler catch metrics relative to LML, 2) explore effects of stocking rates and stocked fish sizes for producing fishery benefits, and 3) evaluate the potential for negative impacts of stocking via density dependence and/or genetic changes in the stock.

Methods

Model background and strategy

We modified an age-structured simulation model for Murray cod (Allen *et al.* 2009) to include stock enhancement and provide equilibrium predictions of stocking effects on fishery sustainability and angler catch metrics. Modifications included changes to the stock-recruitment function used by Allen *et al.* (2009) to allow for the introduction of hatchery-reared fish, density-dependent survival for both pre-recruit wild and hatchery fish, and contributions of stocked fish to the spawning stock. We also incorporated methods to evaluate relative reproductive fitness effects on population total recruitment that could result from hatchery selection for maladapted fish (Figure 33).

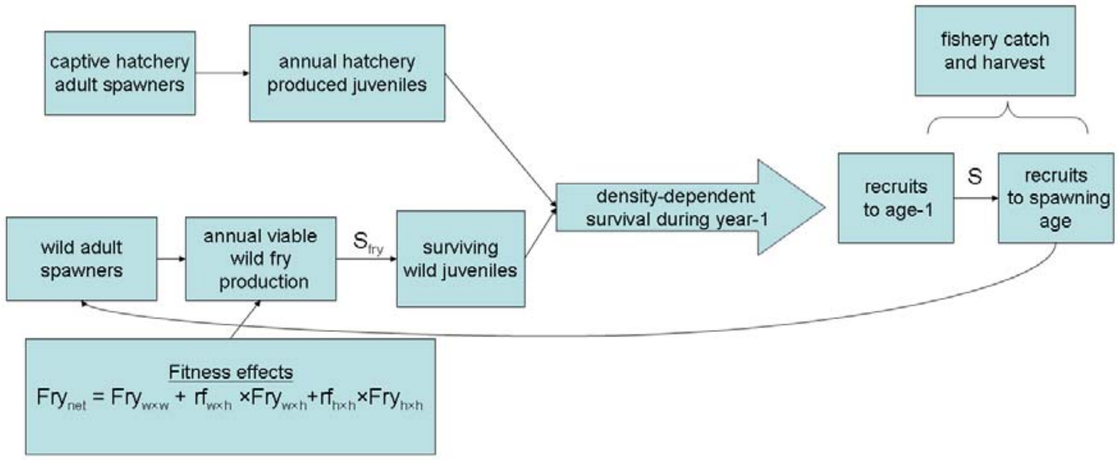

Figure 33: Conceptual diagram of the population dynamics model that incorporates stock enhancement contributions to a wild spawning population, relative fitness of mating combinations, and fishery effects. S_{fry} = parameter for reduced survival from egg to size-at-stocking in the wild relative to high survival owing to intensive hatchery culture (i.e., "hatchery advantage", Lorenzen, 2005). S is post-recruitment survival (i.e., after age-1) assumed the same for wild and hatchery origin fish. Fry_{net} is viable wild fry production from three possible matings that can occur in the wild (wild × wild, w × w; wild × hatchery, w × h; and hatchery × hatchery, h × h) multiplied by the relative fitness (rf) for each mating (rf for w × w = 1).

The age-structured model incorporated a Beverton and Holt stock recruitment function and predicted number-at-age matrices for wild produced and hatchery origin fish. The model assumed that wild fish progeny, progeny from fish that originated in a hatchery and matured in the wild, and hatchery released age-0 fish would all contribute to density-dependent survival and structure year class strength at age-1. Annual recruitment to age-1 from wild adults and hatchery origin adults in the population was estimated using a Beverton-Holt function:

$$R_{w,t} = \frac{a \times Fry_{net,t}}{1 + b \times Fry_{tot,t}} \tag{1}$$

where $R_{w,t}$ is the recruitment of wild spawned fish in year *t*, $a = 0.22$ (Allen *et al.* 2009), $Fry_{net,t}$ is the net reproductive output to size *i* in year *t* from three potential adult matings in the wild: wild × wild, hatchery × wild, and hatchery × hatchery (see below), and $b = 2.11 \times 10^{-6}$ (Allen *et al.* 2009). The quantity $Fry_{tot,t}$, is the total reproductive output to size *i* in year *t* from all matings as:

$$Fry_{tot,t,i} = S_{fry,i} \times \sum_{g} f_g N_{w,g,t} + S_{fry,i} \times \sum_{g} f_g N_{h,g,t} \tag{2}$$

where $S_{fry,i}$ is the survival of wild-hatched fish from egg to size *i*, the size at stocking. The f_g was the age-specific fecundity (Rowland 1998; Allen *et al.* 2009), and $N_{w,g,t}$ is the number of wild fish of age *g* at time *t*, and $N_{h,g,t}$ is the number of hatchery-released fish at age *g* at time *t* in the population. Values $N_{w,a,t}$ and $N_{h,g,t}$ were predicted by applying a survivorship schedule from Allen *et al.* (2009) to the age-1 recruits for each group in each year. The model simply tracked hatchery-origin and wild fish as adults in the population, and the progeny from both sources entered the population as wild recruits.

The parameter S_{fry} reflected higher mortality in the wild from egg to the stocking length *i* relative to mortality in hatcheries during that period because of intense culture (i.e. a "hatchery advantage", Lorenzen 2005). We estimated S_{fry} with a size based mortality model (Lorenzen 1996; Lorenzen 2006) using the mean annual instantaneous natural mortality at one gram (M = 3.13) at temperate latitudes reported by Lorenzen (1996). We converted Lorenzen's annual rates of M to daily instantaneous mortality values, and estimated S_{fry} for a range of potential stocking lengths assuming a juvenile growth rate of 0.5 mm/d based on pond experiments (Ingram 2009).

Recruitment to age-1 for fish released from the hatchery was modeled with a Beverton-Holt function such that the strength of density dependence determining their survival depended on their abundance (i.e. the stocking rate) and wild-spawned juvenile abundance:

$$R_{h,t} = \frac{a \times Fry_{h,t}}{1 + b \times Fry_{tot,t}} \tag{3}$$

where $R_{h,t}$ is predicted recruitment of hatchery released fish in year t, $Fry_{h,t}$ is the number of hatchery released fish in year t, and a, b, and $Fry_{tot,t}$ were the same as in equation 1. Total age-1 recruitment in year t was then found by $R_{w,t}$+ $R_{h,t}$. Hatchery released fingerlings and wild-spawned fish that survived to age-1 were assumed to have equal survival, maturity, growth, and fishing vulnerability schedules to their maximum age.

Using three mating combinations allowed for potentially reduced offspring viability for fish with hatchery genotypes (per Walters and Martell 2004). The distribution of reproductive output in a year was generated from three mating types and the production for each mating in each year was estimated by assuming the genetic composition of the population was at Hardy-Weinburg equilibrium. The proportion of annual fingerling output from wild fish relative to total fingerling production (P_{ww}) was used to partition the total annual fingerling production for the three possible mating combinations. Annual fingerling production for each combination was estimated as:

$$Fry_{ww} = P_{ww}^2 \times Fry_{tot} \tag{4}$$

$$Fry_{wh} = 2 \times P_{ww} \times (1 - P_{ww}) \times Fry_{tot}$$

$$Fry_{hh} = (1 - P_{ww})^2 \times Fry_{tot}$$

Using these results, we could estimate net viable fry production while accounting for potentially reduced reproductive success stemming from hatchery effects (e.g. selective breeding for unfit wild genes in the hatchery, Walters and Martell 2004) with the equation:

$$Fry_{net} = Fry_{ww} + Rf_{wh} \times Fry_{wh} + Rf_{hh} \times Fry_{hh} \tag{5}$$

where Rf_{wh} and Rf_{hh} are the reproductive success for wild × hatchery and hatchery × hatchery matings, respectively, relative to wild × wild matings. Relative fitness values equaled one for all mating combinations and simulations (i.e., Fry_{net} = Fry_{tot}) except for our specific evaluation of reproductive fitness effects (see below).

