CLASSIFICATION OF INLAND SALT LAKES IN WESTERN AUSTRALIA

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ABSTRACT

Many mining operations in the West Australian goldfields face the challenge of managing large quantities of hypersaline dewatering discharge, and often have few disposal options other than to nearby salt lakes. Both the mining industry and regulators recognize the need to firstly identify, and then effectively manage, the impacts of dewatering discharge to salt lakes during the life of a mine. However, this is a difficult task, because there is little information available on the importance or significance of the particular receiving wetlands, also there is a paucity of published background data and relevant guidelines for salt lake ecosystems in general. It is therefore difficult to regulate and manage the use of inland waters when there is little understanding of their resilience to impact, and the role of environmental fluctuations, such as rainfall, in mitigating impact.

In recognition of the issues related to salt lake management, Outback Ecology and Curtin University have collaborated to develop a Masters Project which has been sponsored by the Minerals and Energy Research Institute of Western Australia (MERIWA).

The objectives of the project are;

1. *To collate, collect (if information is not available) and validate all available 'control site' data related to inland salt lakes of Western Australia, particularly related to surface water, sediments and aquatic biota;*
2. *To identify the gaps in knowledge regarding inland salt lakes;*
3. *To use all validated data on hydrological cycle, water quality, sediment chemistry and biota to develop a classification system for inland waters of Western Australia*

The anticipated outcomes of the project are:

1. *A series of baseline data ranges for each lake 'type', as a basis for relevant guidelines, particularly in relation to water and sediment quality;*

2. *A description of typical ecological communities expected for each lake 'type';*
3. *Development of protocols for sampling both aquatic biota in salt lake ecosystems, and collecting physico-chemical data;*
4. *A report detailing the classification system, and summarizing the features of different salt lake types in WA (where data is adequate)*

This paper describes the rationale for the study, the study area, current classification methods, the methods to be used for the Masters study, and some preliminary results.

INTRODUCTION

The need to collect information on both biotic and abiotic components of salt lakes in inland Western Australia has become increasingly important in recent years. Mining companies use salt lakes for the disposal of hypersaline water from their operations, however little is known about the uniqueness of these lakes or the possible impacts of discharge water. An abundance of information pertaining to salt lakes has been collected by both Outback Ecology and Curtin University since 1998. However, most of this data is tied up in unpublished or internal company reports and is unavailable to the public and/or regulators. A Masters project titled 'The Classification of Inland Salt Lakes' was proposed in 2005 and funding was sought from industry to address this issue. Nine sponsors were acquired and the project received a Minerals and Energy Research Institute of Western Australia (MERIWA) grant in late 2005.

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Inland Salt Lakes in Western Australia

The interior of Western Australia has the greatest concentration of salt lakes on the continent (Gentilli 1979). Furthermore, salt lakes in Western Australia display one of the greatest levels of endemism, species diversity and species radiation for salt lakes in Australia (Hebert and Wilson 2000.; Halse and McRae 2001; Remegio et al. 2001). A substantial proportion of the mining activities in Australia are also located within the arid and semi-arid zones of Western Australia, with many of the alluvial mineral deposits associated with the extensive salt lakes (John 2003).

It is increasingly accepted that the inland waters of salt lakes are extremely important refugia, not only for unique species that inhabit them, but also for the many birds that include these lakes in their migratory path. Past disinterest and misunderstanding of these lakes has led to poor management practices. With continued mining activities impacting these systems, the need to manage them effectively and mitigate impacts from dewatering discharge, is apparent. The focus of past and present research has been to study each lake individually, rather than to treat the lakes as a system, sharing similar characteristics. Handley (2003) was the first to compare coastal and inland salt lakes in terms of their algal composition and continued research indicates that there may be features that many of the lakes share. John (2003) indicated a need to recognize flagship species within Western Australian salt lakes to assist in the formulation of practical guidelines for temporary water bodies.

Why Classification?

