Survey and Analysis Of Plant Communities Growing On Gypsum In The Western Australian Wheatbelt

BOTANICAL CONSULTANTS REPORT
FOR THE WHEATBELT NRM REGION AND THE DEPARTMENT OF ENVIRONMENT AND CONSERVATION WESTERN AUSTRALIA
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SUMMARY

Plant communities growing on gypsum are under threat from mining and the impact of altered hydrology associated with areas in the lower part of the landscape in the Wheatbelt of Western Australia. In order to investigate the conservation significance of these communities, data from existing reports and further survey were compiled and analysed.

An overview is given of gypsum deposits in WA, the physical and chemical properties of gypsum affecting plant growth, Australian and overseas research on gypsophilous plant species and the possible environmental impacts of gypsum mining.

Data from 144 sites was included in the analysis. These sites are confined to plant communities growing on gypsiferous soils associated with inland salt lakes or playas and mainly situated within the Avon Wheatbelt NRM Region. Suitable sites were found in the surveys carried out in the WA Agricultural Zone (SAP sites funded by the State Salinity Action Plan) by Lyons et al (2004) (56 sites) and Gibson et al (2004) (4 sites). The Mattiske (1995) survey of a range of gypsum dunes in the Wheatbelt of WA provided 54 sites and quadrat work carried out by DECs Threatened Communities Branch provided 4 sites. Survey work was also carried out in the Lake Magenta and Lake Grace areas in 2009 providing data from 26 quadrats.

The taxonomy of plant species listed was updated to assist with the comparison of data from old reports with more recent records. All data sets were re entered into the Western Australian Herbarium's MAX3 program in 2009 to check for name changes, Voucher specimens were checked on flora base and in a small number of cases voucher specimens were examined in the WA Herbarium and re identified.

449 plant species are recorded in the report as occurring on gypsum soils in the study area. Sources of information include;

- all species recorded in the site/quadrat data including native species, weed species, annuals, geophytes and species recorded adjacent to quadrats on gypsum soils,
- species recorded from 2 sites in the Lake Campion area resurveyed by the author in 2010,
- Rare Flora on Department of Environment and Conservation data bases and
- Relevant records from a list of gypsophilous plants from South Australia compiled by Symon (2006).

Most of the 449 plant species are gypsovags i.e. species also recorded widely on other soil types, probable refuges from adjacent plant communities. The gypsum vegetation communities are largely made up of these species rather than gypsophiles. Only 10 possible gypsophiles are proposed for the study area. This is in contrast with the situation in Spain where almost 50% of the plant species occurring on gypsum in the Iberian Peninsula are gypsophiles. Seven of the gypsophiles are categorised as rare flora and are geographically restricted. The 3 species that are not rare flora, *Chondropyxis halophila*,

Minuria gardneri and *Kippistia suaedifolia* have a wide distribution largely to the north and east of the study area. *Kippistia suaedifolia* also occurs in the Eastern States.

Five Declared Rare Flora and 25 Priority Flora are recorded on gypsiferous soils in the study area and 2 Declared Rare Flora and 15 Priority Flora have also been recorded in "likely sites" but have not as yet been recorded on gypsiferous soils in salt lake systems.

The data set used in the analysis excluded annuals, geophytes, records adjacent to quadrats and weed species in order to make the different data sets as comparable as possible and compensate for different survey frequency and times. 52% of the plant species in this data set were singletons i.e. recorded at only one site.

The multivariate statistics package used to analyse the species information for each quadrat/site was PRIMER v6. Quadrats/sites were classified according to similarities in species composition (presence/absence data) using the Bray-Curtis Similarity Coefficient. The results of the Cluster classification were illustrated in a dendogram. ANOSIM (analysis of similarity) was carried out on a priori groups defined by environmental factors and SIMPER was used to look at characteristic and distinguishing species.

The gypsum vegetation communities were explained as site/quadrat groups based on similarities in species composition. 12 out of the 28 groups are subjectively assessed as having some conservation significance. This assessment was based on the presence of rare flora, gypsophiles, high gypsum content of soils and the number of sites in each group. Groups with a species combination that occurs rarely in the data set are represented in the site/quadrat classification by only 1 or 2 sites and may represent rare vegetation communities. These proposed rare communities are situated within the Lake King, Lake Grace (Chinocup), Lake Magenta, Kondinin and possibly Lake McDermot Lake Systems (area poorly sampled).

There is a high probability that there are other areas of conservation significance that have not been included in the present survey, for example, gypsum dunes within the Lake Campion area (Rick, 2010) were not included in the present analysis as quadrat data was not available.

In the ANOSIM analysis the differences between the species composition of groups based on environmental factors was best explained by the factors Lake System (p 0.1%, Global R 0.338), Area (p 0.1%, Global R 0.191) and ELCODE (p 0.1%, Global R 0.159). The Lake system and Area factors relate to the geological distribution of the floristic groups which reflects changes in rainfall and temperature across the project area and ELCODE relates to zones of inundation. Similar results for floristic groups (from all soil types) were found in the Lyons et al (2004) survey (SAP sites) and in the Mattiske (1995) surveys. Although Gypsum content showed significant differences (p 0.7%) between the species composition of groups the global R at 0.058 was low indicating the differences were only slight.

Maps and tables presenting data on gypsum deposits and mines in the study area are presented in the report and should assist in targeting areas in need of further survey.

The limitations of the project are outlined and the following are recommendations for further study

1. Expand the analysis to include SAP and Mattiske (1995) sites that occur on non gypsiferous soils to help clarify the rarity of some of the gypsum vegetation communities.

2. Carry out further field work to include
    - Areas not previously covered by a spring survey
    - Remnant vegetation growing on gypsum soils in ELCODEs (zones of inundation) not previously surveyed on that particular salt lake.
    - Remnant vegetation situated on soils with a high gypsum content that may be under threat from mining and that has not been previously surveyed. Aerial photographs and the boundaries of mining lease tenements (Tengraph) of the gypsum deposits and mines listed in Appendices 13 and 14 should be examined for possible sites.
    - Further rare flora surveys especially in areas difficult to access eg northern sections of Lake Magenta.

3. Further examine suggested rare vegetation communities growing on gypsum as possible TECs. This includes vegetation communities on dunes in the Lake King, Lake Grace (Chinocup), Lake Magenta, Kondinin and Lake Campion Lake Systems.

4. Expand the species list of plants growing on gypsum by adding species from other consultancy reports. The taxonomy of these species and soil references will need checking.

5. Expand the literature review of research on gypsophilous plant species in Australia and overseas.

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The assistance of Western Australian Herbarium staff and other Botanists, particularly Greg Keighery, Mike Lyons (*Frankenia*), Frank Obbens (*Calandrenia*), Kelly Shepherd (*Tecticornia*), Paul Wilson (*Atriplex, Rhagodia*), Malcolm Trudgen (*Baeckea*) and Mike Hislop (*Leucopogon*) in helping to identify specimens is gratefully appreciated. Access to the WA Herbarium collections was essential for carrying out the project.

Also a sincere thank you to the members of the Wildflower Society of WA who assisted with plant specimen and data collection including soil samples on the 28th October 2009 at Lake Magenta including Pat Wenham, Anne Bellman, Alice Stubber, Brian Moyle, Elizabeth George, Hazel Dempster, Arthur Blundell, Phyllis Robertson, Margaret Larke and Mark Brundrett (photography).

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The project would not have been possible without the financial support of the Western Australian Wheatbelt NRM previously the Avon catchment Council.

Wildflower Sociely of WA members L to R Hazel Dempster, Margaret Larke, Elizabeth George, Alice Stubber, Arthur Blundell (back), Anne Bellman, Pat Wenham, Brian Moyle and Phyllis Robertson.

INTRODUCTION

BACKGROUND

Plant Communities growing on gypsum have been recognized by the Wheatbelt NRM (previously the Avon Catchment Council) in baselining discussions and by botanist Greg Keighery as being in need of further investigation. These communities are under threat from mining and hydrological change associated with areas in the lower part of the landscape in the Wheatbelt of Western Australia.

The objectives of the present study were to undertake a survey and analysis that would contribute considerably to the determination of the conservation significance of vegetation communities growing on gypsum in the Wheatbelt. Specific objectives are listed below.

- Define gypsum communities in terms of their floristic composition and structure, their distribution and susceptibility to threats.
- Provide information on rare and priority species growing on gypsum.
- Provide information to assist with the identification of communities in need of protection through listing as Threatened Ecological Communities.
- Provide information needed to systematically assess applications for mining.

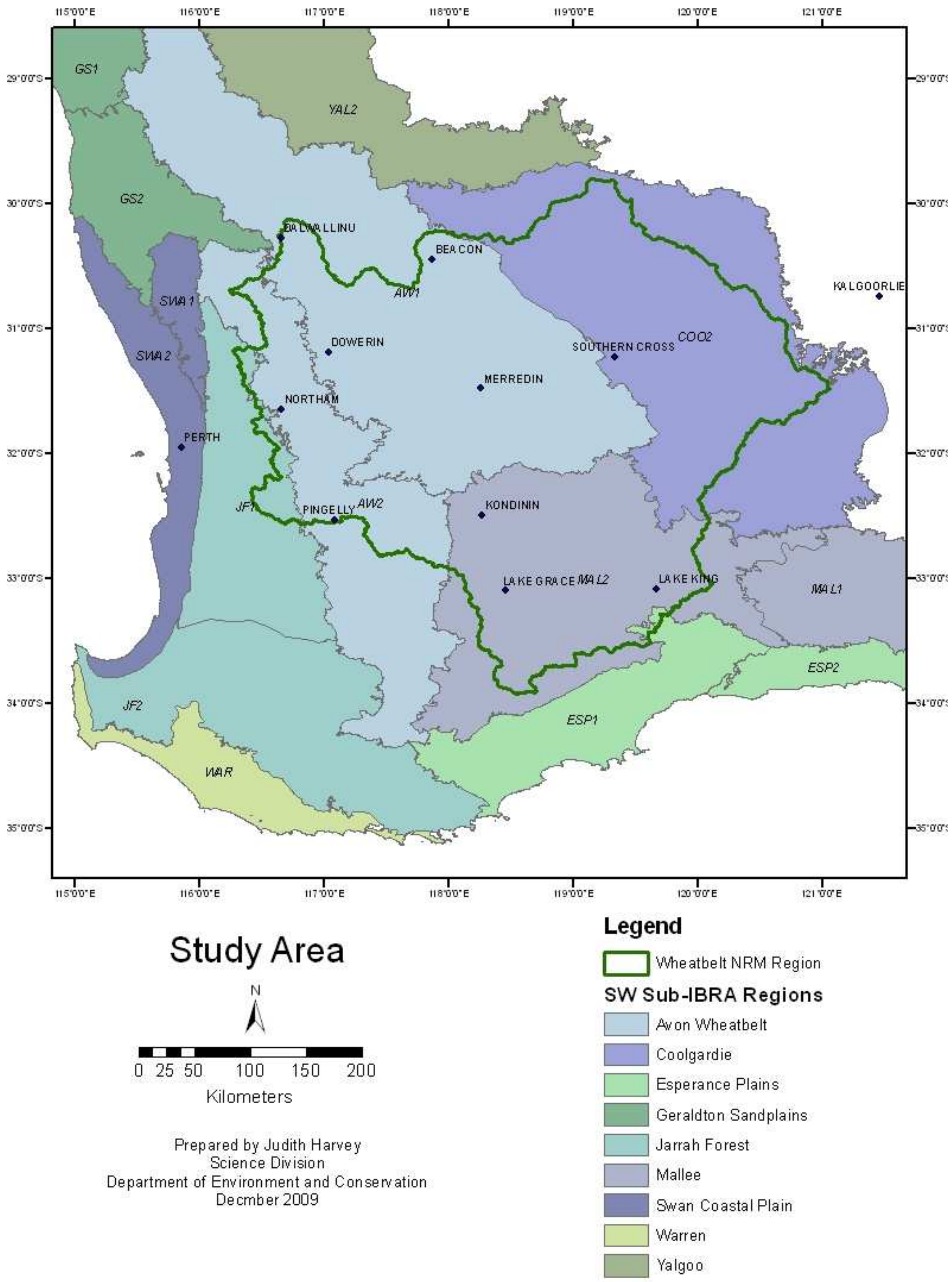
In order to achieve these objectives the following actions were proposed.

- Compile existing data on vegetation communities growing on gypsum deposits. This includes previous work carried out by Botanical Consultants and by the Department of Environment and Conservation including SAP sites (funded through the Salinity Action Plan), TEC (Threatened Ecological Community) and PEC (Priority Ecological Community) descriptions.
- Update the taxonomy of plant species listed to assist with the comparison of data from old reports with more recent records.
- Undertake further survey.
- Produce a data base of all existing data applicable to and used in the analysis.
- Analyze existing data and survey findings on vegetation communities growing on gypsum using PRIMER to determine if these vegetation communities have any conservation significance.
- Research other available references and maps for further locations of gypsum deposits not previously surveyed

STUDY AREA

The project was confined to plant communities growing on gypsiferous soils associated with inland salt lakes or playas. Sites were mainly situated within the AvonWheatbelt P1 (AW1) and Western Mallee (MAL2) IBRA Sub regions (Environment Australia 2004). A small number of sites in the western sections of the Southern Cross (COO2) sub region (near Southern Cross) and Eastern Mallee (MAL1) sub region (NW of Esperance) were included for comparison and in order to utilize all available data. Most of the sites occur in the Avon catchment which defines the Wheatbelt NRM region except those in the northern section of AW1 sub region and in the MAL1 sub region (See Figure 1).

Figure 1 The Avon Catchment area which defines the Wheatbelt NRM Region in relation to the Interim Biogeographic Regionalisation (IBRA) Sub Regions of the South West of Western Australia.



GYPSUM IN WESTERN AUSTRALIA

Gypsum is a naturally occurring mineral with a chemical composition in pure form of $CaS0_4.2H_20$ (dihydrous calcium sulfate). Deposits of gypsum are usually contaminated with impurities such as clay, sand, limestone, iron oxide and plant matter. According to Jones (1994) there are 6 commonly recognized forms of natural gypsum.

1. Rock gypsum of massive selenite – usually deposited in fairly extensive beds under marine conditions.
2. Gypsite, kopi, or flour gypsum – a white floury powder often found on the surface of dry salt lakes and in adjacent dune deposites.
3. Selenite or crystal gypsum. May be found in lake beds, commonly in clay
4. Seed gypsum, gypsum sand or gypsarenite – a porous granular state found with kopi on the surface of dry lakes and in kopi dunes.
5. Satin spar occurs in narrow seams mainly in massive gypsum deposits
6. Cellular or spongy gypsum found under kopi in salt lake and dunes

Western Australian gypsum is produced from the surface mining of gypsite, seed gypsum, crystal gypsum and rock gypsum deposits. WA has some of the purist gypsum in the world as the breakdown and contamination of the mineral has been limited by its recent deposition in an arid environment. Jones (1994) lists the specifications for gypsum use as +70% purity for farming with a 2% maximum NaCl impurity and higher purities for use in cement and plasterboard manufacture of + 80%.

There are three main categories of gypsum deposits in WA. Salt lakes or playas in the arid interior of the state, barred basins in present or former coastal inlets and associated saline lagoons and evaporite sequences in sedimentary rocks (Jones 1994). The present study is confined to the salt lakes in the arid interior mostly to the Wheatbelt NRM region. The gypsum of these salt lake deposits is in the form of seed, granular gypsum, kopi or crystal. Most of these lakes show evidence of some gypsum but comparatively few have economic deposits (De La Hunty and Low, 1958).