We primarily used parameters from Allen *et al.* (2009) to parameterize our model, but used historical stocking and creel survey data from the Goulburn River, Victoria, Australia to apply our model to one specific fishery that was actively stocked with 50,000 fingerlings (45–55 mm total length) per year on average. The Goulburn River is a tributary to the Murray River with moderate angler effort (132 angler h/ha) and average angler catch rates (6.12 fish/ha) relative to other Murray cod fisheries (effort range: 58–253 angler h/ha, catch range: 12.7–1.9 fish/ha) monitored with creel surveys (Brown 2009). The river has natural reproduction of fish and is considered a relatively stable to slightly increasing Murray cod population (Koster *et al.* 2004). All simulations started with 40,000 fish recruiting to age-1 in the unfished condition, which resulted in a predicted catch that was similar to estimated angler catches from 2007 creel surveys on the Goulburn River (Brown, 2009). The fishing mortality rate was not known, and we used F = 0.15 as a hypothesized moderate level of fishing mortality per Allen *et al.* (2009) for the base case model.

Model scenarios

We used the model to evaluate benefits of stocking relative to using LML for maintaining population viability (i.e. potential reproductive output relative to unfished conditions) and fishing quality metrics at the Goulburn River. The Goulburn River was annually stocked with 25,000–72,500 Murray cod fingerlings (i.e. 50 mm TL) from 2001–2008, and we simulated a range of 30,000 to 300,000 stocked fingerlings into the modelled population. We compared effects of stocking to a range of legal minimum length limits from 500 to 800 mm TL. Our base model (i.e. stocking large numbers of 50 mm fingerlings) used average juvenile survival (S_{fry}) for temperate fishes from Lorenzen (1996). This resulted in an average egg to 50 mm TL survival of 0.0048 for wild fish. We modified our base case scenario by changing the S_{fry} survival parameter to evaluate the impact of stocking fewer, larger Murray cod. We simulated a range of 2,000 to 16,000 stocked advanced fingerlings (i.e. 150 mm TL), where wild fish survival from egg to 150 mm was 9.1×10^{-5} via Lorenzen (1996). Model outputs included Spawning Potential Ratio (SPR), catch of trophy fish (i.e. total length exceeding 1000 mm), total harvest (number of fish), and percent contribution of stocked fish to age-1 in the population. Spawning potential ratio was estimated as the ratio of Fry_{net} in the fished condition relative to Fry_{net} at time zero. The SPR is the reproductive capacity of the stock in the fished relative to unfished condition, and values of SPR $\geq$ 35% are desired to decrease recruitment overfishing risks (Mace 1994; Clark 2002; Walters and Martell 2004). We also assessed the model's ability to emulate situations where stocking was hypothesized to have the largest influence on population abundance (e.g. a recruitment limited population) and compared harvest regulations to stock enhancement for fisheries sustainability.

Lastly, we evaluated the potential for angler effort responses to influence the effectiveness of stock enhancement for a recruitment limited population with high fishing mortality. Annual fishing mortality (F_t) was estimated as a function of the vulnerable biomass (B) available to anglers in year t as:

$$F_t = 1 - e^{-q^* B_t} \tag{6}$$

and

$$q^* = -\log_e(1 - 0.4) / B_{equ} \tag{7}$$

where B_{equ} was the equilibrium vulnerable biomass in the fished condition with stocking at 50,000 fingerlings per year to enhance the population (i.e. at the new equilibrium). The angler effort dynamics model assumed that anglers could detect annual changes in the vulnerable biomass that would arise from a range of stocking rates (i.e. relative to stocking 50,000 fingerlings per year and F=0.4) and effort would respond linearly to those vulnerable biomass changes. Angler effort effects were modelled at a fixed minimum length limit of 600 mm (i.e. the current LML in Victoria, Australia) across the range of stocking rates described above. We predicted annual fishing mortality and SPR and compared these results to simulations without angler effort responses.

Results

The base case model indicated that stocking fingerlings was not likely to influence population sustainability or angler catch metrics for the fishery, especially relative to length limits. Values of SPR increased substantially as the LML increased, but stocking had only a minor influence on SPR values (Figure 34). Similarly, catch of trophy fish was not influenced by stocking rates up to 300,000 fish per year. Number of fish harvested declined with increasing length limit as expected, but stocking up to 300,000 fingerlings did not substantially increase harvest for any hypothesized length limit. Under these scenarios, the percent of total age-1 fish that were predicted to be hatchery fish reached 7% at 300,000 stocked fingerlings. Our base case model suggested that recent stocking rates of fingerlings would not substantially influence the Murray cod fishery at the Goulburn River, given an annual exploitation rate of 0.15 and recruitment values required to produce observed catches.

Stocking advanced fingerlings had slightly more influence on fishery metrics than stocking high numbers of fingerlings. For example, stocking 2,000 versus 16,000 advanced fingerlings was predicted to increase SPR from 0.38 to 0.45 with a 600 mm LML (Figure 35). Stocking advanced fingerlings also had the potential to increase catch of trophy fish, and slightly mediated declines in harvest as the LML increased (Figure 35). The percent of total age-1 fish that were predicted to be hatchery fish ranged from 2% at

2,000 advanced fingerlings to 15% at 16,000 advanced fingerlings. The model suggested that stocking smaller numbers of advanced fingerlings caused larger fishery benefits than stocking fingerlings. This resulted because larger fish underwent less density-dependent interactions with wild pre-recruits, and had better survival. For our base model, length limits showed substantially more power to protect stocks from overfishing than stocking fish of either size because SPR values were more strongly influenced by the length limit than the stocking scenarios we considered (Figure 34 and Figure 35).

Stocking programs are sometimes implemented to rebuild stocks that have low recruitment and/or high rates of fishing mortality (Leber 2002), and we explored scenarios where stocking programs could improve Murray cod populations. We simulated a low recruitment system by lowering average wild fish recruitment to 25% of the equilibrium value in our base model. Reduced recruitment simulated poor habitat quality relative to the average recruitment conditions at the Goulburn River, a viable Murray cod fishery. Stocking under a scenario with a 75% recruitment reduction and F = 0.15 showed a higher potential for stocking to improve sustainability and the fishery. Increased stocking rates showed potential to increase SPR, the percentage of age-1 fish of hatchery origin, and trophy catches for all LML (Figure 36). Beneficial effects from stocking were negatively related to the LML. For example, trophy catch at a 500 mm LML was predicted to double as fingerling stocking rate was increased from 50,000 to 300,000, but the same increase in stocking only increased trophy catch by about 60% if the LML was 800 mm TL (Figure 36). High length limits protected adult fish from harvest and resulted in decreased proportional contributions of stocking to recruitment, thus decreasing the efficiency of stock enhancement.