Classification systems are used to simplify a large data set, and in this case will allow wetlands to be grouped according to similar attributes (Semeniuk and Semeniuk 1997). Classification allows informed decisions to be made for the protection, recognition of unique attributes and management of aquatic systems (DOE 2005). A number of classification systems are used throughout Australia, and are discussed below, however these do not adequately describe the salt lakes of the goldfields. Together, Outback Ecology and Curtin University have collected information from approximately 22 of these lakes. The information collected includes sediment and water chemistry, algae, invertebrates and riparian vegetation.

There is a need to combine all available data on WA salt lakes (John, 2003b) and the lack of a classification system for practical use, particularly within the mining industry, was a major concern raised at the 2003 ACMER workshop on Water Quality Issues in Final Voids, Salt Lakes and Ephemeral Streams. The need for the accumulation and integration of data for a range of different water bodies was also expressed by Batley *et al.* (2003) in their review of the current ANZECC/ARMCANZ guidelines.

Current Classification Systems

A number of classification systems have been described for freshwater systems to date but their use is limited to wetlands of the Swan Coastal Plain, South-west and the Wheatbelt (Davis *et al.* 1993; Semeniuk and Semeniuk 1997; Cale *et al.* 2004). The Department of Environment (2005) supports the use of geomorphic classification similar to the system proposed by Semeniuk and Semeniuk (1995), however they also support systems based on biological data such as the study of the wheatbelt completed by Halse *et al*. (2004). The Semeniuk classification system is primarily based on the landform setting and hydroperiods of the wetland.

However other factors such as vegetation, water chemistry, size and landforms can be added to the system for greater definition. Of the six wetlands considered in this preliminary study, all were classified as playas using this system (i.e. intermittently inundated basin). Salinity descriptors used by this system are unreliable for goldfields salt lakes,which display a wide variation in salinity throughout their hydrocycle and may remain dry for extended periods of time (Semeniuk and Semeniuk 1995). When wet however, all lakes considered in this study are all hypersaline for most of their hydrocycle. Adding vegetation parameters to the classification system is possible, although most of the salt lakes in Western Australia show a similar pattern of vegetation distribution, defined by Semeniuk and Semeniuk (1995) as Zoniform (zones of vegetation on the periphery) or Bacataform (vegetation types in no particular pattern but on the periphery).

The Ramsar Convention classification system attempts to classify wetlands on the global scale (Semeniuk and Semeniuk 1997). The Ramsar classification system recognizes three main types of wetlands; Marine/Coastal wetlands, Inland Wetlands and Human-made Wetlands. These are further divided in 42 types. The six salt lakes considered in this study can be broadly classified as Seasonal/Intermittent Lakes (R), according to Ramsar (RAMSAR 2006).

De Deckker (1988) describes four main salt lake types in Australia; large playa lakes, small closed lakes or pans, crater lakes and coastal lakes. Based on this classification the salt lakes of Western Australia consist of either large playa lakes or small closed pan. Large playa lakes are those ‘greater than 10km in size which are most often dry’. Small closed pans are those that ‘fill primarily from rainfall in contrast to the large playa lakes whose filling relies on large drainage catchments’ (De Deckker 1988). The salt lakes included in this Masters project would therefore be classified as large playa lakes. While this description provides some useful information in regard to size and water permanence, little emphasis is given to the biota.

Generally, according to all three classification systems described above, salt lakes of the goldfields were very similar (**Table 1**). The classification system proposed by Semeniuk and Semeniuk (1995) incorporates the most detailed information, related to size, salinity, fluctuating water quality, vegetation pattern and zonation. In contrast, the other systems (DeDeckker (1988) and Ramsar (2006)) only provided classification based on hydroperiod and size. None of the three systems provide information on the biota, including invertebrates and algae, which are present in each wetland. In that context, the presence of unique, ubiquitous and important species, and the management measures required to protect them, is unknown.

Table 1 A selection of lakes considered in the MERIWA Project, and their features according to three existing classification systems.

