Investigation and reporting of past and present ecological characteristics of seven saline lakes in the Corangamite Catchment Management Area

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Produced by Knowledge Media Division, Deakin University

Published by Deakin University, Geelong, Victoria 3217, Australia

First published 2008

Executive summary

The Corangamite Basin in Western Victoria contains one of the most extensive areas of inland salt lakes of varying size and salinity in the world. Saline lakes are particularly threatened by climate change and many of the lakes in the region have been listed as ecologically valuable areas, and are protected by Ramsar, JAMBA and CAMBA.

This study provides a 'snap shot' of the ecological character of seven of the lakes that are found in the region; Lake Corangamite, Lake Colac, Lake Beeac, Lake Martin, Lake Cundare, Lake Gnarpurt and Lough Calvert. The results from this field survey are compared with those from previous studies in order to provide a basis for assessing changes to the ecological integrity of the lakes which may have resulted from the extended low rainfall period experienced by the region during the last several years.

The major components of this study include:

- Literature review of existing published ecological information including sediments, water quality, flora and fauna
- Survey of current ecological conditions of seven target lakes
- Discussion of potential climate change and land-use effects.

Granulometric characteristics varied widely between lakes; inorganic nitrogen levels were low at all lakes except Lake Martin, where a large amount of decomposing organic material was present on the lake bed at the time of the survey. Sediment phosphorus levels were also low in all lakes in comparison with previous studies of lakes in the region, probably due to a reduction in the sediments' capacity for nutrient absorption by the drying lake bed. The release of hydrogen sulphide gas to the atmosphere and the production of acid sulphate soils are problems that may be associated with the drying lake beds.

Lake Martin recorded the highest concentrations of copper and lead, but heavy metal concentrations in all lakes were well below Australian Interim Sediment Quality Guideline (ISQG) trigger levels.

Analysis of water quality parameters was limited due to many of the lakes being dry during the survey period. Recorded salinity levels of remaining water were all well above previously recorded levels for all lakes, due to continuing evaporation and the endorheic nature of the lake systems. The high salinity levels recorded resulted in a depleted floral and faunal community at each of the lakes.

No macrophytes were present within any of the lakes during the survey period and only one phytoplankton species was recorded during a bloom in Lake Corangamite. The dominant terrestrial flora recorded were the salt tolerant species *Sarcocornia quinqueflora* and *Suaeda australis.* Many introduced species were also recorded during the lake flora survey.

Macrofaunal abundance and diversity was diminished at all lakes in comparison with previously published estimates. Incidental recordings of macro-invertebrates and avian fauna also indicated low abundances and diversity. No aquatic macro-invertebrates were recorded from Lake Corangamite, and terrestrial invertebrates were limited at all lakes. Bird diversity and abundance were lower during the survey period in comparison with previous data.

In comparison with other aquatic systems there was both low diversity and abundance of microscopic animals (meiofauna) recorded from all lakes. The most abundant animal taxon amongst the meiofauna was nematodes. Abundance of nematodes from Lake Colac was comparable in this current study with previous work, although the diversity of the group was greatly reduced.

The increasing salinity levels have resulted in the naturally saline lakes of the area becoming hyper saline, and this is reflected in the depleted community composition. The 'fresher' waters of Lake Colac are undergoing community composition changes as the salinity level approaches that of the saline lakes in the Corangamite Basin. The depleted ecological community in the lakes generally has meant that many have lost their ecological values for which they were identified, and which were protected through Ramsar, JAMBA and/or CAMBA treaties.

In view of the precarious state of these lake ecosystems under the current and predicted climate trend for south-eastern Australia it is suggested that further studies include seasonal surveys to more fully evaluate the current annual cycles of the lacustrine biota. The implications of climate change are considered here in a conceptual model in which the responses of dynamic processes may be used as likely indicators for future management of saline lakes.

Acknowledgments

The project was funded by the Salinity Action Plan program within the Corangamite Catchment Management Authority, and we are grateful to CCMA staff, particularly Lucas Oram, Felicia Choo and Donna Smithyman, for their suggestions and assistance during the project.

The authors thank Gordon Gully and David Wood for their help with field work and for providing data from their laboratory sediment studies. We are grateful to the Mullins family for allowing access onto Lough Calvert.

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1 Introduction

1.1 Study area and lakes of interest

The study area has been well described in previous publications such as Bayly and Williams (1975), Williams (1981, 1984) and Radke et al. (2002). The description presented here draws heavily on those works. The lakes of interest lie in the area variously know as Western Victoria, the Volcanic Plains, or the Western Plains. This is an area of Newer Volcanic basalt of Pleistocene to Recent age. The 'Newer Basalts' are sub-divided into plains basalts and younger scoria cones of alkalic or ultra-alkalic chemistry rising up to 150 m above the plains. Vulcanicity began in the Upper Pliocene (about five million years BP) and ceased between 5000 and 7000 years BP. Drainages are poorly integrated resulting in large numbers of lakes in the region most of which are of volcanic origin although some are deflation playas in Pleistocene lacustrine and alluvial deposits that inter-bed with volcanic flows. The area is unusual in that, unlike the rest of the southern half of Victoria, it is almost completely endorheically drained and all saline lakes in the area are terminal water bodies of inland drainage basins.

Large areas of sedimentary material occur at the surface, most notably lacustrine alluvium and Aeolian sands of late Pleistocene and Recent age. Extensive Pliocene marine sediments occur in the south of the region. Soils on the younger basalts are fertile but shallow and stony, being reddish brown to black in colour and loam to clay in texture. Coarse structured black clays from basalt alluvium occur in the area and dark saline soils occur at the edges of some lakes.

The climate of the region is temperate with warm dry summers and cool wet winters. Annual rainfall prior to the period 1997 to 2006 was between 500 and 800 mm. Annual evaporation rate exceeds 1000 mm across much of the region; evaporation exceeds precipitation from October to April and maximal evaporation occurs in January (> 125 mm). Since 1840 levels in the largest crater lakes in the region (e.g. Lake Bullenmerri) have fallen 25–30 m; these lakes previously had high water levels for about 2000 years and the change since 1980 is indicative of a natural climate change about that time (Roger Jones, CSIRO; Radio National interview 6 July 2002). Recorded rainfall in the two months proceeding the survey period was higher than recorded average between 1983 and 1998 (Bureau of Meteorology 2008). However, during the survey period between January and March 2008, rainfall was significantly lower than the recorded average (Figure 1.1). As most salt lakes are terminal basins, they are particularly sensitive to changes in hydrological regimes which are influenced by minimal climate changes (Williams 1981; Timms 2005) and the climate of regions with closed basins often fluctuates more between years than in open systems (Williams 1995). The three most important climatic factors affecting saline lakes are temperature, evaporation and precipitation (Williams 2002).

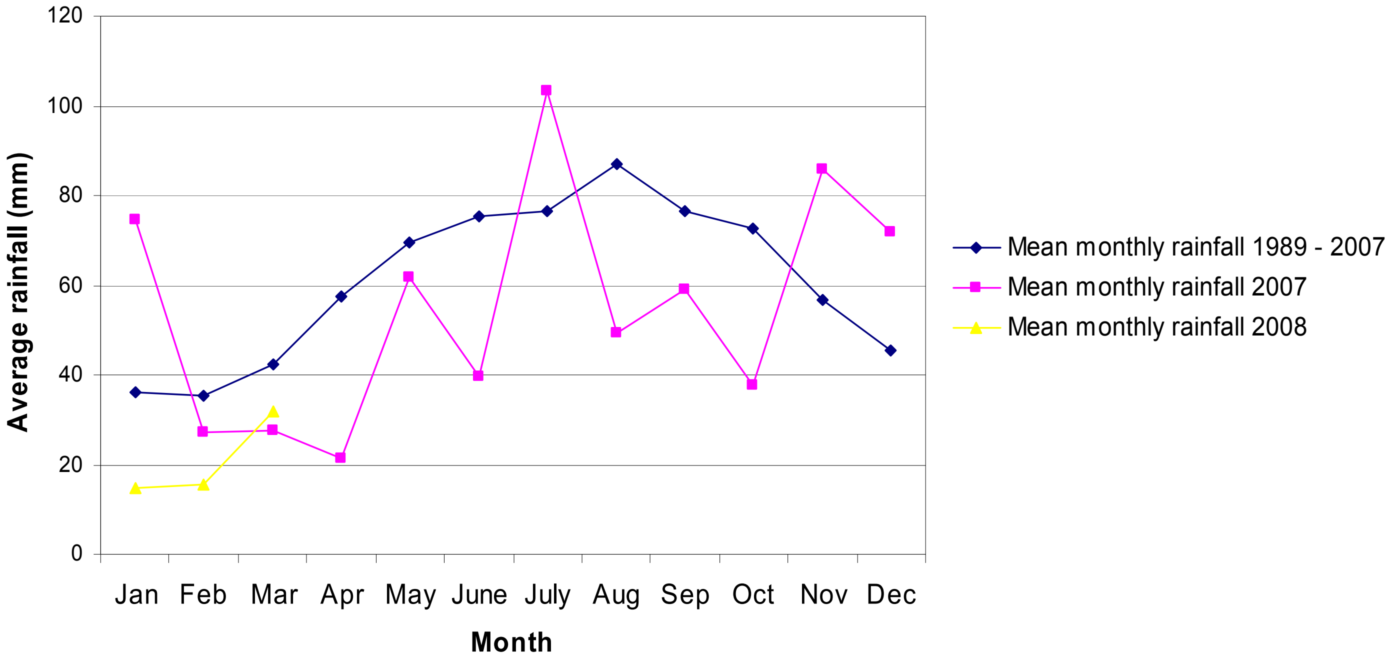


Figure 1.1 Recorded average monthly rainfall for Colac region during the survey period compared with the average monthly rainfall for the region (1883–1998). (Values obtained from the Bureau of Meteorology 2008).

Most lakes in the region occur at altitudes less than 150 m above sea level, with some in the north of the area occur at altitudes between 150 and 300 m above sea level. Groundwater-surface water interactions are an important determinant of lake salinity, with the permeability of strata governing the retention/discharge of solute (Cora et al. 1998 cited in Radke et al. 2001). As a result of this, many of the lakes in this region are naturally saline; in fact, Western Victoria is one of the most extensive areas of inland salt lakes in the world and is quite well known to aquatic ecologists in the northern hemisphere. Historically and seasonally the salinity in these lakes reaches high levels (much saltier than seawater, which has a salinity of 35 g/l). The flora and fauna of these lakes are well adapted to high salinity. Although these lakes may be productive they do represent simplified ecosystems with reduced diversity of plants and animals. They are characterised by shallow turbid water, fine silty substrates and are dominated by microscopic plants (phytoplankton) and microscopic animals (zooplankton). Frequently, they have little or no macrophytic vegetation and are dominated by blue-green algae (Hammer 1981a). The lakes of interest in the present study are:

- Lake Corangamite
- Lake Gnarpurt
- Lake Martin – Cundare Pool

- Lake Cundare
- Lake Colac
- Lake Beeac
- Lough Calvert system.

European settlement began about 1840 at which time the plains were essentially treeless; currently most of the natural grassland that previously existed in the region has been replaced by exotic pasture grasses, clovers, crop plants and weeds. All of the lakes of interest are almost entirely surrounded by grazing land. There is very little remnant vegetation within the region and small areas of recent revegetation can be found in isolated locations along the shores of Lake Corangamite. Land use is almost totally agriculture (sheep, beef and dairy cattle and crops). The dominant land uses in the vicinity of the lakes of interest are summarised in Table 1.1.

Table 1.1 Dominant land uses surrounding the target lakes.

Lake	Dominant land use
Corangamite	South, east shores = dairy cattle, row crops North shore = broad acre crops, sheep
Gnarpurt	Sheep, beef cattle
Martin – Cundare Pool	Broad acre crops, sheep
Cundare	Sheep
Colac	Dairy cattle, urban
Beeac	Sheep
Calvert	Sheep

1.2 Objectives

Predictions made by the 2000 Australian Dryland Salinity Assessment were that by 2050, 40% of wetlands in the Corangamite region would be threatened by salinity (Dahlhaus et al. 2005). This report presents a review of existing ecological knowledge of the seven lakes plus a current survey of seven saline lakes within the Western Victorian region over a three month period to provide information on their current ecological status. Many of the lakes have been noted for their ecological values and several are Ramsar listed sites; however, the area has been subjected to increasing periods of drought and salinisation problems.

Objectives of the review were:

- To review the current state of knowledge on the ecology of the lakes of interest
- To examine trends in and biotic parameters of the lakes of interest
- To make comment on the possible future state of the lakes of interest in a climate change context.

An aim of the survey was to provide a basis for comparison of past and present conditions in the target lakes and to provide an outlook to their future status and management. Although the study addresses multiple aspects of the ecology of these lakes, it was limited by the brief timeframe for investigations to be carried out, and by environmental conditions (i.e. no rainfall) occurring in the region during the survey period. However, the information generated from this survey provides a basis for other studies to expand on or compare with over time.

1.3 Project scope and location

The Corangamite Draft Wetlands Strategy (2004) states that salinisation poses the greatest threat to lakes and wetlands that are naturally saline. Salinisation problems in these lakes mean that salinity values reach levels where the biological diversity of the lakes is jeopardised. One of the two major salinity issues highlighted in the Corangamite Salinity Action Plan is ‘the threat to irreplaceable environmental assets, especially Lake Corangamite’ (Dahlhaus 2003). The Salinity Action Plan aims to meet broader outcomes developed in the Victorian Salinity Management Framework (2002) which aims for ‘a reduction in environmental and economic impacts of salinity’ and impacts of rising groundwater on riverine and wetland environments to be investigated and reduced (Dahlhaus 2003).

The seven lakes studied during the survey have varying levels of naturally occurring (primary) salinity. The lakes are located in the Colac Otway Shire and fall within the target area for salinity management in the Corangamite Salinity Action Plan (Dahlhaus 2003). Lake Corangamite, Lake Gnarpurt, Lake Martin and Lake Cundare are the dominant highly ranked assets at risk in this area, and have been listed as Australian wetlands of national and international importance with threatened water regimes (Davis et al. 2001). Within the Lake Corangamite salinity target area, there are 30 threatened species, seven migratory species, and seven marine protected species (Dahlhaus 2003). Figure 1.2 shows location of the lakes and selected study sites within each lake.

1.4 Contextual framework

To gain an overview of the lakes and a current understanding of their ecological status, selected physio-chemical and biological features were investigated. The sections of this report address:

- Review of historical knowledge on the ecology of the lakes ('looking back')
- Ecological survey to determine current ecological status of each of the lakes incorporating:
    - Sediment analysis for determination of heavy metals and nutrient loads
    - Analysis of water quality parameters where possible
    - Current synthesis of flora and fauna
- Future management issues and climate change effects ('looking forward').

While past data for the lakes is limited, comparison of data compiled for this report with previous studies including similar ecosystems nationally and internationally, is included to assist in the determination of the current ecological status of the lakes.

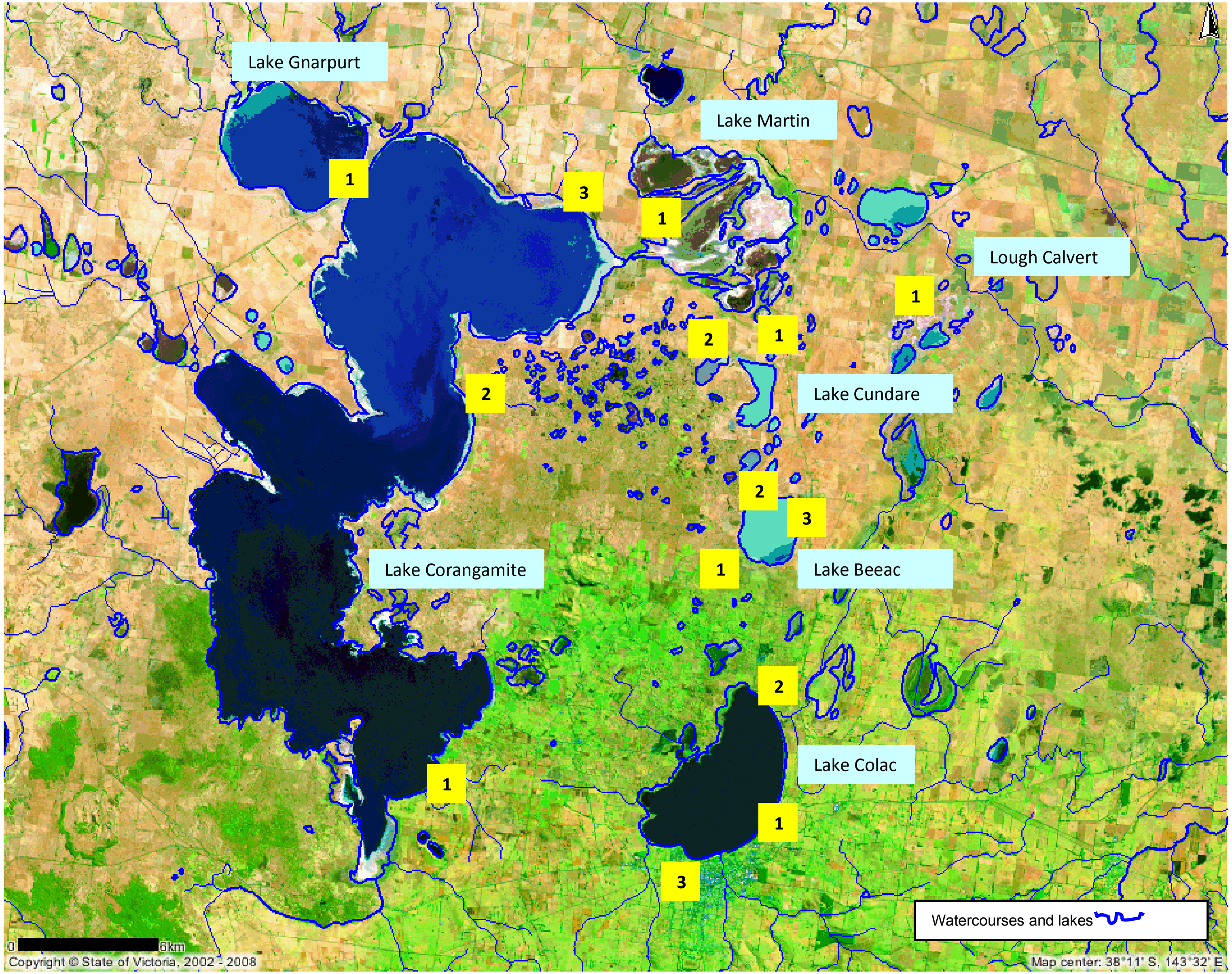


Figure 1.2 Location of lakes and site location within each lake; Map from GeoVic, Department of Primary Industries, Victoria (2002–2008).

2 Saline lakes review

2.1 Method

2.1.1 Approach adopted in review

A review of the published and grey literature relating to the lakes of interest was undertaken. A comparative approach was taken and information was synthesized within key areas of interest (ecosystem components); that is, lakes were compared within key areas rather than compiling long descriptions on a lake-by-lake basis. Where possible, trend analysis ('looking back') was undertaken to describe changes in lake systems to the present time. On the basis of this approach and taking into account potential impacts of climate change in the region, extrapolation of lake condition into the future was attempted ('looking forward') (section 4).

2.1.2 Ecosystem components of interest

The following key areas of interest were the focus of this review:

- Riparian systems
  - – Soils
  - – Vegetation
  - – Invertebrates/vertebrates
- Intra-lake systems
  - – Abiotic ecosystem components
    - – Physical aspects
    - – Water quality: salinity, nutrients, suspended solids, turbidity, oxygen levels
    - – Sediments (will be important due to mobilisation by wind)
- Biotic ecosystem components
  - – Flora
    - – Bacteria
    - – Algae
    - – Macrophytes
  - – Fauna
    - – Micro-invertebrates including zooplankton
    - – Macro-invertebrates including benthos and weed bed forms

  - Fish
  - Waterfowl.

2.2 Results = synthesis of existing information—'looking back'

2.2.1 The significance of the lakes of interest

The significance of the lakes of interest has been comprehensively described by Williams (1992, 1995), Parks Victoria (2001), Timms (2004, 2005) and is summarised in Appendix 1. The lakes support wildlife conservation values, recreational utility values, and cultural values. Five of the lakes are classified as Ramsar and/or CAMBA/JAMBA sites.

2.2.2 Riparian ecosystem components

Shoreline vegetation

At least 90% of the shorelines of the lakes of interest are grazed to the water's edge causing major changes to the riparian vegetation, including a significant reduction in native grassland, woodland and salt marsh communities (Parks Victoria 2001).

2.2.3 Intra-lake abiotic ecosystem components

Data is summarised in Appendix 1.

2.2.4 Physical aspects: origin of lake basins, lake morphology, hydrology

Origin of lake basins

The origin of the lakes in the study region have been described by Currey (1964), Hammer (1986), and Radke et al. (2002), and is summarised in Appendix 1.

The lakes of interest are located in the western plains of south-western Victoria. This is a Cainozoic volcanic province consisting of newer basalts sub-divided into plains basalts of tholeiitic composition and younger scoria cones of alkalic chemistry (Radke et al. 2002). In this area drainage patterns are poorly integrated resulting in a large number of lakes.

The lakes of interest consist of two major groups:

- Newer volcanic lakes: Corangamite, Gnarpurt, Martin – Cundare Pool

  – Formed by collapsed lava flows (Corangamite) or depressions in the plains (Gnarpurt, Martin – Cundare Pool) (Radke et al. 2002)
- Playa lakes: Beeac, Cundare, Colac

  – Formed by deflation of the Pleistocene lacustrine and alluvial deposits that inter-bed with basalt flows. These form a discontinuous cover of variable thickness, marking the former boundary of the mega-Lake Corangamite (Currey 1964). The origin of these lakes is evidenced by the lunettes (curved sand dunes) which have formed on the lee shores (Hammer 1986).

The permeability of groundwater strata in the region plays an important role in control of retention or discharge of solute and therefore in the salinity of lakes (Coram et al. 1998) cited in Radke et al. (2002). The deflation-formed playas to the east of Lake Corangamite (Beeac, Cundare) are highly saline (> 80 g/l) while through flow lakes in newer volcanics (Gnarpurt and Martin) have lower salinities (< 20 g/l) (De Deckker and Williams 1988; Williams 1992; Radke et al. 2002).

Lake morphology

This is summarised in Appendix 1. The lakes vary in size, depth and catchment to lake area ratio and may be classified into four groups (Table 2.1).

Table 2.1 Lake morphology.

Lake	**Morphology**
Cundare, Beeac	Small (< 1000 ha), shallow (< 2 m), small catchment to lake area (< 10:1)
Gnarpurt, Martin – Cundare Pool	Medium size (> 1000, < 5000 ha), moderate depth(> 2, < 4 m), large catchment to lake area (> 10:1)
Colac, Calvert	Medium size (> 1000, < 5000 ha), moderate depth(> 2, < 4 m), small catchment to lake area (< 10:1)
Corangamite	Large (> 20000 ha), deep (> 4 m), small catchment to lake area (< 10:1)

Lakes Gnarpurt and Lake Martin – Cundare Pool are subject to relatively larger inputs from their catchments.

Hydrology

This is summarised in Appendix 1. Williams (1998) classifies saline lakes into three hydrological groups (Table 2.2).

Table 2.2 Lake hydrology classifications.

Lake type	Hydrology
Permanent salt lakes	Water is more or less permanently present (usually deep and confined to semi-arid regions)
Intermittent salt lakes	Water is temporarily present on a seasonal basis (occur in semi-arid regions with a predictable wet season)
Episodic salt lakes	Water is temporarily present only after unpredictable rain has fallen (occur in arid regions with highly unpredictable rain)

The lakes of the study region represent surficial expressions of the shallow, hydraulically conductive basalt aquifer and water levels in the lakes of interest fluctuate in close association with the local water table (Corm et al. 1998, cited in Radke et al. 2002). The individual hydrological regime of a shallow lake or wetland will be determined by geographical position, local hydrology and topography, climate, elevation, and height of watertable (Cameron 1991).

Surface water inputs and groundwater flows to the lakes of interest are in Table 2.3 (from Radke et al. 2002; after Coram et al. 1998, cited in Radke et al. 2002).

Table 2.3 Surface water inputs and groundwater flows to the lakes.

Lake	Surface water inputs	Groundwater flows
Gnarpurt, Martin – Cundare Pool	Streams to the north	From north and north-west
Martin – Cundare Pool	Streams to the north	From north and north-east
Corangamite	Streams to the north and south	From north, west, south (springs on the south-western shoreline), smaller from east
Colac	Streams to the south	From north-west, south-west and south-east
Cundare, Beeac	Surficial flows	From west
Lough Calvert	Surficial flows from north plus overflow from Lake Colac	-

The hydrology of Lake Corangamite has been impacted by diversion of the inflows from the Woady Yaloak River. Over the period 1951 to 1956 high rainfall raised the level of the lake resulting in the inundation of thousands of hectares of freehold land (Parks Victoria 2001). The Woady Yaloak diversion scheme was constructed in 1959 to relieve flooding on the lake's margins by diverting the major inflow to the lake, the Woady Yaloak River, into the Barwon River (Parks Victoria 2001). In the recent past (the last 150 years) the lake has been shallower and smaller at times (e.g. 1933) and deeper and larger at other times (e.g. 1875, 1956) (Williams 1995). Freshwater springs discharge around the lake, particularly along the south-western shore and are important refugia for fauna (Timms 2004).

