The loss of valuable Murray cod in fish kills: a science and management perspective

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Introduction

Four fish kills occurred between November 2002 and February 2004 that involved the deaths of large numbers of big Murray cod *Maccullochella peelii peelii* (up to 50 kg) from some of Australia's most valuable populations of this threatened species. These fish kills have resulted in the loss of valuable environmental assets and caused widespread public concern (Sinclair 2005). This paper examines these fish kills from science and management perspectives. Such an examination provides insight into the commitment, response, effective responsibility and 'ownership' of Murray cod populations, and highlights problems for species conservation due to a lack of preparedness and coordination across management agencies that may have conflicting responsibilities and competing interests for water resources.

The fish kills

The four major fish kills involving Murray cod examined are detailed in **Table 1**. The numbers of dead fish reported in this paper mainly refer to large fish (see Sinclair 2005), and will be underestimates of the total numbers of fish killed as there have been incomplete assessments, not all fish surface or are sighted (especially juveniles), and some carcases may have been removed by predators such as birds, water rats or crayfish. Estimates of Murray cod deaths for the Darling River, for example, could potentially be as high as 5000 (Ellis & Meredith 2004). Unfortunately, these fish kills are not isolated events, being relatively common in the Murray-Darling Basin (Lugg 2000; Ecos 2004).

Table 1. Major fish kills involving Murray cod in the Murray-Darling Basin from November 2002. Note: Assessment of the Ovens River was limited

Water	Date	Affected reach (km)	No adult fish	Suggested causes	Reference
Broken Ck (Vic)	Nov 02	2	179+	Lack of flows, low dissolved oxygen, following decomposing Azolla.	Robinson (2003a), (2003b), Butcher (2003), Ecos (2004).
Ovens R (Vic)	Feb/ Mar 03	70	6+	Sediment 'slug' of up to 3.3% solids and low dissolved oxygen following post-fire rains	J. Lyon, ARIER (unpubl. data), Victorian Government (undated)
Goulburn R (Vic)	Jan 04	15	91	Water release (changed temperature, low dissolved oxygen), herbicide inputs	T. Ryan (unpubl. data), EPA (2004)
Darling R (NSW)	Feb 04	160	3000	Water release from Menindee Lakes (high water temperatures, low dissolved oxygen)	Ellis and Meredith (2004)

Twenty-one reliable reports of fish kill events are recorded for the Goulburn-Broken catchment between 1998 and 2004 (Ecos 2004) and it is recognised that many others may not have been observed or reported. Other fish kills were also reported in the Loddon and Campaspe Rivers during January and February 2004. New South Wales records 34 fish kill reports per year (figures for 1986-1996), but it is estimated that the real number may exceed 60-80 per year (Lugg 2000).

The importance of the biota

Murray cod are a listed, threatened, iconic species, readily identified and highly valued by the public. The fish killed in these events had provided valuable and popular fisheries for recreational anglers. Murray cod are a 'keystone species' in terms of their ecological importance as high level predators in the ecosystem (Koehn 2005). All three Victorian waters affected by these fish kills have been assessed as sites for major research on this species (Koehn unpubl. data) and would rate among the five best Murray cod populations in the State. The Darling River is an important location for Murray cod in NSW (Harris & Gehrke 1997). The importance of the loss of these Murray cod is even greater when placed in the context of their already diminished and fragmented populations. It has been estimated that native fish populations overall in the Murray-Darling Basin are now at about 10% of their natural levels and considerable efforts are underway to rehabilitate them (MDBC 2004). Declines in Murray cod populations have been well documented (Cadwallader & Gooley 1984; Harris & Gehrke 1997), including relatively recent localised extinctions (Koehn *et al*. 1995).