Lake	Existing Classification System		
	Semeniuk and Semeniuk (1997)	**DeDeckker (1988)**	**Ramsar (2006)**
Lake Carey	Megascale, irregular, hypersaline, poikilohaline, bacataform playa	Large Playa Lake	Seasonal/Intermittent Lake (R).
White Flag Lake	Macroscale, irregular, hypersaline, poikilohaline, bacataform playa	Large Playa Lake	Seasonal/Intermittent Lake (R).
Lake Way	Megascale, irregular, hypersaline, poikilohaline, bacataform playa	Large Playa Lake	Seasonal/Intermittent Lake (R).
Lake Miranda	Megascale, irregular, hypersaline, poikilohaline, zoniform playa	Large Playa Lake	Seasonal/Intermittent Lake (R).
Kopai Lake	Mesoscale , irregular, hypersaline, poikilohaline, zoniform playa	Small Closed Lake or Pan	Seasonal/Intermittent Lake (R).).
Black Flag Lake	Macroscale, irregular, hypersaline, poikilohaline, zoniform playa	Small Closed Lake or Pan	Seasonal/Intermittent Lake (R).
Lake Lefroy	Megascale, irregular, hypersaline, poikilohaline, bacataform playa	Large Playa Lake	Seasonal/Intermittent Lake (R).

PROPOSED METHODS FOR CLASSIFICATION AND SAMPLING

There is already a substantial body of information available on WA salt lakes, collected by a variety of companies and institutions. The main task in the preliminary stages of the project described here, after existing data has been collated, will be to consider the validity of the data and identify gaps in knowledge, particularly with regard to identifying suitable indicator species for classification of inland waters. A field sampling program will then be implemented to address gaps in data, and multivariate statistics would be performed on the refined data set. Multivariate statistical analysis will assist in determining parameters for classifying inland waters.

All available data on background values for inland salt lakes will be screened to determine compatibility and robustness. Any data that does not follow appropriate methodology will be removed. The gaps in the data will then be identified.

Data related to the following components will be investigated statistically in developing a predictive model:

1. Algae
2. Invertebrates
3. Riparian vegetation
4. Macrophytes
5. Avian Fauna
6. Chemistry – water and sediment

Inland waters are often temporary in nature and as such, sampling of aquatic biota can be challenging. The following methodologies will be adopted in the analysis of samples.

1. Algae

Algal samples, including cyanobacteria, can be collected during both the wet and dry phases of a lake's hydric cycle. Many of the algae remain as resting stages in the surface sediment of the lake bed and germinate once there is an input of freshwater.

1.1 Phytoplankton

Surface water samples will be collected, using a 500 mL plastic bottle. These will be preserved with Lugol's iodine. The water sample will be used for quantitative analysis of the phytoplankton. Algal cells in 1 mL aliquots of the sample will be counted in a Lund cell and the number of cells per mL of algae calculated. The phytoplankton sample will be used for taxonomic identification, and stored as voucher specimens in the International Diatom Herbarium at Curtin University.

1.2 Periphyton (diatoms)

Where there is sufficient standing water, JJ periphytometers will be placed and collected after 2-3 weeks. The slides will be scraped and the algae identified. The samples will then be "digested" in 70% nitric acid (removal of all organic content) for diatom enumeration and permanent slides made according to John (1983). These will be analysed and the diatom species identified. Permanent slides will then be stored at the International Diatom Herbarium, Curtin University, as voucher specimens.

Previously archived permanent slides will also be analysed to determine any additional diatom information for the relevant sites.

1.3 Benthic Microbial Communities

Surface scrapings of the benthic microbial communities (BMCs) located on the surface of the lake bed will be collected in plastic vials (Nylex No. 20). These will be identified fresh or preserved with Transeau's preservative for later identification. The composition of the BMCs will be determined. Sections of the BMC mat will also be digested for diatom enumeration. The BMCs will be collected during both the wet and dry phases of the hydric cycle as resting stages remain in the sediment.

2. Invertebrates

2.1 Aquatic invertebrates

As inland waters of Western Australia are temporary in nature and the biota has adapted for extended periods of desiccation, aquatic invertebrates can be collected during both the wet and dry phases of the hydric cycle.

Wet Sampling

Aquatic invertebrates in the water column will be collected by isolating a known volume of the surface water using a large plastic cylinder and removing all the invertebrates with a 50 μm net. The sample will then be placed in a plastic vial and preserved for identification and enumeration. This procedure will be repeated three times at each site.