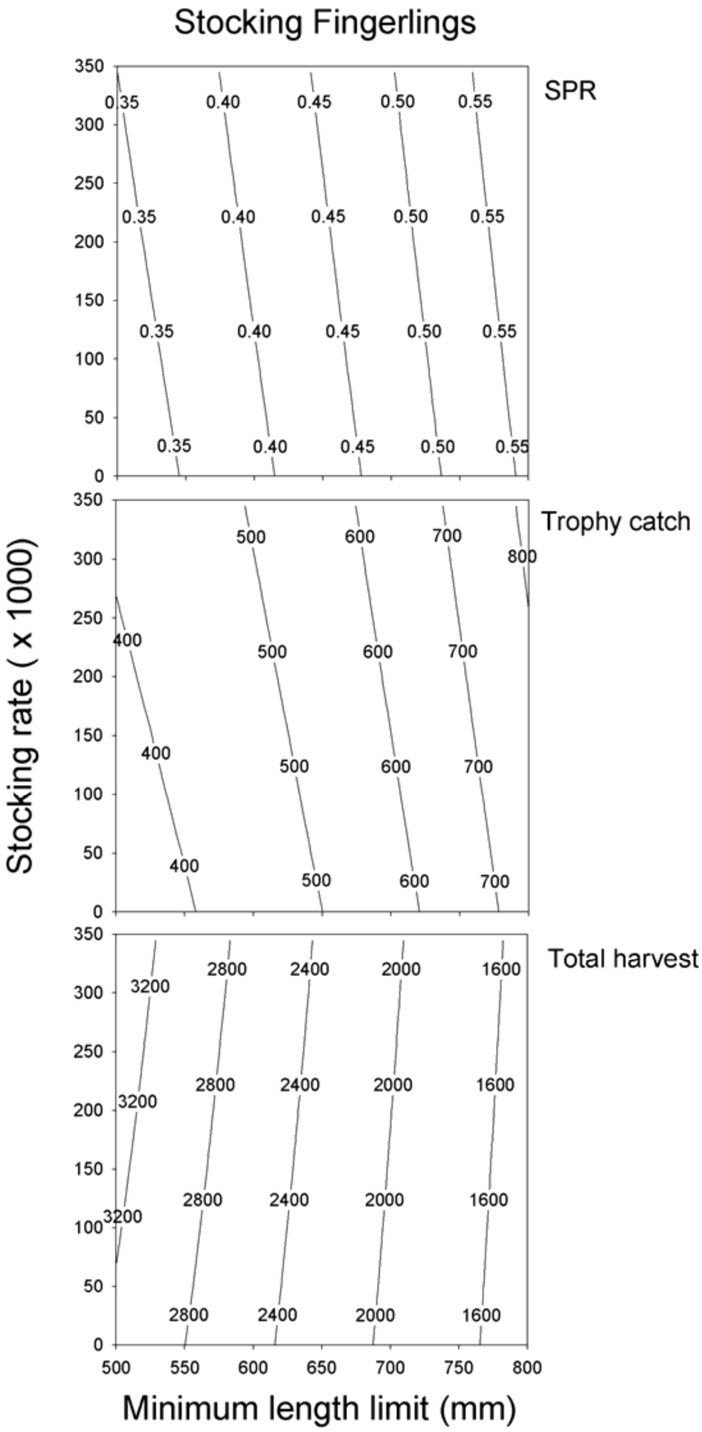

Figure 34: Model predictions of Spawning Potential Ratio (SPR, top panel), number of trophy fish caught (centre panel), and total harvest (number of fish, bottom panel) plotted on the number of fingerlings stocked (y axes) and the minimum length limit (x axis). Simulations are for the base case scenario of F = 0.15 with fingerlings stocked at 50 mm TL.

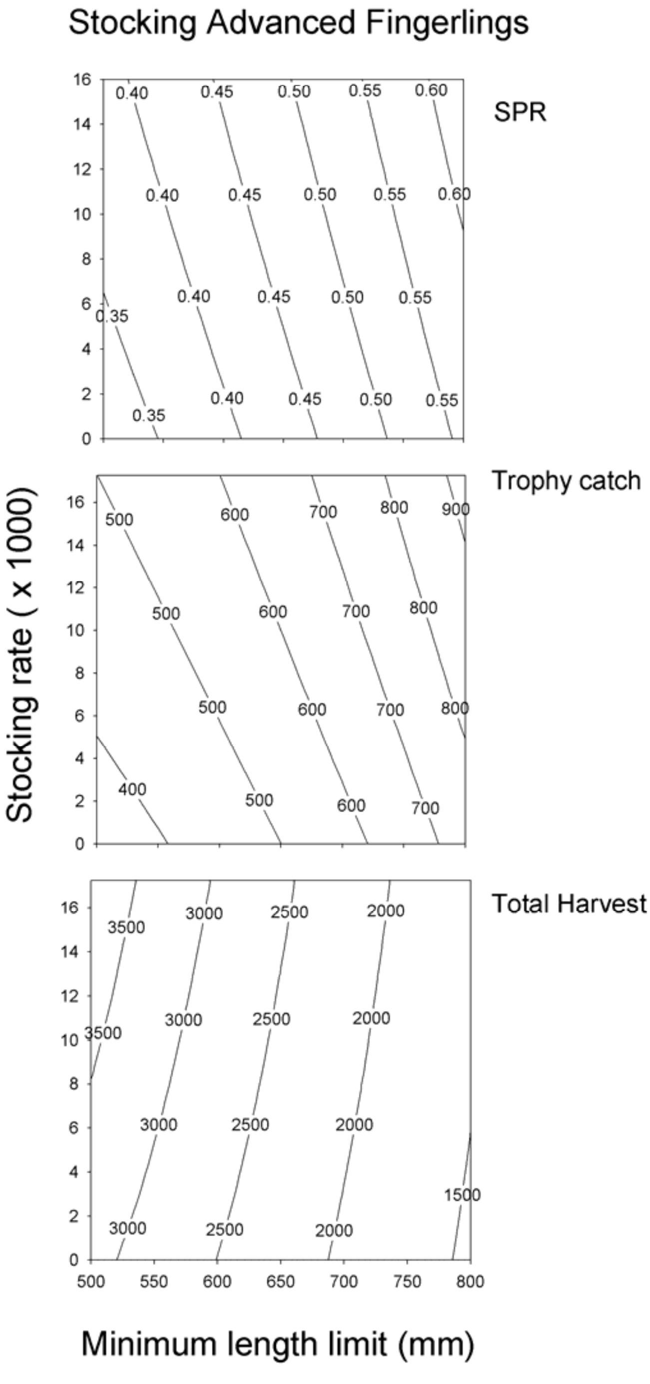

Figure 35: Model predictions of Spawning Potential Ratio (SPR, top panel), number of trophy fish caught (centre panel), and total harvest (number of fish, bottom panel) plotted on the number of advanced fingerlings stocked (y axes) and the minimum length limit (x axes). Simulations are for the base case scenario of F = 0.15 with advanced fingerlings stocked at 150 mm TL.

