Are mine pit lakes representative of regional water bodies? A case study from silica sand mining

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Introduction

Regulators often view pit lakes as natural lakes and impose similar guidelines for long-term water quality and biodiversity objectives (Jones & McCullough, 2011). Where the likely closure endpoint is mine lease to the state conservation reserve, then the likely stakeholder expectation is for the pit lake to be representative of regional natural water bodies. To be regionally representative, we hypothesize that a pit lake would have similar a) water quality, and b) species assemblage, to regional wetlands. Macroinvertebrates are typically the most popular biological community chosen to assess aquatic impacts. Internationally, analysis of macroinvertebrate communities has been the foremost tool for biological assessment of aquatic ecosystems due to the availability of good taxonomic understanding , sensitivity to water quality changes, a speciose community and extensive literature of pollutant effects (Havens *et al.*, 1996; Schofield & Davies, 1996). We focussed on a pit lake that was surrounded by natural wetlands from which it could develop representative, 'natural' water quality and biota.

Study Site

The Kemerton Silica Sand (KSS) mine is located on the Swan Coastal Plain (SCP, a series of sand dune systems), south Western Australia (Figure 1). KSS wetlands are some of the best examples of the SCP wetland complexes still extant on the SCP. The Mediterranean climate results in seasonal wetlands. Approximately 0.5 Mt of sands containing feldspar, silica and mineral sands (mostly titanium oxide) are extracted annually from under <1 m of topsoil, 4 to 7 m of overburden using a surface floating dredge. The dredge pond is essentially a window into the unconfined aquifer. Rehabilitation of the dredge pond involves sectioning off into pit lakes.

