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Literature Review:

Freshwater Macroinvertebrates of the Lower Lakes and Lower River Murray (below Lock 1)

A report prepared for the South Australian Department for Environment and Heritage

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March 2010

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Executive summary

- Macroinvertebrates are an essential part of the aquatic food web, being the major consumers of all type of organic material and they in turn are a major food source for many invertebrates such as fish, birds, tortoises, frogs and water rats.
- There is a high diversity of macroinvertebrates in the Lower Lakes system, from a variety of habitats, ranging from mudflats to emergent vegetation in the littoral areas of the lakes.
- There are no long term data sets for the macroinvertebrates in the Lower Lakes. The most comprehensive scientific surveys have only been carried out in recent years.
- Very few surveys have been undertaken for macroinvertebrates in the Lower Lakes and Lower River Murray. Of these, effort has been concentrated on benthic and littoral sampling to document those invertebrates that live in soft sediments amongst fringing vegetation.
- Despite this uneven level of effort, and sampling at non-optimal times of year (i.e. not autumn or spring), the macroinvertebrate diversity in the Lakes is high, with more than 100 taxa identified to date.
- Wetlands were the habitat type most-often sampled in the Lower River Murray. Diversity of individual wetlands also tended to be quite high, with up to 45 taxa identified per wetland in recent years.
- Little is known about the freshwater macroinvertebrates in Lake Albert, due to the lack of sampling in this Lake, there has only been mudflat sampling (4 sites in one year) and one wetland (Waltowa Swamp)
- The role of macroinvertebrates in freshwater ecosystems is often reported with respect to functional guilds such as functional feeding groups, habitat preference and behaviour. This information has been provided for those macroinvertebrates known to like in the Lakes and the Lower Murray.
- Macroinvertebrates are unlikely to respond directly to changes in water level, but may respond indirectly as habitat availability changes.
- Salinity tolerances are known for some taxa that are found in the lower Lakes and River Murray. However, many of these are based on laboratory assessments, and it is unclear how these may translate to the field.
- Acid tolerances are also known for a few taxa, but interactions with other stressors (including salinity) are not usually known and represent a significant knowledge gap.

Introduction

The Lower Lakes represent a significant ecological asset and form part of a Ramsar-listed site that was listed under the Convention in 1985. The wetlands are recognized for the diversity and abundance of water-birds that use the area, and also the diversity of wetland habitats present. Lake Alexandrina and Lake Albert, including all the islands, make up a total of 92,000ha of wetlands and are surrounded by private property (Paton 2000). The Lower Lakes are also recognized as part of an Icon site under the Living Murray Initiative of the Murray-Darling Basin Authority.

This report aims to identify macroinvertebrates that have been identified as living within the Lower Lakes and Lower River Murray ecosystems, from the primary scientific literature and also from the “grey” literature, such as reports to state and federal government departments and management agencies. Once freshwater macroinvertebrates from the Lower Lakes and Lower River Murray ecosystems have been identified, information about their habitats, habits, functional feeding groups was collated. This information can assist in the formulation of conceptual models for the two ecosystems. Additional information, when available, as to tolerances of salinity and other relevant water quality parameters, were also included.

The review also identifies the lack of information on macroinvertebrates from a variety of habitats, and the patchiness of sampling within the wider area of the Lower Lakes system (such as Lake Albert).

Role of Macroinvertebrates in Freshwater Ecosystems

Background

Macroinvertebrates are defined as being small invertebrate animals that are visible to the naked eye, and they include crustaceans, insects, mites, worms, snails and sponges. They play an important part in the aquatic food web, being the major consumers of all type of organic materials (Bunn *et al*. 1999) and they in turn are a major food source for many vertebrates (e.g. fish, birds, tortoises, water rats and frogs). When sampling for macroinvertebrates, smaller microinvertebrates are often also identified (e.g. cladocerans, copepods and ostracods) in the samples. The scope of this report focuses only on the macroinvertebrates, so any microinvertebrates listed in macroinvertebrate sampling are not included. It is important to note that not all macroinvertebrates have all life stages living in the aquatic environment. For example, many insects have only their larvae being truly aquatic (e.g. dragonflies, mayflies, stoneflies, caddisflies and midges), although some groups have some species with adults that are associated with the water (e.g. diving beetles, springtails, water boatmen and backswimmers). The life cycles of the invertebrates are also relatively short (e.g. weeks to months), therefore any changes in the environment is reflected quickly in the invertebrate population. Within the aquatic environment the macroinvertebrates range across a diverse range of micro-habitats, from sediments (i.e. are benthic) to wetlands to open water, with their diversity increasing in areas that provide abundant and diverse resources.

Macroinvertebrates are an essential component of the aquatic food web, assisting with the grazing and detrital processes, and are essential to a healthy aquatic ecosystem. They form the basis of the diet of many other aquatic species such as fish, tortoises and water rats, as well as composing much of the diet of waterfowl. In addition, macroinvertebrate communities are good indicators of environmental health, because within the community there are a range of sensitivities to environmental conditions, such as salinity, dissolved oxygen and pH. Awareness of the groups that are sensitive or tolerant to changing environmental conditions can assist in understanding the changes that are occurring within the aquatic environment. Macroinvertebrates are ubiquitous, found within a wide range of habitats within the aquatic environment, although the diversity varies, and the advantage of easy sampling and identification makes them a useful monitoring tool.

Macroinvertebrates are generally associated with primary producers (plants or phytoplankton). Plants are generally floating or suspended, or attached to substrate or other plants. The attached plants form the “fringing” vegetation found around waterways, and include emergent and submerged plants. This “near shore” habitat is often referred to as the “littoral” zone of a lake or river. The littoral areas that are shallow and have macrophytes, usually tend to have a higher biodiversity of grazers and detritivores associated with the macrophyte communities, and in turn a higher diversity of the predators that are associated with feeding on these grazers and detritivores.

The suspended or floating forms of primary producers, generally consisting of phytoplankton, can be found in the open water habitats, or the pelagic zone. Small micro-invertebrates and macroinvertebrates feed on the algae and they in turn are eaten by larger macroinvertebrates. The diversity of macroinvertebrates in this area is usually low.

Another group of macroinvertebrates is associated with the sediments, the benthos, as they are the deposit feeders. These are generally sampled with cores taken of the sediment and these invertebrates often form a major food source for wading birds (Paton 2000).

Approach used for literature review

The first aim of the literature review was to identify macroinvertebrates that have been recorded as living in the study area of the Lower Lakes and Lower River Murray ecosystems. The Lower Lakes include Lake Alexandrina and Lake Albert, whereas the River Murray between Lock 1 (below Blanchetown) and Wellington is referred to as the Lower River Murray. The review included a search of scientific literature, government reports and other communications available over the short time period allowed of this review. Dr Peter Hudson also assisted with a search of the South Australian Museum database, but unfortunately could not add any other taxa to the listings in hand.

Once a species list was identified, further basic information was then obtained as to the functional feeding groups, SIGNAL grade (as defined below) and habitat preferences. This provides a baseline on which to develop any conceptual models of macroinvertebrate interactions with their environment, where changes in habitat or water quality can influence the survival or behaviour of various macroinvertebrates. This information is provided in table form in appendix A, attached to this document. The areas of changing habitat quality or water quality are also addressed where information is available.

Macroinvertebrates in the Lower Lakes

The Lower Lakes consist of two large lakes, Lake Alexandrina and Lake Albert. Many of the macroinvertebrate surveys within the CLLMM region have been focused in the Coorong, due to its unique estuarine properties, with many studies undertaken by Geddes (1987, 2003, 2005) and Dittmann *et al*. (2006a,b). In contrast, this literature review aims to collate information on freshwater macroinvertebrates found in the Lower Lakes (Lake Alexandrina and Lake Albert) as well as the lower reaches of the Murray River below Lock 1.

The Murray River is the major source of macroinvertebrates entering the Lower Lakes, but the general health of the River Murray freshwater macroinvertebrates is poor, as assessed and reported by the Australian River Assessment System (AusRivAS) sampling from the sites sampled at Blanchetown and below Murray Bridge (Norris *et al.* 2001). According to AusRivAS, “poor health” of macroinvertebrate communities can mean that families that would be expected to be found were not, and this could be for several or many, therefore a loss of macroinvertebrate diversity is observed. Other sources of macroinvertebrates, which were rated higher by AusRivAS, are the freshwater tributaries that flow into the Lower Lake system at Lake Alexandrina, such as Tookayerta Creek, Finnis River and Angus Creek, all of which were surveyed using the AusRivAS methodology, and are noted as containing many rare macroinvertebrates (Anon. 2003).

The literature search revealed that few surveys of macroinvertebrates have been undertaken within Lake Alexandrina, and very little data were found for Lake Albert. Of the surveys that were undertaken, the majority conducted by Dittman *et al*. (2006a,b; 2009a) and Baring *et al*. (2009) focused on the benthic invertebrates from sediment core samples because this correlated with information on feeding areas for shore-birds. Other surveys by Sinclair Knight Merz (SKM) consulting focused on significant wetlands around the lakes, as part of the survey work undertaken for the Wetlands Baseline Survey report to the South Australian Murray Darling Basin Natural Resources Management Board (SKM 2004, 2006). The two habitat types surveyed were within the littoral zone of the lakes, with either emergent and submerged vegetation or mudflats. Open water was rarely sampled (only by Brandle 2002, with surveys at Hindmarsh Island) and selective sampling for larger invertebrates, such as bivalves and larger crustaceans, were not included.

Wetland habitats surveyed include Hindmarsh Island, Tolderol, Milang Shores, Narrung, Clayton, Teringie, Mundoo Island and Waltowa (in Lake Albert) undertaken by SKM (2004), Pelican Lagoon, Poltalloch, Point Sturt and Loveday Bay by SKM (2006) and five sites at Wyngate NPWSA Reserve on Hindmarsh Island by Brandle (2002) (see Figure 1). These surveys yielded detailed species lists and indicated an overall high diversity of organisms. The wetlands surveyed were typically littoral wetlands, fringing the Lakes, relying on the water level in the lake. The open water habitat, sampled using a plankton net by Brandle (2002), yielded a variety of macroinvertebrates, including snails, worms, hydras, amphipods, shrimp, non-biting midge larvae, water boatmen, damselfly larvae, and also microinvertebrates, such as copepods, seed shrimp and water fleas. The surveys by SKM, using sweep nets in the littoral areas, collected an even greater diversity of organisms (see Appendix A, Table 1)

In 2004, Dittmann *et al.* (2006a) conducted a macrobenthic survey (sediment cores taken from mudflats) which included the Lower Lakes, with 5 sites in mudflat habitats in Lake Alexandrina being sampled. Worms, molluscs, crustaceans and insects were identified from these core samples, with quite a diversity of crustaceans and insects being observed. The following year, 2005, Dittmann *et al.* (2006b) re-sampled only one site (site 9) in Lake Alexandrina for benthic macroinvertebrates but then found only crustaceans and insects. The next two macrobenthic surveys did not include any sites within the Lower Lakes, and it was not until December 2008 that the benthic surveys continued with Baring *et al*. (2009) sampling a total of 16 mudflat sites in Lake Alexandrina and 4 mudflats in Lake Albert (located at Waltowa, Secombes, Albert Station and Vanderbrink). All samples were collected with corers and a low diversity of macroinvertebrates was recorded. However it was noted that two rare taxa, an ephemeropteran family, Leptophlebiidae, and the Plectoptera, were recorded as being present (single specimens) from a site at Teringie (Baring *et al*. 2009).

Tributaries feeding into Lake Alexandrina, Currency Creek and Finnis River, were sampled in 2008/2009 by Dittmann *et al*. (2009a) and this survey included 2 sites, the mouth of Currency Creek and below the confluence of Finnis River/Tookayerta Creek, which could be considered as sites within Lake Alexandrina, because they are influenced by the water regime of the lake. Unfortunately, at the time of sampling the water levels in Lake Alexandrina were falling and the habitat changing, so a low diversity of macroinvertebrates from benthic sampling was observed.

One important feature of the macroinvertebrate community is the variety of life forms, many of which only have a truly aquatic stage when a larva. Identification of some groups (e.g. Odonata) is only possible when the larvae are in their final instar, so sampling time for macroinvertebrates is an important consideration. The surveys conducted to date do not always sample at the optimum time (e.g. spring and autumn) when the macroinvertebrates are most active, and identification has often been to a coarser taxonomic level. The susceptibility of invertebrates to changing environmental conditions (e.g. pH, salinity, temperature etc.) also varies with the different life stages (i.e. eggs, larvae and adults), which are not always noted, or selectively sampled for, in a survey. This is an important consideration when assessing potential environmental threats. There are therefore still many gaps in our knowledge, in particular the basic knowledge in regards to the full extent of diversity of freshwater macroinvertebrates within the Lower Lakes ecosystem, as none of the surveys covered in this review were designed to address this question.

