How can recreational angling regulations help meet the multiple objectives for the management of Murray cod populations

Simon Nicol, Charles Todd, John Koehn and Jason Lieschke
Co-operative Research Centre for Freshwater Ecology
Arthur Rylah Institute for Environmental Research
Department of Sustainability and Environment
123 Brown St, Heidelberg, Vic 3084

Simon.Nicol@dse.vic.gov.au

Introduction

In Australia, angling regulations are applied to help ensure healthy and sustainable fisheries for future generations (QLD DPI 2004; NSW Fisheries 2004; PIRSA 2004). Size limits are set in an attempt to allow fish to reach maturity and complete their breeding cycle, while bag limits help to make sure everyone gets a fair share of the resource, and that a species is not overfished (NSW Fisheries 2004). The effectiveness of such management tools in achieving these goals is too a large extent dependent on the accuracy of the assumptions behind the regulations. Ecological data is inherently uncertain, whereas management regulations by definition cannot be. This uncertainty in information may impact upon the efficacy of a regulation if the proportion of occasions when the assumption(s) behind a regulation are violated is high. For example, size limits for Murray cod are set at >500 mm on the assumptions that fish of this size have reached sexual maturity and have reproductively contributed to the population. Some individuals however are probably larger than 500 mm before they commence breeding. If this proportion is high, then it is possible that not enough individuals have reproductively contributed to the population before capture and the regulations may not be ensuring a healthy and sustainable fishery for future generations. Consequently, for management to be transparent and understood by those stakeholders it affects, it is important that the tool is evaluated periodically to ensure that the assumptions of the regulations are valid.

Murray cod is a large (up to 113 kg), popular angling species once abundant and widespread throughout the Murray-Darling Basin in southeastern Australia. Reductions in the abundance of this species over the past 50 years has led to its listing as a vulnerable species under Australia's *Environmental Protection and Biodiversity Act 1999* (Environment and Heritage 2003a). Despite its increasing rarity, Murray cod continues to be a species keenly sought by anglers and has considerable status as an icon species that is part of Australia's natural and cultural heritage (MDBC 2004). Consequently, the management of Murray cod needs to achieve both conservation (ie., improving its conservation status) and recreational angling objectives (ie., a fishery where take is sustainable and not threatening its conservation status).

In this paper, we present data predominantly from a 100 km reach of the Murray River that indicates that it may be appropriate for the validity of the assumptions behind the current angling regulations to be re-evaluated. In this reach, the current angling regulations for Murray cod restrict take to 2 fish larger than 500 mm per day with only 1 fish larger than 1000 mm per day. The fishing season is closed during September, October and November. Rod fishing is the only permitted technique and is restricted to 1 rod per person with a maximum of 2 hooks (NSW Fisheries 2004). The assumptions behind these regulations are that fish greater than 500 mm are likely to have already contributed to the breeding population at this size. Closing the fishing season in September, October and November will allow individuals above 500mm to breed prior to being available for capture and take. Restricting take per angler aims to limit take as does restricting the fishing equipment to rod fishing with a maximum of 2 hooks (NSW Fisheries 2004).

Study Area

The data used in this paper has been sourced from a variety of different investigations that have been undertaken by the Department of Sustainability and Environment (Arthur Rylah Institute for Environmental Research) in the Murray River between Yarrawonga and Tocumwal. This reach supports populations of several species, including Murray cod that are sought by anglers. The reach was closed to recreational fishing from 1989 to 1994 between Yarrawonga and Cobram (~67 river km) and since its re-opening set lines have been banned.

To examine the variation in length at age we used a subset of the data presented in Anderson *et al.* (1992). The subset of data was restricted to riverine samples from the Murray River and its tributaries upstream of Wentworth.

Methods

Length Frequency data

The data used in the length frequency analysis is an amalgamation of boat electrofishing data collected annually during winter months since 1995. A histogram of the data was computed with a bin range of 100 mm to examine the length distribution. The sampling effort over this period has varied with year. Consequently we do not present any information on year-by-year cohort progression, however the amalgamation of this data provides a visual representation of the size classes present in the population.