Drainage works on lake Gnarpurt, via a drain connecting the lake with Lake Corangamite, have artificially lowered its outlet reducing water levels below natural (Parks Victoria 2001). Surface water runoff is the main source of water for Lake Beeac and the clearing of surrounding land for agriculture has artificially increased surface runoff resulting in higher water levels than would have occurred naturally (Parks Victoria 2001).

2.2.5 Water quality: salinity, nutrients, suspended solids, turbidity, oxygen levels

Water quality is summarised in Appendix 1.

Salinity

Cameron (1991) recognised six categories of Western Victorian wetlands with respect to salinity. Cameron's classification scheme is based on that of Brock and Lane (1983) and includes recently salinised wetlands (Table 2.4).

Table 2.4 Salinity categories of Western Victorian wetlands.

Category	**Salinity range (g/l)**
1. Fresh	< 3
2. Slightly saline	3–10
3. Saline	3–35
4. Slightly to hyper saline	3 – < 35
5. Saline to hyper saline	10–35
6. Hyper saline	> 35

The salinity ranges of the lakes of interest, based on the data presented in Appendix 1, are summarised in Figure 2.1.

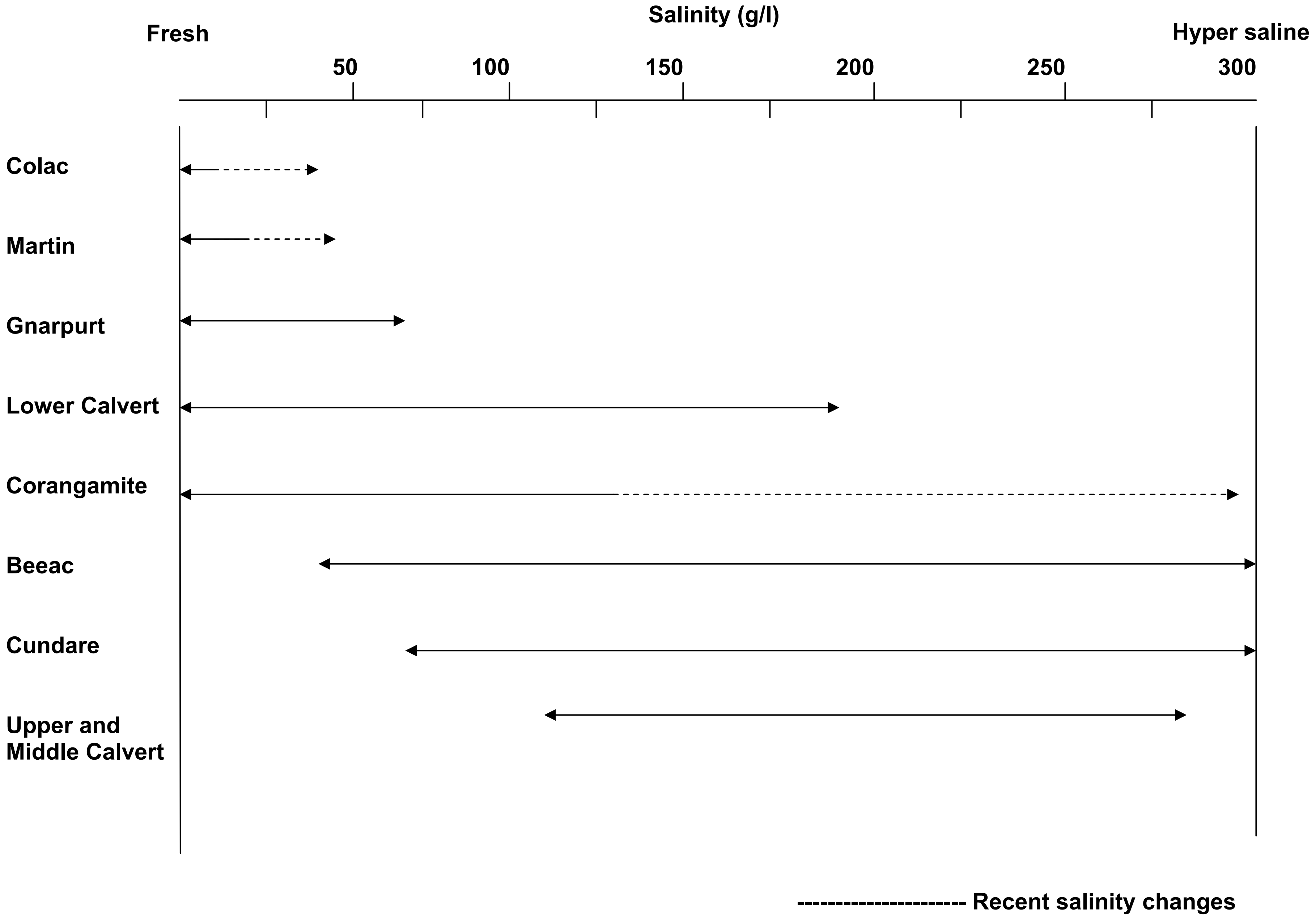


Figure 2.1 Average salinity ranges of the lakes of interest (drawn from Appendix 1).

Prior to 1980 the lakes of the western districts could be classified into six groups (Williams 1992). At that time the lakes of interest in this study were classified as in Table 2.5.

Table 2.5 Salinity classifications of the lakes of interest prior to 1980.

Lake	Type
Group i) Lake Colac	Fresh, permanent
Group ii) Lake Martin – Cundare Pool	Fresh, +/- permanent
Group iii) Lake Corangamite	Shallow, permanent, salinity < 50g/l
Group iv)	Permanent, salinity 50–100g/l
Group v)	Permanent, salinity < 10g/l
Group vi) Lake Beeac and Lake Cundare	+/- ephemeral, salinity > 100 g/l

In 1992 Lake Gnarpurt could be classified into Group iii) but Lough Calvert was not considered. Williams concluded in 1992 that the biological status of most lakes had not changed since 1980 but that there was clear evidence that the status of Cundare Pool and Lake Corangamite had changed. Williams (1992) reclassified Cundare Pool into Group iii) and Lake Corangamite into Group iv). Based upon the classification scheme presented in Williams (1992) the changing status of the lakes of interest can be represented as in Table 2.6.

Table 2.6 Changing salinity status of the lakes of interest from 1980 to 2008.

Lake	1980	1992	2008
Lake Colac	i	i	ii
Lake Martin – Cundare Pool	ii	iii	iii–iv
Lake Corangamite	iii	iv	iv–vi
Lake Gnarpurt		iii	iii–iv
Lake Beeac and Lake Cundare	vi	vi	vi

This indicates a shift upwards in the salinity range of Lake Colac, Lake Martin – Cundare Pool, Lake Corangamite and Lake Gnarpurt.

The salinity of tributaries to some of the lakes is as in Table 2.7 (after Hydrotechnology 1995). Tributary salinities are high, adding to salinity levels in the lakes.

Table 2.7 Salinity of tributaries to some of the lakes.

Lake	Tributary	Mean salinity (g/l) (1993–1994)
Martin – Cundare Pool	Woady Yaloak River	2.2–3.5
Colac	Dean's Creek	1.4–1.6
Gnarpurt	Mundy Gulley	3.2–6.6

Separating historically saline water bodies from recently salinised habitats may be difficult in some cases. Lentic environments in the region sit along a salinity continuum from fresh to hyper saline. The position of a given water body on this continuum will vary with depth, permanence (determined by rainfall, evaporation and groundwater input), and salinity of the surrounding soil (Cameron 1991). The salinity of a given lake or wetland may shift along the continuum seasonally and over longer time intervals. The upper threshold for normally fresh wetlands which have become salinised will overlap with the lower threshold of saline lakes and wetlands. The range of salinity within a given lake or wetland is important as well as the maximum encountered (Brock and Lane 1983).

Of concern are sites which, in the recent past, have shifted into higher salinity categories, particularly at the lower end of the range. Changes from 'fresh' to 'slightly saline' and from 'slightly saline' to 'saline' are likely to have the most profound effects (see below). Cameron (1991) recommended that wetlands below 13 g/l salinity should be given particular attention.

The salinity of terminal lakes and wetlands is strongly positively correlated with adjacent soil salinity (Cameron 1991). Wetlands, even those which may be closely adjacent, differ in permanence due to elevation, depth and catchment size (Cameron 1991). Wetlands at higher elevations tend to dry out in summer as they are beyond the influence of summer watertable; those at lower elevations may be maintained during summer by groundwater discharge and salinity tends to increase as elevation decreases. Wetlands show seasonal variation in salinity, with highest values in late summer to autumn; this will depend upon permanence. If the wetland is permanent due to saline groundwater intrusion then salinity may be high in late summer; if the wetland is impermanent and dries out in late summer then salinity may increase but is likely to be lower in the latter than in the former case. Cameron (1991) concludes that groundwater seepage to wetlands in the region is currently more pronounced than in the past and presents evidence for a dramatic increase in the salinity of some wetlands over the past 25 years. He cites examples of two lakes shifting from salinities of 6–16 g/l, and 16–30 g/l over the last 25 years.

There is characteristically little variation in surface salinities in saline lakes (De Deckker and Williams 1988) due to the well mixed nature of these water bodies. Lake Corangamite shows a slight tendency for salinity to increase in the northern shallower parts of the lake; in 1988 this variation was from 55 g/l in the south to 66 g/l in the north (Rural Water Commission, as cited in Williams 1992).

Vertical salinity differences have not been recorded even in the deepest lakes in the region (Bullen Merri, Gnotuk) (Timms 1976). In large permanent lakes with moderate salinity seasonal fluctuations may occur but are not pronounced (De Deckker and Williams 1988; Williams 1992) and the pattern may vary from year to year as has been documented, for example, in Lake Corangamite (Bayly and Williams 1966). In shallow, temporary and highly saline lakes seasonal fluctuations are marked and show a distinct seasonal pattern (Williams and Buckney 1976; De Deckker and Williams 1988), as had been noted, for example, in Lake Beeac (Williams 1992).

Lakes in the region exhibit secular fluctuations related to longer term variations in climate which are superimposed on seasonal fluctuations (De Deckker and Williams 1988). Whilst these patterns can be related to rainfall fluctuations (De Deckker and Williams 1988), the impact of changes in land and groundwater use on lake levels and salinity for the group of lakes of interest here remain to be determined. However, impacts of intervention in the hydrological cycle on salinity in some of the lakes have been documented. The secular trends in water level and salinity in Lake Corangamite are well documented in De Deckker and Williams (1988) and Williams (1992, 1995). Salinity was low (20–30 g/l) during the 1960s, increased to 30–40 g/l in the 1970s, and progressively increased from 40–50 g/l in the mid 1980s to current levels of more than 100 g/l. The trend is most apparent since the 1980s. This trend correlates strongly with decreases in water level. Prior to European settlement of the region, changes in salinity would have been driven by climatic variation. After settlement, but prior to the 1960s, this pattern would have been influenced by changes in land use of the catchment (Williams 1992). Post the 1960s, changes in salinity reflect the diversion of inflows from the Woady Yaloak River superimposed on land use and climatic changes (Williams 1992 and 1995) discussed above. This has not only increased salinity in the lake but also lowered the water level and exposed large areas of former lake bed (Williams 1992 and 1995).

Ionic composition

Ionic dominance in the lakes of interest is presented in Appendix 1. The ionic composition of the lakes of interest is the result of evaporation of bulk coastal precipitation, carbonic acid weathering of basalt, or the formation of salt crusts due to restricted outflow (Radke et al. 2002). Strong ionic homogeneity in ionic composition is evidenced between the lakes, with Na^+ and Cl^- being the dominant ions (De Deckker and Williams 1988). In moderately saline lakes (< 20g/l) Ca^{++} and $HCO_3^-+CO_3^=$ are generally more important than K^+ and $SO_4^=$ while the reverse is true at higher salinities (De Deckker and Williams 1988). The lakes of interest tend to have high alkalinity due to weathering of reactive basalts (De Deckker and Williams 1988; Radke et al. 2002).

Nutrients

Nutrient levels in waters from the lakes of interest are presented in Appendix 1. No consistent seasonal patterns are apparent in thee lakes of interest. Phosphorus concentrations are generally high and the lakes are eutrophic compared to other standing waters; nitrogen concentrations are at the lower end of the range of most surface waters (De Deckker and Williams 1988). While it is difficult to compare critical nutrient thresholds for lake trophic status from freshwater lakes to terminal saline lakes where background nutrient levels would be expected to be higher even in undisturbed lakes, it is useful nevertheless to consider nutrient concentrations in the lakes of interest relative to published threshold values. Phosphorus concentrations in excess of 100 ug/l in freshwater lakes are indicative of hypereutrophic conditions (Nurnberg 2001). All lakes of interest are either close to or well above this threshold, even taking seasonal and longer term temporal changes into account. Total Phosphorus concentrations are highest in Lakes Cundare, Colac and Beeac.

Many salt lakes in the region, including lakes Cundare and Beeac, are nitrogen limited; Lakes Corangamite and Gnarpurt are exceptions to this and show phosphorus limitation (De Deckker and Williams 1988). This explains why cyanobacteria are successful in salt lakes as they are able to fix atmospheric nitrogen and so are favoured relative to other algal types (Smith 2001). Lake Colac currently appears to be nitrogen limited (see below).

Based upon data in Hunter (1993) on mean flow rates and mean Total Phosphorus concentration in tributaries of the lakes of interest during early the 1990s and prior to the onset of the regional drought from 1996to 2006, annual areal nutrient loading was of the order of 138 gm/ha/yr for Lake Corangamite and 485 gm/ha/yr for Lake Martin – Cundare Pool. Given the long retention time of water in Lake Corangamite due to the lack of flushing, this is a high rate of phosphorus loading.

Nutrient levels in Lake Colac are high (EPA 1980; Khalife et al. 2005). The sediments of Lake Colac contain the highest levels of phosphorus and have the greatest potential for the release of dissolved reactive phosphorus to the water column of three eutrophic lakes studied in the region (Slater and Boag 1978). Phosphorus loading rates for lake Colac were historically high (Slater and Boag 1978). In-lake nitrogen levels (Total Nitrogen and oxidised Nitrogen) appear to have declined over the period 1975 to 1984–2000 but phosphorus levels (Total Phosphorus and Orthophosphate Phosphorus) appear to have increased over the same time period (Khalife et al. 2005) despite management measures (EPA 1980) possibly as a result of release from the sediments. Nutrient limitation appears to have shifted from P limitation in 1975 to N limitation more recently probably as a result of P loading to the lake as described by Khalife et al. (2005). Fifty per cent of the nutrient loading to the lake is delivered by the Barwon Water sewage treatment plant (7300 ug/l Total Phosphorus, 36600 ug/l Total Nitrogen) (Khalife et al. 2005). In addition, stock access to the lakes has contributed to increased nutrient levels (Parks Victoria 2001).

pH

pH in the lakes of interest is presented in Appendix 1. pH tends to be high, generally above eight (alkaline—see above), with no seasonal trend or correlation with salinity; this reflects the parent geology of the region and indicates well-buffered waters (De Deckker and Williams 1988). Short term variation in pH is likely to be driven by increased photosynthesis as a result of algae blooms.

Suspended solids

Suspended solids levels are presented in Appendix 1. Suspended solids in the lakes of interest show a wide range reflecting the influence of wind mixing on resuspension of sediments (inorganic solids), and algal blooms (organic solids).

Turbidity

Turbidity levels are presented in Appendix 1. Turbidity in the lakes of interest is generally high due to wind mixing and algal blooms. Turbidity tends to be high and more variable in shallow lakes (e.g. Lakes Gnarpurt and Martin), while being lower and more stable in deeper lakes (e.g. Lake Corangamite) with no seasonal trends (De Deckker and Williams 1988). Trends in secchi disc depth support these findings (De Deckker and Williams 1988). Turbidity in shallow lakes in the region is generally much higher than in most standing waters. Stock access to the lakes has contributed to increased turbidity (Parks Victoria 2001).

Oxygen

Oxygen levels are presented in Appendix 1. Oxygen concentrations in shallow saline lakes of the region are variable. Low values represent the negative effect of salinity on oxygen solubility, particularly at high temperatures, and the impact of algal bloom senescence. Oxygen levels are generally reasonably high, often at or near saturation values (De Deckker and Williams 1988) despite the negative effect of salinity on oxygen solubility. The relationship between salinity and oxygen concentration may be affected by algal blooms and aggregations of photosynthetic bacteria and stratification (see below). Stock access to the lakes has contributed to decreased oxygen levels (Parks Victoria 2001).

Stratification and oxygen levels

Stratification is an important physical process in lakes as it influences oxygen levels and phosphorus release from the sediments (internal loading). Lake stratification is generally dependant upon depth and exposure to wind mixing. Most saline lakes are polymictic because they are shallow and exposed; as a consequence they tend to mix throughout the water column continually or on a daily basis (Hammer 1986). During a one year study period no stratification was recorded in Lakes Colac or Corangamite (Hammer 1981a cited in 1986). More saline lakes stratify at shallower depths than freshwater lakes due to resistance to wind mixing, and stratification may thus occur even in quite shallow saline lakes. This provides the opportunity for periods of anoxia to develop. However, prolonged thermal stratification in Australian salt lakes is uncommon because not many saline lakes are deep. Lakes Gnotuk and Bullen Merri and Red Rock Tarn are known to stratify (Hammer 1981b cited in Hammer 1986)). The deeper Lakes Gnotuk and Bullen Merri stratify from October-November to April-May-June. Red Rock Tarn is very shallow (2 m deep) but is protected from the wind by its maar basin walls. Stratification occurs seasonally from late November to January.

In shallow polymictic saline lakes oxygen concentrations are near saturation as long as wind mixing occurs. Vertical variation in oxygen concentrations in Lake Corangamite is small (Hammer 1981b cited in Hammer 1986). The shallow Red Rock tarn shows pronounced depletion of oxygen below 1 m but this lake is protected from wind mixing (Hammer 1986). In deeper saline lakes (e.g. Lakes Gnotuk and Bullen Merri) periods of anoxia during stratification are also generally seasonal; severe oxygen depletion of deep waters may occur during stratification (Timms 1976). In shallow saline lakes anoxia may occur temporarily at almost any time the conditions (prolonged windless, clear days) are favourable, particularly where benthic algal mats occur. Such periods of anoxia may not be long-lived in shallow, exposed saline lakes. Supersaturation of oxygen may occur in saline lakes due to high rates of primary production; this may also result from thermal layering and the accumulation of phototrophic bacteria in plates at certain depths (Hammer 1986).

2.2.6 Sediments (will be important due to mobilisation by wind)

Sedimentological processes in shallow playa lakes have been summarised by Hammer (1986). The composition of surficial sediments of lakes in the region has been poorly studied. Marchant and Willams (1977) studied organic matter in the sediments of Pink Lake and Lake Cundare. The sediments of saline lakes consist of four fractions (Last and Schweyen,1983 cited in Hammer 1986):

- highly soluble evaporates (sodium and magnesium sulphates) and halite (sodium chloride)
- poorly soluble precipitates where bicarbonate is available
- clastic inorganic material (allochthonous) brought into the lake by surface runoff, shoreline erosion and wind
- organic matter.

The sediments of Pink Lake consist of black fine grained muds (Marchant and Williams 1977a) typical of deeper lakes (Hammer 1986). The sediments of Lake Cundare are lighter coloured calcareous sands (Marchant and Williams 1977b) typical of shallower lakes and near shore environments (Hammer 1986). Fine clays and evaporates are both readily mobilised by deflation of dry lake beds (Hammer 1986). Many saline lakes in the region were formed by deflation in past times as evidenced by the presence of lunettes on the windward shore of these lakes; for some salt lakes elsewhere in Australia deflation is an active contemporary process (Timms 2005). Deflation of sediments in Lake Gnarpurt as a result of the lake bed being dry for an extended period has been apparent over the last two to three years (authors, pers. observation). These sediments are readily mobilised and have drifted across adjacent farmland to the east and south of the lake under prevailing north westerly winds. These sediments have formed deposits several centimetres thick outside of the lake bed with negative effects on pasture growth. These sediments are mobilised by quite light winds forming light grey coloured dust clouds noticeably affecting visibility in the area. Rewetting of lake beds, saturation of sediments with salty groundwater, and the formation of salt crusts predisposes these lake beds to wind erosion (Reheis 2007). This suggests that lake Corangamite is at risk of sediment mobilisation should it dry further. Timms (2005) hypothesises that parts of the Australian landscape may enter another period of active lunette formation under a climate and land use change scenario.

Exposed sediments from dry lake beds can be major sources of PM10 dust particles which can be deeply inhaled causing health hazards, and may also contain potentially toxic elements such as arsenic and boron (Williams 2001; Reheis 2007) and phytotoxins from previous cyanobacterial algal blooms (Williams 2002). The sediments of Lake Gnarpurt appear to contain very high levels of aluminium (unpublished data). Such sediments can, when wind mobilised, travel long distances due to their fine-grained nature compared to other dust sources, and may have negative impacts on human health, for example, Owens lake, California (Williams 2001; Reheis 2007). These salt-rich dusts from dry playa lakes have elsewhere had a negative impact on soils and vegetation (Reheis 2007), and in particular, have resulted in salinisation of adjacent pastoral land (Williams 1992). This is likely to be the major management issue resulting from further drying of the lakes of interest.

2.2.7 Intra-lake biotic ecosystem components

Salinities of shallow freshwater lakes and wetlands in the region increase over summer as water levels decrease, but salinities in general do not greatly exceed about 3 g/l (Williams 1983). These shallow freshwater lakes and wetlands are characterised by complex and diverse communities of aquatic macrophytes and succession from truly aquatic species to semi-aquatics and short-lived terrestrial species during the dry periods (Williams 1983; Salinity Bureau 1989). Perennial species occupy the margins of wetlands. The aquatic plants indirectly provide food for many invertebrates; decomposing plant matter is ingested by detritivores which are in turn consumed by predators. Emergent macrophytes also play a vital role in providing a food source, nesting habitat and refuge for waterfowl. Aquatic plants are less important than terrestrial plants in the diet of waterfowl (Williams 1983).

Freshwater lakes and wetlands support diverse communities of zooplankton and phytoplankton. The zooplankton dominates the animal communities (Williams 1983). These communities are very productive due to the wet/dry regime of the wetlands. Inundation and subsequent decomposition of volunteer vegetation releases vast quantities of fine organic matter and nutrients into the water. Some of this organic matter is filtered by the zooplankton. The shallow water of wetlands allows good light penetration which, combined with high nutrient levels, stimulates phytoplankton production. The zooplankton graze (filter feed) on phytoplankton.

The macro-invertebrate community, particularly the benthos, of wetlands lacks several important groups which have poor powers of dispersal and/or do not have resistant stages in the life cycle that enable them to survive the dry period. The dominants are odonates (dragon and damselflies), hemipterans (water boatmen, backswimmers), and coleopterans (water beetles). These are all insects which fly as adults. Not surprisingly, coleopterans and hemipterans, dominate the animal portion of the diet of waterfowl (Williams 1983).

The model described above for shallow freshwater lakes and wetlands must be modified when considering saline lakes and wetlands. Flora and fauna of salt lakes are influenced by hydrological type. As described by Williams (1998) the flora and fauna of salt lakes can be summarised as:

Permanent salt lakes:

- fish only occur in this category of salt lakes
- the invertebrate fauna is similar to that of intermittent lakes but includes some forms with no resistance to desiccation at any stage of the life cycle
- lacks forms which require the intervention of a dry phase to complete their life cycle
- macrophytes are present.

Intermittent salt lakes:

- the invertebrate fauna is dominated by species with poor powers of dispersal
- has limited abilities to survive desiccation
- macrophytes are present.

Episodic salt lakes:

- the invertebrate fauna is dominated by species with good dispersal mechanisms
- show little regional endemism
- less diverse than in permanent or intermittent lakes
- lacks forms with limited resistance to desiccation (i.e. unable to survive desiccation over several consecutive seasons)
- macrophytes are not present.

The salt lake fauna of Australia is highly regionalised (Timms 2007).

2.2.8 Flora: algae and macrophytes

Algae

Data on algae is presented in Appendix 1. Algal communities of the lakes of interest are not well studied. Lake Colac has supported frequent blooms of *Anabaena* and *Aphanizomenon* over an extended period (EPA 1980; Cottingham et al. 1995) with water quality issues being recognised as early as 1935 (EPA 1980). Residents report skin irritation after swimming for decades. Lake Corangamite has supported persistent blooms of *Nodularia spumigena* through the 1960s and 1970s and into the early to mid 1990s (Cottingham et al. 1995; Timms 2004). The filamentous algae *Enteromorpha* and *Cladophora* had established abundant littoral growth by 1992 (Timms 2004). When senescent these attached algae form dense mats of decaying material along shorelines contributing to odours, turbidity in shallow water columns and lowered oxygen levels.

Macrophytes

Data on macrophytes is presented in Appendix 1. None of the lakes of interest support emergent vegetation. Shallow, highly saline, intermittent lakes (Cundare and Beeac) support no submerged macrophytes. Fresh and low salinity lakes (Colac and Martin – Cundare Pool) support the highest number of macrophytes. *Ruppia megacarpa* and *Lepilaena preisii* were common in Lake Corangamite until 1980 but had disappeared from the lake by 1992 (Williams 1995; Timms 2004).