Unfortunately, there is also lack of information about changing diversity and density of macroinvertebrates within the Lower Lakes in the past, as survey work for macroinvertebrates has only been undertaken during the last 8 years. Surveys of vegetation in wetlands and algal and plankton studies (e.g. Geddes 1984) have been conducted and provide a better understanding of open waters and vegetation types than macroinvertebrate communities. In addition, there is little information as to any differences between the freshwater macroinvertebrate populations in Lake Alexandrina and Lake Albert. With only one wetland survey (SKM 2004) and four mudflat surveys (Baring *et al.* 2009) undertaken in Lake Albert (Appendix A, Table 3 & 4), it is difficult to make any comparisons with the macroinvertebrate communities found in the larger Lake Alexandrina. From the list of macroinvertebrates identified in Lake Alber, none were found to be exclusive to this region, because they were also identified as occurring in Lake Alexandrina. The invertebrate communities in sediments were dominated by oligochaetes and amphipods, similar to those found in and Lake Alexandrina samples. The single wetland survey at Waltowa by SKM (2004) noted that the wetland was in poor condition at the time of sampling, so there is very little information as to the macroinvertebrates that reside in Lake Albert.

However, the information that has been collected by combining all the survey data for the Lower Lakes indicates that the diversity of macroinvertebrates was relatively high, in comparison with the individual surveys and the total number of taxa identified in the Lower River Murray, with over 100 taxa recorded across all surveys (see Appendix A, Table 1). The diversity of macroinvertebrates occurring within the Lower Lakes can be sub-divided further to occurring in either wetlands or mudflat habitats. Approximately half of the surveys were from wetlands and the other half from mudflats. The level of macroinvertebrate diversity was notably different between these two habitats, with an a range of 18 – 47 taxa recorded in wetland sites but only 2 – 19 taxa recorded in mudflat sites (Appendix A, Table 4)

In Appendix A, the tables for the Lower Lakes (Table 1) and Lower River Murray (Table 2) provide a listing of the taxa identified by the individual surveys, with additional information including their functional feeding groups, SIGNAL score, habitat type and special notes. The latter provides further information, such as known sensitivities to environmental variables such as salinity, temperature and dissolved oxygen. Also included is any available information on bioaccumulation of heavy metals or avoidance behaviour to stressful environmental conditions. This range of information hopefully provides some understanding of the freshwater macroinvertebrate communities and their functional roles as well as their susceptibility to selected pressures within their environment, which could assist in the building of a conceptual model of their unique ecosystem relations.

Some species listed in Table 1 (see Appendix A) were noted as not being recorded by the Lower River Murray wetland surveys and they included some taxa known to be more tolerant of salinity. They include the crab, *Amarinus lacustris*, polychaete worms and the bivalve, *Arthritica helmsii*. However, it should also be noted that approximately half of the surveys undertaken in the Lower Lakes included sampling of mudflats with corers (Appendix A,Table 4), a habitat not sampled in the river, so species like the polychaete worms and the bivalves were more likely to be detected in the Lakes. There were also other species generally thought not to be tolerant of salinity recorded in the lakes but not in the river, so other factors may be affecting their distribution.

Figure 1. Map showing wetland baseline-survey study sites (SKM 2004, 2006, Brandle 2002). Approximate locations of the wetland sites are shown in black triangles

Macroinvertebrates in the Lower Murray River (below Lock 1)

The Australian River Assessment System (AusRivAS) has been assessing sites along the river Murray for macroinvertebrates from below Lock 1 (Blanchetown) to Wellington. Unfortunately the database was not available at the time of this review, but other reports on river health have used this data set and found the condition of the macroinvertebrate communities to be significantly impaired (Norris *et al*. 2001).

Wetlands have been the focal habitat for most of the macroinvertebrate surveys conducted in the Murray River, and the level of taxonomic identification varies with the individual surveys. In 1990, Goonan *et al*. (1992) surveyed selected wetlands along the Murray including three in the section below Lock 1. These three lagoons were Devon Downs North, Wongulla Lagoon and Lake Cartlet. The latter which is a permanent floodplain swamp, had the highest species richness of all the wetlands surveyed, with 36 taxa recorded. In more recent years some wetlands have recorded even higher diversity with up to 45 taxa recorded (SKM 2004)

Surveys of wetlands along the river have recently been conducted by SKM as part of the River Murray wetlands baseline survey for the South Australian Murray Darling Basin Natural Resources Management Board. Wetlands surveyed include Devon Downs South, Kroehns Landing, Forster Lagoon, North Purnong, Riverglades, Swanport, Paiwalla (SKM 2004) and Murrundi, Sweeneys Lagoon, Lake Cartlet, Younghusband West, Reedy Creek and Rocky Gully/Mobilong Swamp (SKM 2006) (Figure 2). These wetlands are comprised of a variety of meso-habitats, such as backwaters (connected to the main channel, but with little or no flow) and billabongs (connected to the main channel at times of flooding) and can have either temporary or permanent water. There are also some that have been constructed, e.g. Rocky Gully that has water pumped in to make it a permanent wetland.

Table 2 (see Appendix A) lists the individual taxa recorded for all the surveys considered above, with approximately 80 taxa identified. It was noted that 10 taxa were identified as occurring in the river system but as yet not identified as occurring in the Lower Lakes. They include the shrimp, *Macrobrachium australiense*, the small bivalve, Corbiculidae, three colepteran families (Hydraenidae, Scirtidae and Hydrochidae), the dipteran family Tipulidae, the snail *Isidorella newcombi*, two hemipterans (*Hydrometra* sp. and *Ranatra* sp.) and the isopod, *Tachaea* sp. There is a possibility that some of these taxa have habitat preferences for wetlands in riverine systems, or may be sensitive to water quality . However it is also possible that they are present in the Lower Lakes but as yet have not been identified.

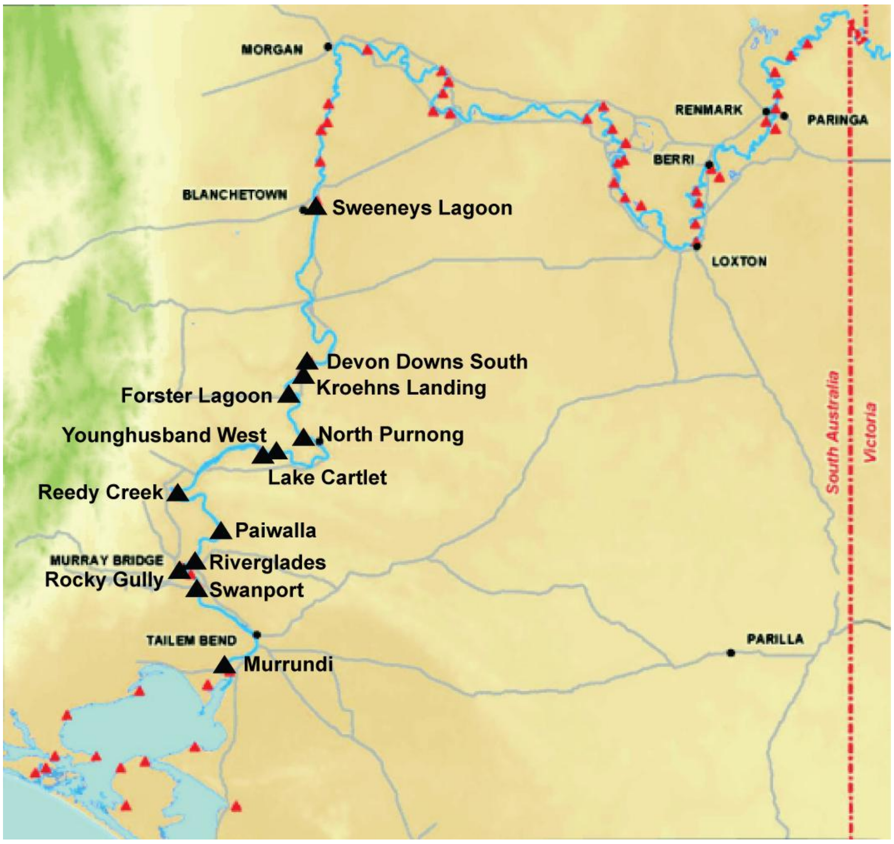


Figure 2. Map showing wetland baseline-survey study sites (SKM 2004, 2006). Approximate locations of the wetland sites are shown in black triangles along the Lower River Murray. Note: small black circles represent major towns within the region and small red triangles denote other wetland baseline survey sites (DWLBC atlas).

Identification of selected macroinvertebrate groups that have been observed in the Lower Lakes and Lower River Murray and their significance

Freshwater macroinvertebrate groups in Australia are, in general, not often studied in detail, and so the following macroinvertebrate groups have been selected to provide some information which may be relevant for further understanding their roles within these aquatic ecosystems.

The groups have been selected to cover a range of habitat preferences, as well as considering their relative abundance within the Lower River Murray and the Lower Lakes. Some groups exhibit a variety/diversity of functional feeding groups (e.g. Decapoda) or have a high abundance and diversity of forms (e.g. Insecta) or they may have a special habitat preference (e.g. Annelida and Platyhelminthes). Other groups can provide additional information on responses to changing environmental conditions (e.g. Mollusca, Amphipoda and Cnidaria) because they are amenable to detailed laboratory toxicity studies, while other taxonomic groups can only be assessed or observed in the field.

Mollusca: Includes the snails (Gastropoda) and mussels (Bivalvia).

Bivalvia: Filter- or deposit-feeders which burrow in the soft sand, silt or mud. Some species of bivalves are known to bioaccumulate heavy metals and algal toxins, so have been suggested as indicator species for these conditions. *Velesunio ambiguus* is typically found in billabongs (hence its common name "billabong mussel") and although not recorded in surveys, it is known to reside in the lakes systems, and has been an important food source to the local indigenous communities over the years. Recently it was recorded that *V. ambiguus* shells were seen to provide substrate for the invasive tubeworm, *Ficopomatus enigmaticus* (Dittman *et al*. 2009b), and although the shells were from dead mussels, it suggests that they were once living in that environment. *V. ambiguus* is also know to tolerate low dissolved oxygen, high water temperatures and can withstand periods of drought by sealing the shell tight and awaiting the return of water. It can also be found in sheltered areas alongside a river, whereas *Alathyria jacksoni* (the "river mussel") is found in habitats with higher flow, like the deeper main channel of the River Murray (Sheldon & Walker 1989). Another interesting feature of this bivalve family, Hyriidae, is the dispersal of young, because in the early stages of life they are parasitic on fish until they are fully developed, when they drop free of their host and into the sediment.

Velesunio ambiguus, like many bivalves, contains a special protein (metallothionein) which helps in binding heavy metals, and thus has potential as biological indicators of heavy metal pollution. Millington and Walker (1983) investigated this possibility for the heavy metals, zinc, iron and manganese, and although there was some bioaccumulation of heavy metals, the link with environmental concentrations was unclear.

Gastropoda: The gastropods are generally scrapers, feeding off bacteria and periphyton on surfaces, and are found amongst vegetation and debris. One group, the Viviparidae, so named because they give birth to live young instead of laying eggs, were once though to be extinct in the Lower River Murray, until they were found living in irrigation pipes, and that change in population was thought to be due to changes in food source (Sheldon & Walker 1997)

Platyhelminthes: Includes flat worms and temnocephalids

Turbellaria: The flat worms, who are free-living and glide over surfaces feeding on prey and scavenging other food.

Temnocephalidae: Ectocommensals, mainly living on large crustaceans like yabbies. There are some species that are predators and others that feed on algae and bacteria.

Cnidaria:

Hydridae: The hydras are generally sessile, attaching to a hard substrate e.g. vegetation, wood and stones, although they can move by either detaching from a surface and drifting or slowly gliding on their base. They feed by catching prey, such as small crustaceans and insects, in the water with their tentacles. Hydras have been found in waters with a range of salinities, and appear to tolerate a wide range of conditions. They have been found suitable for laboratory studies (Pollino & Holdway 1999) so are regularly used in toxicity bioassays. Studies of pesticides, pharmaceuticals (Quinn *et al*. 2008) and heavy metals (Karntanut & Pascoe 2002) have used the hydra as a test organism because of their response to changes in environmental conditions.

Clavidae: These tiny colonial animals are sessile, and some are known to be tolerant of salinity. There is only one species known to occur in Australia and that is *Cordylophora caspia.*

Decapoda: Large omnivorous crustaceans such as crabs, yabbies, freshwater prawns and shrimp.

Hymenosomatidae: The “false spider crab”, *Amarinus lacustris*, is known to occur in slightly saline waters from observations in the field and laboratory studies conducted by Walker (1969). Other species of this genus are known to occur in estuaries or shallow marine environments.

Parastacidae: The large crustacean, the yabby (*Cherax destrustor*) occurs throughout the river and lake systems, and are known to survive drought by burrowing deep and aestivating (slowing down their metabolism). It is a predator, scavenger (omnivore) and detritivore and is considered to be one of the more robust macroinvertebrates. It has been used in toxicity laboratory studies for heavy metals, such as copper, zinc, cadmium, iron and nickel (Skidmore & Firth 1983, Khan & Nugegoda 2007)

Palaemonidae: The freshwater prawns, *Macrobrachium* sp., are generally thought to be fairly tolerant of salinity.