Mark-recapture analysis and multi-strata models

The data used in this analysis has been collected since 1999. All Murray cod caught that were greater than 180 mm in length were tagged with individual identification numbers. These individuals form the basis of a mark-recapture study where we are able to estimate the transition and survival rates between different length and/or age categories. As we were interested in understanding how the current regulations on fishing take were influencing these rates, we grouped the fish into one of three size classes at the time of capture: 1 – < 500 mm; 2 – 500 to 1000 mm; and, 3 – >1000 mm. These categories represented fish that cannot be legally kept (<500 mm); the size class of fish generally targeted by anglers (500 mm to 1000 mm); and fish that are generally considered trophy individuals (>1000 mm). The capture histories were analysed using a multi-strata construct (Hestbeck *et al*. 1991; Brownie *et al*. 1993) from which we can estimate the rates of transition from size class 1 to 2 and from size class 2 to 3 as well as survival rates and recapture rates associated with each size class.

These models are an extension of the open population live recapture model formalised by Cormack (1964), Jolly (1965) and Seber (1965), known as Cormack-Jolly-Seber (CJS) models extended to multiple stages.

Multi-strata models typically estimate three parameters: survival *S*, probability of recapture *p*, and probability of transition *psi*. Since 1999, 2774 Murray cod have been caught and individually tagged with length and weight recorded. Of these fish some have been recaptured with length and weight recorded again. Program MARK (White 1999) was used to analyse the multi-strata data to provide estimates of survival probabilities, capture probabilities as well as transition probabilities for the three size classes.

Angler Mortality

To estimate the recreational angling take, a telephone hotline was established so that anglers that have caught a tagged fish can report its capture. Once the recapture was logged on the hotline, a project officer contacted the angler and obtained details on the length, weight, location and whether the fish was released or kept.
A histogram of the data was computed with a bin range of 100 mm and grouped according to whether the fish was released or kept to examine the length distribution of the fish released and those kept. This data allowed us in conjunction with the multi-strata mark-recapture models to examine the potential effect of angling take in this reach.

Variable Growth

Anderson *et al*. (1992) aged 290 Murray cod using otolith thin sections and estimated age assuming that the 1 October was the birthday (refer to Anderson *et al*. (1992) for methods). We reduced this data set to samples from riverine fish that were caught in the Murray River and its anabranches upstream of Wentworth, and restricted the data to individuals between estimated age 3 and 6. This data was plotted to determine the length range of fish in these sizes classes.

Population level consequences of variable growth

A stochastic model describing the population dynamics and ecology of Murray cod (for a detailed description of this model see Todd *et al*. 2004 and Todd *et al*. in press) was used to analyse the effect that fishing regulations could have on the viability of Murray cod given variable growth. Using an approximate maximum adult population size of 20,000 individuals, we modelled the impact of removing 10% of individuals >500mm in length, removing 30% of individuals >500mm and removing 30% of individuals >700mm. The parameterisation of the model was the same as that described in Todd *et al.* (in press), except that the modified Anderson *et al.* 1992 data set was used to estimate the variability in length for each age class. A simulation period of fifty years was used and 1000 replications generated for each simulation. In this model we assume that Murray cod commence breeding at age 5.

The quasi-extinction probability (Ginzburg *et al.* 1982; Burgman *et al.* 1993) of falling to or below a particular threshold size of female adults at least once in the simulation period was used to summarise the scenarios.

Results

Length Frequency data

A total of 5295 Murray cod were caught in the Yarrawonga to Tocumwal study reach between 1995 and 2004. Visual examination of the length frequency distribution (**Figure 1**) indicates that the number of individuals caught decreased at size classes above 500mm.

Mark-recapture analysis and multi-strata models

Analysis of the data yielded several models that seem plausible, based on the QAIC values (Lebreton *et al*. 1992). Akaike weights were used to determine which of these models had the most support (Burnham & Anderson 1998).