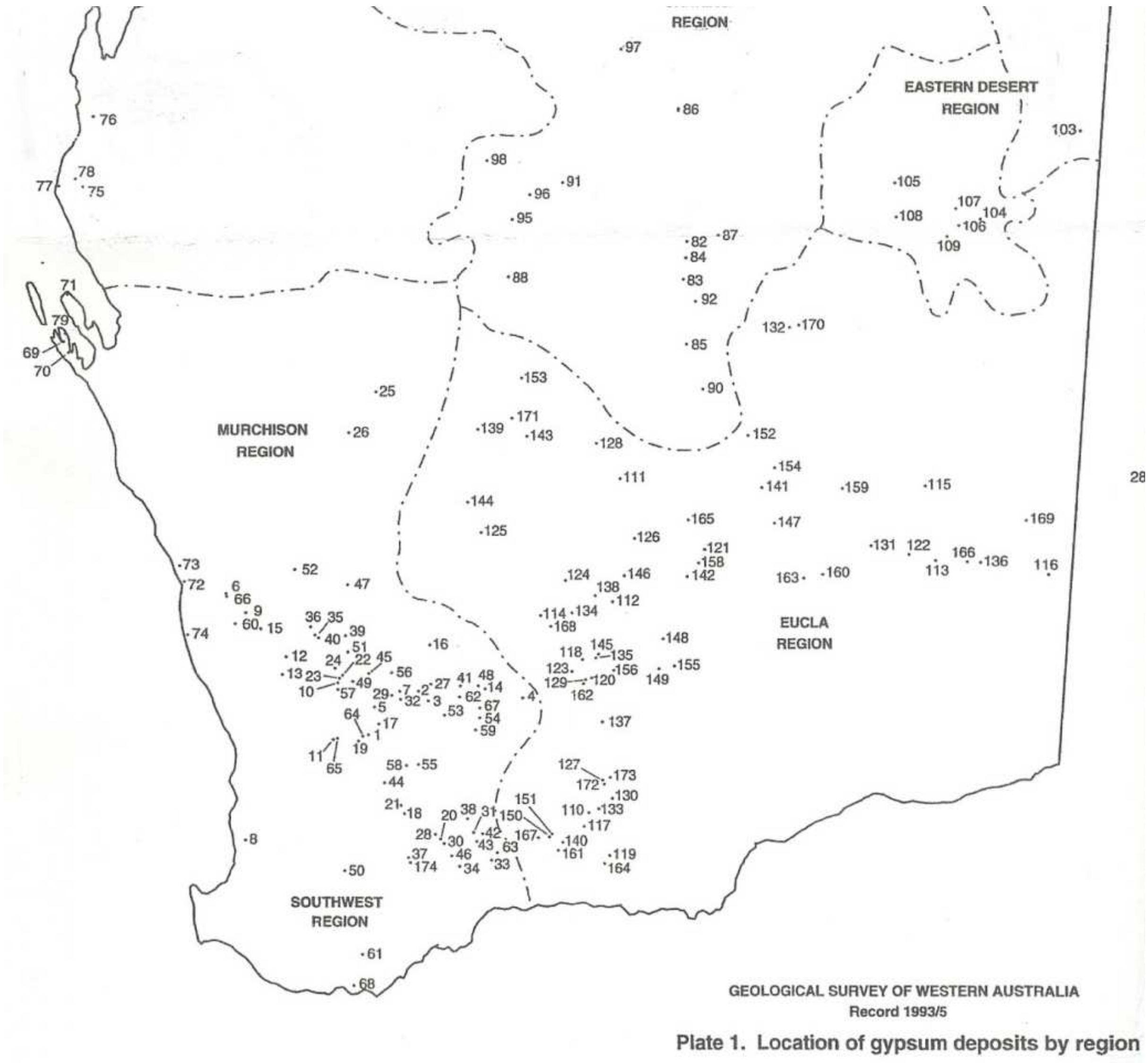
Gypsum occurs on dunes or lake flats. The dunes extend around the south and eastern shores and near shores of the salt lakes while the deposits on the flats also occur towards the eastern section of the lakes. Dunes vary from 0.25m to 20 m or more although most are only a few meters in hight. Seed gypsum on the lake flats is present as banks or ridges of about 30 cm in height or may underlie most of the lake bed to a depth of about 15cm. A compacted form of kopi often occurs on lake flats and sometimes covers the seed gypsum. Dunes and seed flats are formed when gypsum crystals present on the lake surface are accumulated on the shore and near shore by wind action. Finer particles may be blown further and result in a kopi dune behind the seed dune. (De La Hunty and Low 1958, Jones 1994)

Flats of kopi and seed formed by the wind action are packed down by periodic flooding and samphire scrub also helps to stabilize these gypsum soils. Trees, mallee and shrubs such as native pine (*Callitris*) and *Eucalyptus* also help to fix the dunes. Gypsum requires possibly hundreds of years for replenishment (De La Hunty and Low, 1958).

The dunes vary in composition with clay, sand, gypsum and other materials occurring in various mixtures and layering of gypsum and other components can also be found. Gypsum soils can also differ widely in electrical conductivity. The nature and composition of soil bearing gypsum is likely to be unique to a site. Apart from pure gypsum there is no such thing as a typical gypsum soil (Mattiske, 1995).

Part of the the distribution of gypsum deposits in WA recorded by Jones (1994) is illustrated in Figure 2.

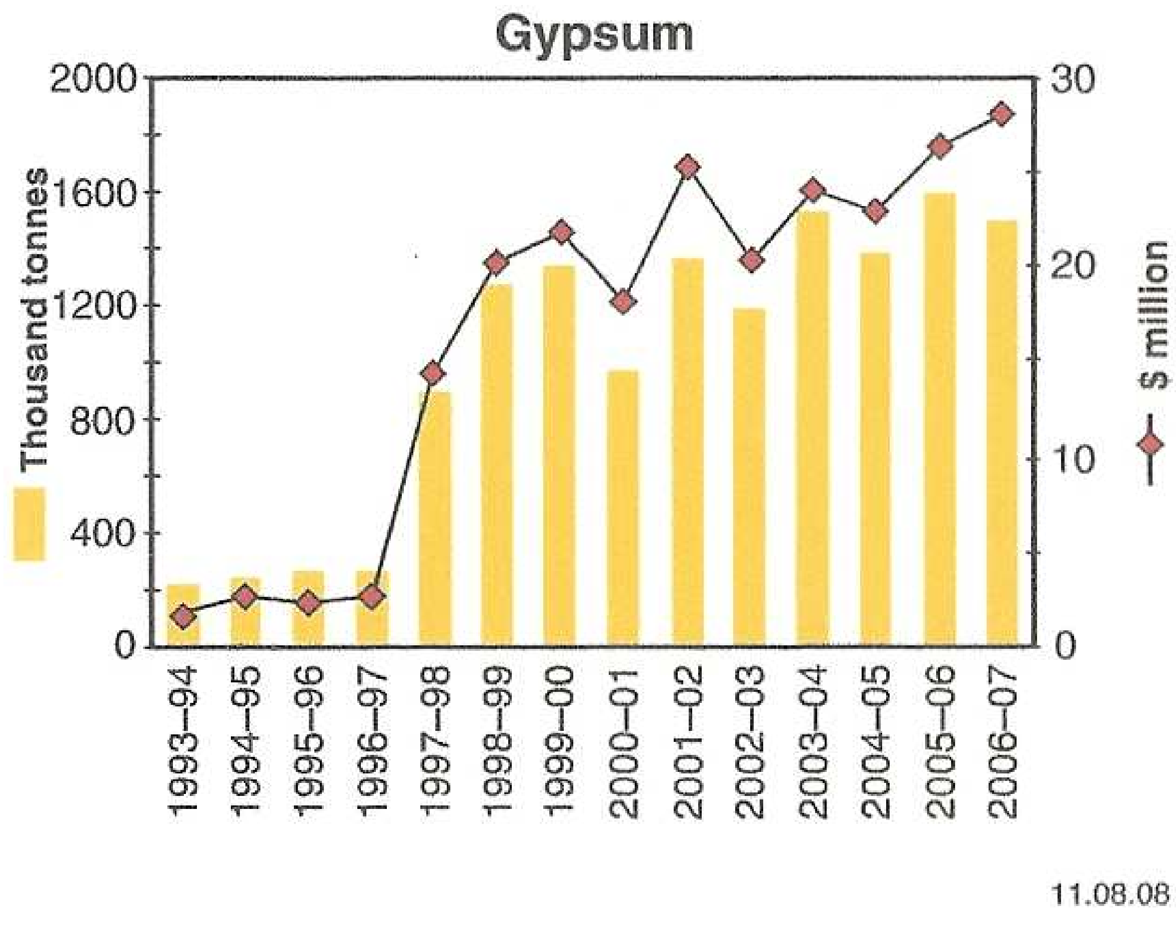
Figure 2. The distribution of gypsum deposits in a section of WA recorded by Jones (1994).



The following update on gypsum production in Western Australia is taken from Fetherston (2008).

"In Western Australia there are about 180 gypsum deposits, with a total resource of potentially economic gypsum of about 1.5 Gt. During 2006–07, gypsum production in Western Australia was 1.5 Mt, valued at $28.40 million (Figure 3). This shows gypsum production in the State has remained relatively constant over the last four fiscal years since 2003–04, averaging around 1.5 Mt pa while value of production has slowly increased over the last three years by about 23%. The bulk of the State's production is exported, primarily to Japan. Within the State, the main gypsum-consuming industries include cement, plaster, agriculture and mining. There may also be opportunities for value-added production such as plasterboard, to supply international and domestic markets."

Figure 3 Gypsum production in Western Australia (Fetherson 2008).



Playa lake deposits
Most of Western Australia's inland gypsum deposits are located in playa lakes in the southwest region. Of these deposits, 13 have gypsum reserves in excess of 1 Mt.
At Lake Moore and Lake Cowan, seed gypsum reserves are estimated at 100 Mt and 12.5 Mt respectively (Jones, 1994). Principal producers from this region include Bywaters at Lake Goorly (industrial and agricultural grade), Cockburn Cement at Lake Hillman (cement grade), Gypsum Industries of Australia (a subsidiary of Westdeen Holdings Pty Ltd) at Cowcowing Lakes South (agricultural grade), HB Brady and Co. from Lake Brown (industrial grade), Whitfield Minerals Pty Ltd from Lake Cowan (gypsum for production of shotcrete, known as 'Aquacrete', for mining industry applications), and Wandell from Scaddan (agricultural grade). In addition, there are about 16 smaller agricultural-grade gypsum producers mining from playa lakes that extend through the agricultural region from north of Esperance on the south coast, almost to Dongara, south of Geraldton (Fetherstone, 2008)

PROPERTIES OF GYPSUM AFFECTING PLANT GROWTH

Gypsiferous soils occupy 100 million ha throughout the word (Verheye and Boyadgiev 1997) and are characterized by a gypsum content of over 5% FAO-UNESCO (1990). These soils are confined to arid and semi-arid climates where low rainfall prevents gypsum from being removed by leaching. Together with the arid conditions, gypsum soils have particularly stressful physical and chemical properties for plant growth. One of the adverse physical features is the presence of a hard soil surface crust which directly influences seed establishment and root penetration. Mechanical instability of the soil material due to its lack of plasticity, cohesion and aggregation which might limit the penetration of plant roots are also adverse physical features. Chemically adverse features of gypsum soils are mainly related to the lack of nutrients caused by the exchange of calcium for other ions retained in the soil complex and by the high concentration of sulfate ions which can be toxic to plants (Palacio et al, 2007).

In relation to crop plants Verheye and Boyadgiev (1997) refer to soils with less than 15% gypsum as defining a soil environment suitable for semi-sensitive and semi-tolerant crops. Soils or horizons with high (e.g. more than 25%) gypsum contents can be used only for tolerant crops.

GYPSOPHILOUS PLANT SPECIES

It is not within the scope of this project to review the literature on gypsophilous plant species worldwide. However a brief summary of recent research is needed to assist with our understanding of the situation in WA. Due to time constraints the following summary is not complete and only covers an internet search where some references were only available in summary or abstract form. A more detailed review is needed to put the WA story in proper perspective.

Gypsophiles, gypsophytes or gypsophilous plants are defined as those species which live or thrive in a gypsum rich soil (Botanical dictionary). Other authors refer to these plants as restricted to (Moore et al, 2007) or occurring only in gypsum soils (Palacio et al, 2007) or as having a very strong preference for gypsum-rich substrates (Mota et al, 2009).

These plants are able to overcome the physical and chemical limitations of gypsum soils and germinate and thrive in gypsum. O'Keefe (2003) refers to the lack of knowledge with reference to gypsophiles in Australia. She outlines 3 different classes of gypsophile

1. Obligate gypsophiles (plants restricted to gypsum soils eg *Kippistia suaedifolia*)
2. Facultative or non-differential gypsophiles (plants that receive some benefit from gypsum but may grow elsewhere eg *Dodonaea viscosa)*
3. Halophytic gypsophiles (plants that have developed a close association with both gypsum and saline conditions eg *Halosarcia* now *Tecticornia*)

In Spain scrublands of the Gypsophiletalia order (garrigues occupying gypsum-rich soils in the Iberian Peninsula, usually very open and floristically characterised by the presence of numerous gypsophilous species) have been listed as ''Priority habitat" for conservation purposes (Martinez-Hermandez et al, 2011). Mota et al (2009) have produced a check list of plant species growing on gypsum in the Iberian Peninsula. 140 species recorded on gypsum were rated by 7 experts on gypsum flora using the following scale

1. Plants that avoid gypsum, prefer other soils or at the most occur there by accident
2. Plants that may be abundant in gypsum but are able to live without apparent problems on other soils.
3. Plants that occur mainly on gypsum but may occur on other substrates
4. Species with a clear preference for gypsum, occur very rarely outside this substrate
5. Species which are absolutely restricted to gypsum (except very occasionally)

Plants with a rating 3 to 5 were considered gypsophiles. 69 species had a rating of 3 or higher indicating that almost 50% of the flora recorded on gypsum in the Iberian Peninsula are gypsophiles.

Gypsophiles include both narrow endemics limited to small gypsum areas and regionally dominant gypsophiles growing in most gypsum areas over large regions (Palacio et al, 2007). Plants that can grow in gypsum soils but also in other non-gypsum soils are referred to as gypsovags (Moore et al, 2007; Palacio et al, 2007). These gyposovags are much more widely spread and can tolerate high concentrations of gypsum. Factors controlling the distribution and performance of gypsophiles and gypsovags are still not fully understood.

Two different models have been proposed to explain the occurrence of edaphic (soil) endemics. In the 'refuge' model, edaphic endemics are stress-tolerant species that are not specifically adapted to the atypical soils in which they grow, but are able to tolerate the adverse and stressful conditions they impose. These species are out-competed from normal adjacent soils by dominant species and take refuge in marginal and unfertile soils, where interspecific competition is weaker. In the 'specialist' model, edaphic endemics are fit for the atypical soils in which they live, being more competitive on them, while becoming less competitive in normal and widely distributed habitats.

Recent research carried out by Palacio et al. (2007) provides evidence to explain the distribution of plants growing in gypsum. Gypsum plants show differences in their leaf chemical composition that are suggestive of their different ecological strategies. Gypsovags and narrow-gypsophile endemics were found to fit the 'refuge' model, being stress-tolerant species that find refuge on gypsum soils from competition. Regionally dominant gypsophiles, those widely distributed in most gypsum areas of large regions, seem to be specifically adapted to gypsum soils and fit the 'specialist' model, being species specifically adapted to gypsum by accumulating in their leaves elements found in excess in gypsum soils.

EVOLUTION OF GYPSOPHILES

The gypsophilic flora of the Chihuahuan Desert forms a large and potentially old edaphic assemblage. Moore and Jansen (2007) have examined the age and biogeography of gypsophily in Tiquilia subg. Eddya, a Chihuahuan Desert plant group entirely composed of gypsophiles (restricted to gypsum) and gypsovags (growing on and off gypsum). Combined analyses of the data suggested that the most recent common ancestor of subg. Eddya was a gypsovag and that gypsophily had evolved twice. Gypsophily is inferred to have been present in subg. Eddya by the early Pliocene (~ 5.3 million years ago).

