MORE THAN WATER QUALITY: ENVIRONMENTAL LIMITATIONS TO A FISHERY IN ACID PIT LAKES OF COLLIE, SOUTH-WEST AUSTRALIA

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ABSTRACT

Marron (*Cherax cainii* Austin) are a freshwater crayfish native to permanent waterbodies in the south-west of Western Australia. A popular aquaculture and sports species, marron are considered a potential end-use fishery species for and have been deliberately released into several historic pit lakes of the Collie coal mining region. This study investigated what environmental factors in these acid mine drainage (AMD) contaminated pit lakes might be affecting the health and success of existing marron fisheries. Although pit lake water quality was often low (pH <4 with elevated metal concentrations) this did not appear to lead to lower marron health indices. Rather, lack of burrow habitat, low biomass and quality of food with further competition for these resources from related non-fishery crayfish species may be the most important factors limiting marron health. Decreased marron health is likely to result in decreased individual growth rate and final fishery biomass. Such ecological considerations are not common to the mine water literature but offer a more holistic perspective to much mine water research and may provide more tangible environmental goals for achieving environmental and social sustainability of mine waters.

1. INTRODUCTION

Large-scale open-cut mining activity has left a legacy of many thousands of mine pit lakes worldwide where mining voids extend below the watertable (Castro & Moore, 1997; Klapper & Geller, 2002). In addition, Acid Mine Drainage (AMD) is arguably the greatest environmental problem facing water management in the international mining industry today (Gray, 1997; Harries, 1998). AMD affected pit lakes typically have reduced environmental and social values, and the resultant water is less valuable as a resource to the mining company (McCullough & Lund, 2006). Such novel yet contaminated waterbodies may also directly or indirectly threaten health and well-being of local communities and natural environments (Doupé & Lymbery, 2005). Nevertheless, large quantities of water in many pit lakes represent potentially valuable resources to mining companies, the environment and community; if appropriate water quality can be achieved (McCullough & Lund, 2006; McCullough *et al.*, 2009).

The Collie Basin, located approximately160 km south-southeast of Perth, is the centre of coal mining in Western Australia. Over 100 years of coal mining in Collie has resulted in the formation of more than 15 pit lakes that range from <1–10 ha in surface area, <10–70 m in depth, 1–50 years in age, in pH from 2.4–5.5, and differ in the extent of rehabilitation (Lund & McCullough, 2008). These pit lakes have very low nutrient concentrations, particularly of carbon and phosphorus (Salmon *et al.*, 2008). The few ecological studies made on Collie pit lakes highlight nutrient limitation restricting algal productivity and hence lake foodwebs (Lund *et al.*, 2000; Lund *et al.*, 2006; Thomas & John, 2006; Salmon *et al.*, 2008).

The large endemic freshwater crayfish marron (*Cherax cainii*) provides a prized recreational fishery in many regional parts of south-western Australia, including Collie (Whiting *et al.*, 2000). Increasing human populations have impacted on natural marron stocks and the quality of the recreational fishery (Molony *et al.*, 2001). Marron have been introduced to Collie pit lakes along with other non-fishery species of crayfish. This marron fishery serves as an example of how mining activities can contribute to sustainable economic opportunities in a post-mining landscape.

2. METHODS

The small mining town of Collie is located in the south-west of Western Australia (Figure 1) and has a Mediterranean climate with hot, dry summers and cool, wet winters (Varma, 2002). The 5 historic (*ca*.1960) pit lakes studied had no remediation prior to natural filling with rainfall and groundwater. The sides of all lakes are general very steep with limited littoral edge and riparian vegetation and the supply of allochthonous nutrients into all the lakes from the limited catchments is probably very small (Lund *et al.*, 2006). Habitat and food resources, however, are likely to be similarly depauperate in other acidic pit lakes.