Estimates of survival, recapture and transition probabilities are presented in **Table 1**. Transition probabilities for size class 2 to size class 1($psi_{2,1}$), size class 3 to size class 1 ($psi_{3,1}$), and size class 3 to size class 2 ($psi_{3,2}$) have not been presented as in reality they are zero, they were also estimated to be zero. The transition probability of size class 1 to size class 3, ($psi_{1,3}$), was estimated to be zero and this reflects the short-term nature of our data and we have not recorded an individual making this transition. The survival rate for size class 3, S_3, is much higher than anticipated, this reflects the smaller sample size for this group.

Angler Mortality

A total of 294 angler records were registered on the hotline between 1999 and 2003. We have not been able to either confirm the size or whether the individuals were released or kept for 29 of these registrations. These fish have not been included in any further analysis. Of the remaining 265 angler records, 70 were kept and the other 195 were released. The length frequency distribution of these captures is

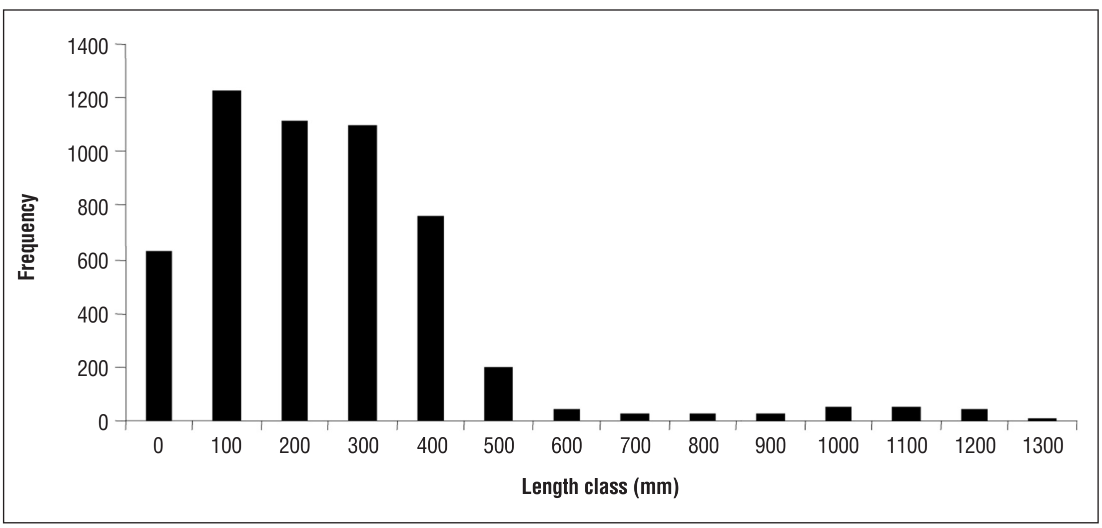

Figure 1. Length frequency distribution of the 5295 Murray cod caught between Yarrawonga and Tocumwal in the period 1995-2004.

Table 1. Parameter estimates using model averaging. Subscripts refer to each size class.

Parameter	Weighted average	95%CI Wgt. Ave. Est.	Model variation
Survival			
S_1	0.4659	0.3874 to 0.5462	3.86%
S_2	0.4890	0.3265 to 0.6539	5.53%
S_3	0.9929	0.9624 to 1.0233	85.61%
Recaptures			
p_1	0.2080	0.0509 to 0.5623	5.86%
p_2	0.2643	0.0574 to 0.6794	8.44%
p_3	0.1615	0.0412 to 0.4632	1.55%
Transitions			
$psi_{1,2}$	0.0681	0.0411 to 0.1108	3.38%
$psi_{1,3}$	0.0000		0.00%
$psi_{2,3}$	0.1204	0.0383 to 0.3197	2.55%

presented in **Figure 2**. In the size class between 500mm and 1000mm, 66 individuals were kept and 141 individuals were released. This equates to an estimated angling mortality in this size range of approximately 32%.

Variable Growth

The aged otolith data of the riverine fish indicates that the length of fish between ages 3-6 can vary between 420 mm and 760 mm (**Figure 3**). Age 3 fish had a mean length of 501 mm and a range of 445 mm – 549 mm. Age 4 fish had a mean length of 559 mm and a range of 440 mm – 703 mm. Age 5 fish had a mean length of 595 mm and a range of 414 mm – 760 mm. Age 6 fish had a mean length of 634 mm and a range of 527 mm – 754 mm.