2.2.9 Fauna: micro- and macro- invertebrates, fish, waterfowl

Micro- and macro- invertebrates

Data on micro- and macro-invertebrates is summarised in Appendix 1. Highest species richness occurs in fresh and low salinity lakes (Colac, Martin – Cundare Pool) within the group of interest. Lowest species richness occurs in the high salinity, intermittent lakes (Beeac, Cundare and Upper Calvert). This trend is in accord with the general relationship between salinity and species richness as described by Williams et al. (1990) and Williams (1998). Largest changes in species richness have occurred in those lakes at the lower end of the salinity spectrum (Colac, Martin – Cundare Pool) or those of intermediate salinity that have been subject to increasing salinity since 1980 (Lake Corangamite).

Lake Corangamite has shown a decrease in biodiversity but none of the species that have disappeared from the lake were endemic (Williams 1992). Williams (1992) recognised three faunal groups from the lake:

1. Taxa found before and after 1980; that is, before and after salinity increases = fauna with broad tolerance (< 1–200 g/l).
2. Taxa found only before 1980 but which no longer occur on the lake = low to moderate salinity group (< 1 to 30–60 g/l).
3. Taxa found only after 1980 = high salinity group (30–300 g/l). All taxa in this group have wide salinity tolerances.

That is, the invertebrate fauna of Lake Corangamite has changed from that typical of a moderately saline lake in the region to that typical of a highly saline lake in the region (Williams 1995; Timms 2004). The major losses of biodiversity have included the amphipod *Austrochiltonia subtenuis* and the gastropod *Coxiella striata*. These disappeared by about 1980 (Timms 2004). The fauna of the lake has changed in this fashion before. The fauna was characteristic of a saline lake when first studied in 1918 and included the saline copepod *Calamoecia clitellata*, the saline isopod *Haloniscus searlei,* the gastropod *Coxiella striata* and the brine shrimp *Parartemia zietziana*; *Austrochiltonia suntenuis* was not recorded from the lake (Timms 2004).

It is highly unlikely that the fauna of Lake Corangamite will revert to its former state in the medium term due to continuing climate change impacts in the region. However, recovery is potentially achievable (if water levels return to about 116 m AHD) within a period of a few (possibly as low as one to two) years as animals that have disappeared from the lake are not restricted to the lake and occur in other localities through the region (Williams 1995; Timms 2004).

Lake Martin – Cundare Pool has shown a change in macro-invertebrate fauna from freshwater forms to moderately saline groups. Lake Colac has shown a decrease in biodiversity since the early 1990s.

Microscopic fauna (meiofauna) of salt lake sediments in Victoria have been very little studied, but are likely to be a significant group in terms of their contribution to benthic biomass, particularly in 'extreme' environments. An ecological description of Lake Colac showed the meiofauna were dominated by nematodes (up to 755 individuals /10 cm^2), and 20 genera were identified (Khalife et al. 2005). This normally abundant and diverse group of benthos is included in the current survey of target lakes.

Fish

Data on fish in the lakes of interest is summarised in Appendix 1. Shallow, intermittent lakes of high salinity (Cundare, Beeac, Lough Calvert) do not support fish. Lakes that have shown the largest change in salinity (Corangamite, Martin – Cundare Pool, Colac) have also shown a decrease in fish species. *Galaxias maculatus* was previously recorded from Lake Corangamite when salinity was less than approximately 30 g/l (Chessman and Williams 1974, 1987) but disappeared from the lake by about 1980 (Timms 2004). *Anguilla australis* previously present in lake but is not recorded in waters above 13 g/l (Chessman and Williams 1974). The change in salinity of the lake has had a major impact on two of the dominant food items of Galaxias (the amphipod *Austrochiltonia subtenuis* and the gastropod *Coxiella* sp.) which together constituted 40% by volume of stomach contents of Galaxias (Chessman and Williams 1987).

Lake Gnarpurt no longer supports Galaxias or eels as it is dry. Eel deaths have been reported from Lake Colac within the last three years (EPA 2007) and it is highly likely that other species of fish previously recorded from Lake Colac are not resident at present.

Waterfowl

Waterfowl data are summarised in Appendix 1. Low to medium salinity lakes in the group of interest (Corangamite, Martine/Cundare Pool, Gnarpurt, Colac, Middle and Lower Calvert) have, in the past, supported the highest number of species and abundance of birds. This has changed as these lakes have either increased in salinity or become dry.

Waterbirds using Lake Corangamite fluctuate greatly in terms of species number and abundance but highly saline conditions are correlated with lower species richness and abundance (Timms 2004). This decline in bird use has been related to the decline of *Galaxias maculatus* plus other major food items for birds (amphipod *Austrochiltonia subtenuis,* gastropod *Coxiella* sp., and the submerged aquatic plant *Ruppia* sp.), plus the islands and other protected areas used by birds for nesting and refuge have become accessible to predators (Williams 1992). The number of species using Lake Martin – Cundare Pool and their abundance has decreased (Williams 1992; Timms 2004) and several species had ceased to use the lake for nesting in 1992 (Williams 1992).

The link between distribution of birds in Western Districts lakes and potential food availability is influenced by salinity (Corrick 1982, cited in Williams 1992). The salinity range that supports highest number of taxa and abundances of macro-invertebrates providing a food base for waterfowl in Lake Corangamite is less than 30–35 g/l (Williams 1992). Timms (2004) has documented the decline in species number and abundance of birds associated with Lake Corangamite as salinity has increased since the early 1990s. Timms has also noted the shift in species dominance from large and small waders and ducks to Australian shelducks and more recently banded stilts which appear to be feeding on the brine shrimp *Parartemia zietziana* which has reinvaded the lake; P. *zietziana* were recorded in the lake over 90 years ago during a previous period of high salinity (Timms 2004). In terms of waterfowl usage Lake Corangamite has become more like the highly saline, intermittent Lakes Beeac and Cundare.

Flora and fauna conclusions

There is strong evidence of major changes in the biota of three of the lakes of interest: Lake Martin – Cundare Pool, Lake Corangamite, and Lake Colac. In 1992 Williams concluded that there was 'firm evidence' that Lake Martin – Cundare Pool and Lake Corangamite had shifted in their salinity and faunal status; in 1992 both were in a higher salinity category than they were in 1980. This trend has continued. To this list of lakes showing change must now be added Lake Colac and Lake Gnarpurt. That is, four of the seven lakes of interest now show signs of significant change.

3 Current ecological survey

3.1 Aim

To survey ecological characteristics of the seven lakes identified to provide an outlook on the current ecological status. This information can be compared with the results of the review of historical data to assist in determining management guidelines for the future.

3.2 Method

Between one and three sites were chosen at each lake depending on lake size and access available to lakes edge. Site positions were located using a Garmin E-trex Legend ® GPS Receiver with ± 15 metre accuracy. The survey period occurred from 23 January to 14 March 2008. Figure 1.2 shows location of each lake site.

3.3 Lake sites

Table 3.1 shows the details of the sites visited. Further descriptions are given in this section, below.

Table 3.1 GPS locations of lake sites.

Lake	Site	Location	GPS	GPS
Corangamite	Site 1	Baynes Road	S 38°12'53.4"	E 143°36'16.8"
	Site 2	Woods Road	S 38°11'44.9"	E 143°37'04.4"
	Site 3	Cundare-Durverny Road	S 38°06'04.4"	E 143°32'47.1"
Colac	Site 1	Queen Street	S 38°19'54.1"	E 143°35'26.5"
	Site 2	Meredith Park	S 38°16'12.6"	E 143°36'24.0"
	Site 3	Rifle Butt Road	S 38°19'45.9"	E 143°33'37.5"
Martin	Site 1	Cotties Road	S 38°05'21.4"	E 143°34'38.8"
Beeac	Site 1	Morrissy Road	S 38°12'53.4"	E 143°36'16.8"
	Site 2	Mingawalla Road	S 38°11'44.9"	E 143°37'14.4"
	Site 3	Bucchanan Street	S 38°11'56.9"	E 143°38'06.8"
Cundare	Site 1	Corangamite Lake Road	S 38°08'38.3"	E 143°37'17.5"
	Site 2	Corangamite Lake Road	S 38°08'35.7"	E 143°36'46.1"
Gnarpurt	Site 1	Foxhow Road	S 38°04'17.4"	E 143°25'07.8"
Lough Calvert	Site 1	Weering School Road	S 38°11'47	E 143°40'29"

Lake Corangamite

Three sites were surveyed around Lake Corangamite. Site one was located at the southern end of the lake and was the only site where water was present during the survey period. The water's edge at this site retreated approximately 50 metres during the survey period. This site showed signs of frequent vehicle access on dry areas of the lake bed. Discarded rubbish was also noted. Site two was located on the eastern side of the lake in an area surrounded by cleared agricultural land. Site three was located at the northern end of the lake near the Lake Martin drainage area. Signs of cattle access were noted.

Lake Colac

Three sites were surveyed around Lake Colac. All sites were shallow and water level dropped noticeably during the survey period. During the survey period the middle section of the lake was completely dry, with an average depth of less than 20 cm occurring across the lake compared, with 2.4 m in average rainfall years. Survey of water quality parameters was limited at all sites due to the shallow nature of the lake. A large fish kill occurred during the survey period with 60,000 carp reported to have died between January and March (EPA Victoria 2008). Dead carp were noted at all three sites from 20 February to 5 March 2008.

Lake Martin

Sampling was restricted to only one site on the western side of the lake due to inaccessibility at other areas. Water was present in the lake on 23 January 2008 but by the end of the survey period in March the lake was completely dry.

Lake Beeac

Three sampling sites were located around Lake Beeac. Site one was at the south-western end of the lake. Site two was at the northern end of the lake and site three was at the north-eastern side of the lake near the old tip site. Water level in the lake decreased rapidly over the survey period. A very small amount of water was present in the lake during a site visit on 23 January 2008. This remnant pool was at the south-west end of the lake due to a north-easterly wind direction. Water level was approximately 3 cm deep. No water was present on any following visits to the lake. Rubbish was noted at each site, with the majority at site three in the form of discarded tyres.

Lake Cundare

Two sampling sites were chosen around the lake. Sites were located on the north and north-eastern side of the lake. While sites were located in close proximity to each other, they were chosen to represent differing sediment and vegetation types that were observed. No water was present in the lake during the survey period.

Lake Gnarpurt

One sampling site was chosen at Lake Gnarpurt due to limited access to most of the shoreline. The site was chosen at the southern end of the lake where the drainage point into Lake Corangamite was located. No water was present in the lake during the survey period and wind-borne transport of dry sediment between Lake Gnarpurt and Lake Corangamite was significant.

Lough Calvert

One site on private land was chosen for sampling in the upper Lough region, as access to the remaining shoreline was limited.

(a) (b) (c) (d) (e) (f)

Figure 3.1 Images of the lakes during the survey period. (a) Lake Corangamite, (b) Lake Colac, (c) Lake Martin, (d) Lake Beeac, (e) Lake Cundare, (f) Lake Gnarpurt. Photos by Kellie House, Deakin University, 2008.

3.4 Sediments of the saline lakes

Physical characteristics of the sediment are important aspects of the environment and are important in determining the biotic composition of benthic organisms. Sediment characteristics determine interstitial space, water and oxygen flow and nutrient concentrations and can be described by particle size, shape and relative proportion of grain sizes within a sample.

3.4.1 Aim

- To analyse granulometric characteristics at each lake site to compare differences within and between the lakes.
- To provide further information that may help explain any differences between benthic organism composition.
- To analyse sediments within each lake for concentrations of trace metals and nutrients. These may be contained in dry wind blown sediment, and pose an adverse affect on humans or other organisms. Wetted contaminants may also cause negative impacts on the lake biota following water replenishment.

3.4.2 Method

Physical characteristics (particle size analysis)

A sediment sample was taken from each site at each lake for particle size analysis. Each sample was weighed and sieved through a series of graduated sieves 1000 µm, 500 µm, 250 µm, 125 µm, 63 µm (wet sieve method). The weight of each sieve's contents as a percentage of the total was calculated and plotted (Appendix 2). Median particle diameter (MD_{50}), Upper and lower quartiles (Q3 and Q1), Sorting Coefficient (Quartile Deviation, QD) and Degree of curve of symmetry (Skewness, Sk) were analysed for each site (Table 3.2). The median particle diameter (MD_{50}) is the average grain size of the sample and the upper and lower quartile indicate the spread of the grain size fractions towards both ends of the sample. The sorting coefficient (QD) is determined by (Q3 –Q1) / 2. A homogenous and well sorted sample will result in a small QD. When fractions are over or under-estimated skewness of the graphed curve will result. The degree of the curve of symmetry (Sk) is determined by $(Q1 + Q3)/2–MD_{50}$ (Giere 1993). These characteristics help to define the physical nature of the interstitial habitat, including the porosity, permeability and penetrability of sediments.

Macronutrients (nitrogen and phosphorus) and heavy metals

Four core samples of 10 cm deep and 6.5 cm diameter were taken from each site at each lake for macronutrient and heavy metal analyses (56 samples). Three out of the four samples from each site were randomly chosen for analysis. Samples were frozen prior to analysis and assessed by ALS Laboratory Group, Melbourne. The concentrations of soluble total inorganic nitrogen (SIN) and total phosphorus were measured. Samples were analysed for Cadmium (Ca), Copper (Cu) and Lead (Pb).

3.4.3 Results

Physical characteristics

Grain size characteristics within each lake varied between lakes and depending on the site at Lakes Corangamite and Colac. Table 3.2 shows the composition by weight of each of the particle size fractions from all lakes. Site one and two at Lake Corangamite contained the greatest percentage of fine/very fine sand, while site three had a higher percentage of silt. Site three at Lake Colac had a more even particle size distribution. Sediment was found to be anoxic at sites one and two for both lakes, and a strong smell of hydrogen sulphide gas was noted at Lake Corangamite (site one) and Lake Colac (site two). An anoxic layer was present for the top 2 cm at Lake Corangamite (site three). The composition of Lake Gnarpurt and Lough Calvert were of fine to very fine sand. An anoxic layer 2 cm deep was also present at both lakes. Lakes Cundare and Beeac had similar grain characteristics, consisting of grey-coloured clay sediment with a large percentage of very fine sand or silt. The granulometric characteristics for Lake Martin differed slightly from all other lakes. The cumulative particle size distribution curve for each site is plotted in Appendix 2.

Table 3.2 Characteristic granulometric indices for particle size samples.

Phi value	Sieve mesh size	Corangamite 1	Corangamite 2	Corangamite 3
0	1 mm (V. coarse sand)	3.1	3.17	13.61
1	500 µm (Coarse sand)	1.97	2.72	17.87
2	250 µm (Med. sand)	17.11	13.13	5.74
3	125 µm (Fine sand)	34.12	37.84	29.63
4	63 µm (V. fine sand)	36.58	35.68	7.18
	< 63 µm (Silt)	7.12	7.46	25.96
MD_{50}		**2.3**	**2.3**	**1.8**
Quartile Deviation		**0.65**	**0.6**	**1.55**
Skewness		**-0.05**	**-0.1**	**-0.05**

Phi value		Colac 1	Colac 2	Colac 3
0	1 mm (V. coarse sand	15.64	18.03	9.66
1	500 µm (Coarse sand)	6.26	5.6	15.64
2	250 µm (Med. sand)	3.11	2.98	11.99
3	125 µm (Fine sand)	5.74	5.24	22.01
4	63 µm (V. fine sand)	27.66	24.42	16.47
	< 63 µm (Silt)	41.59	43.74	24.23
MD_{50}		**3.2**	**3.3**	**2.1**
Quartile Deviation		**0.3**	**1.55**	**1.5**
Skewness		**-0.55**	**-0.95**	**-0.1**

Phi value		Beeac 1	Beeac 2	Beeac 3
0	1 mm (V. coarse sand	22.87	20.45	21.27
1	500 µm (Coarse sand)	5.16	5	5.21
2	250 µm (Med. sand)	2.31	3.22	1.49
3	125 µm (Fine sand)	4.95	4.24	4.5
4	63 µm (V. fine sand)	25.55	28.46	26.56
	< 63 µm (Silt)	39.16	38.64	40.99
MD_{50}		**3.1**	**3.1**	**3.2**
Quartile Deviation		**1.35**	**1.65**	**1.75**
Skewness		**-0.85**	**-0.95**	**-1.25**

Table 3.2 cont.

Phi value		Cundare 1	Cundare 2	Martin 1
0	1 mm (V. coarse sand	28.29	30.33	44.32
1	500 µm (Coarse sand)	6.84	6.52	7.28
2	250 µm (Med. sand)	4.6	3.25	4.37
3	125 µm (Fine sand)	6.74	7.13	4.9
4	63 µm (V. fine sand)	6.09	5.8	3.97
	< 63 µm (Silt)	47.45	46.97	35.16
MD_{50}		**3.1**	**3.2**	**1.5**
Quartile Deviation		**2.5**	**2.5**	**2.65**
Skewness		**-1.8**	**-1.9**	**-0.35**

Phi value		Gnarpurt	Lough Calvert	
0	1 mm (V. coarse sand	5.14	9.65	
1	500 µm (Coarse sand)	0.86	1.82	
2	250 µm (Med. sand)	11.12	24.71	
3	125 µm (Fine sand)	30.75	22.13	
4	63 µm (V. fine sand)	35.63	31.62	
	< 63 µm (Silt)	16.49	10.08	
MD_{50}		**2.6**	**2.2**	
Quartile Deviation		**0.7**	**0.85**	
Skewness		**-0.1**	**-0.35**	

Macronutrients (soluble inorganic nitrogen and phosphorus)

Mean soluble inorganic nitrogen (SIN) and phosphorus levels for each lake are compared in Figures 3.2 and 3.3 respectively. SIN levels within the lakes ranged from < 0.1 to 24.4 mg/kg. Lake Martin had the highest mean SIN concentration (22.1 mg/kg). Phosphorus levels within the lakes ranged from 0.032 to 9.58 mg/kg. Mean concentrations were highest in Lakes Beeac (4.75 mg/kg), Cundare (5.03 mg/kg) and Lake Colac (3.16 mg/kg).

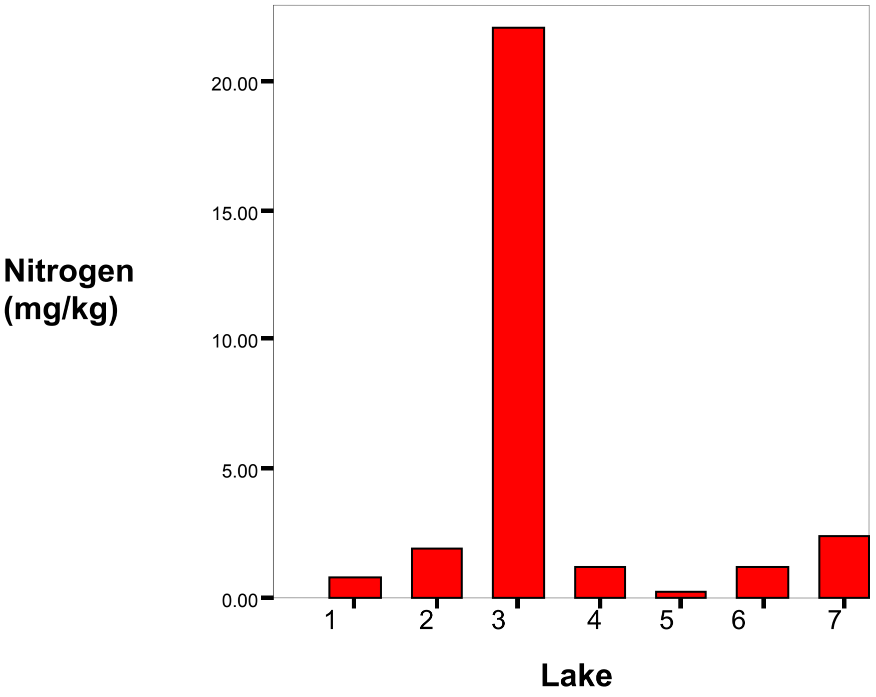


Figure 3.2 Mean soluble inorganic nitrogen levels (mg/kg) for each lake. (1-Corangamite; 2-Colac; 3-Martin; 4-Beeac; 5-Cundare; 6-Gnarpurt; 7-Lough Calvert.)

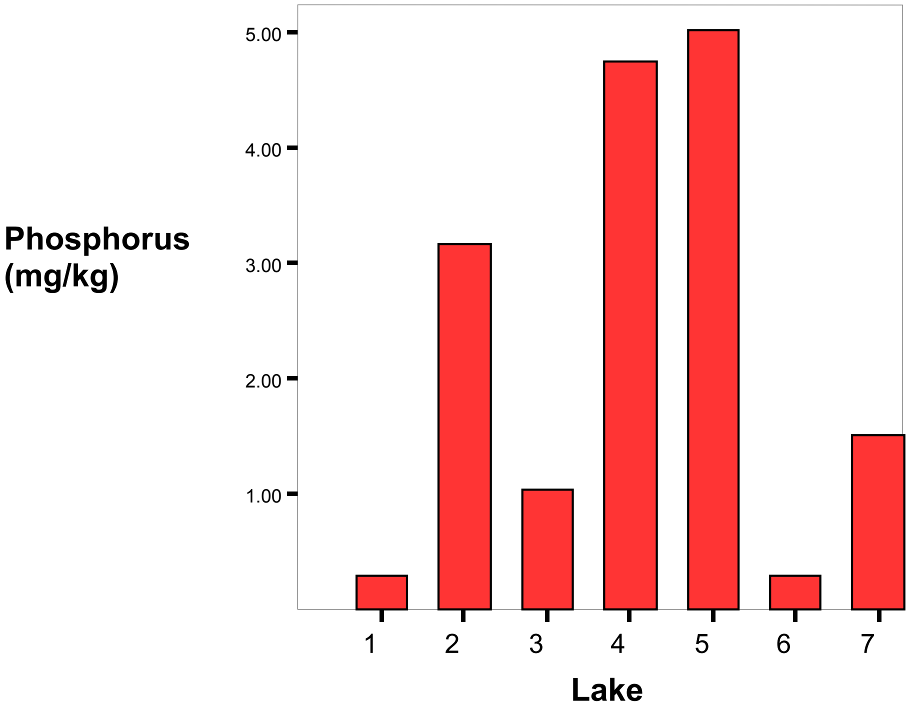


Figure 3.3 Mean phosphorus levels (mg/kg) for each lake. (1-Corangamite; 2-Colac; 3-Martin; 4-Beeac; 5-Cundare; 6-Gnarpurt; 7-Lough Calvert.)

Table 3.3 Soluble inorganic nitrogen and phosphorus levels for each lake site.

Lake	Site	Nitrogen (SIN) (mg/kg)	Phosphorus (mg/kg)
Corangamite	1	0.217	0.302
Corangamite	1	< 0.1	0.328
Corangamite	2	1.6	0.272
Corangamite	2	1.18	0.235
Corangamite	3	0.806	0.286
Corangamite	3	0.631	0.326
Colac	1	1.3	1.42
Colac	1	2.07	1.9
Colac	2	1.56	4.74
Colac	2	0.678	9.58
Colac	3	3.64	0.773
Colac	3	2.03	0.554
Martin	1	19.8	1.1
Martin	1	24.4	0.98
Beeac	1	0.882	4.24
Beeac	1	0.938	3.85
Beeac	2	1.22	3.68
Beeac	2	1.22	9.72
Beeac	3	1.66	3.56
Beeac	3	0.882	3.41
Cundare	1	0.262	6.46
Cundare	1	0.302	5.26
Cundare	2	0.2	3.4
Cundare	2	0.162	5
Gnarpurt	1	1.55	0.179
Gnarpurt	1	0.864	0.426
Lough Calvert	1	2.68	1.64
Lough Calvert	1	1.98	1.4

Table 3.4 Cadmium, copper and lead determinations for lakes Corangamite, Colac, Martin, Beeac, Cundare, Gnarpurt and Lough Calvert.

Lake	Site	Cadmium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)
Corangamite	1	< 0.1	1.3	3.6
Corangamite	1	< 0.1	1.2	3.4
Corangamite	2	< 0.1	3.8	10
Corangamite	2	< 0.1	4.6	8.1
Corangamite	3	< 0.1	3.9	8.1
Corangamite	3	< 0.1	3.2	5.4
Colac	1	< 0.1	< 1.0	1.6
Colac	1	< 0.1	1.3	5.2
Colac	2	< 0.1	5.9	5.9
Colac	2	< 0.1	5.7	6.9
Colac	3	< 0.1	1.1	1.9
Colac	3	< 0.1	4.9	7.3
Martin	1	< 0.1	10.3	11.7
Martin	1	< 0.1	8.8	10.4
Beeac	1	< 0.1	6.4	5
Beeac	1	< 0.1	6.6	3.2
Beeac	2	< 0.1	9.2	6.5
Beeac	2	< 0.1	8.8	7.4
Beeac	3	< 0.1	7.5	8.7
Beeac	3	< 0.1	7	7.7
Cundare	1	< 0.1	8.5	4.8
Cundare	1	< 0.1	7.3	4.7
Cundare	2	< 0.1	9.4	5.4
Cundare	2	< 0.1	9	5.8
Gnarpurt	1	< 0.1	6	4.9
Gnarpurt	1	< 0.1	3	3.1
Lough Calvert	1	< 0.1	8.6	7.6
Lough Calvert	1	< 0.1	8.6	8

Heavy metals

Table 3.4 shows results from heavy metal analyses for cadmium, copper and lead. Cadmium levels at all lakes were well below the Australian Interim Sediment Quality Guideline (ISQG) trigger levels of 1.5 mg/kg. Copper concentrations ranged from < 0.1 mg/kg at Lake Colac to 10.3 mg/kg at Lake Martin. Levels were still well below the ISQG trigger level of 65 mg/kg. Lead concentrations ranged from 1.6 mg/kg to 11.7 mg/kg. Lake Martin also recorded the highest levels of lead at 11.7 mg/kg but levels were still well below the ISQG trigger level of 50 mg/kg.