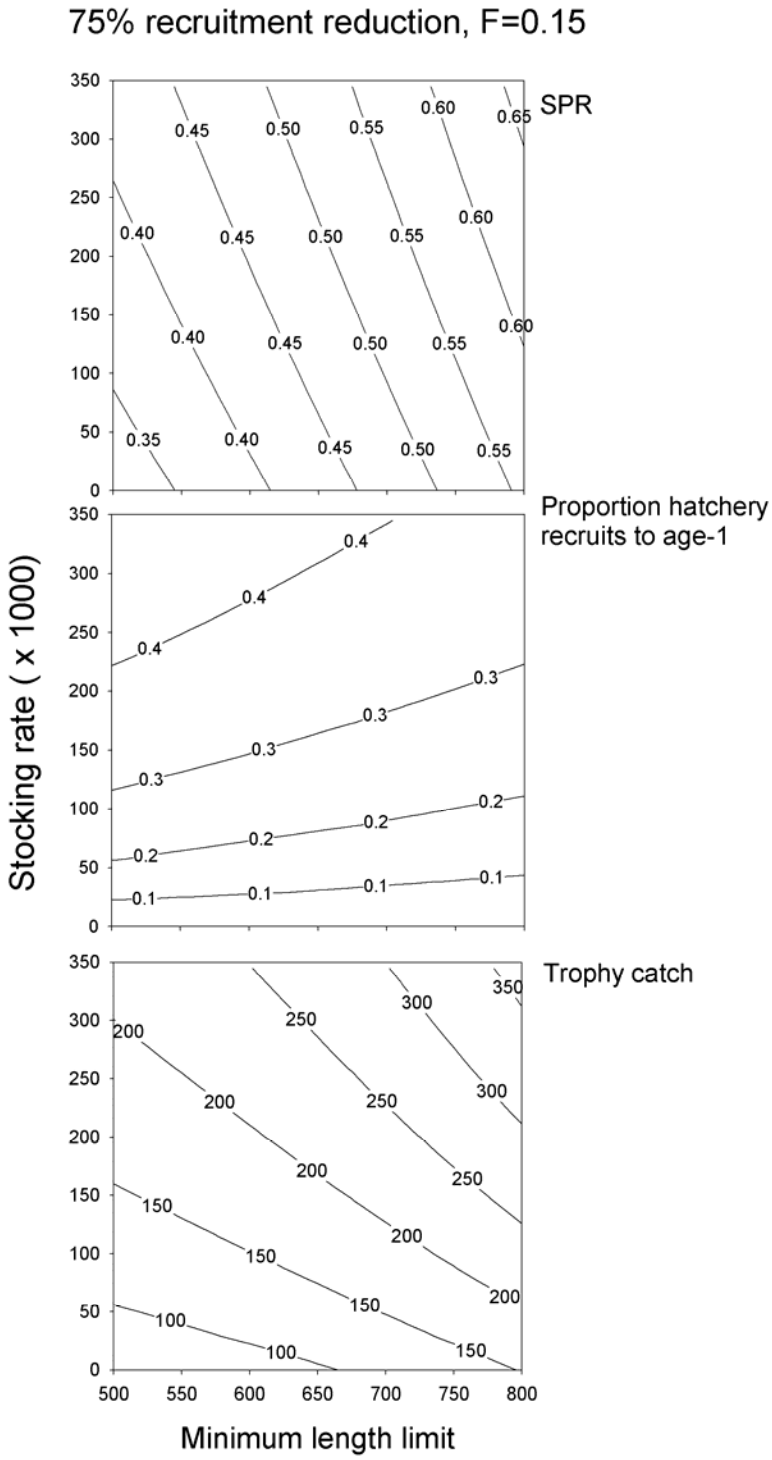

Figure 36: Model predictions of Spawning Potential Ratio (SPR, top panel), proportion hatchery recruits to age-1 (centre panel), and trophy catch (number of fish, bottom panel) plotted on the number of fingerlings stocked (y axes) and the minimum length limit (x axes). Simulations are for the base case scenario of F = 0.15 with 25% of equilibrium recruitment and fingerlings stocked at 50 mm TL.

We then increased fishing mortality from the base case of 0.15 to 0.4 combined with the 75% recruitment reduction to simulate intense fishing effects on a population with low recruitment. This scenario showed stronger contributions of a hatchery program to sustainability and fishery metrics relative to the lower exploitation scenario. Beneficial effects from stocking were again negatively related to the LML (Figure 37). The model showed that stocking could have benefits for populations that are undergoing very low recruitment and/or high fishing mortality, but an interaction between stocking rate and LML will affect the total contribution of the stocking program. Benefits from stocking were stronger under low LML than high LML. Length limits over 700 mm were required to prevent recruitment overfishing (i.e. SPR < 0.35) if fishing mortality was 0.4 (Figure 37).

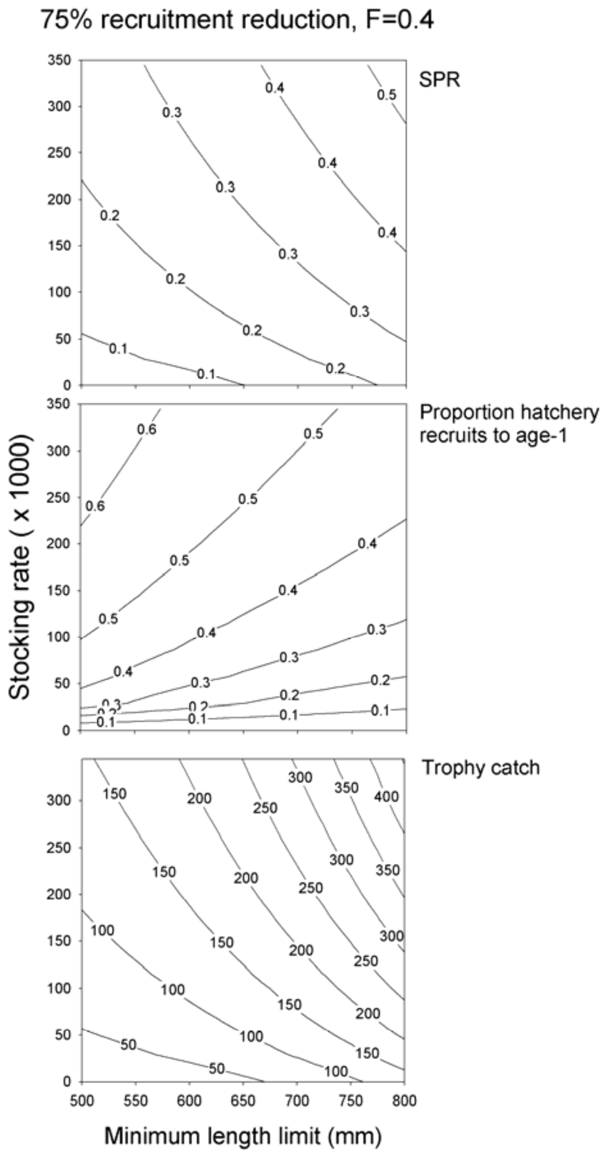

Figure 37: Model predictions of Spawning Potential Ratio (SPR, top panel), proportion hatchery recruits to age-1 (centre panel), and trophy catch (number of fish, bottom panel) plotted on the number of fingerlings stocked (y axes) and the minimum length limit (x axes). Simulations are for the scenario of F = 0.40 with 25% of equilibrium recruitment and fingerlings stocked at 50 mm TL.

Incorporating angler effort responses influenced annual fishing mortality rates and SPR for a fixed 600 mm LML (Figure 38). Angler effort responses were predicted to reduce annual fishing mortality to 0.3 if stocking was eliminated or increase fishing mortality to 0.55 at our highest stocking rates (Figure 38). The SPR values suggested that angler effort responses could reduce the magnitude of recruitment overfishing at low stocking rates (i.e. < 50,000 fingerlings per year), but also lower the potential of rebuilding the population to a sustainable level at higher stocking rates. Thus, the model showed that if stocking increased fish abundance and attracted anglers, it could result in low population abundance and SPR.