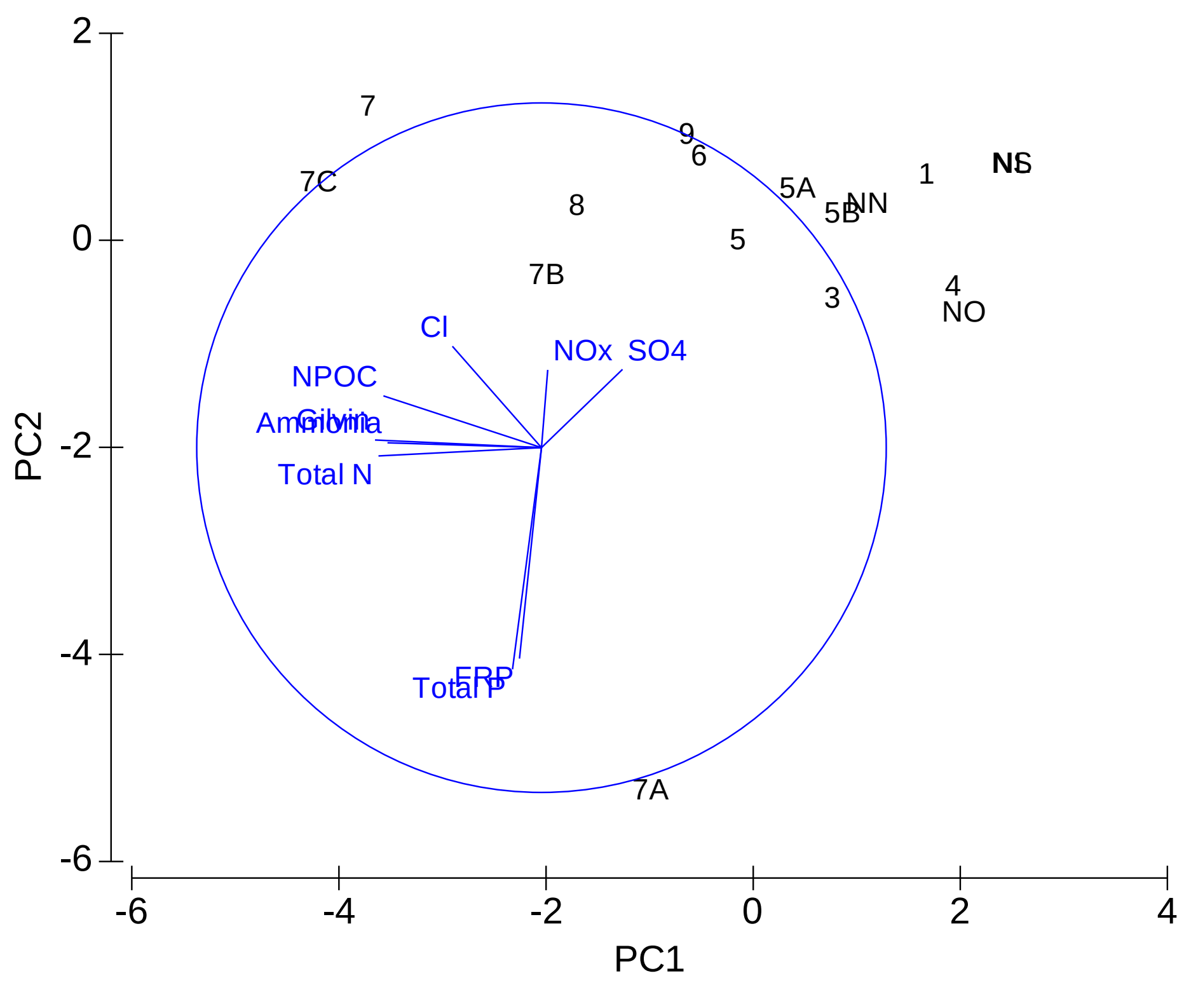

Figure 2. PCA of nutrients, gilvin, Cl and SO_4 for all wetlands PC1 = 45.7%, PC2 = 24.3%.

Sampling Methods

A total of 17 wetlands were sampled (Figure 1), including four pit lakes: a rehabilitated pit lake (NL), a satellite wetland with limited connection to NL (NS), an old unrehabilitated small test pit lake (NO), and a created shallow wetland (NN). Sampling occurred in September 2007 at the time of peak water levels, in a replicated stratified design encompassing each major habitat in the littoral area (<1 m deep).

At each site, a range of physico-chemical parameters were measured *in situ*, and a composite water sample were taken. Water samples were analysed for NH_3-N, NO_x-N, filterable reactive phosphate (FRP-P), Total P-P, Total N-N, SO_4^{2-}, non-purgeable organic C (NPOC), gilvin (g440) as per Kirk (1976), and the metals Al, Ba, Be, Ca, Cd, Cr, Co, Cu, Fe, Mn, Na, Ni, Sb, Sn and V. Aquatic macroinvertebrates were collected in a 250 µm mesh sweep net (face 0.2 x 0.2 m) along a 10 m transect at each site. All macroinvertebrate samples were preserved in 80% ethanol, sorted, counted and identified under stereo microscopy.

Data Analysis

Multivariate data analyses used PRIMER v6 software (Clarke, 1993). Principal Components Analysis (PCA) was used to produce ordinations of normalised physico-chemical and nutrient, NPOC, gilvin and metal data. An MDS ordination of taxa abundance data was completed using a Ln(x+1) transformation (Faith *et al.*, 1987) and the Bray-Curtis dissimilarity matrix (Faith *et al.*, 1987). Differences between *a priori* treatment groups were tested using the Analysis Of SIMilarity (ANOSIM) (Clarke, 1993).