A multidimensional scale ordination (MDS) plot was constructed to display differences between lakes based on sediment characteristics including: mean copper concentration, mean lead concentration, median particle size (MD_{50}), quartile deviation (QD), skewness (Sk) and nitrogen and phosphorus concentrations (Figure 3.4). The resemblance between lakes is indicated by the relative proximity of data points on the plot, so that sites with characteristics in common are clustered together whereas dissimilar sites are positioned further away.

The low stress value (0.04) indicates that the plot is a good representation of the variables. The plot demonstrates that based on the variables used, Lake Martin is significantly different from the other six lakes. Lake Cundare and Beeac show similar characteristics and there is some clustering of samples from Lake Corangamite and Lake Colac (site one and two) with Lake Gnarpurt.

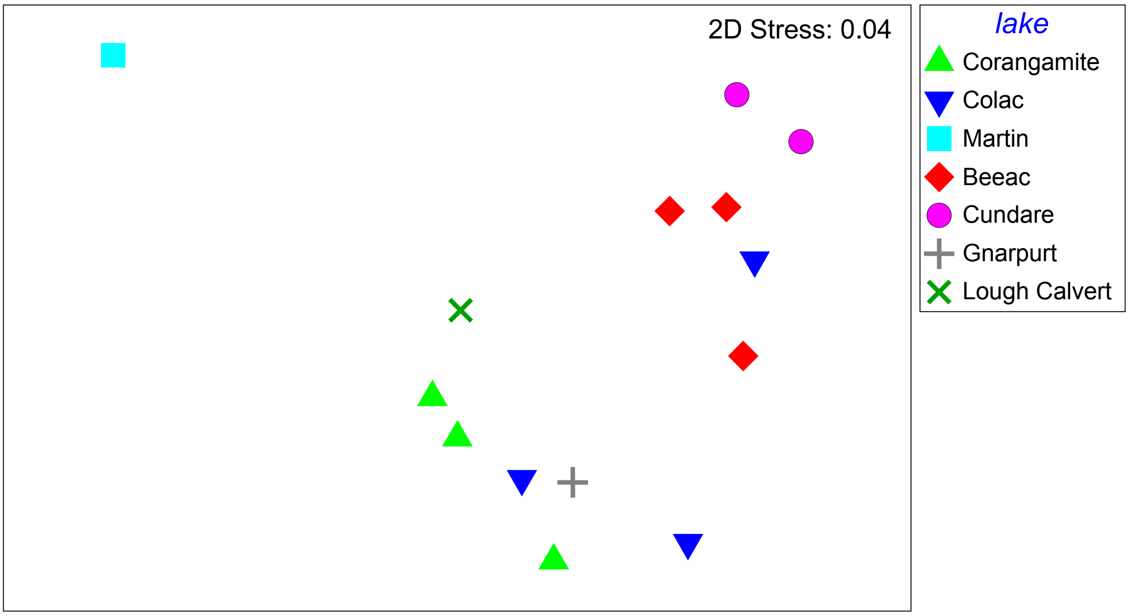


Figure 3.4 Two- dimensional MDS ordination displaying sediment differences between lakes. Factors included were copper concentration, lead concentration, Md_{50} (Median particle size), Qd (quartile deviation), Sk (Skewness), nitrogen and phosphorus levels. Data were normalised to a common scale prior to analysis.

3.4.4 Discussion

Physical characteristics

Over half of the lake sites studied displayed poorly sorted particle sizes. Poorly sorted sediments are characteristic of low wave and current activity (Gray 1981). Fine sediments, with closely packed grains, have poor water circulation and often low oxygen tension. More organic matter is often present in fine-grained sediments, usually resulting in higher abundances of macro- and meio-fauna (Gray 1981).

Anoxic sediment was present at several of the lakes, with a strong odour of hydrogen sulphide present at Lake Corangamite and Lake Colac. Wetlands can emit a range of sulphurous gases including hydrogen sulphide, volatile organic sulphur compounds and sulphur dioxide (Hicks and Lamontagne 2006). In anoxic sediment, sulphate-reducing micro-organisms derive their oxygen from sulphates, and produce hydrogen sulphide gas as a waste product. Rates of hydrogen sulphide production tend to be higher in saline wetlands because more sulphate is available. Hydrogen sulphide may also be produced through the decomposition of organic material. This process was conspicuous at Lake Colac (site two) due to the biodegradation of dead carp. Hydrogen sulphide can cause illness to humans from chronic exposure at low conditions and can even be lethal at high concentrations (Hicks and Lamontagne 2006).

Sulphur dioxide can be produced by sulphide oxidising micro-organisms when previously anoxic sediments are exposed to oxygen, a problem associated with the drying of saline lakes is the exposure of previously anoxic sediment to oxygen, and the loss of the overlying water column to ‘trap’ sulphidic gases produced (Hicks and Lamontagne 2006).

Acid sulphate soils can also be produced with the drying of water bodies. When soils containing iron sulphides are exposed to air the sulphides are oxidised to sulphuric acid and significantly lower the pH of the sediment and any remaining water column. There is the potential for water pH levels to be initially acidic when lakes refill (Land Management Queensland Government 2007).

Macronutrients (nitrogen and phosphorus)

There are no developed criteria for acceptable nutrient levels in sediments. Little data has been collected from undisturbed environments so natural background concentrations are relatively unknown (Deveraux et al. 2000). Inorganic nitrogen levels in Lake Martin were higher than in the other lakes, with a mean concentration of 22.1 mg/kg. This is due to the decomposition of organic matter, which is likely to be from the large amount of bird excreta present on the surface of the exposed bed of Lake Martin.

Phosphorus levels within all lakes (Table 3.3) were low in comparison to other studies, for example 55–320 mg/kg in a recent study of Lake Connewarre (Billows and Gwyther 2007). In a past study by Slater and Boag (1978), of phosphorus levels within sediments of Lakes Colac, Burumbeet and Learmonth, concentrations were found to be as high as 812–1760 mg/kg, 172–526 mg/kg and 517–715 mg/kg respectively. The range for this current study was 0.032–9.58 mg/kg.

Aerial exposure of previously inundated sediments causes ecological changes, particularly to nutrient cycling. Desiccation of sediments causes aging of the minerals responsible for phosphorus absorption, and reduces the sediments capacity to do so (Baldwin 1996; Mitchell and Baldwin 1998). Baldwin (1996) found that distance from the water line and subsequent desiccation correlated with a reduction in phosphorus levels within lake sediment, and Jacoby et al. (1982) found that a net reduction of phosphorus in the water column occurred when sediment that had been exposed to the air was re-submerged. Due to the reduced lake depth during the current study, sediment samples taken for nutrient analysis were all taken from the shoreline where the sediment was exposed to air, and would account for the relatively low levels of phosphorus present within samples analysed.

In lakes, phosphorus is generally a deficient nutrient and one that limits primary production (Mitchell and Wallis 1999). Sediments of lakes contain a pool of phosphorus which may undergo chemical and biological transformations and be released to the overlying water column (Slater and Boag 1978). With the low concentrations of phosphorus and inorganic nitrogen found within the presently studied lakes, it would seem that the sediment does not sequester large reserves of nutrients for subsequent release into the water column.

Heavy metals

Concentrations of lead, copper and cadmium in each lake (Table 3.4) were all below ISQG trigger levels. Concentrations of cadmium were very low in each lake. The highest recorded lead level was found in Lake Martin (11.7 mg/kg). Australian literature on heavy metals in sediments of saline lakes is sparse. However, concentrations of lead and copper were similar to levels found in a saline lake studied in Croatia. Lead levels in that study by Mihelcic et al. (1996) ranged from 8.5–23.3 mg/kg and were comparable with levels in this current study, as were copper levels of 2.6–14.2 mg/kg.

In comparison of sediment characteristics between the seven lakes, Lake Martin was a significant outlier due to sediment containing highest mean copper concentration (9.55 mg/kg) as well as the highest mean lead concentration (11.05 mg/kg). Granulometric characteristics and the higher levels of inorganic nitrogen (Tables 3.2, 3.3) also distinguished Lake Martin from the other lakes included in the present study.

3.5 Water quality

3.5.1 Aim

To measure physico-chemical parameters (temperature, dissolved oxygen, pH and salinity) where possible, and obtain an overview of the current water quality of each lake.

3.5.2 Method

An assessment of water quality was based on the limited data that could be gathered due to drought conditions. Salinity was the main parameter measured at a number of lakes, while dissolved oxygen, pH and water temperature were only measured at Lake Corangamite (site one) due to the shallow depth or lack of water at other lake sites. Water quality parameters were measured on three occasions from Lake Corangamite using an MP TROLL 9000 Profiler®. Salinity readings were taken from lakes Corangamite, Colac, Martin and Beeac using a refractometer where the water was too shallow for a submersible probe.

The number of readings obtained from each lake was variable due to Martin and Beeac drying out completely during the survey period, and Colac dissipating to a degree that remaining water was not accessible from any of the sites. Many of the measurements were greater than the maximum reading available with the refractometer (i.e. greater than 100 ppt). Three readings were taken with a diluted sample (1:4) from Lake Corangamite (site one) which allowed salinity values greater than 100 ppt to be measured.

3.5.3 Results

Salinity levels have been increasing in the lakes over the past few years (Mitchell 1996) co-incident with reducing water levels. Salinity readings for all lakes measured were well above previously recorded levels. The three samples from Lake Corangamite all measured over 300 ppt (Table 3.5), an extremely high level for this lake. The salinity of water from Lake Colac, which was previously classified as a freshwater lake, had reached a similar salinity level to that of seawater by the end of the survey period (32 ppt). Lake Martin also recorded high salinities with the final value of 40 ppt before it dried out completely. Readings taken from Lake Beeac before it dried out were greater than 100 ppt; however, this is not an unusual level for this particular lake.

Table 3.5 Salinity levels from Lakes Corangamite, Colac, Martin and Beeac.

	23 Jan 2008	15 Feb 2008	27 Feb 2008	5 Mar 2008	13 Mar 2008
Lake Corangamite					
Site One	> 100 ppt	> 100 ppt	336 ppt	320 ppt	368 ppt
Lake Colac					
Site One	20 ppt	*	*	*	*
Site Two	14 ppt	32 ppt	*	*	*
Lake Martin					
Site One	40 ppt	*	*	*	*
Lake Beeac					
Site One	> 100 ppt	*	*	*	*
Site Two	> 100 ppt	*	*	*	*

* indicates reading n/a due to the lake drying out during the study.

Dissolved oxygen, pH, temperature and depth were measured at Lake Corangamite on three occasions. Temperature ranged from 18.6°C to 24°C at the beginning of February. DO levels ranged from 9.3 mg/l to 11.6 mg/l (the latter a supersaturated solution). The pH values ranged from 8.3 to 10.9 pH units (see Table 3.6).

Table 3.6 Water quality parameters measured for Lake Corangamite (site one).

Lake Corangamite	2 Nov 2007	6 Feb 2008	15 Feb 2008
DO (mg/l)	9.3	11.6	10.9
pH	10.9	8.4	8.3
Temperature (°C)	19.5	24	18.7

3.5.4 Discussion

Salinity

Salt in excess should be considered a pollutant, as it can have adverse affects on aquatic biota in a similar way to toxicants such as heavy metals (Chisholm Institute of Technology 1989). A major reduction in water levels in all lakes during the survey period resulted in salinity levels that were greater than previously recorded in other studies. Past salinity trends for the lakes are in Appendix 1. During the current study salinity levels in Lake Corangamite were recorded as high as 368 ppt. Similar changes in salinities were also noted at other lakes. The highest salinity reading for Lake Colac was 32 ppt, a significant increase. Lake Martin also recorded a high salinity reading of 40 ppt. Lake Gnarpurt has recorded values of 10.7 ppt in the past (De Deckker and Williams 1988), but was completely dry during the survey period.

Lake Beeac is the only lake where salinities have been recorded in the past as high as those recorded in this study. Bayly and Williams (1966) found that Lake Beeac contained mainly crystalline salt and the small amount of water present was a saturated solution (321 ppt). Large seasonal variation in concentration of dissolved solids was also noted. Lake Cundare is similar to Lake Beeac in salinity levels and variations, although no readings could be taken during this current study. Lake Cundare fluctuates in salinity with values ranging from > 100 ppt to > 300 ppt (De Deckker and Last 1988).

In hyper-saline waters a highly significant correlation exists between community composition and salinity (Williams et al. 1990). Salinisation is likely to reduce biodiversity as species richness generally declines with increasing salinity (Timms 2005). However, various taxonomic groups living in salt lakes react differently to increasing salinity, which can obscure this relationship. Ionic composition is also affected by salinity. All but the least saline lakes in the region are dominated by Na and Cl ions (Williams et al. 1990). When salinity levels reach 100–320 ppt major changes in ionic structure occur. This also affects community diversity and abundance as chemical diversity within the water column is biologically important (Radke et al. 2003).

The lowest points in the landscape, such as lakes, show the first signs of salt damage due to human intervention (Davis 2003). Increased climatic warming also reduces lake water levels and will continue to do so, with many only filling for parts of the year and others drying out completely (Williams 2002). While Khan (2003a) found an increasing trend in salinity between January and March, the increases in salinity that were recorded during the current study were well above levels that would be expected to occur, and well above any levels previously recorded. As other sections of this report show, increasing salinity has had adverse affects on the biota on all levels of the trophic scale in all of the lakes that were studied.

Other water parameters

No persistent stratification occurs within the lakes because they are relatively shallow and mixed by wind. Temperatures in Lake Corangamite ranged from 18.6°C to 24°C and according to Williams (1978) they have been known to fluctuate 20ºC in one day.

All lakes in the region have an alkaline pH of between 8.0 and 9.0 (Williams 1978), although Lake Corangamite recorded levels that showed some fluctuation from 8.3 to 10.9 pH units. High alkalinity can result from photosynthetic activity, although the extreme value of 10.9 is unusually high for saline lakes and may be erroneous. Low pH values may occur in overlying water following oxidation of sulphides in exposed sediment, as mentioned in the previous chapter.

Dissolved oxygen (DO) concentration was recorded from 9.3 mg/l to as high as 11.6 mg/l and with the elevated water temperature gave a supersaturated solution. All parameters measured showed similar values to a study by Khan (2003) of saline lakes in the region, with recorded temperatures as high as 23°C, pH levels of 8.2 to 9.3 pH units and DO concentrations of 7.8 to 10.1 mg/l. De Deckker and Williams (1988), state that oxygen levels are usually high in saline lakes despite the negative effect of salinity on oxygen solubility.

3.6 Flora

3.6.1 Aim

To gauge the diversity of aquatic and terrestrial flora species present at each lake site.

3.6.2 Method

Flora was analysed in two main parts:

- Phytoplankton
- Macrophytes, algae and adjacent lake vegetation.

Phytoplankton

Due to the lack of water in other lakes, Lake Corangamite was the only lake sampled for phytoplankton. Phytoplankton was sampled at site one on 13 March 2008. Sixty litres of water was poured through a plankton net with a mesh size of 50 µm. The sample retained at the bottom of the net was preserved with 10% formalin. Three samples were obtained, and were analysed qualitatively. Phytoplankton was also noted when analysing meiofauna samples from all lakes, and analysed qualitatively. Plankton species were identified where possible from Newell and Newell (1977).

Macrophytes, algae and lake vegetation

Observations of aquatic macrophytes, algae and adjacent fringing vegetation were recorded during site visits. Specimens were identified in the field or returned to the laboratory if necessary. Allen (2007) was used in the identification of many species. This information was used to establish a contemporary record of flora characteristics at each lake site.

3.6.3 Results

Phytoplankton

The only phytoplankton species present in samples from Lake Corangamite was a dinoflagellate putatively identified, and subsequently referred to, as *Rhodomonas.* This species was found in large abundance and was responsible for the red algal bloom that was present at Lake Corangamite from 23 January to 13 March 2008. The resilience of the species was shown from a sample of *Rhodomonas* that was kept in darkness below four degrees for two months and was still alive after this time.

Chaetoceros was identified from sites two and three at Lake Beeac and site two at Lake Colac. Spherical cells or cysts (unidentified) were noted on slides from Lake Corangamite (site one and two), Lake Beeac (all sites) and Lake Colac (site two and three).

Macrophytes, benthic algae and lake vegetation

Beaded Glasswort and Austral Seablite were the dominant flora species within the lakes except Lake Colac, where neither of these species were recorded (see Appendix 3 for full species list of flora). Typical plant communities from the lake edges are shown in Figure 3.5.

Halophytic species represented 22–100% of the total species of flowering plants recorded from each site (Table 3.7). *Sarcocornia quinqueflora* pollen was noted in sediment samples from Lake Corangamite, Beeac and Cundare. Although algae and aquatic macrophytes were absent from all lakes during the survey period numerous, microscopic, brown, spherical algal cysts or plant seeds were noted in slides from all lakes.

Table 3.7 Number of total flora species identified from each lake site. The number of halophytic species is shown in brackets.

Lake	Site	Total no. of flora species identified (including no. of halophytes)
Corangamite	1	11 (5)
	2	12 (10)
	3	10 (9)
Colac	1	9 (2)
	2	7 (2)
	3	17 (8)
Martin	1	5 (4)
Beeac	1	6 (5)
	2	5 (3)
	3	7 (3)
Cundare	1	11 (4)
	2	5 (2)
Gnarpurt	1	3 (3)
Calvert	1	3 (3)

At all lakes, zonation of vegetation occurred to some degree, with a greater proportion of salt tolerant species occurring on the lake bed and littoral zone of the lake, and a greater proportion of introduced weed species occurring higher on the shore, particularly on adjoining roadside edges.

Lake Corangamite had the highest proportion of salt-tolerant species including Beaded Glasswort *(Sarcocornia quinqueflora)*, Austral Seablite *(Suaeda australis)*, Australian Salt Grass *(Distichlis distichophylla)*, Salt Angianthus *(Angianthis preissianus)*, Sea Barley Grass (*Hordeum marinum)* and Creeping Monkey Flower *(Mimulus repens)*

Lake Gnarpurt, Lake Martin and Lough Calvert had sparse vegetation covering and lowest species diversity. Limited vegetation was present on the lake bed and immediate littoral zone (see cover photographs). All species recorded were salt tolerant species.

The floral composition at Lake Colac was different from that of the other lakes. A high proportion of introduced species occurred around the lake and many species recorded at Lake Colac were not recorded at the other lakes. These included Grassy Club Rush (*Isolepis cernua*) and species of *Casuarina* and *Eucalyptus*.

Spiny Peppercress *(Lipidium aschesonii)*, an endangered species under the Environmental and Biodiversity Conservation Act (1999), has been recorded in past studies at Lake Corangamite (Williams 1995) and Beeac (Aussie Heritage 2008), but was not recorded within the surveyed sites of this study.

3.6.4 Discussion

Phytoplankton

Phytoplankton is usually very productive within saline lakes due to good light penetration (Mitchell 1996); however, only a few species usually occur, with lakes often dominated by a single species (Smith 1972; Hammer 1981 (a); Khan 2003). This was seen at Lake Corangamite during this study with only one phytoplankton species recorded, the dinoflagellate *Rhodomonas. Chaetoceros* was recorded from Lakes Beeac and Colac. The dinoflagellates are a large group of flagellate protists, and can be found within marine or freshwater environments. Their populations are distributed depending on temperature, salinity, or depth. While abundance of *Rhodomonas* was high in Lake Corangamite due to an algal bloom, this may cause water quality to decline greatly as the phytoplankton bloom decays, further reducing the biodiversity of the lake (Davis 2003).

Macrophytes, benthic algae and lake vegetation

Timms (2005) suggested that there are two states that may occur under regimes of changing salinity: macrophyte dominated or phytoplankton dominated. No macrophyte species was noted in any of the lakes during the survey, and only one phytoplankton species was found within Lake Corangamite.

Ruppia (a submerged, grass-like flowering plant) used to be a common species found within Lake Corangamite but was not recorded during this survey. The loss of this species has been associated with decline in avian diversity and abundance (Williams 1995). According to Yezdani (1970), submerged macrophytes *(Ruppia megacarpa and Lepilena pressii)* were common in Lake Corangamite. In 1992, Williams (1995) observed no submerged macrophytes but recorded large masses of filamentous algae.

The diatoms *Chaetoceros* and *Nodularia spumigena* and the macrophyte *Ruppia megacarpa* have also been recorded in the past from Lake Gnarpurt. Reed beds of *Ruppia* spp. and *Lepilena* have been recorded in Lake Colac (Khan 2003). However, macrophytes generally are sensitive to salinity changes and are usually absent from salt lakes (Mitchell 1996). The increasing salinity seen in all lakes has contributed to the paucity of macrophyte species, and their recolonisation may depend on lowered salinity levels. If the trend for wide variation in salinity continues it is likely that macrophyte abundance and diversity is threatened even in Lake Colac. Some floral assemblages from the lakes are shown in the photographs in Figure 3.5.

The control of nutrient loads is also important in lakes that are deep enough for macrophytes to recolonise. Resuspension of bottom sediments by wind in shallow environments also inhibits macrophyte colonisation by inhibiting light penetration (Davis 2003). Recolonisation may occur from dormant floral stages that remain viable during a period of desiccation or high salinity, and germinate once conditions are favourable. Diatoms, algal cells, seed pods and *Sarcocornia* pollen were noted within the dried sediments collected from many of the lakes. The importance of water regime as well as salinity levels has been documented for germination of aquatic plants. Brock et al. (2005) found that an increase in diversity of germinating species occurred in communities germinating from seed banks around the edge of a wetland area, compared with species germinating from the same seed bank in areas that were inundated. Much of the terrestrial vegetation within the region was introduced (Williams 1978) and this is also the case at the majority of lake sites studied. The sites that recorded the highest diversity of floral species were those that had the highest levels of introduced species. Many species found around the lakes have been recorded in Allen (2007).

(a)

(b)

(c)

(d)

Figure 3.5 Different vegetation types at: (a) Lake Corangamite (site two), (b) Lake Colac (site three), (c) Lake Corangamite—Austral Seablite, (d) Australian Salt Grass. (Photos (a)-(c) by Kellie Hose, Deakin University (2008), Photo (d) Department of Primary Industries, Victoria 2008.)

3.7 Fauna

3.7.1 Aim

To survey fauna species present at each lake and assess the lake faunal diversity under present drought conditions.

3.7.2 Method

Surveys were completed of two faunal types:

- Zooplankton
- Meiofauna.

Zooplankton

Zooplankton was sampled at Lake Corangamite (site one) on 13 March 2008. Sixty litres of water were poured through a plankton net (mesh size 150 µm). The sample retained in the net was preserved with 10% formalin. Three samples were obtained. Samples were analysed qualitatively.

Meiofauna

Five sediment cores 20 cm deep and 2.5 cm diameter were taken from each site at each lake. Samples were kept below 4°C prior to analysis of abundance and diversity of microscopic multicellular animals (meiofauna).

In the laboratory, each sample was decanted with tap water a standard number of times (8) and rinsed through a series of two sieves: 500 µm and 63 µm, and placed in a Ludox© solution of specific density 1.14 and left for 45 minutes. The liquid part (with suspended meiofauna) was then decanted through a 63 µm sieve, excluding the sediment residue. The collected meiofauna were placed in an embryo dish with a solution (25% ethanol, 5% glycerol and 70% water), and left to evaporate for one to two weeks. Meiofauna were then placed onto slides for species identification. Residual sediment checks occurred randomly at several stages in the process to make sure extraction of meiofauna was complete. Meiofauna were counted and nematodes identified to genus using (Platt and Warwick 1983, 1988; Warwick et al. 1998). Other meiofauna taxa were identified from Higgins and Thiel (1988). Only meiofauna samples yielded sufficient abundances to merit statistical analysis of fauna from the target lakes.

3.7.3 Results

Zooplankton

No zooplankton species were found within samples taken from Lake Corangamite; site one. Empty ostracod shells and copepod moults were the only zoological material found. The water level in other lakes, where present, was too shallow to collect samples.

Meiofauna

The most abundant meiofaunal taxon found was nematodes. A total of ten genera was identified (Table 3.8). However, in comparison with meiofauna from marine, estuarine and freshwater habitats (Coull 1999) overall abundance and diversity was very low within each lake. Oligochaeta was the next most abundant meiofaunal taxon found, with numbers also being generally low. Other meiofaunal taxa found include: Foraminifera, Coleoptera, Polychaeta and Copepoda species. Ostracod shells were noted from Lake Beeac, Corangamite, Colac and Lough Calvert. A benthic diatom species (possibly *Ceratulina pelagica*) was identified on slides from Lake Martin and from Lake Colac (site three).

Univariate analysis

Univariate analysis was used to determine any differences in total abundance of meiofauna, and of nematodes and oligochaetes between lakes by employing one-way analysis of variance (ANOVA). A significant result was determined with a P value of < 0.05.