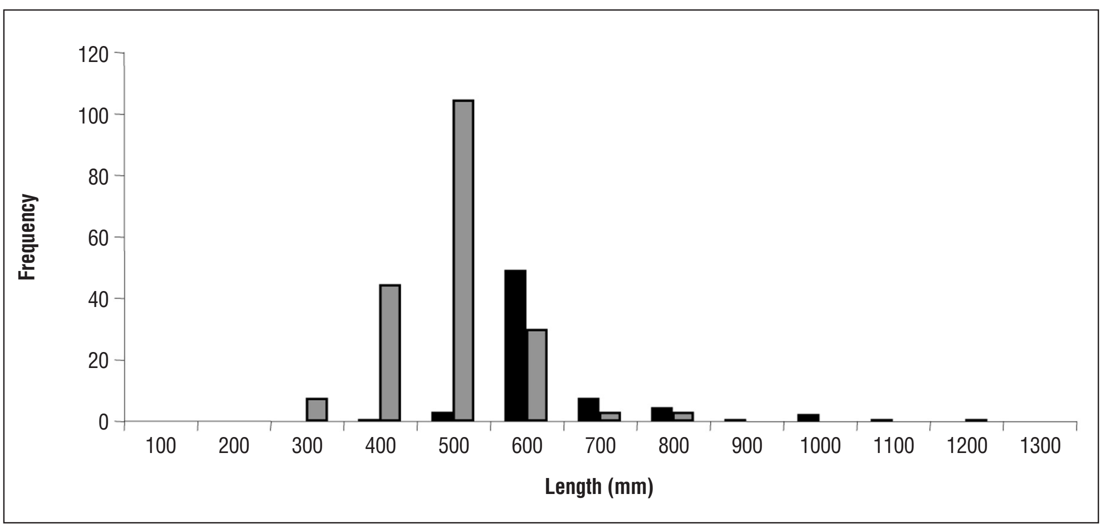

Figure 2. Angler captures from 1999 to 2003. Grey bars represent fish caught and released. Black bars represent fish caught and kept.