5B

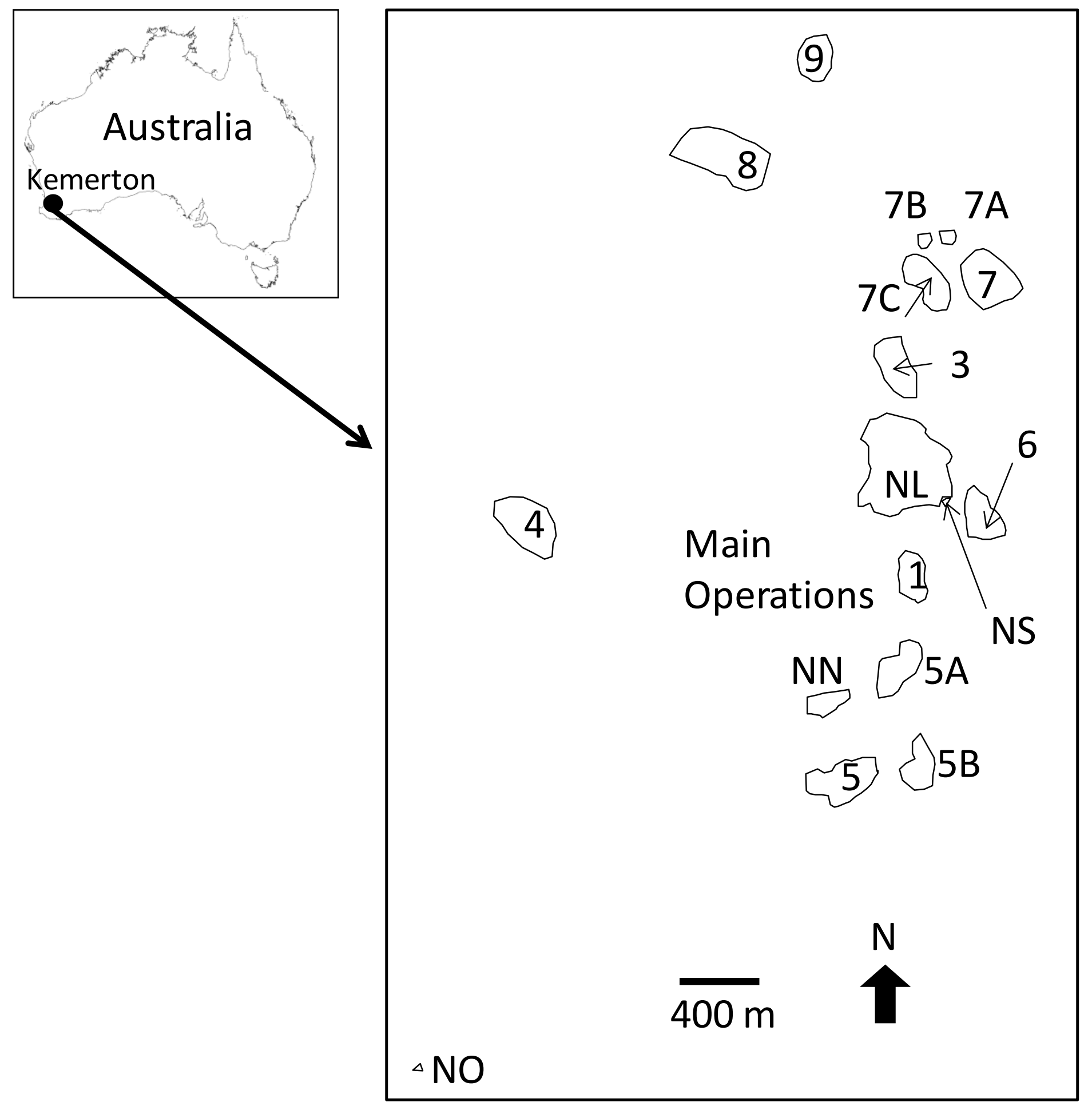

Figure 1. Location of Kemerton Silica Sand mine and wetlands sampled.