While this paper concentrates on deaths of Murray cod, large numbers of other species have also been killed. The Goulburn River fish kill also caused the death of 'several thousand minnows and fingerlings' (EPA 2004). A decline of 71% in total fish numbers has been reported at one site (Cable hole) between October 2003 and February 2004 (before and after the kill) (Koster *et al*. 2004), and they concluded that the fish kill had caused significant impact on the populations of several fish species. This kill also included 14 trout cod *Maccullochella macquariensis* (aged 7-10 years), silver perch *Bidyanus biyanus*, golden perch *Macquaria ambigua*, redfin *Perca fluviatilis* and carp *Cyprinus carpio* (Koster *et al*. 2004; EPA 2004). Of particular importance was the collection of larval trout cod prior to the kill (Koster *et al*. 2004). This was the first evidence for any natural spawning of this species as a result of the hatchery stocking program to re-establish a Goulburn River trout cod population as part of the national recovery plan. It is not known if any adult trout cod survived at this site. Up to 100% of fish populations in the upper reaches of the Ovens River may have been killed by post-fire sediment (J. Lyon, Arthur Rylah Institute for Environmental Research, unpubl. data). Murray cod populations in Broken Creek do not appear to have recovered (S. Saddlier, Arthur Rylah Institute for Environmental Research, unpubl. data) and there appear to have been large decreases in abundance of other species (J. O'Connor, Arthur Rylah Institute for Environmental Research, unpubl. data).

Murray cod is listed as a threatened species under the *Flora and Fauna Guarantee Act 1988* in Victoria (Scientific Advisory Committee 1991) and as a vulnerable species under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC) Act. The 'Lowland Riverine Fish Community of the Southern Murray-Darling Basin', which has been listed under the *Flora and Fauna Guarantee Act 1988* in Victoria (www.nre.vic.gov.au), includes Murray cod as a component species. The Broken Creek, Goulburn River and Ovens River reaches affected by these fish kills all exhibited remnant examples of this fish community.

The value of the fish killed and cost of population replacement

A valuation for the loss of fish populations has not been undertaken in Australia. Components of valuation for the loss of threatened species include: full compensatory damages and restoration activities with a possible claim for restitution; replacement cost and the loss of people's values; costs of managing the fish kill, including transportation and administrative costs; and economic losses to the fishery, including the number of user days lost (Southwick & Loftus 2003). In the case of the examples below, this could mean lengthy fishery closures of up to 52 years. While replacement cost for the population should not solely be used to value

threatened species, as this is only one component of the real cost (Southwick & Loftus 2003), it is one component of the valuation that is relatively easy to calculate.

The population model ESSENTIAL (Todd *et al*. 2001, 2004) was used to model several stocking scenarios to estimate the number of replacement fry (and hence cost), and timeframe needed to re-establish Murray cod populations similar to those lost (**Table 2**). A 50:50 sex ratio was assumed, across the reported fish size range (mainly large fish > 500 mm TL), with an estimated average age of 15 years (Koster *et al*. 2004), and an average fecundity of 30 000 eggs per female (Anderson *et al*. 1992; Koehn & O'Connor 1990). A further assumption of this modelling was that there would be no take of fish, hence stocking would need to be accompanied by a fishery closure over the full recovery period for the population. Any removal of adult fish by anglers would be largely unquantified, would lengthen recovery times and increase the risk of population failure. As the model incorporates stochasicity, scenarios were run for 1000 iterations to give an 80% chance of replacing the adult population. Costings were based on an average fingerling price of $0.60 (W. Fulton, Snobs Creek hatchery pers. comm.) with a 3% inflation factor incorporated for future expenditure (**Table 2**). The Murray cod population lost from the Goulburn River has an 80% chance of replacement in 29 – 34 years, at a cost of between $1.2 and $1.7 M, depending on the stocking strategy. Similarly, the Broken Creek population could be replaced at similar costs in 32 to 37 years. Replacement of 1500 female fish in the Darling River would take 46 – 52 years and cost $1.9 M (**Table 2**). No estimates were made for the Ovens River due to the lack of information regarding fish numbers killed. While these numbers and costs apply only to giving a specified chance of re-establishing the lost populations, there would be an ongoing environmental cost of lost genetic diversity as a result of using hatchery fish (Bearlin & Tikel 2003). It should be recognised that the average number of Murray cod stocked for all Victorian waters since 1990 **(**www.dpi.vic.gov.au**)** is 186 000 per annum, indicating that there is currently unlikely to be the financial commitment or the hatchery capacity to undertake such stocking programs.

