# **Ecological study of** Lake Connewarre Wetlands Complex

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# Executive summary


The Lake Connewarre Wetlands Complex (LCWC) is a 3300 ha coastal wetland system on the Bellarine Peninsula. Lake Connewarre, a shallow estuarine lagoon, is the central feature of the wetlands system and is situated approximately nine kilometres upstream of the mouth of the Barwon River. A cluster of fresh and saline wetlands surround the lake, each governed by its own unique hydrological characteristics.

This study provides a snapshot of the general ecological character of the LCWC as a means of gauging the health of this unique system. Of particular interest is the ecology of Lake Connewarre itself, which influences, and is influenced by, the biological and physicochemical nature and processes that occur within and outside of the wetland system.

Four major components have been the focus of this study:

- Sediments
- Water quality
- Flora
- Fauna.

Bottom sediments of Lake Connewarre exhibit significant variations in physicochemical characteristics. Changes in the depth and texture of sediment layers suggest that deposition of sediments has occurred under varying environmental conditions. Deep sediments at the tidal delta of Lake Connewarre consist of a ‘floating’ sandy layer over a deeper, low-density muddy layer. Relative sedimentation rates appear to increase downstream from the lake entrance to the mid lake region. Total nitrogen and phosphorus concentrations in Lake Connewarre sediments were similar to those found within other south-east Australian bays and estuaries. Arsenic levels in lake sediments were substantially greater than those found in other west Victoria estuaries and mostly exceeded the Australian Interim Sediment Quality Guidelines (ISQG) high trigger levels.

High variations in water quality parameters were evident during the project and on several occasions exceeded the Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000) trigger values for some parameters. Nitrogen and phosphorus concentrations exceeded ANZECC/ARMCANZ trigger levels for all sampling sites. High levels of phosphorus and nitrogen in these waters may be derived from internal loading as nutrients are released from sediments into overlying waters. The red alga *Gracilaria* may be an indicator of nutrient enrichment, but may also play an important role in nutrient cycling and oxygenation/deoxygenation processes within Lake Connewarre.

Lake Connewarre exhibited prolonged saline and hypersaline conditions for much of the study period, most likely brought on by a lack of freshwater inputs from the catchment during the current drought. Such conditions have the potential to shift flora and fauna community structures towards those containing more salt-tolerant species.

Of the 103 plants and algae that were observed approximately half of the species were native. Seasonal constraints limited the number of species that may have been observed over a longer period. Extensive colonies of the red alga *Gracilaria sp.* dominated much of Lake Connewarre, with the alga often entwined with Sea Tassel *Ruppia maritima*. These species may be useful as ecological indicators to reflect the dynamics of water quality and hydrology within the lake.

The LCWC reflected a high level of faunal diversity. Distinctive communities of macroinvertebrates and zooplankton were observed between survey sites. Zooplankton communities exhibited temporal and spatial heterogeneity within the LCWC. This temporal and spatial heterogeneity is typical of plankton communities globally, and is related to the patchiness and dynamics of resources in the environment.

The abundance of meiofauna in the Barwon estuary is similar to that found in estuaries with mangroves elsewhere in the world. Sampling stations along the river were separable on the basis of the assemblage of nematodes identified at each station. Observations of these distinct sets of nematode assemblages along the course of the estuary suggest that meiofauna may be useful as indicators of environmental change or ecosystem disturbance.

Macroinvertebrate diversity was low compared with results from an earlier study in the late 1980s, but was similar to those conducted in 2002. Relatively low diversity recorded during this study may be due to a number of factors, including the nature and timing of sampling events (i.e. seasonal and hydrological influences) and/or consistently high salinity levels within Lake Connewarre leading up to and during the early part of the sampling period. Populations of macroinvertebrates may persist in Lake Connewarre by tolerating the salinity fluctuations or, alternatively, by depending on regular dispersal into the lake from adjoining marine or freshwater populations.

Vertebrate fauna within the LCWC were well represented by birds, fish and frogs. The diverse array of habitats provides areas for breeding and foraging for these fauna groups. Notable observations included large flocks of Chestnut Teal on Lake Connewarre and near Hospital Swamp, whilst a large congregation of Hoary-headed Grebe were recorded on Lake Connewarre on more than one occasion. A pair of Brolga was also sighted on two occasions at the western end of the lake. Timing of the study was not optimal for observing the large numbers of migratory waders. The nationally threatened Growling Grass Frog was also recorded at Reedy Lake.

Notable introduced species include the Red Fox and Fallow Deer. The presence of foxes within the LCWC and neighbouring properties provide an immediate threat to local and migratory fauna, in particular the wetland bird species.

If further shallowing of Lake Connewarre occurs it would be most likely that foraging areas for large and small wader and shorebird species would increase in the medium to long term. However, deeper waters for diving birds and waterfowl would be reduced within the lake.

Several opportunities to conduct further studies have been proposed to assist with the future management of the LCWC. These are presented throughout the report and as recommendations within the concluding section.

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# 1 Introduction

## 1.1 Background and project rationale

The Lake Connewarre Wetlands Complex (LCWC) is a group of saline and freshwater wetlands associated with the Barwon River estuary, one of the largest estuarine systems on the central Victorian coast. These wetlands are highly valued for a wide range of reasons and are listed under the Ramsar Convention as wetlands of international importance. They provide summer feeding habitat for large numbers of migratory waders, shorebirds, waterfowl and other wetland birds (Australian Nature Conservation Agency 1996), they support a diversity of other native vertebrate and invertebrate fauna and their role as a fisheries nursery has also been noted (Tunbridge 1988). However, the wetlands are also renowned for their diverse and unique flora (Yugovic 1985) and distinctive geology as described by Rosengren (1973) and Bird (1993). The lower estuary is a popular destination for recreational anglers and tourists, whilst duck hunters and bird observers utilise other areas of the wetland system. Tunbridge and Glenane (1982), after McCarraher (1976), considered the Barwon River estuary as a valuable resource for recreational fishing. Tunbridge and Glenane (1982) also rated Lake Connewarre as having high conservation value for estuarine fish species and as a valuable fisheries resource for the commercial harvesting of Short-finned Eels *Anguilla australis*.

Despite its international importance, the LCWC has attracted relatively little scientific research. One of the most notable studies was conducted in 1986–87 by Sherwood et al. (1988), who reported ecological and physicochemical analyses of the LCWC made over a 12-month period. Recent investigations into environmental flow allocations for the Barwon River (Lloyd Environmental 2005) have prompted a renewed interest in LCWC and the effects of reduced flows on its ecology. Also with the threat of global warming, low elevation habitats within this and other coastal wetlands are at risk of being significantly altered by the effects of rising sea levels and changes in local weather patterns, including reduced rainfall (and hence reduced river discharge) and greater frequencies of storm surges.

The central feature of the LCWC, Lake Connewarre, has come under considerable public scrutiny in recent decades. The reason is primarily due to the perceived or real deterioration of the condition of the lake brought on by local and catchment-wide processes, mostly associated with years of human habitation and exploitation. Of particular concern is the observed rate of siltation, with reports that much of the lake is becoming noticeably shallower.

In response to these concerns the Lake Connewarre Working Group was formed by local residents, community user groups and management authorities to establish and act on the current and future condition of the lake and its surrounding wetlands. From this group the Lake Connewarre Values Project was initiated, with management of the project taken on by the Corangamite Catchment Management Authority.

## 1.2 Objectives

This study aims to provide a snapshot of the general ecological character of the LCWC as a means of gauging the health of this unique system. Of particular interest is the ecology of Lake Connewarre itself, which influences, and is influenced by, the biological and physicochemical nature and processes that occur within and outside of the wetland system.

Although the study addresses multiple aspects of the ecology of these wetlands, it is limited by the brief timeframe allowable for investigations to be carried out. However, the information generated from this investigation provides a basis for other studies to expand on or compare over time or between other similar estuarine systems. It is hoped that this and further studies provide a better understanding of the LCWC to guide its sustainable use and management towards a healthy functioning wetland ecosystem.

# 2 General methods

## 2.1 Location and general description of the LCWC

The Lake Connewarre Wetlands Complex (LCWC) is a 3300 ha coastal wetland system on the Bellarine Peninsula (Yugovic 1985) on the central Victorian coast. Lake Connewarre, a shallow estuarine lagoon, is the central feature of the wetlands system and is situated approximately nine kilometres upstream of the mouth of the Barwon River. A cluster of fresh and saline wetlands surround the lake, each governed by its own unique hydrological characteristics.

The wetlands receive fresh water from the Barwon River catchment and associated tributary rivers and streams, including the Moorabool and Leigh Rivers. These waters are variably mixed with seawater from Bass Strait within those wetlands influenced by tidal processes. Some wetlands are usually isolated from the fresh and/or saline waters due to natural or artificial barriers. The extent of tidal penetration is limited along the Barwon River by a breakwater nearly two kilometres upstream of where the river flows into Lake Connewarre. A constructed levee bank separates Lake Murtnagurt from the lower Barwon River and any inputs are negligible from this source.

The LCWC is situated at the western end of the Bellarine Peninsula, surrounded by agricultural and pastoral land, and increasingly by urban sprawl emanating from Geelong and its satellite and coastal towns of Leopold, Ocean Grove and Barwon Heads. The pressures from adjacent land activities and development are likely to impact on the ecological character and condition of this natural resource, as are those activities from further up the catchment and those occurring directly within the wetlands system.

The significance of the LCWC is recognised at an international level due to its inclusion in the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula wetlands which are listed under the Ramsar Convention (Department of Sustainability and Environment 2003). The primary reason for its listing is due to its importance as habitat for large numbers of migratory waders and other wetland birds.

## 2.2 Constituent wetlands

For the purposes of this study the LCWC can be broadly divided into six clearly defined wetland areas:

## Lake Connewarre

A 950 ha shallow estuarine lagoon surrounded by extensive coastal salt marsh to the east and south-east, and predominantly cleared farmland to the north and south-west. For logistical reasons associated with this project the wetland also includes sites on the Barwon River upstream of the lake entrance to the lower breakwater.

## Lower Barwon River Estuary (below Lake Connewarre)

A permanently open estuary fringed by extensive areas of coastal salt marsh along most of its length, with mangroves *Avicennia marina* occurring in the lower reaches at Barwon Heads and Ocean Grove. Mudflats at lower tidal elevation support the seagrass *Zostera muelleri* in these lower reaches.

## Reedy Lake

A freshwater reedy marsh dominated by Bullrush *Typha orientalis*, Common Reed *Phragmites australis* and Salt Club-sedge *Bolboschoenus caldwellii* and several less abundant macrophytes. The wetland is fringed by low saline herbfields, with predominantly cleared rural–residential land at higher elevation. The hydrology of Reedy Lake is manipulated for both conservation and recreational purposes (e.g. duck hunting).

## Hospital Swamp

A reedy marsh dominated by *P. australis* and areas of open water. Salinity is variable, from fresh to brackish depending on the control of freshwater inflows from the Barwon River and local hydrogeology. A narrow zone of salt marsh fringes the wetland at higher elevation.

## Salt Swamp

An extensive, coastal salt marsh consisting of Beaded Glasswort *Sarcocornia quinqueflora* herbland, *Wilsonia* herbland, mixed samphire shrubland, Tussock grasslands and *Gahnia filum* sedgeland. This wetland experiences prolonged inundation after major flooding of the Barwon River. Salt Swamp is surrounded by farmland on the west, south and east. The Barwon estuary is to its north.

## Lake Murtnagurt

A small, shallow saline lake surrounded by a floristically rich salt marsh. This wetland is surrounded by two golf courses to the east and west, farmland to the north and coastal sand dunes to the south. This wetland is isolated from the Barwon estuary by a constructed levee bank.

This study particularly focuses on the first four wetlands, as these are more closely related to issues raised by the Lake Connewarre Working Group as part of the larger Lake Connewarre Values Project.

## 2.3 Survey sites

Sites in Lake Connewarre, Lower Barwon River estuary, Reedy Lake, and Hospital Swamp were selected to represent the habitats available and are shown in Figure 2-2. The survey and sampling matrix in Table 2-1 identifies the sites for each survey. Site codes within this table will be used throughout the report to assist the reader with the identification of the locations for each of the survey types.

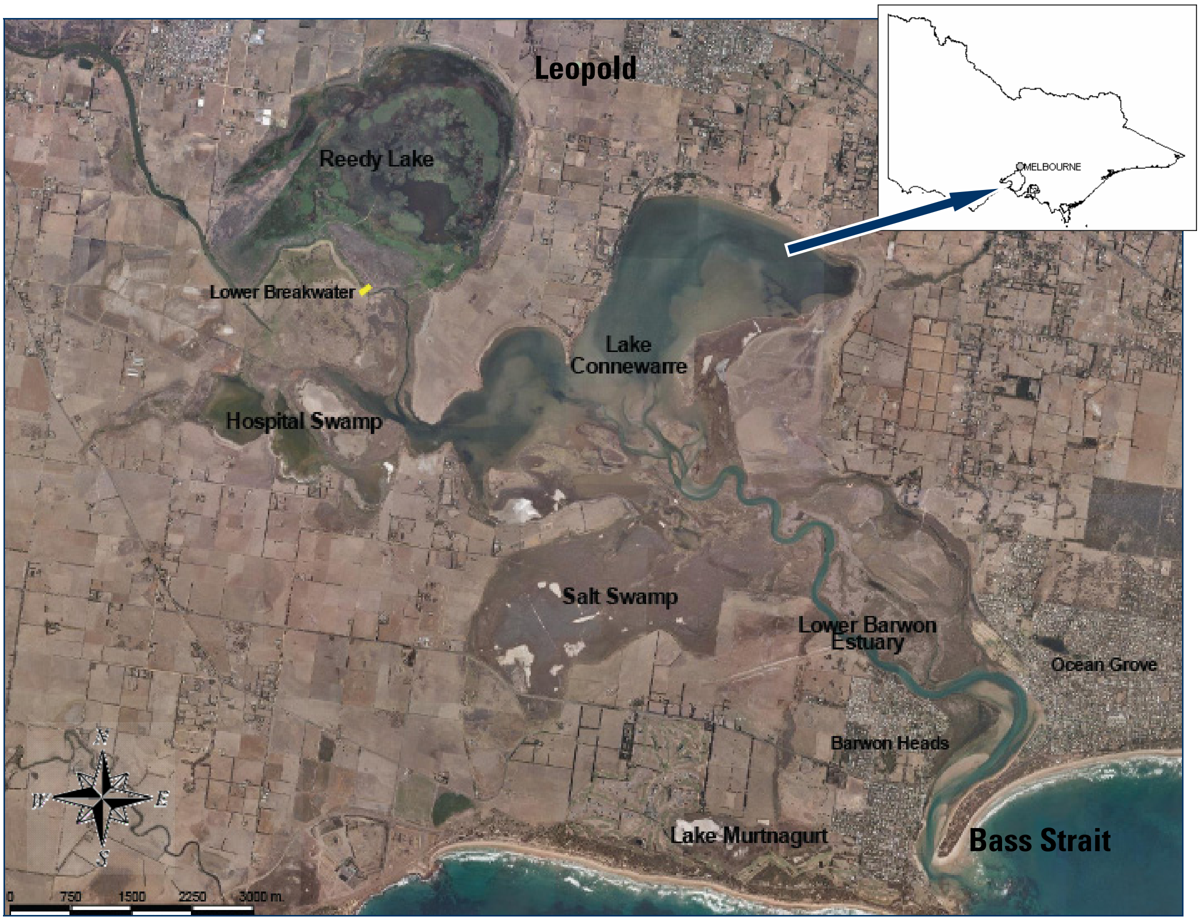



Figure 2-1 Location and extent of the Lake Connewarre Wetlands Complex, incorporating Reedy Lake, Hospital Swamp, Lake Murtnagurt, Salt Swamp and the lower Barwon River estuary. (Map modified from Geovic Mapper, State of Victoria, Department of Primary Industries.)

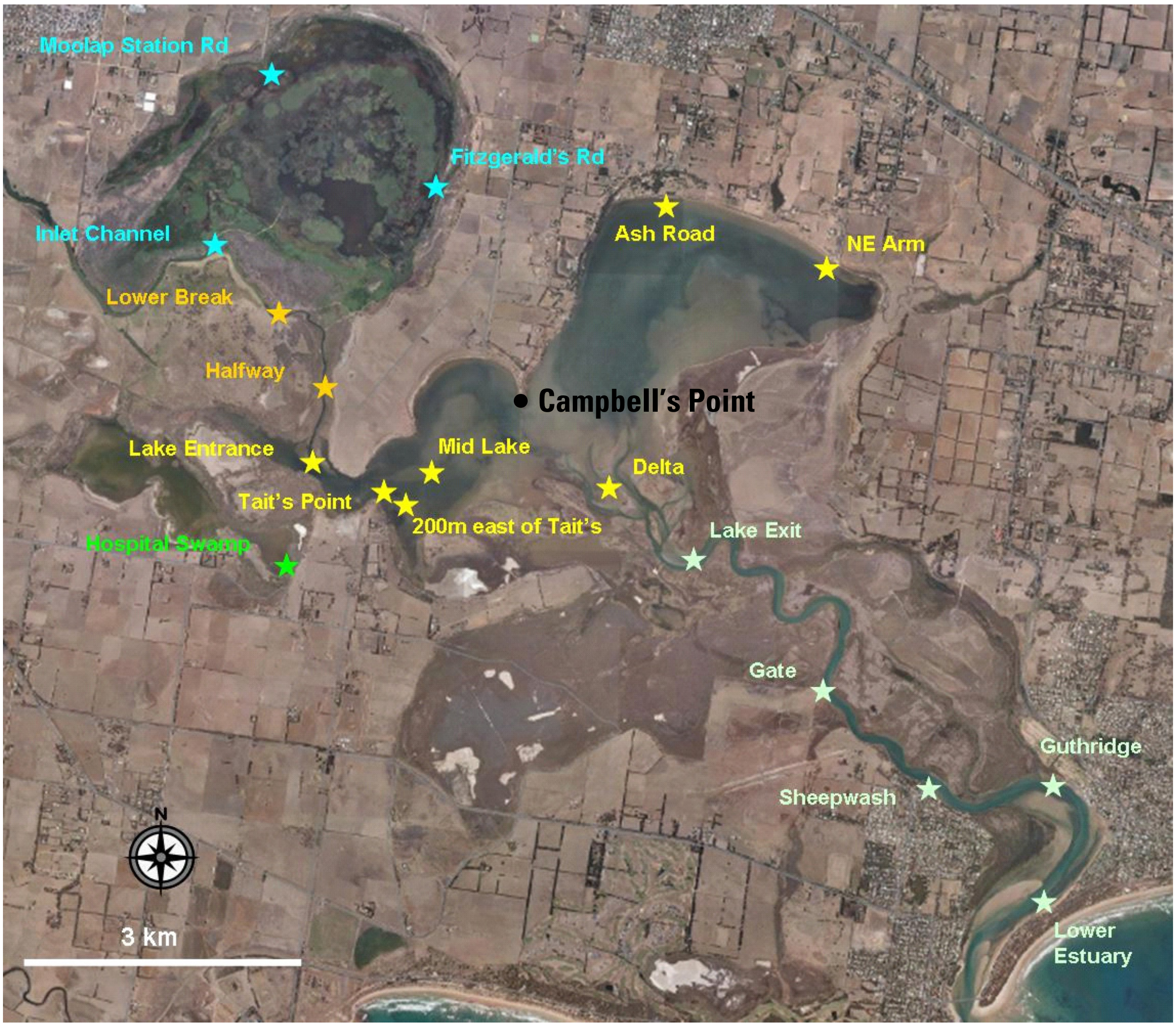



Figure 2-2 Location of survey sites. (Map modified from Geovic Mapper, State of Victoria, Department of Primary Industries.)

**Table 2-1 Matrix identifying survey sites with corresponding surveys (• indicates where surveys occurred).**

| Area | Survey site | Site code | Water quality | Sediments | Flora | Fish | Frogs | Birds | Macroinvertebrates | Plankton | Meiofauna |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lake Connewarre and upper estuary to break** | Lower Breakwater | LBr | • | | | | | | | • | • |
| | Halfway | HWy | • | | | | | | | • | • |
| | Lake Entrance | LEn | • | • | • | • | | | • | • | • |
| | Tait's Point | TP | • | | • | • | | | • | • | • |
| | East of Tait's Point | EoT | | | | | | • | | | |
| | Mid Lake | MLa | | • | • | | | | • | | |
| | Ash Road | Ash | • | • | • | | • | | • | | |
| | North-east Arm | NE | • | • | • | • | • | | • | | |
| | Tidal Delta | De | | • | | | | | | | |
| **Lower Barwon** | Lake Exit | LEx | • | | | | | | | • | • |
| | Gate | Ga | • | | | | | | | • | • |
| | Sheepwash | Sw | • | | | | | • | | • | • |
| | Guthridge/ Golf Course | Gu | • | | • | • | | | • | • | • |
| | Lower Estuary | LoE | • | | • | • | | | • | | |
| **Reedy Lake** | Moolap Station Road | RMo | • | | • | • | • | | • | | |
| | Fitzgerald's Road | RFi | • | | • | • | • | • | • | | |
| | Reedy Lake Inlet | RIn | • | | | • | | | • | | |
| | Hospital Swamp | HSw | • | | • | • | • | • | • | | |
| | Salt Swamp | SSw | | | • | | • | | | | |

## 2.4 Contextual framework

To gauge the condition and character of a wetland and identify its values, several of its components and ecological processes occurring within it require investigation and assessment. A range of measurable ecological indicators linked to such components have been selected within this study to assist in determining the state of the LCWC. These indicators are identified at the beginning of subsequent sections of this report, with each section addressing one of four components of interest.

These sections address:

- Sediments
- Water quality
- Flora
- Fauna.

The report closes with a conclusion and recommendations.

Whilst some components (e.g. hydrodynamics) may not be addressed here, it is important to note that the components selected for investigation have been recognised and are often used as a means of measuring the 'health' of coastal wetlands. Each component has been assigned a set of physicochemical or biological indicators to measure the state of that component. Some indicators of water quality (e.g. dissolved oxygen, heavy metals, total phosphorus and total nitrogen concentrations) can be readily compared to recognised national (ANZECC and ARMCANZ 2000) or state (EPA Victoria 2001) guidelines and, therefore, any departure from these standards is easily identified. Indicators from other components (e.g. species abundance and distribution, community structure and biodiversity indices) do not have recognised standards or objectives to reflect ecosystem health, as these are likely to have naturally high variability within and between estuaries and associated wetlands. Therefore, a reliance on identifying statistically significant changes to these indicators over time and comparisons with other similar wetland systems will assist in the determination of the condition of the wetland.

# 3 Sediments

## 3.1 Aims and research questions

Determine the physicochemical characteristics of Lake Connewarre sediments including:

- Particle size distribution
- Sedimentation rate
- Macronutrient (nitrogen and phosphorus) concentrations
- Heavy metal concentrations (copper, cadmium, lead and arsenic).