There was a significant difference in mean nematode abundance between lakes ($P < 0.002$; $F = 4.849$; 5,30 df). Lake Colac had a greater mean nematode abundance than any other lake. However, Lake Martin had the highest mean species richness (Figure 3.6). Lakes Cundare and Beeac and Lough Calvert had the lowest mean nematode abundances as well as the lowest mean species richness. No nematodes were recorded from samples at Lake Cundare.

Table 3.8 Total number of nematode genera identified at each lake site.

Lake	Site	Total no. of nematode genera identified	Genera
Lake Corangamite	1	0	–
	2	4	*Theristus, Diplolaimella, Oncholaimus, Pandolaimus*
	3	1	*Diplolaimella*
Lake Colac	1	4	*Belbolla, Daptonema, Theristus, Diplolaimella,*
	2	4	*Belbolla, Daptonema, Theristus, Diplolaimella,*
	3	4	*Belbolla, Daptonema, Theristus, Diplolaimella,*
Lake Martin	1	7	*Desmodora, Theristus, Diplolaimella, Chromospirina, Adoncholaimus, Tylenchorhychus, Belbolla.*
Lake Beeac	1	1	*Theristus*
	1	2	*Belbolla, Adoncholaimus*
	3	1	*Chromospirina*
Lake Cundare	1	0	-
	2	0	-
Lake Gnarpurt	1	4	*Belbolla, Theristus, Diplolaimella, Adoncholaimus*
Lough Calvert	1	1	*Theristus*

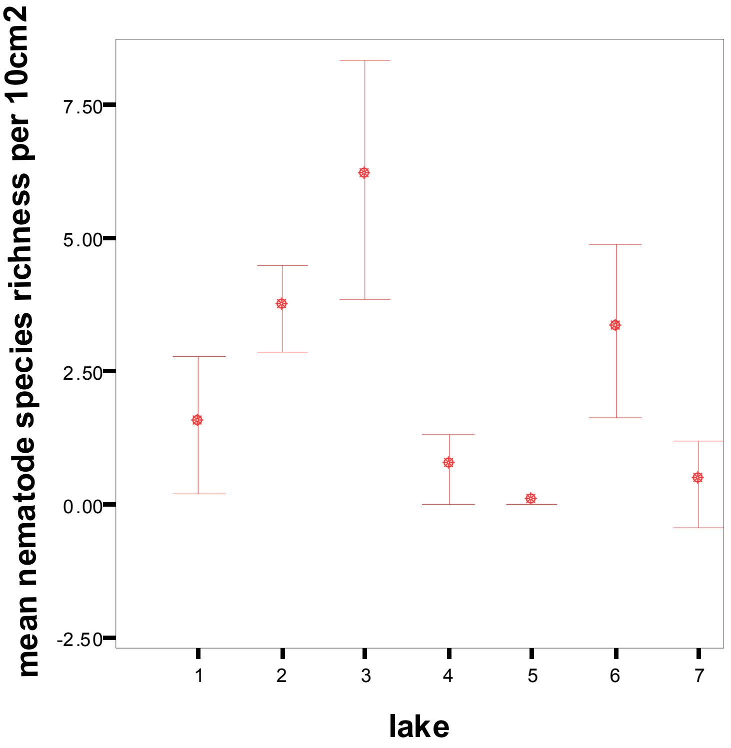


Figure 3.6 Mean nematode species richness between lakes. Error bars show mean +/- S.E, (Lake 1-Corangamite, 2-Colac, 3-Martin, 4-Beeac, 5-Cundare, 6-Gnarpurt, 7-Lough Calvert); n = 5 samples per site.

The second most abundant group within the meiofauna was the Annelid subclass Oligochaeta. A one-way ANOVA found no significant difference in mean oligochaete abundance between lakes ($P < 0.913$, $F = 0.405$; 8,61 df). Lake Martin had the greatest mean oligochaete abundance (and variation) as well as the greatest mean species richness (Figure 3.7). Overall, mean oligochaete abundance was low at each lake.

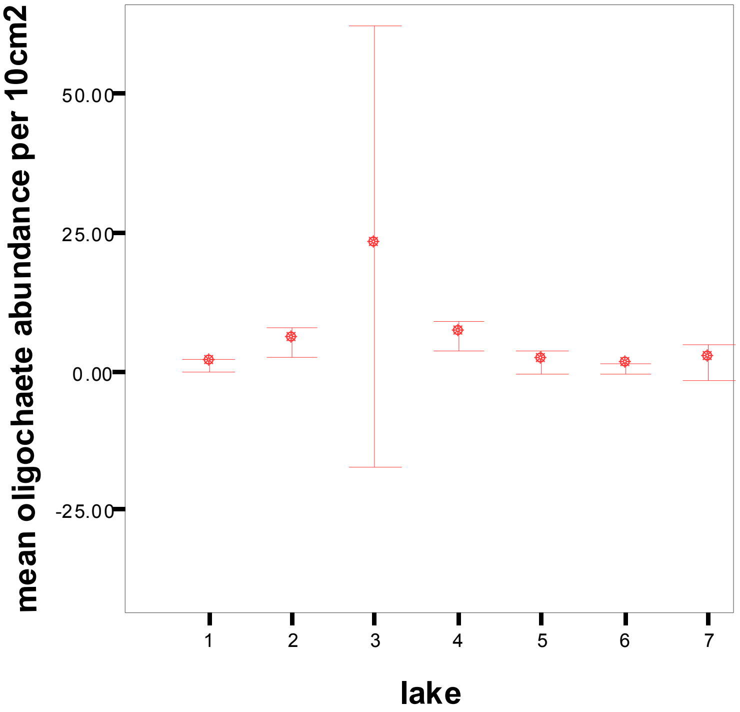


Figure 3.7 Mean oligochaete abundance between lakes. Error bars show mean +/- S.E. (Lake 1-Corangamite, 2-Colac, 3-Martin, 4-Beeac, 5-Cundare, 6-Gnarpurt, 7-Lough Calvert); n = 5 samples per site.

Total abundances for other meiofauna taxa were low (Figure 3.8). The copepod (*Diarthrodes* sp.) was found in greatest abundance at Lake Martin, with 15 individuals recorded from five samples. One individual was also found within samples from Lake Colac (site one), Lake Beeac (site one) and Lough Calvert. Eight individuals of a species of benthic harpacticoid were also found only at Lake Martin. A polychaete (species a) was also found across a few lakes with most individuals found at Lake Colac. A second polychaete (species b) was found only at Lough Calvert. Foraminifera were found at Lakes Corangamite and Colac. Single cases of a rotifer, nauplius larva and coleopteran were found at Lakes Cundare, Martin and Corangamite respectively. These results clearly reflect the lack of suitable habitat for aquatic organisms at the time of collection.

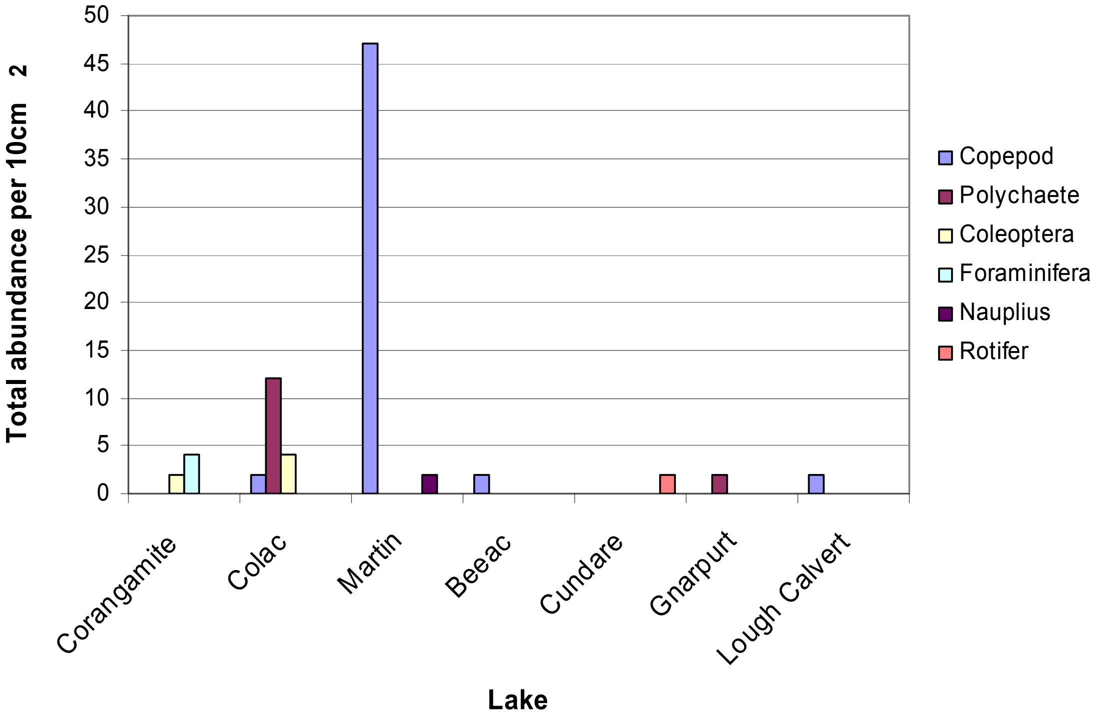


Figure 3.8 Total abundance per 10 cm^2 for other meiofauna taxa found at each lake; n = 5 samples for each site.

Multivariate analysis

Multivariate analysis was used to determine differences between species diversity and composition between lakes. The multidimensional scale ordination (MDS) plot, constructed to analyse meiofaunal community differences between lakes, showed a low stress value for the data, indicating the plot was a good representation in two-dimensions of the variable measured (Figure 3.9).

Analysis of Similarity was conducted to test for differences in meiofaunal communities between lakes. ANOSIM uses a test statistic R which is based on differences between groups (all groups chosen *a priori*) contrasted with differences within groups. R values close to zero indicate that groups are similar, while R values close to one indicate that groups are different. A significance value of < 5% indicates that groups are statistically different. This statistic revealed a significant difference in meiofaunal community between lakes (significance 0.1%).

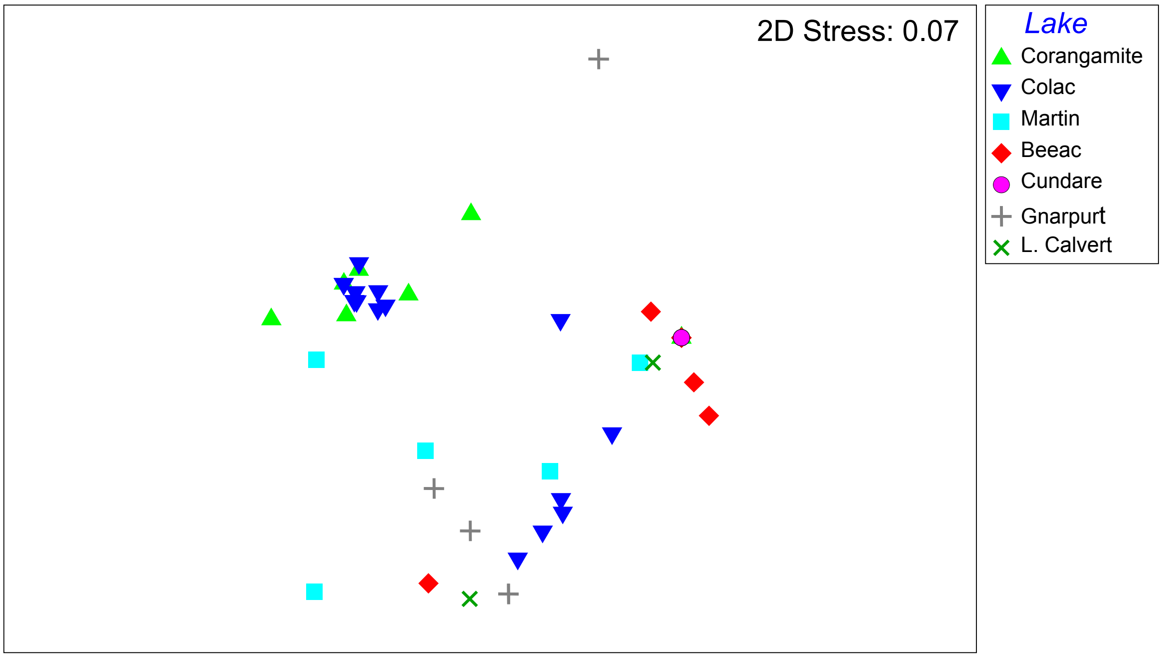


Figure 3.9 Two-dimensional MDS ordination of meiofaunal community between lakes

Pair wise tests were performed when a significant value was obtained to evaluate differences between pairs of lakes. These revealed that Lake Corangamite was significantly different to all other lakes except Lake Colac. Lakes Beeac, Cundare and Lough Calvert all had similar community diversity. Lake Martin was significantly different in meiofaunal community from all lakes except Lough Calvert, as was Lake Gnarpurt. Lough Calvert was similar to many of the lakes, but this was due to its low species diversity and abundance (Table 3.9).

Table 3.9 Summary of pair-wise tests for each lake.

Group	Sample statistic (Global R)	Significance level*
Corangamite and Colac	0.089	12.1%
Corangamite and Martin	0.35	1.5%
Corangamite and Beeac	0.461	0.2%
Corangamite and Cundare	0.301	6.7%
Corangamite and Gnarpurt	0.493	0.4%
Corangamite and Lough Calvert	0.438	2.2%
Colac and Martin	0.223	3.6%
Colac and Beeac	0.556	0.1%
Colac and Cundare	0.529	0.1%
Colac and Gnarpurt	0.308	1.2%
Colac and Lough Calvert	0.409	0.7%
Martin and Beeac	0.655	0.1%
Martin and Cundare	0.428	4.0%
Martin and Gnarpurt	0.228	4.0%
Martin and Lough Calvert	0.118	42.9%
Beeac and Cundare	0.022	50.5%
Beeac and Gnarpurt	0.764	0.1%
Beeac and Lough Calvert	0.487	8.6%
Cundare and Gnarpurt	0.497	2.4%
Cundare and Lough Calvert	0.214	20.0%
Gnarpurt and Lough Calvert	0.209	23.8%

Global R = 0.415; Significance 0.1%; 999 permutations performed.

* Significant comparisons are those with < 5% probability

Further community analysis was conducted using a K-dominance plot (Figure 3.10). Analysis of the plot showed that Lake Martin had the greatest community diversity due to several different taxa found at this site. Lake Cundare had the lowest diversity.

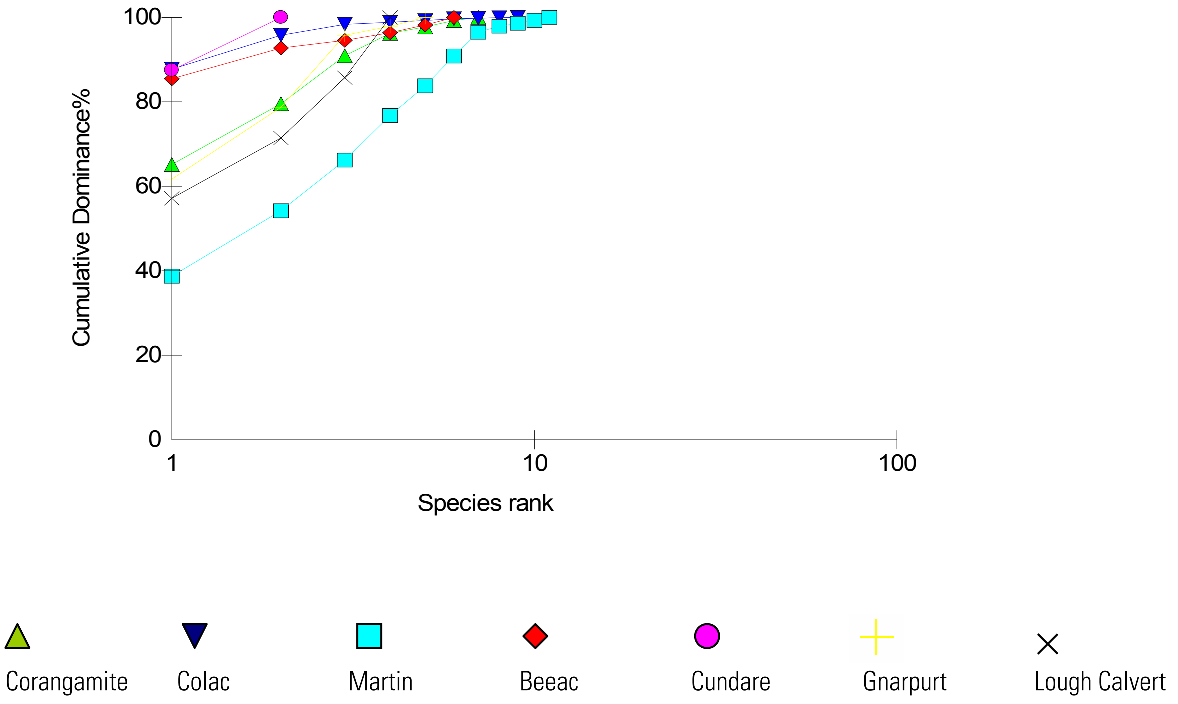


Figure 3.10 Cumulative K-dominance plot showing differences in meiofaunal diversity between lakes. Kruskal stress value = 0.01

A one way ANOSIM was performed to test for meiofaunal differences between sites, for lakes Corangamite, Colac and Beeac where more than one site was studied. No significant difference was found between sites at Lake Corangamite (significance level 10.7%). No significant difference was also found between sites for Lake Colac (10.1%). Sites within Lake Beeac were also very similar (56.9%).

3.7.4 Discussion

The fauna of inland salt lakes are said to posses a substantial biological unity due to the variable and unstable nature of most inland lakes (Williams 1981) and saline lakes usually lack exotic species due to the harsh environment. Saline lake fauna are probably adapted to a wide range of environmental gradients, and are therefore persistent (Timms 2005). The low total diversity and meagre abundance of benthic fauna within each lake reflected the extreme salinity levels recorded within each lake. Changes in ionic composition that occur when salinity values are between 100–300 ppt (Radke et al. 2003) also affect biota as well as the increasing salinity levels. Lake biota must make permanent or temporary adaptations to osmotic stress (Williams 2002) and this cannot occur when salinity levels change over a rapid time scale, or to such a degree that the organism cannot survive.

Zooplankton

Zooplankton and phytoplankton communities are generally very productive due to the wet/dry regime (Mitchell 1996). No zooplankton was found within samples taken from Lake Corangamite. Ephemeral, unstable waters of high salinity are generally uninhabited except for microbial life such as halobacteria, methanogens and cyanobacteria (Herbst 2001). The lack of zooplankton at Lake Corangamite suggested that species previously living within the lake may have been adversely affected by the high salinity; however, samples were only taken at one point in time and may have been affected by seasonal variation.

Some zooplankton have dormant stages that resist desiccation, while other species will produce salt-resistant eggs when salinity levels reach a certain point (Geddes 1976). In all species the upper salinity threshold level for emergence is far below the salinity tolerance level of adult stages. Hatching of zooplankton occurs at all times of the year in correspondence with rainfall when salinity levels fall to a manageable level (Geddes 1976). During microcosm laboratory experiments, brine shrimp (*Paratemia zietziana)* have been recorded hatching from previously desiccated sediment that has been re-inundated, from Lakes Corangamite (Gully 2008, School of Life and Environmental Science Deakin University, pers. comm.), highlighting the possible return of this species once water levels return.

Meiofauna

In most benthic, aquatic environments meiofauna are usually diverse and occur in large abundances (1–10 million individuals per square metre) (Giere 1993). Even in samples from extreme environments the meiofauna are generally orders of magnitude more abundant than macrofaunal organisms, of which there may be few or no individuals. There are several advantages to including meiofauna as an ecological tool, including their sessile habit, high species diversity, short generation time, direct benthic development and ubiquitous distribution. These characteristics are particularly valued in studies of oligotrophic systems, highly polluted situations or in other habitats where larger organisms are scarce, for example, the deep-sea and saline lakes.

The total meiofaunal abundance and diversity across all the saline lakes in this study was low. The highest nematode abundance was found in Lake Colac. A study by Khalife et al. (2005) found that whereas Lake Colac had a sparse benthic macrofaunal assemblage dominated by oligochaetes, there was an abundant and diverse meiofaunal assemblage. In that study nematode abundance ranged from 42–755 per 10 cm^2 and 20 nematode genera were identified. In this current study abundances (14–706 per 10 cm^2) were comparable with Khalife et al. (2005) but diversity had diminished to a total of only four genera. All other lakes had very low abundances.

Lake Colac and Corangamite had a similar species composition with the most common taxa found at both lakes being the nematode genera *Diplolaimella*. Lake Beeac, Cundare and Lough Calvert all had a similar species composition, (and similar sediment characteristics and water quality).

Lake Martin had the highest meiofaunal diversity of all the lakes including the highest abundance of very small oligochaetes recorded from the lakes studied. Oligochaetes are a sub-class of the phylum Annelida and often indicate low oxygen habitats, since they possess respiratory pigments (Giere 1993).

Total abundance for other meiofauna taxa was also very low, with often only one individual being recorded within a sample. Foraminifera and copepods were the most abundant taxa recorded. Foraminiferans occur in all marine environments and some species penetrate into brackish or fresh water. They are most commonly found in fine-grained sediment. Most sediment dwelling foraminiferans live on or near the sediment surface and are generally distributed unevenly in shallow water sedimentary environments (Higgins and Thiel 1988). Copepods are a numerous and diverse group of small crustaceans found within marine and freshwater habitats where they may be second in abundance after nematodes and provide a significant source of protein for other organisms (Higgins and Thiel 1988).

Williams (1995) noted that a faunal change occurred in Lake Corangamite in 1980, from that of a moderately saline lake to that of a highly saline lake. Taxa such as *Cordylophora caspia*, oligochaetes, *Halicyclops ambiguus* and *Austrochiltonia subtenius* and *Coxiella* species were all noted before 1980 and were not present during Williams' study in 1992. Changes in faunal composition due to changes in salinity may be responsible for low meiofaunal abundance and diversity and the absence of zooplankton during this current study. Lack of species diversity and abundance at the lower trophic levels suggests a food chain that is limited to the smallest organisms, with reduced abundance and diversity of top order species such as birds and fish.

Biotic and abiotic characteristics

Lake Martin showed different sediment characteristics from all the other lakes (Figure 3.4) and this correlated with a distinctive meiofaunal community structure. There was a greater species richness of nematodes and other meiofaunal in Lake Martin. Nitrogen concentrations were the highest at this lake due to the decomposition of organic matter from a layer of bird excreta covering the lake, and the median particle size was smaller. Lakes Beeac and Cundare had similar sediment characteristics and similar concentrations of nitrogen and phosphorus, but low nematode species richness and abundance.

3.8 Incidental sightings

3.8.1 Aim

To note incidental recordings of fauna during site visits to gain a greater understanding of the ecological condition of each lake.

3.8.2 Method

Incidental fauna sightings were recorded for two faunal types:

- Macro-invertebrates
- Birds.

Macro-invertebrates

Any sightings of macro-invertebrate burrows or shells were noted during site visits to each lake. A dip net was used to sample aquatic macro-invertebrates at Lake Corangamite (site one). Three sweeps of a 1 x1 m area were made to collect each sample. Three samples were collected.

Birds

Incidental observations of bird species and their abundances occurred during lake visits. Surveys were conducted from the shore at each site on each lake. Species were identified from Pizzey and Knight (1997).

3.8.3 Results

Macro-invertebrates

Overall macro-invertebrate abundance and diversity was very low. (*See Appendix 4 for a complete list of species found).* No aquatic macro-invertebrates were collected during net sweeps at Lake Corangamite, and no burrows or signs of sediment disturbance were noted at any of the lakes. *Coxiella striata* shells were found in large numbers at Lake Corangamite, particularly at site two where beds occurred > 1 m deep. No living *Coxiella* were noted. No adult *Coxiella* were not noted at any other lake, although many hatched out from dry lake sediment during microcosm hatching experiments (Gully 2008, School of Life and Environmental Science Deakin University, pers. comm.).

Living *Theba pisana* (an introduced gastropod) was found on higher parts of the shore at Lake Corangamite site one and two and evidence of shells were found at site three. The shell of this species was also found at Lake Gnarpurt.

Dead *Anoplognathus* spp was found at Lake Corangamite and Lake Beeac in February. Large numbers of dead *Paratemia zietziana* were found at Lake Corangamite, site one and three, but this brine shrimp was not noted at any other lake. However, during microcosm experiments, *Paratemia zietziana* hatched from dry lake sediment from Lake Beeac and Corangamite (David Wood 2008, School of Life and Environmental Science Deakin University, pers. comm.).

Lake Colac had a slightly greater diversity of macro-invertebrates than the other lakes, particularly at site three. Shell remnants of the mollusc *Sphaerium* were noted. The species is a bivalve from the family Tellinidae whose shell is similar to a Pipi in outline but without the brilliant violet colouring. The outer surface of the shell is brown, with a white interior.

Reptiles

The endangered Corangamite Water Skink *(Eulamprus tympanum marnieae)* was observed at site two. The species is listed as Critically Endangered in the Flora and Fauna Guarantee Act (1988) and listed as Endangered in the ANZECC (1995) list of Threatened Australian Vertebrate Fauna. The skink is also a nationally endangered species listed in the Environment Protection and Biodiversity Conservation Act 1999(EPBC).