Symon (2006) proposes that the relative paucity of strict gypsophiles in South Australia may reflect the relatively recent onset of aridity in the region. Jones (1994) submitted samples from one of the larger dunes at Lake Hillman in WA for radiocarbon dating. The results indicate that it is likely that gypsum was formed at various times in the past up to about 35 900 years BP which is recent in Geological terms. In Spain the gypsum deposits were formed during two geological periods, some during the Late Triassic (240-205 million years ago) and others several million years later during the Tertiary (65million - 1.8 million years ago)(Mota et al 2009).

AUSTRALIAN RESEARCH

In Australia Symon (2006) has produced an annotated list of gypsophilous plants that are obligate gypsophiles (substantially confined to gypseous soils) 14 species, or facultative gypsophiles much more widespread but clearly tolerant of high concentrations of gypsum, 233 species. *Austrostipa geoffreyi, Kippistia suaedifolia* and *Minuria gardneri* are among the 14 species tentatively considered obligate gypsophiles and that also occur in the present study area. Other species listed by Symon (2006) as tolerant to gypsum and that also occur in the present study area are included in the species list for this project.

Symon's list is based on herbarium label data, recent collections in South Australia and species from the Mattiske (1995) report from WA. Symon found that more often than not the label data was inadequate. The term "likely sites" was used where a number of collections came from possible sites but where gypsum was not actually mentioned.

A number of Australian plants which are able to overcome the adverse properties of the gypsum soils are described including mallees with roots descending through 4m of gypsum, the herbaceous perennial *Microseris scapigera* with tubers sometimes completely developed in kopi, the roots of some *Austrostipa* species which penetrate gypsum to considerable depths and shrubs (*Atriplex, Rhagodia, Maireana* and *Lawrencia*) with permanent root systems that penetrates well into the gypsum.

At the University of Ballarat, School of Science and Engineering, Marion O'Keefe is studying the ecology of gypsophilous species with particular reference to the endangered (in NSW) *Kippistia suaedifolia*. This project is investigating the nature of gypsophilous flora, how these plants cope with gypsum and compares the flora of abandoned gypsum mines with undisturbed sites.

Kippistia suaedifolia on gypseous dunes adjacent to Nanya saltlakes (NSW). This low shrubland has been listed as vulnerable in NSW (Westbrooke, 2007)

ENVIRONMENTAL IMPACTS OF GYPSUM MINING

Environmental impacts associated with gypsum mining may be significant. The following is a summary of points from Mattiske (1995) and EPA reports and recommendations for Chinocup (1994) and Red Lake (1999) summarizing the main pressures of gypsum mining on the environment.

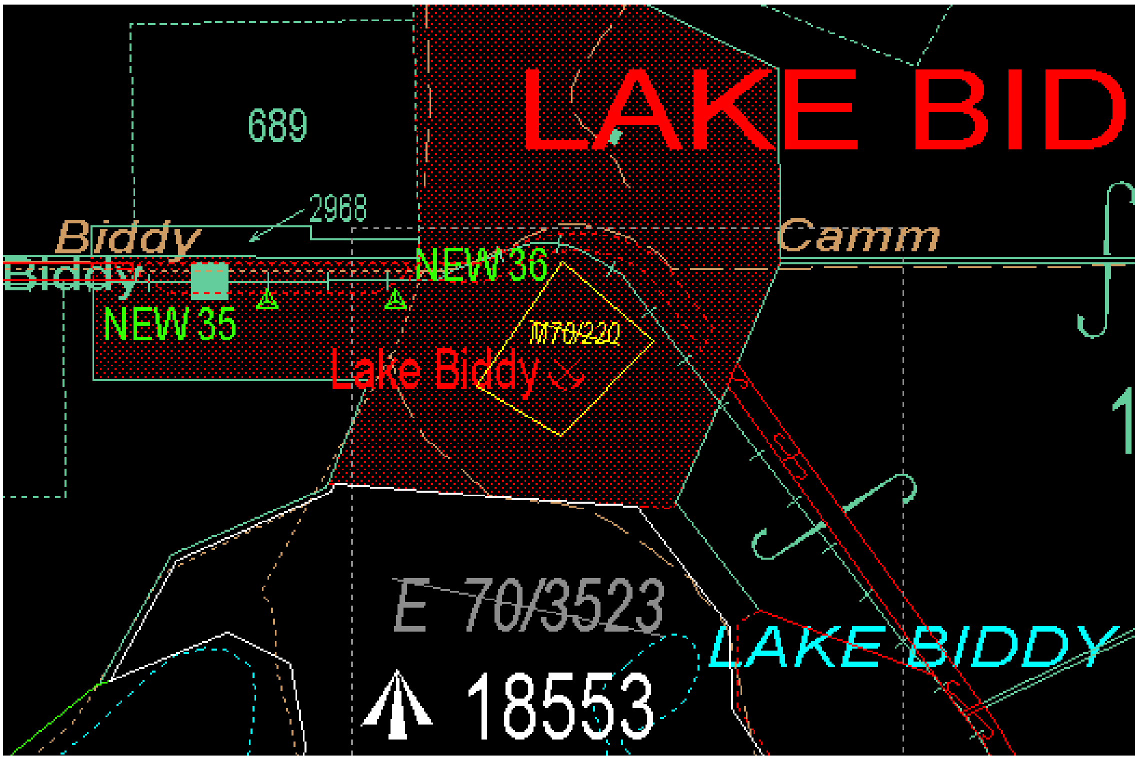
- Disturbance to, or loss of rare, priority flora
- Disturbance to, or loss of habitat-restricted flora ie gypsophiles
- Gypsum tolerant – refuges do not compete with adjacent vegetation and therefore may not survive in adjacent vegetation associations
- Disturbance to, or loss of remnant vegetation, particularly that which is restricted to gypsiferous dunes (possible TECs). The corridors of vegetation associated with dunes and salt lakes are often the only remnant vegetation in some areas
- A reduction in or loss of the environmental values and long term viability of the State's conservation estate. The vegetation and flora found on or adjacent to gypsum dunes are important to the conservation of biodiversity.
- Difficulties in achieving successful rehabilitation.
- Loss of areas adjacent to gypsum deposits (including the ecotone between gypsiferous dunes and other soils) which may also support rare and other significant flora.
- Loss of dunes that can also act as a refuge for terrestrial flora from raised watertables and are particularly important where broadscale hydrological changes and increased salinity has occurred in surrounding areas
- Loss of reservoirs of species that may be valuable as genetic stock for rehabilitation of degraded areas

METHODOLOGY

2009 SURVEY - FIELDWORK

Because of time limitations sites for further survey were selected for sampling from the Lake Grace – Lake Magenta area only. Most of the sites were situated in the Lake Magenta area as this lake system had been poorly sampled in the past. Site selection was aided by consultation with Regan Grant a local gypsum miner and access to Tengraph Online (Dept of Mines and Petroleum website) which provides maps of mining leases both current and lapsed. Figure 4 below illustrates the location of the lapsed gypsum mining lease on Lake Biddy (M70/220). This provides information on the exact location of gypsum in the area. Jones (1994) refers to the gypsum deposit and mining lease at Lake Biddy.

Figure 4 **Map of the location of expired gypsum mining lease M70/220 at Lake Biddy.**



Twenty seven 10m x 10m quadrats were sampled in October and the beginning of November totaling 7 full days in the field over the following dates -20, 21, 22, 23, 28, 31 October 2009 and on 1, 3 November 2009. Two days were also spent in the field selecting sites for survey. Members of the Wildfower Society of WA assisted with data collection on 28 October 2009.

Information recorded in each quadrat included:

- GPS location at the NW corner of the quadrat
- Vegetation classification (Muir, 1977)
- Vegetation condition (Keighery, 1994)
- Inventory of plant species
- % cover and height for each plant species recorded
- Physical description including general soils and topography. Soil samples were taken at 0-10cm depth - collected at 30 regularly spaced points within the quadrat and bulked and from 40-50cm at one central point with an auger. Samples were analysed by the Chemical Centre of WA.
- A high resolution digital photograph
- Adjacent species were recorded where species characteristic of the gypsum vegetation community were outside of the quadrat boundary

Vegetation association descriptions were based on the classification system devised by Muir (1977) which was specifically designed for describing wheatbelt vegetation (see Table 1). The condition of the vegetation described follows the Vegetation Condition Scale modified from Trudgen (1991) by B.J. Keighery (1994) for the Swan Coastal Plain Survey (Table 2). Plant specimens were collected for all species recorded in quadrats and were determined with reference to diagnostic keys and reference to specimens at the WA Herbarium. Plant specimens of special interest will be vouchered and lodged at the WA Herbarium.

Because of the difficulties involved with the taxonomy of some plant species from salt lake habitats, experts involved in revising particular genera were consulted wherever possible to ensure accuracy with identification. Most *Tecticornias* were identified by Kelly Shepherd, *Calandrenias* by Frank Obbens, *Frankenia* sp. southern gypsum confirmed by Mike Lyons and *Atriplex* and *Rhagodia* species confirmed by Paul Wilson.

Data recorded is presented in Appendix 1.

TABLE 1 - MUIR SYSTEM OF VEGETATION CLASSIFICATION

LIFE FORM/ HEIGHT CLASS	**CANOPY COVER**			
	DENSE 70-100% d	**MID-DENSE 30-70% c**	**SPARSE 10-30% i**	**VERY SPARSE 2-10% r**
T Trees > 30m **M** Trees 15-30m **LA** Trees 5-15m **LB** Trees < 5m	Dense Tall Forest Dense Forest Dense Low Forest A Dense Low Forest B	Tall Forest Forest Low Forest A Low Forest B	Tall Woodland Woodland Low Woodland A Low Woodland B	Open Tall Woodland Open Woodland Open Low Woodland A Open Low Woodland B
KT Mallee tree form **KS** Mallee shrub form	Dense Tree Mallee Dense Shrub Mallee	Tree Mallee Shrub Mallee	Open Tree Mallee Open Shrub Mallee	Very Open Tree Mallee Very Open Shrub Mallee
S Shrubs > 2m **SA** Shrubs 1.5-2.0m **SB** Shrubs 1.0-1.5m **SC** Shrubs 0.5-1.0m **SD** Shrubs 0.0-0.5m	Dense Thicket Dense Heath A Dense Heath B Dense Low Heath C Dense Low Heath D	Thicket Heath A Heath B Low Heath C Low Heath D	Scrub Low Scrub A Low Scrub B Dwarf Scrub C Dwarf Scrub D	Open Scrub Open Low Scrub A Open Low Scrub B Open Dwarf Scrub C Open Dwarf Scrub D
P Mat plants **H** Hummock Grass **GT** Bunch grass > 0.5m **GL** Bunch grass < 0.5m **J** Herbaceous spp.	Dense Mat plants Dense Hum. Grass Dense Tall Grass Dense Low Grass Dense Herbs	Mat plants Mid-Dense Hum. Grass Tall Grass Low Grass Herbs	Open Mat plants Hummock Grass Open Tall Grass Open Low Grass Open Herbs	Very Open Mat plants Open Hummock Grass Very Open Tall Grass Very Open Low Grass Very Open Herbs
VT Sedges > 0.5m **VL** Sedges < 0.5m	Dense Tall Sedges Dense Low Sedges	Tall Sedges Low Sedges	Open Tall Sedges Open Low Sedges	Very Open Tall Sedges Very Open Low Sedges
X Ferns Mosses, liverwort	Dense Ferns Dense Mosses	Ferns Mosses	Open Ferns Open Mosses	Very Open Ferns Very Open Mosses

Table 2 Vegetation Condition Scale

Table 3 : Vegetation Condition Scale Modified from Trudgen 1991 by B.J. Keighery for the Swan Coastal Plain Survey 1994
1 = Pristine Pristine or nearly so, no obvious signs of disturbance
2 = Excellent Vegetation structure intact, disturbance affecting individual species and weeds are non-aggressive species. For example damage to trees caused by fire, the presence of non - aggressive weeds and occasional vehicle tracks.
3 = Very Good Vegetation structure altered, obvious signs of disturbance. For example disturbance to vegetation structure caused by repeated fires, the presence of some more aggressive weeds, dieback, logging and grazing.
4 = Good Vegetation structure significantly altered by very obvious signs of multiple disturbances. Retains basic vegetation structure or ability to regenerate to it. For example disturbance to vegetation structure caused by very frequent fires, the presence of some very aggressive weeds at high density, partial clearing, dieback and grazing.
5 = Degraded Basic vegetation structure severely impacted by disturbance. Scope for regeneration but not to a state approaching good condition without intensive management. For example disturbance to vegetation structure caused by very frequent fires, the presence of some very aggressive weeds, partial clearing, dieback and grazing.
6 = Completely degraded The structure of the vegetation is no longer intact and the area is completely or almost completely without native species. These areas are often described as 'parkland cleared' with the flora composing weed or crop species with isolated native trees or shrubs.

DATA ANALYSIS

SITE SELECTION FROM PREVIOUS SURVEYS

The following criteria were used to select sites from previous vegetation and flora surveys carried out by consultants and the Department of Environment and Conservation personnel that included sites with gypsiferous soils.

- Gypsum sites situated on inland salt lakes in the study area
- Data collected from 10x10m Quadrats or equivalent (5.64 m from central point). In some cases tree species from 20x20m quadrats were included.
- Sites under water at the time of survey were not included
- Soil analysis with % gypsum available or area covered by a mining lease indicating high quality gypsum
- Sites containing 1-100% gypsum were included

Suitable sites were found in the following surveys:

- Lyons et al (2004) - SAP sites funded by the State Salinity Action Plan,
- Gibson et al (2004) - SAP sites funded by the State Salinity Action Plan,
- Mattiske Consulting Pty Ltd (1995) and
- Quadrat work carried out by Rosemary Rees (Threatened Communities Branch) at Chinocup and Wendy Chow east of Lake Magenta NR.

Mattiske (1995) – 54 sites

In 1995 Mattiske Consulting Pty Ltd carried out a survey to produce "A review of Botanical values on a range of Gypsum Dunes in the Wheatbelt of Western Australia". Lakes situated in the Department of CALM (now DEC) Wheatbelt Region were visited with most occurring in the Avon–Wheatbelt and Mallee Biogeographic Regions of the SW botanical province as well as Lake Baladjie, Lake Deborah and Lake Seabrook in the Coolgardie Biogeographical Region. Sites were selected to provide a comparison between vegetation on dunes and adjacent vegetation which may be expected to have similar characteristics. Survey points were placed within vegetation associations on lake beds and in the peripheral vegetation associations. Each survey point included the area 5.64 m from a central point and trees within 20m. Information recorded included:

- Vegetation descriptions using Muir (1977) and a description of topographical position (crest of dune, lake floor etc.)
- All plant species present, the height and cover recorded for each species individually. Species recorded within and outside of the 5m radius
- Soil description and soil samples collected at a central point for each site. Taken at depths of 0-10cm and 40-50cm.
- GPS position and sites permanently marked.
- Photograph facing south from 10m north of central peg

SAP Sites – 60 sites

These sites were from "A biodiversity survey of the Western Australian agricultural zone". Most sites were from Lyons et al (2004) with only 4 sites included from Gibson et al (2004). The survey area included all the Avon wheatbelt and parts of the Mallee, Geraldton Sandplains, Esperance Sandplains, Jarrah Forest and Swan Coastal Plain bioregions. Wetlands were selected to sample the range of wetland types and were stratified to capture variation in water quality, salinity type, size and degree of water permanence. Quadrats were selected to sample the major structural vegetation zones and elevation zones. Most were established between August and December 1998 to 2000 and nearly all were sampled on two occasions. The following information was recorded for each quadrat:

- All vascular plant species
- Soil sample from 5-15 cm was collected at 30 regularly spaced points within each quadrat and bulked. Soil analysis included % gypsum
- GPS and elevation accurate to +/-10 m.
- Site description
- Climate attributes derived from ANUCLIM
- Elevation categories (ELCODE) 1, Wetland basin/floor; 2, zone of typical inundation/wave action; 3, elevated flat inundation in extreme events; 4, terrestrial.