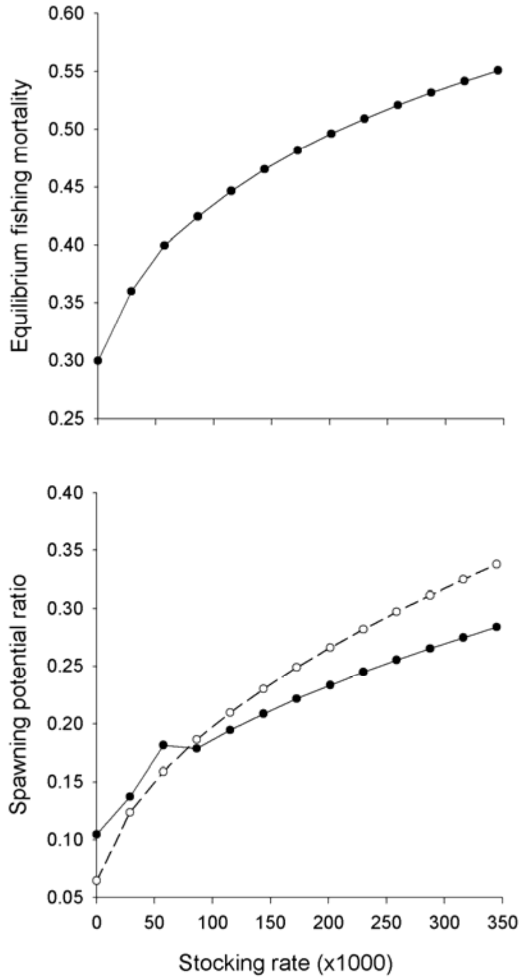

Figure 38: Model predictions of equilibrium annual fishing mortality (F_t, top panel), SPR (bottom panel) plotted on the number of fingerlings stocked (y axes) at a fixed minimum length limit (600mm). Simulations were conducted with angler effort responses to deviations from equilibrium vulnerable biomass when F=0.4 at annual stocking rate of 50,000 fingerlings (solid line in both panels). For SPR, the predictions for fishing effort responses (solid line) are shown with comparison to a fixed fishing mortality rate (dashed line, F=0.4) at 25% base case recruitment and fingerlings stocked at 50 mm TL.

We simulated the effect of reduced reproductive fitness, relative to wild × wild mating, for hatchery × wild and hatchery × hatchery matings in a population with a 75% recruitment reduction, F = 0.15, and an annual stocking rate of 50,000 fingerlings (i.e. a scenario where stocking had high success, Figure 36). We predicted total recruitment to age-1 by varying relative fitness from 0.0 to 1.0, where 1.0 represented an equal reproductive fitness to wild ×wild mating. Results showed that reduced fitness of hatchery × hatchery crosses had minor impacts on total recruitment to age-1 in the population (Figure 39). Conversely, reduced fitness of hatchery × wild caused large impacts to total recruitment to age-1 in the population (Figure 39). This occurred because hatchery × hatchery crosses would be relatively rare in the population at an annual stocking rate of 50,000 fingerlings, but reduced fitness of hatchery × wild crosses resulted in large numbers of fish with reduced effective reproductive output. In cases where stocked fish represented a significant fraction of the total recruits (15–20%), either due to very high stocking densities or very low natural recruitment, reduced fitness of hatchery fish would have substantial population-level consequences.

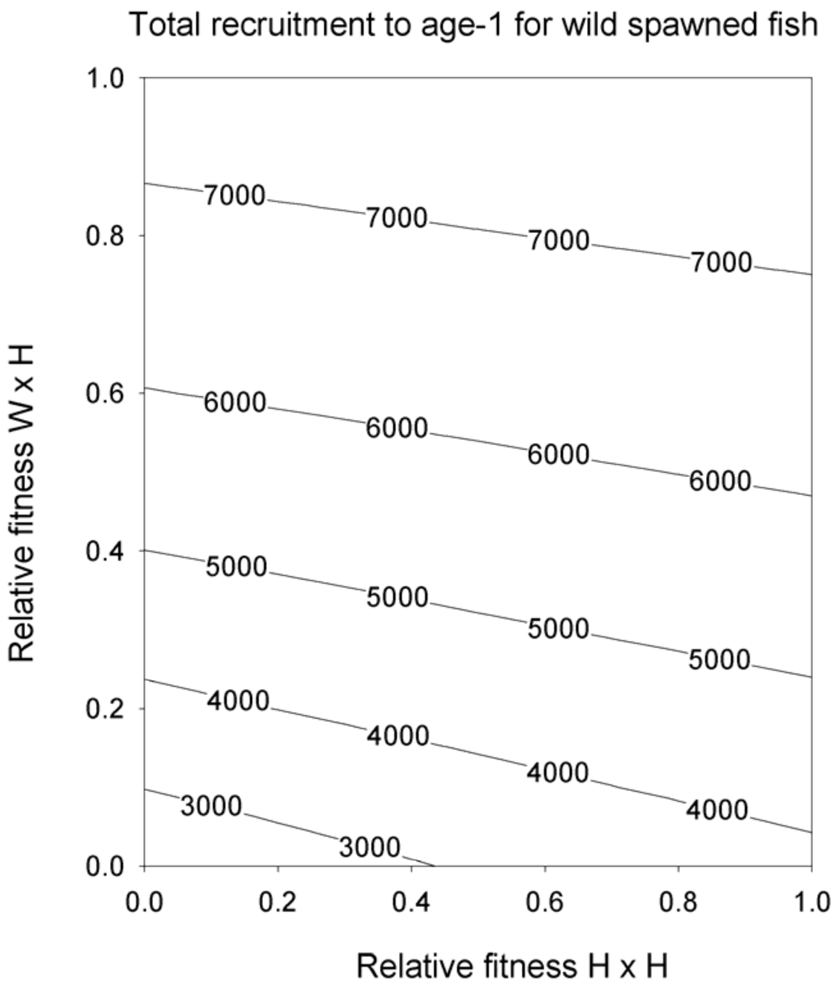

Figure 39: Model predictions of the number of recruits to age-1 for fish hatched in the wild plotted on the relative fitness of wild × hatchery crosses (W × H, y axis) versus the relative fitness of hatchery × hatchery (H × H, x axis) crosses. Simulations were conducted at 25% of base case recruitment, F = 0.15, and 50,000 fish stocked at 50 mm TL.

Discussion

Our population model expanded on an existing simulation model to include a popular fisheries management strategy (i.e. stock enhancement) whose effects were largely unknown. Simulations showed that interactions between wild population abundance (e.g. natural recruitment), stocking strategy (i.e. size at stocking and stocking density), and the fishery (i.e. management regulations and fishing mortality) determined the potential for stocking to contribute to sustainability and fishery metrics. In most cases, increasing LML had larger positive effects than stocking. The model illustrated cases where stocking could substantially benefit fisheries, such as those with very low natural recruitment (e.g. due to habitat loss) or overfishing. The model also highlighted the importance of considering angler effort dynamics and relative fitness among mating combinations for scenarios where stocking was predicted to enhance Murray cod populations.

We found a lack of benefits from stocking under our base case scenario, which resulted from density-dependent mortality during the juvenile life stage. The strength of density dependent mortality for stocked fish depended on the abundance and size at stocking, the abundance of wild spawned fish, and total juvenile recruitment regulation. Stocking fish at 50 mm TL in our base model caused stocked fish to undergo high mortality along with pre-recruit wild-hatched fish. Stocking advanced fingerlings increased the contribution of stocked fish to the population, because larger fish underwent less density-dependent mortality. They still made a minor contribution relative to wild-hatched fish. The influence of stocking fingerlings in our example was low due to (1) high juvenile mortality, and (2) stocking rates that were not substantial relative to the model-predicted natural recruitment to age-1. Our base case model suggested that hatchery fingerlings could partially replace but would not significantly augment wild recruits because stockings were small relative to wild production. Similarly, Scharf (2000) found no population level effects of stocking early juvenile red drum *Sciaenops ocellatus* in Texas estuaries, and hypothesized that density-dependence during juvenile stages limited the potential for small stocked fish to contribute to a year class. This was also shown empirically by Hilborn and Eggers (2000) for the Kodiak Island pink salmon hatchery, where increasing the size at stocking improved hatchery contributions, but additive population level effects were minimal.