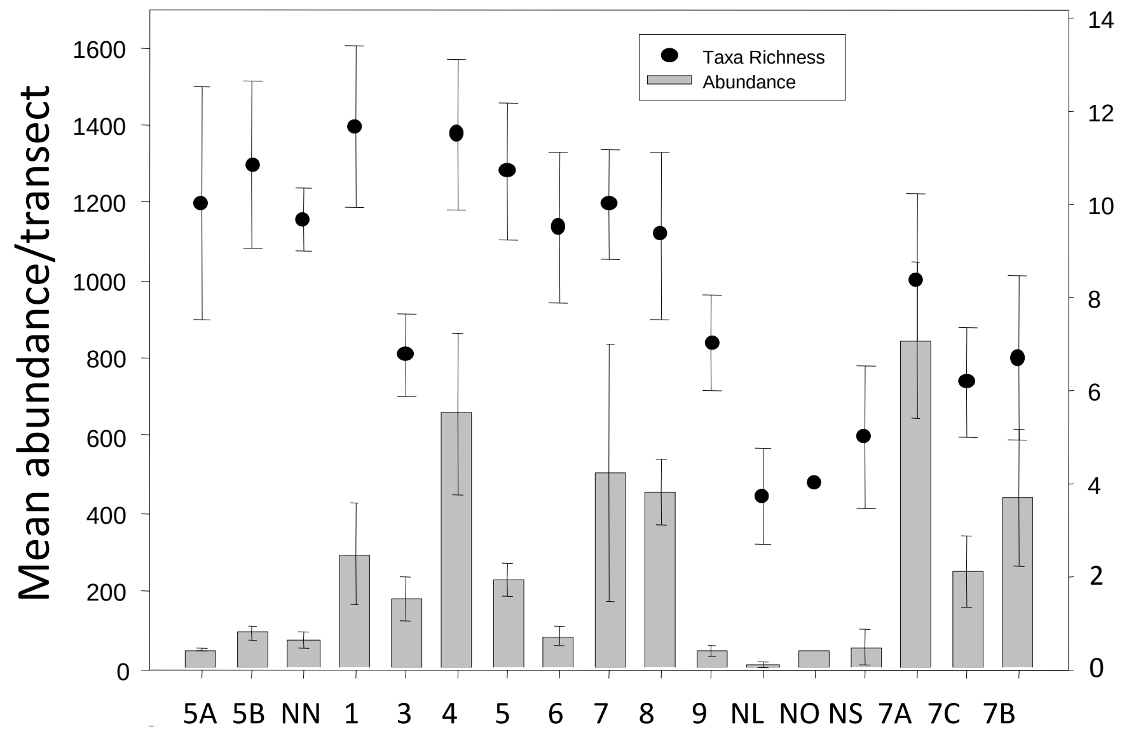

Figure 3. Mean aquatic macroinvertebrate abundance and taxa richness per transect in KSS wetlands.