The samples will be counted whole for the larger specimens (> 500 μm). For the smaller specimens 1 mL aliquots of the sample will be placed in a Sedgewick – Rafter Chamber and 3 replicas counted for each sample.

Dry Sampling

The surface sediment of a lake will be collected by scraping the top 1 cm of lake bed from a known area and placing it in a calico bag. The presence of the aquatic invertebrates (e.g. *Parartemia*) in a known quantity can be determined by examining the resting stages in the sieved sediment, under a dissecting microscope.

3. Riparian Vegetation

Dominant plant species will be identified and recorded at each site assessed.

4. Macrophytes

The presence of the various macrophytes will be recorded at each of the sites. This will include the presence of resting stages for charophytes (stoneworts) and seeds of monocotyledons such as *Ruppia*.

5. Birds

Where there are no previous observations, opportunistic bird counts will be performed at the study sites. This will be confined to the periods when there is water in the lakes. Activities such as nesting sites and breeding behaviour will also be recorded.

6. Chemistry

Where there is insufficient chemical data, both water and sediment samples will be collected from those sites and sent to a NATA approved laboratory for analysis. Surface water and sediment will be analysed for basic parameters (ph, TDS, EC), major anions and cations, metals and nutrients.

Some data already collected for the seven lakes in this study is presented in the following section.

PRELIMINARY RESULTS

Only a portion of the data set has been validated at the time of writing. Therefore, only a limited data set is presented in this paper (Table 1 and Table 2). The salt lakes that are discussed vary in size, shape, water chemistry and biota. The methods that have been discussed above were employed to assess each of the parameters.

The seven lakes discussed in this paper range from saline to hypersaline depending on their stage of the hydrocyle (Table 2). All are ephemeral in nature, inundated intermittently (once in every 3 – 5 years). The persistence of water in these lakes is often short lived due to high evaporation rates, leading to considerable variation over time in most parameters. The pH range of surface water was large, ranging from acidic to alkaline. Both invertebrate and algal species present in these lakes are typical of saline ecosystems.

Table 2 Between-lake comparison of abiotic and biotic parameters

Lake	Parameter				
	Size (km^2)	Salinity (EC)	pH	Algae	Invertebrates
Lake Carey	1,000	5,500 – 130,000	6.6 – 8.2	*Amphora coffeaeformis* *Hantzschia amphioxys* *Navicella pusilla*	*Parartemia* sp. *Reticypris* sp. *Diacypris* sp.
White Flag Lake	31	NA*	NA	*Amphora coffeaeformis* *Navicula* sp.	*Parartemia* sp. Ostracod
Lake Way	270	26,000 – 85,000	5.6 – 7.o	*Amphora coffeaeformis* *Navicula durrenbergiana* *Hantzschia amphioxys*	*Parartemia* sp. *Reticypris* sp Cyclopoida
Lake Miranda[1]	200	35,400 – 43,100	7.1 – 9.4	*Pleurosigma* sp. *Gyrosigma* sp. *Hantzschia vivax*	Copepods *Branchionus* Ostracods
Kopai Lake	0.5	24,000 – 91,000	7.8 – 8.3	Amphora coffeaeformis *Navicula* sp. *Luticola* sp.	*Daphniopsis* sp Ostracods
Black Flag Lake	7	22,900-	8.5	*Amphora coffeaformis* *Navicula* sp. *Hantzschia* sp.	*Triops* sp. *Parartemia* sp.
Lake Lefroy	570	NA	NA	*Achnanthes* sp *Navicula durrenbergiana*	*Parartemia* sp. Ostracods

*Note- No baseline or control site water quality has been reported at White Flag Lake or Lake Lefroy since 2000.
[1] – (John et al. 2000)

Principal Component Analysis (PCA) was used to look at the similarity between the sediment and water chemistry at each lake. PCA produces a graph on which samples with similar chemistry are located close together, while those with markedly different chemistries are located further apart, with an axis that pulls the data in a certain direction depending on the concentration of a particular element (Clarke and Warwick 2001). Note that the amount of variation in the data and how representative the data is in the plot, is indicated by the percent variation explained by the first two axis. A value of 50% or over is considered a good representation of the data.

