Limiting factors for crayfish and finfish in acidic coal pit lakes

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Abstract World-wide, open-cut mining operations often leave pit lakes at closure. The Collie Lake District in south-west Australia has 13 pit lakes from open-cut coal extraction, with more expected. Many lakes may offer beneficial end uses as fisheries habitat for biodiversity or for recreational species. However, pit lakes may have degraded water quality due to Acid and Metalliferous Drainage (AMD). A literature review and survey for marron (endemic crayfish of biodiversity and recreational value) and fin-fish (of only biodiversity value) found that crayfish were likely more limited by habitat and food availability, and fin-fish by water quality. Management of these mild acidic water bodies must address both issues if sustainable fisheries and aquatic biodiversity are desired beneficial end uses.

Key Words beneficial end use, fishery, pit lake, AMD

Introduction

Due to operational and regulatory practicalities, pit lakes will continue to be common legacies of mine lease relinquishments. Pit lake water quality is often degraded by Acid and Metalliferous Drainage (AMD) which may lead to acidic water with elevated metal concentrations. Degraded water quality reduces pit lake environmental values and may limit end use opportunities. Closure guidelines increasingly require consideration of post-mining land use of equivalent capacity to pre-mining conditions.

Unplanned or inappropriate management of these novel geographical features can lead to both short- and long-term liability to mining companies, local communities, the government and the nearby environment during mining operations or after lease relinquishment (Doupé and Lymbery 2005). However, the potential for pit lakes to provide many and diverse benefits to companies, communities, and the environment is frequently unrecognised and yet may be a vital contribution to the sustainability of the open-cut mining industry (McCullough *et al.* 2009a). Sustainable pit lake management aims to minimise short and long term pit lake liabilities and maximise short and long term pit lake opportunities (McCullough and Lund 2006). Improved water quality remediation technologies for AMD are offering more avenues for pit lakes resource exploitation than ever before (Wren *et al.* 2011; Kumar *et al.* in press), at the same time mining companies, local communities, and regulatory authorities are becoming more aware of the benefit these resources can offer (Jones and McCullough in press).

In Australia, as in many countries, mining companies are often given no specific advice on end use options (Kumar *et al.* 2009). Rather, mining companies interested in developing an end-use approach regulatory authorities and other stakeholders with their preferred option and then these agencies make judgements as to whether this end-use is acceptable (McCullough *et al.* 2009a). Nevertheless, most developed countries and states are consistent in their requirement for mining companies to plan and/or rehabilitate to minimise or prevent entirely any potential deleterious effects of the pit lake water body on regional ground and surface resources (Jones and McCullough in press). The focus of most general or *ad hoc* pit lake regulation is given to protecting human and ecological communities from effects of the pit lake. For example, in Australasia, closure guidelines are based on ANZECC/ARMCANZ (2000) criteria; generally for ecosystem protection requirements. Such guidelines generally emphasize either a demonstration of null-negative effects of the lake when treated passively, or require active management to achieve the required level for compliance (Kuipers 2002). Nevertheless, an onus increasingly remains with industry to demonstrate that end use values have been explored with stakeholders and that if possible and desired, they are a key objective when determining closure criteria (Jones and McCullough in press).

The south west of Western Australia is regarded as highly biodiverse, with eight of the ten native freshwater fish found in the south-west endemic (Morgan *et al.* 1998). At least five species of native freshwater fish with limited distributions are also specifically found in the Collie region itself (Whiting *et al.* 2000). However, the biodiversity hotspot tag comes at a price, as these areas are listed for having the most endemic species and being the most threatened areas in the world (Myers *et al.* 2000; Malcolm *et al.* 2006).

The large endemic freshwater crayfish marron *(Cherax cainii)* also provides a prized recreational

Figure 1 Identifying anaesthetised fish next to Centaur Lake.

fishery in many regional parts of south-western Australia, including the Collie district (Whiting *et al.* 2000). Increasing human populations have impacted on natural marron stocks and the quality of the recreational fishery (Molony *et al.* 2001). However, marron have been introduced to Collie pit lakes along with other non-fishery species of crayfish.

Methods

An *ad hoc* survey was made of selected Collie pit lakes for crayfish in 2005 and for finfish in 2009. A literature review also collated the results of other surveys made; most of them unpublished reports and theses.