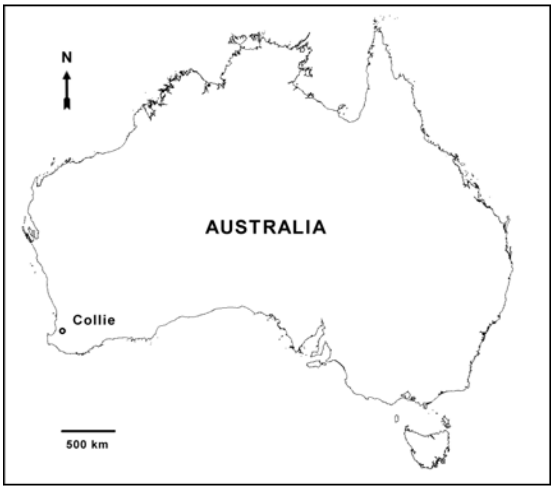

Figure 1. Location of pit lakes sampled in Collie, Western Australia

Measurements of dissolved oxygen (mg L^{-1}), pH, oxidation reduction potential (ORP, Ag/AgCl reference), specific conductance, chlorophyll *a*, turbidity and temperature were made in 2005 with a Hydrolab Datasonde 4a multi-parameter probe. In each lake, a pooled sample of surface water was taken and filtered through 0.5 µm glassfibre filter paper (Pall Corporation Metrigard™). Filtered samples were acidified and analysed by Inductively Coupled Plasma Atomic Emission Spectrophotometry (ICP-AES) for Al, As, B, Ca, Cd, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Se, Si, Sn, and Zn.

Littoral benthic macroinvertebrates were collected over 1 $m^2$with kick-nets, sorted from upper sediments and the dry macroinvertebrate mass approximated by loss-on-ignition (LOI) (APHA, 1998). Upper sediment samples were sieved through nested 1 000 and 250 µm sieves and the FPOM and CPOM mass and the dry macroinvertebrate mass approximated by LOI as also per the macroinvertebrate samples. Samples of the littoral sediment were collected at 1.0 m water depth and the upper 5 mm of digested and analysed for benthic periphytic algae biomass was spectrophotometrically determined as chlorophyll a as µg cm^{-2} (APHA, 1998). Phytoplankton biomasses were measured from lake surface and bottom water samples spectrophotometrically as per benthic algae. Three habitat traps were also set in each lake over three weeks. These traps act as refugia as analogues to large debris and trap crayfish that use them for such cover habitat (Mitchell *et al.*, 1994).

Marron (n = 28) and any other co-habiting crayfish (n = 9) were captured with three black ‘Opera House’ traps set overnight around the littoral margin of each lake (Campbell & Whisson, 2000). Marron were kept on ice and dissected within 48 h to remove gills, hepatopancreas, tail muscle and female reproductive organs. The wet weight of the hepatopancreas and tail muscle was measured and the dry weights of these tissues determined by drying for 16 h at 80°C. The wet and dry weights of the hepatopancreas were used to calculate the wet hepatopancreatic index, the dry hepatopancreatic index and the hepatopancreas moisture for each individual. A tail muscle moisture index was then determined from the wet and dry weights of the tail muscle (Jussila & Evans, 1998). Statistical analyses were undertaken with SPSS (2004) and Primer (PRIMER-E Ltd, 2006).

3. RESULTS

Pit Lake Environmental Quality

pH was highest in Lake Centaur at 6.3 and lowest in Blue Water and Ewington Lakes at 3.5 and 3.7 respectively (Table 1). Dissolved oxygen was near saturation in all lakes studied. Generally inversely-correlating with pH, EC and ORP were highest in lower pH lakes, except for Lake Centaur where high specific conductance was associated with inflowing saline waters. Concentrations of Al, Cu and Zn were above Australasian environmental water quality guidelines (ANZECC/ARMCANZ, 2000) for the protection of aquatic ecosystems (95%) in all pit lakes. Concentrations of Fe, Ni and Pb were elevated in some of the lower pH lakes. Concentrations of As (<0.01), Cd (<0.006), Cr (<0.001), Hg (<0.02), Se (<0.02) and Sn (<0.02) were all below detection limits (all as mg L^{-1}).