Lake Chinocup (PEC) and Lake Magenta (TEC)
Data from 3 quadrats at Lake Chinocup was collected by Rosemary Rees on 22nd September 2004, 22nd October 2004, 9th November 2004 and 21st November 2005.
Data from 1 quadrat in UCL east of Lake Magenta NR (same area as Mattiske G226) was recorded by Wendy Chow, Mal Graham and M Hunter on 13th November 2008.

The following information was recorded on Wildflower Society data forms from "Bushland Plant Survey" by Keighery (1994) and published by the Wildflower Society of WA.

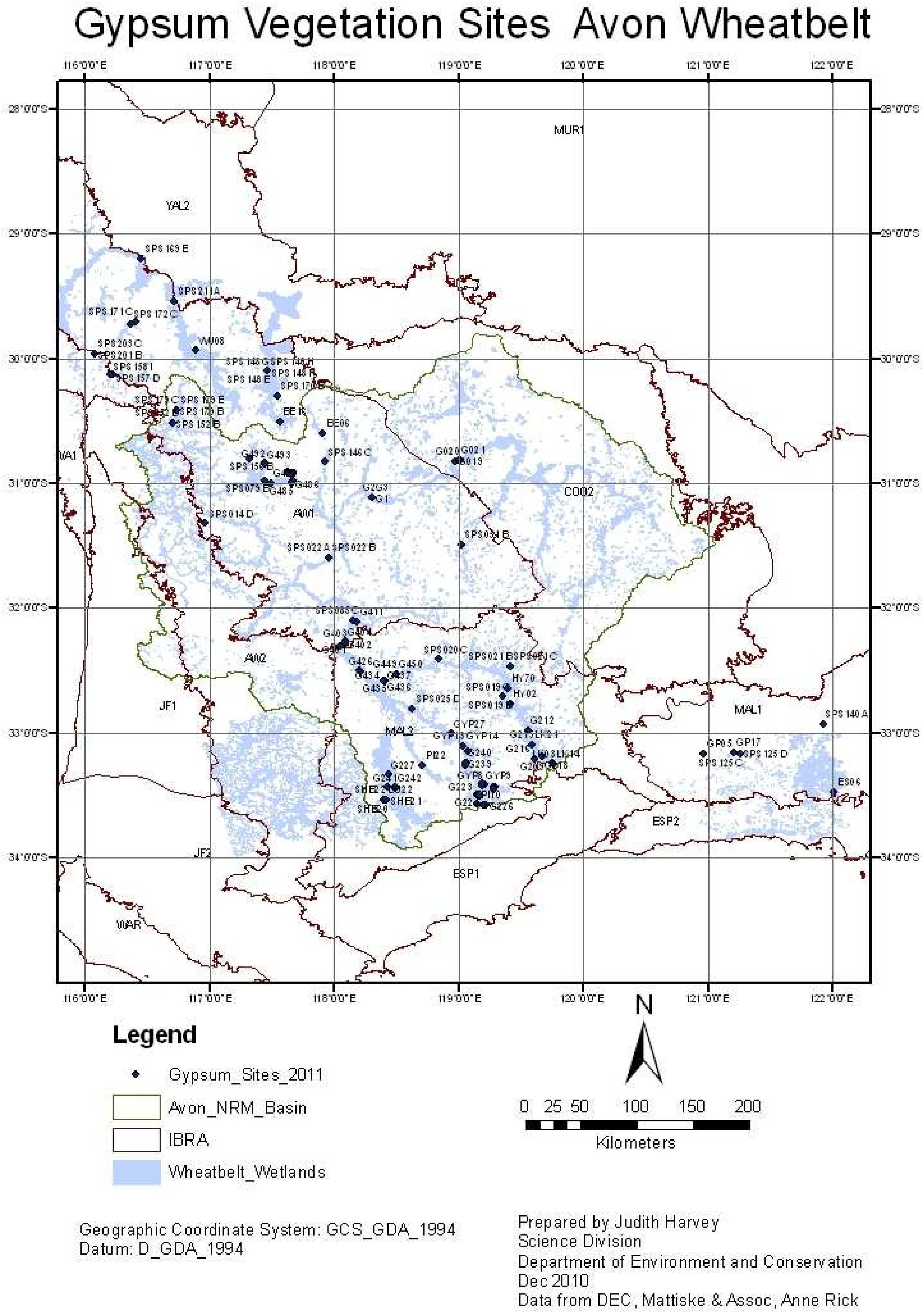
- Location of quadrat
- Description of soils and topography. No soil analysis was available. The Chinocup quadrats were in the area of a mining lease and the UCL was in the area of Mattiske (1995) site G226
- Vegetation description - modified Muir (1977)
- Species list of individual plants in each quadrat

Table 3 summaries the differences between data collection techniques used in the surveys contributing to the data set used in the present project. Figure 4 illustrates the location of the sites included in the project.

Table 3 Differences between data collection techniques used in the surveys contributing to the data set.

Survey	Date of field work	No. visits	Data collection	Weeds	Adjacent Species	Topography	Soil samples	No sites Total 144
Mattiske (1995)	November 1994 to January 1995.	1	5.64 m from central point. Trees within 20m	Weeds to genus in field. Few collections	+5m species recorded.	Description	Taken at 0-10cm and 40-50cm from central point. Analysis % gypsum	54 Total in survey 170
Lyons et al (2004)	Between August and December 1998 to 2000	2	10x10m quadrats, 5x20m in some narrow vegetation zones	Weeds included	No adjacent species recorded	Description and ELCODE	5-15 cm was collected at 30 regularly spaced points within quadrat and bulked. Analysis % gypsum	56 Total in survey 813
Gibson et al (2004)	October 1997 to September 2000 Spring surveys	2 except Esperance and Grasspatch areas	Overstorey 20x20m quadrats Nested 10x10m	Weeds included	No adjacent species recorded	Description	Stratified bulked soil sample from top 10 cm Analysis % gypsum	4 Total in survey 1511
PEC, TEC	September, October , November 2004 November 2005	1 and 4	10x10m quadrats	Weeds included	Adjacent species recorded	Description	Description only. Mine site indicating high gypsum content at Chinocup. East Magenta same area as G226	4 Total in survey 6
2009 Survey	October beginning November 2009	1	10x10m quadrats	Weeds included	Adjacent species recorded	Description and ELCODE	0-10cm- collected at 30 regularly spaced points and bulked 40-50cm – one central point with auger. Analysis % gypsum	26 Total in survey 27

Figure 5 The location of sites included in the project.



TAXONOMY UPDATE – NAME RECONCILIATION

In order to compare the different sets of data the taxonomy needed to be updated so that the same names were in use and where the taxonomy of certain groups had been revised that the taxonomy was revised for all data. This was done by

- All data sets were re entered into the Western Australian Herbarium's MAX3 program in 2009 to check for name changes
- Voucher specimens were checked on flora base
- In a small number of cases voucher specimens were examined in the Herbarium and re identified

For example *Frankenia* aff. *sessilis* recorded during the SAP survey has been re-identified as *Frankenia* sp. southern gypsum from vouchers collected. Specimens identified as *Frankenia* sp.1 in the Mattiske survey but without a voucher in the WA Herbarium were collected from Mattiske sites at Lake Cobham, Lake Magenta and Lake Lockhart in 2009 and also found to be *Frankenia* sp. southern gypsum. A voucher specimen of *Frankenia sessilis* identified by the author in 2005 for Rosemary Rees from UCL east of Lake Magenta was re examined in the collections at the WA Herbarium and again found to be *Frankenia* sp. southern gypsum. *Darwinia* sp. Karonie was also recorded under different names including *Darwinia* aff. *diosmoides*, *Darwinia halophila* ms and *Darwinia drummondii*.

In some cases where taxonomic revision has resulted in a number of new species and no voucher specimens were available for re-identification or where there is confusion in the taxonomy of certain groups the taxonomy follows that of the SAP sites eg *Melaleuca uncinata* group, *Frankenia setosa/glomerata* complex, *Austrodanthonia setacea* group.

In the case where the identification of plants has been only to Genus or a query exists in the name due to a lack of flowering material or confusion in the taxonomy of the group the reconciliation of plant names follows the procedure set out in Griffin (2008) which involved several considerations

- Taxa recognized only at the generic level (eg Acacia sp.) were omitted
- Taxa recognized at the species level for one survey and at the intraspecific at another were reduced to the specific level for the analysis
- Taxa which could have been confused i.e. through similar appearances were merged if it appeared likely that there was a different application in different surveys.
- Taxa which had undergone nomenclatural revision since early surveys were recorded were merged or renamed
- ? and aff. were removed when justified

Taxonomic updates for the Mattiske and SAP sites and name reconciliation for the Mattiske sites can be found in Appendix 3, 4 and 5.

DATA QUALITY

The main factors affecting the quality of the data was time of survey and the number of times the sites were surveyed. The SAP sites were surveyed at least twice in the spring which maximized the number of annuals and geophytes collected. A number of the Mattiske (1995) sites were sampled in December and January and the recent survey carried out in October 2009 was in a dry year with the number of annuals limited by the season. Mattiske (1995) sites and the 2009 quadrats were only sampled once. Two data sets were run with and without annuals and geophytes. In some cases with the full data set the SAP data was separating in the analysis substantially based on the presence of annuals and geophytes. The data set without the annuals and geophytes was therefore thought to be the most useful. It should be noted also that some groups identified in the analysis only contained SAP or Mattiske sites because these were the only sites sampled in that area.

Gypsum was collected only at the surface in the SAP sites and both at the surface and at 50cm for the 2009 quadrats and the Mattiske (1995) sites. Therefore there may be SAP sites with gypsum at depth that were not used in the analysis. The influence of layering and multiple soil types within one dune was not investigated.

ELCODE had been previously attributed to the SAP wetland vegetation sites (see p19). The author attributed an ELCODE to other sites based on field work (2009 quadrats) but only on site descriptions and photos where available for other sites.

Mattiske (1995) and the 2009 survey both recorded species of interest adjacent to the quadrats sampled. These species were thought to be typical of the gypsum vegetation and have been included in the species list of plants recorded on gypsum for the project area Appendix 10. Adjacents were not included in the analysis.

Weed species were recognized to Genus in the field and sparingly collected in the Mattiske (1995) survey and were not included in the analysis. Because singletons made up such a large part of the data sets they were included in the analysis.

INFREQUENTLY OCCURRING TAXA

In the data set that included annuals and geophytes but no adjacents 42% of the plant species were singletons i.e. recorded at only one site. With the data set that excluded the annuals and geophytes this increased to 52%. In this data set over half of the singletons were terrestrial species not commonly occurring in wetlands and three were rare species. Some of the quadrats that showed a high number of singletons were at the periphery of the study area eg SPS148H (Lake Moore) with the most singletons of 8. Four of the sites containing singletons were from areas that were poorly sampled.

DATABASES

The following data sets were accumulated in EXCEL spread sheets and are available on the CD with the report

- All species recorded at gypsum sites including adjacents, weeds, annuals and geophytes
- Species at gypsum sites used in the analysis
- Site descriptions including GPS location, % gypsum, soil description, topographical description, ELCODE and vegetation description.

- Gypsum sites and factors used in the analysis
- Quadrat classification (PRIMER) site data Appendix 11, 12
- Gypsum Species List Appendix 10

PRIMER Analysis
The multivariate statistics package used to analyse the species information for each quadrat/site was PRIMER v6 (Clarke & Gorley, 2006). Quadrats/sites were classified according to similarities in species composition (presence/absence data) using the Bray-Curtis Similarity Coefficient. The results of the Cluster classification were illustrated in a dendogram. A SIMPROF test (similarity profile) was used in conjunction with cluster to test the significance of divisions displayed in the dendogram. A SIMPROF test was carried out at each node of the dendogram. Groups were examined at the 15 group level with some groups distinguished further if divisions were shown to be statistically significant by the SIMPROF test.

nMDS (non-metric multidimensional scaling) was used to simplify and display the data to see which factors best explained differences between groups.

ANOSIM (analysis of similarity) was carried out on a priori groups defined by environmental factors.

SIMPER was used to look at characteristic and distinguishing species.

Environmental Factors
Factors ie environmental attributes for each site/quadrat used in the analysis are outlined below.

Area

North	21 samples
Central	26 samples
South	89 samples
Esperance	8 samples

ELCODE

2 – zone of typical inundation/wave action	73 samples
3 - elevated flat inundation in extreme events	34 samples
4 - terrestrial	37 samples

Gypsum group

1	1-19%	36 samples
2	20-39%	19 samples
3	40-59%	15 samples
4	60-79%	13 samples
5	80-100%	61 samples

Lake Systems

Cowcowing Lake (Lake Wallambin, Koorda Salt Lake, Cowcowing lakes)	15 samples
Damboring	5 samples
Gunyiddi-Latham	6 samples
Kondinin (Lake Kurrenkutten, Seagroat, Kondinin Salt Marsh)	23 samples
Lake Moore (Lake Moore, Lake Harvey, Lake Mollerin)	6 samples
Lake Grace (Chinocup, Lake Altham, Lake Pingrup, South Lake Grace)	9 samples
Lake King (L King, L Camm, L Pallarup, L Milarup, L Hurlstone, L Varley)	17 samples
Lake Magenta (L Cobham, L Lockhart, L Buchan, L Burkett, L Magenta)	35 samples

Samples not included in the Lake System analysis

Only Lake Systems with more than 3 samples (sites) were used in the analysis. Esperance was excluded as the samples were not confined to a lake system and were spread over a wide area.

Bandee Lakes (Kellerberrin)	2 samples
S Beacon	1 sample
Boases Salt Seep	1 sample
Emu Rock Lake	2 samples
Esperance area (Pyramid lake, Quarry Lake, N Esperance)	8 samples
Fishers Lake (North Lake Magenta)	1 sample
Lake Brown	3 samples
Lake Deborah	3 samples
Lake Goorly	1 sample
Lake Gounter (Hyden)	1 sample
Lake McDermot	1 sample
Lakelands NR	1 sample
E Mongers	1 sample
Nullanulla Lake (S Southern Cross)	1 sample
Weelhamby Lake (N Perenjory)	1 sample

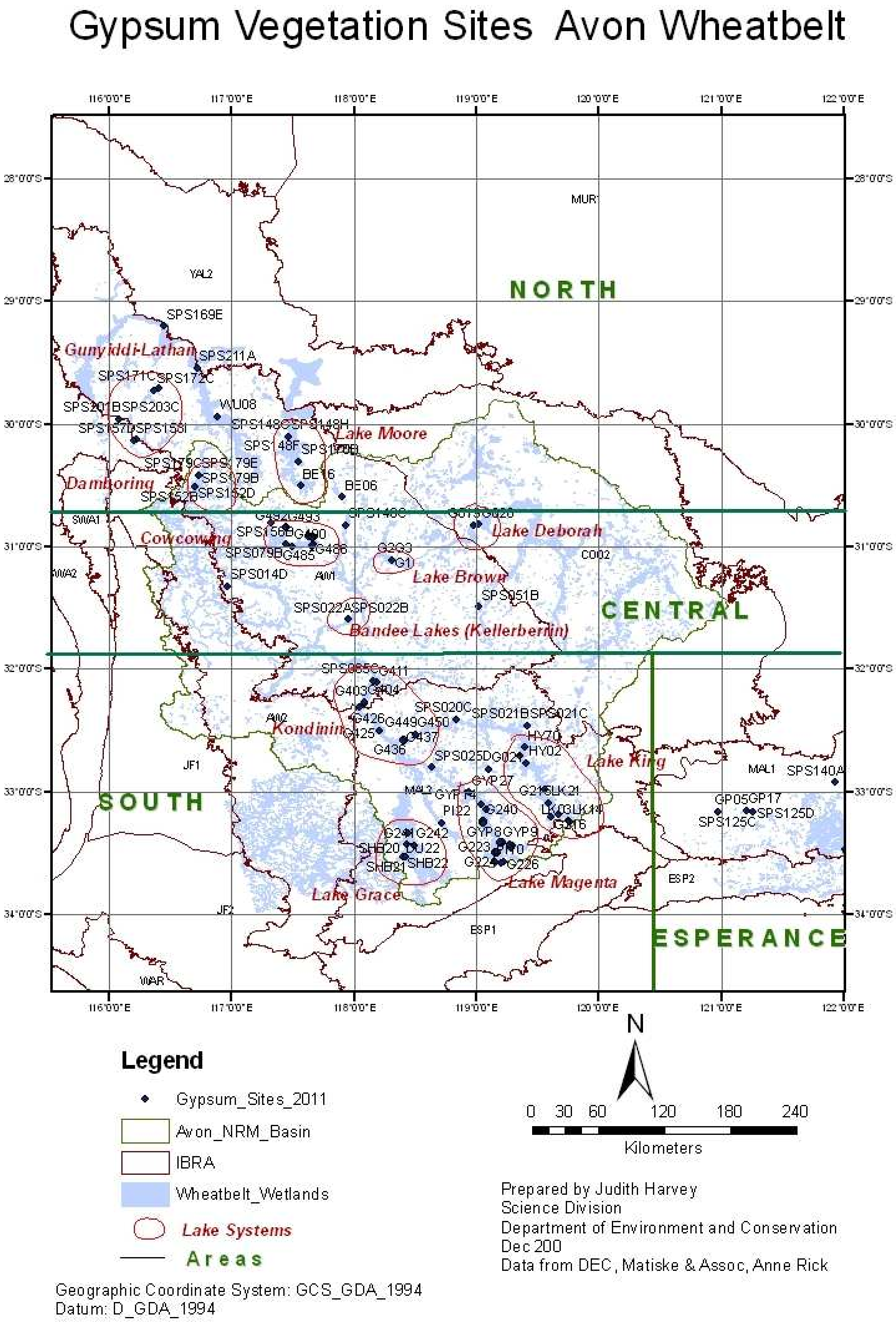
RARE FLORA AND THREATENED ECOLOGICAL COMMUNITIES

The Department of Environment and Conservation supplied information on Declared Rare and Priority plants known to occur in the salt lake systems occurring in the study area. Information was included from the Threatened (Declared Rare) Flora database (DEFL) and the WA Herbarium Specimen database (waherb). Search coordinates used were those used by Mattiske (1995) and also coordinates for the Kondinin area (See Appendix 8). Further rare species information was obtained from species site data. DEC also provided information on Threatened Ecological Communities (TEC) and Priority Ecological Communities (PEC).