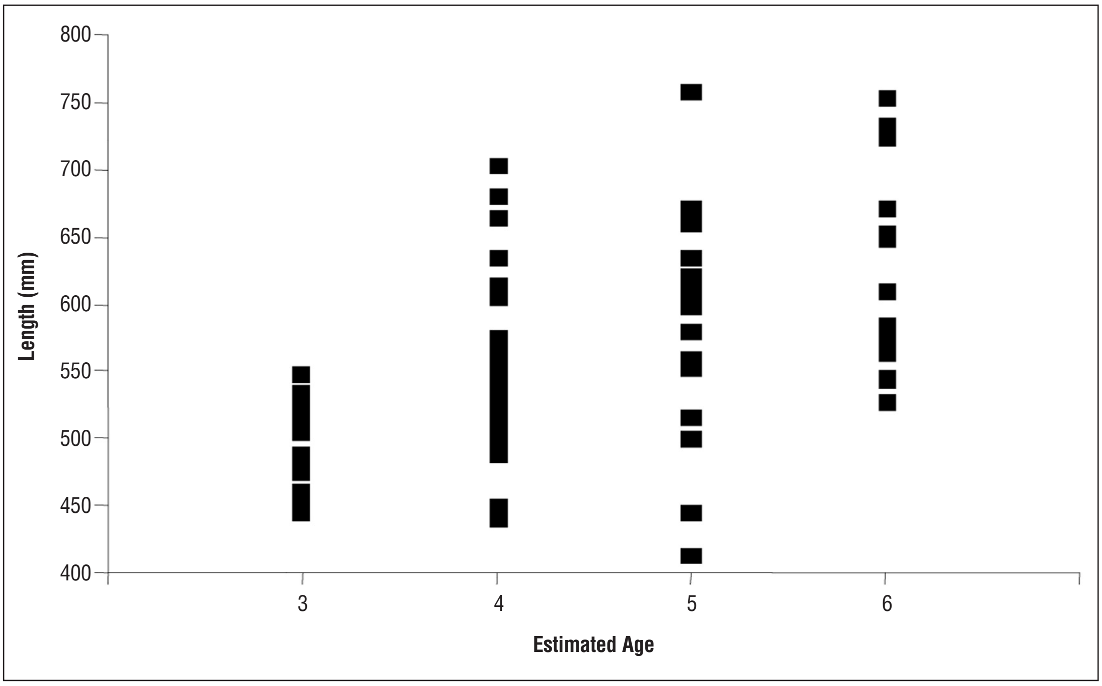

Figure 3. The length of fish and their estimated age from otolith analysis for riverine fish (from Anderson et al. 1992).

Population level consequences of variable growth

The quasi-extinction curves for the three angling mortality curves are plotted in **Figure 4**. Under the scenario of a 10% angling mortality of fish > 500 mm, the probability of the female adult population size falling below 1000 individuals was 0.2. This probability increased to 0.9 when the angling mortality increased to 30%.
When the angling mortality was 30% but the size limit for removal was increased to 700 mm this probability was 0.25.

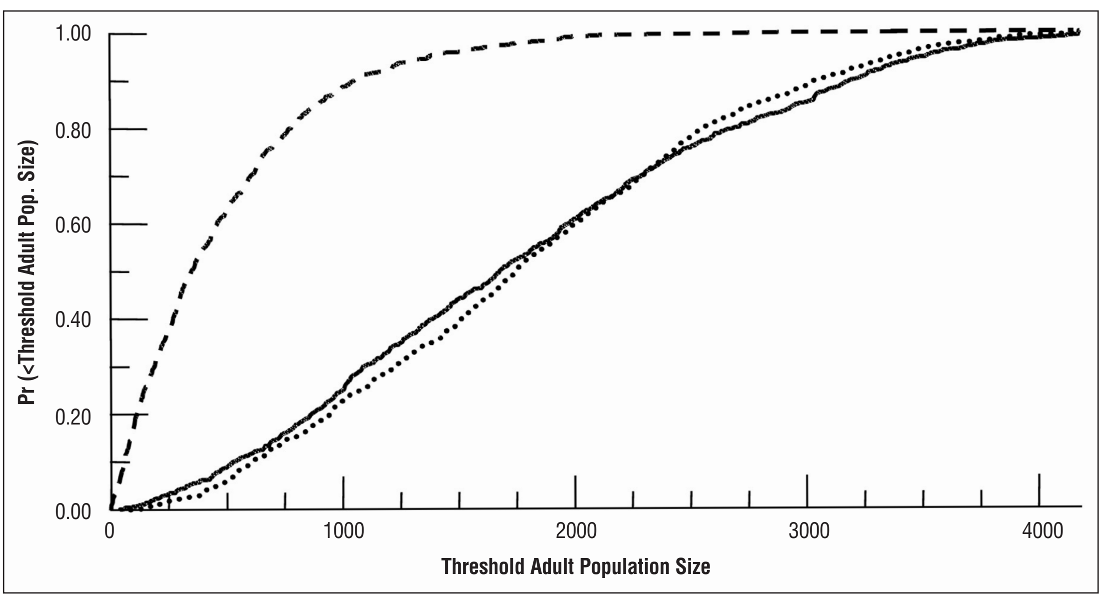

Figure 4. Quasi-extinction probability curves for 10% angling mortality for fish >500mm (solid black line), 30% angling mortality for fish >500mm (dashed line) and 30% angling mortality for fish >700mm (dotted line).

Discussion

The length frequency histogram of the electrofishing data identified a lower than expected count of fish that were greater than 500 mm (**Figure 1**), given the number of fish in the smaller size classes, in the study reach. Length frequency distributions that are an amalgamation of years remove the influence of biases that can occur between years (eg., a high mortality event for a particular cohort). Consequently, the absence of individuals in the size classes over 500 mm in this amalgamated data set suggest that progression into these size classes has been minimal since 1995.