McCullough *et al.* (2009b) evaluated the marron and other crayfish fisheries of five pit lakes over two days in mid-September 2005. Crayfish were captured with three black 'Opera House' traps set overnight around the littoral margin of each lake and baited with cat biscuits (Campbell and Whisson 2000). In 2009, crayfish and fish were also surveyed for during April with sweep nets for three 1 m^2 quadrats per lake during macroinvertebrate sampling and in November 2009 with 10 m Japanese Seine transects three per lake along the littoral fringe (McCullough *et al.* 2010). Fish were anaesthetised with Aqui-S, identified and then gently returned (Figure 1). Water quality as basic physico-chemistry was simultaneously collected with a Hydrolab Datasonde 4a multiparameter probe.

Results and Discussion

Although dominated by marron, a total of three different endemic crayfish were found in Collie pit lakes. Finfish diversity and abundance was found to be low in the four pit lakes studied with only three species of native freshwater fish and an invasive species observed. Finfish diversity and abundance increased with increasing lake pH, indicating pit lake water toxicity may limit some species.

Historically, a previous study found marron in all pit lakes surveyed (Table 1). However, the authors concluded that Collie District pit lake marron were distressed by acidic conditions and that this physiological stress was limiting population sizes (Storer *et al.* 2002).

Pit lakes typically display very poor benthic habitat structure, particularly so around their littoral habitat as a result of depauperate riparian vegetation there (Van Etten in press). Further competition for depauperate food resources by co-occurring other species of crayfish be for typically limited food resources in pit lakes of algae and organic detritus in pit lakes (Kalin *et al.* 2001) may also limit marron population health.

Historically, *Gambusia holbrooki* and an endemic galaxiid fish (probably western minnow, *Galaxias occidentalis*) was first recorded in Collie pit lakes by Lyons (1997) during sweep net sampling of Lake Stockton aquatic vegetation in Spring. The endemic western pygmy perch (*Nannoperca vittata*, formerly *Edelia vittata*) has been also observed in Black Diamond Lake in 2005 coexisting with previously recorded feral freshwater poeciliid Gambusia (*Gambusia holbrooki*),. Both fish are primarily surface feeders, therefore introduced *Gambusia* probably com-

*Table 1 Marron presence and abundance in Collie pit lakes from 1997–1999 surveys of Storer et al. (2002), McCullough et al. (2009b), September 2005 marron surveying (catch per trap night)*and April and November 2009 surveying with sweep nets. P = present, – = no data collected.*

	Lake	Marron	Gilgies (*C. quinquecarinatus*)	Koonacs (*C. plebejus*)
1997–1999	Blue Waters	P	-	-
	Ewington	P	-	-
2005	Black Diamond	4	0	0
	Blue Waters	7	0	0
	Centaur	6	0	0
	Ewington	2	8	1
	Stockton	10	0	0
2009	Lake WO5D*	0	Abundant	0

Table 2 *Results of November 2009 Collie pit lakes fisheries sampling: numbers of fish caught for each species and surface water pH, Electrical Conductivity (EC, mS/cm), Oxidation-Reduction Potential (ORP, mV) and Dissolved Oxygen (DO, mg/L) at time of sampling.*

Lake	pH	EC	ORP	DO	*Edelia vittata*	*Galaxias occidentalis*	*Gambusia holbrooki*
Kepwari	4.3	2.850	399	7.8	0	0	0
Black Diamond	4.4	0.473	243	8.2	1	0	5
Stockton	4.5	0.476	342	7.4	2	0	0
Centaur	6.6	2.545	185	8.4	1	8	25

Figure 2 *Healthy adult Western minnow (*Galaxiidae: Galaxias occidentalis*) caught in Lake Centaur, November 2009.*