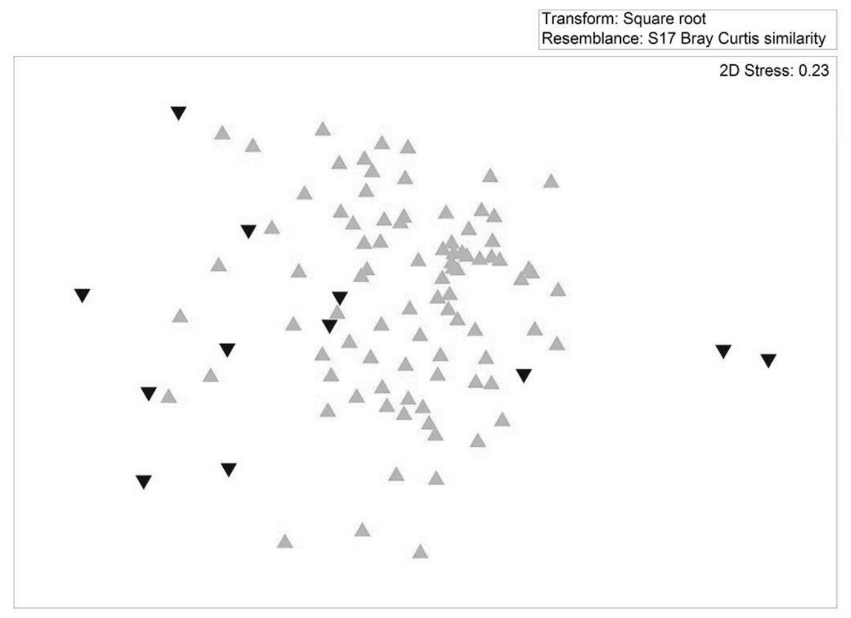

Figure 4. nMDS of natural and new pit lake wetland macroinvertebrate assemblages

Table 1. Mean (±SE) concentrations of KSS wetland physico-chemical parameters. *N=1.

	pH	Conductivity	Dissolved O_2	Turbidity	Nutrients ($\mu g\ L^{-1}$)					NPOC	SO_4	Gilvin
Site		($mS\ cm^{-1}$)	(%)	(NTU)	Ammonia	NOx	Total N	FRP	Total P	($mg\ L^{-1}$)	($mg\ L^{-1}$)	(g440)
1	8.0 ± 0.1	1.6 ± 0.03	77 ± 6	0 ± 0	13	90	692	6	<20	28	125	15
3	5.2 ± 0.1	0.3 ± 0.03	56 ± 4	5 ± 0	96	19	936	2	58	48	10	45
4	6.3 ± 0.0	0.4 ± 0	86 ± 2	0 ± 0	27	14	399	2	35	16	23	15
5	5.8 ± 0.1	0.5 ± 0.03	74 ± 7	0 ± 0	137	24	1358	2	20	66	13	68
5A	7.2 ± 0.7	1.2 ± 0.05	105 ± 16	13 ± 6	66	14	792	6	<20	32	65	24
5B	7.2 ± 0.1	1.1 ± 0.18	66 ± 10	10 ± 1	98	21	1300	<2	<20	56	74	56
6	6.1 ± 0.3	0.6 ± 0.07	59 ± 2	0 ± 0	200	339	1397	36	<20	75	49	81
7	7.0 ± 0.0	1.8 ± 0.02	90 ± 6	1 ± 1	272	67	4643	2	30	111	75	130
7A	4.8 ± 0.1	0.6 ± 0.07	55 ± 3	0 ± 0	132	17	2632	297	416	49	23	75
7B	5.3 ± 0.1	0.3 ± 0.00	82 ± 6	0 ± 0	300	29	2608	2	64	88	16	124
7C	5.7 ± 0.1	1.1 ± 0.03	55 ± 4	0 ± 0	356	28	4375	2	44	135	31	157
8	5.3 ± 0.0	0.8 ± 0.03	60 ± 6	0 ± 0	222	24	2659	2	20	101	30	90
9	4.7 ± 0.0	1.3 ± 0.04	47 ± 2	0 ± 0	22	104	1780	5	<20	108	79	79
NL	7.7 ± 0.1	1.2 ± 0.00	117 ± 4	40 ± 16	22	98	573	2	20	22	296	11
NO	8.0 ± 0.5	0.9 ± 0.3	121 ± 2	12 ± 4	38	<2	559	2	41	15.2	10	3
NN*	7.9	0.2	114	3	78	99	1060	2	20	41	103	34
NS	5.6 ± 0.0	0.7 ± 0.03	90 ± 2	38 ± 4	22	98	573	2	20	22	296	11