Crayfish habitat was lowest and competition by gilgies (*Cherax quinquecarinatus*) and koonacs (*Cherax plebejus*) was highest in Lake Ewington (Figure 2). Primary production as benthic and phytoplanktonic algae and CPOM and FPOM organic matter fractions was highest in Stockton and Centaur Lakes and lowest in Black Diamond and Blue Waters Lakes. Benthic macroinvertebrate biomass was highest in Black Diamond and Blue Waters Lakes and lowest in Stockton and Centaur Lakes.

Marron Health

Mean marron body weight was greatest in Centaur Lake (162 mg) then next highest in Blue Waters Lake (124 mg). Marron body weight was similar in Black Diamond, Ewington and Stockton Lakes (Figure 3). All hepatopancreatic indices were very similar across all five pit lakes.

Table 1. Collie pit lake physico-chemical and metal concentrations (mg L-1 unless indicated). Shading indicates value exceeds Australasian water quality guidelines (ANZECC/ARMCANZ, 2000)

Lake	pH	DO	EC (mS cm^{-1})	ORP (mV)	Al	Ca	Cl	Cu	Fe	Mn	Ni	Pb	Zn
Black Diamond	4.7	12	0.61	233	0.11	6.5	131	0.002	0.032	0.130	<0.004	<0.01	0.015
Blue Waters	3.5	12	2.25	370	2.80	11.0	452	0.002	0.380	0.081	0.039	<0.01	0.150
Centaur	6.3	11	2.11	153	0.09	20.0	603	0.003	0.280	0.011	<0.004	<0.01	0.015
Ewington	3.7	13	1.46	300	1.40	3.1	339	0.004	0.260	0.023	0.005	0.030	0.037
Stockton	4.1	12	0.57	378	0.49	2.9	137	0.003	0.150	0.087	0.020	<0.01	0.120

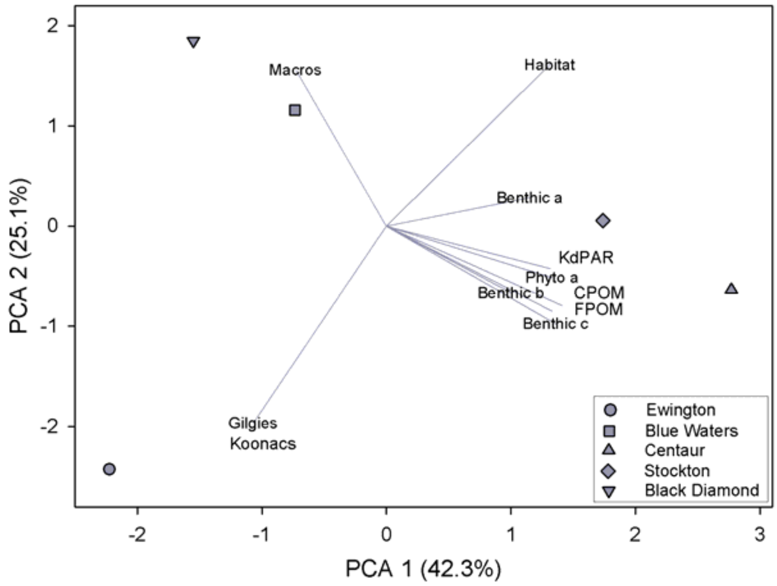

Figure 2. PCA ordination (first two principal components) of indicators of primary and secondary productivity, habitat and competition of Collie pit lakes