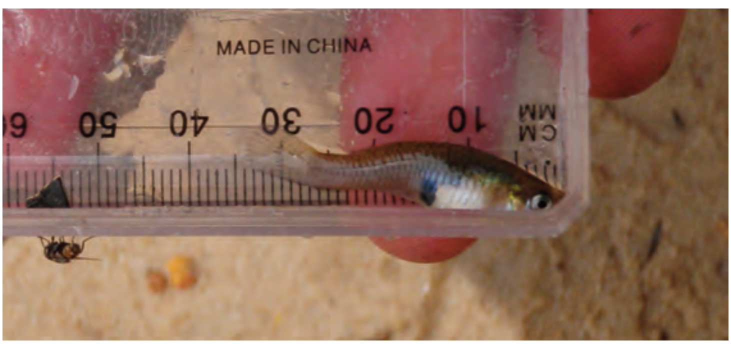

Figure 3 *One of the very common* Gambusia *(*Poeciliidae: Gambusia holbrooki*) caught in Lake Centaur, November 2009. This individual is a mature gravid female.*

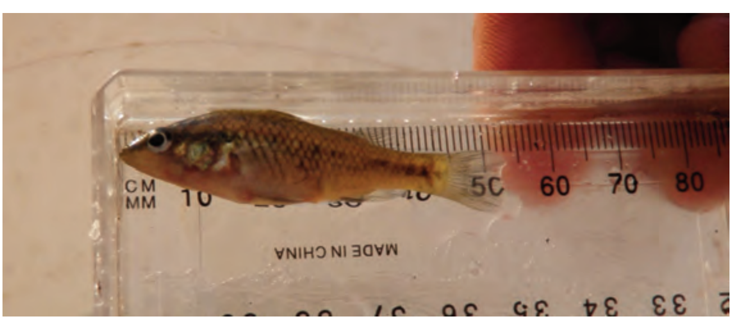

Figure 4 *Western pygmy perch (*Nannopercidae: Nannoperca vittata*) from Lake Stockton, November 2009. Note: caudal fin damage.*

pete directly with pygmy perch for allochthonous invertebrate foods. A recent study does not give methods or sources of information but comments that western-pigmy perch were also observed in Stockton Lake in 2004 (Thomas and John 2006). A dead western minnow was also observed in Lake Stockton during spring 2005 (pers. obs.).

Water quality in all lake surveyed showed high EC either due to evapo-transpiration in the Mediterranean climate with the highest EC due to filling with saline river water (Table 2). pH was low in all but one lake and was inversely correlated with ORP. DO was high in all lakes. The 2009 survey found that finfish diversity and abundance was low in the four pit lakes studied during the November 2009 survey. Finfish diversity and abundance also both increased with increasing lake pH, indicating pit lake water toxicity may limit some species. For example, *G. occidentalis* was only found in Lake Centaur, although some individuals have historically be found in more acidic Lake Stockton in Spring 1997 (Lyons 1997) and a dead individual was observed in 2005 (McCullough *et al.* 2010). Although western pygmy perch were found in Stockton Lake in the November 2009 survey, one of two fish showed significant damage to the caudal fin, consistent with lesions resulting from damage by acidic water. We also suspect the beaches where these fish were captured may have less acidic water as a result of natural stream flow into the lake at this point as shown by more turbid water there suggesting that they were not surviving in the main lake, just in areas near the stream.

The primary toxic component of Collie pit lake water at the typical pH 4–5 range of many district lakes is likely due to aluminium (Neil *et al.* 2009). Aluminium buffered water has been responsible for fish kills in another lake in the district area with aquacultured exotic species (Stephens and Ingram 2006).

Conclusions

To assist with the conservation of a species, whether it be for conservation, or as a fishery managers must have an understanding of the habitat requirements required for their survival (Bonnett and Sykes 2002). For an aquatic species, water quality is key habitat criteria. This marron fishery for recreation and the presence of endemic finfish in the Collie pit lakes serves as an example of how development of end uses in pit lakes can contribute to different sustainability objectives in a post-mining landscape. The finfish fishery demonstrates how water quality is likely to remain a key important variable to be considered in mine closure for controlling the range of environmental beneficial end uses able to be achieved by pit lake restoration. The marron fishery demonstrates that water quality is the beginning of developing environmental beneficial end uses with requirements for other ecological needs, especially those for higher organisms) such as food and habitat as otherwise potential obstacles for further ecosystem development in pit lakes. Incorporating pit lakes into a mine rehabilitation and closure plan at an early stage may avoid many closure costs and risks by considering pit lake designs that reduce environmental liabilities such as AMD by taking proactive steps to reduce or even prevent these problems developing.

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