## 3.2 Method

On 3 April and 25 April 2007, sediment cores were sampled from five locations within Lake Connewarre using a 1.5 m long, 40 mm diameter polycarbonate tube. Sites were accessed by boat or by wading, depending on the site's proximity to the shore. The geographic coordinates of each site were recorded using a Garmin E-trex Legend® Cx GPS receiver with an accuracy of ± 15 m. Table 3-1 lists the positions of each sample site. Core segments were placed in acid washed (HCl) polyethylene bags and frozen prior to heavy metals analysis. A sample of the top 100–150 mm of sediment was collected and stored at 4° C for particle size and Total Organic Compound (TOC) analyses.

**Table 3-1 Geographic coordinates where sediments were collected (Map Datum – GDA, UTM Coordinate System, Zone 55).**

| Sample point | Site name | Easting | Northing |
|---|---|---|---|
| LEn | Lake Entrance | 274325 | 5765165 |
| Mid | Mid Lake | 275599 | 5765015 |
| De | Tidal Delta | 277305 | 5764924 |
| Ash | Ash Road | 278012 | 5767800 |
| NE | North-east Arm | 279533 | 5767241 |
| EoT | 200 m east of Tait's Point | 275245 | 5764651 |

On 20, 21 and 22 of July 2007, further sediment sampling was carried out using the above method. On these occasions triplicate core samples were collected at the above locations except for the site 200 m east of Tait's Point due to problems penetrating the sediment and retaining the sample in the corer. A site referred to as Mid Lake was sampled instead. Intact cores were returned to the laboratory, bisected longitudinally, photographed and separated into layers according to apparent changes in particle size, colour and texture. Each section was homogenised and stored at $4^{o}$ C for further analyses.

### 3.2.1 Physical characteristics

Particle size distribution was determined by separating particle size classes through a series of sieves (wet sieve method) of various mesh sizes (4 mm, 2 mm, 1 mm, 500 µm, 250 µm, 125 µm and 63 µm) and determining each class as a proportion of the total weight of sediment. Cumulative percentage frequency curves were used to derive median particle size (MD50), quartile deviation and skewness of each sediment sample.

### 3.2.2 Sedimentation rates

An estimate of the relative rates of sedimentation was made at four locations within Lake Connewarre between 14 June and 22 August 2007. Four PVC sedimentation tubes (200 mm long by 85 mm inside diameter), closed at the bottom and mounted (open end up) into weighted plastic crates, were installed on the lake bed at each of the four sites (LEn, TP, Mid and EoT). The tubes were retrieved after 69 days. Macrofauna were removed from each tube (if present) and sediments were transferred into separate graduated measuring cylinders. Sediments were allowed to settle over three days and the volume of settled sediments was recorded. Sediment volume data were converted to mean relative annual sedimentation rates, expressed in centimetres per year.

### 3.2.3 Nutrients

Nutrient analyses were carried out on one of the replicate cores taken from the set of samples collected at each of the five sites in July. Cores were divided into segments of one or two definable layers and homogenised as required for analyses. Table 3.2 lists the core segments selected for analyses and their corresponding depth ranges. Samples were analysed for total phosphorus (TP) and total nitrogen (TN) at the Water Quality Laboratory, Deakin University as per standard methods.

**Table 3-2 Sediment core segments for nutrient analyses and corresponding depth ranges. Notation for core segment layers are as follows: upper case letters = site, lower case letters refer to visually discernible sediment layers (a = surface layer), 2 = core two of three cores samples per site.**

| Site | Shallow or deep segment | Core segment layers | Depth range (cm) |
|---|---|---|---|
| A. Lake Entrance (LEn) | S | A2a | 0–35.5 |
| | D | A2b and A2c | 35.5–44.8 |
| B. Mid Lake (Mid) | S | B2a | 0–9.5 |
| | D | B2b | 9.5–29 |
| C. Lake Exit/Delta (De) | S | C2a | 0–16 |
| | D | C2b | 16–57 |
| D. Ash Road (Ash) | S | D2a and D2b | 0–28.5 |
| | D | D2c and D2d | 28.5–56 |
| E. North-east Arm (NE) | S | E2a | 0–25.5 |
| | D | E2b | 25.5–32.5 |

### 3.2.4 Heavy metals

Sediment cores sampled on 3 April and 25 April 2007 were analysed for Cadmium (Cd), Copper (Cu) and Lead (Pb). Each frozen core segment was tested for leachable heavy metal concentrations, which followed modified methods 3050B and 3051 as specified in the USEPA guidelines (1996). Lead, cadmium, and copper were analysed using Flame Atomic Absorption Spectrometry (FAA).

**Table 3-3 Digestion settings for microwave digester.**

| % Power (max. 600w) | Temperature (°C) | Ramp time to reach temperature (min.) | Duration at temperature (min.) |
|---|---|---|---|
| 75 | 120 | 3 | 2 |
| 100 | 140 | 2 | 2 |
| 100 | 160 | 2 | 2 |
| 100 | 180 | 2 | 2 |
| 100 | 190 | 2 | 20 |

Each sample was filtered through a 63 μm nylon sieve. The fraction retained on the sieve was filtered using a No. 1 glass filter and then dried. Samples of 1.5–2 g were weighed out and microwave digested (MARS microwave digester; 1600 watt) in nitric acid (15 mL). Table 3-3 outlines digester settings.

## 3.3 Results

### 3.3.1 Physical characteristics

Table 3-4 shows the composition by weight of each of the particle size fractions from sediments collected at five sites in Lake Connewarre. For Ash Road, North-east Arm and 200 m east of Tait's Point the majority of the sediment was represented by fine to medium sand particles between 125 and 500 µm. Almost 46% of sediments collected from Lake Entrance was silt, whereas particle sizes in cores from the Delta area were more evenly spread between silts to medium sands.

**Table 3-4 Percentages of particle size fractions, median particle size (MD50), quartile deviation and skewness of sediment cores collected from five sites at Lake Connewarre.**

| | | Percentage of total sediment core retained on sieve | | | | |
|---|---|---|---|---|---|---|
| **Phi value** | **Sieve mesh size** | **Lake Entrance** | **200 m east of Tait's Point** | **Ash Road** | **North-east Arm** | **Delta** |
| –2 | 4 mm (Pebble) | 1.37 | 4.29 | 2.44 | 3.76 | 1.48 |
| –1 | 2 mm (Granule) | 1.99 | 5.74 | 2.33 | 3.78 | 2.22 |
| 0 | 1 mm (Very coarse sand) | 4.72 | 5.62 | 3.71 | 4.60 | 2.09 |
| 1 | 500 µm (Coarse sand) | 5.04 | 6.47 | 2.76 | 3.85 | 3.31 |
| 2 | 250 µm (Medium sand) | 8.44 | 23.95 | 40.59 | 31.36 | 23.71 |
| 3 | 125 µm (Fine sand) | 14.46 | 44.66 | 44.16 | 37.99 | 17.62 |
| 4 | 63 µm (Very fine sand) | 18.02 | 8.15 | 2.96 | 6.44 | 15.86 |
| | < 63 µm (Silt) | 45.98 | 1.12 | 1.04 | 8.22 | 33.71 |
| **MD50 (µm)** | | **71** | **207** | **236** | **227** | **112** |
| **Quartile deviation** | | **2.55** | **1.48** | **0.89** | **1.58** | **2.31** |
| **Skewness** | | **0.016** | **–0.52** | **–0.31** | **–0.078** | **0.25** |

### 3.3.2 Sedimentation rates

The mean volume of sediment accumulated in each set of four tubes after 69 days is shown in Table 3-5. The average daily rate of deposition varied between 1.6 mL at Lake Entrance and 9.1 mL in the mid-lake. It must be stressed that these values are affected by the presence of the collecting tubes, and represent comparative sedimentation between stations, not the rate at which particles settle in the lake in the absence of interference from the edges of a tube. Figure 3-1 compares the relative sediment accumulation rates for the four sites measured. It shows that sedimentation rates were significantly greater at Mid Lake during the 69-day period than at Lake Entrance or Tait's Point. Also, relative sedimentation rates at Tait's Point were significantly greater than at Lake Entrance for the same period.

**Table 3-5 Sediment deposition rates into vertical tubes positioned in Lake Connewarre.**

| Site | Mean volume after 69 days (mL) | Daily rate (volume) (mL/day$^{-1}$) | Annual rate (depth) (cm/yr$^{-1}$) |
|---|---|---|---|
| Lake Entrance | 112.5 | 1.6 | 11.9 |
| Tait's Point | 306.3 | 4.4 | 28.5 |
| East of Tait's Point | 243.7 | 3.5 | 22.7 |
| Mid Lake | 628.7 | 9.1 | 58.6 |

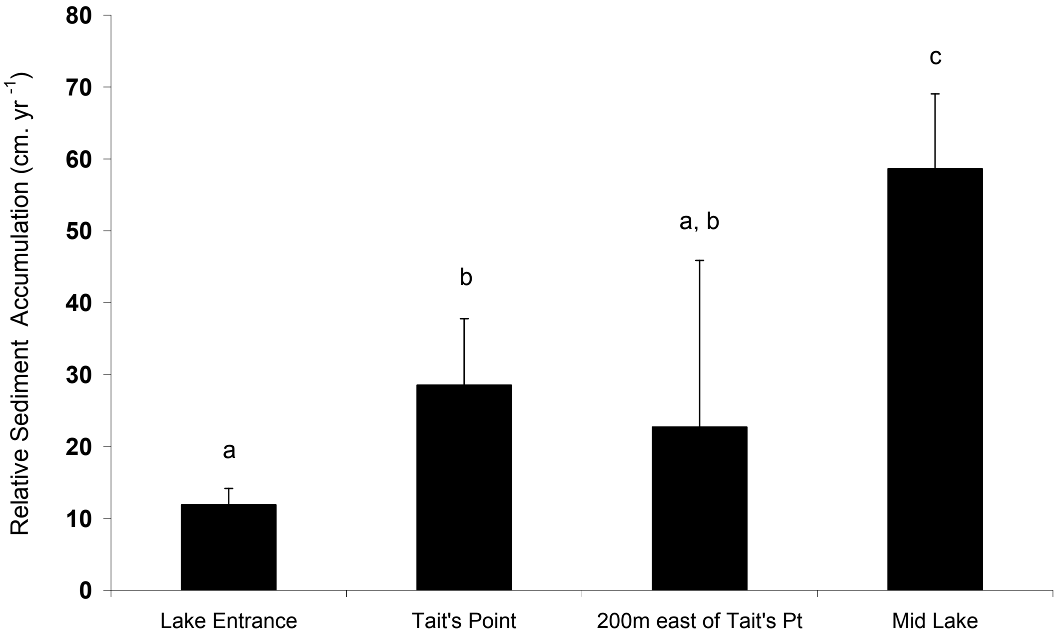



Figure 3-1 Mean relative annual sedimentation rates (± 95% C.I.) for Lake Connewarre west of Campbell's Point. Letters indicate statistical differences between sites. The number of samples per site was four, except Lake Entrance which was two.

### 3.3.3 Nutrients

Levels of total nitrogen (TN) and phosphorus (TP) in Lake Connewarre varied with sediment depth and between sample sites. TN and TP concentrations are compared in Figure 3-2 and Figure 3-3 respectively. Highest concentrations of TN were found in the deeper fine sediments of Mid Lake (2,400 mg/kg) and Lake Exit/Delta (1,430 mg/kg). The lowest TN concentrations were found within the upper sandy layer of the Lake Exit/Delta sediments (340 mg/kg) and the deeper layer of the sediments from the North-east Arm (320 mg/kg). TP concentrations were lower at sites on the north east shore of the lake (Ash Road, 60 mg/kg and North-east Arm, 55 mg/kg). Trends in TP concentration with sediment depth were not clear from the results.

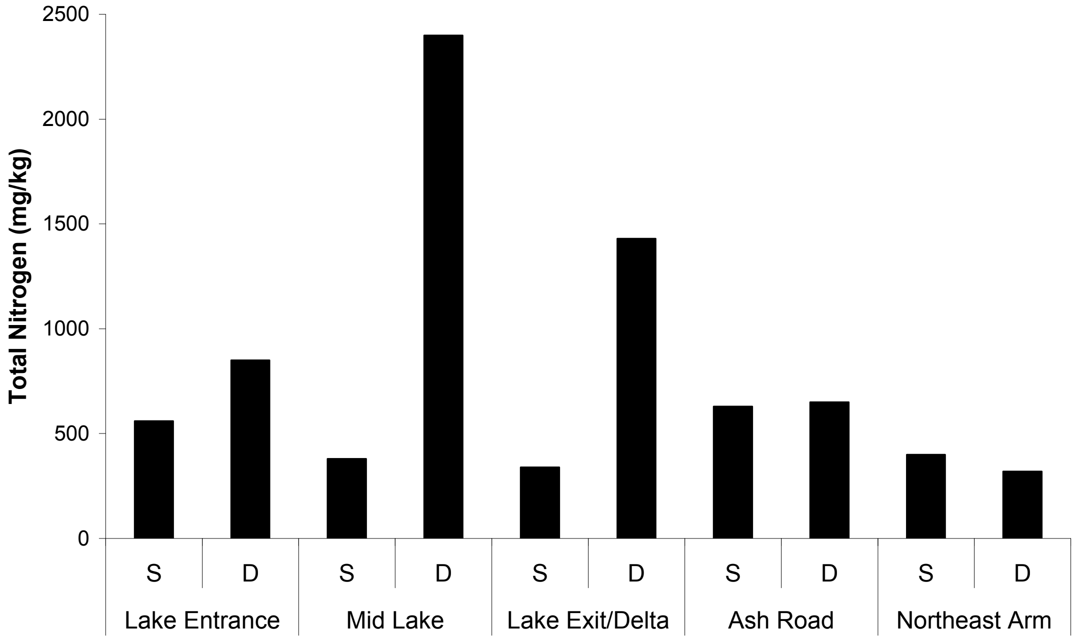



Figure 3-2 Total nitrogen levels of sediment layers in Lake Connewarre. S – Shallow layers, D – Deep layers as described in Table 3-2.

## 3.3.4 Heavy metals

Table 3-6 shows results from heavy metal analyses for cadmium, copper and lead. There was no distinct pattern in concentration with sediment depth for these elements.

Cadmium concentrations varied between 1.5 and 3.6 mg/kg and equalled or exceeded the Australian Interim Sediment Quality Guideline (ISQG) low trigger value of 1.5 mg/kg for all sites at each sediment depth. Copper concentrations ranged from 17.3 to 29.8 mg/kg and were under the ISQG trigger value of 65 mg/kg for that element for all sites at each depth range. Lead concentrations ranged between 14.9 mg/kg and 51.0 mg/kg. The low ISQG trigger value of 50 mg/kg was exceed only within the deeper part of the sediments at the Ash Road site.

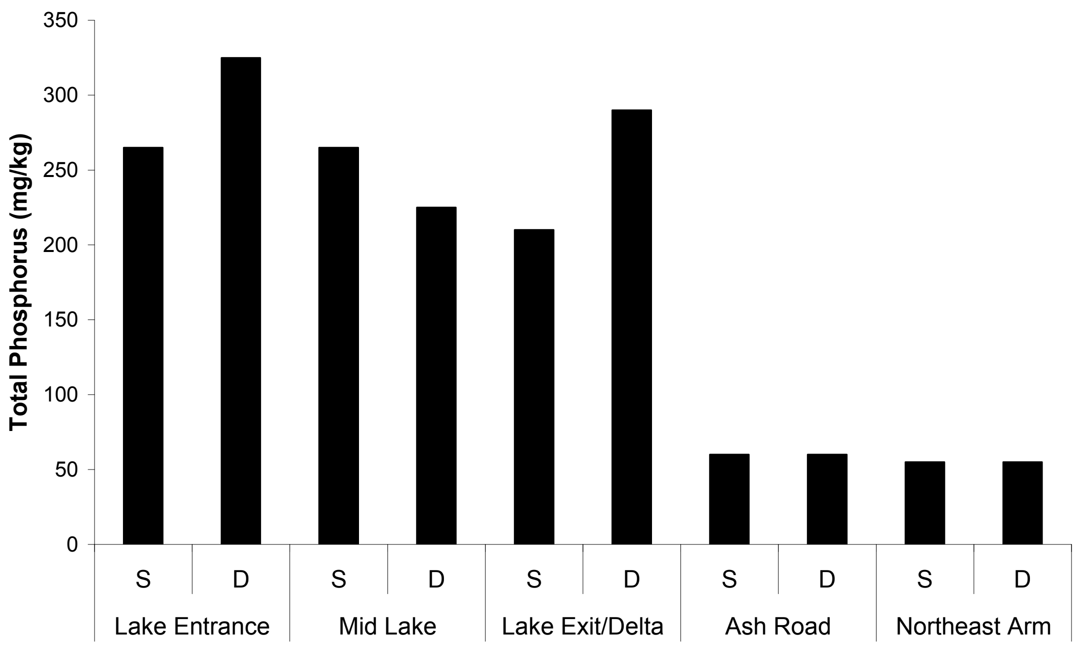



Figure 3-3 Total phosphorus levels of sediment layers in Lake Connewarre. S – Shallow layers, D – Deep layers as described in Table 3-2.

Total arsenic concentrations were found to exceed the ISQG high trigger value for this element in all but five determinations. Samples marginally lower than the high trigger value were collected from sediments where the Barwon River flows into Lake Connewarre (Lake Entrance).

The highest arsenic level was recorded within sediments of Mid Lake within the top 9.5 cm. The concentration of 202 mg/kg for this sample was more than double that of other cores within Mid Lake and all other locations. This very high result was considered an outlier and was not used in the calculation of the mean arsenic levels for that core layer. Figure 3-4 compares arsenic concentration between sites, and sediment depths within Lake Connewarre and with the ISQG trigger values for arsenic (ANZECC and ARMCANZ 2000). Table 3-7 presents the arsenic concentrations for individual sediments layers collected from the five lake Connewarre sites, along with their depth ranges.

**Table 3-6 Acid leachable cadmium, copper and lead determinations for Lake Connewarre sediments. Figures in bold represent values exceeding the low ISQG trigger value for that element.**

| Site | Core layer* | Cadmium (mg/kg)a | Copper (mg/kg)[a] | Lead (mg/kg)a |
|---|---|---|---|---|
| A. Lake Entrance | A1 | **2.5** | 27.8 | 44.0 |
| | A2 | **2.0** | 27.6 | 35.0 |
| | A3 | **2.0** | 18.8 | 23.3 |
| C. Lake Exit (Delta) | C1 | **3.1** | 17.4 | 24.2 |
| | C2 | **2.8** | 25.1 | 39.8 |
| | C3 | **2.6** | 21.7 | 33.2 |
| D. Ash Road | D1 | **2.5** | 17.3 | 14.9 |
| | D2 | **2.0** | 29.8 | 42.7 |
| | D3 | **2.6** | 23.0 | 46.8 |
| | D4 | **3.6** | 27.6 | **51.0** |
| E. North-east Arm | E1 | **2.4** | 22.6 | 20.9 |
| | E2 | **1.5** | 18.6 | 20.1 |
| | E3 | **3.2** | 26.6 | 42.3 |
| F. 200 m east of Tait's Point | F1 | **2.1** | 26.2 | 34.6 |
| | F2 | **2.1** | 26.9 | 38.0 |
| | F3 | **2.1** | 21.9 | 33.8 |
| **ISQG trigger value (low)** | | **1.5** | **65** | **50** |
| **ISQG trigger value (high)** | | **10** | **270** | **220** |

* Core layers for this data do not correspond with core layers for arsenic analyses.

a – Total metal concentration per dry weight of sediment.

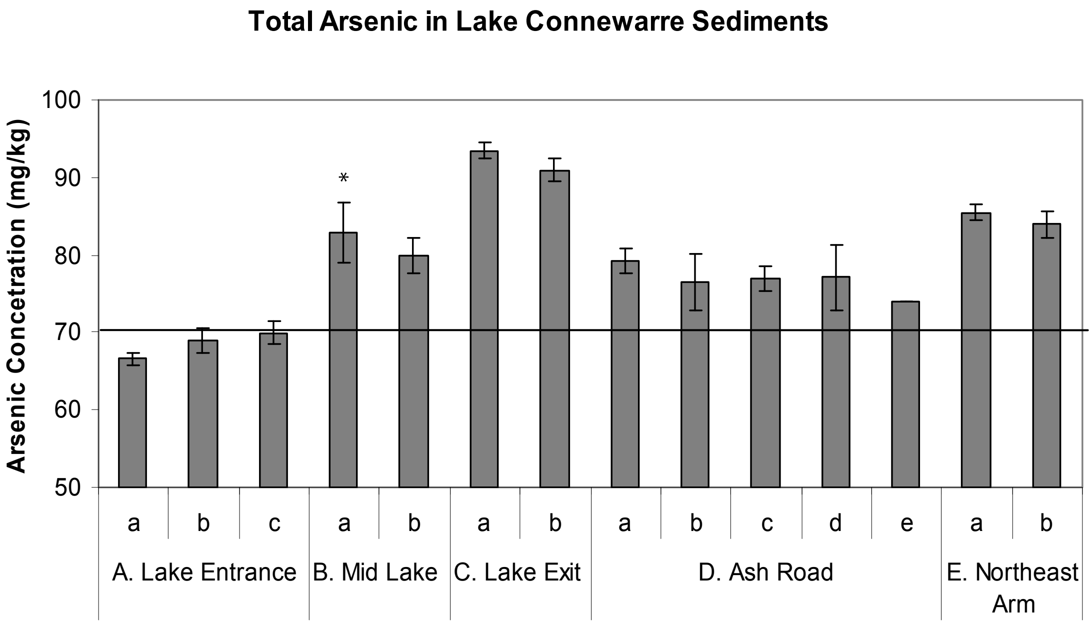



Figure 3.4 Mean arsenic levels in Lake Connewarre sediments. Letters a–e represent the depth range for sediment layers shown in Table 3-8. The horizontal line indicates the high ISQG trigger value for arsenic at 70 mg/kg. The asterisk indicates an outlier value of 200 mg/kg for core segment B2a is not represented (see Table 3-7).