Multi-dimensional scaling (MDS) plots were used to assess differences between the algal and invertebrate community structure. Unlike PCA the MDS ranks the similarities within the data (Clarke and Warwick, 2001). Like PCA it produces a plot with sites located close together having similar community structure. On the MDS plot, sites are grouped according to the percent similarity they have with each site (e.g. if sites have 20% of species in common this group will be represented by dotted green line).

Surface Water

Collection of surface water in the salt lakes of the goldfields has been restricted in the past due to below-average rainfall, however cyclonic activity in recent times has allowed for collection of surface water in 2000, 2004 and 2006. However, due to the distance between these lakes and the variability of rainfall in the region it is rare for a filling event to occur in these lakes at the same time. Hence the data used to date in the PCA plots has been recorded at varying times in each of the lakes' hydrocycle. This is one of the concerns to be addressed in the study.

Although scarce, some trends were noted in the PCA plot of surface water chemistry (Figure). Most of the lakes showed considerable variation between sites in terms of water chemistry. In contrast the water chemistry, in terms of salinity, pH and major cations and anions was similar throughout Lake Way. While salinity in Lake Way was similar to that of Lakes Miranda and Carey, the composition of salts was different with the Lake Way sites showing greater concentrations of K, Mg and SO_4. Both of the Lake Kopai sites reported a higher pH than all of the other lakes. By contrast, salinitywas generally lower in the Kopai and Black Flag Lakes than the other lakes.