Birds

Overall avian diversity was low at each lake. (See Appendix 5 for list of birds found at each lake.)

Birds were seen on all site visits to Lake Colac and Martin, but were rarely seen during site visits to other lakes. Lake Colac had a greater diversity of bird species. Ten species were sighted at site two during the survey period, compared to only two at both Lakes Corangamite and Martin (Table 3.10).

The Australasian Shoveler was seen in the greatest abundance at Lake Colac during site visits at the end of February. The water–level was greatly reduced in the lake at this time and the birds were noted in flocks of around 50–100 individuals on exposed areas of the lake bed. Black Swans and Pelicans were only noted at Lake Colac at the start of the survey period when the water levels were highest. Australian Ravens and Whistling Kites were noted in the greatest abundance at the end of the survey period when the abundance of dead carp was greatest, particularly at site two.

Banded Stilts were noted in the greatest abundance at Lake Martin in early January. By the end of the survey period in March this species was absent, and the lake bed was dry.

Birds were not noted at Lake Cundare or Lough Calvert and only one pair of Hooded Plovers was sighted at Lake Beeac. No birds were observed at Lake Corangamite site two and three and were only sighted at site one at the start of the survey period.

Table 3.10 Total number of avian species recorded from each lake site.

Lake	Site	Total no. of avian species
Lake Corangamite	1	2
	2	0
	3	0
Lake Colac	1	3
	2	10
	3	4
Lake Martin	1	2
Lake Beeac	1	0
	2	0
	3	1
Lake Cundare	1	0
	2	0
Lake Gnarpurt	1	1
Lough Calvert	1	0

3.8.4 Discussion

Macro-invertebrates

Macro-invertebrates are particularly sensitive to salinity changes (Mitchell 1996). However, many invertebrates of saline lakes can tolerate salinities higher than recorded elsewhere for their taxonomic grouping (Bayly 1972). The low diversity and abundance of macro-invertebrates recorded at all lakes during this study, suggests that salinity changes have occurred so rapidly or to such a level that many macro-invertebrate species have been excluded.

Fauna noted in 1992 in Lake Corangamite had wide ranges of salinity tolerance and were not expected to be affected by increasing salinity levels (Williams 1995). But in 2005, the biota had fallen from 24 previously recorded species to a simple community of brine shrimp (*Paratemia zietziana*), a copepod *(Calamoecia clitellata*), an ostracod (*Australocypris robusta*), and isopod (*Halaniscus searlei)* (Timms 2005). This current study found no aquatic macro-invertebrates within Lake Corangamite and only one living species (*Theba pisana)* on higher parts of the shore. Dead *Coxiella striata* were found in large numbers and have only been found alive at this lake when salinities were between 21 and 122 ppt (Bayly and Williams 1966). Current salinity levels during this study reached 368 ppt at Lake Corangamite, 40 ppt at Lake Martin and 32 ppt at Lake Colac. No other living macro-invertebrates were noted, suggesting this faunal size group has almost disappeared from the lake at this point in time.

Macro-invertebrates have been recorded from all lakes in the current survey in past studies (Bayly and Williams 1966; Geddes 1976; Marchant and Williams 1977 b; Williams 1978); however, they were recorded only from Lake Colac during this study. Williams (1992) suggested that the fauna of Lake Colac is significantly different compared to the other lakes of the region. This lake was generally considered a 'freshwater' lake compared with the higher salinities of the other lakes in the region. A higher diversity of macro-invertebrates was recorded at this lake, but all of these were noted on higher terrestrial parts of the lake. None were noted from within the lake or the lakes edge.

Few species of macro-invertebrates are found in lakes when salinity levels are > 100 ppt (Mitchell 1996) Penetration of invertebrates into inland saline lakes from other areas is said to be high (Bayly and Williams 1966), and taxa may propagate from nearby areas if water levels rise. Williams (1995) stated than no animal found within Lake Corangamite was restricted to the lake and repopulation from other nearby streams is possible.

Dispersal stages of propagules of different lake taxa are an important consideration, to ascertain what level of diversity will return to the lakes once water returns. During mesocosm experiments Brock et al. (2005) found that organisms emerging into waters with salinity between 100 and 500 ppt showed a decrease in abundance and species richness compared with organisms hatching into lower salinities. Loss of faunal species and viable dormant stages will result in a decreased diversity when lakes refill. If salinity levels do not decrease markedly then it is possible that some species may never return.

Birds

With the paucity of lower order organisms, consumers such as birds are greatly affected. This study found very few bird species at the lakes during the survey period. Lake Colac had the greatest diversity, with a total of ten species sighted. All the other lakes had very limited bird diversity with four lakes having two species or less. These data were from incidental sightings and it is likely that other species may frequent the lakes. Birds are one of the most important natural resources of saline lakes (Comin et al. 1999). Many of the lakes are Ramsar listed sites and the reduction of avian fauna noted in the current study requires confirmation from more intensive surveys.

Fifty four bird species have been recorded in the past from Lake Corangamite (Williams 1995), ten of which are migratory. Corrick (1982) noted 14,000 hoary headed grebes, 1900 Musk Duck, 7500 Coot, 1400 great crested grebe, 8200 black swans and 100 chestnut teal at varying times on the lake. Several sites on the lake such as Wool Wool and Vaughan Island held breeding colonies of such species as Pelicans, Straw necked Ibis and Sacred Ibis (Department of Primary Industries 2008), and the lake has been noted as one of the most important water bird habitats in Victoria (Williams 1995). However, in 1992 Williams (1995) noted that a great reduction in bird numbers had occurred with only a few species frequenting the lake, and in that year at least, the lake no longer met its Ramsar requirements. During the survey period of this current study, only two species were sighted at Lake Corangamite (Silver Gull and Pacific Black Duck). The effects of the present drought on water bird habitat is currently exacerbated by the recent drying of Lake Gnarpurt, which is closely linked to Lake Corangamite and normally provides an important drought refuge (Department of Primary Industries 2008).

Loss of the food species known to be consumed by birds, such as *Coxiella*, *Galaxias maculatus* and *Austrochiltonia subtenuis,* has greatly decreased the value of the lake for birds (Williams 1995). The salinity at which the food base for birds flourishes is 30–35 ppt (Williams 1995). Therefore extreme salinities noted during this study were likely to be responsible for the reduction or complete loss of food species and consequent reduction in bird abundances.

The amount of salt marsh habitat in the area indicates that large or significant numbers of migratory waders and possibly Orange-bellied parrots could be found (Department of Primary Industries 2008). Orange-bellied parrots were not sighted at any of the lakes during the end of March, which is the time when they arrive in Victoria. The parrots have been recorded at Lakes Martin and Cundare and the other saline lakes of the Corangamite region (Biodiversity Information Resources and Data 2008; Appendix 1).

Carp in Lake Colac

The loss of carp in Lake Colac due to increased salinities is a further indicator of ecosystem stress. According to EPA reports, the first signs of carp dying in the lake occurred in February 2008 and continued into March with approximately 500 tonnes or 60,000 fish dying in total (EPA Victoria 2008). Carp, however, cause increased risk of algal blooms due to alteration of nutrient content, re-suspension of sediments via disturbance, damage to macrophtyes and feeding directly on zooplankton (Khan et al. 2003). The loss of carp may be considered a positive aspect of the rising salinity and decreasing water levels within the lake. Carp eggs are reported to survive ‘almost indefinitely’ (Colac Otway Shire 2007) so the species may return with increasing water levels.

3.9 Lakes overview

This study was performed over a three month period from January to March. While these months generally bring reduced rainfall and increased evaporation, the salinity levels recorded during this study exceeded historically recorded levels for most of the lakes. The predicted trend for Victoria at this time is increasing climatic warming and drought conditions, and with this in mind it can be assumed that the lakes in the area will continue to degrade at an increasing rate.

The drying conditions enabled collection of only one set of samples from some sites. Seasonal changes were not followed and the biological and physio-chemical data necessarily represent a ‘snap-shot’ of the lake conditions at the time.

3.9.1 Current lake status

Saline lakes are important natural assets with a wide range of values including scientific, conservation, aesthetic, cultural, economic, recreational and ecological attributes (Williams 2002). The overall outcome of this study was that all the lakes investigated were found to be in a progressively degrading state. It is likely that anthropogenic pressures on the lakes over the years, such as groundwater extraction, land clearing and industrial and agricultural practices (Khan et al. 2003; Timms 2005) have increased the vulnerability of the saline lake ecosystems to the impacts of increasing climatic warming and atmospheric changes.

The main cause of declining biotic communities in all lakes is the decreasing water level and subsequent rising salinity levels; and the increased impact that occurs when changes occur on such a short time scale. Out of the seven lakes studied, five were completely dry by the end of the survey period, and water levels in the remaining two (Lakes Corangamite and Colac) had dropped markedly. Consequently, salinity levels were well above previously recorded levels for all lakes where water parameters were measurable.

The impact that increasing salinity has on the biota is determined by original lake salinity levels. Williams (1995) found that an increase of 20 ppt in Lake Corangamite (which brought levels to 35 ppt) was a highly significant increase and almost led to the complete disappearance of fish, amphipods, snails and *Ruppia*, with associated consequences for avian fauna. In that year Williams (1995) states that Lake Corangamite no longer met the requirements for its Ramsar listing. Given the large salinity levels noted during this study, and reduced biodiversity, it would seem that Lake Corangamite and the other Ramsar lakes in this study may no longer meet Ramsar requirements.

Lake Beeac and Cundare are the two lakes which seem to be the least adversely affected. These lakes were naturally hyper saline and have often seen large fluctuations in salinity levels or drying out of the lake bed (Bayly and Williams 1966). However, the results of the present study show even these niche ecosystems are degrading with a loss of biotic abundance and diversity due to prolonged drought.

As salinity increases, the biota of the lakes undergoes changes in community structure. For example, the extreme conditions have resulted in convergence of the community structure in Lake Colac with that of the other lakes that are more saline. In this study macrophytes and aquatic vegetation were absent from all lakes, including Lake Colac, due to variable and increased salinity levels. Phytoplankton was reduced to one species in large abundance in Lake Corangamite. The biota, where measurable, was reduced in abundance and diversity at all lakes.

4 Potential climate and land use change effects—'looking forward'

4.1 Climate change effects

Predicted effects of climate change in western Victoria (based on CSIRO modelling; Comin and Williams 1994; Williams 2002; Timms 2005) include:

- reduced winter rainfall
- reduced runoff
- reduced stream flows (predictions for flow in Barwon/Woady Yaloak Rivers)
- increased variability of stream flow
- increase in severe summer storm events
- increased summer temp
- increased evaporation rates
- increased summer storm events; that is, increased erosive runoff events compounded by loss of vegetation cover.

Small changes in hydrological budgets will be amplified in shallow salt lakes (Williams 2002; Timms 2005).

4.2 Salinity tolerance of Australian aquatic biota

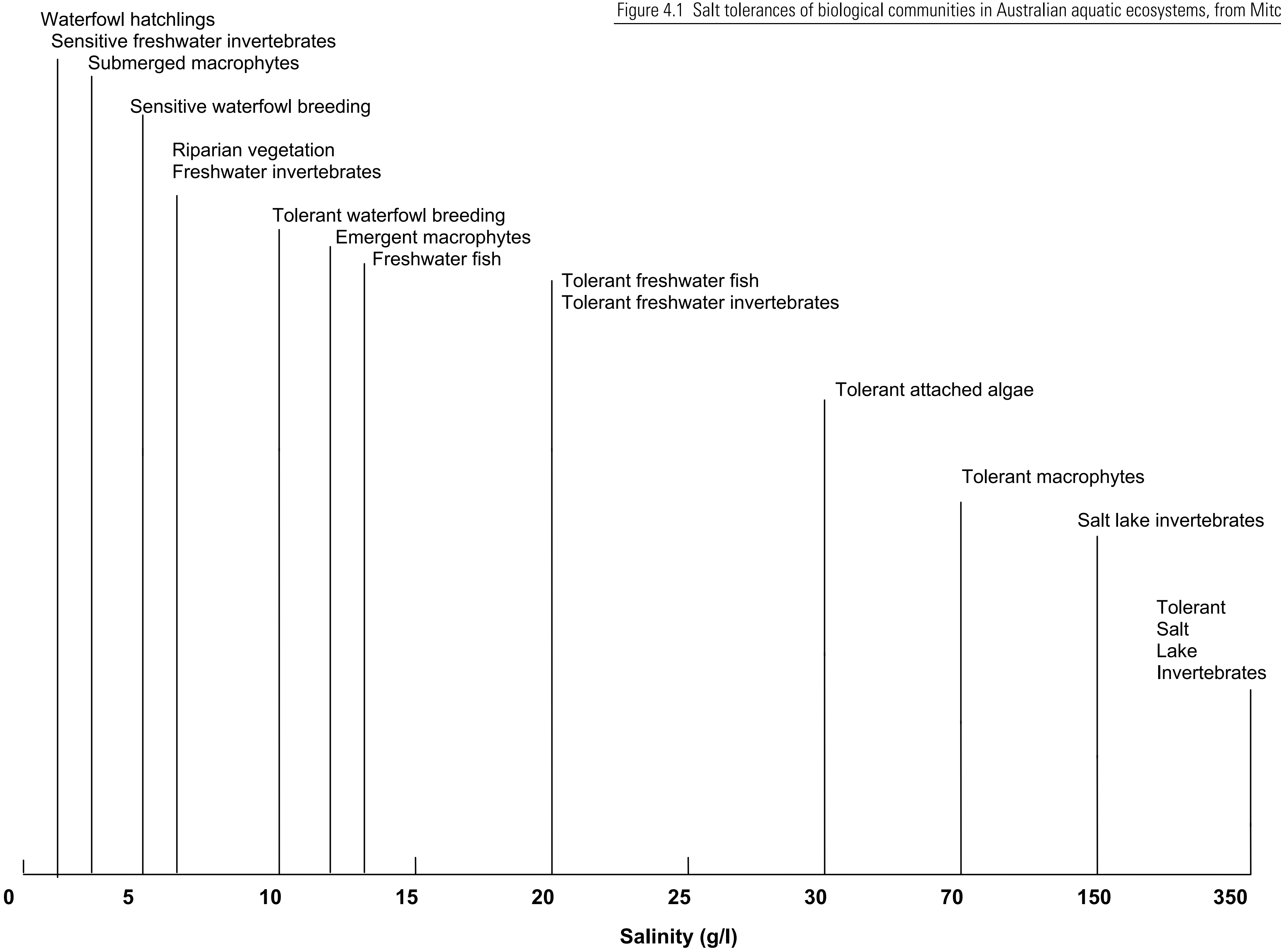
Australia has a large, diverse salt tolerant aquatic fauna, but the diversity of aquatic ecosystems decreases as salinity increases; for example, the number of taxa from waters between 1 and 10 g/l is only 50% of that recorded below 1 g/l (Williams 1981). There is a large group of salt tolerant 'freshwater' species (occur from 1–20 g/l) in lakes in this region and a less diverse group inhabiting moderately saline environments (10–60 g/l). Salt tolerances of aquatic organisms (based on field records) are summarised in Figure 4.1 (based on Chessman and Williams 1974; Clucas and Ladiges 1980; Halse 1987; Salinity Bureau 1989; Hart et al. 1990, 1991; Cameron 1991).

Most freshwater macrophytes cannot tolerate salinities in excess of 4 g/l; above this salinity freshwater macrophytes disappear leaving a much reduced diversity of halophytic species (Salinity Bureau 1989). Cameron (1991) showed a weak decrease in species richness of aquatic and semi-aquatic plants with increasing salinity in wetlands. This has also been reported for wetlands in the Kerang area (O'Donnell 1990, cited in Cameron 1991) but variability is common and other factors may limit producer communities and mask the effect of salinity. These factors include lag effects at recently salinised sites in that plant currently existing at a given site may not persist in the long term (Salinity Bureau 1989). Cameron (1991) identified four groups of macrophytes in wetlands in the region based on the range of salinity over which species were recorded (Table 4.1). Field salinity ranges of macrophytes correspond well with Salinity Bureau (1989) projections. Macrophyte species richness decreases as salinity increases in saline lakes (Salinity Bureau 1989).

Table 4.1 Macrophyte groups of wetlands in the region based on salinity range.

Salinity range	Macrophyte species
< 1.4 g/l	*Azolla filiculoides, Eleocharis sphacelata, Vallisneria americana, Lemna dispersa, L. trisulca*
1.4–4.7 g/l	*Phragmites australis, Myriophyllium sp., Triglochin procera*
4.7–8.5 g/l	*Potamogeton pectinatus, Typha sp.*
> 8.5 g/l	*Ruppia megacarpa, Lepilaena cyclindrocarpa*

Figure 4.1 Salt tolerances of biological communities in Australian aquatic ecosystems, from Mitchell (1996).



The only macrophyte genus present in highly saline lakes or wetlands is *Ruppia* (after Brock 1981 and 1985). In wetlands already affected by increased salinity where freshwater macrophytes are disappearing they are not being replaced quickly by halophytes (dispersal takes time) (Salinity Bureau 1989). Even the emergent reed *Phragmites australis*, which is common and forms dense stands in the Hopkins River Basin, is restricted to salinities less than 12 g/l (Clucas and Ladiges 1980). Riparian vegetation associated with wetlands displays a range of tolerance and some, like members of the *Casuarina* genus, are quite salt tolerant (Salinity Bureau 1989). However, 5–7 g/l appears to be the upper limit of tolerance of many species and most fail to germinate by about 12 g/l (Salinity Bureau 1989). Adverse effects could be expected to occur as low as 2 g/l.

Invertebrates display a wide range of salinity tolerances although two groups are apparent. The limit of tolerance for the 'freshwater' group is between 5 and 7 g/l (Salinity Bureau 1989); this group includes annelids, crustaceans and insects. For the more sensitive of these organisms 2 g/l is the upper limit of salinity tolerance with insects and molluscs being most sensitive. Macro-invertebrates, particularly dragonflies, mayflies, some stoneflies, caddis flies, some hemipterans and molluscs, will be very sensitive to salinity change with effects apparent above 2 g/l (Salinity Bureau 1989). The second group consists of salt lake forms which are more salt tolerant; this group, including ostracods, calanoid copepods, anostracans and some hemipterans, are not tolerant 'freshwater' forms but represent a very different fauna. Freshwater fish appear to be quite tolerant with limits from 10–20 g/l being common. However, few native freshwater fish have salinity ranges above 13 g/l in Victorian waters (Chessman and Williams 1974). Cameron's (1991) study of wetlands in the region showed changes in community composition at salinities of 4.5–8.2 g/l, 12–19 g/l, and 19–23 g/l, with crustaceans (ostracods and amphipods), hemipterans and molluscs (the hydrobiids Coxiella striata and Potamopyrgus niger) dominating more saline sites. Leptocerid trichopterans, odonatans and coleopterans tended to dominate in sites of lower salinity. Thus, plants and invertebrates are the most sensitive to changes in salinity.

Many waterfowl utilise brackish waters and some, like the black swan, are quite salt tolerant. However, many of those species living in saline environments, such as the chestnut teal, require freshwater nearby to drink (Salinity Bureau 1989). This is particularly important for hatchlings. Although the adults of many waterbirds are quite salt tolerant the salt glands remain undeveloped for about a week after hatching; in saline wetlands hatchlings rely on freshwater seeps (Halse 1987). The normal salinity at the time of hatching (spring) is low and older birds can cope with salinity increases during summer as salt glands become functional (Halse 1987). However, without access to freshwater, ducklings cannot survive if salinity exceeds 2 g/l (Salinity Bureau 1989). Even the more salt tolerant species cannot breed above 5–10 g/l without access to freshwater and some such as grebes, blue billed ducks, musk ducks, shovelers and pink eared ducks, will not breed successfully above 5 g/l (Halse 1987).

The relationship between salinity and species richness has been described by Hammer (1986), Williams et al. (1990) and Williams (1998). Over the broadest range of salinity species richness is negatively correlated with salinity; over intermediate ranges of salinity these relationships break down and are non-significant. Species richness is highest in lakes at the low end of the salinity range and decreases dramatically over a narrow range of salinity at the low end of the salinity range (0–10 g/l); the steepness of the decline in species richness with increasing salinity decreases at an intermediate salinity range (10–50 g/l) and then decreases gradually with increasing salinity above this (50–360 g/l). This is modelled by Williams (1998) and who has suggested that salinity will exert a major influence on community complexity at lower salinities but that other factors become more important at higher salinities. This will mean that an increase in salinity above 50 g/l will not of itself necessarily exert dramatic effects on species richness of saline lakes in the region. Other factors may be involved and may modify the effect of salinity. These modifying effects may be indirect. These factors include:

- geographical location
- oxygen availability which is reduced at high salinity
- ionic composition; certain species are excluded when concentrations of particular ions or the ratios of particular ions reach critical values
- low pH which excludes certain species
- hydrology (summarised in section 2.2.4)
- palaeoclimatic events: previous periods of aridity coupled with the lack of availability of refugia impact on species richness
- human intervention
- biological interactions such as predation and competition.

Reduced diversity in salt lakes reflects the physiologically demanding nature of those environments; to survive in these habitats organisms must be simultaneously adapted to high salinity and desiccation. The latter mandates for resistant stages in the life cycle (Williams 1983).

4.3 Past periods of climate change: palaeolimnology of lakes in the region

Palaeolimnological studies of lakes in the region prior to 1986 have been summarised by Hammer (1986). Studies since that time have been conducted by De Deckker (1986) and De Deckker et al. (1988). Radiocarbon dating was used to determine the age of sediment layers from lake sediment cores, and the chemical composition of muds and the fossilised shells of micro-organisms preserved in the muds were used to determine climate and salinity. These studies have shown that both climate and lake salinity have changed dramatically over the last 10,000 years (De Deckker 1986; Hammer 1986; De Deckker et al. 1988). The impact of these changes on a given lake will depend upon its depth and volume, whether or not it is an open or closed system (Hammer 1986), and whether or not it is connected to the groundwater (De Deckker 1986). Results for Lakes Keilambete, Gnotuk, Bullen Merri and Purrumbete, all within or slightly west of the region of interest) are summarised in Table 4.2 (based on De Deckker 1986; Hammer 1986).

Lake Keilambete is recognised as the lake most sensitive to changes in rainfall as it has little contact with regional groundwater and has a small catchment area relative to lake surface area—water level and salinity will therefore be more closely associated with changes in rainfall than for other lakes in the region (De Deckker 1986). Nevertheless, there are some broad climatic trends evident in the palaeolimnology of lakes across the region of interest suggesting a regional pattern of water level change (De Deckker 1986).

Table 4.2 Impacts of climate change on lakes Kielambete, Gnotuk, Bullen Merri and Purrumbete.

Approx. years BP	Kielambete	Gnotuk	Bullen Merri	Purrumbete
0–300	Shallower, saline 17.5–70 g/l	Shallower	Deeper, brackish	No change in water level
300	Shallower, 10–43 g/l Ruppia		“	“
300–2000	Deeper, fresher Trees drowned around 2000 BP	Deeper	“ < 13.4 g/l Trees drowned around 2000 BP	“
2000–3000	Shallower, saline 45–77.5 g/l Trees Diacypris compacta	Shallower	Shallower, saline 2–7 g/l	“
3000–4000	Deeper, fresher 19–43 g/l	Deeper	Deeper	“
4000–7000	Deeper, fresher 19–43 g/l Ruppia	Deeper	6400–7400 BP shallower, up to 5.8 g/l 7400–8000 BP deeper, fresher < 3g/l	“
8000–10,000	Shallower, saline 43–182 g/l Diacypris compacta	Shallower	8000–8700 BP shallower	
> 10,000–18,000	Lake dry	Lake dry	Lake not dry	

Salt lakes in the region appear to have undergone periods of drying and filling over the last 10,000 years with most lakes being dry before that time. These changes have caused shifts in macro invertebrate (ostracod and cladoceran), macrophyte and algae communities in the lakes (De Deckker 1986). Some lakes, such as lake Keilambete, have shown recovery of species when salinity conditions became more favourable; this indicates that a source of colonisers must have been available within the region. Lakes Gnotuk and Bullen Merri were colonised by fish on several occasions despite having elevated crater rims and no tributary streams (De Deckker 1986). The increase in salinity in Lake Keilambete about 3000 years BP dramatically altered the aquatic flora and fauna (ostracod and cladoceran zooplankton) of the lake. The lake flora shifted from freshwater algae to halophytic macrophytes as salinity increased beyond 15 g/l (De Deckker et al. 1988).

Lakes Gnotuk and Keilambete dried completely between 10,000 and 18,000 years BP; the aquatic biota of these lakes has therefore been ‘completely reconstituted’ at times in the past (De Deckker 1986). There is no evidence that important elements of the fauna of Australian lowland lakes became extinct during this period

(De Deckker). This begs the question of how the aquatic biota survived previous periods of aridity. The answer to this question ('looking back') may shed light on how the aquatic biota will adapt to future periods of aridity ('looking forward'). De Deckker (1986) argues that the biota survived past periods of aridity in refuges consisting of:

- coastal lakes that have since been inundated by rises in sea level
- large lakes in Tasmania
- some permanent inland water bodies such as mound springs
- rare inland water bodies that escaped the full impact of arid conditions.