Amphipoda: Commonly known as ‘scuds’ or ‘side swimmers’, this groups contains some species from the families Ceinidae and Corophiidae that are known to be tolerant of salinity. Laboratory studies have recently been conducted in Australia by King *et al*. (2006) using estuarine amphipods, investigating the acute toxicity and bioaccumulation of heavy metals (both aqueous and sediment-bound), which could have implications for species found in the Lower Lakes

Annelida: The segmented worms

Oligochaetes: These worms that live in the sediments are mainly detritivores feeding on organic material and bacteria, with the exception of some species of *Chaetogaster*, which are carnivorous. Generally oligochaetes can survive low dissolved oxygen concentrations, and have been used as indicators of poor water quality, due to their ability to survive under those conditions. There is at least one species that prefers saline environments. Another feature of the oligochaetes is their ability to bioaccumulate heavy metals. There have been numerous studies examining the toxicity and bioaccumulation of heavy metals, such as cadmium and copper, and the identification of metallothionein-like proteins in freshwater oligochaetes (Deeds & Klerks 1999). A range of annelid worms have been identified from surveys of the benthos in Lake Alexandrina, so it is possible that there are species which possess the ability to bioaccumulate heavy metals.

Polychaetes: The free-living bristle worms are mainly known to be marine and estuarine, but some are known to occur in freshwaters. Some worms, such as the family Capitellidae, are known to adapt to low oxygen levels. One freshwater species is also known to be an ectoparasite in some freshwater crayfish.

Hirudinea: The leeches, like the other annelids, appear to be fairly tolerant of low dissolved oxygen, as well as being found in areas with a range of salinities and temperatures.

Insecta: There is a great variety of insects inhabiting aquatic ecosystems and some groups that have truly aquatic life stages are known to be reliable indicators of water quality.

Ephemeroptera: The mayflies spend most of their life as an aquatic larva, which is, even then, relatively short (two weeks to less than a year) and can have a range of sensitivities to water quality, although they are generally not very tolerant of water pollution. Mayflies have been known to bioaccumulate pollutants, in particular pesticides (e.g. organochlorides) and occasionally heavy metals. One study investigated the short-term toxicity of heavy metals in relation to freshwater acidification (Gerhardt 1994) which could provide some insights to how this group may react to acidification in Lower Lakes and River Murray.

Odonata: These predatory insects can be found in a range of habitats, from fresh to saline waters, with the different families exhibiting a range of tolerances to environmental conditions.

Trichoptera: The larvae of this group, the caddisflies, are quite diverse, as seen in their range of functional feeding groups from gathering collectors to predators. They can be found in a range of water bodies including saline waters. Overseas studies have shown that some trichopterans are capable of bioaccumulating heavy metals, such as cadmium and zinc (Timmermans *et al*. 1992) and pesticides (Belluck & Felsot 1981).

Understanding Macroinvertebrates in Aquatic Ecosystems

When trying to understand the processes of aquatic ecosystems, there are various approaches to understanding the features of the macroinvertebrate community groups. The macroinvertebrates themselves can be categorized according to their feeding preferences (functional feeding groups), habitats and behaviour (or habit). In addition, a relationship between macroinvertebrates and water quality has been developed in Australia. This relationship is known as the SIGNAL biotic index, and it uses a grading from 1 (fairly tolerant) to 10 (sensitive) to represent the water quality sensitivities of a number of taxa (Chessman 2003a). The SIGNAL grades can be used to give an indication of water quality when assessing macroinvertebrate communities at a given site. Chessman (2003b) highlights the relationship between SIGNAL scores and water quality; for example high SIGNAL scores were indicative of relatively clean water with low quantities of suspended and dissolved substances whereas a low score may indicate any of several kinds of physical or chemical enrichment or contamination. For a more detailed investigation as to how individual taxa respond to selected water quality criteria (e.g. temperature, salinity, pollutants etc), laboratory testing or field testing needs to be undertaken. The results can provide a better understanding of individual taxa responses. However, when dealing with a complex system, like the aquatic environment, care must be taken when applying knowledge gained from laboratory testing, as not all parameters of a natural system are incorporated, including interactions between water-quality features and interactions between species. In addition, when dealing with a group like the macroinvertebrates, there are different life stages that may demonstrate varying degrees of tolerance towards changing environmental conditions. Another consideration is habitat quality, where changes in habitat, e.g. decline in emergent vegetation, will affect the selection of that habitat for occupancy by a species.

Below is a brief description of some of the terminology used to describe macroinvertebrates.

Functional Feeding Groups: The use of Functional Feeding Group classification helps in providing an understanding of the food web relationships within the macroinvertebrate community. The classifications include:

Predators; those that feed on others (e.g. dragonfly larvae) including those that are parasitic (e.g. mites)

Shredders; feed on coarse organic material, such as plant leaves and stems

Piercers; those that pierce the tissue of other living organisms (e.g. plants and animals) and suck out juices, such as the Hemipterans (“bugs”)

Scrapers/Grazers; those macroinvertebrates that feed on attached algae or bacteria, for example the snails

Collectors; this group feed on the fine organic matter found in the aquatic ecosystem, and can be further categorized as being either Filtering Collectors (e.g. mussels) or Gathering Collectors (e.g. mayfly larvae)

Omnivores; There are some macroinvertebrates that are able to feed on both living and dead organic matter, for example, the large crustacean, the yabby.

Habitat and Habit: Where the organism resides and how it moves.

Burrower; organism that burrows, often is a consumer of fine organic matter (e.g. worms) but not always (e.g. the yabby, which is a predator and scavenger, omnivore)

Sprawler: stretches out on a substrate (vegetation, rocks etc)

Climber; macroinvertebrates that feed in amongst submerged vegetation

Swimmer; those organisms that swim in the water by controlling their movements (i.e. not drifters who are unable to control their movement in the water)

Clinger; those organisms that cling to surfaces

Skater; those that skate over the water surface (e.g. the hemipterans, water treaders)

Divers; organisms that dive from the surface and down into the water column (e.g. the predacious diving beetles),

Tables 1 and 2 in Appendix A list the taxa recorded by surveys in the Lower Lakes and Lower River Murray, and incorporate information on Functional Feeding Groups, SIGNAL grades (indicating sensitivity to water quality), Habitat and Habit and other special notes. The special notes may include general information on tolerances to environmental conditions (e.g. salinity) or toxicological information for a taxon's response to a selected water quality parameter. The next section in this review focuses on some of the potential environmental changes that could influence macroinvertebrate communities living in the Lower Lakes in the future.

Challenges in the changing environment

The effect of drought conditions in the Murray-Darling catchments impacts the end of the system at the Lower Lakes, with declining inflows through the Lower River and hence into Lake Alexandrina and Lake Albert. The consequences of this low flow, apart from lowering water levels, is a decline in the quality of the water, especially with rising levels of salinity and the potential of acidification from exposed acid-sulfate soils. It is unlikely that macroinvertebrates would respond directly to changing water levels, but are likely to respond to changes in habitat availability. The majority of macroinvertebrates associated with wetlands, found in the littoral zone of the lakes, are linked to their habitats of emergent and submerged vegetation, so any reduction in habitat extent due to drought will no doubt affect the macroinvertebrate communities. The link between the habitat type and macroinvertebrate communities is not well understood in the Lower Lakes, although there have been investigations to categorize wetland types (Australian Water Environments 2007); the link with their associated macroinvertebrate communities has not been made.

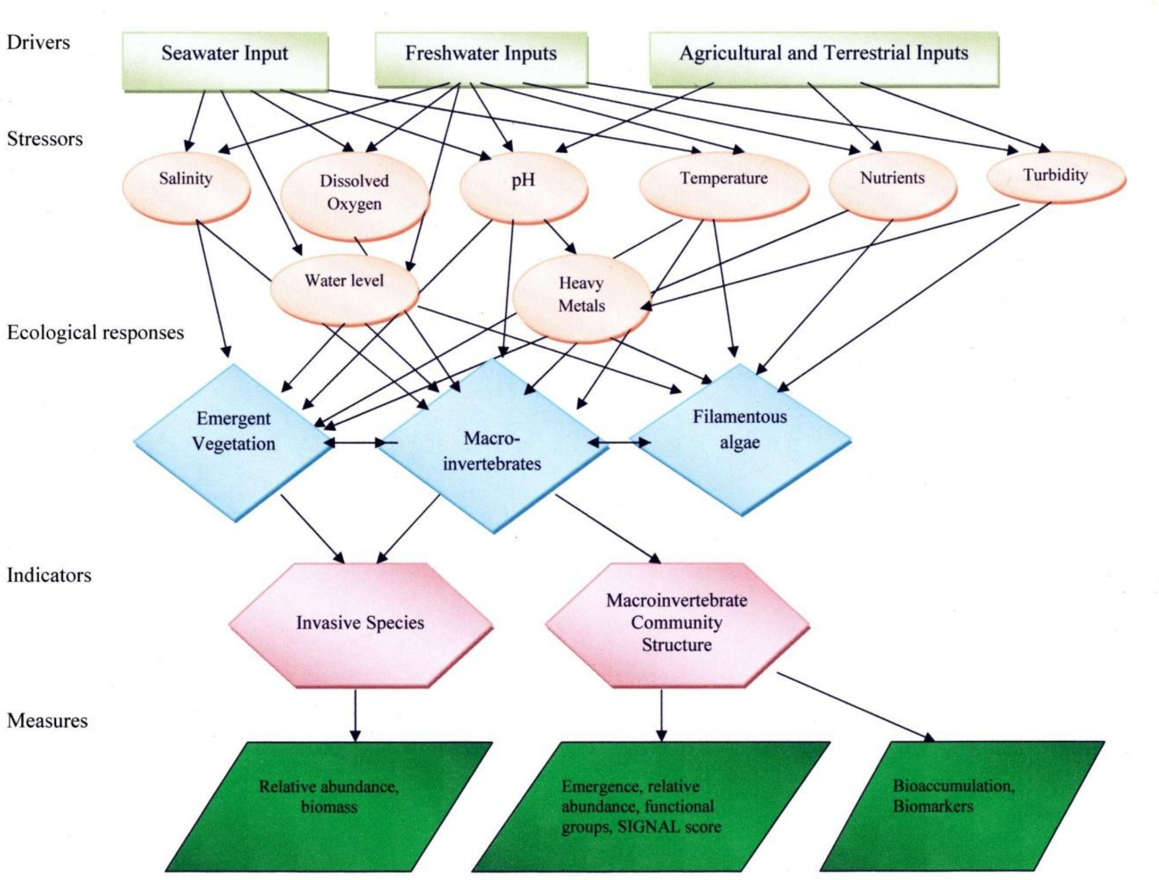
Conceptual Models of Macroinvertebrates in Freshwater Ecosystems

Conceptual models are used to express ideas about how an ecosystem can function. The complexity of a system can be best understood at various levels, as the different ecosystem components are identified. The development of conceptual models of whole ecosystems is a complex process that needs identification of the overall scope and scale of the model, the habitats to be focused upon, then the individual components need to be identified and in some instances further models developed for the components. Reports by Wilkinson *et al*. (2006; 2007a,b) on a best practice framework for monitoring and evaluation of water-dependent ecosystems provide much information that assists in the designing of conceptual models. To build a conceptual model of an aquatic ecosystem one first has to identify the objective, or problem that one wishes to understand. Then the type of conceptual diagram is selected, one which would best describe the feature that one wishes to communicate. For example, a basic food web can describe the interactions between biological components, or a combination of chemical and biological interactions can help view the process of bioaccumulation of toxicants.

A conceptual model of freshwater macroinvertebrates in the Lower Lakes, for example, should consider the stressors and drivers of the ecosystem. The major components of a conceptual model are the drivers (the major external influencing factors), stressors (those components of an ecosystem that may cause significant changes in ecological systems) and the attributes (the complex ecosystem components that respond to the drivers and stressors). In an aquatic ecosystem the main driver might be water inflow, while the stressors could be salinity, acidity, pathogens, nutrients, turbidity, heavy metals, pesticides etc. Figure 1 presents a basic conceptual model, using of some of the components relevant to the Lower Lakes, incorporating some of the environmental variables and freshwater macroinvertebrates. The drivers for the Lower Lakes can be related to water input (freshwater and seawater) and agricultural and other terrestrial inputs. The stressors in this example are those perturbations to a system that can cause significant changes to the ecological components, such as water quality and water level. One component of the ecosystem not considered in this model is habitat. Aquatic habitats for macroinvertebrates are varied (e.g. emergent vegetation, open water and sediments) and these micro-ecosystems can present different sets of stressors to the inhabiting macroinvertebrate communities, as they are exposed to different environmental conditions.