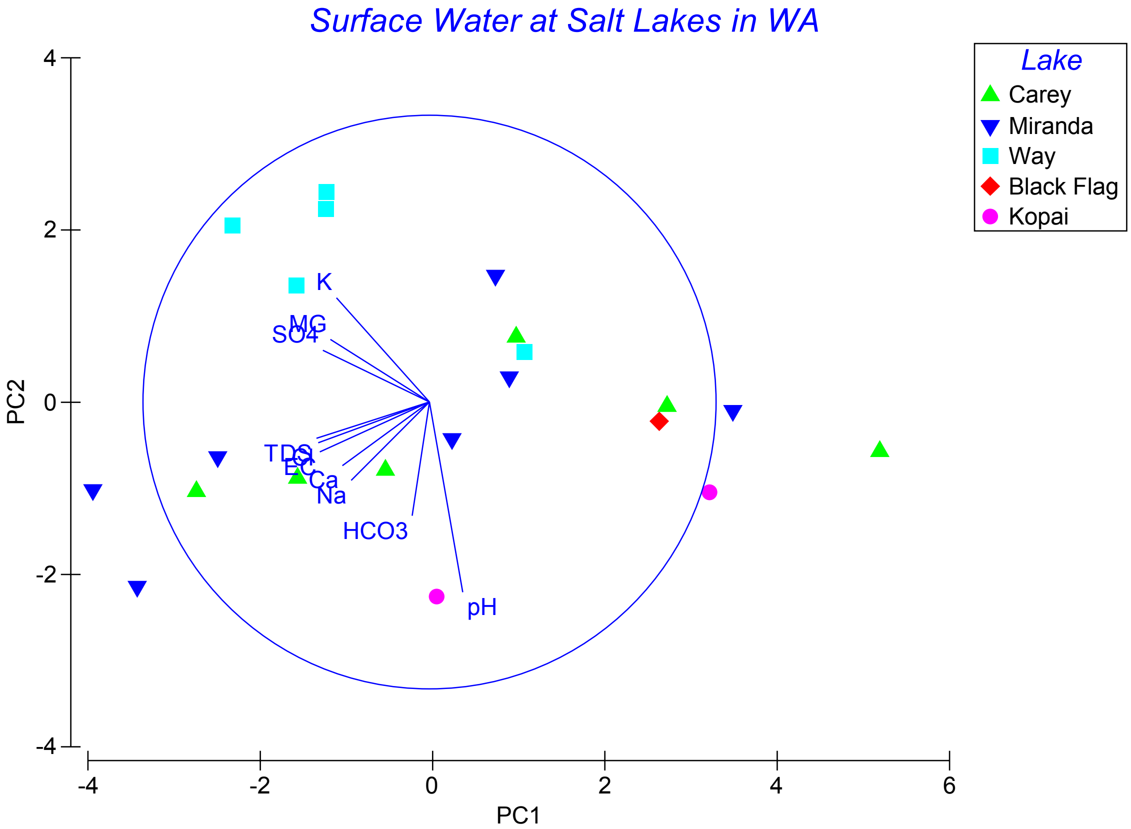

Figure 1 PCA plot of water chemistry at five lakes in the goldfields. Note that 78.4% of the variation in the data is explained by first 2 axis. Note that no baseline or control site surface water data has been recorded at Lake Lefroy and White Flag Lake since 2000.

Sediment

A PCA plot of sediment chemistry was completed using the data collected during 2005 at each of the lakes, with the exception of Lake Miranda (data collected in 2003) (Figure). Although data was collected at different times of the year and data was limited at some sites, some generalizations could be made in regards to the relationship between the lakes. The PCA plot was produced using pH, EC and metal concentrations (Ni, Cu, As and Pb). Generally each lake reported unique sediment chemistry. White Flag Lake reported higher concentrations of As and Cu in comparison to the other six lakes, while pH in sediment was much lower than the other lakes assessed. The two sites at Black Flag Lake reported high salinity and concentrations of Ni, Cr and Pb, while Lakes Carey, Miranda and Way recorded lower concentrations of metals in sediment than Black Flag, White Flag, Lefroy and Kopai Lakes. Sediment collected at Lake Carey was different in that it recorded a much higher pH than all other sites. In terms of sediment chemistry, Lake Lefroy and White Flag Lake were very similar, although only one site at Lake Lefroy recorded sufficient data to be included.