Stocking with hatchery produced fish is not the only population rehabilitation option, and indeed is treating the symptom rather than the true cause of the environmental problem. The importance of natural recruitment is emphasised by the outputs of the population model, in that once the stocked fish reach adulthood, their natural reproductive output becomes greater than the added stocked fish. This also highlights the benefits of protecting adult fish and their reproductive output, until the population has recovered. True recovery of fish populations is best achieved through a rehabilitation plan that incorporates a range of actions, including measures to prevent future fish kills. This requires an understanding of the processes that caused the fish kill in the first place. It may be more cost effective to translocate adult fish, improve habitat, install and operate fishways to encourage natural recolonisation or to provide environmental water to enhance natural population recruitment.

Table 2. Number of years and total cost to achieve > 80% chance of replacement of lost adult populations for the Goulburn River, Broken Creek and Darling River for various stocking regimes

Site	No 15 y.o. females	Population recovery periods, cost and stocking regime for Murray cod replacement					
		200 000 fingerlings per y for 10 y	Total cost ($M)	50 000 fingerlings per y for up to 40 y	Total cost ($M)	2 000 000 fingerlings one-off	Total cost ($M)
Broken Creek	90	32	1.36	37	1.7	37	1.2
Goulburn River	45	29	1.36	34	1.5	34	1.2
Darling River	1500	46	1.36	52	1.9	49	1.2
TOTAL			4.08		5.1		3.6

The cost of these fish kills

This paper is not able to undertake a full economic evaluation (Southwick & Loftus 2003) for aspects of these fish kills such as possible claim for damages restitution, the loss of people's values, and economic losses to the fishery including the number of user days lost (potentially up to 52 years). The costs of immediate management of the fish kills however (including transport and administrative costs) is estimated to be about $50 000 each. The cost of the Goulburn River audit is expected to be in excess of $300 000 (EPA budget of about $200 000 plus in kind contributions from government departments and other agencies). Combined with the population replacement costs (**Table 2**), a full cost of these three fish kills would range between $4 M – $5.6 M, not including the cost of lengthy fishery closures.

Management response to the fish kills

Management responses are needed before (if the kill is predictable through deteriorating water quality for example), during and after fish kills. Fish kills often occur however, with little warning and there is the need to facilitate a rapid response and to conduct an immediate on-site investigation. Fish kills are usually transient events, with cause and effect often difficult to definitively determine (**Table 1**). The purpose of timely investigations is to collect factual information about the size, cause and extent of the kill. Data collected can include fish numbers, species identifications, water, sediment and biological samples and observations of fish behaviour (MDBC 2003). This is the first step in the investigation of the kill, with this data being analysed and follow-up investigations being used to focus the appropriate management responses. Such responses should include processes that pro-actively prevent anthropogenic fish kills in the future and provide planning and actions to rehabilitate the fish population.

While there was a major public outcry following these fish kills (Sinclair 2005), evaluation of the management of these fish kills indicates that responses have been variable (**Table 3**). Initial responses were not always comprehensive, did not follow uniform procedures and were often delayed. In most cases, much of the initial information obtained was not collected systematically. Immediate quantification of the actual numbers of fish killed was not always undertaken and many of the more comprehensive surveys to determine the remaining fish populations only occurred after an extended time period, with results potentially influenced by recolonisation. In most instances, confirmed identification of all species affected was not undertaken and little data was collected on fish size distributions. Fish carcases were not retained and, as a consequence, an opportunity to gain valuable scientific data on the age-structure of the Murray cod populations was lost. Such data can be gained only from destructive sampling, which is not permitted under normal circumstances, especially for larger, threatened species such as Murray cod. As a consequence of poor initial on-site investigations, much of the information needed to determine the cause of the kills was lost. Such investigations were also hampered by a relative paucity of pre-event data (EPA 2004). Considerable difficulty was encountered in readily obtaining unpublished fish kill reports for the writing of this paper.