Sampling bias may explain the length frequency distribution observed. The use of boat electrofishing may be biased towards the capture of fish in the size class 1 as larger individuals may be occupying habitats that decrease capture (eg deeper water). The estimated capture probabilities for size class 1 and 2 (0.2080 and 0.2643 respectively, see **Table 1**) however indicates that the gap in our length-frequency data for this size class is unlikely to be related to the sampling technique. Estimated mean transition probability from size class 1 to 2 was 0.0681 and estimated mean survival for size class 2 fish was 0.4890 (**Table 1**). These values also support the length frequency data in that progression to this size class and survival within this size group is low in this reach.

The low count of individuals in size class 2 and 3 in the length frequency distribution also coincides with the minimum legal length for angling take. Angling mortality was estimated to be 32 % for size class 2 and 3 with individuals from size class 2 dominating the take. This level of take may be contributing to this low count. Assuming that our sample of tagged fish is representative of the population in this reach, in the absence of fishing the expected mean survival estimate for size class 2 could have been as high as 0.809 (i.e. the addition of the estimated survival (S_2) and the estimated angling mortality (0.32)).

We assume that the 100 km size of the study reach encompasses the necessary requirements for the population to be viable. The low count of fish in size class 2 and 3 has consequences for the viability of the population in this reach. These consequences relate to a lower than expected number of breeding fish contributing to annual recruitment. There is uncertainty in the age and size at sexual maturity and fecundity relationship for Murray cod. The age of first breeding for female Murray cod is reported to be from age 5, however some individuals may commence breeding at age 4 (Koehn & O'Connor 1990). The information on variable growth (**Figure 3**) from Anderson *et al.* (1992) suggests that a proportion of fish at ages 3 and 4 are above 500 mm. The uncertainty in the age of first reproduction may have consequences for interpreting the length frequency data. If age rather than size is the primary driver of when Murray cod commence breeding, then it is plausible that a number of the fish caught and kept by anglers have not yet reproductively contributed to the population. This would place greater emphasis on size class 3 fish to drive reproductive output and successful recruitment in this population. The population viability may be further threatened if reproductive senescence occurs in size class 3 fish, or if fish in this class experience high mortality events as well.

Modelling the influence of this variable growth on the viability of the population indicated that the risk of the adult population falling to levels that would invoke IUCN conservation rules (<1000 females) was high (0.9) under existing angling regulations and the estimated angling mortality (~30%). Two alternative regulations were simulated (reducing angler mortality to 10 % or increasing the minimum size limit for take to 700 mm). Under both of these scenario's the probability of falling to below 1000 females was substantially improved (0.2 and 0.25 respectively). This evaluation of the population viability suggests that either more knowledge is required about age, length and fecundity or this uncertainty needs to be incorporated into angling regulations through either increasing the minimum length for take or by further limiting the number of fish taken.

The management of Murray cod is attempting to not only ensure that the species is healthy and viable from a conservation perspective, but also to ensure that the recreational fishery is sustainable and meets community needs. Both of these objectives are achievable when the species is healthy in terms of abundance, distribution and the threats to the species have been managed. When the viability of the species is threatened, there is potential conflict in achieving these objectives. As viability deteriorates, conservation imperatives will take a higher priority over recreational fishing. Angling regulations are designed with the hope of avoiding such conflicts. The recreational fishing regulations have been set in an attempt to allow fish to reach maturity and complete their breeding cycle, while bag limits help to make sure everyone gets a fair share of the resource, and that a species is not overfished (NSW Fisheries 2004). These regulations need to be tested for the veracity of the assumptions underpinning them. In scenarios where conservation concerns override angler opportunity, it is important that the assumptions underpinning the regulations are validated. This will avoid arguments that are based upon opinion rather than data.