Legal minimum lengths were substantially more effective at preventing overfishing and maintaining the fishery than stocking across all the scenarios we evaluated. Decreasing fishing mortality for spawners, by increasing the LML, resulted in much higher recruitment than high stocking rates despite a hatchery advantage that acted to increase per-capita survival from egg to stocking sizes in hatcheries. Increased LML can fail to improve fishery sustainability if discard mortality is high (Coggins *et al.* 2007). Discard mortality for Murray cod appears low (≤10%), making length limits a viable management option, but potential mortality trade-offs should be considered when imposing length limit changes for species with higher levels of discard mortality. The model suggested that stocking could benefit fisheries with low recruitment and/or relatively high fishing mortality. Stocked fish could contribute substantially to a year class in these simulations, and these results were supported from field studies in some Victorian waters where stocked fish were common in angler catches. Hall and Douglas (2008) reported almost 50% of Murray cod collected in the Loddon River, Victoria were hatchery released fish and they concluded that stocking was likely making a large contribution to the fishery. The Loddon River was a low density population because the average angler catch rate in creel surveys was < 0.01 fish/hr whereas average angler catch rates at other rivers ranged from 0.08 –0.03 fish/h (Brown 2009). The Loddon River also had one of the highest angler effort estimates (253 h/ha) among rivers sampled by creel surveys (range = 44 - 253 hrs/ha, Chapter 3). Thus, those field observations support our model predictions of a type of system where stocking would have the highest potential to contribute substantially to fish abundance and angler catches.

The ability of stock enhancement to improve population sustainability was sensitive to potential angler effort responses and biomass dependent fishing mortality. Our angling effort response model implied that increased stocking rates could cause fishing mortality to increase, and vice versa. The potential for angler effort responses to fish abundance is dependent on many factors (e.g. harvest regulations, Beard *et al*. 2003; proximity to other opportunities, Cox *et al.* 2003; Post *et al.* 2008) that have been highlighted as an area of continuing research importance (Pereira and Hansen 2003 and references therein). Of further importance is the need to recognize the potential for management strategies to mask population declines or result in counter-intuitive results (Lewin *et al.* 2006) as seen in our simulations where high stocking rates increased fishing mortality and reduced SPR relative to lower stocking rates. Leber (2002) and Walters and Martell (2004) warned that attracted fishing effort from stocking could increase fishing mortality on an already depressed wild population. In contrast, fishing mortality reductions at low stocking sizes increased SPR relative to fixed F simulations, but SPR was still below a level considered sustainable. We did not have data to indicate how fishing effort would respond to management changes in Murray cod fisheries, and future use of this model should seek to measure these responses. Angler effort dynamics should be expected to affect the efficiency of stock enhancement and regulation policies both within a system and across multiple systems.

Our results indicated that any reduction in reproductive fitness for hatchery progeny could have implications for realized recruitment to age-1. Realized recruitment could be less than 50% of potential recruitment if reproductive fitness of hatchery progeny was greatly reduced relative to wild progeny reproductive fitness. Catastrophic examples of hatchery genetic effects have been presented for multiple enhancement programs (see Walters and Martell 2004). Our results showed that a stocking program could appear to be successful, even in the presence of reduced reproductive fitness for hatchery fish, because hatchery fish would represent a significant portion of the total population. Realized recruitment would be much lower than potential recruitment due to reduced fitness of hatchery fish and the effects would not be apparent from evaluations of percent contribution of hatchery fish. Reduced fitness for hatchery × wild crosses had much larger effects on potential recruitment than reduced fitness for hatchery × hatchery matings. This occurred because of hatchery × wild matings were much more common than hatchery x hatchery matings in the simulated populations. We presume hatchery × wild matings would commonly occur in wild populations experiencing stocking, indicating the importance of hatchery fish fitness for enhancing total recruitment.

Although our simulations demonstrated some scenarios where stocking was predicted to enhance population sustainability and the fishery, we included several assumptions that may restrict our results to a "best case" description. There were no data available on survival of hatchery released Murray cod to maturity, and, our assumptions of equal survival, growth, and maturity would likely overestimate stocking contributions if differences between wild and hatchery released fish existed. These important parameters have been shown to be lower for hatchery fish in many cases (Lorenzen 2005), and much attention has been directed at increasing post-release performance of hatchery fish (e.g. Brown and Day 2002). Our use of a Beverton-Holt stock-recruitment function to describe density-dependent pre-recruit survival could also contribute to our simulations being "best case" descriptions. For example, our estimated benefits of stocking for spawning potential ratio and recruitment would be overestimated if Murray cod exhibit overcompensation at highest stock abundances (e.g. a Ricker stock recruitment relationship). The form of the stock recruitment curve is not known for Murray cod, and our use of the Beverton and Holt curve served as a best case scenario for stocking to influence total fish abundance.

Our simulations demonstrated some cases where stock enhancement could benefit fisheries, but we caution that those cases represented best case scenarios rather than the expected outcomes for most conditions where stock enhancement is applied (e.g. existing wild fish recruitment, moderate fishing quality, etc.). Similar to Allen *et al.* (2009) we found our model's estimates to be most sensitive to changes in natural mortality and growth parameters and model estimates of SPR were robust to changes (i.e. 95% confidence intervals for natural mortality at length from Lorenzen, 1996, 2006) in our S_{fry} parameter.

Conclusions

Public and political support for stocking programs has generally been favourable even in the absence of impact evaluations (Leber 2002), and stock enhancements to improve population sustainability are likely to continue in the future. Thus, our modelling approach and results should provide insight into the types of systems stocking could result in fishery improvements. Our model scenarios indicated that systems with low recruitment and/or high fishing mortality would provide the highest potential for stocking to cause a significant proportional increase in stock abundance. In contrast, stocking systems that currently have substantial natural recruitment will not benefit population sustainability or the fishery. Field experiments to test our results could use an adaptive experimental approach as described by Walters and Hilborn (1978) and suggested by Leber (2002). Potential treatments would include high LML or catch and release regulations at a range of stocking rates for some systems, and stocking without length limits in others. An experimental framework could isolate the impacts of stocking versus harvest regulations, which would reduce the ambiguity in uses of both practices simultaneously. Leber (2002) called for a predictive capability to determine the potential for stocking success. Modelling approaches, like those presented here, combined with adaptive experimental research are necessary for quantitatively resolving the role of stocking programs relative to other tools used for fisheries management.

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Chapter 8. Management Implications

Size at Maturity

- The size at maturity assessment was basic biology undertaken using a non-destructive sampling support method. The information collected gives scientific support for the present length based fisheries management regulations.
- The information also informs the fisheries modelling approach to management scenario testing.
- The finding of differences in Murray cod growth rates in the lower Murray River compared to other fisheries regions suggests that management of this fishery may require further examination.

Creel Surveys

- Reduction of the number of rods/lines per angler to two may have had little effect in removing any fishing 'pressure' from Murray cod stocks. Anglers using from one to five rod/lines showed no difference in catch rates for Murray cod but anglers with two rods harvested (i.e. the retained catch) Murray cod at a greater rate than those with a single rod.
- Analysis of a subset of the interviews in 2006–07 on a study reach where set-lines were legal fishing gear, showed only a slightly higher (non-significant increase) catch rate for anglers using set-lines. However, it is acknowledged that this research project was unable to measure the effect of the removal of large numbers of set-lines that were legal in much of the fishery prior to this study.
- Although catches varied from reach-to-reach, and at a finer scale within reaches, the study shows that an 'average hectare' of river yields from 2 to 12 Murray cod as a recreational catch per season, and less than two (0–1.4) Murray cod are harvested per hectare.
- Bait used on single-hooks is by far the most popular and successful method used in the recreational Murray cod fishery along the Murray River and its Victorian tributaries. Cheese, shrimps and bardi grubs were the three most popular successful baits for Murray cod. In total these three baits accounted for 54% of the catch. Lures accounted for 13% of the Murray cod catch. Lure-caught Murray cod included proportionally more fish larger than the LML than fish caught on bait.
- Bait fishing anglers should use large hooks (> 5/0) for several reasons;
    - Most Murray cod were caught on relatively small hooks (relative to the gape of the fish) from size 1/0 to 4/0. Few anglers fished with hooks sized 5/0 or larger. There was some evidence that anglers using such large hooks catch proportionally more fish larger than the present LML (60cm, TL), although more research effort into selectivity of large hook-sizes is warranted.
    - A third of Murray cod caught were deep-hooked. However, the probability of deep-hooking varied with fish-size and hook-size. Using large hooks (5/0 and larger) gives the bait-fishing angler the best chance of only shallow-hooking a Murray cod. As hook-size decreases and fish-size increases the chance of deep-hooking reaches a maximum. Due to the species' voracity and large gape-size, large hooks do not *just* catch large Murray cod; but any small cod caught when using a large hook are less likely to be deep-hooked.
    - Differential survival rates of some fish species by hook-size indicate that this should be experimentally investigated for Murray cod to determine if there is a trade-off with large hooks causing low survival when they are ingested deeply.
- Voluntary release rates (of fish larger than LML) are moderate (14–32%) and to date only contribute moderately to the sustainability of this fishery. The high overall release rates observed (63–95%), are mainly compulsory release due to fish being smaller than the legal minimum length.
- Given the likely importance of the survival of small Murray cod, in the sustainability of this fishery, more should be done by all stakeholders to try and achieve practice-change to maximise survival of