GYPSUM DEPOSITS NOT PREVIOUSLY SURVEYED

Gypsum deposits occurring in the study area (Jones 1994) were listed and GIS layers prepared. A current list (2009) of gypsum projects including site type, developmental stage and latitude and longitude was accessed from the Department of Mines and Petroleum web site and GIS layers prepared.

Figure 6 Representation of the Area and Lake System factors used in the PRIMER analysis



RESULTS

FLORA SURVEY

A total of 449 vascular plant species are recorded in Appendix 10 (EXCEL data base on attached CD) as occurring on gypsiferous soils. Appendix 10 includes plant species from the following sources

- Sites selected for analysis in the current project including annuals, geophytes, weeds and species recorded adjacent to the quadrats but in the same vegetation community occurring on the gypsum substrate
- 2 sites on gypsum dunes covered by old gypsum mining leases in the Lake Campion Nature Reserve revisited by the author in 2010. The gypsum content of the soils has been analysed by Freeman (1994). The taxonomy of these sites surveyed by the author in 1990 (Coates, 1990) has now been updated (Rick, 2010). Site data was not included in the PRIMER analysis as quadrat data was not available.
- Plants occurring in the study area and listed in Symon (2006) "A list of gypsophilous plants for Southern Australia"
- Rare Species recorded on gypsiferous soils in the DEFL and WAherb at the coordinates requested.

Due to time restrictions records of plants growing on gypsum from other consultancy reports were not included in this project. Before other species can be added to the list the presence of gypsum needs to be confirmed by checking data on soil analysis or confirming that a gypsum mining lease covered the area surveyed. The taxonomy would also need to be updated and voucher plant specimens checked on Flora Base where possible.

The families with the largest representatives of genera and species are listed in Table 4. The families Asteraceae (daisies), Chenopodiaceae (salt bush, samphire etc), Poaceae (grasses), Myrtaceae and Frankeniaceae were the most strongly represented in the flora of the study area as would be expected in salt lake areas.

COMMONLY OCCURRING SPECIES

The most frequently recorded weed and native species are listed in Tables 5 and 6. Species were included only if they occurred in at least 6 of the 13 lake systems listed in Appendix 10 to compensate for the uneven sampling of these systems (eg Lake Magenta with 35 sites). It should be noted that Lake Systems in Appendix 10 differ from those used in the data analysis (p23) as species recorded in quadrats situated on isolated lakes (often with only one site) were included in data for the nearest Lake System in Appendix 10.

All species listed in Tables 5 and 6 have wide geographical distributions and are not confined to gypsiferous soils. Many have been recorded from a range of soils indicating their ability to adapt to different soil types. They were all recorded on soils with a wide range of gypsum content from all gypsum groups 1-5.

Table 4 Number of species and genera represented within the major families

Family	No. species	No. Genera	Weeds
Asteraceae	85	45	11
Chenopodiaceae	64	13	0
Poaceae	47	25	19
Myrtaceae	43	7	0
Fabaceae	24	11	4
Frankeniaceae	15	1	1

Table 5 Frequently recorded weed species

Taxon Name	Number of sites (total 154 sites)	Numberof lake systems (total 13)
**Mesembryanthemum nodiflorum*	39	11
**Vulpia myuros*	37	8
**Parapholis incurva*	32	9
**Bromus rubens*	22	9
**Sonchus oleraceus*	21	10
**Hypochaeris glabra*	18	9
**Avena barbata*	17	7
**Lolium rigidum*	13	7

Table 6 Frequently recorded native species

Taxon Name	Number of sites	Number of lake systems
Senecio glossanthus	34	12
Tecticornia halocnemoides	39	10
Austrostipa elegantissima	33	9
Tecticornia pergranulata	24	9
Tecticornia indica	11	9
Atriplex paludosa	32	8
Carpobrotus modestus	26	8
Bromus arenarius	15	8
Atriplex vesicaria	14	8
Senecio pinnatifolius	13	8
Disphyma crassifolium	40	7
Tecticornia moniliformis	38	7
Rhagodia drummondii	27	7
Austrodanthonia setacea	25	7
Darwinia sp. *Karonie* (K. Newbey 8503)	25	7
Enchylaena tomentosa	21	7
Alyxia buxifolia	19	7
Atriplex holocarpa	16	7
Santalum acuminatum	13	7
Tecticornia doleiformis	13	7
Maireana oppositifolia	41	6
Tecticornia syncarpa	24	6
Calandrinia sp. ?Meckering	23	6
Exocarpos aphyllus	20	6
Frankenia cinerea/punctata	18	6

GYPSOPHILES AND GYPSOVAGS

Symon (2006) found that a lack of critical collecting details on many of the herbarium labels made the compilation of the South Australian list of gypsophiles and gypsum tolerant species (gypsovags) difficult. Many specimen labels in the WA Herbarium lack any soil details and others are very general. Symon used the term "likely sites" in his data.

It is not surprising that the soils on many herbarium labels are incomplete in relation to gypsum content. Determining the gypsum content of soils can be difficult at lower concentrations and therefore sites where the soils have been analyzed provide the only reliable data. Sites that occur in areas delineated for mining are usually reliable as soil samples would have been taken at the time of the mining tenement proposal. Some of the rare flora collections from Lake King only mention gypsum in more recent collections where soil analysis or past mining now indicate the presence of gypsum.

Soil analysis of top soils and soils to 50cm will not provide information on the gypsum content of deeper soils. At site GYP001 the gypsum content of the top soils was 12% and at 50cm 2.6 %. Information provided from a proposed mining lease indicates that at about 1m the gypsum is pure enough for mining (~70%). Dunes may be composed of a range of gypsum content with thin to deep layers of other soil types covering the gypsum. A number of small annual herbs live in the shallow soils above the gypsum and it is difficult to know whether these are truly gypsophilous or merely tolerant (Symon 2006).

Table 7 only lists 10 species which may be possible gypsophiles. Even using the more general definition of a gypsophile (substantially confined to gypsum soils) it is difficult to find any species in the study area that meet this criteria using information from herbarium labels. Collections of the 57 species listed by Mattiske (1995) as potential gypsophiles were checked on Flora Base. Most of these plants were widely recorded on other soil types. Only *Kippistia suaedifolia* and *Hydrocotyle hexaptera* ms are included in Table 7 as possible gypsophiles. *Austrostipa geoffreyi, Kippistia suaedifolia* and *Minuria gardneri* are among the 14 species tentatively considered gypsophiles by Symon (2006) and also occur in the present study area

Table 7 Possible gypsophiles recorded in the study area.

Taxon	Conservation Classification	Number of Herbarium specimens	Soil descriptions Herbarium specimens	Comments
Angianthus sp. Altham (M.N. Lyons 2623)	P1	1	Gypsum -1	Only one collection available
Austrostipa geoffreyi	P1	5	Gypsum - 3 Likely site - 1 No soils - 1	List in Symon (2006)
Frankenia sp. southern gypsum	P1	3	Gypsum – 2 No gypsum - 1	
Chondropyxis halophila		12	Gypsum-5 Likely sites-5 No soils-2	

Goodenia integerrima	R	14	Gypsum – 2 Likely sites – 9 No soils - 3	Low gypsum dunes forming low islets within salt lake. From Declared Rare Flora DEC reference
Goodenia salina	P2	6	Gypsum – 4 Likely sites – 1 No soils - 1	Recently collected from Lake Cobham. Surface soils did not appear to contain gypsum but adjacent to gypsum soils
Hydrocotyle hexaptera ms	P1	6	Gypsum – 2 Likely sites – 3 No soils - 1	
Hydrocotyle sp. Truslove (M.A. Burgman 4419)	P1	6	Gypsum – 2 Likely sites – 2 No soils - 2	
Kippistia suaedifolia		44	Gypsum – 19 Likely sites – 14 No soils – 11	Listed in Symon (2006) 14 collections in WA with soil descriptions did not mention gypsum
Minuria gardneri		16	Gypsum – 4 Likely sites – 10 No soils – 2	Listed in Symon (2006). 10 collections in WA did not mention gypsum soils

DECLARED RARE AND PRIORITY FLORA

Tables 8 and 9 are compiled from information supplied from the Threatened (Declared Rare) Flora database (DEFL), the WA Herbarium Specimen database (waherb) and information recorded at sites included in the present project. Coordinates used in the rare flora search are provided in Appendix 8 and more detailed information on rare flora sites can be found in Appendix 9. The species recorded have been classified by the Department of Environment and Conservation into categories which reflect their conservation status. These categories are listed in Appendix 7. The 5 Declared Rare and 25 priority plants listed in Table 8 have been recorded on gypsiferous soils. Table 9 lists Rare and Priority plants which have been recorded in “likely sites” in salt lake systems but have not as yet been recorded on gypsiferous soils. Two DRF and 15 priority plants have been recorded in “likely sites”. These Tables include general site descriptions from data base information, the number of herbarium specimens present at the WA Herbarium from Flora Base, the Number of herbarium labels that mention gypsum in soil descriptions, geographical distribution and classification as a gypsophile or gypsum tolerant (gypsovag).

Table 8 Rare and Priority flora recorded on gypsum soils

Taxon	Conservation Classification	Site Description from database	Number Herbarium Specimens	Number Labels where soil descriptions mention gypsum	Geographical Distribution	Suggested Gypsophile (g) or gypsum tolerant (t)
Adenanthos pungens subsp. *pungens*	R	Dune sand / gypsum	14	2	Chinocup, Nr Stirling Ranges	t
Angianthus halophilus	P3	Sandy ridge/island in lake - gypsum	7	1	Lake King, Lake Grace, Lake Cairlocup	t
Angianthus sp. Altham (M.N. Lyons 2623)	P1	gypsiferous dune near GYP026	1	1	Lake Altham	?g only 1 collection
Astartea sp. Esperance (A. Fairall 2431)	P1	sand, clay, sandy gravel, gypsum	5	0	Esperance area	t
Austrostipa geoffreyi	P1	Lake margins and dunes gypsum , sand, gypsum dune	5	3	Lake Grace, Lake King	g
Blennospora phlegmatocarpa	P2	gypsum dune, loam clay over clay, loam, salt flat, low sandy rise, small dune, saline flat, saline drainage line,	68	4	most of project area	t
Conostephium pungens	P2	gypsum and sandy soils	3	1	Chinocup	t
Eucalyptus exigua	P3	Embankment lake edge clay, gypsum	29	1	Lake King north to COO2 sub region NW to Cowcowing	t
Eucalyptus quaerenda	P3	gypsum, sandy soils over clay and sandy soils, near salt lake	43	3	Lake Altham area to Lake King and upper Phillips River	t
Fitzwillia axilliflora	P2	saline lake, edge salt lake, saline basin, gypsum	10	0	Newdegate /Lake Bryde North to Morawa area	t
Frankenia conferta	R	salt lake edge, sand over clay, salt lake - clay and sand clay, gypsum	24	7	Coorow, lake Moore, Lake Mollerin	t

Frankenia drummondii	P3	lunette/low dune adjacent saline pan - sandy loam soils, loamy sand road verge, gypsum dune, sandy clay, low rise trace gypsum loamy sand, sand dune sand, sandy loam, 10m from salt pan	28	3	Kondinin to Salmon Gums	t
Frankenia sp. southern gypsum (M.N. Lyons 2864)	P1	Low rise gypsum, gypsum, saline grey clay	3	2	S Pingaring, Quarry Lake area, Lake Magenta. L King	g
Goodenia integerrima	R	gypsum clay, clay sand, margin salt lake, islet in salt lake, sandy island in salt lake	14	2	Lake King	g
Goodenia salina	P2	gypsiferous dune on shore of saline pan, previous gypsum mine, islet in salt lake, loamy sand , gypsum	6	4	Lake King, Lake Altham, Lake Cairlocup	g
Gunniopsis rubra	P3	G?rubra G492 100% gypsum, loam over clay mid slope, hard pan, valley, loam, sand, saline, mid slope of valley, clay loam	26	0	mainly AW1. Wide range of habitats including banded ironstone	t
Haegiela tatei	P4	gypsum dune, sand dune, Greens mining lease, gypsum	22	5	Mainly MAL1 and MAL2. 2 sites in COO2 and 1 site east of Geraldton	t
Hakea ?rigida	P2	gypsum dune, loamy sand, sand on rise sandy gravel	15	0	Campion area east to Kalgoorlie	t
Hydrocotyle hexaptera ms	P1	sandy island, sand fringing salt lake, low flat subject to inundation, gypsum	6	2	Lake King, Gunyiddi	g
Hydrocotyle sp. Truslove (M.A.Burgman 4419)	P1	white sand over gypsum in flats, sand - loam, samphire flat gypsum,	6	2	Scadden, Truslove	g
Hydrocotyle vigintimilia	P1	low gypsum, salt lake	3	0	Arrowsmith Lake and NW of Esperance	t
Microseris scapigera	P3	Kopi dune, lunette adjacent to saline pan, sand, gypsum	18	2	Mainly MAL1 and MAL2. South Australia	t

Millotia steetziana	P2	saline flat, sandy soils over clay, rise adjacent to salt lake - sand, sandy soil west shore, sand/loam rise in saline drainage line, gypsum	8	0	Kondinin, Chinocup, Lake King	t
Pimelea halophila	P4	sandy island, raised white island, islet in salt lake, clatey sand, sand over clay, agjacent to gypsum mine, edge of salt lake clay loam, sandy soil with gypsum	20	3	Lake King to N and E of Esperance	t
Podotheca pritzelii	P3	low dune beside salt lake, sand, valley flat, sand over clay, gypsum	18	0	Campion north to Geraldton area	t
Ptilotus fasciculatus	R	Flat, clay, sandy silt, saline flood plain, gypsum	18	0	Kondinin area north to Geraldton area	t
Roycea pycnophylloides	R	samphire/gypsum dune edge of salt lake, low rise, loamy sand trace gypsum , sandy salt lands, very low sandy rise, clay pan, sand, clay, seasonally inundated flat, lake, sand salt clay pan, clay, adjacent to salt lake	57	6	Cunderdin to lake King	t
Sarcocornia globosa	P3	Saline flat adjacent to salt lake, sand , sandy clay, gypsum, Southern shore	20	3	Chinocup and Lake Fox to East Geraldton	t
Tecticornia annelida	P1	Gypsum, loam over clay, sandy clay, low dune, flat, sand	11	0	AW1 Gunyiddi to E Geraldton	t
Tecticornia fimbriata	P3	Gypsum, clay pan, low dune , shore salt lake, sand, clay	23	4	northern section AW1	t

Table 9 Rare and Priority Flora recorded for salt lakes but not on gypsiferous soils.