A search of the literature yielded very little information on freshwater macroinvertebrate conceptual models, demonstrating the interaction with their environment. A basic model was (see Figure 1B, Appendix B) developed by the Trinity River Restoration Program (2005) and included aspects such as Supply (e.g. water flow actions, allochthonous debris and sediment supply) Habitat (e.g. quality, quantity and vegetative characteristics), and Survival and Mortality (e.g. available food and predation). All of these could be incorporated into a model for the CLLMM region. However the main areas of concern for the Lower Lakes would need to be addressed and thus refinement of this model would be required. Such refinements would need to include the availability of water (quantity), which can affect habitat parameters (i.e. vegetation), and changing water quality, in particular salinity, pH, DO, temperature and the bioavailability of heavy metals (associated with increasing acidity).

Figure 1. An example of a basic conceptual model for freshwater macroinvertebrates in the Lower Lakes.
Note: Not all interactions/links are covered in this diagram. The interactions between the stressors is also not covered, which can be an important factor, the obvious example being the link between D.O. and temperature.



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Using the process for conceptual model design developed in Wilkinson *et al*. (2006; 2007a,b), a simple model for the Coorong (MDBC 2006) has been developed, where the macroinvertebrates in the mudflat environment were modeled for their emergence and survivorship, against water quality and turbidity (see Figure 2B Appendix B).

Conceptual models for Lake Alexandrina and Lake Albert, as well as selected wetland types, have been developed by Souter (2009), which incorporated the main drivers and stressors for the ecosystems. These control models are the first step in understanding ecosystem functions. The lake system models involve the "biota" as an ecosystem attribute but, in the selected wetland types, macroinvertebrates are introduced as a separate attribute (see example, Figure

3B Appendix B). Water quality parameters considered in these models include pH, salinity, metals/metalloids, turbidity, nutrients and dissolved oxygen. Further development of models could incorporate information about macroinvertebrates and their relationships with water quality parameters.

The Lower Lakes at present have the potential for gradual changes in water quality, in particular, changes brought about through increasing salinity and acidification from acid sulfate soils, as well has lowering of the water levels in the lakes. When considering the interactions between water quality and macroinvertebrates, information from laboratory and field-based studies, as well as general observations, provide an indication as to possible effects and responses. Other reviews (e.g. Lester *et al*. 2008) have identified responses of selected macroinvertebrate taxa to salinity, heavy metals and acidification, and this information can assist in building a conceptual model. In general, it is assumed that all freshwater macroinvertebrates will eventually be lost from an ecosystem that experiences changes from a freshwater to a saline environment. However the degree to which individual taxa may respond will vary, and so the invertebrate community would be expected to gradually change in its composition/diversity/abundance over time, with the loss of various taxa as they succumb to the changing environment.

Suter (1996) presents guidelines for developing conceptual models for ecological risk assessment, which are more designed to understand the source, transport, exposure, fate and interaction with biota of contaminants in ecosystems. In this report a generic conceptual model for aquatic biota is presented (see Figure 4B Appendix B), which could be adapted to a Lower Lakes ecosystem model. The US EPA have developed a number of models for aquatic ecosystems, with programs such as CADDIS, BASS and AQUATOX (Rashleigh *et al*. 2008), which are available via the internet. These have been developed to address the various needs of managers and can incorporate some features of the biota, such as potential for bioaccumulation and trophic interactions.

Salinity tolerance in macroinvertebrates

Already there have been observed changes in the macrobenthic communities in Lake Alexandrina with more salinity-tolerant species now present where seawater intrusions have occurred (Rolston *et al*. 2010). Many of Australia's aquatic species have some degree of tolerance of salinity, as it is a natural feature of many inland waters in Australia, especially the lowland rivers (Williams, 1980). As salinity increases in the aquatic environment there may be loss of those intolerant species but also an increase in more tolerant species (McEvoy & Goonan 2003). The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) suggest a threshold of 1500 $\mu S\ cm^{-1}$ for salinity in rivers, and has been a useful trigger in monitoring salinity. Since the formulation of the ANZECC guidelines in 2000, further investigations into the salinity tolerance of Australian macroinvertebrates have been undertaken to obtain information about the sensitivity/tolerances and trigger points to guide management decisions.

Although the focus here is on the direct effects of salinity on macroinvertebrates, it should be remembered that there is little known about the indirect impacts of salinity on food web structures or complex ecosystem process (James *et al*. 2003). Nielsen *et al.* (2003) reviewed information available on the how the structure and function of aquatic ecosystems could change with salinity. In their review, the lack of knowledge concerning life stages of aquatic fauna and their sensitivity to salinity, the sublethal effects of salinity, and changes to ecosystem functioning was highlighted. It was suggested that the second- and third-order effects (e.g. effects of increasing salinity on primary and secondary production, nutrient dynamics and food-web structure) must be taken into account when developing an understanding of the effects of salinity in an aquatic ecosystem. The development of conceptual models for salinity has the potential, in part, to address some of these issues if the knowledge gaps are given consideration.

Investigations into the direct toxicity of salinity to Australian macroinvertebrates have been a topic for research in recent years (Kefford *et al*. 2004, 2007a,b) providing much information for individual species (see Appendix A, Tables 1 & 2 for details). Generally, the insect group Ephemeroptera was seen to be one of the more sensitive to rises in salinity and the crustaceans one of the more tolerant groups.

Dunlop *et al*. (2008) conducted research into developing salinity trigger values for aquatic ecosystems and highlighted the need for developing and assessing these values for the local relevant communities. Laboratory-based studies (72 hour acute toxicity tests) were tabulated for a range of taxa from Australia, providing a base on which to build further (see Appendix A, Tables 1 & 2 for details). Horrigan (2007) combined observations of species distributions from the field with laboratory-derived information on tolerance to salinity, and found that there was a good correlation between them. More information on the sensitivity of individual taxa to salinity is tabulated in Appendix A.

A review of the sensitivity of key biota to salinity in the Lower Lakes suggests that, while it is generally known that macroinvertebrates can tolerate slight changes in salinity, there are knowledge gaps pertaining to salinity thresholds for individual species known to be present in the ecosystem (Lester *et al*. 2008). Also highlighted was how salinity change may be presented in the ecosystem, as the rate of change, could be an important factor. Other knowledge gaps were also identified such as the sensitivity of other life stages of the resident biota, the importance of refugia, and the interactions of salinity and other stressors. It was concluded that, although freshwater macroinvertebrates can generally tolerate small changes in salinity, there is not adequate knowledge available at present to predict which species would be adversely affected, either through direct or indirect effects. It was also observed that the more salt-tolerant species residing in the Coorong and near the barrages are capable of colonising a more saline ecosystem. Overall it was hypothesized that the introduction of seawater would result in the gradual invasion of the salt-tolerant species and a sharp decline in freshwater species, resulting in a depauperate macroinvertebrate fauna over the transition period (Lester *et al*. 2008).

Acid-sulfate soils and bioavailability of heavy metals

Decreasing water inflows has resulted in exposure of large areas of acid sulfate soils, which has the potential to cause acidification of the lake water from later rewetting of the dry soil (Simpson *et al*. 2008, Fitzpatrick *et al*. 2008). There is potential for the release of acid, metal and nutrients into the aquatic environment when the dry acid sulfate soils are rewetted, resulting in possible deleterious effects on the aquatic biota either from direct toxicity or due to chronic effects from the bioaccumulation of heavy metals. Acid sulfate soils have been identified as occurring in the Lower River Murray and the Lower Lakes (Simpson *et al*. 2008, Fitzpatrick *et al*. 2008), including some of the wetlands surveyed for macroinvertebrates (e.g. Murrundi, Lake Cartlet, Kroehns Landing, Devon Downs North and South), so there is a definite risk to these communities.

Studies on the rewetting of the acid sulfate soils have indicated high levels (exceeding the water quality guidelines) of some heavy metals (e.g. copper, zinc cadmium and aluminum) (Simpson *et al*. 2008). Information on the response of selected macroinvertebrate taxa to heavy metals is available, but the compounding environmental influences that could be found in the river or lake systems cannot be factored into laboratory testing. The toxicity data, through water quality guidelines, can provide some guidance as to the potential impact from acid sulfate soil rewetting on the macroinvertebrate community. Studies on macroinvertebrates that consider the combination of freshwater acidification and toxicity of heavy metals are few. Gerhardt (1994) used artificial streams to simulate the natural environment when assessing the impact of heavy metals toxicity (iron and lead) due to freshwater acidification, on mayfly species. Gerhardt (1994) found that both metals (i.e. $Fe2+$ and $Pb2+$) were more toxic at pH 4.5 than pH 7. The mayflies lost their escape behavior when exposed to metals, and those effects were more pronounced at pH 4.5 than 7. The physiological and behavioural responses to toxicants are more sensitive, and in terms of response time, they are among the first reactions against toxicant stress at sublethal doses. The acidification of surface waters (which could be a potential threat in the Lakes) down to pH 5 causes an increase of aqueous Pb, if the content of organic ligands in the water is low. In addition, Fe may be more toxic at low pH. Corfield (2000) provides field-study observations from the Richmond River on NSW, where acid sulfate run-off into the river can be linked to changes in the macrobenthic community structure (i.e. relative abundances and species composition). Two species of polychaetes were shown to be sensitive to the chemical speciation of aluminum. Hence, increases in relative abundances of either polychaete may, in absence of ongoing water quality measurements, provide a good indication of the degree of exposure to acid-sulfate runoff in the Richmond River.

With the potential dual risks from salinity and acidification, and the limited current knowledge of freshwater macroinvertebrates in the Lower Lakes, difficulties may be experienced in modeling of this ecosystem. There is a distinct knowledge gap with the responses of macroinvertebrates to these changing conditions.

Conclusions.

This literature review has identified a high diversity of freshwater macroinvertebrates from the Lower Lakes and the Lower River Murray, even though there have been few surveys of the area (see Appendix A, Table 3) using a range of methods and varying degrees of taxonomic identification. Increased surveillance could reveal even more species, including those that are considered rare in the region (e.g. Plecoptera in the Lower Lakes, Baring *et al*. 2009), which would have implications for indicator species selection.

As the macroinvertebrates are an essential part of the ecosystem, it is reassuring to see that there is quite a range of functional feeding groups represented amongst the listed taxa. Unfortunately any potential changes in the macroinvertebrate communities over the last few decades were not able to be assessed due to the paucity or lack of historical data. Such information could have provided a reference, or baseline, for any future changes to the ecosystem. However the taxonomic list collated from the variety of sampling techniques (quantitative and qualitative) and range of habitats has provided a list of taxa known to occur in the Lower Lakes.

Taxa identification is seen as the first step in understanding the unique ecological systems of the Lower Lakes. Although detailed research has been undertaken into other components of the ecosystem, such as vegetation mapping, fish and bird surveys, there is still relatively little known about the freshwater macroinvertebrates, in particular their spatial distribution, habitat preference and sensitivities to water quality. The literature can provide some guidance on stressors, such as salinity and acidity, but the adaptation of this information to the field situation is complicated by other environmental factors.

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Appendix A.

Listings of Macroinvertebrate groups

and

Site information

Appendix A

Table 1. List of Macroinvertebrate groups recorded for the Lower Lakes (Lake Alexandrina and Lake Albert) including functional feeding groups, SIGNAL Score, habitat type and references. The habitats sampled were from the littoral area (wetlands) and mudflats of the lakes.