The information presented in this paper indicates that the current angling regulations are achieving the desired goal of restricting angling take to fish greater than 500 mm in length and minimising angling take of fish greater than 1000 mm. The regulations however may not be achieving the desired level of control on the amount of take occurring in the Yarrawonga to Tocumwal reach. Estimated angler take was 32 % in this reach and the modelling undertaken suggest that this may explain the low numbers of fish in size classes greater than 500 mm. An evaluation of the risk that angler take at this level has on the viability of the population suggest that the population is at a high risk of collapse given the uncertainty in our knowledge about the species. Based on this information we would recommend that either a re-evaluation of the angling regulation be undertaken or resources be allocated to minimising the uncertainty in the age and length at sexual maturity, and fecundity relationships. This could be achieved by establishing a working relationship with anglers, by collecting frames, reproductive organs and otoliths for ageing of fish that they have kept.

More importantly, the length frequency and mark-recapture data used in this paper was collected for other purposes and it is serendipitous that it can be applied to the management of Murray cod. Furthermore, we are unclear if this information could apply to other reaches or populations within the Murray-Darling Basin. If we are to establish management standards for Murray cod, where we are able to demonstrate that the regulations we employ are valid, then a rethink of the current approach may be required.

Additionally, the rethink also needs to include a process where cross-jurisdictional concerns can be incorporated in a participatory manner, so that the management of Murray cod may be applied in a cohesive Basin-wide approach. The importance of participatory management has been demonstrated in advancing contentious marine fisheries, where there are multiple and potentially conflicting objectives (Smith *et al.* 1999, Smith *et al.* 2001). This approach has some benefit for the management of Murray cod, given that both conservation and fisheries objectives are set for the species and the potential for conflict dependent upon the status of the Murray cod population.

To develop a participatory management approach for Murray cod requires the establishment of a Murray cod assessment group. The assessment group must include representatives from fisheries, conservation, and river management stakeholders (both Government and public) and be responsible for the assessment, setting research priorities, enforcement and setting fishing regulations. The assessment group under the marine model implements a process called management strategy evaluation (MSE, Smith *et al.* 1999). MSE involves assessing the consequences of a range of management options and making explicit the trade-offs in performance across a range of management objectives. Key steps include turning broad objectives into specific and quantifiable performance indicators, identifying and incorporating key uncertainties in the evaluation, and communicating the results effectively to stakeholder groups and decision-makers (Smith *et al.* 1999).

We argue that a Murray cod assessment group would improve the management of Murray cod into the future. If not for the coincidence of the data set used in this paper being available, we would not have been in a position to examine the management of Murray cod, other than an emotive assessment based upon opinion. The effective application of an MSE approach to Murray cod management would remove any reliance upon serendipitous data sets, as continual evaluation underpins the approach, creating pro-active rather than reactionary management. Furthermore the requirement to turn broad objectives into quantifiable performance indicators would require all stakeholders to agree upon explicitly stated levels of exploitation and conservation risk.

These indicators would make the evaluation of the effectiveness of any management tool, such as angling regulations, transparent and common practice.

Acknowledgements

We thank Sandy Morison and Geoff Gooley (PIRVIC, Queenscliff) for use of their otolith data to examine the variable growth data. The authors would like to thank all who assisted with data collection in particular John Mahoney, Peter Fairbrother and John McKenzie. Tim O'Brien and Andrew Bearlin provided editorial comments.

References

Anderson, J.R., Morison, A.K. and Ray, D.J. 1992. Age and growth of Murray cod *Maccullochella peelii* (Perciformes: Percichthyidae), in the lower Murray-Darling basin, Australia, from thin-sectioned otoliths. *Australian Journal of Marine and Freshwater Research* 43: 983–1013.

Brownie, C., Hines, J.E., Nichols, J.D., Pollock, K.H. and Hestbeck, J.B. 1993. Capture-recapture studies for multiple strata including non-Markovian transitions. *Biometrics* 49: 1173-1187.

Burgman, M.A., Ferson, S., and Akçakaya, H.R. 1993. *Risk Assessment in Conservation Biology*. Chapman and Hall, London.

Burnham, K.P. and Anderson, D.R. 2002. *Model selection and multimodel inference: a practical information-theoretic approach*. 2nd Edition. Springer-Verlag, New York.