For each of the documented events, there was initially little reaction by Fisheries or Conservation agencies, nor to date, any substantial action taken to address the loss of resource. Given that definitive causes have not been identified, there is little likelihood of prosecutions or legal action being taken against any party in relation to these kills, as would be possible under legislation. More importantly, no agency, water authority or other party has publicly accepted any responsibility for these kills, nor is it clear where such responsibility would lie. No fishery closures have been enacted to protect remaining fish populations and no plans have been suggested or implemented to attempt to rehabilitate these populations. Hence, the loss of these valuable public assets has occurred without any reparation or compensation. The lack of definitive causes, slow investigations and a lack of rehabilitation plans have left many stakeholders dissatisfied (Sinclair 2005).

Following the Darling River fish kills, Bundaberg Rum donated a sum of $20 000 for restocking of the lower Darling River with the hope of 'being able to see a marked change in the river in the near future' (Palmer 2004). While the sentiment of this stocking is to be commended, as it appears to be the only reparation measure that has been undertaken, the amount of money and the subsequent number of fish is inadequate to replace the lost population.

Table 3. Management reponses to fish kills in Broken Creek, Ovens, Goulburn and Darling Rivers. Y = yes; N = no; C = considered; S = some/partial; I = in progress; WQ = water quality; ID = identified.

Immediate response	**Data collection**							
Water	**Emergency action**	**Fishery closure**	**Behavioural observations**	**Accurate no's killed**	**Specimens retained**	**All fish species ID.**	**WQ measurements**	**WQ samples**
Broken Ck (Vic)	N	N	N (S)	Y	N	N	N (S)	N
Ovens R (Vic)	S	N	Y	N	Y	Y	Y	Y
Goulburn R* (Vic)	C	N	Y	S	Y (S)	N	Y	Y
Darling R (NSW)	N	N	N	N	N	N	S	N
Post-kill response								
Water	**Specimen autopsy**	**Results analysed**	**Later investigation**	**Pre-kill fish pop. data**	**Surveys of remaining fish pops.**	**Evaluation of response**	**Management plan**	**Population rehab. plan**
Broken Ck (Vic)	N	N	Y (S)	N	N	N	S	N
Ovens R (Vic)	Y	N	Y	Y	Y	S	S	N
Goulburn R (Vic)	Y	S/I	I	N	S	I	I	N
Darling R (NSW)	N	N	Y	S	S	N	N (I)	N

* macroinvertebrate and algal samples also taken.

Modelling indicates that this stocking alone would only give a 50% chance of population re-establishment after 75-100 years. Stocking at this level on an annual basis for 5 years would give an 80% chance to replace the lost population after 60 years. This would need to be undertaken in conjunction with a complete fishery closure for this recovery period.

The apparent lack of responsibility and coordination for the protection of Murray cod populations in Victoria may in part be explained by current resource management agency responsibilities for aquatic resources (**Table 4**).

Table 4. Agency responsibilities for managing aquatic resources in Victoria.