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Acarina					Maximum field salinities recorded at 9.2gL (Horrigen *et al.* 2007)		
Acarina	Trombidioidae	Predators (parasites)	none	Littoral, parasitic	Parasitic on insects and other invertebrates	Amongst submerged & emergent vegetation	SKM (2004)
Acarina	Astigmata, *Histiostoma* sp.	gathering collectors?, Predators (parasites)	none	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004)
Acarina	Hydracarina, Eylaidae *Eylais* sp.	Predator	4-7	Littoral, swimmer	Feeds on small crustaceans and insect larvae. One species known to be tolerant of salinity	Amongst submerged & emergent vegetation Mudflats	SKM (2004,2006)
Acarina	Hydracarina, Hydrobatidae	Predator	4-7	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004)
Acarina	Hydrocarina, Oxidae	Predator	4-7	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004)
Acarina	Oribatida	Scrapers, shredders	none	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004,2006)
Acarina	Hydracarina, Hydrachnidae	Predators	4-7	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004)
Acarina	Mesostigmata	Predators	none	Littoral, swimmer	Prey on other mites, Dipteran larvae and insect eggs	Amongst submerged & emergent vegetation	SKM (2004)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Acarina	Halacaroidea, Pezidae, *Peza* sp.	predators, predators (parasites) shredders?	none	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004)
Acarina	Hydracarina, Unionicolidae	predators	4-7	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004, 2006)
Acarina	Hydracarina, Pionidae, *Piona* sp.	predator	4-7	Littoral, swimmer		Mudflats	SKM (2006)
Acarina	Hydracarina	predator	4-7	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004, 2006)
Amphipoda	Amphipoda spp.	shredders, scrapers, filtering collectors	3	Littoral, benthic, crawlers, swimmers,	Tolerant of salinity range of 10-60ppt (Geddes & Butler 1984; James *et al.* 2003; Geddes 2005).	Mudflat	Dittmann *et al.* (2006a,2009) ; Baring *et al.* (2009)
Amphipoda	Hyalidae (formerly Ceinidae). *Austrochiltonia australis*	shredders	2	Littoral, crawlers, swimmers	LC50 salinities recorded at 34.3gL (Dunlop *et al.* 2005).	Open water Amongst submerged & emergent vegetation Large woody debris Mudflat	Brandle (2002), SKM (2004, 2006)
Amphipoda	Corophiidae Corophiidae SA sp1.	shredders	4	Littoral, crawlers, swimmers	Considered to be salinity tolerant	Amongst submerged & emergent vegetation	Brandle (2002)
Amphipoda	Talitridae, Talitridae sp.	shredders	3	Littoral, crawlers		Open water Amongst submerged & emergent vegetation	Brandle (2002)
Amphipoda	Eusiridae, Pseudomera sp.	Shredders	7	Littoral, crawlers, swimmers		Open water Submerged vegetation Emergent vegetation Large woody debris	SKM (2004, 2006), Brandle (2002)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Bivalvia	Galeommatidae, *Arthritica helmsii*			Benthic, burrower	Tolerates a wide range of salinities, 15-45ppt; suffers mortality during prolonged conditions (e.g. several months) of high temperature and salinity (Kanangjembo *et al.* 2001)	Mudflats	Dittmann *et al.* (2006a)
Bivalvia	Unionoida, Hyriidae *Velesunio ambiuus*	Filtering collectors	5	Benthic, burrower	Prefers slow-flow,still water. Settles in mud/silt/sand. Can tolerate low DO, high temperature and long periods of desiccation. Sustainable populations are unlikely at salinities > 3.5gL (Walker 1981). Potential for bioaccumulation of pollutants.	Mudflats	Pers Obs
Bryozoan		Filtering collectors	4	Littoral		Variety of habitats	SKM (2006)
Cnidaria	Hydrazoa, Clavidae, *Cordylophora caspia*	Predators	3	Littoral, benthic, sessile	Some are known to be tolerant of salinity	Submerged vegetation Emergent vegetation Large woody debris Submerged and Emergent vegetation, mudflats	SKM (2004, 2006)
Cnidaria	Hydrazoa, Hydridae *Hydra* sp.	Predators	2	Littoral, benthic, sessile	Some sensitivity to salinity, acidity and heavy metals	Open water Submerged vegetation Emergent vegetation Large woody debris	Brandle (2002) SKM (2004, 2006)
Coleoptera	Curculionidae	Shredders	2	Littoral, crawlers, climber, sprawler		Amongst submerged & emergent vegetation Large woody debris	SKM (2004)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Coleoptera	Elmidae	Shredders (adults), scrapers (larvae)	7	Littoral, crawlers, clinger	Intolerant of saline and polluted water. Not usually found in still waters.	Amongst submerged & emergent vegetation Large woody debris	SKM (2004)
Coleoptera	Hydrophilidae, *Bersosus* sp.	Predators (larvae), Shredders (adults)	2	Littoral, pelagic, benthic, crawlers, swimmers, climbers	LC50 salinities recorded at approximately 23.8gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 28.3gL (Horrigen *et al.* 2007)	Amongst submerged & emergent vegetation Large woody debris Mudflat	SKM (2004,2006), Dittmann *et al.* (2006b)
Coleoptera	Ptiliidae	Unknown	3	Benthic?		Mudflats	Dittmann *et al.* (2006b)
Coleoptera	Dytiscidae	Predators	2	Littoral, pelagic, benthic, swimmers, divers, crawlers	LC50 salinities recorded at > 20.4gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 28.3gL (Horrigen *et al.* 2007)	Mudflats Amongst submerged & emergent vegetation	Dittmann *et al.* (2006b) SKM (2006), Baring *et al.* (2009)
Coleoptera	Staphylinidae	Predator	3	Littoral, clinger, climber, burrower	Some species have burrowing larvae	Mudflats	Baring *et al.* (2009)
Collembola			1	Littoral/surface dwelling		Mudflats	Baring *et al.* (2009)
Collembola	Entomobryidae	gathering collectors	1	Littoral/surface dwelling		Amongst submerged & emergent vegetation	SKM (2004)
Collembola	Hypogastruridaae	gathering collectors	1	Littoral/surface dwelling		Amongst submerged & emergent vegetation , Water surface	SKM (2006)
Collembola	Isotomidae	gathering collectors	1	Littoral/surface dwelling		Amongst submerged & emergent vegetation Water surface Mudflat	SKM (2004, 2006)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Collembola	Sminthuridae, *Katianna* sp.	gathering collectors	1	Littoral/surface dwelling		Submerged vegetation Emergent vegetation Large woody debris Mudflat	SKM (2004, 2006)
Decapoda						Submerged and Emergent vegetation and large woody debris	SKM (2004)
Decapoda	Atyidae, *Caridina indistincta*	Gathering collectors, filtering collectors, Predators	3	Littoral, swimmer	LC50 salinities recorded at >27.2gL for C.*wilkinsi* (Dunlop *et al.* 2008). Maximum field salinities recorded at 8.16gL (Horrigen *et al.* 2007)	Open water adjacent to emergent vegetation	Brandle (2002) SKM (2006)
Decapoda	Atyidae, *Paratya australiensis*	Gathering collectors, filtering collectors, Predators	3	Standing water, benthic and littoral areas, swimmer	Maximum field salinities recorded at 8.16gL (Horrigen *et al.* 2007)	Open water adjacent to emergent vegetation Submerged vegetation Emergent vegetation Large woody debris	Brandle (2002); SKM (2004, 2006)
Decapoda	Hymensomatidae, *Amarinus lacustris*	Gathering collectors	3	Benthic, crawler, climber, burrowers	Known to occur in slightly saline waters, salinity tolerances between 10-58ppt (Geddes & Butler 1984; James *et al.* 2003; Geddes 2005)	Submerged vegetation Emergent vegetation Large woody debris	SKM (2004)
Decapoda	Parastacidae, *Cherax* sp.	Gathering collectors, Predators	4	Benthic, burrowers	Sensitive to heavy metals e.g. copper and zinc (Skidmore & Firth 1983). LC50 salinities recorded at greater than 45gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 8.16gL (Horrigen *et al.* 2007).	Submerged vegetation Emergent vegetation Large woody debris	SKM (2004)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Diptera	Muscidae	Predators	1	Benthic, sprawler		Submerged vegetation Emergent vegetation Large woody debris	SKM (2004)
Diptera	Empididae	Predators	1	Benthic, sprawler, burrower		Submerged vegetation Emergent vegetation Large woody debris	SKM (2004)
Diptera	Ephydridae	Shredders, scrapers	2	Benthic, sprawler, burrower		Submerged vegetation Emergent vegetation Large woody debris Mudflats	SKM (2004, 2006)
Diptera	Chironomidae, Chironominae sp. *Cladotanytarsus* sp. *Paratanytarsus* sp. *Chironomus* sp. *Polypedilum* sp. *Chironomini* sp. Chironomidae sp. Orthocladiinae Tanypodinae	Gathering & filtering collectors, Predators, Shredders, Scrapers	3 - 8	Benthic, littoral, burrower	As a group are generally tolerant of poor water quality. LC50 salinities recorded at approximately 78gL (Dunlop *et al.* 2008). Have a wide pH tolerance (Fiske 1987).	Submerged vegetation Emergent vegetation Large woody debris Mudflats Open water	SKM (2004, 2006), Brandle (2002) Dittmann *et al*. (2006a, 2006b, 2009) Baring *et al*. (2009)
Diptera	Ceratopogonidae Dasyheleinae spp.	Predators, gathering collectors, scrapers	4	Benthic, littoral, sprawler, burrower		Mudflats Submerged & emergent vegetation Large woody debris	Dittmann *et al*. (2006b, 2009); SKM (2004, 2006); Baring *et al*. (2009)
Diptera	Dolichopodidae.	Predator, Shredder ?	3	Benthic, crawlers		Mudflats	Dittmann *et al*. (2006b), Baring *et al*. (2009)
Diptera	Culicidae, Culicinae	Filtering collector, Scrapers, Predators	1	Littoral, Pelagic, swimmers	Maximum field salinities recorded at 19.7gL (Horrigen *et al.* 2007)	Submerged & emergent vegetation, mudflats	SKM (2006)