Taxon	Classification	Site description from data base	Number of Herb. Specimens	Geographical Distribution	Comments
Acacia inceana subsp. latifolia	P1	Red brown earth samphire salt lake, sandy loam slight rise samphire flat, sandy loam rise in salt lake. roadside	6	Wubin	Likely sites. Slight rise in salt lake
Angianthus micropodioides	P3	Saline drainage line, dune, sand , low rise adjacent to saline wetland, sand, sandy flat adjacent to salt lake	21	Cunderdin area north to Lake Harvey	Likely sites. Associated with salt lakes, Dunes including E side of lake
Drosera salina	P2	Drainage line sand, adjacent salt lake sandy soils over clay, sand over clay silt	11	MAL1, MAL2	Associated with salt lake margins
Eremophila serpens	P4	sandy soils, sandy loam, dunes, margin of salt lakes	33	Hyden, Newdegate, Esperance	Associated with salt lakes
Eremophila subteretifolia	R	sand or sandy loam, margin of salt lakes	15	Lake king area and NW Ravensthorpe	Associated with salt lakes
Eucalyptus spathulata subsp. salina	P3	edge salt lake, slight rise, flat sand-clay duplex clay loam flat	14	Quairading, Narambeen, Brookton, Kondinin	Edge of salt lakes including dunes
Frankenia brachyphylla	P2	Southern shore, sand high water line of salt lake, salt lake margin sandy loam	3	Koolyanobbing, Truslove	Likely sites.
Frankenia bracteata	P1	Salt lake, clay, sandy rise, slope edge salt lake	12	Cunderdin area north to Mullewa area	salt lakes
Frankenia glomerata	P3	Salt lakes, beach and dune E and S of lake, sand/clay, loamy sand, clay loam	28	Most AW1 and 2 locations N of Wiluna	Salt lakes, beach and dune E and S of lake
Frankenia parvula	R	TEC	10	Cunderdin area to COO2	sandy soils, salt lakes
Hydrocotyle muriculata	P1	raised margin of salt lake, clay loam	14	MAL2	SE edge of salt lake, gypsum tolerant species associated

Hypoxis salina	P1	saline drainage line, sandy soils over clay	4	Chinocup	Associated with salt lake margins and gypsum tolerant species associated
Lepidium genistoides	P2	sandy silt, low dune between salt lakes	21	Koorda area to Souther Cross area	Salt lakes some associated species gypsum tolerant
Lepidobolus spiralis	P2	sand fringing salt lake	3	Lake King, Frank Hann NP	edge of salt lakes
Scaevola tortuosa	P1	salt lake fringe	9	North of Esperance to Cunderdin	Edge of salt lakes
Stylidium pulviniforme	P3	G221, small dune west shore, sand, clay	20	Lake Cobham to Salmon Gums and into COO2	Salt lakes, saline sand
Tribonanthes minor	P3	sand within saline drainage line, slight rise above salt lake , shallow sand at lake edge, sand over clay, flat terrain	5	Lake king, Chinocup	Salt Lake edge

PRIMER ANALYSIS

QUADRAT CLASSIFICATION

The data set used for the analysis excluded annuals, geophytes, weeds and adjacent species but included singletons (see Method section - Data Quality). The quadrat classification was examined at the 15 group level (~17% similarity). The SIMPROF test indicates those divisions which are statistically significant (black lines). The groups were further divided where the SIMPROF test indicted significantly different clusters within the groups (28 groups). The results are displayed by the dendogram in Figure 7. Information for Groups including sites and species composition can be found in Appendix 11 and 12 (EXCEL spread sheets on CD available with the report). Table10 summarises the data. It should be noted that some goups only contained SAP or Mattiske sites because these were the only sites sampled in that area.

SIMPER (Similarity Percentages) identifies those species most responsible for typifying the Group and those most responsible for distinguishing the groups. When interpreting the results the sim/SD ratio refects the consistency of the contribution of the species and should be over 1.0 and a result of over 50% shows a good level of % contribution. Species in blue in Table 10 indicate species with sim/SD ratios usually 1.0 or over but occasionally just below. % contributions range from 93.03 to 7.14%. See Appendix 16 for SIMPER results. Dissimilarity % contribution was usually <16% which was considered too low to be useful for identifiying distinguishing species. The highest value was 20.07% with a Diss/SD ratio of 2.5 for *Tecticornia lylei* and 18.06% Diss/SD ratio of 1.81 for *Tecticornia halcnoimoides* for distinguishing between Groups 3a and 2.

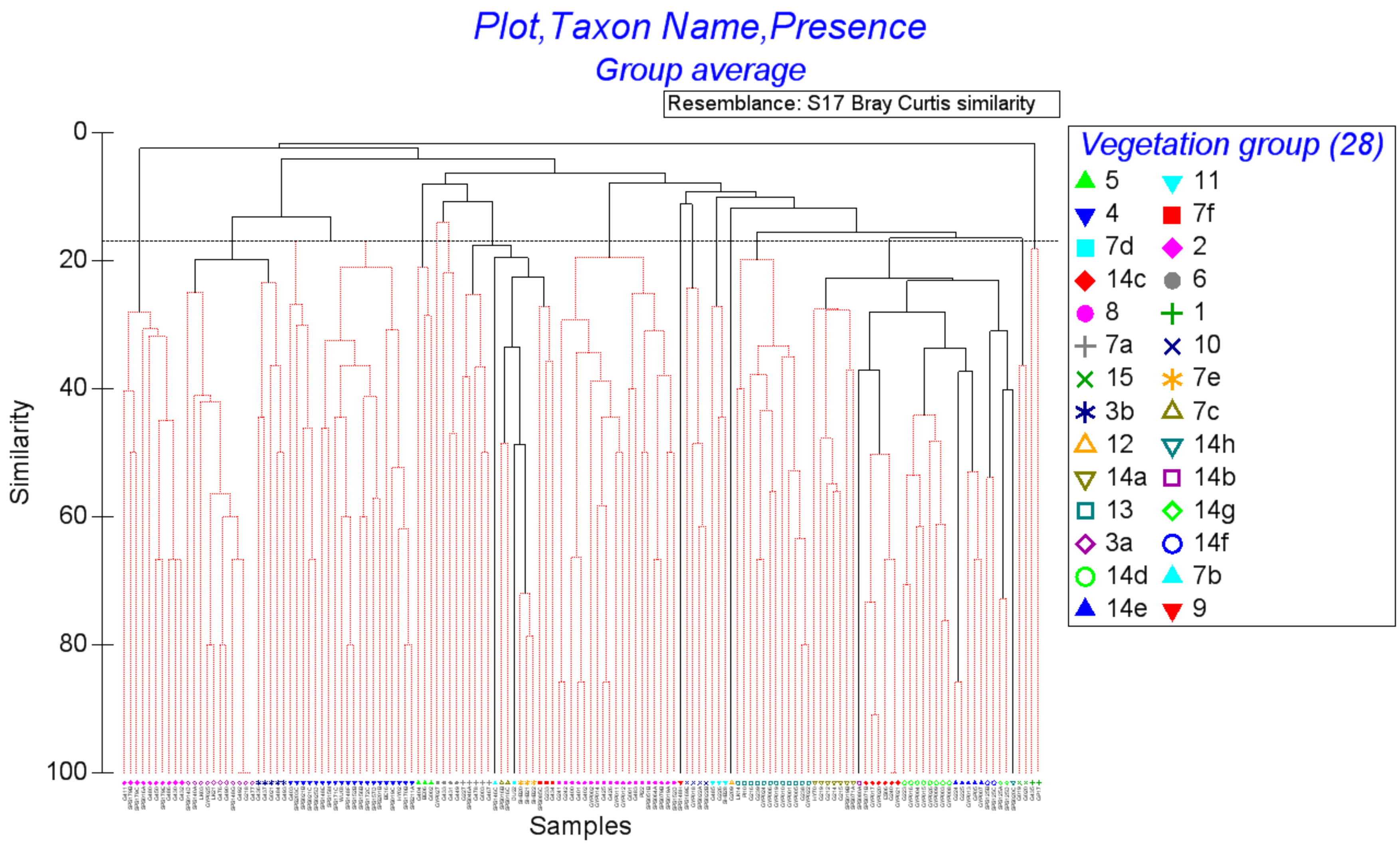


Figure 7 Dendogram of the Quadrat Group Classification

Figure 8	Ordination - nMDS (non-metric Multidimensional Scaling)

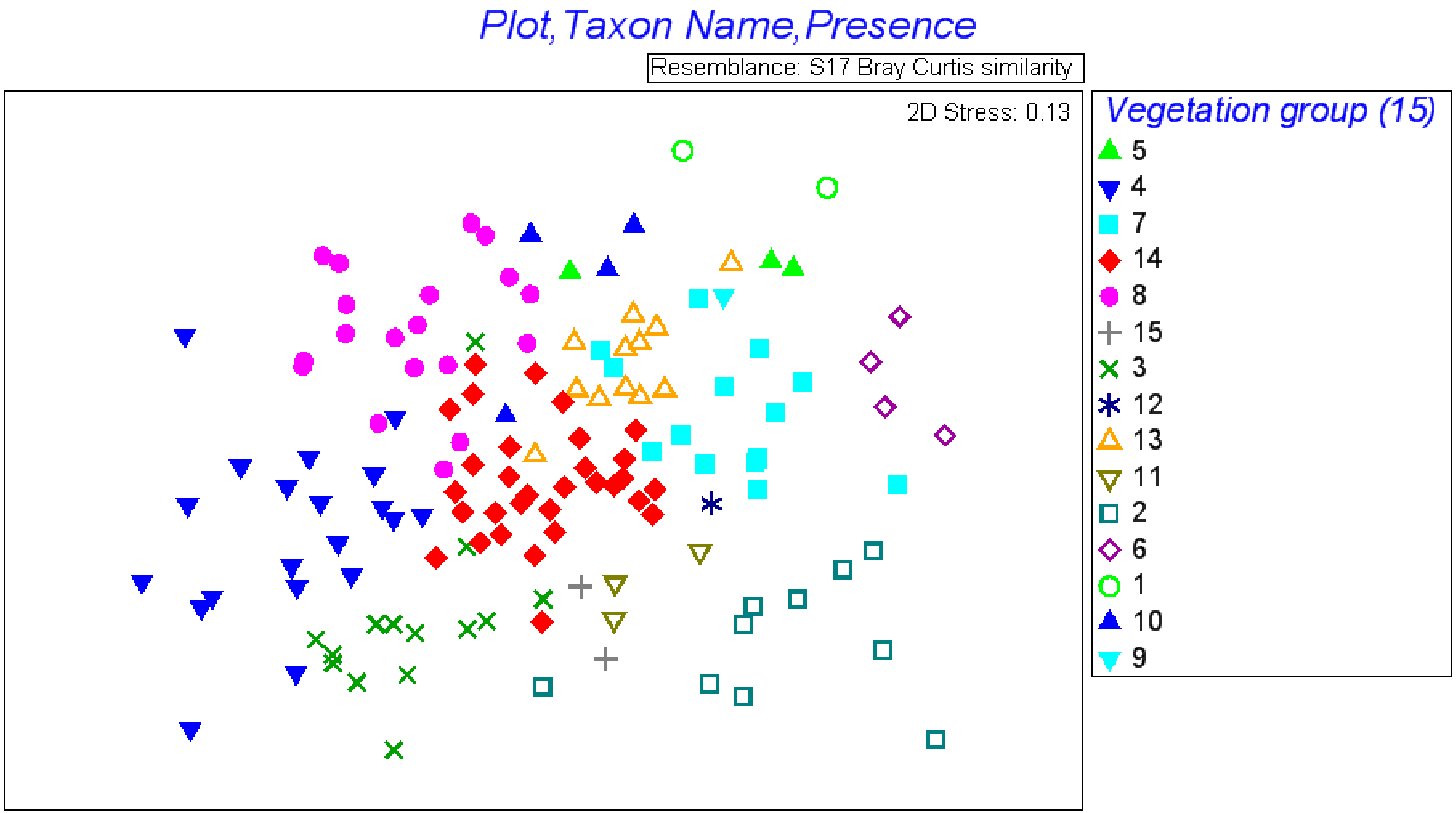


Table 10 Summary of characteristics for the Quadrat / Site Group Classification. (Elcodes in bracets occur only occasionally within the quadrat/site group)

Group	No. of Sites	Characteristic Species / Structural Dominants	% Gypsum	ELCODE	Location	Rare Flora and possible gypsophiles	Species /quadrat	Characteristics for Conservation significance
Low rises, ridges on and adjacent to the lake bed - subject to inundation								
2	10	Tecticornia lylei Darwinia sp. Karonie Frankenia cinerea/punctata. Melaleuca species present.	7-100%	2 (3) Mean 2.1	Damboring Cowcowing, Kondinin	Blennospora phlegmatocarpa	1 to 5	Range of gypsum content in soils. Characteristic species not confined to gypsum. Wide distribution. 1 priority species.
3a	11	Tecticornia halocnemoides all sites	9-100% most over 75%	2	Esperance, Lake King, Lake Magenta, Cowcowing, Gunyiddi-Latham, Lake Goorly-Lake Moore		1 to 5 Many species poor sites.	Wide distribution across the study area. Many species poor sites. Range of gypsum content. No rare flora recorded or gypsophiles. Characteristic species not confined to gypsum.
3b	5	Carpobrotus modestus Tecticornia halocnemoides Tecticornis pergranulata Melaleuca species present.	5-80%	2	Cowcowing, Lake Deborah, Kondinin	Ptilotus fasciculatus DRF, Roycea pycnophylloides DRF, Sarcocornia globosa	5 to 6	Characteristic species not confined to gypsum. Range of gypsum content. Rare flora present in Kondinin sites. conservation significance
4	20	Atriplex holocarpa Frankenia conferta Tecticornia halocnemoides Tecticornia dolieformis Gunniopsis septifraga Tecticornia loriae Tecticornia peltata Melaleuca species present.	1-99%	2 (3) Mean 2.25	Gunyiddi-Latham Cowcowing, Damboring, Emu Rock lake, Lake Goorly Lake Moore, Gulson NR and Lake Varley	Fitzwillia axilliflora, Haegiela tatei , Frankenia conferta DRF, Tecticornia annelida , Hydrocotyle hexaptera (gypsophile) Tecticornia fimbriata, Frankenia sp. southern gypsum (gypsophile)	1 to 9	Wide distribution across the study area. Wide range of gypsum content. Characteristic species not confined to gypsum except some rare flora. Most sites contain rare flora and possible gypsophiles. conservation significance
Large and small dunes (terrestrial) and ridges subject to inundation in extreme events								
5	3	Enchylaena tomentosa Rhagodia drummondii Atriplex stipitata. Eucalyptus loxophleba (2% gypsum site) Melaleuca pauperiflora (2% gypsum site) Eucalyptus myriadena (2% gypsum site)	2-90%	4 (3) Mean 3.67	Kondinin, Lake Brown, S Beacon		3 to 6	Most sites with low gypsum content. Charactereistic species not confined to gypsum

6	4	Lomandra effusa Darwinia sp. Karonie Daviesia benthamii Santalum acuminatum Callitris preissii Eucalyptus spathulata Eucalyptus eremophila, Allocasuarina huegeliana Allocasuarina acutivalvis Melaleuca uncinata group Eucalyptus longicornis Eucalyptus phenax Melaleuca thyoides	26-100%	4	Lake Biddy, Kondinin	Blennospora phlegmatocarpa G433	5 to16	Characteristic species not confined to gypsum. Range of gypsum content in soils. One Priority flora
7a	5	Austrostipa elegantissima, Callitris columellaris Darwinia sp. Karonie Rhagodia drummondii Kippistia suaedifolia G227 only	2-100%	3(2) Mean 2.8	Lake Grace, Cowcowing, lake Brown	Eucalyptus exigua, Austrostipa geoffreyi (gypsophile) Kippistia suaedifolia (gypsophile)	3 to14	Characteristic species are not confined to gypsum. Sites occur on soils with a range of gypsum content. Two priority plants and the gypsophiles (*Austrostipa geoffreyi, Kippistia suaedifolia* - 1 site) possible conservation significance
7b	1	Alyxia buxifolia Atriplex semilunaris Austrostipa elegantissima Austrostipa pycnostachya Casuarina obesa Darwinia sp. Karonie Didymanthus roei Dysphania sphaerosperma Enchylaena tomentosa Exocarpos aphyllus Frankenia aff.cinerea Frankenia desertorum Gunniopsis septifraga Hakea preissii Melaleuca uncinata group Melaleuca halmaturorum Rhagodia crassifolia Tecticornia indica Trachymene pilosa	50%	3	Lake McDermot	Minuria gardneri possible gypsophile	19	Species recorded are not confined to gypsum except *Minuria gardneri* a possible gypsophile. This area was poorly surveyed with only one site from the SAP survey included from the data set however Lake McDermot is adjacent to the Cowcowing Lake system. 1 site – possible rare vegetation type
7c	2	Alyxia buxifolia Austrodanthonia setacea group Austrostipa elegantissima Austrostipa juncifolia Billardiera lehmanniana Comesperma integerrimum Darwinia sp. Karonie Leucopogon sp kau Rock Eucalyptus longicornis Callitris preissii and Casuarina obesa	76-77%	4 (3) Mean 3.5	Kondinin	Blennospora phlegmatocarpa Podotheca pritzelii	16 to 17	Characteristic species not confined to gypsum. Only 2 sites from Kondinin. High gypsum content. 2 priority flora. Possible conservation significance.