**Table 3-7 Arsenic determinations of Lake Connewarre sediment cores at various sediment depth ranges by HG-AAS based on a 6:1 [HNO3+ H2SO4] heated acid digestion from oven dried sediment samples. Five replicate readings were taken from each sample. ISQG trigger values for arsenic are 20 mg/kg (low) and 70 mg/kg (high).**

| Site | Core | Layer | Depth range (cm) | [As] (mg/kg)[a] | %RSD[b] |
|---|---|---|---|---|---|
| A. Lake Entrance | 1 | a | 0–36 | 65.8 | 4.6 |
| | 2 | a | 0–35.5 | 66.7 | 3.1 |
| | | b | 35.5–44.8 | **70.1** | 4.0 |
| | | c | 44.8–55.5 | **71.0** | 5.6 |
| | 3 | a | 0–35.5 | 67.4 | 2.5 |
| | | b | 35.5–45.5 | 67.8 | 3.5 |
| | | c | 45.5–65 | 68.9 | 7.1 |
| B. Mid Lake | 1 | a | 0–13.5 | **80.1** | 1.8 |
| | | b | 13.5–28.5 | **80.2** | 6.9 |
| | 2 | a | 0–9.5 | **202*** | 8.8 |
| | | b | 9.5–29 | **77.6** | 4.3 |
| | 3 | a | 0–12 | **85.7** | 1.0 |
| | | b | 12–34 | **82.1** | 6.6 |
| C. Lake Exit (Delta) | 1 | a | 0–19.5 | **92.3** | 3.7 |
| | | b | 19.5–60 | **91.7** | 4.6 |
| | 2 | a | 0–16 | **93.8** | 6.0 |
| | | b | 16–57 | **92.0** | 4.5 |
| | 3 | a | 0–16 | **94.3** | 3.9 |
| | | b | 16–49.5 | **89.2** | 8.5 |
| D. Ash Road | 1 | a | 0–20 | **78.7** | 2.9 |
| | | b | 20–46 | **76.9** | 3.8 |
| | 2 | a | 0–13 | **81.1** | 8.0 |
| | | b | 13–28.5 | **79.9** | 4.1 |
| | | c | 28.5–40.5 | **78.0** | 5.6 |
| | | d | 40.5–56 | **80.1** | 5.4 |
| | 3 | a | 0–8.5 | **77.9** | 7.0 |
| | | b | 8.5–30 | **72.7** | 4.9 |
| | | c | 30–42 | **75.8** | 5.1 |
| | | d | 42–52.5 | **74.1** | 6.9 |
| | | e | 52.5–59.5 | **73.9** | 4.3 |
| E. North-east Arm | 1 | a | 0–26.5 | **85.4** | 1.9 |
| | | b | 26.5–33 | **83.7** | 2.5 |
| | 2 | a | 0–25.5 | **86.6** | 6.8 |
| | | b | 25.5–32.5 | **85.8** | 3.9 |
| | 3 | a | 0–17 | **84.5** | 6.8 |
| | | b | 17–22.5 | **82.3** | 4.9 |

a – Dry weight total arsenic concentration.

b – Percentage relative standard deviation.

* – Indicates an outlier arsenic concentration.

Figures in bold indicate samples that exceed the ANZECC high trigger levels.

## 3.4 Discussion

### 3.4.1 Physical characteristics

The bottom sediments of Lake Connewarre exhibit significant variations in physicochemical characteristics. Distinct sediment layers, dominated by particle size fractions which were generally 'silty' or 'sandy' in texture, were observed from cores taken from selected sites around the lake. Changes in the depth and texture of these layers suggest that deposition has occurred under varying environmental conditions, both spatially and temporally. Similar observations were made by Longmore et al. (2004), showing that the proportion of fine sediments (< 63 μm) varied with depth and location.

### 3.4.2 Sedimentation rates

Broad variations in median particle size and relative sedimentation rates between sites during the present study may be explained by differential hydrodynamic processes within the lake. These processes will be driven by a combination of elements. Physical drivers are likely to include river flow velocities, tidal patterns, wind velocities and direction, and water depth. Temporal and spatial fluctuations of these elements will differentially affect rates of sediment deposition, erosion and resuspension within the lake. Other influential factors will include the suspended sediment loads of incoming waters (fresh and marine derived), bioturbation by benthic and demersal fauna, and the effects of benthic macrophytes and macroalgae in attenuating flows across areas of the lake bed. Also, the flocculation of suspended clay particles from the Barwon River is likely to occur on entering Lake Connewarre when salinities are high enough to dissipate surface charges on these particles. Understanding and quantifying the relative contribution of all of these agents may assist in predicting future sedimentation processes within the lake.

Of particular interest is the sediment profile within the tidal delta at the exit of the lake. A 'raft' of predominantly sandy sediments 'floats' over a much deeper, low-density muddy layer (see Appendix 1c for image of sediment core). The depth of sediment at this point is unknown, as the 1.5 m core sampler was too short to penetrate the full depth at this location. The coarser surface sediments are likely to be sourced from the lower Barwon estuary. In support, Stokes (2002), in agreement with Rosengren (1973; cited in Dahlhaus et al. 2007), concluded that sediment deposition on the delta occurs during the flood tide while the ebb tide scours channels through the delta.

Relative sediment deposition rates measured over a 69-day period during the present study should not be interpreted to reflect the long-term deposition rates for Lake Connewarre. The method of capturing sediments in sediment tubes is dependant on tube diameter and can only be used to compare relative sedimentation rates throughout the lake. These short-term results do not allow for the alternating processes of deposition and resuspension associated with hydrodynamic fluctuations and the mass balance of sediment inputs and outputs of the system which occur over longer timeframes. Sherwood et al. (1988) point out that due to the shallow depth of the lake, wind-driven turbulence remobilises bottom sediments. These resuspended particles may deposit elsewhere in the lake or may be flushed out of the lake on falling tides or during periods of high discharge. Therefore, the balance between deposition and resuspension/erosion will be linked to the dynamics of coinciding multiple, cooperative or opposing driving factors.

There was a positive trend in the sediment deposition rate with distance from the lake entrance. This trend may be explained by the reduction in flow velocity as the narrow channel of the Barwon opens out into the much broader Lake Connewarre and flow-induced turbulence reduces with increasing distance from the lake entrance.

Figure 3-5  An area of Lake Connewarre between the lake exit (delta) and Campbell's Point. This area was too shallow to traverse by canoe (July 2007).

Aerial photographs of Lake Connewarre (Figure 2-2) show areas of deep and shallow water. Lighter areas indicate the shallower regions of the lake, mainly from the tidal delta at the lake exit and extending towards Campbell's Point. Figure 3-5 provides an indication of how shallow the waters were in the delta area in July 2007. Further sediment deposition within this area of the lake will most likely lead to the formation of intertidal sediments and subsequent colonisation of the highest areas by salt marsh vegetation This would eventually separate the north-east section of the lake from the western section. It is also likely that the east and south-east shoreline of the lake will contract as salt marsh vegetation advances on accreting sediments in these areas. If patterns of lower than average river discharges (that fail to scour lake sediments and transfer them to the lower estuary or out to sea) are to prevail, accretion of sediments will most likely occur at a faster than normal rate. Efforts to provide sufficient environmental flow allocations to the estuary are important to avoid unnaturally high sedimentation rates within Lake Connewarre.

It is also possible that much of the pre-European river flows from the Barwon would have deposited large amounts of sediments into Reedy Lake before entering Lake Connewarre, thus containing the rate of shallowing within the lagoon. Currently Barwon River discharges bypass Reedy Lake, allowing much of the suspended sediments to settle out in Lake Connewarre.

It is likely that a combination of reduced river discharges to scour the lake bed (in particular the advancing sediments from the lower estuary) over recent years and the long-term transfer of sediments from the catchment to Lake Connewarre without passing through Reedy Lake has contributed to increased sedimentation rates within Lake Connewarre.

### 3.4.3 Nutrients

Total nitrogen concentrations in Lake Connewarre sediments were similar to those found within other south-east Australian bays and estuaries. Total nitrogen levels in Lake Connewarre (320–2400 mg/kg) were comparable with Port Phillip Bay (200–2000 mgN/kg) (Longmore et al. 2004, after Nicholson et al. 1996) and Burrill Lake and the Clyde River estuary (up to 3000 and 3200 mg/kg respectively) on the south coast of New South Wales (OzEstuaries 2003, after Anderson et al. 1981). In comparison, nitrogen levels in the Gippsland Lakes sediments were as high as 13,000 mg/kg (Longmore et al. 2004, after Longmore 2000). Results from the present study are also comparable to those from a previous study of Lake Connewarre in 2004 (500–7000 mg/kg) (Longmore et al. 2004).

Total phosphorus levels in Lake Connewarre sediments were also comparable to other bays and estuaries, but maximum levels were about one third of the maximum concentrations found in the previous study at this site (Longmore et al. 2004) and for other locations, including Port Phillip Bay (100–1000 mgP/kg) (Longmore et al. 2004, after Nicholson et al. 1996) and Gippsland Lakes (1–970 mgP/kg) (Longmore et al. 2004, after Longmore 2000).

### 3.4.4 Heavy metals

Copper and lead levels within Lake Connewarre sediments were mostly below the ISQG low trigger values and are not considered to be of direct concern to the environment. However, there may be cause for concern with regard to cadmium and arsenic concentrations. Although some Australian soils are known to contain naturally high levels of arsenic, concentrations in Lake Connewarre sediments may have been elevated by human-induced processes. Early wool scouring mills, tanneries and fellmongeries that operated along the banks of the Barwon River at Geelong from the mid 1800s (Dahlhaus et al. 2007) discharged their effluents directly into the waterway. Throughout this period, arsenic-based products were often used in sheep dips to control ectoparasites. As a result of scouring, arsenic would have been subsequently transferred into effluents during the scouring process. It is likely that much of this wool scouring effluent, carrying arsenic residues, would have settled on the lake bed. It is also likely that water and sediments washed out from mines in the Ballarat region would have provided a source of arsenic (Leigh Catchment Group 1999) to the lake and lower estuary, via the Leigh River.

Arsenic levels in Lake Connewarre sediments were substantially greater than those found in other estuaries in western Victoria. Hindson (2007) reported values of between five and 15 mg/kg for sediments collected from Lake Yambuk (a shallow lagoon) and the Surrey River estuary between November 2006 and February 2007. Whilst all measurements for Lake Yambuk and the Surrey River were below the ISQG low trigger value of 20 mg/kg, sediments sampled from Lake Connewarre reflected arsenic levels in excess of the high trigger level of 70 mg/kg or just below it.

Measurements of arsenic carried out during the present study detected only total arsenic levels. However, it is the inorganic forms of arsenic that are known to be the most toxic (Phillips and Depledge 1986; FSA 2005). Further investigation to determine the composition of organic and inorganic species of arsenic may assist in clarifying the environmental and health risks associated with the exposure of high levels of arsenic in Lake Connewarre sediments by aquatic flora/fauna and humans.

# 4 Water quality

## 4.1 Aims and research questions

1. Measure and evaluate core water quality parameters (temperature, salinity, pH and dissolved oxygen) of the LCWC.
2. Measure the concentrations of macronutrients, nitrogen and phosphorus.
3. Establish the nutrient status of the LCWC waters and identify potential sources of N and P.
4. Provide supporting environmental information to the biotic data set, to assist in explaining the ecological processes occurring within the wetland system over the course of the investigation.

## 4.2 Method

Nine monitoring sites were selected within the LCWC to gauge the quality of water within the wetland system:

- Above Breakwater (Barwon River, immediately upstream of the barrage)
- Lower Breakwater (Barwon River, immediately downstream of the barrage) (LBr)
- Halfway (approximately halfway between lower breakwater and entrance to Lake Connewarre) (HWy)
- Lake Entrance (where water flows into Lake Connewarre from the Barwon River) (LEn)
- Tait’s Point (southern shore of Lake Connewarre) (TP)
- Lake Exit (Barwon River, immediately downstream of Lake Connewarre) (LEx)
- Gate (approximately halfway between lake Connewarre and the Sheepwash) (Ga)
- Sheepwash (near the end of Sheepwash Road, Barwon Heads) (Sw)
- Guthridge Street (near the end of Guthridge Street, Ocean Grove) (Gu).

In-situ water quality measurements also coincided with fish surveys and macroinvertebrate surveys at the following sites:

- Reedy Lake (end of Moolap Station Road)
- Reedy Lake (end of Fitzgerald's Road, Leopold)
- Reedy Lake (inlet channel)
- Hospital Swamp (end of access track, Lake Road, Connewarre)
- Lower Estuary (at the 21W Beach Identification Sign)
- Ash Road (southern end of Ash Road, Leopold)
- North-east Arm (southern end of Brinsmead Lane, Wallington).

### 4.2.1 Core physicochemical parameters

In situ measurements of water temperature, pH, salinity and dissolved oxygen (DO) were collected over ten occasions between 13 February and 8 September 2007. These were measured with an In-situ® MP Troll 9000 sonde, connected to a Rugged Reader® portable hand-held personal computer. Not all sites were measured on each of the ten occasions due to logistic constraints or as complementary data for individual biotic sampling.

### 4.2.2 Nutrients

Water samples were collected at the above sites on 3 April 2007 and analysed for total phosphorus (TP) and total nitrogen (TN). Surface water samples were collected in 125 mL acid-washed (HCl), polyethylene bottles and stored in refrigerated conditions before analysis. A deep water sample from the Lower Break was collected with an alpha bottle at approximately 2.8 m and transferred to a polyethylene bottle. Samples were analysed for TP and TN using standard methods from the Deakin University Water Quality Laboratory at Warrnambool, Victoria.

## 4.3 Results

### 4.3.1 Core physicochemical parameters

Water temperatures varied seasonally from 8.4 °C in winter (Lower Breakwater, 16 July 2007) to as high as 23.4 °C in summer (Lake Entrance, 13 February 2007). Temperature measurements collected from 19 sites for the study period are presented in Figure 4-1. Temperatures within Lake Connewarre fluctuated by at least 12 °C from mid February to early September 2007. In February temperatures tended to be warmer in Lake Connewarre and surface waters of the river above the lake entrance compared with waters in the lower estuary (i.e. downstream of LEx).

Salinity varied widely throughout the wetlands, from 1.7 PSU recorded below the Lower Breakwater on 16 July 2007 to 43.7 PSU recorded on 14 March 2007 from Sheepwash. Within Lake Connewarre salinity varied from 6 PSU on 8 September 2007 (LEn) to 40.4 PSU on 12 April 2007 (TP). Figure 4-2 shows salinities recorded during the survey period, including the salinity ranges at each site.

DO concentrations ranged from 3.73 mg/L at the Lower Breakwater on 8 September 2007 to 11.85 mg/L at Tait's Point on 8 September 2007. Results are shown in Figure 4-3.

The pH of waters within the LCWC ranged from 7.15 pH units at Fitzgerald's Lane, Reedy Lake (29 June 2007) to 9.73 pH units at the Lower Break (12 April 2007). Results are shown in Figure 4-4. pH levels exceeded the upper ANZECC trigger value of 8.5 pH units for 34 of the 59 measurements during the study period.

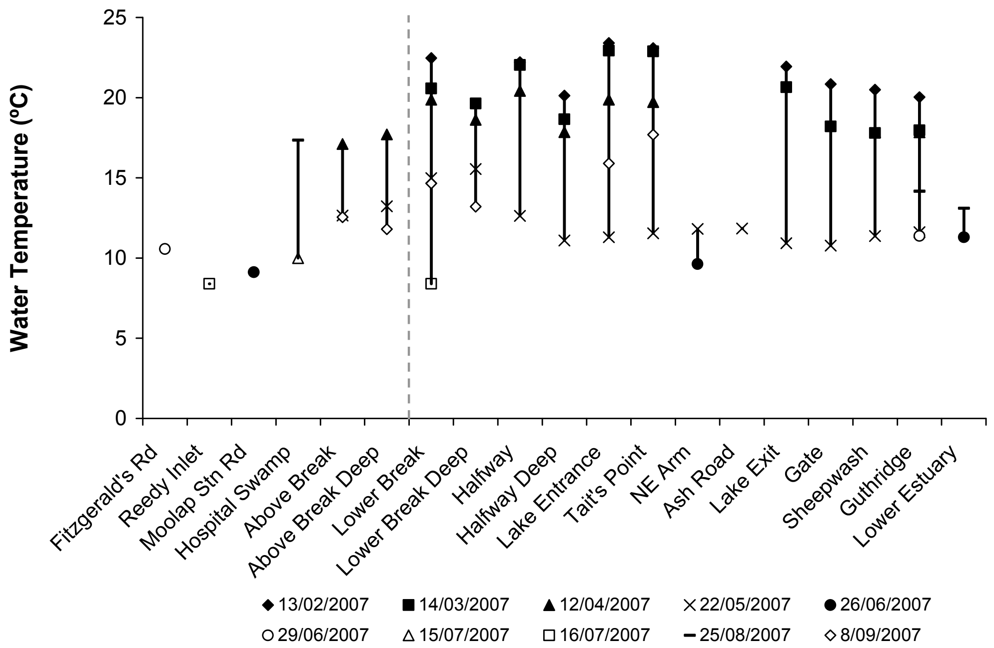



Figure 4-1 Water temperature of LCWC between 13 February and 8 September 2007. Dashed line separates estuarine waters from freshwater wetlands.

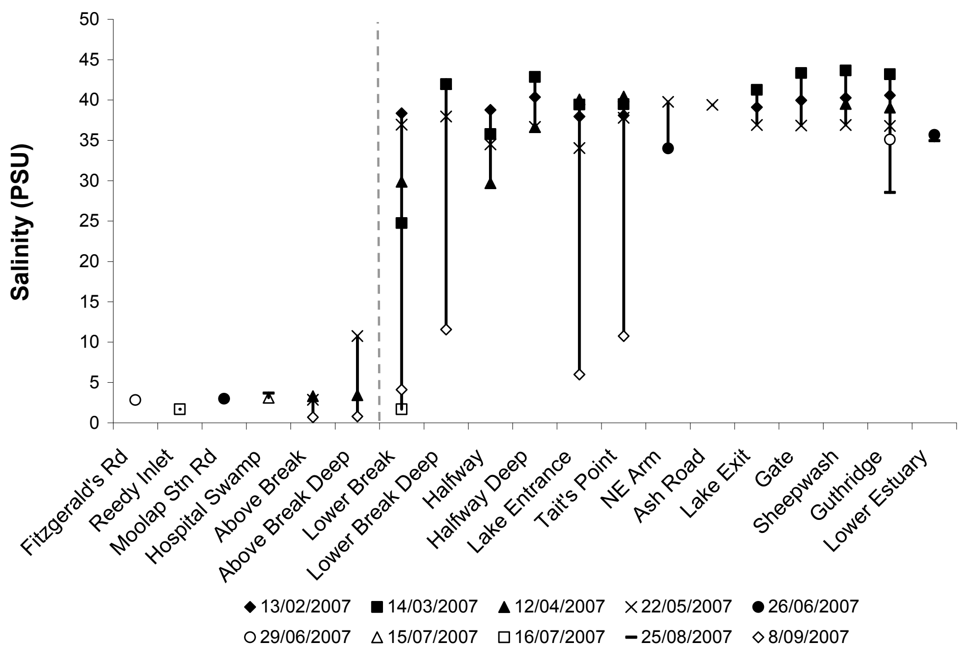



Figure 4-2 Salinity of LCWC waters between 13 February and 8 September 2007. Dashed line separates estuarine waters from freshwater wetlands.

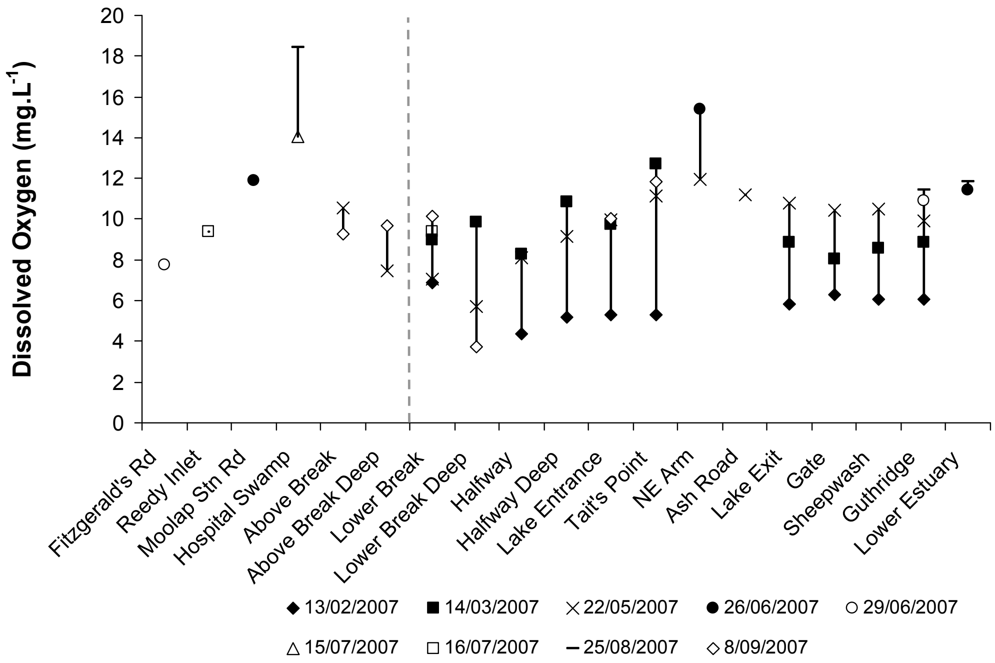



Figure 4-3 Dissolved oxygen concentrations of LCWC waters between 13 February and 8 September 2007. Dashed line separates estuarine waters from freshwater wetlands.

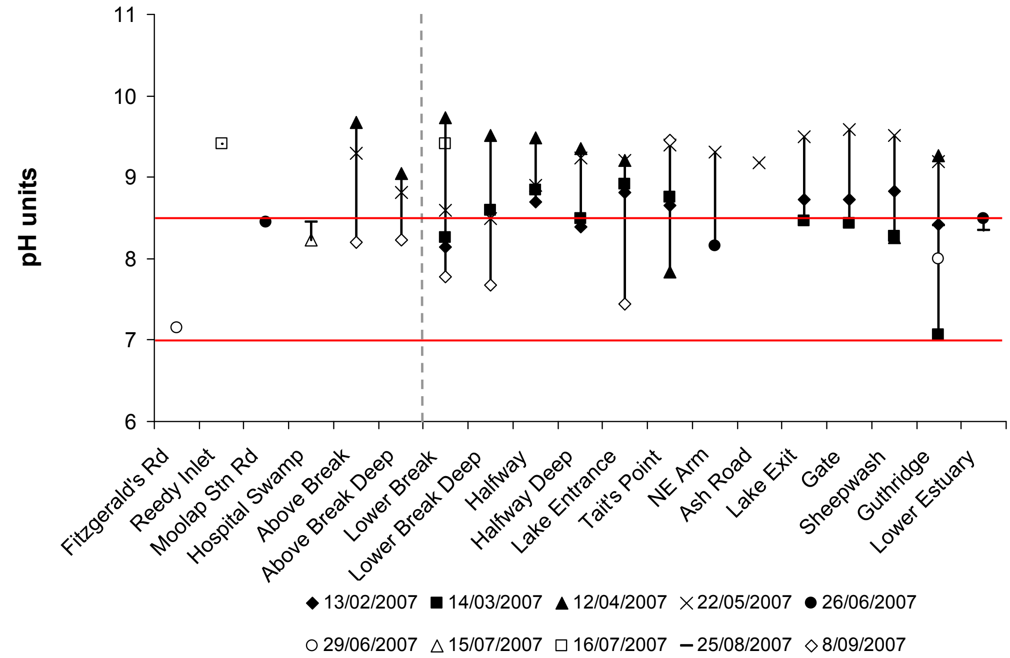



Figure 4-4 pH levels of LCWC waters between 13 February and 8 September 2007. Dashed line separates estuarine waters from freshwater wetlands. Horizontal line indicates lower and upper ANZECC trigger value for pH [7.0 and 8.5 respectively] for estuarine waters within south-east Australia (ANZECC & ARMCANZ 2000).

### 4.3.2 Nutrients

Total phosphorus concentrations within the LCWC varied from 0.04 mg/L$^{-1}$ (NE, Ash, Sw) to 0.09 mg/L in the deeper waters of the Lower Break (Figure 4-5). Concentrations exceeded the ANZECC trigger value for total P (≤ 0.03 mg/L) for south-east Australian estuaries (ANZECC & ARMCANZ 2000) at all of the eight sites surveyed. There appears to be a general trend of TP levels increasing with distance upstream from the river mouth.