Major Group	Further identification	Functional Feeding Group	SIGNAL Grade	Habitat /Habit	Special Notes	Collected from these habitats	Habitat location References
Diptera	Psychodidae	Gathering collectors	3	Benthic, burrower		Submerged and Emergent vegetation	SKM (2004)
Diptera	Sciomyzidae	Predators, Parasites	2	Littoral, burrower	Maximum field salinities recorded at 11.5gL (Horrigen *et al.* 2007)	Submerged & emergent vegetation	SKM (2004,2006)
Diptera	Stratiomyidae	Gathering collectors	2	Littoral, swimmer, sprawler		Submerged & emergent vegetation	SKM (2004)
Ephemeroptera	Baetidae, *Cloeon* sp.	Scrapers, Gathering collectors	5	Benthic, Littoral, crawler, swimmer, clinger	Toxicity of heavy metals (iron and lead) due to freshwater acidification has been studied in Ephemeroptera species by Gerhardt & Palmer (1998). LC50 salinities recorded between 3.74 and 5.4gL (Kefford *et al.* 2004). Maximum field salinities recorded at 8gL (Horrigen *et al.* 2007).	Submerged & emergent vegetation Large woody debris Mudflats	SKM (2004,2006)
Ephemeroptera	Caenidae	Gathering collectors	4	Benthic, Littoral, crawlers, sprawler	Salinity tolerances approximately 8gL (Horrigen *et al.* 2007; Dunlop *et al.* 2008).	Submerged and Emergent vegetation and large woody debris	SKM (2004)
Ephemeroptera	Leptophlebiidae	Scrapers, shredders	8	Littoral, benthic, crawlers, swimmer, clinger	Single specimen collected at Teringie. LC50 salinities recorded at greater than 5.4gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 2.7gL (Horrigen *et al.* 2007).	mudflats	Baring *et al.* (2009)
Gastropoda	Hypsogastropoda, Bithynidae	Scrapers	3	Littoral, crawler	Tolerant of mild salinities	Submerged and Emergent vegetation	SKM (2004)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Gastropoda	Hygrophila, Ancylidae, *Ferrissia* sp.	Scrapers	4	Littoral, crawler	Freshwater limpets have been shown to accumulate heavy metals, such as copper (Gerhardt & Palmer, 1998). Have been found in pH of 4.75 (Fiske 1987).	Submerged vegetation Emergent vegetation Large woody debris	SKM (2004, 2006)
Gastropoda	Hypsogastropoda, Hydrobiidae	Scrapers	4	Littoral, crawler	Maximum field salinities recorded at 25.4gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SKM (2004)
Gastropoda	Hygrophila, Lymnaeidae, *Austroplea* sp.	Scrapers	1	Littoral, crawlers		Variety of habitats	SKM (2006)
Gastropoda	Hygrophila, Physidae, *Physa acuta*	Scrapers	1	Littoral, crawler	Maximum field salinities recorded at 3.3gL (Horrigen *et al.* 2007)	Submerged vegetation Emergent vegetation Large woody debris Mudflats	SKM (2004, 2006) Dittmann *et al.* (2006a)
Gastropoda	Hygrophila, Planorbidae, *Pygmanisus* sp. Glyptophysa sp.	Scrapers	2	Littoral, crawler	Maximum field salinities recorded at 9.3gL (Horrigen *et al.* 2007)	Submerged vegetation Emergent vegetation Large woody debris Open water	SKM (2004, 2006) Brandle (2002)
Hemiptera	Notonectidae Notonectidae sp.	Predators	1	Littoral, pelagic, swimmers	LC50 salinities recorded at approximately 10gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 12gL (Horrigen *et al.* 2007).	Mudflats Submerged vegetation Emergent vegetation Large woody debris	Dittmann *et al.* (2006a) SKM (2004, 2006)
Hemiptera	Belastomatidae	Predators, piercers	1	Littoral, swimmers, climbers	LC50 salinities recorded at greater than 23.8gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 1.2gL (Horrigen *et al.* 2007).	Submerged vegetation Emergent vegetation Large woody debris	SKM (2004)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Hemiptera	Corixidae *Sigara* sp *Agraptocorix*a sp. *Micronecta robusta* *Micronecta annae* *Micronecta* spp	Predators. Macrophyte piercers	2	Littoral, pelagic, swimmers	LC50 salinities recorded at approximately 10gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 12gL (Horrigen *et al.* 2007).	Open water Mudflats Submerged vegetation Emergent vegetation Large woody debris	Brandle (2002) Dittmann *et al.* (2006b) SKM (2004, 2006), Baring *et al.* (2009)
Hemiptera	Hebridae	Predators	3	Littoral, surface swelling striders		Submerged vegetation Emergent vegetation Large woody debris	SKM (2004)
Hemiptera	Mesoveliidae	Predators	2	Littoral, skater		Submerged vegetation Emergent vegetation Large woody debris	SKM (2004)
Hemiptera	Naucoridae	Predators	2	Littoral, clingers, crawlers, swimmers	LC50 salinities recorded at greater than 13.6gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 4.1gL (Horrigen *et al.* 2007)	Submerged vegetation Emergent vegetation Large woody debris	SKM (2004)
Hemiptera	Pleidae, *Paraplea* sp.	Predators	2	Littoral, swimmers, crawlers	LC50 salinities recorded at greater than 13.6gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 8gL (Horrigen *et al.* 2007).	Submerged vegetation Emergent vegetation Large woody debris	SKM (2004)
Hemiptera	Veliidae Veliidae sp. *Microvelia* sp.	Predators, Scavengers	3	Littoral, skater		Mudflats Submerged vegetation Emergent vegetation Large woody debris	Dittmann *et al.* (2006b) SKM (2004, 2006)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Hirudinea	Glossiphoniidae	Predators	1	Littoral, benthic, crawler		Submerged Emergent vegetation	SKM (2004)
Isopoda		Shredders, Predators (parasites)	3	Littoral, benthic, sprawler		Mudflats	Dittmann *et al*. (2006a)
Isopoda	Janiridae	Shredders	2	Littoral, benthic, sprawler		Submerged and Emergent vegetation	SKM (2004)
Lepidoptera	Crambidae (formerly Pyralidae)	Shredders	2	Littoral, climber, swimmer		Submerged vegetation Emergent vegetation	SKM (2004)
Nematoda	Nematoda spp.	Predators	3	Littoral, benthic, crawlers	Nematodes are normally extremely resilient and tolerant of reducing environments (Hodda and Nicholas 1985). Nematodes don't rapidly migrate from stressful conditions as many species can survive stress (e.g. dehydration and oxygen) (Bongers and Ferris 1999).	Open water Submerged vegetation Emergent vegetation Large woody debris Mudflats	Brandle (2002) SKM (2004, 2006), Bird (1995), Nicholas (1993)
Nemertea		Predators, Gathering collectors	3	Littoral, benthic, crawlers		Submerged and Emergent vegetation	SKM (2004)
Odonata	Aeschnidae	Predators	4	Littoral, Benthic, climber, swimmer		Submerged vegetation Emergent vegetation Large woody debris	SKM (2004)
Odonata	Coenagrionidae Coenagrionidae sp.	Predators	2	Littoral, Benthic, crawlers, swimmers	Maximum field salinities recorded at 28.4gL (Horrigen *et al*. 2007).	Submerged vegetation Emergent vegetation Large woody debris Mudflats	SKM (2004, 2006) Dittmann *et al*. (2006b), Baring *et al*. (2009)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Odonata	Lestidae, *Austrolestes annulosa*	Predators	1	Littoral, Benthic, climber, swimmer		Open water Submerged vegetation Emergent vegetation Large woody debris	Brandle (2002), SKM (2004, 2006)
Odonata	Zygoptera	Predators		Littoral, Benthic, climber, swimmer	LC50 salinities recorded at greater than 13.6gL (Dunlop *et al.* 2008)	Submerged vegetation Emergent vegetation Large woody debris	SKM (2004)
Odonata	Libellulidae	Predators	1-4	Littoral, Benthic, climber, swimmer	Maximum field salinities recorded at 10.3gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SKM (2004)
Odonata	Hemicorduliidae *Hemicordulia* sp.	Predators	5	Littoral, Benthic, climber, swimmer	Maximum field salinities recorded at 9.3gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SMK (2006)
Oligochaeta		Gathering collectors	2	Benthic, burrowers	Have a highly variable salinity tolerance (Giere 2006). May resuspend / swim in the water column to migrate to more favourable areas (Nilsson *et al.* 2000)	Mudflats Submerged and Emergent vegetation	Dittmann *et al.* (2006a, 2009), SKM (2004, 2006); Baring *et al.* (2009)
Oligochaeta	Naididae, *Chaetogaster* sp.	Gathering collectors	2	Benthic	Some species of *Chaetogaster* are carnivorous.	Open water adjacent to emergent vegetation	Brandle (2002)
Oligochaeta	Tubificidae, Tubificidae spp.	Gathering collectors	2	Benthic, burrowers		Open water adjacent to emergent vegetation	Brandle (2002)
Plectoptera			10		Not tolerant of salinity. Single specimen collected at Teringie. Salinity tolerances between 8.5 and 13.6gL (Kefford *et al.* 2004)	Mudflat	Baring *et al.* (2009)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Polychaeta	Spionidae *Boccardiella novaehollandiae*		1	Benthic	Tolerant of a salinity range between 25 and 45ppt	Mudflat	Geddes 2005; Dittmann *et al*. (2009); Baring *et al* (2009)
Polychaeta	Capitellidae, *Capitella* sp.	Gathering collectors	1	Benthic	This family contains species that are tolerant of salinity, and can adapt to low DO. Salinity tolerances between 10-55ppt.	Mudflats	Dittmann *et al*. (2006a, 2009); Baring *et al*. (2009)
Polychaeta	Nereididae *Simplisetia aequisetis*		1	Bethic	This family contains species that are tolerant of salinity. Reported in salinities between 16 and 35ppt and occurrence in subtidal sediment of the Coorong in salinities up to 70ppt.	Mudflats	Baring *et al*. (2009)
Trichoptera					Salinity tolerances range between 6.1 and 26.2gL (Kefford *et al.* 2004). Generally tolerant of low pH thev been recorded in pH of 2.45 (Fiske 1987)		
Trichoptera	Ecnomidae	Predators, Gathering collectors	4	Benthic, clinger	LC50 salinities recorded at 10.88gL (Dunlop *et al.* 2005).	Submerged vegetation Emergent vegetation	SKM (2004, 2006)
Trichoptera	Hydroptilidae	Scrapers, Predators, Piercers	4	Littoral, benthic, clinger, climber	Found in water at pH less than 3.6 (Winterbourn 1998).	Submerged vegetation Emergent vegetation	SKM (2004, 2006)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL Grade**	**Habitat /Habit**	**Special Notes**	**Collected from these habitats**	**Habitat location References**
Trichoptera	Leptoceridae	Shredders, Scrapers, Predators, gathering collectors	6	Littoral, benthic, climber, clinger, swimmer, sprawler	LC50 salinities recorded at greater than 13.6gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 12gL (Horrigen *et al.* 2007).	Submerged vegetation Emergent vegetation Mudflats	SKM (2004, 2006), Baring *et al*. (2009)
Tricladia	Temnocephalida Temnocephalidae	Predators (parasites)	5	Parasitic, crawler		Submerged and Emergent vegetation	SKM (2004)
Tricladia	Turbellaria Dugesiidae	Predators	2	Littoral, Benthic, crawler, swimmer	LC50 salinities recorded at greater than 6.8gL (Dunlop *et al.* 2008)	Submerged vegetation Emergent vegetation Large woody debris Mudflats	SKM (2004,2006)

**General notes: pH can have direct toxic effects on shredders because of osmotic stress or indirect effects as a result of the toxicity of heavy metals, particularly aluminum, which become soluble at low pH (Griffith and Perry 1993)

Table 2. List of Macroinvertebrate groups recorded for the Lower River Murray, below Lock 1, including functional feeding groups, SIGNAL Score, habitat type and references.

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL grade**	**Habitat /Habit**	**Special notes**	**Collected from these habitats**	**Habitat location References**
Acarina					Maximum field salinities recorded at 9.2gL (Horrigen *et al*. 2007)		
Acarina	Halacaroidea, Pezidae *Peza* sp. Elyaidae	Predator	none	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004, 2006) Goonan *et al*. (1992)
Acarina	Hydracarina, Pionidae *Piona* sp.	Predator	4-7	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004)
Acarina	Orbatida	Scrapers	none	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004), (2006)
Acarina	Trombidioidae	Predators (parasites)	none	Littoral, parasitic	Parasitic on insects and other invertebrates	Amongst submerged & emergent vegetation	SKM (2004, 2006)
Acarina	Astigmata *Histiostoma* sp.	gathering collectors, Predators (parasites)	none	Littoral, swimmer		Amongst submerged & emergent vegetation	SKM (2004, 2006)
Acarina	Mesostigma Ascidae	Predators (parasites)	none	Littoral, swimmer	Preys on other mites, Dipteran larvae and insect eggs	Amongst submerged & emergent vegetation	SKM (2006)
Amphipoda					Tolerant of salinity range of 10-60ppt (Geddes & Butler 1984; James *et al*. 2003; Geddes 2005).		

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL grade**	**Habitat /Habit**	**Special notes**	**Collected from these habitats**	**Habitat location References**
Amphipoda	Hyalidae (formerly Ceinidae) *Austrochiltonia* sp.	Shredders	2	Littoral, crawlers, swimmers	LC50 salinities recorded at 34.3gL (Dunlop *et al.* 2005).	Amongst submerged & emergent vegetation Large woody debris	SKM (2004, 2006)
Amphipoda	Eusiridae *Pseudomera* sp.	Shredders	7	Littoral, crawlers, swimmers		Amongst submerged & emergent vegetation Large woody debris	SKM (2004, 2006)
Bivalvia	Corbiculidae	filtering collectors	4	Benthic, burrower		Amongst submerged & emergent vegetation	SKM (2004), (2006)
Bryozoa		Filtering collector	4	Littoral, sessile		Submerged and Emergent vegetation and large woody debris	SKM (2006)
Cnidaria	Hydrazoa Hydridae, *Hydra* sp.	Predators	2	Littoral, sessile	Some sensitivity to salinity, acidity and heavy metals	Amongst submerged & emergent vegetation large woody debris	SKM (2004, 2006)
Cnidaria	Hydrazoa Clavidae *Cordylophora* ap.	Predators	3	Littoral, sessile	Some are known to be tolerant of salinity	Amongst submerged & emergent vegetation large woody debris	SKM (2004, 2006)
Coleoptera	Hydrophilidae *Berosus* sp.	Predators (larvae) Shredders (adults)	2	Littoral, benthic, crawlers, swimmers	LC50 salinities recorded at approximately 23.8gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 28.3gL (Horrigen *et al.* 2007)	Submerged vegetation Emergent vegetation	SKM (2004, 2006), Goonan *et al.* (1992)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL grade**	**Habitat /Habit**	**Special notes**	**Collected from these habitats**	**Habitat location References**
Coleoptera	Dytiscidae	Predators	2	Littoral, crawlers, swimmers, divers	LC50 salinities recorded at > 20.4gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 28.3gL (Horrigen *et al.* 2007)	Submerged vegetation Emergent vegetation Large woody debris	SKM (2004, 2006)
Coleoptera	Hydraenidae	Scrapers (adults) Predators (larvae)	3	Littoral, clingers		Submerged vegetation Emergent vegetation Large woody debris	SKM (2004, 2006); Goonan *et al*. (1992)
Coleoptera	Curculionidae	Shredders	2	Littoral, crawlers		Amongst submerged & emergent vegetation	SKM (2004, 2006)
Coleoptera	Scirtidae	filtering collectors (larvae)	6	Littoral, crawlers, climbers		Amongst submerged & emergent vegetation	SKM (2004)
Coleoptera	Hydrochidae, *Hydrochus* sp.	Shredders (adults) unknown (larvae)	4	Littoral, climbers		Amongst submerged & emergent vegetation	Goonan *et al*. (1992)
Collembola	Sminthuridae *Katianna* sp.	gathering collectors	1	Littoral/surface dwelling		Amongst submerged & emergent vegetation large woody debris	SKM (2004, 2006)
Collembola	Hypogasturidae	gathering collectors	1	Littoral/surface dwelling		Amongst submerged & emergent vegetation large woody debris	SKM (2004, 2006)
Decapoda	Atyidae *Paratya* sp. *Caridina* sp.	Predators gathering collectors filtering collectors	3	Littoral, benthic	LC50 salinities recorded at > 27.2gL for *C.wilkinsi* (Dunlop *et al.* 2008). Maximum field salinities recorded at 8.16gL (Horrigen *et al.* 2007)	Amongst submerged & emergent vegetation large woody debris	SKM (2004, 2006); Goonan *et al*.(1992)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL grade**	**Habitat /Habit**	**Special notes**	**Collected from these habitats**	**Habitat location References**
Decapoda	Parastacidae *Cherax* sp.	gathering collectors Predators	4	Burrowers, crawlers	Sensitive to heavy metals e.g. copper and zinc (Skidmore & Firth 1983). LC50 salinities recorded at greater than 45gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 8.16gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SKM (2004)
Decapoda	Palaemonidae *Macrobrachium australiense*	gathering collectors	4	Littoral, Benthic, crawlers, swimmers		Amongst submerged & emergent vegetation large woody debris	SKM (2004, 2006); Goonan *et al*.(1992)
Diptera	Ceratopogonidae, Ceratopogoninae Dasyheleinae	gathering collectors Predators Scrapers	4	Littoral, benthic, burrowers, planktonic, sprawlers		Amongst submerged & emergent vegetation large woody debris	SKM (2004, 2006); Goonan *et al*.(1992)
Diptera	Chironomidae Chironominae Orthocladiinae Tanypodinae	gathering collectors Predators Shredders Scrapers	3-8	Littoral, benthic, burrowers	LC50 salinities recorded at approximately 78gL (Dunlop *et al.* 2008). Have a wide pH tolerance (Fiske 1987).	Amongst submerged & emergent vegetation large woody debris	SKM (2004, 2006); Goonan *et al*.(1992)
Diptera	Dolichopipodidae	Predators Shredders?	3	Benthic, crawlers		Amongst submerged & emergent vegetation large woody debris	SKM (2004)
Diptera	Muscidae	Predators	1	Benthic, sprawler		Submerged and Emergent vegetation and large woody debris	SKM (2004)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL grade**	**Habitat /Habit**	**Special notes**	**Collected from these habitats**	**Habitat location References**
Diptera	Stratiomyidae	gathering collectors	2	Littoral, sprawler, swimmers		Submerged and Emergent vegetation and large woody debris	SKM (2004); Goonan *et al*.(1992)
Diptera	Culicidae	Filtering Collectors Scrapers Predators	1	Littoral, pelagic, swimmers	Tolerant of low dissolved oxygen and salinity. Maximum field salinities recorded at 19.7gL (Horrigen *et al.* 2007)	Submerged and Emergent vegetation and large woody debris	SKM (2004), Goonan *et al*.(1992)
Diptera	Ephydridae	Shredders, Scrapers		Benthic, sprawler, burrowers,		Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006)
Diptera	Psychodidae	gathering collectors	3	Benthic, burrowers		Submerged and Emergent vegetation	SKM (2004)
Diptera	Tipulidae	Shredders, Gathering collectors , Predators	5	Benthic, burrowers		Submerged and Emergent vegetation	SKM (2004)
Diptera	Empididae	Predators	1	Benthic, sprawler, burrowers		Submerged and Emergent vegetation	SKM (2004)
Diptera	Sciomyidae	Predators, Parasites	2	Littoral, burrowers	Maximum field salinities recorded at 11.5gL (Horrigen *et al.* 2007)	Submerged and Emergent vegetation	Goonan *et al.* (1992)