Cadwallader, P.L. 1978. Some causes of the decline in range and abundance of native fish in the Murray-Darling River System. *Proceedings of the Royal Society of Victoria* 90: 211-224.

Cormack, R.M. 1964. Estimates of survival from the sighting of marked animals. *Biometrika* 51: 429-438.

Environment and Heritage. 2003a. Murray Cod (*Maccullochella peelii peelii*). Nationally Threatened Species and Ecological Communities Information Sheet. Department of the Environment and Heritage, July 2003. www.deh.gov.au/biodiversity/threatened/information/factsheets/murray-cod.html

Environment and Heritage. 2003b. *Maccullochella peelii peelii* (Murray Cod, Cod, Goodoo). Advice to the Minister for the Environment and Heritage from the Threatened Species Scientific Committee (TSSC) on Amendments to the list of Threatened Species under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). www.deh.gov.au/biodiversity/threatened/species/m-peelii-peelii.html

Ginzburg, L.R., Slobodkin, L.B., Johnson, K. and Bindman, A.G. 1982. Quasiextinction probabilities as a measure of impact on population growth. *Risk Analysis* 2: 171–181.

Hestbeck, J.B., Nichols, J.D. and Malecki, R.A. 1991. Estimates of movement and site fidelity using mark-resight data of wintering Canada geese. *Ecology* 72: 523-533.

Jolly, G.M. 1965. Explicit estimates from capture-recapture data with both death and immigration stochastic model. *Biometrika* 52: 225-247.

Koehn, J.D. and O'Connor, W.G. 1990. *Biological Information for management of native freshwater fish in Victoria*. Government Printer, Melbourne

Lebreton, J.-D., Burnham, K.P., Clobert, J.and Anderson D.R. 1992. Modeling survival and testing biological hypotheses using marked animals: case studies and recent advances. *Ecological Monographs* 62: 67-118.

MDBC 2004. *Native Fish Strategy for the Murray-Darling Basin: 2003-2013*. Murray-Darling Basin Commission, Canberra.

Musick, J.A. 1999. Ecology and conservation of long-lived marine animals. *American Fisheries Society Symposium* 23: 1-10.

NSW Fisheries 2004. NSW Recreational Freshwater Fishing Guide 2004/05. www.fisheries.nsw.gov.au/rec/fw/home_freshwater.htm

PIRSA 2004. The need to regulate. Primary Industry and Resources South Australia. www.pir.sa.gov.au/dhtml/ss/section.php?sectID=1132&tempID=10

QLD DPI. 2004. Recreational fishing in Queensland – Freshwater a brief guide to rules and regulations from December 13 2003. Department of Primary Industry Queensland. www.dpi.qld.gov.au/extra/pdf/fishweb/FWPDF1.pdf

Reynolds, J.B. 1983. Electrofishing. In L.A. Neilsen and D.L. Johnson (eds). *Fisheries Techniques*. American Fisheries Society, Bethesda, Maryland. Pages 147-163.

Seber, G.A.F. 1965. A note on the multiple recapture census. *Biometrika* 52: 249-259.

Smith, A.D.M., Sainsbury, K.J. and Stevens, R.A. 1999. Implementing effective fisheries systems – management strategy evaluation and the Australian partnership approach. *ICES Journal of Marine Science* 56: 967-979.

Smith, D.C., Smith, A.D.M. and Punt, A.E. 2001. Approach and process for stock assessment in the south east fishery, Australia: a perspective. *Marine and Freshwater Research* 52: 671-681.

Todd, C.R., Nicol, S.J. and Koehn, J.D. 2004 Density-dependence uncertainty in population models for the conservation management of trout cod, *Maccullochella macquariensis*. *Ecological Modelling* 17: 359-380.

Todd, C.R., Ryan, R., Nicol, S.J. and Bearlin, A.R. (submitted). The impact of cold water releases on post-spawning survival, the implications for Murray cod (*Maccullochella peelii peelii*) and possible amelioration: A case study of the Mitta Mitta River, in south-eastern Australia. *River Research and Applications*.

White, G.C. 1999. Program Mark. www.cnr.colostate.edu/~gwhite/mark/mark.htm