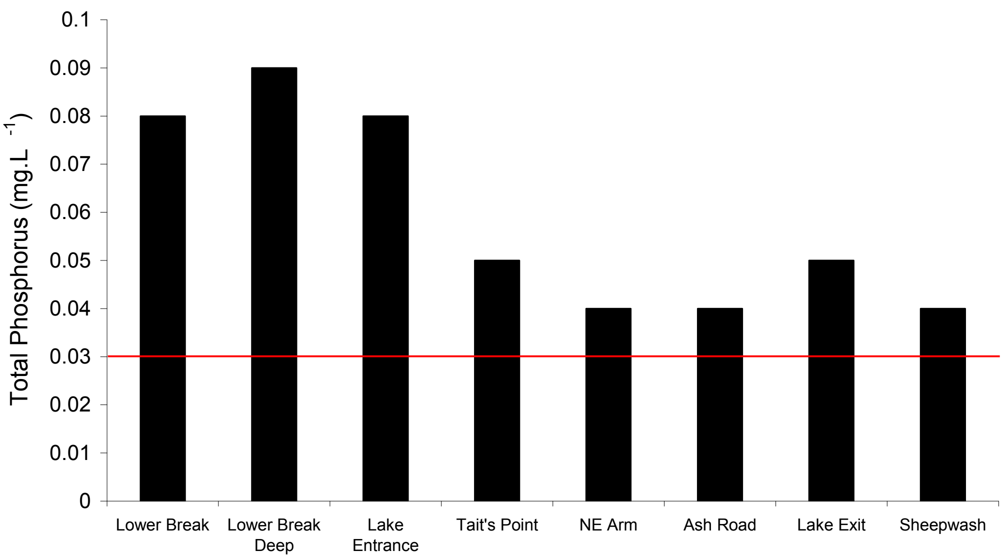



Figure 4-5 Concentrations of total phosphorus for LCWC waters. Horizontal line indicates the ANZECC trigger value for total P [≤ 0. 03 mg/L] in estuarine waters within south-east Australia (ANZECC & ARMCANZ 2000).

Total nitrogen concentrations ranged from 0.49 mg/L at Sheepwash to 0.78 mg/L at the Lower Breakwater (Figure 4-6). Concentrations exceeded the ANZECC trigger value for total N (≤ 0.3 mg/L) for south-east Australian estuaries (ANZECC & ARMCANZ 2000) at all sites. TN concentrations also appear to increase with distance from the river mouth.

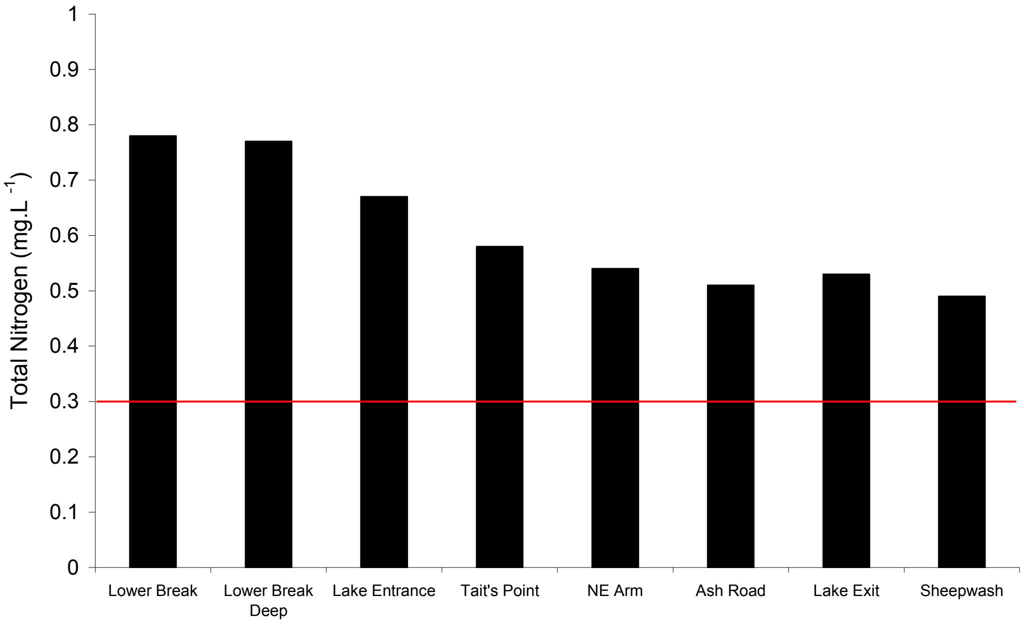



Figure 4-6 Concentrations of total nitrogen for LCWC waters. Horizontal line indicates the ANZECC trigger value for total N [≤ 0. 3 mg/L] in estuarine waters within south-east Australia (ANZECC & ARMCANZ 2000).

## 4.4 Discussion

Whilst some physicochemical parameters were generally within an acceptable range for estuarine and fresh water bodies, other parameters exceeded ANZECC trigger values applicable to these aquatic ecosystems.

Variations in pH levels were generally moderate, but on occasions were high (e.g. 7.45 to 9.21 at Lake Entrance). The carbonate–bicarbonate buffering system, which is particularly strong in marine waters (ANZECC & ARMCANZ 2000, after Stumm & Morgan 1996), would be expected to moderate pH levels within the lower estuary and Lake Connewarre. A low pH value of 7.06 at Guthridge on 14 March 2007 could have been due to insufficient warm up and equilibration of the probe at the time of measurement. Well mixed waters within a free flowing lower estuarine channel would be expected to reflect a pH reading of approximately 8–8.5 pH units during periods of low freshwater flows (due to the dominance of seawater). Sites immediately upstream at Sheepwash and Gate were 8.27 and 8.44 pH units respectively on the same day of this spurious result at Guthridge. These results are typical of estuarine pH levels. Measurements of pH > 9 were recorded throughout Lake Connewarre (but not at Tait's Point) and at Guthridge on 12 April 2007. These results should also be interpreted with caution.

Estuaries are known for their highly variable, brackish conditions where seawaters are diluted by riverine flows (Morrissey 1995). Salinities in Lake Connewarre and the lower estuary rarely fell below 35 PSU between February and July until a substantial rainfall event in July increased the freshwater discharge from the Barwon catchment. Low freshwater inputs during the early part of the survey period (identified by the lack of water passing over the lower breakwater supported by river discharge data as shown in Figure 4-7), water temperatures exceeding 20 °C on a regular basis and the heightened effects of evaporation over the shallow expanses of Lake Connewarre are likely to have combined to allow salinities to be consistently above that of seawater during the summer and early autumn periods of 2007. Salinities were considerably higher at Tait's Point (TP) and at the end of Brinsmead Lane (NE) during this survey period compared to those experienced in 1986–87 by Sherwood et al. (1988). Salinities recorded from these sites between March 1986 and March 1987 did not exceed 30 PSU.

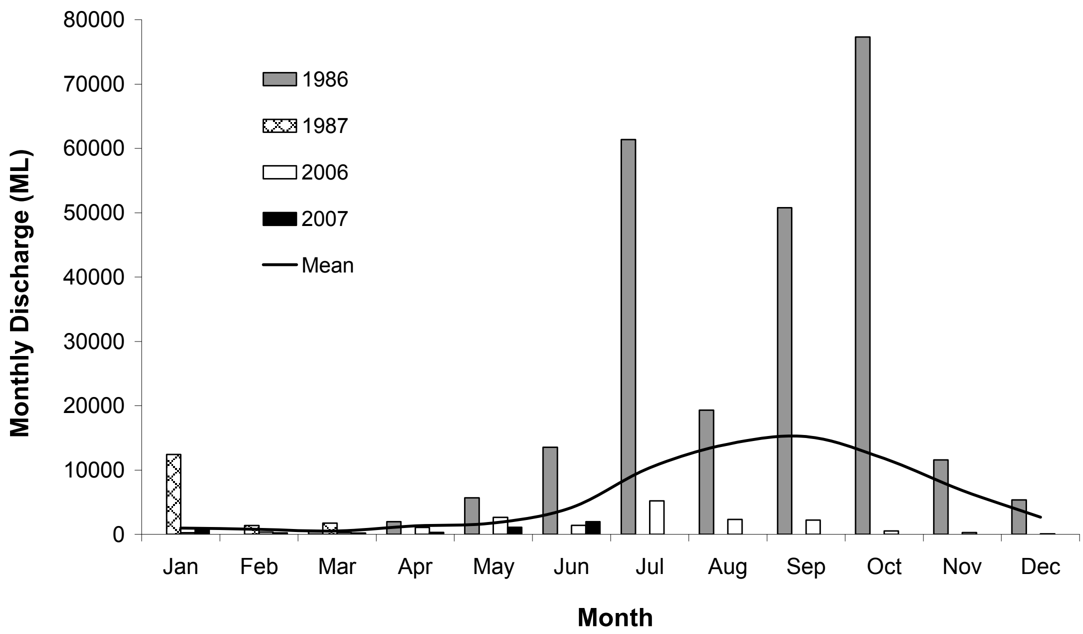



Figure 4.7 Comparison of monthly discharges from the Barwon River (Pollocksford) that immediately preceded and coincided with the present study and that of Sherwood et al. (1988). Mean monthly discharge (shown as line) derived from data collected between 1974 and 2006. Data sourced from the Victorian Water Resources Data Warehouse web site (DSE 2007).

Prolonged saline to hypersaline conditions within Lake Connewarre, brought on by a lack of freshwater inputs prior to and during much of the study period (associated with the current drought), may have the potential to shift flora and fauna community structures towards those containing more salt-tolerant species. This may make it difficult for less tolerant species to establish or occupy the lake for periods long enough to complete life cycle phases. The outcome is likely to be a reduction in biotic diversity within the lake.

Shifts in the dominance of aquatic plant species may occur due to changes in salinity. However, it is difficult to separate salinity from the other seasonal characteristics (e.g. temperature, irradiance, day length) that affect changes in the growth and standing crop of seagrasses in estuaries (Kerr and Strother 1990). Other physicochemical factors, in particular nutrient concentrations, also influence plant community composition. Multivariate analysis of relationships between physical parameters and community characteristics may assist in isolating dominant environmental factors that influence these ecosystems.

As part of his assessment of environmental flows to support fish communities within Lake Connewarre, Tunbridge (1988) recommended that during low river flows from January to April, salinities should not exceed 28 parts per thousand (ppt, or PSU) and during high flow should be less than 20 ppt. During low-flow conditions of the present study salinities within the lake were shown to be well above Tunbridge's recommended 28 ppt. Further study of the relationships between lake salinity and fish community structure and dynamics may provide answers to the effects of reduced freshwater inputs on the lake's fisheries resources.

Dissolved oxygen (DO) concentrations within estuaries are known to be highly variable over time (Flemer et al. 1999). Fluctuations in DO from this study ranged from hypoxic to well oxygenated. Most decreases in DO are a result of respiration by plants, animals and aerobic bacteria (Boulton and Brock 1999). Nocturnal plant respiration may explain low DO levels in waters measured early in the morning. High DO concentrations in the LCWC are most likely attributed to the diurnal release of oxygen from aquatic algae and vascular plants within these wetlands. Very high DO levels in Hospital Swamp may be related to the presence of actively growing *Nitella* sp. at the time of measurement.

High levels of total N and P, wide fluctuations of DO and the extensive occurrence of the red alga *Gracilaria* sp. suggest that Lake Connewarre may experience seasonal eutrophication. Future routine monitoring of these and other indicative parameters within the lake would help understand trophic dynamics. High concentrations of total N and P have previously been recorded in Lake Connewarre: levels exceeded ANZECC trigger levels for both nutrient elements during autumn and winter of 2002 (Mondon et al. 2003). Lake waters were shown to be phosphorus limited. Potential sources of these nutrients are likely to come from catchment runoff (e.g. livestock manure and agricultural fertilisers in rural area and stormwater from urban areas) and excreta from visiting wetland birds. An opportunity exists to conduct a mass balance of nutrient inputs and outputs within Lake Connewarre to determine the relative contribution from known sources of these nutrients.

High levels of phosphorus and nitrogen in these waters may also be derived from internal loading as nutrients are released from sediments into overlying waters. Many estuaries are known to act as nutrient sinks, due to their depositional characteristics (Elliot and de Jonge 2002). Nutrient fluxes between sediments and overlying waters can occur under favourable conditions. Release of phosphates from sediments into the water column may be a regular occurrence as oxygen levels in the water continually fluctuate between oxic and hypoxic conditions. McAuliffe et al. (1998) found that sediments collected from the Harvey Estuary in Western Australia consistently displayed increased phosphorus release into overlying water as DO levels fell during laboratory experiments. They also found that the critical DO concentration to enhance such a release was approximately 4 mg/L.

The red alga *Gracilaria* within Lake Connewarre may be an indicator of nutrient enrichment, but may also play an important role in nutrient cycling and oxygenation/ deoxygenation processes. Nutrient enrichment has the potential to shift the dominance by seagrasses to that of algae within estuaries and tidal channels. This has been observed in the Skagerrak and Baltic regions of Europe, where a transition in the dominance by seagrass (*Zostera*) to one of algal (*Cladophora* and *Enteromorpha*) dominance occurred (Elliot and de Jonge 2002). Qu et al. (2003) observed that actively growing macroalgal mats in Lake Illawarra, NSW, suppressed nutrient flux between estuarine sediments and overlying waters by assimilating readily available nutrients. However, Tyler and McGlathery (2006) found that nitrogen uptake by *Gracilaria vermiculophylla*, transformation and release back into the water column within a shallow lagoon on the Virginia coast (USA) (supported by laboratory trials) occurred over a very short timeframe (i.e. minutes to hours). They also showed that the mean nitrogen release from *G. vermiculophylla* amounted to 67% of the gross daily uptake. A study of the role of *Gracilaria* and other aquatic macroalgae and macrophytes from Lake Connewarre may be beneficial in understanding nutrient dynamics and controlling the balance between seagrasses and macroalgae within the lake.

The importance of seagrass habitat as nursery areas for juvenile fish is well known, and any shifts from seagrass-dominated to algae-dominated habitat may have significant affects on fish community structure, diversity and productivity. However, little is known about the value of *Gracilaria* as habitat for estuarine fauna or as fish nursery areas. A comparative study of seagrass (e.g. *Ruppia*, *Zostera*) versus *Gracilaria* as habitat for fish (particularly juveniles) within Lake Connewarre may provide useful information on the nature and productivity of fisheries within the Barwon River and nearby coastal areas.

# 5 Flora

## 5.1 Aims and research questions

Survey for, and gauge the diversity of, aquatic and wetland flora within selected areas of the LCWC.

## 5.2 Method

Flora investigations were divided into two major components:

- Phytoplankton
- Aquatic/wetland macrophytes and algae.

Methods for each component are outlined below.

### 5.2.1 Phytoplankton

Phytoplankton samples were collected at eight locations within the LCWC. These included sites from the lower Barwon estuary (Guthridge, Sheepwash, Gate, Lake Exit) and from Lake Connewarre and the Upper Barwon estuary to the lower breakwater (including Tait's Point, Lake Entrance, Halfway and Lower Breakwater). These stations are similar to those used by Sherwood et al. (1988).

#### Abiotic parameters

Physicochemical measurements of the water were taken each day of sampling with an MP Troll 9000 multi parameter probe. These included salinity, dissolved oxygen, pH and temperature. These and nutrient loadings are reported in section 4.3.

#### Phytoplankton sampling procedure

A plankton net (similar to that shown in Figure 5-1) with a mouth aperture of 200 mm and mesh size of 50 μm was used to collect phytoplankton. The samples were collected once a month over a three-month period from February until April 2007. At each location the samples were filtered as per Steedman (1976) and Debes (2006). In March, a known volume (60 L) of the sampled water was collected from the side of a small, shallow-draft motorboat and poured into the net. The retained organisms were collected for identification and counting. In April, phytoplankton was sampled by towing the net behind the same boat. The volume of sampled water was determined by measuring the rate of flow of water that passed through the net using a rotor-type flowmeter mounted in the mouth of the net. The filtered volume for the February collection was not determined, allowing only qualitative analysis of samples.


Figure 5-1 Typical tow net for plankton sampling <www.orhab.org/images/educationImages/PlanktonNetUpright.jpg>.

Filtered samples were collected in the cod end of the net and concentrated in a 200 mL container. All samples were preserved in ten per cent formalin and kept in a cool room in the dark for further analysis (as per Eaton et al. 1995; Newell 1977, Smith 1996; Steedman 1976).

In April, an extra sample of phytoplankton from each station was collected to measure the concentration of chlorophyll a, b and c. These samples were stored without formalin and kept on ice and in the dark prior to analyses (as per Boney 1989; Humphrey 1960).

## Analysis in laboratory

For qualitative analysis of the phytoplankton, random sub-samples of collected samples were taken and placed on a slide for observation using an optical microscope. Photomicrographs were taken of the common phytoplankton species (observed at 20x and 40x) with an optical microscope and digital camera.

For counting the number of cells per litre a Sedgwick-Rafter counting cell (Figure 5-2) was used following the technique described by Eaton et al. (1995). A Sedgwick-Rafter cell measures approximately 50 mm long by 20 mm wide by 1 mm deep. The total area of the bottom is approximately 1000 $mm^2$ and the total volume is 1 mL.

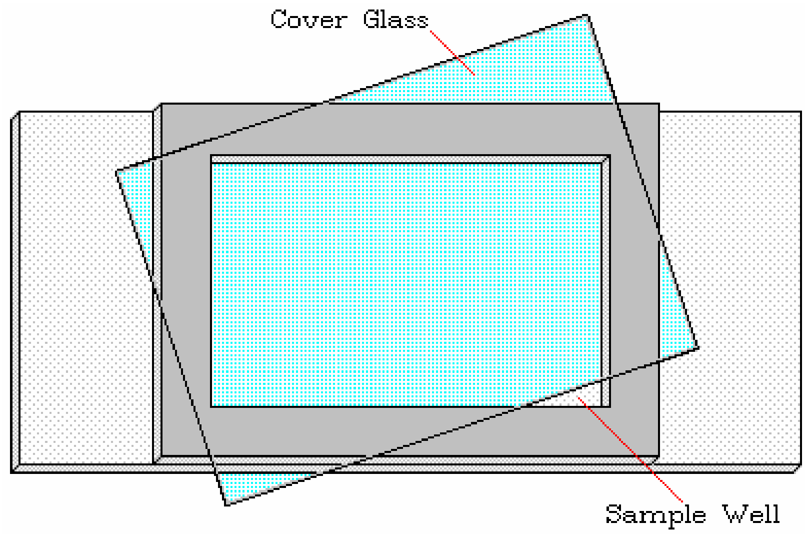



Fig. 5-2 Sedgwick-Rafter counting cell <http://el.erdc.usace.army.mil/zebra/zmis/image/moni0018.gif>.

Cell counts were made under a low magnification (20x) by random selection of ten fields (1 $mm^2$) per 1 mL for each sample.

Chlorophyll was extracted from phytoplankton in order to estimate the biomass of biological primary producers in the water. Within a few hours of collection each chilled and dark-stored water sample was filtered through a membrane filter of 0.45 µm porosity with the aid of a vacuum pump. The filter was then ground with a tissue grinder and the chlorophyll extracted over a 12-hour period using acetone, and determined by spectrophotometry. The optical density of the extracts was measured at 664, 647 and 630 nm to determine *Chla*, *Chlb* and *Chlc* respectively (Eaton et al. 1995; Humphrey 1960; Rosser 2004; Gallegos 1992). The total chlorophyll concentration in mg/L was derived.

### 5.2.2 Aquatic and wetland macrophytes

Observations of aquatic macrophytes, algae and adjacent fringing vegetation were recorded during surveys targeting fauna, water quality and sediments at selected locations within the LCWC. Taxa were identified in the field or returned to the laboratory for closer examination. This information was used to characterise the habitat within and surrounding the survey sites as well as to establish a current record of characteristic flora species for each location.

## 5.3 Results

### 5.3.1 Phytoplankton

#### Abundance

Figure 5-3 shows that the density of phytoplankton in the Barwon estuary ranged between 250 and 5000 cells/L during the late summer and autumn of 2007. There was a very high abundance in April at Lake Exit. This peak is also obvious in the chlorophyll content of the water, as shown in Figure 5-4.

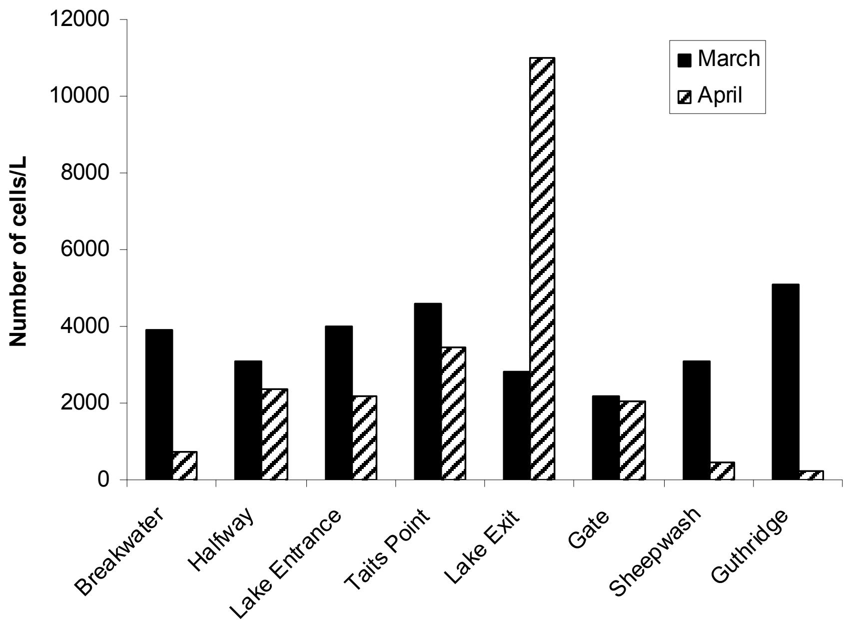



Figure 5-3. Phytoplankton abundance (cells/L) at each station in March and April.

### Chlorophyll determination

The two stations in the lake (Lake Entrance and Tait's Point) both showed much higher concentrations of chlorophyll compared with the stations along sections of the river both above and below the lake.