Major Group	Further identification	Functional Feeding Group	SIGNAL grade	Habitat /Habit	Special notes	Collected from these habitats	Habitat location References
Ephemeroptera	Baetidae, *Cloeon* sp.	Scrapers Gathering Collectors	5	Benthic, littoral, crawlers, swimmers, clinger	Toxicity of heavy metals (iron and lead) due to freshwater acidification has been studied in Empheroptera species by Gerhardt & Palmer (1998). LC50 salinities recorded between 3.74 and 5.4gL (Kefford *et al.* 2003). Maximum field salinities recorded at 8gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006) Goonan *et al*. (1992)
Ephemeroptera	Caenidae *Tasmanocoenis* sp.	Gathering Collectors	4	Benthic, crawlers, swimmers, sprawler	Salinity tolerances approximately 8gL (Horrigen *et al.* 2007; Dunlop *et al.* 2008).	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006); Goonan *et al*. (1992)
Gastropoda	Hypsogastropoda, Bithynidae	Scrapers	3	Littoral, crawlers	Tolerant of mild salinities	Submerged and Emergent vegetation and large woody debris	SKM (2004)
Gastropoda	Hypsogastropoda, Hydrobiidae *Potomopyrgus niger*	Scrapers	4	Littoral, crawlers	Maximum field salinities recorded at 25.4gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SKM (2004), Goonan *et al*. (1992)
Gastropoda	Hygrophila, Physidae, *Physa* sp.	Scrapers	1	Littoral, crawlers	Maximum field salinities recorded at 3.3gL (Horrigen *et al.* 2007)	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL grade**	**Habitat /Habit**	**Special notes**	**Collected from these habitats**	**Habitat location References**
Gastropoda	Hygrophila, Planorbidae, *Isidorella newcombi*	Scrapers	2	Littoral, crawlers		Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006); Goonan *et al*. (1992)
Gastropoda	Hygrophila, Ancylidae *Ferrissia* sp.	Scrapers	4	Littoral, crawlers	Freshwater limpets have been shown to accumulate heavy metals, such as copper (Gerhardt & Palmer, 1998). Have been found in pH of 4.75 (Fiske 1987).	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006)
Hemiptera	Corixidae *Agraptocorixa* sp. *Micronecta* sp. *Sigara* sp.	Predators Macrophyte peircers	2	Littoral, pelagic, swimmers	LC50 salinities recorded at approximately 10gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 12gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006); Goonan *et al*. (1992)
Hemiptera	Mesoveliidae *Mesovelia* sp.	Predators	2	Littoral, skaters		Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006)
Hemiptera	Notonectidae Anisops sp.	Predators, Peircer	1	Littoral, pelagic, swimmers	LC50 salinities recorded at approximately 10gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 12gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006)
Hemiptera	Veliidae	Predators Scavengers	3	Littoral, surface dwelling striders		Submerged and Emergent vegetation and large woody debris	SKM (2004)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL grade**	**Habitat /Habit**	**Special notes**	**Collected from these habitats**	**Habitat location References**
Hemiptera	Belastomatidae	Predators, piercers	1	Littoral, swimmers, climbers		Submerged and Emergent vegetation and large woody debris	SKM (2004)
Hemiptera	Naucoridae, *Naucoris* sp.	Predators	2	Littoral, clingers, crawlers, swimmers	LC50 salinities recorded at greater than 13.6gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 4.1gL (Horrigen *et al.* 2007)	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006)
Hemiptera	Pleidae *Paraplea* sp.	Predators	2	Littoral, swimmers, crawlers	LC50 salinities recorded at greater than 13.6gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 8gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SKM (2004)
Hemiptera	Hebridae *Merragata* sp.	Predators	3	Littoral, skaters		Submerged & emergent vegetation	SKM (2006)
Hemiptera	Hydrometridae *Hydrometra* sp.	Predators Scavengers	3	Littoral, skaters		Submerged & emergent vegetation	Goonan *et al*. (1992)
Hemiptera	Nepidae *Ranatra* sp.	Predators	3	Littoral, climbers, crawler		Submerged & emergent vegetation	SKM (2006)
Hirudinae	Glossiphoniidae	Predator	1	Littoral, benthic, crawlers, suckers		Submerged & emergent vegetation and large woody debris	SKM (2004)
Isopoda	Janiridae *Heterias* sp.	Shredders	2	Littoral, crawlers, sprawler		Submerged & emergent vegetation and large woody debris	SKM (2004)
Isopoda	Corallanidae *Tachaea* sp.	Predators (parasites)	2	Littoral, benthic		Submerged and Emergent vegetation	SKM (2006)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL grade**	**Habitat /Habit**	**Special notes**	**Collected from these habitats**	**Habitat location References**
Lepidoptera	Crambidae (formerly Pyralidae)	Shredders		Littoral, crawlers, swimmer		Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006); Goonan *et al*. (1992)
Nematoda		Predators	3	Littoral, benthic, crawlers, parasites	Nematodes are normally extremely resilient and tolerant of reducing environments (Hodda and Nicholas 1985). Nematodes don't rapidly migrate from stressful conditions as many species can survive stress (e.g. dehydration & oxygen) (Bongers and Ferris 1999).	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006)
Nemertea		Predators Gathering collectors	3	Littoral, crawlers		Submerged and Emergent vegetation and large woody debris	SKM (2004)
Odonata	Libellulidae *Diplacodes* sp.	Predators	1 – 4	Littoral, Benthic, crawlers, swimmers	Maximum field salinities recorded at 10.3gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation	SKM (2006)
Odonata	Aeschnidae *Hemianxa* sp.	Predators	4	Littoral, Benthic, crawlers, swimmers		Submerged and Emergent vegetation and large woody debris	SKM (2004, (2006)
Odonata	Coenagrionidae	Predators	2	Littoral, Benthic, crawlers, swimmers	Maximum field salinities recorded at 28.4gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006)
Odonata	Hemicorduliidae	Predators	5	Littoral, Benthic, crawlers, swimmers	Maximum field salinities recorded at 9.3gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SKM (2004)

Major Group	**Further identification**	**Functional Feeding Group**	**SIGNAL grade**	**Habitat /Habit**	**Special notes**	**Collected from these habitats**	**Habitat location References**
Odonata	Lestidae	Predators	1	Littoral, Benthic, crawlers, swimmers		Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006)
Oligochaeta		Gathering collectors	2	Benthic, burrowers	Have a highly variable salinity tolerance (Giere 2006). May re-suspend/swim in the water column to migrate to more favourable areas (Nilsson *et al.* 2000)	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006); Goonan *et al*. (1992)
Trichoptera	Hydroptilidae *Orthotrichia* sp. *Hellyethira* sp. *Hydroptila* sp.	Scrapers Predators	4	Littoral, benthic, clinger, climber	Found in water at pH less than 3.6 (Winterbourn 1998).	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006); Goonan *et al*. (1992)
Trichoptera	Leptoceridae *Oecetis* sp. *Trienodes* sp. *Triplectides* sp.	Shredders Scrapers Predators	6	Benthic, littoral, climber, clinger, swimmer, sprawler	LC50 salinities recorded at greater than 13.6gL (Dunlop *et al.* 2008). Maximum field salinities recorded at 12gL (Horrigen *et al.* 2007).	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006); Goonan *et al*. (1992)
Trichoptera	Ecnomidae *Ecnomus* sp.	Predators Gathering Collectors	4	Benthic, clinger	LC50 salinities recorded at 10.88gL (Dunlop *et al.* 2005).	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006); Goonan *et al*. (1992)
Tricladia	Temnocephalidae	Predators (parasites)	5	Ectocommensal. Parasitic, crawler		Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006)
Tricladia	Turbellaria Dugesiidae	Predators	2	Littoral, benthic, glides over surfaces	LC50 salinities recorded at greater than 6.8gL (Dunlop *et al.* 2008)	Submerged and Emergent vegetation and large woody debris	SKM (2004, 2006)

Table 3. Summary table for invertebrate sampling within the CLLMM region, highlighting sites surveyed within the Lower Lakes.

Year of Survey	Total no. of sites - Lower Lakes	Sites located in Lake Alexandrina	Sites located in Lake Albert	Habitat sampled	Reference
2002	5	5	0	Wetlands	Brandle (2002)
2003	5	4	1	Wetlands	SKM (2004)
2004	5	5	0	Mudflat	Dittmann *et al.* (2006b)
2005	1	1	0	Mudflat	Dittmann *et al.* (2006a)
2005	4	4	0	Wetlands	SKM (2006)
2006	0	0	0	Mudflat	Dittmann & Nelson (2006)
2007	0	0	0	Mudflat	Dittmann *et al.* (2008a)
2008	20	16	4	Mudflats	Baring *et al.* (2009)
2008/2009	2	2	0	Mudflats and littoral zone	Dittmann *et al.* (2009a)

Table 4. Species richness as recorded by total number of taxa for wetland sites in the Lower Lakes and Lower River Murray (green shading = wetlands, blue shading = mudflats - sediment samples)

Total no. of taxa	***Location***	***Region***	***Reference***
18	Point Sturt	Lower Lakes (Alexandrina)	SKM (2006)
20	Loveday Bat	Lower Lakes (Alexandrina)	SKM (2006)
20	Poltalloch	Lower Lakes (Alexandrina)	SKM (2006)
40	Pelican Lagoon	Lower Lakes (Alexandrina)	SKM (2006)
37	Rocky Gully	Lower River Murray	SKM (2006)
37	Reedy Creek	Lower River Murray	SKM (2006)
35	Younghusband	Lower River Murray	SKM (2006)
38	Lake Cartlet	Lower River Murray	SKM (2006)
21	Sweeney’s Lagoon	Lower River Murray	SKM (2006)
31	Murrundi	Lower River Murray	SKM (2006)
33	Tolderol	Lower Lakes (Alexandrina)	SKM (2004)
47	Hindmarsh Island	Lower Lakes (Goolwa Channel)	SKM (2004)
29	Clayton	Lower Lakes (Goolwa Channel)	SKM (2004)
21	Waltowa	Lower Lakes (Albert)	SKM (2004)
47	Milang Shores	Lower Lakes (Alexandrina)	SKM (2004)
24	Paiwalla	Lower River Murray	SKM (2004)
34	Swanport	Lower River Murray	SKM (2004)
45	Riverglades	Lower River Murray	SKM (2004)
42	North Purnong	Lower River Murray	SKM (2004)
35	Forsters Lagoon	Lower River Murray	SKM (2004)
35	Kroehns Landing	Lower River Murray	SKM (2004)
30	Devon Downs South	Lower River Murray	SKM (2004)
30	Lake Cartlet	Lower River Murray	Goonan *et al*. (1992)
23	Wongulla Lagoon	Lower River Murray	Goonan *et al*. (1992)
25	Devon Downs North	Lower River Murray	Goonan *et al*. (1992)
22	Hindmarsh Island	Lower Lakes	Brandle (2002)