7d	1	Actinostrobus pyramidalis Alyxia buxifolia Billardiera lehmanniana Calandrinia eremaea Carpobrotus modestus Comesperma integerrimum Conostephium drummondii Darwinia sp. Karonie Dianella brevicaulis Enchylaena tomentosa Eucalyptus kondininensis Rhagodia drummondii Threlkeldia diffusa	71%	4	Chinocup		22	Characteristic species not confined to gypsum. 1 site only from Chinocup on soils with high gypsum content. Possible conservation significance.
7e	3	Alyxia buxifolia Atriplex hymenotheca Austrostipa pycnostachya Billardiera lehmanniana Calandrinia eremaea Carpobrotus modestus Rhagodia drummondii Threlkeldia diffusa Eucalyptus aff. incrassata Actinostrobus pyramidalis	gypsum dunes	4 (3) Mean 3.67	Chinocup	Adenanthos pungens subsp. pungens	11 to 15	Characteristic species not confined to gypsum. 3 sites from Chinocup on soils with high gypsum content. DRF Possible conservation significance.
7f	3	Austrostipa elegantissima Rhagodia drummondii Austrostipa pycnostachya, Enchylaena tomentosa Thysanotus manglesii Disphyma crassifolium Melaleuca lanceolata Eucalyptus longicornis Eucalyptus phenax Eucalyptus aff. quadrans Melaleuca lanceolata	8-95%	4	Kondinin, Lake Grace (S Pingrup)	Blennospora phlegmatocarpa	9 to18	Characteristic species not confined to gypsum. Range of gypsum content. 3 sites from Kondinin-Lake Grace area. 1 priority flora
Low rises, ridges on and adjacent to the lake bed – subject to inundation								
8	19	Tecticornia pergranulata Tecticornia syncarpa Tecticornia doleiformis. Melaleuca species present.	2-97%	2 (3) Mean 2.3	L Magenta, L Grace, L King, Kondinin, Cowcowing Southern Cross Damboring	Frankenia sp. southern gypsum	1 to 9	Characteristic species not confined to gypsum. Wide distribution. Range of gypsum content. 1 priority plant
Large and small dunes, ridges - subject to inundation in extreme events mostly terrestrial								
9	1	Atriplex paludosa Austrostipa elegantissima Erodium cygnorum Goodenia mimuloides Kippistia suaedifolia Lepidium rotundum Lycium australe Maireana atkinsiana Maireana erioclada Maireana trichoptera Sclerolaena obliquicuspis Solanum orbiculatum Swainsona gracilis Swainsona purpurea	11%	4	Lake Moore	Kippistia suaedifolia gypsophile	15	Low gypsum content. Northern and wide spread species not confined to gypsum except *Kippistia suaedifolia* a gypsophile.

		Tecticornia disarticulata Zygophyllum aurantiacum						
10	4	Atriplex vesicaria Sclerolaena diacantha Atriplex paludosa Austrodanthonia setacea group Frankenia pauciflora	3-8%	2,3,4 Mean 2.75	Kellerberrin, lake Magenta Lake Goorly-Lake Moore	Frankenia sp southern gypsum GYP018	4 to 8	Sites from all three ELCODE categories. The Kellerberrin sites with ELCODEs 2 and 4 are degraded with weed species. Low gypsum sites
11	3	Lawrencia squamata Frankenia sp. southern gypsum Austrodanthonia acerosa Maireana erioclada. Casuarina obesa at Cowcowing	5-20%	4,	Lake Magenta, Cowcowing	Blennospora phlegmatocarpa Frankenia sp. southern gypsum. TEC UCL east Lake Magenta.	4 to 9	Low gypsum, TEC "Herblands and Bunch Grasslands " annuals not included in the analysis conservation significance
12	1	Alyxia buxifolia Austrostipa drummondii Dianella brevicaulis Enchylaena tomentosa Lepidosperma tenue Lomandra effusa Olearia revoluta Scaevola spinescens Tecticornia moniliformis. Eucalyptus aff quadrans adjacent	80%	4	Lake king		9	Species recorded not confined to gypsum. 1 site. Soils with high gypsum content. Possible rare vegetation type – conservation significance
13	12	Exocarpos aphyllus Atriplex paudosa Austrodanthonia setacea group Maireana oppositifolia Rhagodia crassifolia Pittosporum angustifolium Tecticornia pterygosperma Lawrencia squamata Enchylaena tomentosa. Eucalyptus kondininensis Eucalyptus aff. quadrans Callitris columellaris Melaleuca hamulosa Melaleuca lanceolata Melaleuca thyoides	2-100%	4(3) Mean 3.75	Lake King, Lake Magenta	Frankenia sp. southern gypsum Haegiela tatei Microseris scapigera Millotia steetziana	7 to 13	Characteristic species not confined to gypsum. Range of gypsum content. 4 priority Flora in 2 sites at L Magenta – possible conservation significance
Ridges, rises, dunes - some subject to inundation, some subject to inundation in extreme events, some terrestrial - Lake Altham, Lake Magenta, Lake King, Esperance								
14a	7	Carpobrotus modestus Maireana oppositifolia Leucopogon sp. Kau rock Kippistia suaedifolia Tecticornia moniliformis. Melaleuca species and Callitris columellaris.	95-100%	3 (2) Mean 2.86	Lake King	Angianthus halophilus (1 site), Frankenia sp. southern gypsum (1 site), Goodenia salina (2 sites), Austrostipa geoffreyi (1 site), Hydrocotyle hexaptera (1 site), Pimelea halophila 2 sites Kippistia suaedifolia (6 sites)	7 to15	High gypsum content. All sites from Lake King. Kippistia suaedifolia (gypsophile) which occurs at 6 sites. Rare Flora recorded are also proposed gypsophiles – conservation significance

14b	1	Atriplex vesicaria Disphyma crassifolium Goodenia salina Lawrencia diffusa Lawrencia glomerata Maireana oppositifolia Tecticornia syncarpa Wilsonia humilis	28%	3	Lake Magenta,	Goodenia salina , Haegiela tatei	8	Characteristic species are not confined to gypsum except rare flora *Goodenia salina*. Priority plant *Haegiela tatei* was also recorded. Only 1 site UCL east SPS080A Lake Magenta – possible rare vegetation type
14c	6	Maireana oppositfolia Calandrinia sp. ?Meckering 5 sites, Tecticornia syncarpa , Frankenia sp. southern gypsum Disphyma crassifolium	27-97%	2	Lake Magenta, Lake King, Esperance	Frankenia sp. southern gypsum Hydrocotyle hexaptera	4	Characteristic species are not confined to gypsum. Distribution the southern section of the study area. Range of gypsum content. 2 priority flora.
14d	8	Disphyma crassifolium Tecticornia moniliformis Frankenia sp. southern gypsum Frankenia tetrapetala Lawrencia squamata Maireana oppositifolia. Eucalyptus spathulata Melaleuca hamulosa	54-100%	3,4 Mean 3.25	Lake Magenta, Lake Altham	Frankenia sp. southern gypsum	7 to14	Characteristic species are not confined to gypsum except *Frankenia* sp. southern gypsum - a Priority plant. Range of gypsum content.
14e	5	Disphyma crassifolium Tecticornia moniliformis Frankenia sp. southern gypsum. Melaleuca species present	54-100%	2,(3) Mean 2.2	Lake Magenta ,	Frankenia sp. southern gypsum	2 to 12	Characteristic species are not confined to gypsum except *Frankenia* sp. southern gypsum. Range of gypsum content.
14f	2	Alyxia buxifolia Austrostipa elegantissima Calandrinia granulifera Calandrinia sp. Meckering Callitris columellaris Dianella brevicaulis Disphyma crassifolium Exocarpos aphyllus Frankenia tetrapetala Lepidium rotundum Ptilotus halophilus Rhagodia drummondii Scaevola spinescens Tecticornia moniliformis. Eucalyptus eremophila Melaleuca uncinata group.	1 -14%	4	Esperance	Ptilotus halophilus Astartea sp. Esperance	22 to 30	Characteristic species are not confined to gypsum. Low gypsum content. 2 priority plants. The Esperance area was poorly sampled.
14g	2	Austrostipa juncifolia Calandrinia granulifera Disphyma crassifolium Frankenia setosa complex Frankenia tetrapetala Gunniopsis septifraga Tecticornia halocnemoides Tecticornia moniliformis	42-78%	2	Esperance		10	Characteristic species are not confined to gypsum. 2 sites with high gypsum content. Esperance area poorly sampled

Gypsum <5%								
14h	1	Atriplex hymenotheca Austrodanthonia setacea group Austrostipa elegantissima Disphyma crassifolium Frankenia desertorum Frankenia tetrapetala Olearia incondita Tecticornia halocnemoides Tecticornia moniliformis	1%	4	Lake Gounter (Hyden)	Blennospora phlegmatocarpa	9	Characteristic species are not confined to gypsum. Low gypsum content
Gypsum <5%								
15	2	Frankenia cinerea complex Tecticornia moniliformis	2-5%	2	Lake Deborah		4 to 7	Area poorly sampled with only three sites (G19, G20, G21) from the Mattiske study included in the data set. Low gypsum content (2-5%).
Gypsum <10%								
1	2	Eucalyptus myriadena	2-10%	4	Esperance, Kondinin		5 to 6	Characteristic species are not confined to gypsum. Low gypsum content

The following groups are assessed as having conservation significance. The species composition of these groups includes rare flora, proposed gypsophiles and/or is rare in the data set. Groups that include only 1 or 2 sites and are confined to well surveyed areas may represent rare vegetation associations and will need further investigation as TECs. This assessment of conservation significance is subjective and also takes into consideration the gypsum content of the soils as communities occurring on high gypsum concentrations are especially under threat from mining. The characteristics of groups contributing to their conservation significance are outlined in Table 10 (highlighted in red). The current data set only includes sites with gypsum soils (1-100%) and does not tell us if these groups are rare in a data set that includes sites occurring on other soil types.

Groups with sites mainly from ELCODE 2, that is, these sites occur on low rises (banks) and ridges on and adjacent to the lake bed, subject to inundation. Characteristic species are tolerant of salt and water logging eg species of the genera *Tecticornia*, *Frankenia*, *Calandrinia*, *Maireana*, occasional *Atriplex, Disphyma crassifolia* and some *Melaleuca* species.
Groups 3b and 4 are of conservation significance because of the presence of a number of rare flora and possible gypsophiles. These groups include sites with a wide distribution across the study area.

Groups with sites mainly with ELCODE 3 ie sites occur on ridges and low dunes, subject to inundation in extreme events only. Generally more species per quadrat occur in these areas. Typical species are from the genera *Atriplex*, *Austrostipa*, *Callitris*, *Casuarina*, *Eucalyptus*, *Melaleuca*, *Darwinia*, *Rhagodia*, *Lawrencia*, *Maireana* and *Leucopogon*. Some of these species are less tolerant of salt and waterlogging but species such as *Tecticornias* and *Dysphyma crassifolia* may still be present.
Groups 7a (Lake Grace Cowcowing Lake Brown, 5 sites, rare flora), **Groups 7b** (Lake McDermot, 1 site)**, Groups 14a** (L King, 1 site), **14b** (Lake Magenta, 1 site, rare flora) are of conservation significance.

Groups with sites mainly with ELCODE 4 ie sites occur on dunes, low dunes and ridges, mainly terrestrial. These sites tend to be species rich. A range of genera and species including *Eucalyptus*, *Melaleuca*, *Callitris*, *Actinostrobus*, *Allocasuarina* and *Casuarina obesa*, as well as chenopodiaceae, grasses and a wide range of other shrubs and perennial herbs have been recorded.
Group 7c (Kondinin, 2 sites), **Group 7d** (Chinocup, 1 site), **Group 7e** (Chinocup, 3 sites DRF), **Group 11** (includes TEC east Lake Magenta, 3 sites), **Group 12** (Lake King, 1 site), **Group 13** (Lake King Lake Magenta, 12 sites, rare flora) are of conservation significance.

Group 11 includes 2 sites from UCL east of Lake Magenta NR in an area classified as a TEC "Herblands and Bunch Grasslands on gypsum lunette dunes alongside saline playa lakes". This Group also includes a site from Cowcowing. The Cowcowing site did not cluster with the 2 TEC sites in a previous analysis of the data that included annuals. Group 7e includes 3 sites from Chinocup. These sites are situated close together on the gypsum dunes.

ENVIRONMENTAL ATTRIBUTES
Environmental attributes (factors) were assigned to all sites/quadrats to further explore the patterns in the data. These factors were ELCODE (elevation zones), Gypsum group, Area and Lake System. Only Lake Systems with over 3 samples were used in the analysis. Esperance was not used as the samples were not confined to a Lake System as such but were spread over a wide area. For factors see Methods and Appendix 6.

ANOSIM is an analysis of similarity. The analysis tests for differences in the composition of variables (species) between a priori groups of samples. When interpreting the results p determines if there are significant differences between the groups p <5%, p results of tests with < 35 permutations are unreliable. R reflects the extent of those differences. R ranges from +1 to -1. An R value of 0.75 and above indicates strong differences between groups and 0 indicates no statistical difference.

The results of the ANOSIM tests are listed in Table 11. Lake System (Global R 0.338) was the factor with the greatest R value followed by Area (Global R 0.191). These factors relate to the geological distribution of the data which reflects changes in rainfall and temperature across the project area.

Pairwise tests between Lake Systems showed higher R values. The overall results indicate that in general the further apart the Lake Systems the greater the difference in species composition. These results are particularly true with Lake Magenta with 35 sites spread across all ELCODEs (13 sites ELCODE 2, 8 sites ELCODE 3 and 14 sites ELCODE 4).