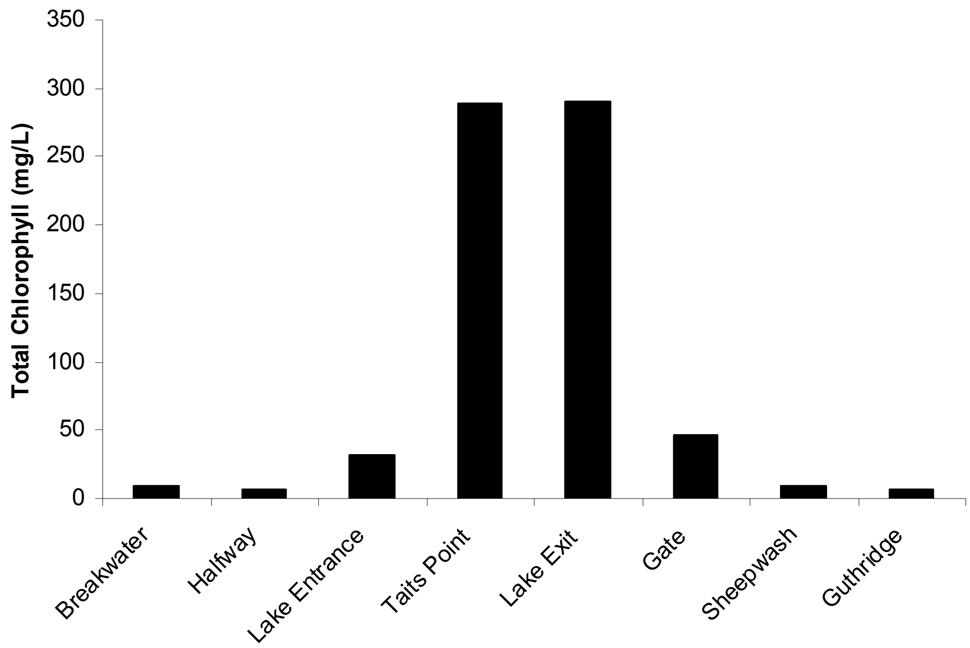



Figure 5-4 Chlorophyll concentration measured by acetone extraction.

## 5.3.2 Aquatic and wetland macrophytes

One hundred vascular plants and three algae were identified from eight sites within the LCWC. Of these, 52 are native to the area, four are considered native to Australia but outside their natural range and 57 are introduced species. Three species are listed under the Victorian Rare or Threatened Species List (VROTS):

- Marsh Saltbush *Atriplex paludosa* subsp. *paludosa*
- Grey Mangrove *Avicennia marina* subsp. *australasica*
- Yellow Sea-lavender *Limonium australe.*

One plant of Marsh Saltbush was found on the shore of Lake Connewarre at Ash Road. It was also observed along scattered sections of the Barwon estuary below the lake. Grey Mangrove forms extensive, estuarine shrubland within the mid tidal zone of the lower estuary at Barwon Heads and Ocean Grove. Colonisation of mangrove seedlings were evident upstream of the boat ramp near the Ocean Grove Golf Course. Scattered colonies of mangrove were also found further upstream towards Lake Connewarre and within some of the small creeks which drain the surrounding salt marsh. One mangrove seedling was also found growing on the shore of Lake Connewarre at Ash Road. A small population of Yellow Sea-lavender was located within salt marsh near the Ocean Grove Golf Course.

Extensive colonies of the red alga *Gracilaria sp.* (see Figure 5-5) were found throughout most of Lake Connewarre. The alga often coincided with Sea Tassel *Ruppia maritima;* however, *Gracilaria* appeared to dominate macrophyte biomass for the lake bed. *Ruppia* was sparse within the lake, as was the Dwarf Grass Wrack *Zostera muelleri*. An unidentified, fine, filamentous, epiphytic alga was found attached to *Gracilaria* and *Ruppia* throughout much of the lake. Large numbers of the small estuarine mussel *Xenostrobus securis* were often attached to clumps of *Gracilaria*, or *Gracilaria/Ruppia* communities. Small colonies of the green alga *Enteromorpha intestinalis* was also observed in Lake Connewarre at the delta near the lake exit.

Intertidal sandflats and mudflats of the lower estuary near Barwon Heads and Ocean Grove supported patches of Dwarf Grass Wrack *Z. muelleri*, of various sizes and sparseness.

## 5.4 Discussion

The presence of plant assemblages reflects the prevailing environmental conditions associated with a given habitat. In the case of aquatic systems, plants are responsive to a range of factors, including water quality (e.g. salinity, nutrients), light intensity (associated with water clarity/turbidity), temperature, and hydrological variations (e.g. inundation duration, timing, frequency and depth) (Boulton and Brock 1999).

Relationships between plant communities and prevailing environmental conditions are just as evident within the LCWC. The variety and variability of the array of abiotic factors within the LCWC contributes to the wetland system's floristic diversity, both spatially and temporally. This diversity is reflected in Yugovic's (1985) study of the Lake Connewarre Game Reserve, where he identified over 20 floristic associations and 215 species (of which 137 were native and 18 were recognised as having conservation significance). In the present study seasonal conditions through autumn and winter limited the number of plants that could be observed, and the scope of the project did not allow for such a detailed task to be carried out.

Figure 5-5 A dense cover of the red algae *Gracilaria sp.* at the delta near the exit of Lake Connewarre. The larger strand of detached macroalga (Macrocystis) has washed in from coastal waters.

Such a detailed survey and mapping of the flora has not been carried out for this area since Yugovic's work. After 23 years an opportunity exists to repeat this study to determine long-term changes in the character and spatial patterns of vegetation communities throughout these wetlands. However, the dynamic nature of some wetland plant communities should be considered when comparing changes over long periods. Accompanying information on water quality and hydrological data could also be used to better understand the relationships between these factors and plant community structure and dynamics. This may provide an important tool for the future management of the flora of the LCWC, in particular, manipulating hydrological conditions for the conservation of threatened plant species and communities or for controlling invasive weed species. Observed shifts in plant communities could also be useful as indicators for the early detection of hydrologic or water quality changes (from surface and groundwater sources), as well as climatic and sea level rise changes associated with global warming. *Gracilaria*, *Ruppia* and *Zostera*, may be useful as indicator species within Lake Connewarre, to reflect changes within this extreme and dynamic system.

# 6 Fauna

## 6.1 Aims and research questions

Survey for, and gauge the diversity of, aquatic and wetland fauna groups within the LCWC including:

- Zooplankton
- Meiofauna
- Aquatic macroinvertebrates
- Fish
- Frogs
- Reptiles
- Birds
- Mammals.

## 6.2 Method

Vertebrate surveys and invertebrate sampling were carried out at predesignated locations throughout the LCWC. These locations are listed in Table 2.1. All fauna surveys were carried out under the conditions of the Department of Primary Industries Victorian Fisheries Permit RP 752, the Department of Sustainability and Environment (Permit No. 10004104) and the Deakin University Animal Ethics Committee (AEC No. AWC4/05_A11/2007). The following sections detail the methods used for each of the fauna groups.

### 6.2.1 Zooplankton

Zooplankton was sampled in the same manner as that used for phytoplankton, except that a net with a 150 µm mesh was used. In the laboratory, samples were filtered through a sieve with a mesh size of 63 µm. The filtered concentrate was diluted in 250 mL of water. Three sub-samples of 15 mL each were placed in a counting tray (Figure 6-1) and analysed with the use of a stereomicroscope (as per Newell 1977). Zooplankton was identified to various taxonomic levels and each taxonomic group was counted and densities determined.

Figure 6-1 Zooplankton counting tray <www.hydrobios.de/images/produkte/plankton/planktonkammer.jpg>.

### 6.2.2 Meiofauna

Samples of meiofauna were collected on six dates from a boat using a Wildco Petit Ponar benthic grab. Upon retrieval, the removable panels on top of the grab were removed to allow access to the sediment without disturbing it. A sample of sediment was taken from the grab using a 30 mL syringe to extract a core of surface area 20 $mm^2$. The sample was then bagged and fixed with an equal volume of ten per cent formalin. Five independent samples were obtained for each station by collecting one core from each of five grab samples. Two cores were randomly selected for processing and the remaining three were archived. Meiofauna was extracted from the sediment by decantation and rinsing; organisms were separated using Ludox flotation and evaporated to glycerol before mounting on slides as described in Somerfield and Warwick (1996). Nematodes were identified to genera at 400x magnification using Platt and Warwick (1988, 1983) and Warwick et al. (1998). Multivariate analyses of the nematode counts were performed using the PRIMER-E package, version 6.

### 6.2.3 Aquatic macroinvertebrates

Aquatic macroinvertebrates were sampled at each site using one of the following methods. The methods selected were based on the suitability and limitations of each sampling method with certain habitat types.

#### Dragging a dip net over a 1 $m^2$ quadrat

This technique was used to dislodge and capture fauna over vegetated substrata inundated with shallow water (e.g. seagrass beds in the lower estuary, the beds of Reedy Lake and Hospital Swamp). Three replicate samples were collected.

### Hand-picking fauna within a 0.5 m x 0.5 m quadrat

This technique was adopted within mangrove habit at low tide (Guthridge). The previous method was deemed inappropriate due to the obstruction by pneumatophores and stems. Three replicate samples were collected.

### Collection of sediments and seagrass/algae patches using a Petit Ponar Grab

Areas supporting seagrass and/or macroalgae were sampled with a Petit Ponar benthic grab. Five replicate samples, each 0.15 x 0.15 m, were collected from Lake Connewarre. This method was adopted to incorporate sampling of flora from the lake bed and to avoid difficulties with using other sampling methods from the boat.

All macroinvertebrate abundances recorded from the various sampling procedures were converted to densities of macroinvertebrate taxa (numbers/$m^2$ of substrate).

## 6.2.4 Fish

Fish sampling occurred diurnally on seven days between 25 June and 8 September 2007. Fish were sampled from nine locations within the LCWC using one or more of the following methods. The sampling methods selected were based on the constraints of each method with certain habitat types. Table 6.1 shows the methods used for each sampling site.

The contents of each haul were separated into taxonomic groups (generally to species level). Individuals were counted and bulk weights recorded for each taxon on site. Species were identified from Hutchins and Swainston (1999), Kuiter (1999) or McDowall (1996). The total fish abundances for each haul were combined to obtain an aggregate for each sample site.

**Table 6.1 Fish survey dates and sampling methods employed for each site surveyed**

| Site | Date surveyed | Bait trapping | Fyke netting | Seine netting |
|---|---|---|---|---|
| **LEn** | 8 Sep 07 | • | • | • |
| **TP** | 14 Jul 07 | • | • | |
| **NE** | 25 Jun 07 | • | • | • |
| **Gu** | 29 Jun 07 | • | • | • |
| **LoE** | 26 Jun 07 | • | • | • |
| **RFi** | 29 Jun 07 | • | • | |
| **RMo** | 26 Jun 07 | • | • | |
| **RIn** | 16 Jul 07 | • | • | |
| **HSw** | 15 Jul 07 | • | • | |

Aggregate bulk weight for each sample site was determined by combining total bulk weights from each haul for that site. These were weighed to the nearest 0.1 g using an A and D® HL200 EX portable electronic balance. The balance was shielded from the wind by placing it inside a Perspex box to reduce reading fluctuations caused by wind turbulence.

#### Bait trapping

Each of five bait traps (1 mm mesh size) was placed 10–20 m away from adjacent traps in waters deep enough to cover the trap and allow fish to pass through the entrances at both ends of each trap. Mashed pre-frozen bluebait was placed into the zip-locked pouches as an attractant for small fish. Bait traps were secured by tying to wooden stakes and retrieved after two hours. All fish caught were identified, counted and a sub-sample of each species was weighed to the nearest 0.1 g.

#### Fyke netting

A two-winged fyke net (3 mm mesh size) was used to catch larger fish species. Each wing was angled at 45° to the net entrance, creating an angle of 90° to encourage fish moving towards the net opening into the chamber of the net. The fyke net was secured with three stakes 1.8 m long. Where a current or flow was detected, the net was placed with the entrance facing into the flow. The net was retrieved after two hours and all fish removed for identification, counting and weighing.

#### Seine netting

Three consecutive, shore-based seine net hauls were carried out using a 6 m x 1.2 m seine net (3 mm mesh size) at sites where netting was not hindered by vegetation or other obstructions. Each haul, at least ten metres, was 20 m in length and parallel to the shore. Hauls were carried out in water up to 1.2 m deep. After each haul nets were returned to shore where fish were identified, counted and a sub-sample of each species weighed to the nearest 0.1 g.

### 6.2.5 Frogs

The presence of frog species was noted from the recognition of incidental calls throughout the survey period and from targeted surveys at six locations. Targeted surveys were carried out on the evening of 18 September 2007. The timing of this survey was chosen to allow sufficient time for frog populations to develop and become active after the inundation of Reedy Lake and Hospital Swamp in July 2007. Table 6.2 shows the locations and times that the surveys occurred. Calls were recorded over a 20-minute period at each site. The identities of the calls were later verified by comparing the recordings to digital audio files of known species (Amphibian Research Centre 2007).

**Table 6.2 Location and times of targeted frog surveys carried out on the evening of 18 September 2007.**

| Survey Location | Site | Time (PM) |
|---|---|---|
| Reedy Lake, end of Moolap Station Road | RMo | 6.50 |
| Reedy Lake, end of Fitzgerald's Road, Leopold | RFi | 7.30 |
| Ash Road, southern end leading to Lake Connewarre | Ash | 7.55 |
| North-east Arm, end of Brinsmead Lane, Wallington | NE | 8.20 |
| Salt Swamp, Barwon Heads Road, Connewarre | SSw | 9.00 |
| Hospital Swamp, Hospital Swamp Road, Connewarre | HSw | 9.35 |

### 6.2.6 Reptiles

Incidental observations for reptiles were carried out during visits to each shore-based survey site. However, with visits occurring during the cooler months no signs of reptiles were recorded and will not be addressed in the results.

### 6.2.7 Birds

Incidental observations of bird species and their abundances were recorded on most field trips to all sites during the course of the study. Observations were aided by Minolta Weathermatic 7x42 field binoculars. Surveys were conducted from the shore or from a boat, depending on the location and nature of other concurrent field studies. Species were identified from Simpson and Day (1999) and Slater et al. (1995) as required.

### 6.2.8 Mammals

Incidental observations of mammal species or signs of mammals were recorded during the course of the study. Observations were aided by Minolta Weathermatic 7x42 field binoculars where required. Species were identified from Menkhorst (2001) and Triggs (1996).

## 6.3 Results

### 6.3.1 Zooplankton

A total of 21 taxa were identified from 24 samples, collected on three occasions between February and April 2007.

Copepods were the dominant group, with the greatest abundance occurring at Lake Exit (2734 individuals), and the lowest at Halfway with 367 individuals (Table 6-3). The stations that presented lowest diversity were

Tait's Point and Lake Entrance (11 taxa), compared with Guthridge (18 taxa) followed by Lake exit (15 taxa), Sheepwash, Gate and Breakwater (14 taxa each) and Halfway with 13 taxon. In total the samples contained 21 zooplankton taxa.

**Table 6-3 Total number of individuals sampled per station (see methods) during February, March and April.**

| Station / Taxon | LBr | HWy | LEn | TP | LEx | Ga | Sw | Gu |
|---|---|---|---|---|---|---|---|---|
| **Acantharea** | - | - | - | - | - | - | - | 1 |
| **Acarina** | 1 | - | 6 | 1 | - | - | - | - |
| **Actinopterygii** | - | - | - | - | - | - | - | 1 |
| **Amphipoda** | - | - | - | - | 1 | 4 | 2 | 4 |
| **Appendicularia** | 1 | 1 | - | - | 2 | 6 | 4 | 3 |
| **Bivalvia** | - | 1 | - | - | - | - | - | - |
| **Chaetognatha** | - | - | - | - | - | 1 | - | - |
| **Copepoda** | 923 | 367 | 456 | 755 | 2734 | 715 | 770 | 1257 |
| **Decapoda** | 1 | 3 | - | - | 30 | 23 | 8 | 7 |
| **Eggs** | 3 | 3 | 2 | 6 | 94 | 141 | 21 | 24 |
| **Fish larvae** | 1 | 1 | - | - | 7 | 6 | 1 | 2 |
| **Foraminifera** | 48 | 10 | 38 | 15 | 14 | 41 | 228 | 131 |
| **Hydrozoa** | 68 | 62 | 10 | 6 | 7 | 7 | 13 | 4 |
| **Nauplii larvae** | 93 | 65 | 111 | 21 | 48 | 27 | 237 | 125 |
| **Nematoda** | 14 | 168 | 40 | 1 | - | - | 3 | 5 |
| **Oligochaeta** | 11 | 3 | 1 | 7 | 2 | 5 | 4 | 1 |
| **Ostracoda** | 11 | 17 | 30 | 5 | 39 | 48 | 27 | 35 |
| **Polychaeta** | 40 | - | 4 | - | 6 | 22 | 25 | 45 |
| **Protozoa** | 184 | 39 | 46 | 188 | 23 | 5 | - | 4 |
| **Siphonophora** | - | - | - | 1 | 1 | - | 3 | 2 |
| **Thaliacea** | - | - | - | - | 1 | - | - | 1 |

The multidimensional scale ordinations (MDS) for all samples by month and station are shown in Figure 6-2. In MDS plots, the proximity of points in the figure indicates their similarity (calculated for biological data by the Bray-Curtis coefficient) in terms of species composition and abundance. Axes do not have labels in these plots since they represent similarity of multi-dimensional data in 2-D space. The degree to which the data is adequately represented by the plot is given by the stress value, which indicates a good fit when the stress is less than 0.2. A clear and significant difference was displayed between the monthly samples of zooplankton, all stations combined.

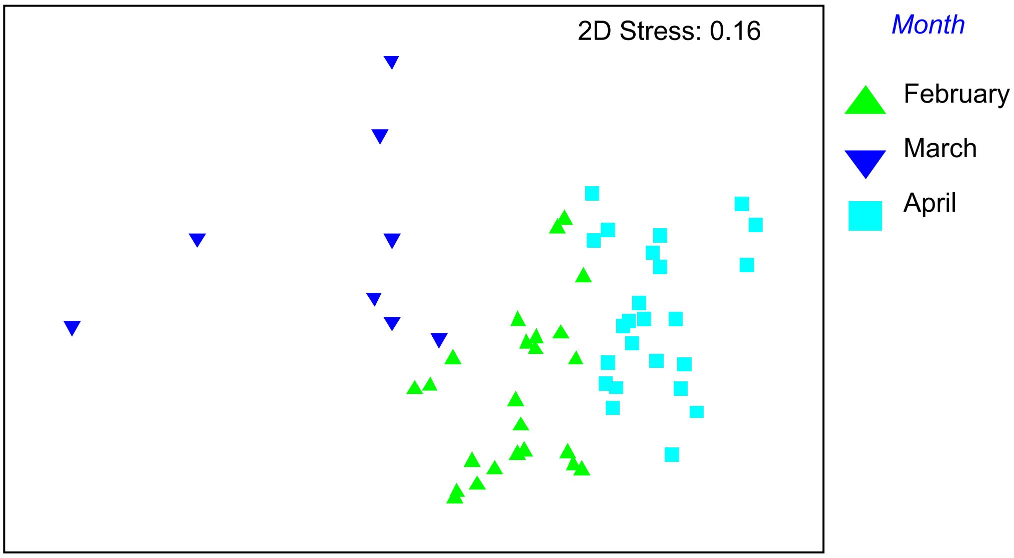



Figure 6-2 Zooplankton composition over three months, all stations combined. Stress value: 0.16.

When data for a single month (e.g. March, Figure 6-3) was displayed in a multivariate ordination plot the stations were easily separable, showing that the composition of the plankton was different between stations, as well as between times.

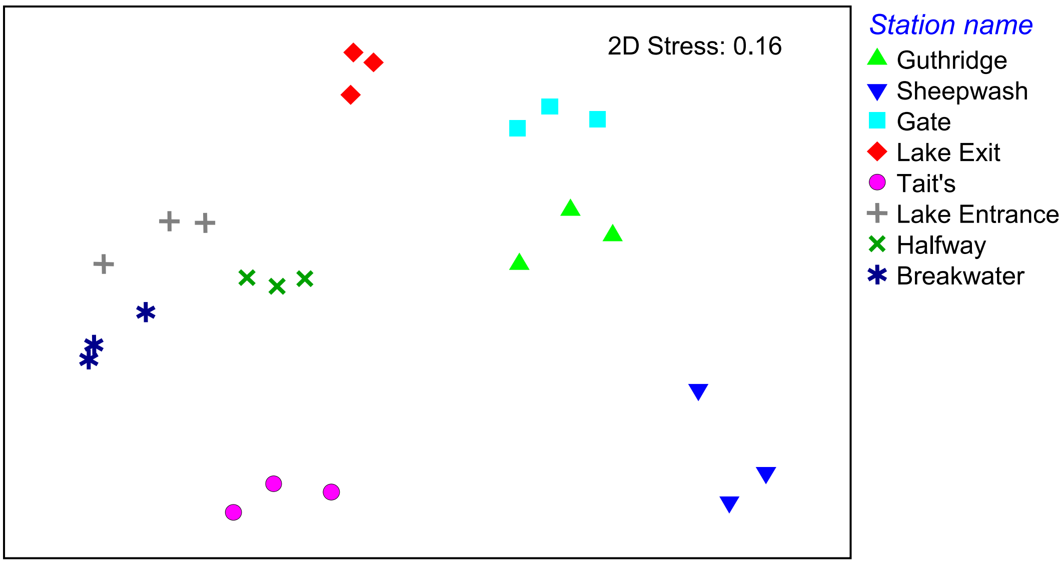
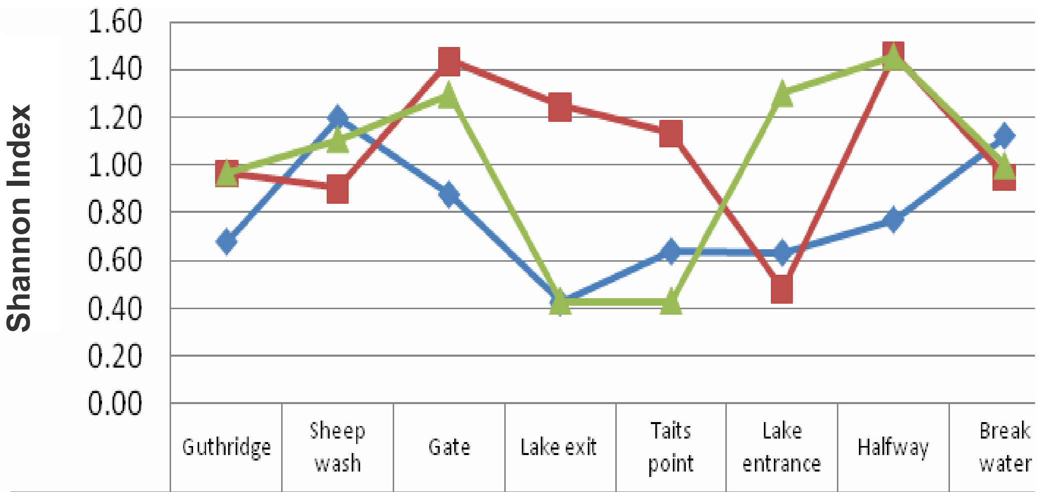



Figure 6-3 Zooplankton at eight stations in March 2007.

The diversity of zooplankton in the eight stations each month was estimated using the Shannon Index (see Figure 6-4). The site with the highest zooplankton diversity was Halfway in April, and again Halfway and Gate in March. The lower diversity stations were Lake Exit, Tait's Point and Lake Entrance.




| | Guthridge | Sheep wash | Gate | Lake exit | Taits point | Lake entrance | Halfway | Break water |
|---|---|---|---|---|---|---|---|---|
| February | 0.68 | 1.20 | 0.88 | 0.43 | 0.64 | 0.64 | 0.77 | 1.12 |
| March | 0.97 | 0.90 | 1.44 | 1.25 | 1.14 | 0.48 | 1.46 | 0.95 |
| April | 0.97 | 1.11 | 1.30 | 0.43 | 0.43 | 1.30 | 1.46 | 1.00 |

Figure 6-4 Shannon Diversity Indices for zooplankton assemblages at each location for February, March and April.