Total no. of taxa	***Location***	***Region***	***Reference***
3	Site 9 (Tolderol)	Lower Lakes (Alexandrina)	**Dittmann *et al.* (2006a)**
19	Site 8 (Clayton)	Lower Lakes (Alexandrina)	**Dittmann *et al.* (2006b)**
7	Site 9 (Tolderol)	Lower Lakes (Alexandrina)	**Dittmann *et al.* (2006b)**
7	Site 10 (Mulgundawa)	Lower Lakes (Alexandrina)	**Dittmann *et al.* (2006b)**
12	Site 11(Pelican Lagoon)	Lower Lakes (Alexandrina)	**Dittmann *et al.* (2006b)**
12	Site 12 (Point Sturt)	Lower Lakes (Alexandrina)	**Dittmann *et al.* (2006b)**
6	Currency Creek Mouth	Lower Lakes (Goolwa Channel)	**Dittmann *et al.* (2009a)**
10	Finnis River Mouth	Lower Lakes (Goolwa Channel)	**Dittmann *et al.* (2009a)**
5	L16 (Mundoo Channel)	Lower Lakes (Alexandrina)	**Baring *et al.* (2009)**
6	L17 (Ewe Island)	Lower Lakes (Alexandrina)	**Baring *et al.* (2009)**
5	L6 (Pelican Point)	Lower Lakes (Alexandrina)	**Baring *et al.* (2009)**
9	L10 (Terengie)	Lower Lakes (Alexandrina)	**Baring *et al.* (2009)**
7	L9 (Narung)	Lower Lakes (Alexandrina)	**Baring *et al.* (2009)**
6	L4 (Milang)	Lower Lakes (Alexandrina)	**Baring *et al.* (2009)**
4	L5 (Poltalloch)	Lower Lakes (Alexandrina)Lower Lakes	**Baring *et al.* (2009)**
3	L3 (Tolderol)	Lower Lakes (Alexandrina)	**Baring *et al.* (2009)**
6	L15 (Eckerts Rd)	Lower Lakes (Alexandrina)	**Baring *et al.* (2009)**
6	L18 (Boggy Lake)	Lower Lakes (Alexandrina)	**Baring *et al.* (2009)**
5	L11 (Loveday)	Lower Lakes (Alexandrina)	**Baring *et al.* (2009)**
2	L13 (Seacombes)	Lower Lakes (Albert)	**Baring *et al.* (2009)**
3	L14 (Lake Albert Station)	Lower Lakes (Albert)	**Baring *et al.* (2009)**
5	L8 (Waltona)	Lower Lakes (Albert)	**Baring *et al.* (2009)**
8	L12 (Vanderbrink)	Lower Lakes (Albert)	**Baring *et al.* (2009)**
5	L1 (Goolwa)	Lower Lakes (Goolwa Channel)	**Baring *et al.* (2009)**
3	L7 (Hindmarsh Island)	Lower Lakes (Goolwa Channel)	**Baring *et al.* (2009)**
8	L2 (Clayton)	Lower Lakes (Goolwa Channel)	**Baring *et al.* (2009)**
6	Currency Creek Mouth	Lower Lakes (Goolwa Channel)	**Baring *et al.* (2009)**
4	Finniss River mouth	Lower Lakes (Goolwa Channel)	**Baring *et al.* (2009)**

Appendix B

Examples of Conceptual Models

Appendix B. Examples of Conceptual Models

Figure 1B. Draft conceptual model for aquatic invertebrates developed by the Trinity River Restoration Program (2005)

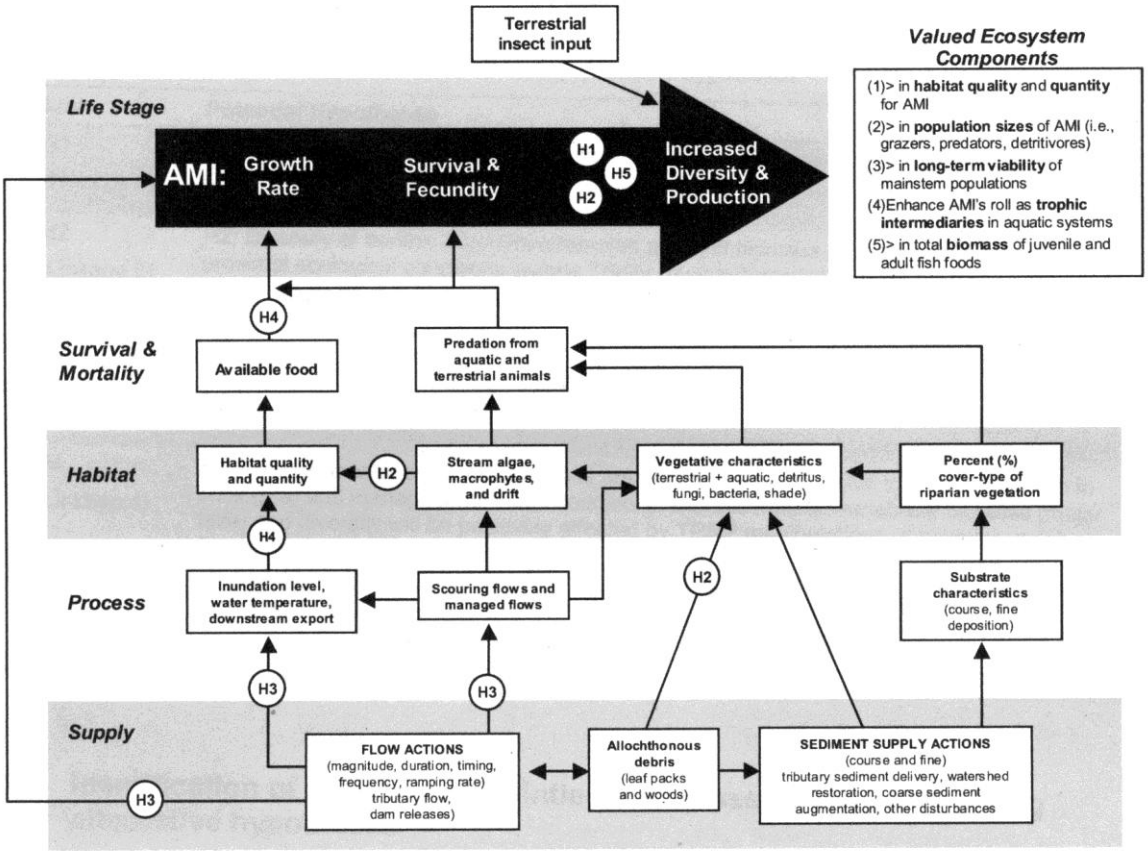

Figure 2B. Conceptual model developed for the invertebrate emergence and survivorship in the Coorong by the Murray Darling Basin Commission (MDBC, 2006)

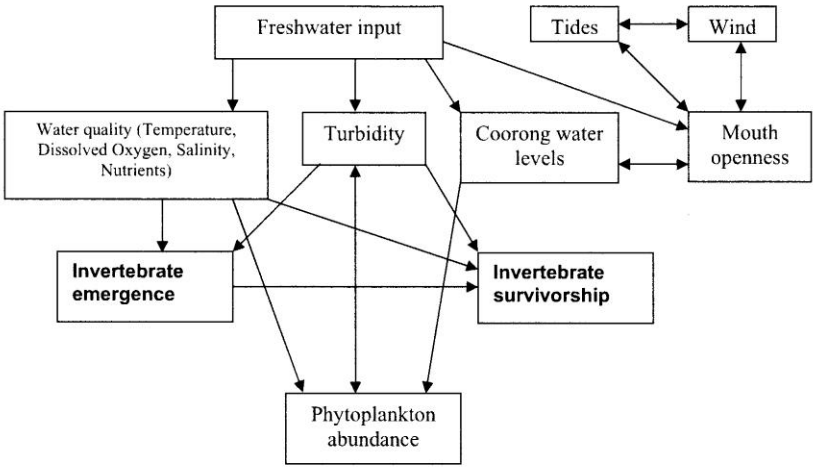

Figure 3B. Example of conceptual diagram for a wetland in Lake Albert by Souter (2009)

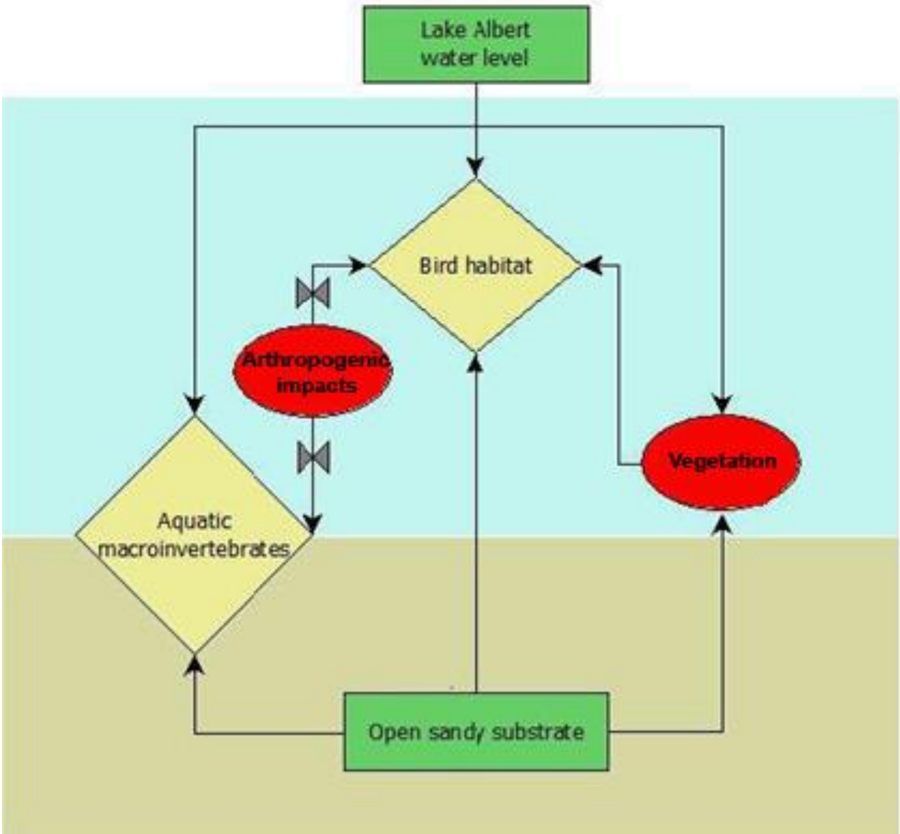

Figure 4B. Example of a generic conceptual model for an aquatic ecosystem from Suter (1996)

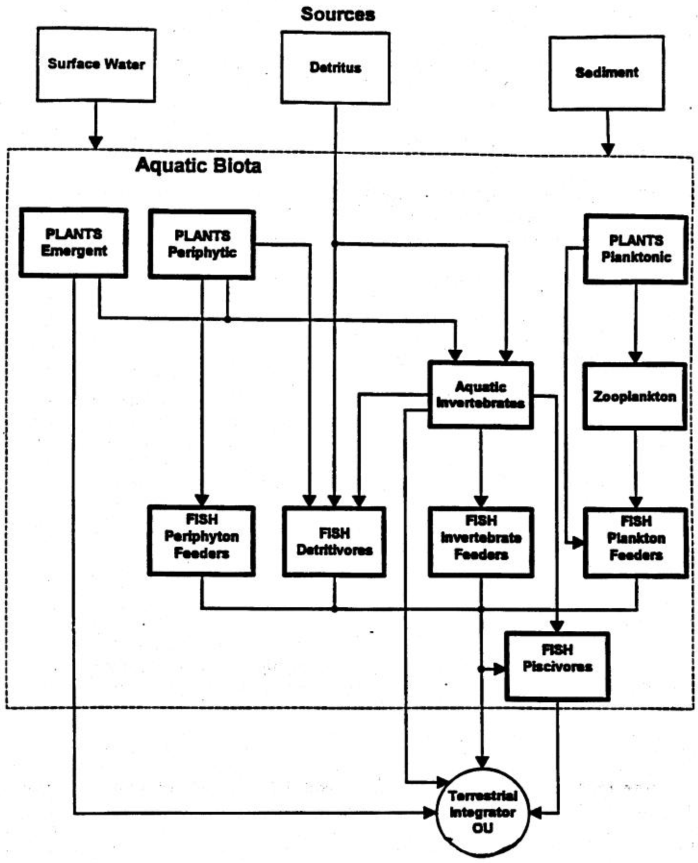

Fig. 5. Generic conceptual model for aquatic biota.