Implications: in a landscape like Western Victoria shallow terminal lakes come and go—the fauna changes and appears, at least in some cases, to be able to recover (e.g. reoccurrence of certain species of ostracod and halophytic macrophyte in Lake Keilambete after several thousand years in response to the development of more favourable salinity conditions). In the short term, lake systems are changed dramatically in terms of their flora and fauna. Shallow playa lakes will respond to the predicted effects of climate change by reverting to the state apparent during previous periods of low rainfall and higher temperatures. Recovery processes in a particular locality will be dependant upon two factors:

- Short term cyclic climatic variation (wetter and drier periods) within a longer term climatic change trend
- The proximity of the locality to suitable aquatic refuges.

The latter may be problematic given that the future period of aridity due to climate change will not be correlated with lower sea level as was the period prior to 10,000 BP. This may mean that some of the potential refuges available in coastal areas during that period may be unavailable in the future. This would have been the most suitable type of refuge for the halobiont fauna of inland salt lakes during past periods of aridity. However, this type of refuge is now greatly reduced due to transgression by sea levels over the past 10,000 years.

Changes in lake levels in the region over more recent times (the last 150 years) have been correlated with periods of low rainfall (EPA 2007). Williams (2002) predicts that by 2025, most natural salt lakes will have undergone some negative change. Williams predicts that many permanent lakes will have decreased in size and increased in salinity, and that many shallower more temporary lakes will be drier for longer periods. He has also suggested that new salt lakes will appear in the landscape due to the salinisation of previously fresh water bodies and the anthropogenic formation of salt lakes as a result of land and water use processes.

The state of catchments at the present time will, of course, differ dramatically from that prevailing during past periods of climate change. This means that the press disturbance of climate change will be additive to the press disturbance of land use change. The relationship between climate and lakes is indirect (as it acts through the agent of weather) (Hammer 1986). The relationship between weather and lakes is more direct. As a consequence the effects of a climate change on lakes may be delayed and may also be obscured to some degree by human activity in lake catchments. This means that the future effects of climate change may not emulate the past effects of change even if it is to a similar climatic state. The hydrology of the region has been altered by human activity and shallow playa lakes are accumulating materials that they were not during the past. This means that predicting future impacts of climate change ('looking forward') by examining the effects of past periods of climate change ('looking back') has a degree of uncertainty. Postulating on potential ecosystem recovery pathways will also involve uncertainty. This will be particularly so for catchments where human intervention has reduced or eliminated hydrologic refugia. However, 'looking back' remains the best tool available for 'looking forward'.

4.4 Conceptual model for predicting climate change effects—'looking forward'

Four key communities occur in shallow lake and wetland environments. These are:

- Producers
  - attached algae
  - macrophytes (emergent and submerged)
- Consumers
  - invertebrates
  - vertebrates (primarily fish and waterfowl).

Riparian vegetation should be considered within the producers due to its role in contributing organic matter, habitat and shoreline stabilization. The food chain linkages between these communities must be borne in mind when considering the impacts of salinisation due to climate change. Similarly, the physical and chemical factors other than salinity that limit these communities must be considered. Salinity may impact organisms directly through physiological effects or indirectly through habitat or food chain effects. Salinity may act indirectly through food chain linkages or by contributing to changes in other physical or chemical limiting factors.

Based upon previously published work of salinity tolerances, the expected direct effects of increases in salinity due to climate change can be considered. In making this type of assessment both concentration of dissolved salts and exposure time are important; organisms can withstand higher salinities if exposed for shorter periods of time. Thus, it is useful to think of two types of salinity disturbance: a 'press' saline disturbance which corresponds to the gradual, persistent increase in salinity of a system such as a wetland subject to saline groundwater input; and a 'pulse' saline disturbance which corresponds to short-lived, rapid exposure to elevated salinities (the salinity increase may be marked but only persist for a short time) such as flushing of a saline pool in a river, or flushes of water from saline tributaries. Salinity effects due to climate change will be press disturbances.

Increasing salinity to between 5 and 10 g/l in shallow freshwater lakes and wetlands in Western Victoria can be expected to reduce submerged, emergent and riparian vegetation (e.g. Clucas and Ladiges 1980; Halse 1987; Salinity Bureau 1989). This vegetation is important refuge and nesting habitat for waterfowl and the associated vertebrate and invertebrate communities provide food for waterfowl and other waterbirds. The macro-invertebrates of wetlands will be directly affected at about 2 g/l. Salinity induced changes in macrophytes will greatly affect the micro invertebrates associated with plant communities and changes in phytoplankton will affect zooplankton grazers. Due to their relatively high tolerances fish will not be affected directly but the loss of habitat (aquatic plants) will expose them to greater predation and disturbance to invertebrate communities will reduce their food base.

The micro- and macro invertebrates associated with aquatic plants are important for waterfowl, and a diverse food base including frogs and crustaceans, is important for specialist feeders such as darters and egrets (Crome 1988). The effects of salinity on hatchlings will mean that as salinity in wetlands increases they will become unsuitable as breeding habitat for waterfowl. While saline (5–10 g/l) wetlands could be used by adults of some species (e.g. grey teal, black swan, coots and cormorants) (provided suitable food was available) the number of resistant breeding species would be reduced by about 50% (Halse 1987). In this context the beneficial role that wetland birds such as ibis and ducks may play in feeding on insects (crickets and grasshoppers) on agricultural land (Williams 1983) should be borne in mind.

The situation is likely to be much more complex than simply the projection of direct effects of salinity. A conceptual model of the potential effects of climate change on shallow lakes in western Victoria has been developed and is presented in Figure 4.1. This model is based upon the likely effects on shallow lakes of a change from wet to dry conditions. The model assumes a continuum of conditions from 'wet' = freshwater to 'dry' = saline under a climate change scenario. The model is also based upon the concept of alternative stable states (Scheffer and van Nes 2007) and the assumption that climate change is likely to push shallow lakes through a series of states of varying stability over time. The model focuses on changes in shallow lakes in intermediate salinity ranges i.e. those lakes experiencing largest changes in salinity as a result of changes in rainfall. From Figure 3 the critical salinity range would appear to be 7–30 g/l (see below). However, correlations between salinity and species richness over this range of salinity in lakes of the region are weak (Williams et al. 1990) suggesting that at intermediate salinities and over narrow salinity ranges factors other than salinity are important in determining the occurrence of taxa. Similarly, correlations between salinity and species richness over the range 100–200 g/l are also weak (Williams et al. 1990). This situation is influenced by the broad salinity tolerance of many taxa in saline lakes of the region (Williams et al. 1990). Species present in low salinity lakes (less than 10 g/l) have the narrowest range of tolerance (Williams et al. 1990).

As a result of the factors discussed above, highly saline lakes (i.e. lakes with a clear history of periods of very high salinities above 150 g/l) and dryness (e.g. Lakes Beeac and Cundare) will not change features dramatically; they will revert to a former extreme state at 'dry' end of continuum—although mobilisation of beds under prolonged dry conditions may impact on shoreline processes and may impact on re-colonisation if resting stages are lost from lake beds. Lakes in this category are Beeac, Cundare, and Upper and Middle Calvert. Lakes with lower salinities (below 13 g/l) which may be elevated as a result of climate change are most at risk; these lakes are likely to move to a new state (and through a series of subsequent stable states if salinity continues to increase) and may lose biodiversity if organisms inhabiting lakes do not have adequate resting stages as part of life cycle. Greatest biodiversity losses are likely due to changes over the range 4–13 g/l (Mitchell 1996). Lakes in this category are Colac and Martin – Cundare pool.

The model presented in Figure 4.2 is based on information from a variety of sources: Hammer (1981, 1986), Williams et al. (1990), Mur et al. (1993), van der Molen and Boers (1994), Jeppesen et al. (1994), Moss (1994), Williams (1998), Davis et al. (2003). Rip et al. (2007), Mooij et al. (2007), Gross et al. (2007), Scheffer and van Nes (2007), Blindow and Schutte (2007).

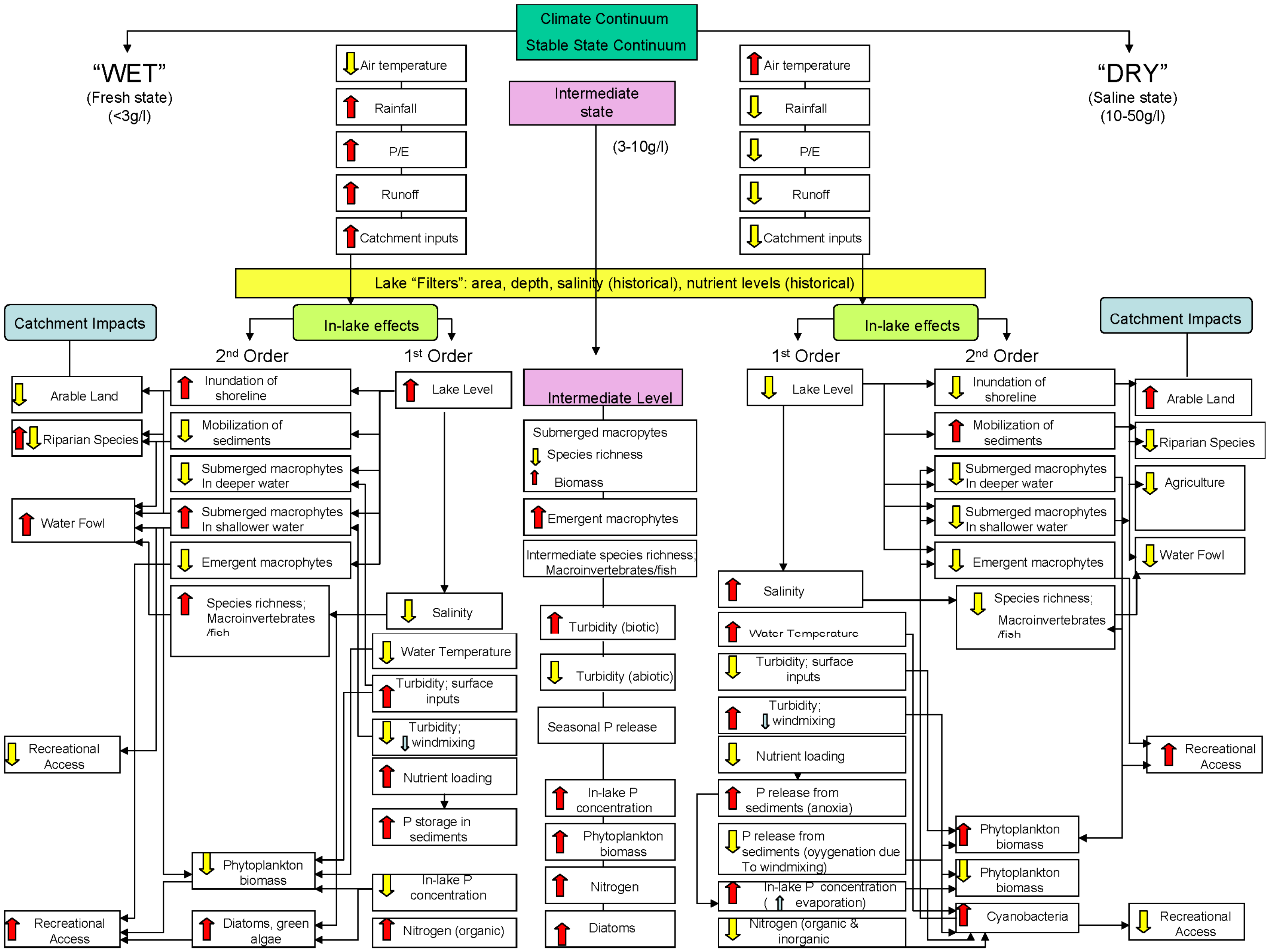


Figure 4.2 Conceptual model of potential effects of climate change on shallow lakes of the volcanic plains of western Victoria.

The conceptual model presented above can be used to predict the potential effects of climate change on lakes in the region. Intra-lake biotic components will respond to climate change but the nature of the response will be affected by key features of lakes such as area, depth, starting salinity, and starting nutrient levels. These factors act as a 'filters'; the effects of climate change will be mediated by these filters and are likely to be highly site specific.

Potential effects of climate change on the areas of lake systems reviewed above can be summarised as in Table 4.3.

Table 4.3 Potential effects of climate change on lake systems.

Lake system component	**Potential effects of climate change (drying)**
Riparian soils	Reduced soil moisture, increased wind erosion
Riparian vegetation	Decline in species number and density (will contribute to increased wind erosion)
Riparian fauna	Decline in species richness
Lake area	Reduced
Lake depth	Reduced
Salinity	Increased
Nutrients	Increased
Suspended solids	Increased (due to increased wind mixing as lake becomes shallower)
Oxygen levels	Reduced
Bacteria	Increased benthic algal mats
Algae	Shift to blue-greens, semi-permanent blooms
Macrophytes	Decline in species number and density
Micro- and macro- invertebrates	Decline in species number, shift to highly salt tolerant forms
Fish	Decline in species number
Waterfowl	Decline in species number and abundance, shift in species

This review has shown that major changes have occurred in several of the lakes of interest have occurred since the 1992 study of Williams. Based upon the current data further changes have occurred in:

- Lake Gnarpurt—previously classified as permanent (Williams 1992) and is clearly not
- Lake Martin – Cundare Pool
- Lake Colac
- Lake Corangamite.

Lakes Cundare and Beeac are in a drying phase but this represents a typical state for such lakes at certain times. The status of Lough Calvert is difficult to assess—Lower Calvert is probably now much drier for longer periods than in the past and Middle and Upper Calvert are probably also drier for longer periods. That is, the frequency of drying has probably increased (or the frequency of wetted periods has decreased).

In 1992 Williams considered that only Lakes Martin – Cundare Pool and Corangamite showed any change from their historical situation. The situation has clearly changed and other lakes in the region are showing effects predicted by the model presented in Figure 4.2 above.

The conservation status of Lake Corangamite and Lake Martin – Cundare Pool has changed. Lake Martin – Cundare Pool can no longer support stock watering/irrigation. In the case of Lake Corangamite there has been a loss of ability to support bird populations—the number of species using the lake and their abundance has decreased (Williams 1992; Timms 2004) and several species had ceased to use the lake for nesting in 1992 (Williams 1992). Williams (1992) argued that, as a result of these changes, Lake Corangamite had lost those values that were the basis of its selection as a Ramsar site. Lake Corangamite could dry completely if current rainfall trends continue. This would result in deflation and mobilisation of lake bed sediments.

The situation in Lake Corangamite is complex as a climate change effect must now be superimposed upon an effect due to water diversion. Changes due to water diversion were already evident in Lake Corangamite (Williams 1992) prior to the onset of the drying period from 1997. The lake has been through previous periods of high and low rainfall, high and low water level, and low and high salinity. During those cycles the lake recovered its biodiversity when salinity decreased due to increased rainfall. However, the circumstances have changed and the current diversion of inflows will mean that even if rainfall returns to higher levels than at present the lake will not receive the same inflows as it would have prior to the 1960s. This means that recovery in the sense of previous periods of the lake's history is no longer possible.

Lake Colac is apparently heading for a period of dryness. Shallow, highly saline intermittent lakes such as Cundare and Beeac are expected to dry quite frequently. Larger, deeper fresh and more moderately saline lakes are expected to dry infrequently.

4.5 Future management issues: climate and land use change effects

4.5.1 Climate change effects

Salt lakes are particularly sensitive to changes in their hydrological budget which are influenced by small changes in the climatic variables of precipitation and evaporation (Williams 2002; Timms 2005). Climate change models predict decreased runoff for much of the Australian continent (Timms 2005) and for streams in the region (CSIRO modelling). Global warming will exert greater effects on salt lakes than on freshwater lakes (Williams 2002). This will be compounded by the greater increase in temperature expected in those regions where salt lakes occur (Williams 2002). Based upon the model presented by Williams (2002) and the findings of Timms (2004, 2005) the following changes to lakes in the region may be expected:

- Permanent, deep lakes in the region will become smaller, shallower and more saline; some may eventually become dry.
- Shallow seasonally filled lakes will become episodic and eventually dry.
- Episodic lakes will remain drier for longer.
- Biodiversity will decrease.
- The biota will increasingly be dominated by species with good powers of dispersal and resistant stages in the life cycle.
- Waterfowl use of the lakes will decrease and a species shift will occur.

In a climate change scenario previous concepts of ‘permanence’ of lakes will need to be revisited.

4.5.2 Land use change effects

Diversion of freshwater inflows for agriculture and other human needs is considered by Williams (2002) to be the most important impacting activity on large permanent salt lakes. Salt lakes respond rapidly to alterations in hydrological budget and inflow diversions cause a rapid decrease in lake volume with concomitant effects on water chemistry. This in turn impacts on biota where greatest effects occur in lakes with low original salinity and least effects occur in lakes that were originally hyper saline (Williams 2002). The increase in salinity in Lake Corangamite as a result of diversions of flows from the Woady Yaloak River has resulted in a decrease in biodiversity (Timms 2004 and 2005), the disappearance of fish, amphipods, snails and the macrophyte *Ruppia* from the lake (Williams 1995 and 2002) with consequent effects on waterfowl (Timms 2004 and 2005).

Increased pressure on groundwater resources in the region is likely as surface water resources decrease under a climate change scenario. The importance of the link between groundwater levels and lake levels in the region has been discussed above (Radke et al. 2002). Overuse of groundwater resources has caused decline in lake levels in some groundwater-fed lakes within the region, for example the Red Rock Complex (Timms 2005).

An increase in severe summer storm events in cleared catchments and catchments in which overgrazing by cattle and sheep has occurred are likely to generate increased silt loads to salt lakes and contribute to a reduction in depth (Williams 2002). This will exacerbate the effects of reduced rainfall. Nutrient loading to lakes from agriculture in lake catchments will continue and may increase as a result of increased silt loads. Combined with the effects of increased evaporation this will elevate nutrient levels in lakes and stimulate further blue green alga blooms; the lakes within the region are likely to be shifted to blue green algae dominance.

Not only will land use changes impact on the lakes of interest but changes in the lakes as a result of climate change may impact on land use in the region. Increased nutrient levels may shift the lakes to blue green alga dominance; export of compounds of blue green algae origin from the lake may be a possibility. It is highly likely that Lake Corangamite will become dry. If the lake bed material is mobilised, as has happened for the bed of Lake Gnarpurt, then impacts on the surrounding catchment are likely. Almost certainly sediments from Lake Corangamite will be distributed onto soils in the catchment. This is likely to increase the salinity of soil in the region and impact on agriculture and terrestrial ecosystems including lake riparian systems. Revegetation of riparian areas is likely to be increasingly difficult. Dust carried by wind action across the towns of Colac, Camperdown and Cressy is likely to impact on human health via one or more of a variety of potential mechanisms such including:

- deeply inhaled fine dust particles
- dust born heavy metals
- dust born or volatilised windborne phytotoxins
- windborne blue green algae spores.

Climate change in the region is likely to result in the 'export' of impacts from lakes onto the landscape and the future of the region needs to be considered based on the model presented in Figure 4.3. This represents a new paradigm for considering landscape effects in the region.

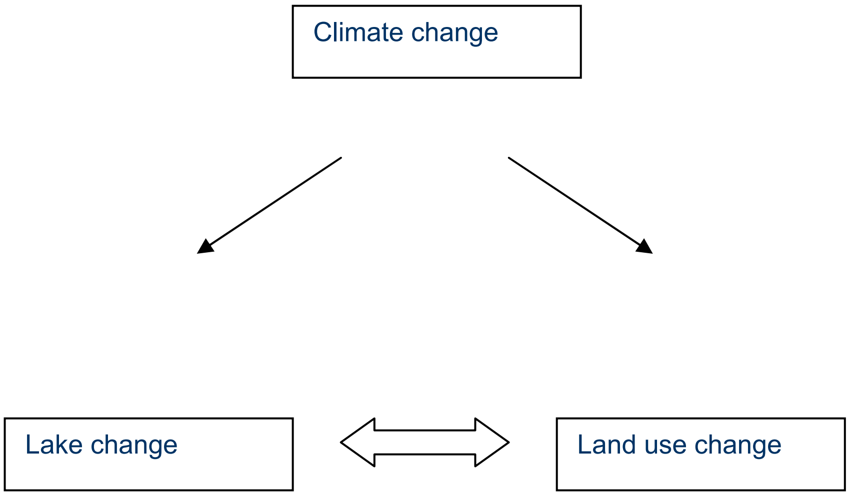


Figure 4.3 Model of the interactive effects of climate change on lakes and land use in the Corangamite region.

5 Conclusions

The overall effects of climate change and continued trends in land use in the region on the group of lakes of interest can be summarised as:

- Small, shallow natural salt lakes will dry up
- Small, shallow, man-made salt lakes will increase; these will display different chemical properties to natural salt lakes
- Lakes at the higher end of the salinity spectrum (Beeac, Cundare, Upper and Middle Calvert) will enter their typical dry phase (they will flip between wet and dry states depending upon short term rainfall changes); the fauna of these lakes is adapted to this dry state
- Lakes at the lower end of the salinity spectrum (Colac, Martin, Lower Calvert) will show most change; salinity will increase and the fauna will change (as has already occurred)
- Lakes in the middle of the salinity spectrum (Corangamite, Gnarpurt) will move to a highly saline state not experienced before in recorded history (as has already occurred) or to a dry state which occurs much less frequently than is the case for lakes at the high end of the spectrum (as has already occurred). Whilst the fauna of lakes at the high end of the salinity spectrum are adapted to periods of hyper salinity or dryness, the fauna of lakes in the middle of the salinity spectrum may not be adapted to these conditions
- Large, deep salt lakes will become shallower and more saline, and may dry completely
- Salt lakes with macrophytes will shift to cyanobacteria dominance
- Human access to salt lakes will decrease as a result
- Salt lakes with cyanobacteria will shift to benthic microbial mat dominance
- Species richness of salt lake faunas will decrease
- Regional specialisation will be lost due to local extinction as a result of reduced refuge availability
- Use of salt lakes by many species of waterfowl will decrease but may increase for some (smaller number) migratory species
- Sediments of lake beds will be mobilised by deflation potentially impacting on human health and agriculture.

The group of lakes of interest will be lost from the landscape and significant ecological values will be lost. Regional biodiversity will decrease as a result. Waterfowl will be especially impacted and loss of biodiversity in this group will be significant in the region. Some of the lakes of interest previously acted as refuges for waterfowl in times of drought; this capacity will be exceeded. Increasing salinities in the lakes of interest and, ultimately, drying of the lakes as a result of climate change cannot be avoided. Exacerbation of these effects by continued groundwater extraction could potentially be managed but this is unlikely due to increased pressure on subsurface water as availability of surface water decreases. The major management issue in the lakes of interest will become mobilisation of lake bed material and the impact of this on human health, agriculture and terrestrial ecosystems. Climate change will increase salinity in the lakes of interest; wind mobilisation of lake bed sediments will salinise the landscape further. A new management paradigm that links lake changes to landscape changes is required in the region. Management techniques to reduce mobility of sediments (in-lake techniques) and to mitigate these effects (on-land techniques) need to be investigated as a matter of priority.

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Appendices

A1 Summary of physio-chemical and biological features of selected lakes of the Volcanic Plains Region of Western Victoria

A2 Granulometric characteristics

A3 Flora species recorded from each lake

A4 Macro-invertebrates recorded from each lake

A5 Avian fauna recorded from each lake

Appendix 1: Summary of physio-chemical and biological features of selected lakes of the Volcanic Plains Region of Western Victoria

	Corangamite	**Gnarpurt**	**Martin–Cundare Pool**	**Cundare**	**Colac**	**Beeac**	**Lough Calvert**
State of knowledge	Well studied	Not well studied	Poorly studied	Relatively well studied	Relatively well studied	Relatively well studied	Very poorly studied
Significance	Largest natural lake and largest permanent salt lake in Australia; Ecological (high habitat diversity, rarity of species and communities), hydrological, scientific, cultural and aesthetic values; Ramsar, CAMBA species, JAMBA species; Among the 199 most outstanding geological features of Victoria; Aboriginal activity = fish trap on south shore, midden of shellfish on northern shore	Ecological and hydrological values; Eel harvest; Aboriginal burial site on north-west shore; Ramsar	Ecological (important habitat (size, diversity), rarity of species and communities) and hydrological values; Eel harvest; Recreational fishing; Duck hunting	Ecological values (high value for biodiversity, rarity of species and communities); possible Aboriginal site; Ramsar	Recreational value; Eel harvest; Water for agriculture	Ecological and hydrological values; Ramsar	Ecological (rarity of species and communities) and hydrological values; Occasional eel harvest; Duck hunting; CAMBA species; JAMBA species; Potential habitat for Orange bellied parrot
Type	Depressions in lava flows; regional drainage blocked by lava flows; Lunettes, beaches of *Coxiella*	Lava collapse or depression in lava flow; Lunettes	Flooded basin over former river floodplain (Cundare Pool) connected to natural saline lake (Lake Martin)	Lava collapse	Depression in lava flow	Playa	Local floodplain and lunette complex; playa system with 3 lunette associations

	Corangamite	Gnarpurt	Martin–Cundare Pool	Cundare	Colac	Beeac	Lough Calvert
Hydrology	Permanent saline lake	Semi-permanent saline lake	Impounded at entrance to Lake Corangamite, inundating Woady Yaloak River floodplain and former Lake Martin	Seasonal and intermittent hyper saline lake; direct connection with subsurface brine	Permanent freshwater lake, upper level regulated; partially closed, surface outflow (via Lough Calvert) in certain seasons (water level above EL117.40)	Seasonal and intermittent hyper saline lake; Ephemeral, dry in summer–direct connection with subsurface brine	Seasonal saline marsh (Upper), semi-permanent saline lake (Middle), seasonal freshwater pond/marsh (Lower = Lake Thurrumbong); Groundwater discharge; formerly flowed from north Lower to Upper Lough then to east, now flows to south via drainage scheme and into Birregurra Creek; wetlands infrequently interconnect at high water levels
Tributaries	Gnarkeet Chain of Ponds (NW), Lake Martin overflow (Woady Yaloak River) (NE), Pirron Yallock Creek (S)	Mundy Gulley Creek (NW)	Woady Yaloak River (NE)	?	Borongarook Creek (SE), Dean’s Creek (SW)	?	Occasional overflow from Lake Colac overflow (W) via Lake Colac-Birregurra Creek constructed flood channel
Land use	Permanent pasture	Permanent pasture	Permanent pasture	Permanent pasture	Urban and industrial use, permanent pasture	Permanent pasture	Permanent pasture
Riparian zone	Grass or groundcover; Spiny peppercress present (endangered)	Grass or groundcover	Grass or groundcover	Grass or groundcover	Isolated patches of introduced or replanted native vegetation; mostly grass	Grass or groundcover; Thin band of chenopod shrub land; Spiny peppercress present (endangered)	Grass or groundcover; Diverse salt marsh flora including Sarcornia and Halosarcia (U)
Area (ha)	23,300–25, 160	2580–2732	4020	300–395	2668	608	2750
Mean depth (m)	2.9–6	1.9–2.57	2	0.6	2.4	1.2	?