Pairwise tests

Lake Magenta – Gunyiddi-Latham	R 0.715
Lake Magenta – Lake Moore	R 0.647
Lake Magenta – Damboring	R 0.63
Lake Magenta – Cowcowing	R 0.594
Lake Magenta - Kondinin	R 0.479
Lake Magenta - Lake Grace	R 0.33
Lake Magenta - Lake King	R 0.226

Lake King however showed less difference in species composition with Northern Lake Systems than expected. This reflects the species composition of the Lake King sites with ELCODE 2 (8 sites) which were present in groups 3a, 4, and 8 - groups with a wide distribution across the study area including Northern Lake Systems, Cowcowing Lakes and Kondinin.

Kondinin and Cowcowing Lakes Systems show very little difference in species composition with an R value of 0.075 and no significant differences were found between the species composition of the Damboring, Gunyiddi-Latham, Lake Moore and Cowcowing Lake Systems occurring in the northern section of the study area.

Differences between the species composition of ELCODEs representing different elevation zones were significant (p 0.1%) with Global R 0.159. All pairwise tests were also significant with the greatest differences in species composition between ELCODEs 4 and 2 (R 0.26) and ELCODEs 2 and 3 (R 0.106). There was little difference between the species composition of ELCODES 4 and 3 (R 0.055).

Some Lake Systems did not contain sites from all ELCODE categories for example all 6 quadrats sampled in the Gunyiddi-Latham system were ELCODE 2. The nearest report of dunes in this area is at Coorow siding with kopi banks reaching 1.0m. The Gunyiddi deposit has kopi banks to 15cm. Appendix 13 lists gypsum deposits from Jones (1994). Forty five deposits are listed in the SW region within the study area and only a total of 21 record gypsum dunes (information on the size of the dunes was not always available). Further survey work is needed to ensure that all areas are well surveyed covering all ELCODEs present in these areas.

Gypsum content showed a significant difference (p 0.7%) but with global R at 0.058 the differences were only slight. Only 2 pairwise tests showed significant results ($p<5\%$), Gypsum content 5 and 2 with an R value of 0.121 and Gypsum content 1 and 5 (R0.098).

Table. 11 Results of the ANOSIM (analysis of similarity) tests

	R Statistic	Significance Level %	Permutations
LAKE SYSTEM			
Global Test	**Global R 0.338**	**0.1%**	**999**
Pairwise tests			
Lake Magenta, Gunyiddi-Latham	0.715	0.1	999
Lake Grace, Gunyiddi-Latham	0.711	0.1	999
Lake Moore, Lake Magenta	0.647	0.1	999
Lake Magenta, Damboring	0.63	0.1	999
Lake Magenta, Cowcowing Lake	0.594	0.1	999
Lake Moore, Lake Grace	0.54	0.2	999
Lake Grace, Damboring	0.483	0.2	999
Lake Magenta, Kondinin	0.479	0.1	999
Lake Grace, Lake Magenta	0.33	0.1	999
Lake King, Gunyiddi-Latham	0.275	0.3	999
Lake Moore, Kondinin	0.256	0.1	999
Kondinin, Gunyiddi-Latham	0.235	0.1	999
Lake King, Lake Magenta	0.226	0.1	999
Lake King, Damboring	0.217	1.9	999
Lake Grace, Cowcowing Lake	0.205	0.6	999
Lake Moore, Lake King	0.178	1.9	999
Lake King, Kondinin	0.131	0.3	999
Lake King, Cowcowing Lake	0.122	1.8	999
Kondinin, Cowcowing Lake	0.075	4.2	999
Damboring, Gunyiddi-Latham	0.273	5.4	462

Lake Moore, Damboring	0.171	10	462
Cowcowing Lake, Gunyiddi-Latham	0.063	19.5	999
Lake Moore, Cowcowing Lake	0.049	22.1	999
Lake Grace, Lake King	0.023	32.6	999
Lake Grace, Kondinin	0.001	43.9	999
Cowcowing Lake, Damboring	-0.019	57.3	999
Lake Moore, Gunyiddi-Latham	-0.031	57.8	462
Kondinin, Damboring	-0.066	88.5	999
AREA			
Global Test	**Global R 0.191**	**0.1%**	**999**
Pairwise tests			
North, South	0.276	0.1	999
North, Esperance	0.217	1.9	999
South, Central	0.208	0.1	999
North, Central	0.114	0.4	999
Esperance, Central	0.029	33	999
South, Esperance	-0.049	69.5	999
ELCODE			
Global Test	**Global R 0.159**	**0.1%**	**999**
Pairwise tests			
4, 2	0.26	0.1	999
2, 3	0.106	0.1	999
4, 3	0.055	0.9	999
GYPSUM CONTENT			
Global Test	**Global R 0.058**	**0.7%**	**999**
Pairwise tests			
5, 2	0.121	0.4	999
1, 5	0.098	0.1	999
1, 2	0.042	9.7	999
5, 3	0.038	20.2	999
4, 2	0.031	23.2	999
4, 3	0.027	25.2	999
5, 4	-0.016	58.3	999
1, 4	-0.029	73.5	999
3, 2	-0.031	77.3	999
1, 3	-0.05	88.7	999

THREATENED AND PRIORITY ECOLOGICAL COMMUNITIES

The Department of Environment and Conservation provided results of a search undertaken on the Threatened Ecological Communities database. The following ecological communities are associated with gypsum.

TEC - "Herblands and Bunch Grasslands on gypsum lunette dunes alongside saline playa lakes" is listed as a TEC (Vulnerable). Represented by sites G226 and SHB28 in the present survey. The level of gypsum at G266 was 5% at 0 and 50cms.

PEC - Gypsum Dunes (Lake Chinocup)" PEC (Priority 2) *Eucalyptus* aff. *incrassata* mallee over low scrub on gypsum dunes. Represented by SHB20, 21 and 22 in the present survey.

FURTHER LOCALITIES OF GYPSUM DEPOSITS NOT PREVIOUSLY SURVEYED

Appendix 13 summarizes information from Jones (1994) with regard to gypsum deposits in the study area. Deposits in red are areas in the SW but not in the study area. Appendix 14 contains information from the Department of Mines and Petroleum web site 2009 listing gypsum projects with site type, developmental stage and latitude and longitude. These areas have been plotted on arcview by Judith Harvey (Dept. of Environment and Conservation) see figures Appendix 15.

RESULTS OF PREVIOUS SURVEYS

Previous Surveys - Mattiske (1995)

Mattiske presents data from different biogeographic regions to show differences in the gypsum flora of these regions. Analysis is carried out on sites surveyed in the Wheatbelt. Vegetation groups were classified using plant species presence/absence data. Cluster distances were calculated using the Jaccard Coefficient for binary data and linkage was by group averaging. The site groupings did not correspond well with the soil classification groupings. Mattiske therefore suggests that soils are not the only influence on the vegetation at the sites and that position overrides the influence of the soils (and gypsum) on vegetation composition. This may relate to latitude and longitudinal differences such as position in the rainfall gradient. Mattiske concludes that the flora and vegetation of salt lake margins, and in particular gypsiferous substrates, is not uniform and that it reflects the influence of the region, the lake chain, the lake, topography and substrate variability.

Previous Surveys - Lyons et al (2004)

Lyons et al (2004) uses both site/quadrat groups and species assemblages to explain patterns in the data. Kruskal-Wallace non-parametric ANOVA showed significant differences ($P<0.0001$) between groups at the 12, 26 and 39 group levels for all environmental attributes. The three dimensional ordination (stress 0.21), showed significant linear correlations with 31 of the 34 environmental attributes measured. Strongest correlations were found for the climate variables, annual temperature range, mean diurnal temperature and annual rainfall. Elevation code (0.3864), substrate pH

(0.3184) and EC (0.2283) showed the strongest correlations of the non-climatic parameters followed by gypsum (0.2206).

Appendix 17 summarises data for quadrat groups containing gypsum. These fall into 4 categories

- Group 1.6 a small heterogenous group with 2 out of 7 quadrats containing high levels of gypsum
- Groups 1.8, 5, 8.1(weeds degraded), 8.2 all with low mean gypsum and few quadrats containing gypsum
- Groups 3, 6, 7 all small groups with species poor quadrats dominated by *Tecticornia* shrubs.
- Group 9.2 with quadrats that mostly contain gypsum, mean gypsum 19.93%. Many sites from coastal areas not included in the present study area.

Appendix 18 summarises data for species assemblages which are associated with salt lakes and occur in the study area. Extra data from the present project has been added to the summary ie “Number of species recorded on gypsum”. Appendix 10 (Gypsum species list for the present project) has been used to obtain these values. Assemblages 2.6 and 3.3 show percentage gypsum as a significant term in the GLM model (Generalized linear models of the relationship between soil attributes, elcode etc and assemblage richness).

Although gypsum is a significant factor influencing the distribution of plant species in terms of site/quadrat groups and species assemblages in the SAP survey further information is needed to clarify the relationship.

DISCUSSION

FLORISTIC SURVEY

446 plant species are recorded in Appendix 10 as occurring on gypsum soils in the study area. The families with the largest representatives of genera and species are listed in Table 4. The families Asteraceae (daisies), Chenopodiaceae (salt bush, samphire etc), Poaceae (grasses), Myrtaceae and Frankeniaceae were the most strongly represented in the flora of the study area as would be expected in salt lake areas.

Most of the 446 plant species are gypsovags i.e. species also recorded widely on other soil types, probable refuges from adjacent plant communities. Table 6 lists commonly occurring species many with wide distributions across the study area. The gypsum vegetation communities are largely made up of these species rather than gypsophiles. Only 10 possible gypsophiles are listed in Table 7 for the study area. This contrasts with the situation in Spain where almost 50% of the plant species occurring on gypsum in the Iberian Peninsula are gypsophiles (Mota et al, 2009).

In the present study area, 7 of the gypsophiles are categorised as rare flora and are geographically restricted. The 3 species that are not rare flora, *Chondropyxis halophila*, *Minuria gardneri* and *Kippistia suaedifolia* have a wide distribution largely to the north and east of the study area. *Kippistia suaedifolia* also occurs in the Eastern States. Symon (2006) proposes that the relative paucity of strict gypsophiles in South Australia reflects the recent onset of aridity in the region. Gypsum dunes in WA have only formed in recent geological times, about 35900 years BP (Jones, 1994) whereas the main gypsum deposits in the Iberian peninsula were formed in the Late Triassic (~240 million years ago) and others during the Tertiary (65-1.8 million years ago) (Mota et al 2009).

Five Declared Rare and 25 priority plants have been recorded on gypsiferous soils (Table 8) and 2 DRF and 15 priority plants have also been recorded in “likely sites” but have not as yet been recorded on gypsiferous soils in salt lake systems (Table 9). Other species including rare flora located adjacent to or between gypsum deposits are also of conservation significance (Mattiske, 1995). There is a need for further rare flora surveys especially in areas difficult to access. Lake King is well surveyed adjacent to the causeway but to the author’s knowledge the first plant collections for the northern section of Lake Magenta were carried out in the 2009 survey.

CONSERVATION SIGNIFICANCE OF PLANT COMMUNITIES GROWING ON GYPSUM

In the present project the gypsum vegetation communities were explained as site/quadrat groups. 12 out of the 28 groups are assessed as having some conservation significance. This assessment is subjective and is based on the presence of rare flora, gypsophiles, high gypsum content of soils and the number of sites in each group. Groups with a combination of species that occur rarely in the data set are represented in the site/quadrat classification by only 1 or 2 sites and may represent rare vegetation communities.

Site/quadrat groups 3b, 4, 7a, and 13 are considered of conservation significance because of the presence of rare flora and gypsophiles.

Group 7b (Lake Mc Dermot 1 site), Group 7c (Kondinin 2 sites), Group 7d (Chinocup 1 site), Group 7e (Chinocup 3 sites DRF), Group 11 (includes TEC east Lake Magenta 3 sites), Group 12 (Lake King 1 site), Groups 14a (L King 1 site) and 14b (Lake Magenta 1 site rare flora) are of conservation significance as they may represent rare vegetation communities. These groups all occur on dunes (ELCODEs 3 and 4).

Group 7e (Chinocup with 3 sites) was included as the 3 sites were close together and are represented by SHB20, 21 and 22 in the Chinocup PEC. Group 11 includes 2 sites from the TEC "Herblands and Bunch Grasslands on gypsum lunette dunes alongside saline playa lakes" east of Lake Magenta. It should be noted that the Cowcowing site in Group 11 does not cluster with these sites when the analysis is run with annuals.

There is a high probability that there are other areas of conservation significance that have not been included in the present survey, for example, gypsum dunes within the Lake Campion area (Rick, 2010) were not included in the present analysis as quadrat data was not available.

Plants must also tolerate salt and water logging to survive at ELCODE 2. Some of the samphire areas that occur on gypsum flats and banks are important areas for rare flora. Other floristic groups situated on ELCODE 2 show similarities in species composition across the landscape and contain species which are also widely found on non gypsum soils. Further analysis is needed which includes sites with non gypsum soils to see if the gypsum sites are significantly different in their species composition. The flora on the dunes is more diverse and species rich. Plants do not necessarily need to tolerate salt or water logging. Comparison with data from non gypsum dunes would confirm the rarity of the floristic groups listed above that occur on gypsum.

ENVIRONMENTAL FACTORS

Only sites with a gypsum content of 1-100% were involved in the present survey. In the ANOSIM analysis the differences between the species composition of groups based on environmental factors was best explained by the factors Lake System (p 0.1%, Global R 0.338) and Area (p 0.1, Global R 0.191). These factors relate to the geological distribution of the floristic groups which reflects changes in rainfall and temperature across the project area. ELCODE (p 0.1%, Global R 0.159) was also significant in explaining the patterns in the floristic composition of the data. Similar results for floristic groups were found for all soils in the Lyons et al (2004) survey (SAP sites) and gypsum soils in the Mattiske (1995) survey.

Although Gypsum Content showed significant differences (p 0.7%) between the species composition of gypsum groups the global R at 0.058 was low indicating that the differences were only slight.

SURVEY LIMITATIONS

1. Only 144 sites in a large area with many salt lakes.
2. Weeds were not included in the analysis. The presence of weeds would indicate degraded areas eg in Group 10 the Kellerberrin sites with ELCODEs 2 and 4 are degraded and include 12 weed species at site SPS022A and 8 weed species at site SPS022B with *Avena barbata* (wild oats) prominent.
3. Survey intensity. SAP sites were surveyed at least twice in the spring. Some of the Mattiske sites were surveyed in December and January and all sites other than the SAP sites and TEC/PEC sites were only sampled once. Eliminating annuals and geophytes from the analysis helps to make the different data sets more comparable however there are still concerns as many annual Asteraceae are characteristic of salt lake floras.

4. Taxonomy. There were difficulties with some of the taxonomy eg *Frankenia* despite recent revisions.
5. Some areas and factor groups were poorly sampled.

RECOMMENDATIONS FOR FURTHER STUDY

1. Expand the analysis to include SAP and Mattiske (1995) sites that occur on non gypsiferous soils to help clarify the rarity of some of the gypsum vegetation communities.

2. Carry out further field work to include
   - Areas not previously covered by a spring survey
   - Remnant vegetation growing on gypsum soils in ELCODEs (zones of inundation) not previously surveyed on that particular salt lake.
   - Remnant vegetation situated on soils with a high gypsum content that may be under threat from mining and that have not been previously surveyed. Aerial photographs and the boundaries of mining lease tenements (Tengraph) of the gypsum deposits and mines listed in Appendices 13 and 14 should be examined for possible sites.
   - Further rare flora surveys especially in areas difficult to access eg northern sections of Lake Magenta

3. Further examine suggested rare vegetation communities growing on gypsum as possible TECs. This includes vegetation communities on dunes in the Lake King, Lake Grace (Chinocup), Lake Magenta, Kondinin and Lake Campion Lake Systems.

4. Expand the species list of plants growing on gypsum by adding species from other consultancy reports. The taxonomy of these species and soil references will need checking.

5. Expand the literature review of research on gypsophilous plant species in Australia and overseas.

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