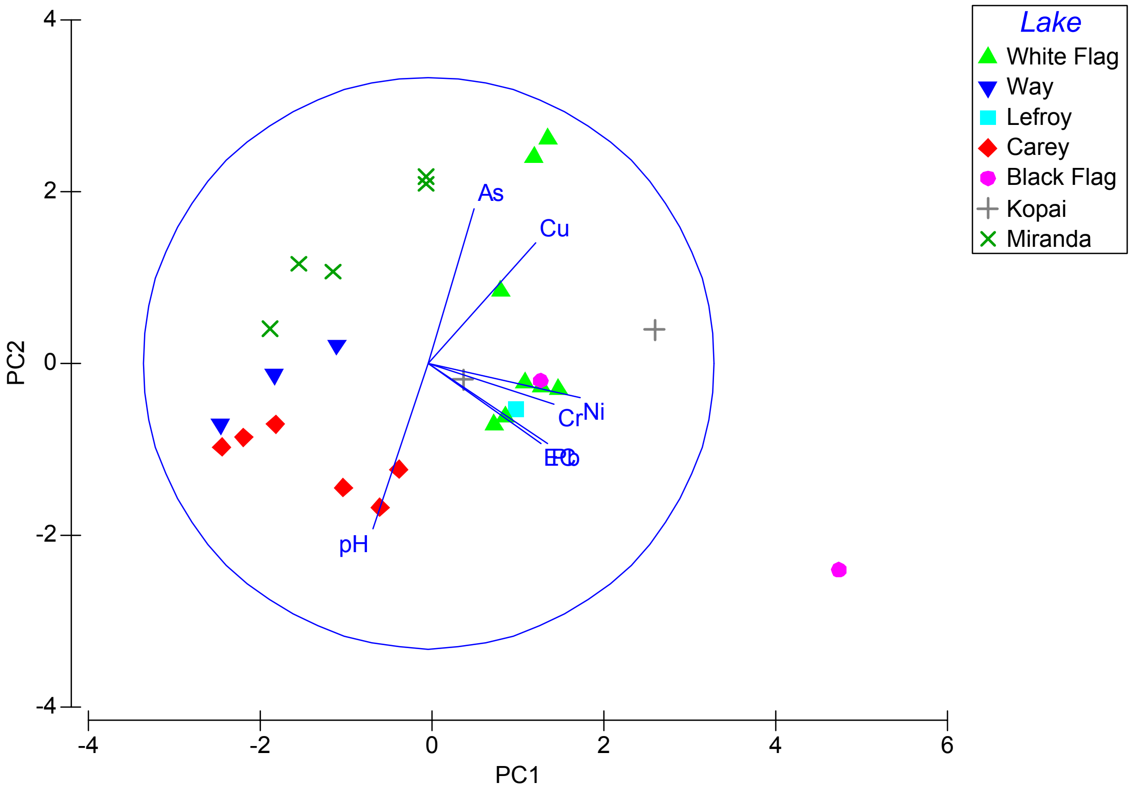

Figure 2 PCA plot of sediment chemistry at six salt lakes in the goldfields. 64.4% of variation in the PCA plot is explained by the first two axis

<u>Algae</u>

In terms of algae, only the benthic diatoms were considered (Figure). The plot was based on presence/absence data collected from each site in 2005 (with the exception of Lake Miranda which was assessed in 2003). The dashed lines surrounding the sites represent the proportion of species which each site has in common. For example at Lakes Carey, Lefroy and Way, 40% of the species recorded at each site occur at all three lakes (Figure 3). Lake Miranda recorded quite a unique diatom structure in comparison to the other six lakes. Community structure at Black Flag and Kopai Lakes was similar, as was one White Flag site, however there was a great degree in variation recorded at the White Flag sites which may indicate some impact, however further investigation is needed.

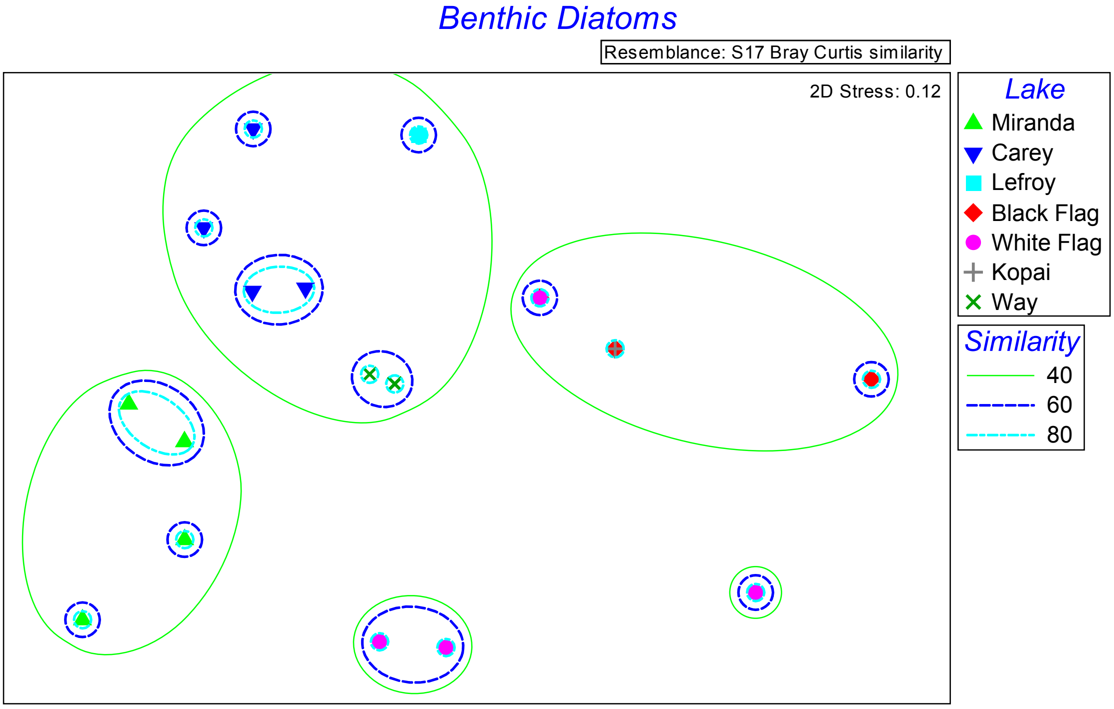

Figure 3 MDS plot of Diatoms at the selected seven lakes

Invertebrates

The MDS of aquatic invertebrates was based on taxa presence/absence data at each of the lakes. The community structure of invertebrates at Lake Miranda was unique, hence their absence from the plot (outside the boundary). Community structure at Lake Way was most similar to Lake Carey, while Kopai Lake recorded a slightly different array of species. One of the Lake Carey sites was quite different in comparison to the other sites, recording similar species to Black Flag and White Flag Lakes.