Key Results

- Key physico-chemical parameters are shown in Table 1. A PCA ordination of wetland nutrient, gilvin, Cl and SO_4 concentrations (Figure 2) showed that wetlands 7, 7A, 7B, 7C and 8 with high gilvin, ammonia, Total N, NPOC and Cl. Water chemistry of wetland 7A clearly separated from other wetlands due to the enrichment with P. NO and 4 were very similar reflecting their rain-fed water quality. NL and NS were very similar to 1, reflecting their common water sources. The NN wetland was very similar to wetlands 5, 5A and 5B; showing that location appears more important than creation mechanism.
- Most metals measured had detection limits above those of ANZECC/ARMCANZ (2000) trigger values for 99% aquatic ecosystem protection; or had concentrations under the relevant trigger values. However, lead exceeded guidelines (0.006 to 0.015 mg L^{-1} depending on hardness) in 5A (0.1 mg L^{-1}), 8 (0.2 mg L^{-1}) and 9 (0.1 mg L^{-1}. Zinc and Al also exceeded guidelines for many wetlands.
- Wetlands were all oligotrophic with very low FRP at <6 µg L^{-1} and Total P <70 µg L^{-1}; with the exception of 7A (297 µg L^{-1} FRP and 416 µg L^{-1} Total P) and 6 (339 µg L^{-1} NOx , no Total P measured).
- 147 macroinvertebrate taxa were collected in total. Macroinvertebrate communities were generally dominated by zooplankton, then chironomid larvae (an order of magnitude less abundant) and then Coleoptera, Culicidae and Hemiptera larvae.
- Only one taxon (*Necterosoma* beetle larvae) was common across all wetlands and only 10% of taxa were found in over half of the wetlands. Forty percent of taxa only occurred in one wetland with all wetlands except 7B and NO having unique species.
- Natural wetlands had an overall mean of 309 ± 49 macroinvertebrates per sample and a mean of 850 macroinvertebrates per sample in 7A. Natural wetland macroinvertebrate samples were also moderately diverse, with an overall mean of 9±0.0 taxa per sample to a maximum of 19 taxa per sample in 1 and 4.
- Macroinvertebrate community abundance and diversity was lower in pit lakes NO, NL and NS showing only a mean of 24 ± 10 macroinvertebrates per sample and a mean of 4±1 taxa per sample (Figure 3). NN had a high taxa richness comparable to most other natural wetlands. Compared to 1 the other permanent wetland, NL still demonstrated low macroinvertebrate biodiversity.
- Pit lake macroinvertebrate community structure was significantly different to natural wetlands (Global R = 0.536, P<0.01). Macroinvertebrate assemblage differences were primarily due to zooplankton dominance in natural wetlands and chironomid larvae dominance in pit lake wetlands (Figure 4).

Conclusions

KSS natural wetlands were oligotrophic and had high aquatic macroinvertebrate biodiversity. The small test pit lake (NO) was dissimilar to NL; presumably due to rainwater rather than groundwater inputs. The satellite waterbodies (NS) around NL were more physically similar to natural wetlands and had slightly higher macroinvertebrate taxa richness compared to pit lake NL. This suggests that greater shallow areas and/or more riparian vegetation would develop pit lake macroinvertebrate assemblages to be more representative of nearby wetlands. The newly created seasonal wetland NN had similar taxa richness to natural wetlands., indicating the importance of bathymetry for biodiversity. The water quality and macroinvertebrate assemblage of new pit lakes were all significantly different to the natural wetlands. Pit lake NL intercepted deeper and harder/more alkaline than other wetlands, except wetland 1. The permanence and depth of pit lake NL are also distinctive features ensuring that its water quality will always be different to the natural wetlands. The NL pit lake is only a few years old with very limited riparian vegetation and relatively unstable banks. This wetland habitat is therefore not suitable for many macroinvertebrates, limiting their abundance and diversity.

The new pit lake wetland habitats appear to be on a water quality and ecological developmental trajectory to representativeness of regional wetlands. However, it appears that physical structure is one of the most important determining factors influencing the development of representative aquatic macroinvertebrate taxa. NL pit lake is relatively new and it is anticipated that as the riparian vegetation develops that the lake's biota will continue to increase in diversity and abundance. Due to its permanence and depth, NL pit lake will likely never be representative of a natural regional wetland, but, nevertheless, can still contribute significantly to regional aquatic ecosystem values that are currently severely threatened on the SCP.

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