released fish. The uptake of 'best-practice' for released Murray cod survival in this fishery is presently poor. Use of nets or jaw-grippers to land fish is low. Hooks were most often removed from deep-hooked fish, instead of the recommended 'cutting the line close to the jaw and leaving the hook in the fish'.

- Periodic repetition of some or all of these surveys is recommended to establish a time-series of statistics on the recreational fishery. These data could be used to evaluate future management decisions, through the use of such data in quantitative Murray cod population models (Allen *et al.* 2009), and in an adaptive management approach as advocated in recent Murray cod management workshops (Nicol *et al.* 2005).
- To enable evaluation of the sustainability of the recreational fishery, the present catch-density and harvest-density estimates should be viewed in the context of comparable population-density estimates collected from representative sites around the Murray-Darling Basin.
- To achieve practice-change to modify angler-behaviour towards techniques that improve post-release survival, increased and more effective efforts must be made to advocate 'best-practice' for improved released fish survival targeting anglers fishing for Murray cod. The present study acts as a benchmark to evaluate levels of practice-change achieved in the future.
- Experimental examination of the potential trade-off between increasing damage from using large hooks, and of large hooks reducing the incidence of deep-hooking, warrants investigation. Until this is complete, the recommendations made to anglers should be to "use large hooks for Murray cod to reduce the number of small fish being deep-hooked and increase your chances of catching one large enough to harvest."
- Effects of the South Australian moratorium on Murray cod fishing (commenced 2009) may have ramifications for cross-border fisheries through increased effort in open fisheries. The present work is suitable as a benchmark for SA residents fishing NSW and Victorian waters. The SA moratorium may serve as a *de facto* 'protected area' for Murray cod and presents opportunities to study effects on adjoining fisheries, to increase understanding of the potential role of protected areas in the sustainable management of Murray cod stocks.
- Further analysis of existing angler interview data at finer spatial scales than presented here may provide increased knowledge of the relationship between catch and effort and ease-of-access for anglers. This may inform resource managers about the level of Murray-cod protection/exploitation that could be provided by management of physical angler-access.
- This detailed information of angler harvest now needs to be put in context in relation to the fisheries concerned, i.e. what portion of the population of the fishery does this harvest represent?

Release Survival

- The short term post-release hooking mortality rate estimate of 2% for recreationally-caught Murray cod in the southern Murray-Darling River system when combined with creel survey data indicates that discard mortality can be at least as important to consider in any stock assessment as death due to harvest. This figure should be considered as conservative as compounding effects of multiple capture, short term observation period and protection of released fish would all tend to increase mortality.
- Estimates of fishing mortality would identify whether discard mortality has significant implications for sustainability of Murray cod fisheries. Our estimates raise concern that discard mortality could limit the effectiveness of fishing regulations that cause large numbers of fish to be caught and released (e.g., minimum lengths, slot-lengths). Future studies of discard mortality should consider these population level implications, because a low rate of D can represent substantial mortality relative to harvest.
- This study could be extended to further examine the relationships between some of the variables relating to catch (e.g. hook size, hook removal, landing/handling) and release mortality levels with a view to management changes that would preferably reduce capture levels in the first instance or at least increase post-release survival.

Population Modelling

Length Limit Assessment

- Murray cod fisheries can be managed sustainably, but the choice of harvest regulation is important.
- The current LML of 60 cm will protect Murray cod from overfishing as long as fishing mortality is less than about 20% of the stock per year.
- Higher levels of fishing mortality risk recruitment overfishing, and could be unsustainable.
- Higher LML regulations would protect stocks from overfishing, increase total angler catch and catches of trophy fish, but will lower harvest. Managers should recognize this trade off and identify the types of fisheries that anglers wish to have when setting regulations.
- Our model output included expected changes in angler catch rates, which could make presenting regulation choices more relevant to anglers.
- Estimates of fishing mortality are needed for informed management of Murray cod throughout the basin.

Stocking influencing fisheries success

- In most simulations, increasing LMLs were predicted to be more effective at preventing recruitment overfishing (i.e., spawning potential ratio < 0.3) than increasing stocking rates.
- In systems with good recruitment, stocking fewer large juveniles (e.g. 150 mm) was predicted to have a higher contribution than stocking many small juveniles (e.g. 50 mm). Benefits (i.e. reducing recruitment overfishing and improving fishing) of stocking systems with natural recruitment were minimal.
- Simulations indicated that systems with minimal natural recruitment (e.g. rivers and lakes with very low natural recruitment) should be the major focus of stocking programs, which can create fisheries. Stocking was predicted to have stronger benefits in systems with low recruitment potential (e.g., poor juvenile habitat) and/or with high fishing mortality rates that limited spawner abundance and reproductive output.
- In scenarios where stocking was predicted to improve population sustainability, potential for angler effort responses following stocking could compromise the intention of stocking programs via attracting angler effort that would increase fishing mortality.
- Use of percent contribution of hatchery fish to recruitment as a measure of stocking success can be misleading, because hatchery fish can replace wild fish resulting in no additive effects on recruitment. Future studies should address whether stocking is additive to natural recruitment.
- Simulations of relative fitness of hatchery versus wild fish showed that recruitment potential could be largely compromised as stocking contributions increased, and that genetics quality assurance programs in hatcheries are important.
- Modeling efforts could be improved by including field-measured estimates of fishing mortality and comparisons of hatchery versus wild fish growth and survival within stocked systems.

Benefits and Adoption

Benefits

The major beneficiaries of the outcomes of this work will be firstly fisheries managers and ultimately recreational anglers, other sectors associated with the recreational fishing industry and the environment in general.

Managers will benefit from having sound scientific information on which to base management rules. They will also benefit from being able to examine the possible impact of changing management rules by using the population models developed during the course of this project. There is also now a benchmark in relation to angler catch and harvest against which future comparisons can be made.

The angling public will benefit from having a sustainably managed fishery into the future. This in turn can have benefits to industries and regions that depend on recreational fishing for parts of their income.

Sustainable management of Murray cod also has a flow-on environmental benefit for this iconic species.

Adoption

The first part of the adoption process involves transfer of information and uptake by fisheries managers. Chapters 4, 5, 6 and 7 are widely available as stand-alone peer-reviewed publications. There have already been a number of presentations and workshops based on the results of the various aspects of this project.

The major one of these was a specific Murray cod workshop convened by Fisheries Victoria and sponsored by FRDC held at Mulwala on 22–23 February 2010. This was titled "Enhancing the Murray cod recreational fishery – a basin wide approach to research and management". This involved participation from fisheries researchers and managers from all major agencies across the Murray-Darling Basin.