## 6.3.2 Meiofauna

A total of 84 species were recorded from 3566 nematodes in 109 samples from eight stations between two and 15 km upstream from the Barwon River mouth. Only six nematode genera *Daptonema, Dichromadora, Parodontophora, Leptolaimus, Viscosia* and *Sabatieria* from 84 were recorded from every station.

The stations along the river were separable on the basis of the assemblage of nematodes identified at each station. Figure 6-5 is an ordination plot of pairwise differences on which (as above for zooplankton) the relative proximity of the stations indicates their rank similarity. The superimposed arrows and numbers indicate the order and distance (km) of each station from the river mouth.

The species richness (S), Shannon diversity (H'), and Multivariate Dispersion (MD) for each station is shown in Table 6-4. The MD is a measure of variation within the species composition of the sample, and is thought to be greater for disturbed or contaminated sites than for more stable, control sites (Clarke et al. 2006).

An inventory of all nematode species is provided in Appendix 2.

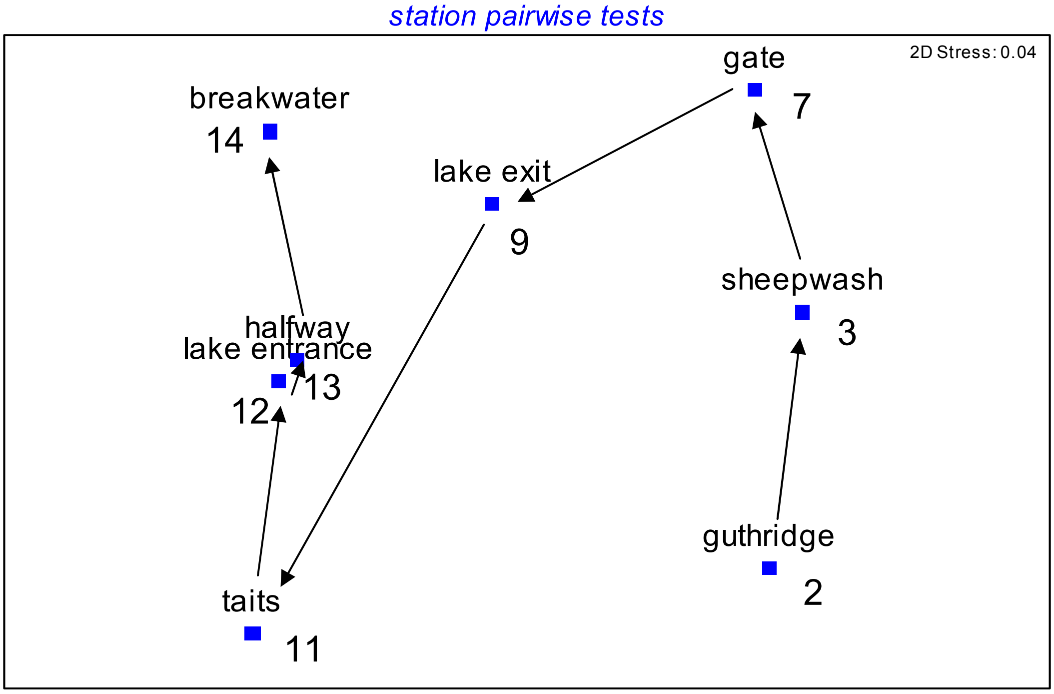



Figure 6-5 Station pairwise plots for nematode assemblages along the Barwon estuary, in which the proximity of points indicates their biotic similarity. The arrows and numbers indicate order and distance (km) from river mouth.

**Table 6-4 Assemblage characteristics of nematodes from the Barwon estuary. The values for MD are based on Bray-Curtis similarity.**

| Distance from river mouth | Station (samples) | Total no. of species | Mean S, SD per sample | H′ | Multivariate dispersion |
|---|---|---|---|---|---|
| 2 | Guthridge (14) | 58 | 13.8 ± 4.4 | 2.3 ± 0.4 | 1.1 |
| 3 | Sheepwash (14) | 52 | 10.8 ± 4.3 | 1.9 ± 0.5 | 1.3 |
| 7 | Gate (14) | 42 | 11.8 ± 2.9 | 2.1 ± 0.3 | 0.9 |
| 9 | Lake Exit (13) | 16 | 2.2 ± 0.9 | 0.6 ±0 .4 | 1.6 |
| 11 | Tait's Point(14) | 29 | 10.6 ± 2.2 | 1.9 ± 0.3 | 0.3 |
| 12 | Lake Entrance (14) | 30 | 8.4 ± 3.0 | 1.8 ± 0.4 | 0.92 |
| 13 | Halfway (12) | 28 | 8.1 ± 4.3 | 1.7 ± 0.6 | 0.95 |
| 14 | Breakwater (14) | 25 | 7.1 ± 3.4 | 1.6 ± 0.6 | 0.99 |

With the exception of the station at Lake Exit the species richness displayed a clear trend from 58 species at the most seaward station to 25 at the Breakwater furthest upstream. The trend in the Shannon Index shows a corresponding and inverse relationship between diversity and distance from the sea. There was a very low value for both richness and diversity measures at Lake Exit, where the lake bed is only a few centimetres deep and there is a deltaic arrangement of sand bars. There were significant differences in the Shannon index between Lake Exit and all other stations, and also between the most seaward station at Guthridge and both of the two uppermost stations at Halfway and Breakwater.

### 6.3.3 Aquatic macroinvertebrates

A total of 52 macroinvertebrate taxa were recorded from ten sites within the project area. Appendix 3 lists the taxa observed at each site during the survey along with their respective population densities. Reedy Lake exhibited the greatest diversity of macroinvertebrates, with 20 taxa identified from two sites. Sixteen taxa were identified from the mangrove and seagrass areas within the lower reaches of the Barwon River estuary (two sites), 14 taxa recorded from one site at Hospital Swamp and 14 taxa from Lake Connewarre (five sites on two occasions).

Insects were the most diverse macroinvertebrate group sampled from the fresh waters of Reedy Lake (nine taxa) and Hospital Swamp (six taxa). Molluscs contributed most to the diversity in the mangrove and seagrass areas of the lower estuary (eight taxa), whilst crustaceans and molluscs contributed most to the macroinvertebrate diversity on the bed of Lake Connewarre (seven and five taxa respectively). Contributions of representative macroinvertebrate taxa to the major taxonomic groups for each wetland surveyed are shown in Table 6-5.

Within Lake Connewarre, the minute bivalves *Arthritica semen* and *Melliteryx helmsi* were numerically dominant. Estimated combined densities of these two species exceeded 32,000 individuals/$m^{-2}$ at Tait's Point on 8 March 2007. These two species contributed to more than 80% of the macroinvertebrate community at all sites within the lake. The small mussel *Xenostrobus securis* was also present in Lake Connewarre in large numbers (459 individuals/$m^{-2}$ at Tait's Point to 6414 individuals/$m^{-2}$ at Lake Entrance). This species was most often found attached either to rocks, or to the base of Sea Tassel *Ruppia spp,* the rhodophyte *Gracilaria* or in clumps consisting of a combination of both. Large masses of shells from *X. securis* were occasionally found washed up on the north shore of the lake between Ash Road and Brinsmead Lane (NE) during the course of the survey.

**Table 6-5 Number of taxa represented for each broad taxonomic group of aquatic invertebrates within the LCWC.**

| Major taxanomic group | Lake Connewarre | Lower Estuary | Reedy Lake | Hospital Swamp |
|---|---|---|---|---|
| Cnidaria | - | 1 | - | - |
| Mollusca | 5 | 8 | 2 | 1 |
| Crustacea | 7 | 4 | 5* | 3^ |
| Insecta | - | - | 9 | 6 |
| Acarina | - | - | 3 | 3 |
| Turbellaria | - | - | 1 | 1 |
| Polychaeta | 2 | 3 | - | - |
| **Total number of taxa represented** | **14** | **16** | **20** | **14** |
| **Number of major groups represented** | **3** | **4** | **5** | **5** |

*– Includes four taxa of freshwater zooplankton.

^ – Includes two taxa of freshwater zooplankton.

### 6.3.4 Fish

Eleven taxa of fish were collected from netting surveys during the survey period. These are listed in Table 6-6 along with their abundances for each survey site, their total numbers collected and the corresponding percentage of total catch. An additional species, the Short-finned Eel *Anguilla australis* was observed in Lake Connewarre from the survey boat between Lake Entrance and Tait's Point on 8 March 2007. Eight taxa were collected from the Barwon River estuary below Lake Connewarre, whereas four taxa were collected (and an additional one sighted) from Lake Connewarre, two species from Reedy Lake and one species from Hospital Swamp. The highest number of taxa sampled at any one site was six. This occurred within the shallow intertidal zone of the Lower Estuary (LoE) over sand, interspersed with sparse patches of the seagrass *Zostera muelleri*.

Atherinids and the Tamar River Goby *Afurcagobius tamarensis* were the most widely distributed taxa, with both being found at four of the nine sites. The Atherinids were found between Tait's Point (TP) and the lower estuary at Ocean Grove (LoE). *A. tamarensis* was found in the saline waters of Lake Connewarre and the fresh waters of the inlet channel at Reedy Lake (RIn).

**Table 6-6 Abundances of fish and percentage of total catch recorded from netting surveys.**

| | Survey site | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species / common name** | **LEn** | **TP** | **NE** | **Gu** | **LoE** | **RFi** | **RMo** | **RIn** | **HSw** | **Number of individuals** | **% of total no. of individuals** |
| *Aldrichetta forsteri* Yellow-eye Mullet | - | - | - | - | 5 | - | - | - | - | 5 | 0.9 |
| *Arripis trutta* Eastern Australian Salmon | - | - | - | - | 1 | - | - | - | - | 1 | 0.2 |
| *Sillaginoides punctata* King George Whiting | - | - | - | - | 1 | - | - | - | - | 1 | 0.2 |
| *Atherinidae* (Hardyheads/Silverfish) | - | 14 | 174 | 97 | 161 | - | - | - | - | 446 | 78.4 |
| *Galaxias maculatus* Common Jollytail | - | - | - | - | - | - | - | 1 | 1 | 2 | 0.4 |
| *Hyporhamphus melanochir* Southern Sea Garfish | - | - | - | 13 | 27 | - | - | - | - | 40 | 7.0 |
| *Contusus brevicaudus* Prickly Toadfish | - | - | - | 2 | - | - | - | - | - | 2 | 0.4 |
| *Tetractenos glaber* Smooth Toadfish | - | - | - | 1 | - | - | - | - | - | 1 | 0.2 |
| *Afurcagobius tamarensis* Tamar River Goby | 15 | 1 | 6 | - | - | - | - | 10 | - | 32 | 5.6 |
| *Tasmanogobius lasti* Lagoon Goby | 35 | - | - | - | 1 | - | - | - | - | 36 | 6.3 |
| *Phylipnodon grandiceps* Flathead Gudgeon | 3 | - | - | - | - | - | - | - | - | 3 | 0.5 |
| **Number of individuals per site** | **53** | **15** | **180** | **113** | **196** | **0** | **0** | **11** | **1** | **569** | **100.0** |
| **Number of taxa** | **3** | **2** | **2** | **4** | **6** | **0** | **0** | **2** | **1** | **11** | |

A total of 569 fish was collected during the survey period. The greatest number of individuals (196) was collected from the Lower Estuary (LoE), followed by 180 from the north-east arm of Lake Connewarre (NE). No fish were caught at two of the three surveyed sites at Reedy Lake (RFi and RMo).

The family Atherinidae (possibly consisting of more than one species of Hardyhead, putatively *Atherinasoma microstoma* and *Leptatherina presbyteroides*) were the numerically dominant taxa (n = 446), contributing to 78.4% of the overall catch. This taxon was most abundant within the shallows along the shore of the north-east arm of Lake Connewarre (NE) (174) and the lower estuary (LoE) (161). Large numbers (96) were also collected from the intertidal mudflats below the White Mangroves (*Avicennia marina*) adjacent to the Ocean Grove Golf Course (Gu).

Atherinids dominated the biomass of the overall catch, contributing 519 g/wet wt (58.2%). The Southern Sea Garfish *Hyporhamphus melanochir* contributed 24.9% of the overall biomass, whilst the remaining 16.9% consisted of the other nine species. The majority of the biomass was collected from the two sites on the Barwon River estuary below Lake Connewarre (85.6%), compared with 13.1% from Lake Connewarre (three sites), and 1.3% from Reedy Lake (three sites) and Hospital Swamp (one site) combined. See Table 6-7 for the distribution of fish biomass with respect to species and sample locations.

### 6.3.5 Frogs

A total of five frog species was identified during the survey period. Table 6-8 indicates the species recorded at the six survey sites. All five species were heard on the eastern shore of Reedy Lake (Fitzgerald's Road), including the nationally threatened Growling Grass Frog (GGF) *Litoria raniformis* (EPBC 1999). This was the only location where the GGF was encountered. The low frequency and isolated location of calls of this species suggested that abundance was much lower than of other species present at that site. The Spotted Marsh Frog *Limnodynastes tasmaniensis* was the most widespread species, being encountered at all sites during the targeted survey. The chorus of frog calls during the targeted survey at the two sites on the shores of Reedy Lake and Hospital Swamp indicated that the abundances for all recorded species, except the GGF, were high and very widespread. The frog calls from Salt Swamp were only heard from the south side of Barwon Heads Road, emanating from beyond the road verge.

**Table 6-7 Biomass (g/wet wt.) of fish recorded during the survey period.**

| | Survey site | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species / common name** | **LEn** | **TP** | **NE** | **Gu** | **LoE** | **RFi** | **R Mo** | **RIn** | **HSw** | **Biomass (g/wet wt.)** | **% of total biomass** |
| *Aldrichetta forsteri* Yellow-eye Mullet | - | - | - | - | 68.1 | - | - | - | - | 68.1 | 7.6 |
| *Arripis trutta* Eastern Australian Salmon | - | - | - | - | 15 | - | - | - | - | 15.0 | 1.7 |
| *Sillaginoides punctata* King George Whiting | - | - | - | - | 9.6 | - | - | - | - | 9.6 | 1.1 |
| *Atherinidae* (Hardyheads/Silverfish) | - | 11.6 | 70.2 | 146.7 | 290.4 | - | - | - | - | 518.9 | 58.2 |
| *Galaxias maculatus* Common Jollytail | - | - | - | - | - | - | - | 5.5 | 3.9 | 9.4 | 1.1 |
| *Hyporhamphus melanochir* Southern Sea Garfish | - | - | - | 69.4 | 153 | - | - | - | - | 222.4 | 24.9 |
| *Contusus brevicaudus* Prickly Toadfish | - | - | - | 9.6 | - | - | - | - | - | 9.6 | 1.1 |
| *Tetractenos glaber* Smooth Toadfish | - | - | - | 1.2 | - | - | - | - | - | 1.2 | 0.1 |
| *Afurcagobius tamarensis* Tamar River Goby | 10.9 | 4.3 | 1.5 | - | - | - | - | 2.1 | - | 18.8 | 2.1 |
| *Tasmanogobius lasti* Lagoon Goby | 16.9 | - | - | - | 1 | - | - | - | - | 17.9 | 2.0 |
| *Phylipnodon grandiceps* Flathead Gudgeon | 1.2 | - | - | - | - | - | - | - | - | 1.2 | 0.1 |
| **Total biomass captured per site** | **29.0** | **15.9** | **71.7** | **226.9** | **537.1** | **0** | **0** | **7.6** | **3.9** | **892.1** | **100.0** |

**Table 6-8 Presence of frog species at six locations within and adjacent to the LCWC.**

| | | Survey site | | | | | |
|---|---|---|---|---|---|---|---|
| **Family** | **Species / common name** | **RMo** | **RFi** | **Ash*** | **NE** | **SSw** | **HSw** |
| **Hylidae** | *Litoria ewingi* Southern Brown Tree Frog | • | • | • | • | | • |
| | *Litoria raniformis* Growling Grass Frog (V, e, L) | | • | | | | |
| **Myobatrachidae** | *Crinia signifera* Eastern Common Froglet | • | • | • | | • | • |
| | *Limnodynastes dumerili* Pobblebonk | • | • | • | | | |
| | *Limnodynastes tasmaniensis* Spotted Marsh Frog | • | • | • | • | • | • |
| | **Number of species recorded** | **4** | **5** | **4** | **2** | **2** | **3** |

* – Calls were located within farmland, approximately 150–200 m north of the Lake Connewarre shore.

V – Listed as 'vulnerable' under the EPBC Act 1999.

e – Listed as 'endangered' within Victoria (DSE 2007).

L – Listed as a threatened species under the *Victorian Flora and Fauna Guarantee Act 1988*.

### 6.3.6 Birds

A total of 51 bird species was recorded from 14 site visits between 14 March and 22 July 2007 (See Table 6-9). Of these, 47 were native and four were introduced. Eight species were of conservation significance, including four listed under Schedule 2 of the *Victorian Flora and Fauna Guarantee Act 1988*, five listed as 'vulnerable' and three listed as 'near threatened' within the list of Victorian Rare or Threatened Species (VROTS). No threatened species listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC) were observed during the survey period; however, several are listed as marine or migratory species under EPBC. Of the 51 species identified, 29 were wetland birds, three were raptors and the remaining 19 included other birds not considered obligate wetland species.

Thirty-six species were observed at Lake Connewarre, seven at Reedy Lake, 33 at Hospital Swamp and 19 along the lower reaches of the Barwon River estuary (from below Lake Connewarre to Ocean Grove).

More than 2400 birds were recorded from 14 site visits. Over 1186 individuals were recorded from Lake Connewarre, 11 from Reedy Lake, more than 970 from Hospital Swamp and 259 from the Lower Barwon estuary. Table 6-9 provides a summary of bird observations for the survey period, along with conservation status of each species.

Notable observations during the study included:

- A large congregation of Hoary-headed Grebe on Lake Connewarre observed on two occasions
- Two separate sightings of a pair of Brolga on the north-west shore of Lake Connewarre
- Large congregations of Chestnut Teal in the north-east arm of Lake Connewarre and in a constructed wetland adjacent to Hospital Swamp.

**Table 6-9 Bird records for the four major wetlands of the LCWC.**

| Family | Species / common name | Status | Lake Connewarre | Reedy Lake | Hospital Swamp | Lower Barwon |
|---|---|---|---|---|---|---|
| **Accipitridae** | Circus approximans Swamp Harrier | | 3 | 3 | 2 | 1 |
| | *Haliastur sphenurus* Whistling Kite | | 14 | | 4 | 4 |
| **Anatidae** | *Anas castanea* Chestnut Teal | | 130+ | | 200+ | 43 |
| | *Anas superciliosa* Pacific Black Duck | | | | 6 | |
| | *Biziura lobata* Musk Duck | v | 2 | | | |
| | *Cygnus atratus* Black Swan | | 84 | | 52 | 41 |
| **Anhingidae** | Anhinga melanogaster Darter | | 2 | 1 | | |
| **Ardeidae** | *Ardea alba* Great Egret | F, v | 23 | | | 20 |
| | Egretta novaehollandiae White-faced Heron | | 13 | | 14 | 20 |
| **Artamidae** | *Gymnorhina tibicen* Australian Magpie | | 9 | | 2 | |
| **Campephagidae** | *Coracina novaehollandiae* Black-faced Cuckoo-shrike | | 1 | | | |
| **Charadriidae** | *Vanellus miles* Masked Lapwing | | 6 | | 1 | 14 |
| **Columbidae** | *Streptopelia chinensis* Spotted Turtle-Dove | * | | 1 | | |
| **Corvidae** | *Corvus coronoides* Australian Raven | | | | 2 | |
| **Cuculidae** | Cacomantis flabelliformis Fan-tailed Cuckoo | | 1 | | 1 | |
| **Dicruridae** | Grallina cyanoleuca Magpie-lark | | | | 3 | |
| | Rhipidura leucophrys Willie Wagtail | | | | 5 | |
| **Falconidae** | *Falco cenchroides* Nankeen Kestrel | | 1 | 1 | | |
| **Fringillidae** | *Carduelis carduelis* European Goldfinch | * | | | 20+ | |
| **Gruidae** | Grus rubicunda Brolga | F, v | 4 | | | |
| **Hirundinidae** | *Hirundo neoxena* Welcome Swallow | | 1 | | 200+ | |

**Table 6-9 cont.**

| Family | Species / common name | Status | Lake Connewarre | Reedy Lake | Hospital Swamp | Lower Barwon |
|---|---|---|---|---|---|---|
| **Laridae** | Larus novaehollandiae Silver Gull | | 137 | | 1 | 22 |
| | *Larus pacificus* Pacific Gull | N | 3 | | | 2 |
| | *Sterna albifrons* Little Tern | F, v | 1 | | | |
| | *Sterna bergii* Crested Tern | | 1 | | | 5 |
| | *Sterna caspia* Caspian Tern | F, n | 3 | | | |
| **Maluridae** | *Malurus cyaneus* Superb Fairy-wren | | 6 | 2 | 5 | |
| **Meliphagidae** | Anthochaera carunculata Red Wattlebird | | | | 1 | |
| | *Epthianura albifrons* White-fronted Chat | | | 2 | 3 | 2 |
| | *Lichenostomus chrysops* Yellow-faced Honeyeater | | 6 | | 2 | |
| | *Lichenostomus penicillatus* White-plumed Honeyeater | | | 1 | 6 | |
| | Manorina melanocephala Noisy Miner | | | | 3 | |
| **Muscicapidae** | *Turdus merula* Common Blackbird | * | | | 1 | |
| **Pardalotidae** | *Acanthiza chrysorrhoa* Yellow-rumped Thornbill | | 4 | | 1 | |
| **Pelecanidae** | Pelecanus conspicillatus Australian Pelican | | 34 | | 8 | 5 |
| **Phalacrocoracidae** | *Phalacrocorax carbo* Great Cormorant | | 18 | | | |
| | *Phalacrocorax melanoleucos* Little Pied Cormorant | | 151 | | | 35 |
| | *Phalacrocorax sulcirostris* Little Black Cormorant | | 132+ | | | 1 |
| | Phalacrocorax varius Pied Cormorant | n | 1 | | 1 | 12 |

**Table 6-9 cont.**

| Family | Species / common name | Status | Lake Connewarre | Reedy Lake | Hospital Swamp | Lower Barwon |
|---|---|---|---|---|---|---|
| **Podicipedidae** | *Podiceps cristatus* Great Crested Grebe | | 4 | | 1 | |
| | Poliocephalus poliocephalus Hoary-headed Grebe | | 300+ | | 7 | |
| **Psittacidae** | *Psephotus haematonotus* Red-rumped Parrot | | | | 1 | |
| **Rallidae** | *Porphyrio porphyrio* Purple Swamphen | | | | 50 | |
| **Scolopacidae** | *Tringa nebularia* Common Greenshank | | 1 | | | 3 |
| **Sturnidae** | *Sturnus vulgaris* Common Starling | * | | | 1 | |
| **Sylviidae** | *Cisticola exilis* Golden-headed Cisticola | | 2 | | 1 | |
| **Threskiornithidae** | *Platalea flavipes* Yellow-billed Spoonbill | | 53 | | | 1 |
| | *Platalea regia* Royal Spoonbill | v | 11 | | | 4 |
| | *Threskiornis molucca* Australian White Ibis | | 18 | | 65 | 24 |
| | Threskiornis spinicollis Straw-necked Ibis | | | | 300+ | |
| **Zosteropidae** | Zosterops lateralis Silvereye | | 6 | | | |
| | **Number of records** | | **1186+** | **11** | **970+** | **259** |
| | **Number of species** | | **36** | **7** | **33** | **19** |

F – Listed under the Victorian *Flora and Fauna Guarantee Act 1988*.