Agency	Responsibility	Reference
Water authorities	Ensure water delivery Goulburn-Murray Water aims to maximise water resource availability for customer use, while meeting key environmental goals and contributing to a sustainable and productive natural environment.	DNRE 2002 www.g-mwater.com.au
Catchment Management Authorities (CMAs)	Caretakers of river health Priority setting responsibilities for catchments Waterway, regional drainage and floodplain management	DNRE 2002
Fisheries Victoria	Provide management directions for fishing activities, fish stocks and habitat in accordance with government policy and the requirements of the community to ensure the sustainability of the base while optimising economic and social benefits. To manage fisheries resources in partnership with stakeholders as the framework for the sustainable utilisation of commercial and recreational fisheries. • Sustainable fisheries • Enhancement and promotion of recreational fish in opportunities • Habitat advocacy	DNRE 2002 www.dpi.vic.gov.au
Sustainability and Environment	Identify the best options for restoring biodiversity Establish management actions to manage threatening processes or to protect threatened species Allocating water resources Overseeing performances of the water sector and CMAs Protecting biodiversity Provide input and leadership to the *Living Murray Initiative*	DNRE 2002
EPA	To enable the safe clean and sustainable environment that Victorians seek. Maintain standards of environmental quality through works approvals, licences, inspections, pollution abatement notices and land use planning referrals. Minimise wastes, prevent pollution and address community concerns, complemented by inspection and enforcement activities.	www.epa.vic.gov.au

These management responsibilities mean that while fisheries and conservation agencies appear responsible for fish, such responsibilities are far from definitive, and water agencies remain responsible for water supply. Actions relating to flow regulation, including water releases, appear implicated in the three largest fish kills reported here. While drought may exacerbate water quantity and quality problems, the three fish kills that occurred in regulated river systems cannot be classified as 'natural' occurrences. In Broken Creek, for example, any downstream escape by fish was prevented by the presence of weirs. In multi-use environments such as rivers, management to protect biodiversity must be actively undertaken in the same way as water delivery is actively planned and undertaken. This highlights the potential conflict between the use of water for irrigation and domestic use and the protection of aquatic environmental assets, and emphasises the need for coordination between fishery managers, water and environmental protection/conservation agencies (Southwick & Loftus 2003). In order to maintain such environmental assets, active, targeted management must be undertaken, otherwise consequences such as these fish kills will result. Anglers and conservation organisations, users and stakeholders of the 'biological resource', currently appear marginalised from management of these public assets.

Discussion

Fish provide a powerful tool for assessing aquatic environments as they are sensitive to most forms of human disturbance, cover all trophic levels and therefore can effectively integrate a whole range of ecological processes in waterways (Harris 1995). The fish kills examined in this paper have involved substantial numbers of a large, iconic, threatened angling species. The loss of such numbers of Murray cod from valuable riverine populations has the potential to further threaten their conservation status. The Darling River fish kill has been suggested as the 'biggest cod kill in history' (Sinclair 2005). These kills and the initial lack of response to them, highlight serious deficiencies in waterway management and the protection of threatened fish species. The lack of any recompense highlights a real lack of concern and protection of such major public biological assets.

Even though fish kills have occurred often in the past, these recent events have highlighted a general lack of preparedness, inadequate emergency plans, and in the case of Victoria at least, lack of formal fish kill protocols. A conceptual framework for a multi-agency response is currently being pursued (Marsh 2004), supplemented by draft fish kill protocols for Victoria (EPA in prep) and the Murray-Darling Basin (MDBC 2003). The levels of preparedness for managing fish kills need to be increased, especially targeted toward Murray cod and other threatened species. It is hoped that valuable lessons have been learned and improved operational procedures, management plans, inter-agency arrangements, fish kill protocols and preventative management measures will be positive developments resulting from these fish kills.

An environmental audit appears to be a tool that could assess a range of cumulative environmental impacts on native fish populations that may have contributed to these fish kills. While the Goulburn River audit 'is not an investigation into the most recent, or any other, fish kills' (Nolan ITU 2004), it provides a wider scope for improved environmental management. It will identify relevant land and water management policies, strategies, plans and operational procedures, assess their adequacy and determine roles and responsibilities of management agencies (Nolan ITU 2004). There is a need to integrate accountability for environmental assets such as fish populations, with clear responsibilities, accountabilities and pre-determined cost-sharing arrangements. It is hoped that findings from this audit have wider applicability to other rivers.