The proceedings of this workshop are now published[8] and detail agreement on priorities for further work required to complement the results of this study; in particular the determination of the proportion of populations that are harvested by anglers.

Further Development

The project has provided all the information that it set out to collect. Some of this could certainly be refined and this would also result in more accurate population modelling. The other major work that is required to enable detailed figures to be put around sustainable harvest levels is to determine what proportion of the Murray cod population does the angler harvest determined during this study represent.

Fisheries managers are now aware of the work that has been done although there is more analysis that can be done from the creel data. There is also a need to follow up on this in conjunction with the release survival work and look at ways of reducing released fish mortality through angling practice change.

There is also capacity to extend the results of the creel surveys to the angling public to inform them of the results of the work including the best methods to catch fish; the most productive baits and fishing times etc and also the importance of best practice fish handling methods.

[8] Enhancing the Murray Cod recreational fishery – A basin-wide approach to research and management. Summary of workshop 22-23 February 2010, Department of Primary Industries, Fisheries, Melbourne.

Planned Outcomes

1. Evaluation of the level of angler participation in recreational fisheries for Murray cod across the Basin.
   This outcome has social implications for resource managers in relation to use patterns and demographics. It is also of benefit from a community perspective in relation to angling promotion and tourism.
2. Definition of recreational impacts (harvest, release survival) on the resource.
   Results from these studies provide the information for determining exploitation rates by recreational fishers for input to predictive population models. Managers will benefit from the harvest information whilst anglers will benefit from determination of the best release techniques.
3. Determination of size at maturity for Murray cod across the Basin.
   This outcome is critical for management of the populations as it is the major control option for regulating catch. Managers will benefit from this, as will anglers as they both have a stake in sustainability of the fisheries.
4. Sound biological and social basis for sustainable management of the fishery including a means of evaluating various management scenarios.
   Input of the results of the catch, release survival and length at maturity studies, along with presently known population parameters such as age, growth and fecundity into a population model will provide the basis for management recommendations that have the best chance of achieving sustainability of the fisheries. A further benefit of the scenario testing is the ability to evaluate a number of management strategies including varying length (slot) limits. There is an overarching public and environmental benefit from sustainability of the fisheries.

Outcomes achieved to date

Outcome 1

- The levels of angler participation in a major part of the recreational Murray cod fishery in the Murray-Darling Basin have been accurately benchmarked.

Outcome 2

- The catch and harvest rates for a major part of the total recreational fishery have been benchmarked for future reference.
- Knowledge obtained on fishing methods has been combined with estimates of survival of released angler caught fish to provide an accurate measure of angling mortality in the fishery.
- The information has been used to inform population models for the fishery.

Outcome 3

- Size at maturity assessments have confirmed the validity of the present LML regulations for the fishery.
- Information on size at maturity has also been used to inform population models for the fishery

Outcome 4

- Population models have been constructed and used to assess likely impacts of various management scenarios on the fishery.
- There is a sound body of information available for future reference.
- Fisheries managers have been informed of the results of the work and have been involved in setting priorities for further research.

Conclusions

The project has met each of its planned objectives to the extent necessary to accurately support the conclusions drawn.

Size at maturity

This basic biological information is critical because the management of the fishery is primarily based on legal minimum length. Murray cod populations were sampled in a non-destructive manner to assess size at maturity and information was collected from across the range of the species. This information, both from a traditional management use (i.e. allow for at least one spawning before the species is subject to harvest), as well as when used in a population model can be used to validate the legitimacy of current minimum size regulations pertaining to Murray cod and also forecast the outcomes of alternative regulation scenarios or future fishery trends. The results support the setting of uniform Murray cod size-based regulations over large spatial scales giving scientific support to current regulations and allows the use of mathematical fishery models to.

In addition to achieving the intended objective, the finding of differences in Murray cod growth rates in the lower Murray River suggests that this fishery should be looked at in more detail.

From a scientific perspective, some extra size at maturity information on Murray cod from the mid-NSW streams would complement the present data.

Angler harvest

The surveys of angler catch and associated angling method and demographics represent the most detailed information of this type ever collected for any freshwater fishery in Australia. The creel surveys covered an area that, according to the 2003 National Recreational and Indigenous Fishing Survey, represents about 50% of the national Murray cod fishery. As such, it sets a benchmark for future assessments and provides a huge amount of information for future use for both anglers and fisheries managers. It has achieved each of the objectives set for this specific part of the project:

- Complete a stratified, random, survey of recreational fishers on important Murray cod fisheries.
- Provide whole-fishery estimates of the Murray cod catch, (retained and released components), effort and catch characteristics (including non-Murray cod by-catch)
- Describe and quantify fishing practices potentially important to the released survival rate for Murray cod.
- Provide estimates of recreational catch and retained catch that can be used in modelling simulations of a range of Murray cod management scenarios.

Outputs from the creel survey have already been noted by fisheries managers in Victoria and other states, they have been used in the preparation of population models and they will be further disseminated to anglers via popular articles and talks.

The angler harvest is only half of the story in relation to sustainability of the fishery. It now remains to assess what proportion of the wild populations this harvest represents. The need to make that link was always appreciated but it is a complex project in itself and it was never an objective of this project.

It was an associated objective of the original FRDC proposal to seek other funding to undertake more extensive creel surveys of Murray cod fisheries in central and northern NSW. Applications to relevant funding bodies for that work were submitted, but they were not successful.

Release survival

The objective of this part of the project was to estimate the survival rate of Murray cod that were released by anglers. This objective was achieved. Whilst the estimated mortality rate of around 2% is quite low, the number of fish that are caught and released in this fishery means that 2% is a significant figure in the overall angler harvest rate for the fishery. This output has been incorporated into the population models and it will also form the basis for further consideration of angler practice change in the fishery.

Population modelling

An age structured model was developed from data collected during the surveys as well as from known biological parameters for Murray cod. This model was used to firstly to analyse the effect of varying the LML on the sustainability of the fishery. The significant findings were:

- Murray cod fisheries can be managed sustainably, but the choice of harvest regulation is important.
- The current MLS of 60 cm will protect Murray cod from overfishing as long as fishing mortality is less than about 20% of the stock per year.
- Higher levels of fishing mortality risk recruitment overfishing, and could be unsustainable.

Secondly, modelling was used to examine the comparative effect of stocking hatchery fish on sustainability. The findings from this were as follows:

- In most simulations, increasing LMLs were predicted to be more effective than increasing stocking rates at preventing recruitment overfishing.
- In systems with good recruitment, stocking fewer large juveniles (e.g. 150 mm) was predicted to have a higher contribution than stocking many small juveniles (e.g. 50 mm). Benefits (i.e. reducing recruitment overfishing and improving fishing) of stocking systems with natural recruitment were minimal.
- Stocking was predicted to have stronger benefits in systems with low recruitment potential (e.g. poor juvenile habitat) and/or with high fishing mortality rates that limited spawner abundance and reproductive output.
- Simulations indicated that systems with minimal natural recruitment (e.g. rivers and lakes with very low natural recruitment) should be the major focus of stocking programs, which can create fisheries.

Both modelling approaches highlighted that better estimates of fishing mortality are required for better informed management of Murray cod fisheries throughout the Murray Darling Basin. This task is now the focus of various research proposals.

The modelling outcomes exceeded the original objectives of the project largely through the input of Mike Allen and staff. Their ongoing involvement is a significant outcome of the project and has greatly assisted not only in the analyses of the data but importantly in getting messages out to stakeholders.

References

All references used are cited in conjunction with the relevant papers.

Appendix 1

None attached. All papers included in body of report.

Intellectual Property

Any information gathered during the course of the project either presently is, or will be made freely available for further use as required. Some of this information represents the first and only such information available for this fishery.

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