* – Introduced species, not native to Australia.

v – Listed as vulnerable within the Victorian Rare or Threatened Species list (VROTS).

n – Listed as near threatened within the Victorian Rare or Threatened Species list (VROTS).

+ – Indicates an approximation of number of birds, in excess of that shown.

### 6.3.7 Mammals

Four mammal species, or signs thereof, were identified during the study period. All were introduced species. These included:

- Red Fox *Canis vulpes*
- European Rabbit *Oryctolagus cuniculus*
- House Mouse *Mus musculus*
- Fallow Deer *Dama dama.*

Fifteen skinned fox carcasses were found within a *Phragmites australis* reed bed at Hospital Swamp on 15 July 2007. All animals were in an early stage of decomposition. A Swamp Harrier *Circus approximans* was feeding on one of the bodies, whilst two Whistling Kites were circling at low altitude over the area. Even on close inspection, there were no clear signs of how these animals had died (e.g. gunshot wounds or other). A fox skull was found at the Lower Breakwater on 16 July 2007.

Rabbit scats were found at Hospital Swamp and Tait's Point. Live rabbits were also observed around the Tait's Point area and near the north-east shore at the end of Brinsmead Lane, Wallington.

On 26 June 2007 two deer were observed at Reedy Lake, approximately 200 m south of the end of Moolap Station Road (RMo). Identification of markings suggests that they were Fallow Deer *Dama dama.*

## 6.4 Discussion

### 6.4.1 Zooplankton

The patchiness of zooplankton communities was clearly shown by the data collected along the Barwon estuary between the seaward station at Guthridge Street and the artificial 'head' of the estuary at Breakwater. A particular collection of zooplankton taxa (a community) was described from each station, showing that the river is resolved into contrasting parts by the fauna. The particular combinations of physical and chemical variables at each point characterise the stations and each station has a distinctive collection of zooplankton. In addition to this spatial patchiness, the analyses of the zooplankton in February, March and April demonstrated different zooplankton composition at the stations in each month. This temporal and spatial heterogeneity is typical of plankton communities globally (e.g. Edgar 2001) and is related to the patchiness and dynamics of resources in the environment.

### 6.4.2 Meiofauna

Not only is the estuarine meiofauna assemblage very diverse, but throughout the span of the estuary (15 km) there is a distinctive 'set' of nematodes at eight stations only a few kilometres apart. Although the assemblage composition did alter with time at each station, this variability was generally less than the spatial changes recorded. These findings suggest that the meiofauna may be a useful ecological tool for monitoring benthic conditions at fixed points along the river. Having quantified the natural fluctuations in community characteristics it should be possible to detect signals of imposed disturbance (by monitoring the multivariate index of dispersion, for example). Natural variations in meiofauna communities can to some extent be reduced for monitoring purposes by using artificial substrates, as described by Gwyther and Fairweather (2005). Future changes to meiofauna along the river bed will reflect changes in the physicochemical parameters, and regular meiobenthic surveys are suggested in order to validate signals of disturbance caused by pollution or climate change in the future.

### 6.4.3 Aquatic macroinvertebrates

The diversity of macroinvertebrates for this study (52 taxa) was considerably less than that found by Sherwood et al. (1988) (138 taxa) two decades earlier. Diversities could not be directly compared due to possible differences in sampling methods, locations and the selection of habitat within each sampling location (reported methodology from the 1988 study lacked sufficient detail to repeat). However, some comparisons can be made between the respective community compositions. Both studies identified mollusca and crustacea as the dominant taxonomic groups found within the lower estuary and Lake Connewarre, whereas insects contributed the most number of taxa to freshwater communities within Reedy Lake and Hospital Swamp for both studies.

Mondon et al. (2003) identified 18 and 25 benthic macroinvertebrates within the Barwon estuary for autumn and winter of 2002 respectively. These figures are comparable to this study (29 taxa from Lake Connewarre and the lower estuary); however, details of the taxonomic composition from the 2002 study were not reported.

The relatively low diversity of macroinvertebrates recorded during the present study may have been due to a number of factors:

- The sampling of discrete plots (quadrats) rather than a broader sampling regime throughout all habitat types, which has the potential to capture a greater range of species.
- Reedy Lake and Hospital Swamp were sampled soon after they were inundated. Therefore, it may be expected that macroinvertebrate communities would have had insufficient time to fully establish in terms of diversity and abundance.

- Timing of macroinvertebrate sampling in winter may reflect a poorer diversity of species compared to other seasons when taxa are more likely to be present, active or more easily observed due to the characteristics of a particular life history stage (e.g. greater size or adult/larval form rather than as eggs).
- Consistently high salinity within Lake Connewarre, leading up to and during the early part of the sampling period, may have suppressed species richness by allowing only saline-tolerant species to prevail in the lake.

Extreme fluctuations in salinity from fresh to hypersaline within Lake Connewarre may also limit the diversity of estuarine fauna. Current research at Deakin University has shown that the mussel (*X. securis*) from Lake Connewarre is tolerant of salinities between five and 40 PSU, but mortality within 24 hours occurred when salinities fell below five PSU and above 40 PSU (Cornwell, Gwyther and Toop, unpublished data).

Populations of macroinvertebrates may persist in Lake Connewarre by tolerating the salinity fluctuations or, alternatively, by depending on regular dispersal into the lake from adjoining marine or freshwater populations. Some of the species recorded (e.g. the crab *Amarinus* and the minute bivalve *Arthritica semen*) are typical of highly variable estuaries and may be ephemeral species in the lake, surviving within a narrow salinity regime.

Another observable feature of the macroinvertebrate community is that most of the lake mollusca and crustacea are small in comparison to marine and freshwater counterparts. Small size is indicative of opportunistic fauna that are adapted to stressful or disturbed conditions (Warwick 1986). As the estuarine invertebrate populations may already be under considerable osmotic stress, in what must be considered an 'extreme' environment, it is likely that deterioration of the environmental conditions may exceed the tolerance of the fauna, leading to the loss of some species in the Barwon estuary system. Diminishing macroinvertebrate diversity and /or abundance may have considerable ramifications on the presence of fish and wetland birds that are reliant on those taxa as a food source. This trophic cascade effect may increase the risk of losing some higher order species from the system.

### 6.4.4 Fish

Most of the fish species sampled during this study are commonly found within Victorian estuarine waters and have been observed previously within the LCWC. The 12 fish taxa encountered represented about one third of all species previously identified within the LCWC (See Appendix 4). Of these 12 taxa, five (42%) are recognised as commercially important (i.e. in professional or recreational fisheries) compared with 18 (50%) of those previously listed. Most of the fish caught during the present study were small species or juveniles of larger species. This may suggest that sampling methods employed (e.g. seine nets) were not effective enough to catch larger, strong swimming species that can avoid capture, and/or were not comparable to sampling efforts, survey locations or methodologies used in previous surveys (e.g. number and type of nets; the duration and timing of deployment). For instance, fish surveys of Lake Connewarre, Reedy Lake and Hospital Swamp carried out during 1986 and 1987, employed a range of sampling techniques, including gill, fyke, seine and plankton netting and the use of Rotenone (Tunbridge 1988). These methods were used to target larger commercially important species. Also the sites from the 1986–87 study were sampled bimonthly for 13 months, a luxury not afforded to the present study, which is multi-focused in nature and part of a broader ecological investigation.

During this study, all commercially important species except for the Short-finned Eel were caught downstream of Lake Connewarre. This is in contrast to Tunbridge's (1988) findings that identified 18 such species within the lake. There are insufficient data to determine if the habitat conditions in Lake Connewarre during the present study were unfavourable to commercially important species, or if methods of sampling were the main factor in not capturing these species. As salinity is closely related to the freshwater discharge into Lake Connewarre (Sherwood et al. 1988), the observation of low species richness in fish compared to that recorded by Tunbridge (1988) may be a response to the indirect effect of sustained high salinities or other physicochemical parameters driven by the low freshwater flows that persisted prior to and during 2007. A targeted study that relates fish community structure and dynamics to changes in habitat variables (e.g. salinity, temperature, depth, substratum) within Lake Connewarre may assist in explaining how fish species and communities respond to short- and long-term shifts in habitat condition due to such factors as reduced freshwater flows, nutrient enrichment, siltation and sea level rise (associated with global warming).

Estuarine fisheries species and their productivity have been flagged as suitable indicators for environmental flow allocations to estuarine ecosystems (Gillanders 2007, after Robins et al. 2005). This is due to their economic and social value, and availability of sufficient data on their life history and long-term abundances. Staunton-Smith et al. (2004, in Gillanders 2007) were able to significantly correlate the strength of year classes of barramundi with the amount of summer and freshwater flows into the Fitzroy River estuary, in north Queensland. Such correlative analyses between fisheries catch data and freshwater flow variables may assist in providing future targets for freshwater flow allocations to the LCWC and other estuarine systems. Staunton-Smith et al. (2004) in Gillanders (2007) believed that the higher flows during wet years increases the accessibility, productivity or carrying capacity of juvenile fish habitat, thus increasing the survivorship of young fish. Similar investigations for the LCWC may be warranted, considering that environmental flow allocation is an important issue for the Barwon River and its estuary.

The lack of fish at two of the survey sites on Reedy Lake was most likely related to the short period of inundation of these habitats prior to the survey events. It is believed that there would have been insufficient time for fish to colonise these areas and establish sufficient populations to reflect potential assemblage characteristics. Sufficient time would also be required for food sources (in the form of plankton, aquatic plants and algae, and macroinvertebrate communities) to establish in order to attract fish to these areas.

### 6.4.5 Frogs

Changes in the abundance and distribution of frogs over time are considered important indicators of aquatic ecosystems health. This is due to the fact that frogs are sensitive to changes in their environment (Beeton et al. 2006), such as pollution, habitat change and climate change. Within the LCWC, it appears that the suite of frog species that occur today are much the same as those observed in the early 1960s and early 1970s.

Four of the five frogs species recorded during this investigation, are considered to be common and widespread throughout the Geelong and Bellarine Peninsula. However, the Growling Grass Frog, a species once widespread across most of Victoria (except the drier parts of the north-west of the state) but now considered to persist in isolated populations within the state (NSWDEC 2005), was recorded in this study at Fitzgerald's Road, Reedy Lake. This species is listed as threatened under the *Flora and Fauna Guarantee Act 1988* and classified as vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999*.

All species encountered during this study have previously been recorded on the Atlas of Victorian Wildlife database for the LCWC (DCNR 1993).

### 6.4.6 Birds

The tally of 51 bird species observed during the study period is considerably low in comparison to the 199 species previously recorded and listed on the Atlas of Victorian Wildlife database. Low diversities and abundances are most likely attributed, in part, to:

- A significant proportion of the survey occurring outside of the season when large numbers of migratory wader species visit the wetlands
- Reedy Lake being surveyed for birds when the wetland was dry and soon after lake inundation when food sources (e.g. macroinvertebrates and new growth of wetland plants) for wetland birds were scarce.

Although the LCWC is known as an overwintering location for the nationally endangered Orange-bellied Parrot, none of this species was sighted during the survey period. This is in contrast to records of nine individuals made by multiple observers from three sites on Lake Connewarre in May 2006 (Morley 2006).

Observations of tall waders, such as the Great Egret and the Royal and Yellow-billed Spoonbills on the shoals within the tidal delta area at the exit of Lake Connewarre, provide an indication of the shallowness of the waters within this part of the lake (see front cover photo). Further shallowing of the lake via net sediment accretion would most likely increase the foraging areas for large and small wader and shorebird species in the medium to long term. However, deeper waters for diving birds and waterfowl would be reduced within the lake.

### 6.4.7 Mammals

The low number of mammal observations recorded during this study is likely to be a reflection of the low sampling intensity and methods used, and the depleted condition of surrounding terrestrial habitat that once would have supported a larger diversity of native species. Also the presence of predatory exotic fauna such as foxes and cats is likely to have had a large effect on the local reduction of native mammal populations. The same threat also applies to other native vertebrate groups (especially birds, frogs and reptiles). Loss of suitable habitat and predation by foxes and cats are significant threatening processes that have led to the local extinction of some small mammal species within the vicinity of the LCWC (in particular the Eastern Barred Bandicoot *Perameles gunnii*). Although it is difficult to gauge the effects of foxes on native fauna, effects are generally considered to be locally significant and isolated small mammal populations are those most at risk (Menkhorst 1996).

Mammal surveys that incorporate trapping, spotlighting and hair tube deployment will provide a more precise means of assessing the local mammal community compared with records of incidental observations.

The status of the Fallow Deer population within the LCWC is unclear, but it is thought that numbers are low (Lachie Jackson, Parks Victoria, pers. comm. 2007). Future monitoring of the species would assist in gauging population characteristics and dynamics. The effects of fallow deer on the wetland system and its inhabitants are currently unknown.

Efforts should be made to monitor and protect existing patches of native grasslands and woodlands surrounding the LCWC. The continuation of revegetation programs surrounding the lake system should also be encouraged to contribute to the reinstatement of habitat for native wildlife. Financial assistance and sound technical advice to landholders is crucial in designing and establishing such areas that incorporate habitat for native mammals and other fauna species. Integrated planning and management of these areas is required to bolster native fauna populations. At the landscape level, wildlife corridors need to be incorporated into the management of the wetlands to link neighbouring patches of remnant vegetation and allow the dispersal of fauna between these patches. Other aspects to address include feral animal and weed control, planting of sufficient understorey layers for shelter, nesting and food supply and including structural habitat features such as logs and rocky areas where appropriate.

# 7 Conclusions and recommendations

The Barwon River coastal plain is represented by a dynamic estuarine and lagoon system with extremely variable physicochemical conditions, particularly of salinity. The biota is a highly adapted collection of marine and some freshwater species that are able to respond to extreme fluctuations in environmental conditions and thereby exploit wetland resources. Many macroinvertebrate species within Lake Connewarre are small, indicating their opportunistic nature when conditions are favourable (Warwick 1986). Some sessile species have a broad range of tolerance to physicochemical conditions (e.g. salinity tolerance of the mussel *X. securis*).

Other mobile fauna may disperse to fresh or marine environments as conditions become less favourable. However, the presence of the lower breakwater probably restricts the dispersal of some species into freshwater systems under particular flow conditions (e.g. migratory fish such as galaxid species). Such structures are known to interrupt the life cycles and migratory patterns of many of Australia's native fishes.

The LCWC is recognised for its importance as bird and fish habitat. Appropriate management of the system is crucial to maintain these faunal communities within the constraints of natural fluctuations and long-term transgression of the wetland system. One area of management is that of human occupation and visitation around the wetlands to minimise disturbances to these faunal groups and their habitats. A balance needs to be struck.

The natural hydrological cycle of these wetlands must be understood in the context of future management. All lakes and estuaries may be considered geologically ephemeral, with corresponding changes to the position of contact with the sea. Even without human activities in the future it would be expected that Lake Connewarre will naturally fill with riverine transported sediment and the existing system gradually change into a swamp or salt marsh ecosystem. It is not clear what effect past and recent land management has had on sediment loads, but it is likely to be significant. Although some biota may lose their habitat if the lowest lying parts of the estuary gradually fill in, there will be added mudflat area within accreting bends and around riverine sandbars over which mangroves, and seagrasses, will eventually colonise. This is already evident along the river between Ocean Grove and the estuary mouth.

The following recommendations are provided to assist in developing a better understanding of the LCWC, in particular Lake Connewarre, for future management:

### Physicochemical and hydrological data acquisition

Collect further data concerning changing sedimentations rates and patterns within Lake Connewarre. Investigate and quantify the relative contributions of the agents that drive sediment processes in Lake Connewarre (e.g. river flow velocities, tidal patterns, wind velocities and direction, and water depth) to assist in predicting future sedimentation rates within the lake.

### Environmental flow provision

Determine and provide sufficient environmental flow allocations to the Barwon estuary that are designed to avoid unnaturally high sedimentation rates within Lake Connewarre.

### Metal species studies

Determine the composition of organic and inorganic species of arsenic to assist in clarifying the environmental and health risks associated with the exposure of high levels of arsenic in Lake Connewarre sediments by aquatic flora/fauna and humans.

### Nutrient balance and budget

Investigate the nutrient cycling between sediments, the water column and biota within Lake Connewarre and incoming nutrient sources. Conduct a mass balance of nutrient inputs and outputs and determine the relative contribution from known sources of these nutrients.

### Removal of excessive nutrients

Investigate ways to mitigate the effects of nutrient enrichment of Lake Connewarre and other wetlands within the LCWC (e.g. the potential to harvest *Gracilaria* from Lake Connewarre to remove nutrients assimilated from waters and sediments).

### Fish habitat requirement

Conduct a comparative study of seagrass (e.g. *Ruppia*, *Zostera*) versus *Gracilaria* as habitat for fish (particularly juveniles) within Lake Connewarre as a means to measure changes in the structure, density and productivity of fish communities with changes in benthic flora.

### Long-term monitoring

A comprehensive study (e.g. based on Yugovic's work) is needed to determine long-term changes in the character and spatial patterns of vegetation communities throughout the LCWC. Provide accompanying information on water quality and hydrological data over time, to help understand the relationships between these factors and plant community structure and dynamics within the LCWC. This is essential to address likely changes due to future climate trends.

## Research into effects of disturbance to benthic flora

Investigate the roles of *Gracilaria*, *Ruppia* and *Zostera* as indicator species within Lake Connewarre, to reflect changes in hydrology and water quality (surface and groundwater), including factors such as river discharge patterns, rising sea levels, salinity and nutrients.

## Establishment of ecological indicator systems

Establish a protocol using estuarine macroinvertebrates and/or meiofauna as indicators of estuarine and associated wetland condition. Changes in assemblage structure should be assessed and related to the degree and nature of disturbance. Use these integrated systems to assess system responses to climate-change induced alterations in the plant and animal composition of the wetlands.

## Fish studies

Carry out a targeted study that relates fish community structure and dynamics to changes in habitat variables (e.g. salinity, temperature, depth, substratum) within Lake Connewarre to assist in explaining how fish species and communities respond to short- and long-term shifts in habitat condition due to such factors as reduced freshwater flows, nutrient enrichment, siltation and sea level rise (associated with global warming).

## Control of pest species

Continue the control of pest plants and animals (in particular foxes and cats) within and surrounding the LCWC and continue to improve habitat conditions for native fauna surrounding and linking the wetland system. Monitor changes to native fauna populations to gauge the efficacy of these management measures.

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# Appendices

A1 Lake Connewarre sediment cores showing distinct layers

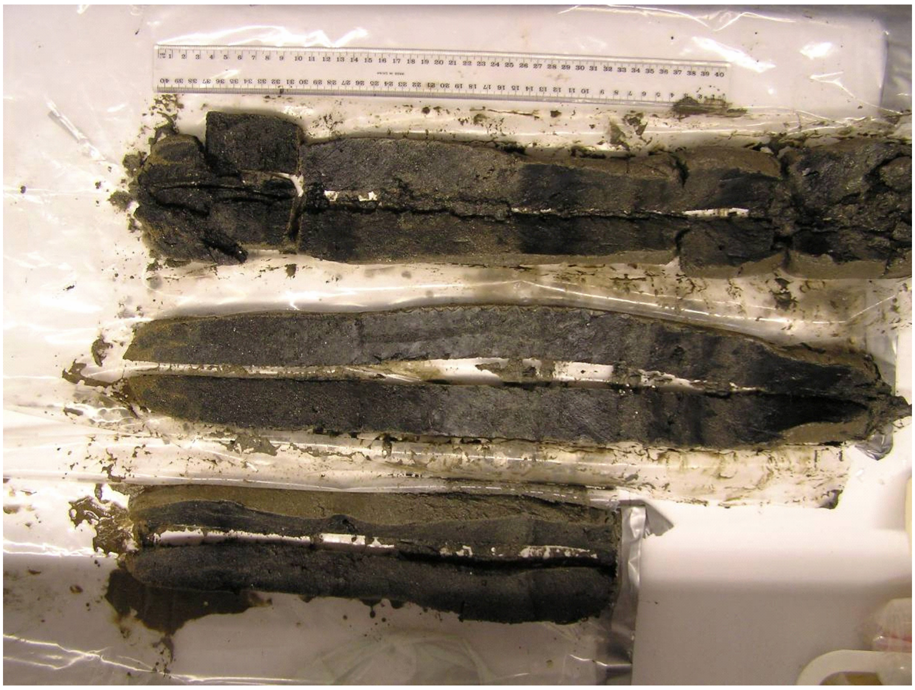
A2 Inventory of nematode genera from the Barwon estuary

A3 Macroinvertebrate species list, incorporating species density for each surveyed site

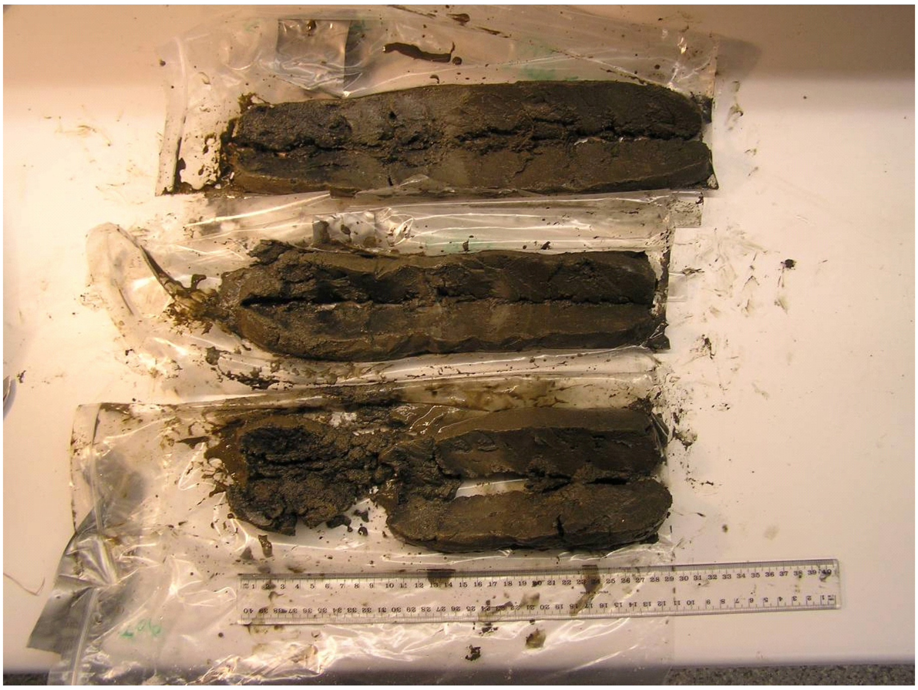
A4 Inventory of fish species recorded from the Atlas of Victorian Wildlife (AVW) and the Victorian Aquatic Fauna (VAF) database searches for the Lake Connewarre Wetlands Complex (search conducted May 2007)