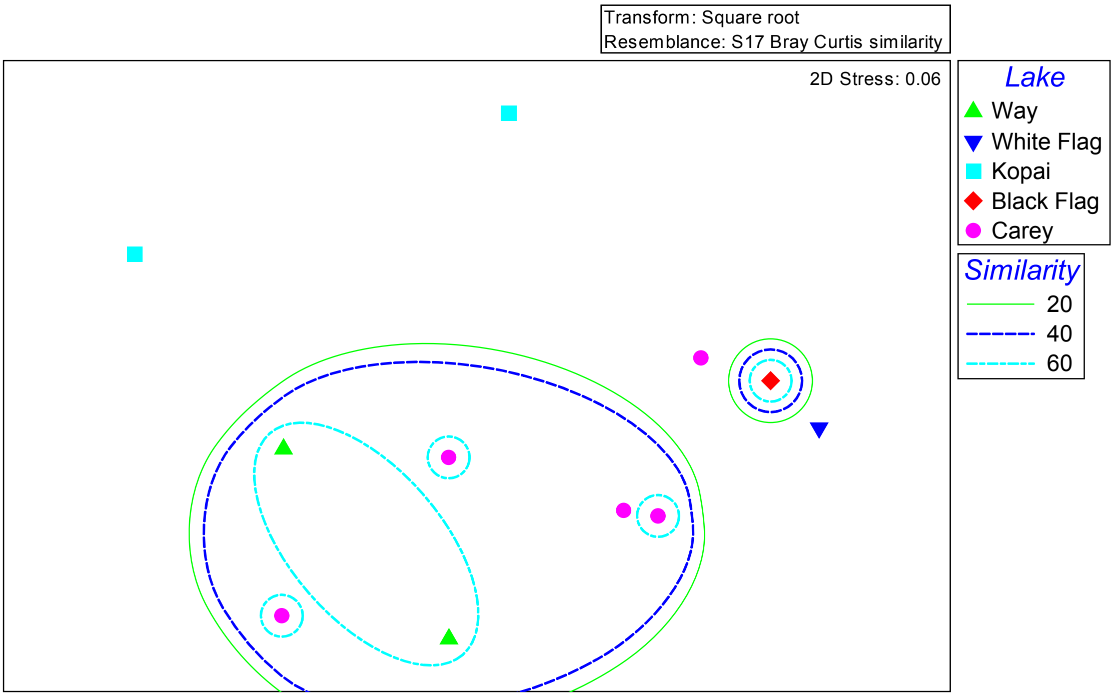

Figure 4 MDS plot of aquatic invertebrates at each of the Lakes included in the study.

CONCLUSION

On the basis of the classification systems presented in this paper, the seven salt lakes considered are quite similar in their characteristics. The initial interpretation of biological data presented in this paper shows some commonality with Semeniuk's geomorphic classification system in that Lakes Carey, Miranda and Way shared some similar biological characteristics. However White Flag Lake and Lake Lefroy were given the same Semeniuk classification but appeared quite different to Lakes Way, Miranda and Carey.

The relationship between parameters such as water chemistry and invertebrates was not clear. For example Lake Carey and Miranda recorded similar water chemistry, although invertebrate community structure was different. By contrast, sediment chemistry and benthic diatom data produced similar plots, indicating that the sediment chemistry may be a stronger influence on the diatom community structure. The initial data interpretation shows some contrasting trends, and these trends may vary or be strengthened when additional, validated data points are statistically analysed.

With the unpredictability in salt lake inundation in Western Australia, sediment chemistry provides a more uniform and reliable data set. Similarly in the biological data, diatom communities can be collected in both wet and dry conditions and therefore seem to be the most reliable data set. The initial results suggest that classification using these factors, and others that may be easily collected in both wet and dry conditions, would be most useful.

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