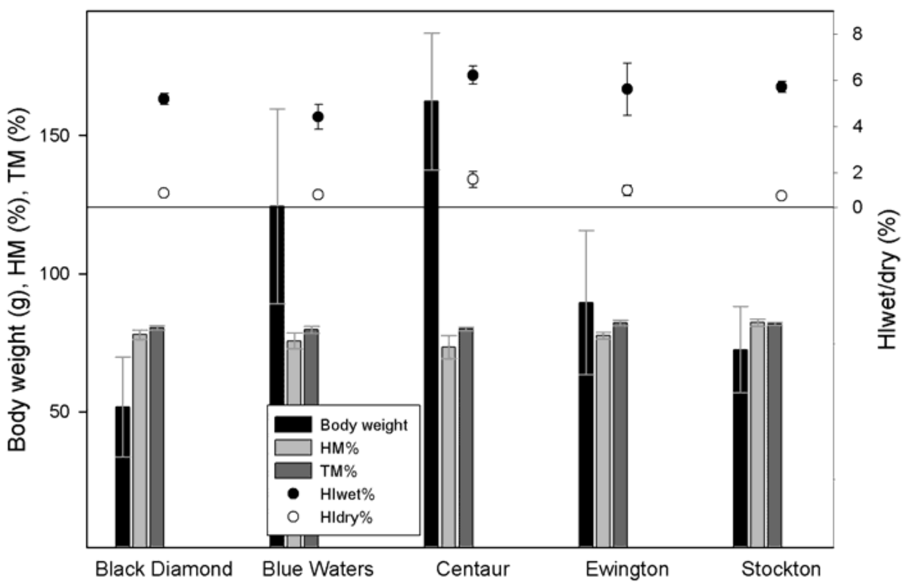

Figure 3. Collie pit lake mean marron health indices (± standard error). HM% and TM% = hepatopancreas and tail moisture % content, HIwet% and HIdry% = hepatopancreatic wet and dry indices

4. DISCUSSION

Of all mining legacies, pit lakes are frequently the most severe environmental impacts to a mining region (Younger, 2002), and yet in a dry(ing) climate such as Australia, the newly developing vast open cut pit lakes could also represent a great potential boon for communities left behind once mining is complete (McCullough & Lund, 2006). Such post-mining use of an industry legacy would help advance expectations of best-practice mining which, although claiming development toward environmental and social sustainability, still cannot demonstrate how this can actually be achieved once mining operations are completed (Nichol, 2006). We hope that this research serves to move the research field of both mining sustainability forward from considerations and suggestions of potential beneficial enduses of mining legacies to realisation of significant environmental and community benefit as potentially the first time recreational fisheries have been considered as a direct outcome from mining activities.

A previous study using solely water quality data suggested Collie pit lake marron were distressed by acidic conditions and that this physiological stress was limiting population sizes (Storer et al., 2002). This current study found circum-neutral pit lake had larger marron, but of comparable health to those from acidic pit lakes. We therefore conclude that pit lake water across a range of water qualities makes little difference to individual marron health. However, acidic pit lakes differ from natural water bodies in more ways than just their water chemistry and this current study also simultaneously measured a holistic suite of parameters in addition to water quality; including habitat, inter-specific competition and food resource type and availability. These previously unconsidered environmental parameters may be more important to successful establishment of a marron fishery in Collie pit lakes. For example, refugia such as fallen logs and rocky outcrops often form important refuge habitat from predation and competition in water bodies (Foster, 1993). Indeed, much like other constructed water bodies (such as dams), pit lakes typically display very poor benthic habitat structure required by large animals such as fish and crayfish and there is often strong competition for these physical resources (Foster, 1993). Further competition for depauperate food resources by other species of crayfish co-occurring in pit lakes may also limit marron population health (France, 1996). Such competition may be for typically limited food resources in pit lakes of algae and organic detritus (Kalin *et al.*, 2001). These simple ecological principles may best explain limitations to marron in acidic pit lakes where previous assessment of water quality alone has not.

Mine water environmental values are most typically addressed by funding bodies and researchers through physical and chemical approaches and are less frequently directly studied through ecological approaches. However, ecological approaches to mine water research opportunities may often more clearly articulate targets and guide remediation methods for the long term sustainability of pit lake systems specifically i.e., the “what are we actually setting water quality targets/remediating water quality for?” questions (Kalin, 2009). Ecological perspectives may be complimentary to many existing study directions recognising mine waters-affected water bodies such as pit lakes as more than a simple geochemical environment with further fundamental requirements needing to be addressed if a representative functional and sustainable ecosystem is to be achieved. Such incorporation of ecological perspectives to mine water research and management is likely to translate into improved environmental outcomes as well as providing tangible goals of opportunities to cheaply and effectively achieve environmental and social sustainability targets.

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