A5 Dominant plant list for selected sites within the Lake Connewarre Wetlands Complex

# Appendix 1
# Lake Connewarre sediment cores showing distinct layers



a. Lake Entrance



b. Mid Lake

c. Lake Exit/Delta

d. Ash Road

# Appendix 1 cont.

e) North-east Arm

# Appendix 2
# Inventory of nematode genera from the Barwon estuary

| Nematode genera from the Barwon estuary | | |
|---|---|---|
| *Acantholaimus* | *Epsilonema* | *Pomponema* |
| Actinolaiminae | *Gammanema* | *Prochromadorella* |
| *Actinonema* | *Gonionchus* | *Prooncholaimus* |
| *Adoncholaimus* | *Halalaimus* | *Pselionema* |
| *Astomonema* | *Hopperia* | *Ptycholaimellus* |
| *Anaplostoma* | *Hypodontolaimus* | *Quadricoma* |
| *Anticoma* | *Laimella* | *Sabatieria* |
| *Antomicron* | *Leptolaimus* | *Siphonolaimus* |
| *Axonolaimus* | *Linhomeous* | *Spiliphera* |
| *Bathylaimus* | *Metachromadora* | *Spilophorella* |
| *Calyptronema* | *Metadesmolaimus* | *Spirinia* |
| *Camacolaimus* | *Metoncholaimus* | *Stephanolaimus* |
| *Chaetonema* | *Metalinhomeous* | *Steineria* |
| *Chromadora* | *Microlaimus* | *Syringolaimus* |
| *Chromadorella* | *Molgolaimus* | *Terschellingia* |
| *Chromadorina* | *Monoposthia* | *Thalassoalaimus* |
| *Chromospirina* | *Nemanema* | *Thalassomonhystera* |
| *Cobbia* | *Neochromadora* | *Theristus* |
| *Comesoma* | *Nudora* | *Tricoma* |
| *Comesa* | *Odontophora* | *Tripyloides* |
| *Daptonema* | *Oncholaimellus* | Tylenchid |
| *Desmodora* | *Oncholaimus* | *Viscosia* |
| *Desmogerlachia* | *Onyx* | |
| *Desmoscolex* | *Oxystomina* | |
| *Dichromadora* | *Pandalaimus* | |
| *Diplolaimella* | *Paracanthonchus* | |
| *Doliolaimus* | *Paralinhomeous* | |
| *Enoploides* | *Parodontophora* | |
| *Enoplolaimus* | *Paroxystomina* | |
| *Ethmolaimid genus* | *Phanoderma* | |

# Appendix 3:
# Macroinvertebrate species list, incorporating species density for each surveyed site

| | Scientific name | Common name | VROTS | Origin | Guthridge St | NE Arm | Ash Road | Hospital Swamp | Reedy Lake (RMo) | Reedy Lake (RFi) | Salt Swamp |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Vascular plants | *Acacia longifolia subsp. Longifolia* | Sydney Golden Wattle | | # | | | | • | | | |
| | *Acacia longifolia subsp. sophorae* | Coast Wattle | | # | | | | • | | | |
| | *Acaena echinata* | Sheep's Burr | | | | | | • | | | |
| | *Allocasuarina verticillata* | Drooping Sheoak | | | | | | • | | | |
| | *Anagallis arvensis* | Pimpernel | | * | | | • | | | | |
| | *Apium annuum* | Annual Celery | | | • | | | | | | |
| | *Apium prostratum subsp. prostratum* | Sea Celery | | | | | • | | | | |
| | *Arctotheca calendula* | Cape Weed | | * | | | • | • | | | |
| | *Atriplex paludosa subsp. paludosa* | Marsh Saltbush | r | | • | | • | | | | |
| | *Atriplex prostrata* | Hastate Orache | | * | • | | • | | • | • | • |
| | *Austrodanthonia caespitosa* | Common Wallaby-grass | | | | | • | | | | |
| | *Avena spp.* | Wild Oat | | * | | | • | | | | |
| | *Avicennia marina subsp. australasica* | Grey Mangrove | r | | • | | • | | | | |
| | *Azolla filiculoides* | Pacific Azolla | | | | | | | | • | |
| | *Bolboschoenus caldwellii* | Salt Club-sedge | | | | | | • | • | • | • |
| | *Brassica fruticulosa* | Twiggy Turnip | | * | | | | • | | | |
| | *Briza maxima* | Large Quaking-grass | | * | | | • | | | | |
| | *Bromus catharticus* | Prairie Grass | | * | | | • | | | | |
| | *Bromus hordeaceus subsp. hordeaceus* | Soft Brome | | * | | | • | | | | |
| | *Cerastium glomeratum s.l.* | Common Mouse-ear Chickweed | | * | | | • | • | | | |
| | *Cirsium vulgare* | Spear Thistle | | * | | | • | | | | |
| | *Clematis microphylla* | Small-leaved Clematis | | | | | | • | | | |
| | *Cortaderia selloana* | Pampas Grass | | * | | | | • | | | |
| | *Cotula coronopifolia* | Water Buttons | | * | | | | | • | • | • |

| | Scientific name | Common name | VROTS | Origin | Guthridge St | NE Arm | Ash Road | Hospital Swamp | Reedy Lake (RMo) | Reedy Lake (RFi) | Salt Swamp |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Vascular plants | *Crassula helmsii* | Swamp Crassula | | | | | | | • | • | |
| | *Cynara cardunculus* | Spanish Artichoke | | * | | | | • | | | |
| | *Dactylis glomerata* | Cocksfoot | | * | | | • | • | | | |
| | *Disphyma crassifolium subsp. clavellatum* | Rounded Noon-flower | | | • | | • | | | | |
| | *Distichlis distichophylla* | Australian Salt-grass | | | • | | • | • | | | • |
| | *Ehrharta erecta var. erecta* | Panic Veldt-grass | | * | | | • | | | | |
| | *Einadia nutans* | Climbing Saltbush | | | | | | • | | | |
| | *Eleocharis acuta* | Common Spike-sedge | | | | | | | • | • | |
| | *Eucalyptus camaldulensis* | River Red-gum | | | | | | • | • | | |
| | *Eucalyptus viminalis* | Manna Gum | | | | | | • | | | |
| | *Foeniculum vulgare* | Fennel | | * | | | | • | | | |
| | *Frankenia pauciflora var. gunnii* | Southern Sea-heath | | | • | | • | | | | |
| | *Gahnia filum* | Chaffy Saw-sedge | | | • | | | • | | | • |
| | *Galenia pubescens var. pubescens* | Galenia | | * | | | • | • | | | |
| | *Helminthotheca echioides* | Ox-tongue | | * | | | • | | | | |
| | *Hemichroa pentandra* | Trailing Hemichroa | | | • | | • | • | | | |
| | *Holcus lanatus* | Yorkshire Fog | | * | | | • | | | | |
| | *Hordeum leporinum* | Barley-grass | | * | | | • | | | | |
| | *Hordeum marinum* | Sea Barley-grass | | * | | | • | | | | |
| | *Melicytus dentatus* | Tree Violet | | | | | | • | | | |
| | *Hypochoeris radicata* | Cat's Ear | | * | | | • | | | | |
| | *Juncus kraussii subsp. australiensis* | Sea Rush | | | • | | • | • | | • | • |
| | *Juncus spp.* | Rush | | | | | • | | | | |
| | *Lagurus ovatus* | Hare's-tail Grass | | * | | | | | | | |
| | *Leptospermum laevigatum* | Coast Tea-tree | | # | | | | • | | | |
| | *Limonium australe* | Yellow Sea-lavender | r | | • | | | | | | |
| | *Lolium spp.* | Rye Grass | | * | | | • | | | | |
| | *Lophopyrum ponticum* | Tall Wheat-grass | | * | | | | • | | | |
| | *Lycium ferocissimum* | African Box-thorn | | * | | | • | • | | | |
| | *Malva parviflora* | Small-flower Mallow | | * | | | • | | | | |

| | Scientific name | Common name | VROTS | Origin | Guthridge St | NE Arm | Ash Road | Hospital Swamp | Reedy Lake (RMo) | Reedy Lake (RFi) | Salt Swamp |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Vascular plants | *Medicago polymorpha* | Burr Medic | | * | | | • | | | | |
| | *Melaleuca lanceolata subsp. lanceolata* | Moonah | | | | | • | • | | | |
| | *Melilotus indicus* | Sweet Melilot | | * | | | • | | | | |
| | *Microlaena stipoides* | Weeping Grass | | | | | • | • | | | |
| | *Mimulus repens* | Creeping Monkey-flower | | | | | | | • | • | |
| | *Muehlenbeckia florulenta* | Tangled Lignum | | | | | • | • | • | | |
| | *Myoporum insulare* | Common Boobialla | | # | | | • | | | | |
| | *Myriophyllum spp.* | Water-milfoil | | | | | | | • | • | |
| | *Oxalis pes-caprae* | Soursob | | * | | | | • | | | |
| | *Oxalis spp.* | Wood Sorrel | | | | | | • | | | |
| | *Parapholis incurva* | Coast Barb-grass | | * | | | • | | | | |
| | *Phalaris aquatica* | Toowoomba Canary-grass | | * | | | • | | | | |
| | *Phragmites australis* | Common Reed | | | | | | • | • | • | |
| | *Plantago coronopus* | Buck's-horn Plantain | | * | • | | • | | | | |
| | *Plantago lanceolata* | Ribwort | | * | • | | • | • | | | |
| | *Poa labillardierei* | Common Tussock-grass | | | | | • | | | | |
| | *Polygonum aviculare s.s.* | Hogweed | | * | | | • | | | | |
| | *Puccinellia stricta* | Australian Saltmarsh-grass | | | • | | | | | | • |
| | *Raphanus raphanistrum* | Wild Radish | | * | | | • | | | | |
| | *Rhagodia candolleana subsp. candolleana* | Seaberry Saltbush | | | | | • | • | | | |
| | *Romulea rosea* | Onion Grass | | * | | | • | • | | | |
| | *Rosa rubiginosa* | Sweet Briar | | * | | | • | • | | | |
| | *Rumex brownii* | Slender Dock | | | | | | • | | | |
| | *Rumex crispus* | Curled Dock | | * | | | • | | | | |
| | *Rumex spp. (naturalised)* | Dock (naturalised) | | * | | | • | | | | |
| | *Ruppia maritima s.l.* | Sea Tassel | | | | • | • | | | | |
| | *Samolus repens* | Creeping Brookweed | | | • | | • | | | • | • |
| | *Sarcocornia quinqueflora* | Beaded Glasswort | | | • | | • | • | | • | • |
| | *Sclerostegia arbuscula* | Shrubby Glasswort | | | • | | | | | | |
| | *Selliera radicans* | Shiny Swamp-mat | | | • | | • | | | • | |

Appendix 3 cont.

| | Scientific name | Common name | VROTS | Origin | Guthridge St | NE Arm | Ash Road | Hospital Swamp | Reedy Lake (RMo) | Reedy Lake (RFi) | Salt Swamp |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Vascular plants | *Senecio pinnatifolius* | Variable Groundsel | | | | | • | • | • | • | |
| | *Silybum marianum* | Variegated thistle | | * | | | | • | | | |
| | *Sonchus asper s.l.* | Rough Sow-thistle | | * | | | • | | | | |
| | *Sonchus oleraceus* | Common Sow-thistle | | * | | | • | • | | | |
| | *Spergularia marina s.s.* | Lesser Sea-spurrey | | | • | | • | | | | |
| | *Suaeda australis* | Austral Seablite | | | • | | • | • | | | |
| | *Taraxacum officinale spp. agg.* | Garden Dandelion | | * | | | | • | | | |
| | *Tetragonia implexicoma* | Bower Spinach | | | | | | • | | | |
| | *Triglochin procera s.l.* | Water Ribbons | | | | | | | | • | |
| | *Triglochin striata* | Streaked Arrowgrass | | | • | | • | | | | • |
| | *Typha orientalis* | Broad-leaf Cumbungi | | | | | | | • | • | |
| | *Ulex europaeus* | Gorse | | * | | | • | | | | |
| | *Vicia sativa* | Common Vetch | | * | | | • | • | | | |
| | *Vulpia bromoides* | Squirrel-tail Fescue | | * | | | • | | | | |
| | *Wilsonia humilis* | Silky Wilsonia | | | | | | | | | • |
| | *Zostera muelleri* | Dwarf Grasswrack | | | • | • | | | | | |
| Algae | *Enteromorpha intestinalis* | | | | | | | | | | |
| | *Gracilaria sp* | | | | | • | • | | | | |
| | *Nitella sp* | | | | | | | • | | | |

For site abbreviations see Table 2.1.

# Appendix 4
# Inventory of fish species recorded from the Atlas of Victorian Wildlife (AVW) and the Victorian Aquatic Fauna (VAF) database searches for the Lake Connewarre Wetlands Complex (search conducted May 2007)

| Species | Common name | AVW | VAF |
|---|---|---|---|
| ***Acanthopagrus butcheri*** | **Black Bream** | • | • |
| *Afurcagobius tamarensis* | Tamar River Goby | | • |
| ***Aldrichetta forsteri*** | **Yelloweye Mullet** | • | • |
| ***Ammotretis rostratus*** | **Longsnout Flounder** | | • |
| ***Anguilla australis*** | **Short-finned Eel** | • | • |
| *Arenigobius bifrenatus* | Bridled Goby | • | • |
| ***Argyrosomus hololepidotus*** | **Mulloway** | | • |
| ***Arripis georgianus*** | **Tommy Ruff** | | • |
| ***Arripis trutta*** | **Eastern Australian Salmon** | | • |
| *Atherinosoma microstoma* | Small-mouthed Hardyhead | • | • |
| *Carassius auratus** | Goldfish | • | |
| ***Cyprinus carpio**** | **European Carp** | • | • |
| *Galaxias brevipinnis* | Broadfin Galaxias | • | • |
| *Galaxias maculatus* | Common Galaxias | • | • |
| *Galaxias truttaceus* | Spotted Galaxias | • | |
| *Gambusia holbrooki** | Mosquitofish | • | |
| *Geotria australis* | Pouched Lamprey | • | |
| ***Girella tricuspidata*** | **Luderick** | | • |
| *Gymnapistes marmoratus* | Cobbler | | • |
| *Hyperlophus vittatus* | Sandy Sprat | • | |
| ***Macquaria colonorum*** | **Estuary Perch** | | • |
| ***Mugil cephalus*** | **Sea Mullet** | | • |
| ***Perca fluviatilis**** | **Redfin** | • | • |
| *Philypnodon grandiceps* | Flat-headed Gudgeon | | • |
| ***Pomatomus saltatrix*** | **Tailor** | | • |
| *Prototroctes maraena* | Australian Grayling | • | • |
| *Pseudaphritis urvillii* | Tupong | • | • |
| ***Pseudocaranx dentex*** | **Silver Trevally** | | • |
| ***Pseudocaranx wrighti*** | **Sand Trevally** | • | |
| *Retropinna semoni* | Australian Smelt | • | • |
| ***Rhombosolea tapirina*** | **Greenback Flounder** | | • |
| ***Salmo trutta**** | **Brown Trout** | | • |
| ***Sillaginodes punctata*** | **King George Whiting** | | • |
| *Tasmanogobius lasti* | Lagoon Goby | • | |
| *Tetractenos glaber* | Smooth Toadfish | | • |
| ***Tinca tinca**** | **Tench** | • | |

Species considered as commercially or recreationally significant are in bold print.

* – Introduced species.

# Appendix 5
# Dominant plant list for selected sites within the Lake Connewarre Wetlands Complex

| | | Macroinvertebrate survey results* | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Taxa** | **LEn1** | **LEn2** | **TP1** | **TP2** | **Mid1** | **Mid2** | **Ash1** | **Ash2** | **NE1** | **NE2** | **Gu** | **LoE** | **Rfi** | **Rmo** | **HSw** |
| **Phylum Cnidaria** | *Anthopleura aureoradiata* | | | | | | | | | | | | 48 | | | |
| **Phylum Mollusca** | | | | | | | | | | | | | | | | |
| **Class Gastropoda** | *Austrocochlea constricta* | | | | | | | | | | | 37 | 6.3 | | | |
| | *Austrocochlea odondis* | | | | | | | | | | | | 0.3 | | | |
| | *Austrocochlea porcata* | | | | | | | | | | | | 0.3 | | | |
| | *Bembicium melanostomum* | | | | | | | | | | | 91 | | | | |
| | *Coxiella sp.* | | | | | | | | | | | | | | | 0.3 |
| | *Nassarius burchardi* | | | | | | | | | | | | 0.7 | | | |
| | Planorbidae 1 | | | | | | | | | | | | | 2.3 | 64 | |
| | Planorbidae 2 *Gyraulis sp* | | | | | | | | | | | | | | 47 | |
| | *Polynices sordidus* | | | | | | | | | | | | 0.3 | | | |
| | *Polynices conicus* | | | | | | | | | | | | 0.3 | | | |
| | *Salinator fragilis* | | 7.4 | 37 | 81 | 200 | 119 | | 7.4 | | 14.8 | 2.7 | | | | |
| **Class Bivalvia** | *Arthritica semen* & *Melliteryx helmsi* | 14813 | 11258 | 32404 | 15369 | 15924 | 17776 | 16665 | 13332 | 15554 | 9258 | | | | | |
| | *Laternula gracilis* | | | 37 | | | | | | | | | | | | |
| | *Xenostrobus securis* | 6414 | 2555 | 459 | 844 | 2185 | 2466 | 763 | 689 | 481 | 311 | | | | | |
| **Phylum Arthropoda** | | | | | | | | | | | | | | | | |
| **Subphylum Crustacea** | | | | | | | | | | | | | | | | |
| **Class Cirripedia** | *Elminius modestus* | | | | | | | | | | | 237 | | | | |
| **Class Malocostraca** | | | | | | | | | | | | | | | | |
| **Order Isopoda** | *Cirolana sp.* | | | | | | | | | | | 6.7 | 0.3 | | | |
| | *Exosphaeroma bicolor* | | | | | | | 7.4 | 22 | 111 | 22 | | | | | |
| **Order Amphipoda** | *Allorchestes compressa, Gammaropsis sp.,* | 30 | 7.4 | 44 | 178 | | 81 | 30 | 59 | 96 | 44 | | | | | |
| | *Paracorphium excavatum,* | | | | | | | | | | | | | | | |
| | *Dimorphostylis coletaxi* | | | | | | | | | | | | | | | |
| | Ceinidae | | | | | | | | | | | | | 15 | | |
| | Gammaridea | | | | | | | | | | | | 6.3 | | | |
| | Paramelitadae | | | | | | | | | | | | | | | 7.3 |
| **Order Decapoda** | *Amarinus lacustris* | | | | 7.4 | | | | | | | | | | | |
| | *Brachynotus spinosus* | | | | | | | | | | | 1.3 | | | | |
| | *Palaemon dolospina* | | 30 | 30 | 7.4 | | | | 22 | 15 | 15 | | | | | |

| | | Macroinvertebrate survey results* | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Taxa** | **LEn1** | **LEn2** | **TP1** | **TP2** | **Mid1** | **Mid2** | **Ash1** | **Ash2** | **NE1** | **NE2** | **Gu** | **LoE** | **Rfi** | **Rmo** | **HSw** |
| **Class Branchiopoda** | *Daphnia carinata* | | | | | | | | | | | | | 10790 | 774 | 630 |
| **Class Ostracoda** | Ostracoda (unidentified) | | | | | | | | | | | | | 3000 | 12 | 897 |
| **Class Copepoda** | Calanoida (unidentified) | | | | | | | | | | | | | | 351 | |
| | Cyclopoida (unidentified) | | | | | | | | | | | | | | 27 | |
| **Subphylum Hexapoda** | | | | | | | | | | | | | | | | |
| **Class Insecta** | | | | | | | | | | | | | | | | |
| **Order Coleoptera** | Dytiscidae (larvae) 1 | | | | | | | | | | | | | | | 2 |
| | Dytiscidae (adult) 1 | | | | | | | | | | | | | | 1.3 | 6 |
| | *Haliplus sp* (Haliplidae) | | | | | | | | | | | | | 1.0 | 0.3 | 2.7 |
| | Hydrophilidae 1 | | | | | | | | | | | | | 7.0 | 37 | 0.7 |
| | Hydrophilidae 2 | | | | | | | | | | | | | 1.3 | 31 | 0.3 |
| **Order Hemiptera** | *Anisops sp* (Notonectidae) | | | | | | | | | | | | | 0.3 | 0.3 | |
| | *Micronecta sp* (Corixidae) | | | | | | | | | | | | | 0.7 | 3.0 | 2.0 |
| **Order Diptera** | Chironimidae | | | | | | | | | | | | | 1.3 | | |
| | Culicidae | | | | | | | | | | | | | 13 | 0.3 | |
| | Stratiomyidae | | | | | | | | | | | | | | 5.7 | |
| **Subphylum Chelicerata** | | | | | | | | | | | | | | | | |
| **Class Arachnida** | | | | | | | | | | | | | | | | |
| **Order Acarina** | Acarina 1 | | | | | | | | | | | | | | 14 | 0.7 |
| | Acarina 2 | | | | | | | | | | | | | | 11 | 13 |
| | Acarina 3 | | | | | | | | | | | | | | 11 | 13 |
| **Phylum Platyhelminthes** | | | | | | | | | | | | | | | | |
| **Class Turbellaria** | *Mesostoma sp* | | | | | | | | | | | | | | 36 | 217 |
| **Phylum Annelida** | | | | | | | | | | | | | | | | |
| **Class Polychaeta** | Capitellidae sp. | | 600 | 481 | 15 | 44 | 81 | 518 | 7.4 | 259 | 141 | | | | | |
| | Nereididae sp. 1 | 44 | 44 | 1274 | 274 | 963 | 896 | 378 | 326 | 585 | 141 | | | | | |
| | Nereididae sp. 2 | | | | | | | | | | | | 5.3 | | | |
| | Nereididae sp. 3 | | | | | | | | | | | | 27 | | | |
| | Polychaeta (unidentified) | | | | | | | | | | | | 59 | | | |
| | **Density (no. individuals/m$^2$)** | **21302** | **14502** | **34767** | **16776** | **19317** | **21420** | **18361** | **14465** | **17102** | **9947** | **375** | **154** | **13831** | **1426** | **1792** |
| | **Number of taxa** | **4–8** | **7–11** | **8–12** | **9–13** | **5–6** | **6–10** | **7–11** | **8–12** | **7–11** | **8–12** | **6** | **12** | **11** | **18** | **14** |
| | **Total number of taxa** | **> 52** | | | | | | | | | | | | | | |

* – 1 and 2 refer to survey dates 8 March and 22 May 2007 respectively for Lake Connewarre sites. All other sites were surveyed once.

Ecological study of Lake Connewarre Wetlands Complex

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