There are several management actions that could have assisted the protection of Murray cod that have not been undertaken to date. Murray cod is listed as a threatened species under the *Flora and Fauna Guarantee Act 1988* in Victoria, and 'The input of toxic substances to streams', 'The prevention of passage of aquatic biota as a result of the presence of instream structures' and 'Alteration to the natural flow regimes of rivers and streams' are also listed as Potentially Threatening Processes. No Action Statements have yet been produced to outline the management actions for either the species or these threats. Murray cod is also listed as a vulnerable species under the EPBC Act 1999

with a Recovery Plan currently being prepared. No critical habitats have been declared for Murray cod, despite provisions under both these Acts. All three Victorian rivers affected by these fish kills would have been worthy of consideration for declaration as critical habitats for Murray cod. Perhaps such declarations may have placed a greater emphasis for the need for environmental protection of these river reaches.

The role that these fish kills have played in the overall conservation status of Murray cod is unknown. They have clearly contributed to the decline of the species in certain areas and while a range of management actions are being implemented to improve the species' conservation status, the success of many of these programs may be limited unless such fish kills are addressed. Murray cod is currently listed as a vulnerable species in Victoria and the magnitude of the fish kills in that State however, warrants an urgent reassessment of this status.

Resource managers and the public have both failed to realise the value of these fish populations. The reality that we do not have the ability, resources or will to replace fish populations such as those lost must be incorporated into the risk management of these species. The suggestion of restocking with hatchery fish to replace these fish populations is not a realistic one with current facilities and commitments. Any replenishment of fish populations through restocking should be supplemented by a fishery closure to minimise the risk to return on this investment. Population recoveries are only likely to occur over long time frames. Population restoration is an expensive, if not unrealistic, option and highlights the need for improved management for fish kill prevention.

The need for the rehabilitation of native fish populations in the Murray-Darling Basin has clearly been determined (MDBC 2004). Fish kills, such as the examples in this paper, put population gains made from other river rehabilitation activities, including provision of additional environmental water, at risk. There is a need for the protection of environmental assets such as fish populations through proactive management actions, in the same manner as water supply assets are protected. Similarly, some form of 'insurance' to provide funds to rehabilitate such assets if they are damaged should be instigated. Water held within, and released from storages must be of appropriate environmental standards to maintain ecosystem biodiversity. Continuous water quality monitoring at each weir, with early warning devices may ultimately be necessary to prevent the release or passing of water of inappropriate quality or to provide an alert to allow emergency plans to be enacted.

Murray cod is a large, threatened, iconic fish species, highly valued by anglers and the wider community. The death of large numbers of this species has not only caused the loss of a valuable component of aquatic biodiversity, but also the loss of some community faith in the management of river ecosystems.

Recommendations

1. Responsibility for the protection of fish populations and their habitats be clarified to ensure the integration of instream habitat, fish stock conservation and water management programs.
2. A standard, comprehensive, fish kill protocol be agreed to and implemented across the Murray-Darling Basin, with detailed investigations conducted to understand the causes and impacts of all major fish kills.
3. Incorporate ecological scientific expertise into a dedicated fish kill response team.
4. Collection and retaining of fish carcases for investigative and scientific proposes should be standard procedure for large fish kills or those involving threatened species.
5. A fish kills database should be established for the Murray-Darling Basin.
6. Information and data on fish kills be made readily and publicly available on a fish kills website.
7. Immediate fishery closures should be enacted following fish kills to protect remaining populations. Closures should be reassessed following investigation and publication of a population management/ recovery plan.
8. Mechanisms should be investigated and implemented to ensure funding is available for population rehabilitation following fish kills. This may be funded by the responsible party or through 'insurance' that covers biological assets.

9. Strengthening of partnerships between key research institutions and water management agencies is required to enable better understanding of multiple impacts on fish populations and provide consequent improvements to waterway management.
10. Continuous water quality monitoring should be undertaken for key parameters at each weir/dam, with early warning devices to prevent the release or passing of water of inappropriate quality or to provide alerts for emergency plans to be actioned.
11. Priority protection measures need to be enacted for critical Murray cod populations.
12. The conservation status of Murray cod in Victoria should be reassessed in light of these fish kills.

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