	Corangamite	Gnarpurt	Martin–Cundare Pool	Cundare	Colac	Beeac	Lough Calvert
Max. depth (m)	4.9–approx. 6; Decreasing trend since 1960	2.4–4.6	2.4	0.6	2.4	1.8	?
Shoreline length (km)	135–159	22.5–25	34	?	26	?	?
Shoreline development	2.5–2.8	1.25–1.3	1.5	?	1.49	?	?
Catchment: Lake area	5.1:1	15.2:1	33.3:1	3.2:1	8.1:1	6.2:1	?
Salinity range (g/l) and trends	12–123; > 300 recent Increasing trend since mid 1960s. Weak seasonal pattern. Small increase from south basin to shallower water in north basin	7.2–65	2.9–57	< 100 – > 300 Seasonal pattern, large seasonal change	1.3 – > 20	50 – > 300 Seasonal pattern, large seasonal change	4–284
1866	20						
1875	18.4						
1891	45						
1933	105						
1938	64						
1939	123						
1950	50						
1951	62						
1952	34						
1956	14.2						
1963	26.3						
1964	29.1						
1965	20.8		4.8				

	Corangamite	Gnarpurt	Martin–Cundare Pool	Cundare	Colac	Beeac	Lough Calvert
1970	35.1		15–57				17–140 (U)
1972				77.7–347.0	3.4	55.5–317.8	
1975	42.9				1.7–2.1		
1979–1980	26.8–39.1	7.2–13.7	2.9–8.4		1.3		
1985	58.3						
1989	67.4						
1990–1993	67–50	11.3–13.7	6.8–20.3	204.2	1.5–1.8		284 (U); 120–262 (M); 4–198 (L)
1994	22.9–25.6	8.9		162.7			
1996	42	15.4		178.6			
1998	40						
2000–2002	80–110	13.5		150	3.3–7.0	88	
2003	49.1	64.6		90.1			
2008	> 300		> 40		> 20		
Dominant ions	Na^+, Cl^- >> Mg^{++}, HCO_3^- $+CO_3^=$	Na^+, Cl^- >> Mg^{++}, HCO_3^- $+CO_3^=$	Na^+, Cl^- >> Mg^{++}, HCO_3^- $+CO_3^=$	Na^+, Cl^- >> Mg^{++}, HCO_3^-+	Na^+, Cl^- > Mg^{++}, HCO_3^- $+CO_3^=$	Na^+, Cl^- >>> Mg^{++}, HCO_3^- $+CO_3^=$	?
SS (mg/l)	40–1095	43–230		35–5300	6–180	900	?
Turbidity (NTU)	4–67 Influenced by wind and algae biomass—much higher in south basin than on east shore, high on windward shore where prevailing wind accumulates algae	8–104	3–260	145.8–350 (“high”)	5–145 (“high”)	130 (“high”)	?
Secchi disc depth (m)	0.06–5.60	0.08–0.55	0.03–0.25	0.065	?	0.06	?
pH	7.9–9.05	7.1–8.85	7.0–9.9	8.2–8.6	6.5–9.1	> 8.0–9.1	8.2–8.4

	Corangamite	**Gnarpurt**	**Martin–Cundare Pool**	**Cundare**	**Colac**	**Beeac**	**Lough Calvert**
Dissolved oxygen (mg/l)	10.0–11.6 (79–125%) Very low along southern shoreline, strong H_2S	9.2–11.8	5.1	3.0–9.6	3.2–14	10.1	2.9
Total P (ug/l)	110–550	120–620	97–170	490–5,800	1975: 3–283; 1984–2000: 670–2110	1,800	?
Soluble P (ug/l)	9–170	10–65	5–26	2,100	1975: 10–650; 1984–2000: 44–1790	1,200	?
Total N (ug/l)	1020–13,1110	553–6,760	335–1990	1,040–12,080	1975: 700–5800; 1984–2000: 1750–3840	3,100	?
$N0_3^=$ (ug/l)	< 3–760	< 3–240	30–280	< 3–850	1975: 2–3000; 1984–2000: 3–1136	10	?
Trophic status	Eutrophic (P)	Eutrophic (P)	Eutrophic (P)	Eutrophic (P)	Eutrophic	Eutrophic (P)	?
Limiting nutrient	P	N and/or P	N	N	1975 = P 1984–2000 = N	N	?
Emergent vegetation	Absent	Absent	Absent	Absent	1974: 44 macrophyte spp.	Absent	?
Submerged vegetation	1979: 3 spp. at low salinity (*Ruppia megacarpa* = dominant; *Lepilaena preisii*); 2001: 3? 2008: Absent	1? (*Ruppia*)	Abundant, several species; *Ruppia* (dominant)	Absent	1974: 44 macrophyte spp.	Absent	?
Chl a (ug/l)	10–310	8.6–79.0		< 0.5–123	14.5–66.7	22	?

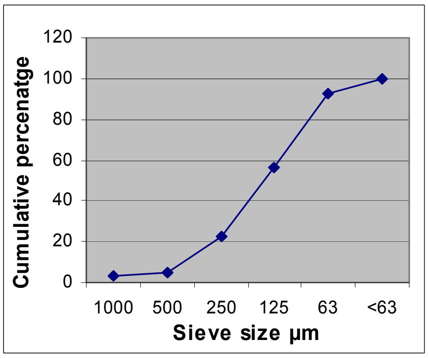
	Corangamite	Gnarpurt	Martin–Cundare Pool	Cundare	Colac	Beeac	Lough Calvert
Algae	11 spp. *Nodularia spumigena* (continuous bloom) (strandline deposits on east shore)–density influenced by wind action; *Anabaena circinalis*, *Spirulina subsala*, *Enteromorpha ralfsii, Cladophora* sp.; Dense mats of decaying floating green filamentous algae and benthic pink algae along south shore; healthy benthic green algae onshore in north basin	Nodularia spumigena (continuous presence)		Dunaliella	1974: 36 spp. Blue green blooms since early 1970s: *Anabaena circinalis,* *Aphanizomenon* spp., *Oscillatoria* spp., *Spirulina subsala*		?
Macro-invertebrates	Cnidaria 1 spp. Rotifera 4 spp. Anostraca 1 spp. Nematoda 1 spp. Annelida 2 spp. Cladocera 1 spp. Copepoda 3 spp. Ostracoda 6 spp. Isopoda 1 spp. Amphipoda 1 spp. Mollusca 1 spp. Insecta 4 spp.	Cnidaria 1 spp. Rotifera 4 spp. Annelida 2 spp. Cladocera 1 spp. Copepoda 5 spp. Ostracoda 3 Isopoda 1 spp. Amphipoda 1 spp. = dominant Mollusca 1 spp. Insecta 4 spp.	Rotifera 2 spp. Annelida 1 spp. Cladocera 5 spp. Copepoda 4 spp. Ostracoda 4 spp. Amphipoda 1 spp. Mollusca 2 spp. Insecta 20 spp.	Anostraca 1 spp. Copepoda 3 spp. Ostracoda 4 spp. Isopoda 1 spp.	Cnidaria 1 spp. Rotifera 10 spp. Copepoda 5 spp. Ostracoda 3 spp. Isopoda 1 spp. Amphipoda 1 spp. Insecta 9 spp. Annelida 4 spp. Cladocera 6 spp. Decapoda 1 spp. Mollusca 1 spp. Oligochaeta = dominant in 2005	Anostraca 1 spp. = dominant Copepoda 3 spp. Ostracoda 4 spp. Isopoda 1 spp.	Ostracoda 3 spp. Copepda 3 spp. Cladocera 1 spp.

	Corangamite	**Gnarpurt**	**Martin–Cundare Pool**	**Cundare**	**Colac**	**Beeac**	**Lough Calvert**
Instantaneous invert. spp. richness (historic)	Moderate (19 spp. in 1979–1980; 10–13 spp. post-1980)	Low (4–14 spp. from 1964–1992)	28 (when fresh) 16 (when saline)	Low (3 spp.)	High (34–42 spp. from1972–1992); 2005: "sparse"	Low (6–7 spp. from 1965–1992)	Low (7 (U))
Invert. salinity tolerance	Fauna has shifted from moderately saline to highly saline groups		Fauna has shifted from essentially freshwater to moderately saline groups	Most species < 100 g/l	Freshwater	Most species < 100g/l	?
Fish (historic)	*Galaxias maculatus* (1971), *Anguilla australis*	*Galaxias maculatus* (1964), *Anguilla australis*, *Onchorynchus tschawytscha*	*Galaxias maculatus*, *Anguilla australis*	-	*Anguilla australis*, *Perca fluviatilis*, *Retropinna semoni*, *Galaxias maculatus*, *Philypnodon grandiceps*	-	?
Birds (historic)	Australasian shoveler (significant), Australian pelican (significant), Blue billed duck, Freckled duck, Cape Barren goose, Coot, Hoary-headed grebe, Great crested grebe, Black swan, Musk duck	Horny-headed grebe, Crested grebe, Little black cormorant, Musk duck, silver gull, Pelican, Spur-winged plover, Red necked stint, Whiskered tern	Very large numbers: Australian shelduck, Grey teal, Australasian shoveler, Pink eared duck, Eurasian coot, Black swan, Straw necked ibis, Banded stilt, Silver gull, Red necked stint Freckled duck, Cape Barren goose. Also: Hoary headed grebe, Little black cormorant, Little pied cormorant, Black cormorant, Black duck, Blue winged shoveler, Musk duck, White eyed duck, Pelican, Yellow billed spoonbill, Red capped dotterel, White faced heron, White egret, Spur winged plover, Whiskered tern	Banded stilt (significant)	Large variety	Banded stilt (significant–high production of brine shrimp), Red-necked avocet, Whiskered tern	Sharp tailed sandpiper (U), Curlew sandpiper (U, L), Brolga (U), Red capped plover (U, L), Red necked avocet (U), Banded stilt (U, M), Hoarey headed grebe (U), Black swan (U, L), Sacred ibis (U, M), Straw necked ibis (U, M, L), Masked lapwing (U), Double banded Plover (M, L), Long toed stint (M), Pectorial sandpiper (M), Cape Barren Goose (M), Gull billed tern (M, L), Pink eared duck (M, L), Eurasian coot (M), Glossy ibis (M), Silver gull (M, L), Great egret (L), Caspian tern (L), Grey teal (L), Chestnut teal (L), Australasian shoveler (L), Orange bellied parrot (L)

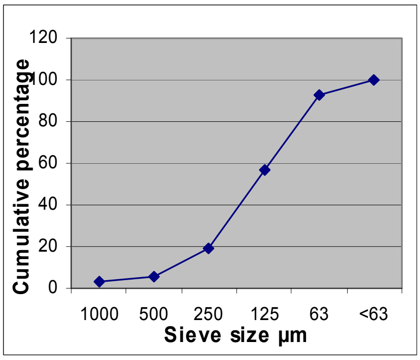
	Corangamite	**Gnarpurt**	**Martin–Cundare Pool**	**Cundare**	**Colac**	**Beeac**	**Lough Calvert**
Impacting processses	Climatic; Non-point sources; Diversion of inflow from Woady Yaloak River; Increasing salinity	Climatic; Non-point sources	Climatic; Non-point sources; Verge grazing; Possibly leadshot	Climatic; Non-point sources	Climatic; Sewage effluent; Dairy processing industry; Stormwater input; Sedimentation; Increasing salinity	Climatic; Non-point sources; Leaching from rubbish tip on shore	Climatic; Non-point sources; Grazing; Artificial drainage system, reduced frequency and extent of inundation especially in Upper Lough; Increasing salinity in Lower Lough
Degree of change to 2008	Significant change	Significant change	Significant change	No major change	Significant change	No major change 1965–2001	Significant change?

Sources: Major source = Williams (1992) who summarises all relevant literature available at the time, plus Chessman and Williams (1974), Williams and Buckney (1976), Geddes (1976), Marchant and Williams (1977a.), Slater and Boag (1978), Williams (1978), EPA (1980), Gutteridge, Haskins and Davey (1980), Hammer (1981a), Myers (1980), Myers (1981), Williams (1981), Williams (1984), De Deckker and Williams (1988), Lidston (1993), Schalken and Lloyd (1994), Cottingham et al., (1995), Williams (1995), Muston (2001), Barrot (2003), VWRDW (2003), Timms (2004), Khalife et al. (2005), Usbach and James (undated), analysis of samples collected from Lake Corangamite in December 1994, Lake Beeac in May 2001, and from Lakes Gnarpurt, Corangamite and Cundare in September 2003, Gully (2008, School of Life and Environmental Sciences, Deakin University; pers. comm.).

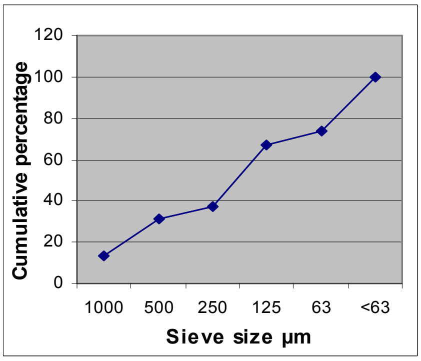
Appendix 2: Granulometric characteristics for (a) Lake Corangamite (i, ii, iii), (b) Lake Colac (i, ii, iii), (c) Lake Beeac (i, ii, iii), (d) Lake Cundare (i, ii), (e) Lake Martin, (f) Lake Gnarpurt and (g) Lough Calvert



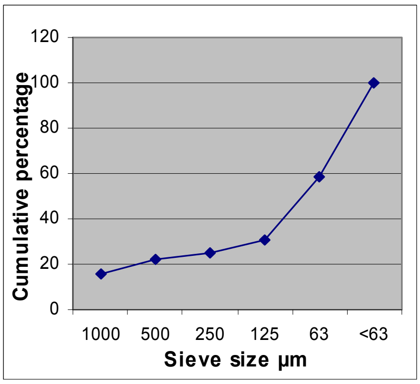
(a) (i)



(a) (ii)



(a) (iii)



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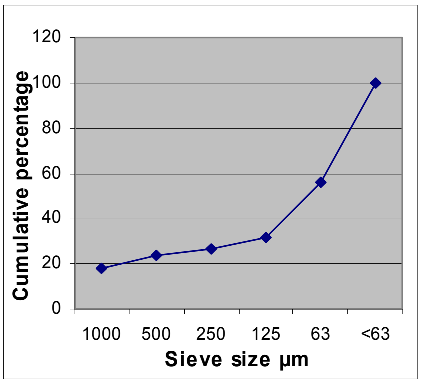

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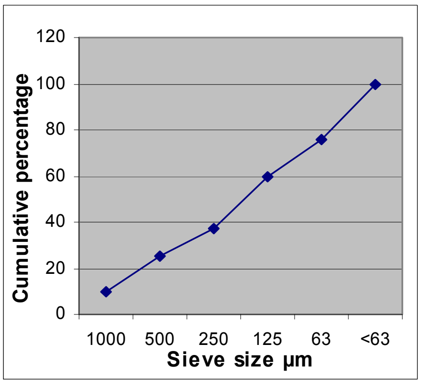

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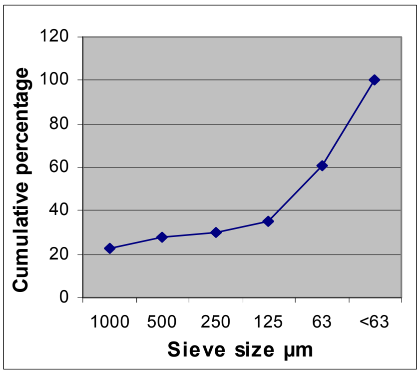
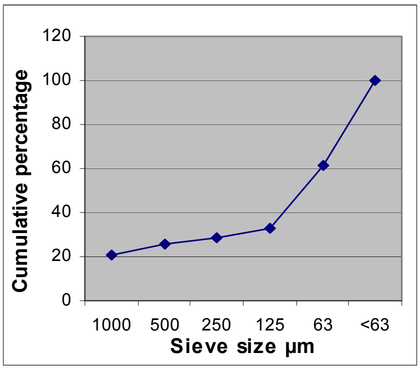


(c) (i)



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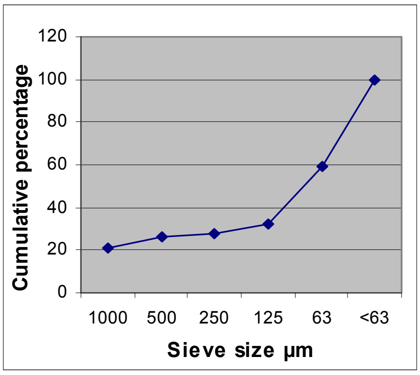
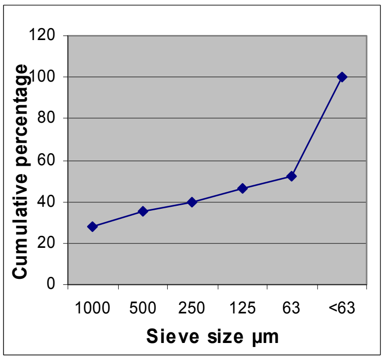
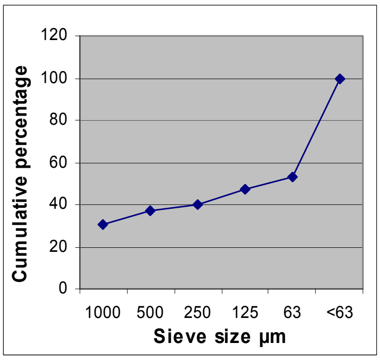


(c) (iii)

Appendix 2 cont.



(d) (i)



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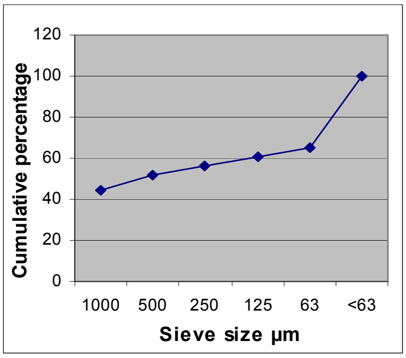
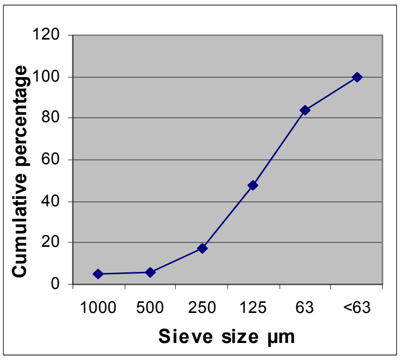
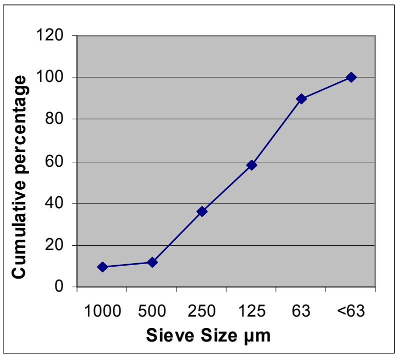


(e)



(f)



(g)

Appendix 3: Flora species recorded from each lake

Scientific name	Common name	CM	CM	CM	CL	CL	CL	M	BC	BC	BC	CD	CD	GP	LC
		Site One	Site Two	Site Three	Site One	Site Two	Site Three	Site One	Site One	Site Two	Site Three	Site One	Site Two	Site One	Site One
Sarcocornia quinqueflora	Beaded Glasswort		•	•				•	•	•	•	•	•	•	•
Suaeda australis	Austral Seablite	•	•	•				•	•	•	•	•			
Juncus acutus	Spiny Rush		•	•											
Lachnagrostis filiformis	Common Blown-grass	•	•		•	•	•							•	•
Aster subulatus	Aster-weed	•	•		•	•	•			•					
Sporobolus mitchellii	Rats Tail Couch		•		•		•		•			•			
Parapholis stringosa	Slender Barb Grass		•	•											
Casuarina spp.	She Oak						•								
Galenia pubescens	Galenia											•			
Lophopyrum elongatum	Tall Wheat Grass											•	•		
Chloris truncata	Windmill Grass				•										
Cirsium arvense	Perennial Thistle				•	•	•					•	•		
Schienoplectus pungens	Sharp Club Rush				•	•									
Bolboschoenus caldwelli	Sea Club Rush	•				•									
Enchylaena tomentosa	Ruby Salt Bush	•													
Ficinia nodosa	Knobby Club Rush	•													
Cynodon dactylon	Couch Grass	•					•								
Eucalpt spp. 1	Eucalpt						•								
Eucalpt spp. 2	Eucalpt						•				•				
Isolepis cernua	Grassy Club Rush						•								
Banksia spp.	Banksia										•				
Rheum rhabarbarum	Rhubarb											•			
Distichlis distichophylla	Australian Salt Grass		•												
Angianthis preissianus	Salt Angianthus		•	•			•								
Senecio pinnatifolius	Variable Groundsel	•	•		•		•	•		•	•	•	•		
Wilsonia backhousei	Narrow-leaf Wilsonia		•	•										•	•
Mimlus repens	Creeping Monkey Flower		•												
Polypogon monspeliensis	Annual Beard Grass	•					•								
Plantago coronopus	Buck's Horn Plantain					•	•				•				
Lolium perenne	Perennial Rye Grass			•			•	•	•	•		•	•		
Sonchus oleraceus	Common Sow Thistle				•	•	•		•		•				
Hordeum marinum	Sea Barley Grass			•				•	•			•			
Themeda triandra	Kangaroo Grass	•		•			•								
Lepilaena preissii	Small-fruited Watermat			•											
Rumex crispus	Curled Dock	•			•		•					•			

Appendix 4: Macro-invertebrates recorded from each lake

		CM	**CM**	**CM**	**CL**	**CL**	**CL**	**M**	**BC**	**BC**	**BC**	**CD**	**CD**	**GP**	**LC**
Scientific name	**Common name**	**Site One**	**Site Two**	**Site Three**	**Site One**	**Site Two**	**Site Three**	**Site One**	**Site One**	**Site Two**	**Site Three**	**Site One**	**Site Two**	**Site One**	**Site One**
Coxiella striata		•	•	•											
Anoplognathus spp.	Christmas Beetle	•	•						•						
Theba pisana	White Italian Snail	•	•	•										•	
Paratemia zietziana	Brine Shrimp	•		•											
Phaulacridium vittatum	Wingless Grasshopper						•								
Harmonia conformis	Common Spotted Ladybird						•								
Sphaerium spp.							•								
Helix aspersa	European Brown Snail						•								

Appendix 5: Avian fauna recorded from each lake

		CM	CM	CM	CL	CL	CL	M	BC	BC	BC	CD	CD	GP	LC
Scientific name	**Common name**	**Site One**	**Site Two**	**Site Three**	**Site One**	**Site Two**	**Site Three**	**Site One**	**Site One**	**Site Two**	**Site Three**	**Site One**	**Site Two**	**Site One**	**Site One**
Larus navciehollandiae	Silver Gull	•			•	•									
Anas superciliosa	Pacific Black Duck	•													
Pelecanus conspicillatus	Australian Pelican				•										
Anas rhynchotis	Australasian Shoveler				•	•	•								
Cygnus atratus	Black Swan					•									
Epthianura albifrons	White-fronted Chat					•									
Gymnorhina tibicen	Australian Magpie					•									
Thinormis rubricollis	Hooded Plover					•	•				•				
Haliastur sphenurus	Whistling Kite					•									
Corvus coronoides	Australian Raven					•									
Carduelis carduelis	European Goldfinch					•									
Rhipidura leucophyrs	Willie Wagtail					•									
Platycercus elegans	Crimson Rosella						•								
Charadrius ruficapillus	Red-capped Plover						•	•						•	
Cladorhynchus leucophalus	Banded Stilt							•							

Investigation and reporting of past and present ecological characteristics of seven saline lakes in the Corangamite Catchment Management Area

June 2008

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