ECOLOGICAL CHARACTER DESCRIPTION OF THE MUIR-BYENUP SYSTEM RAMSAR SITE SOUTH-WEST WESTERN AUSTRALIA

Report Prepared for Department of Environment and Conservation, 2009

CENRM Report: CENRM085

Centre of Excellence in Natural Resource Management
The University of Western Australia

Department of Environment and Conservation
Our environment, our future

Australian Government

TITLE: **Ecological Character Description of the Muir-Byenup System Ramsar Site South-west Western Australia: Report prepared for the Department of Environment and Conservation**

PRODUCED BY: **CLAIRE FARRELL AND BARBARA COOK**

Centre of Excellence in Natural Resource Management
The University of Western Australia
Unit 1, Proudlove Parade, Albany, 6332
Telephone: (08) 9842 0839
Fax: (08) 9842 8499
Email: cfarrell@cyllene.uwa.edu.au

PRODUCED FOR: **DEPARTMENT OF ENVIRONMENT AND CONSERVATION**
17 Dick Perry Avenue
Technology Park, Western Precinct
Kensington WA 6151

CONTACT: **MICHAEL COOTE**

DATE: **SEPTEMBER 2009**

PUBLICATION DATA: **Farrell, C. and Cook, B. 2009. Ecological Character Description of the Muir-Byenup System Ramsar Site South-west Western Australia: Report prepared for the Department of Environment and Conservation, CENRM085. Centre of Excellence in Natural Resource Management, University of Western Australia. September 2009.**

ACKNOWLEDGEMENTS

Funding for the development of this document was sourced jointly from the Natural Heritage Trust (NHT) and the State and Commonwealth contributions to the National Action Plan for Salinity and Water Quality (NAP). NHT and NAP are jointly administered by the Australian Government departments of Agriculture, Fisheries and Forestry and the Environment, Water, Heritage and the Arts and the WA Natural Resource Management Office. In-kind contributions were gratefully received from the organisations represented on the Technical Advisory Group (TAG).

The TAG included the following stakeholders:

Mr Roger Hearn, Department of Environment and Conservation, Manjimup
Mr Paul Roberts, Department of Environment and Conservation, Manjimup
Ms Jennifer Higbid, Department of Environment and Conservation, Perth
Ms Margaret Smith, Curtin University, Perth
Dr Peter Taylor, Birding South West, Manjimup
Ms Emily Lewis, Warren Catchments Council
Ms Lee Fontanini, Warren Catchments Council

Expert advice was also provided by Roger Hearn. Jennifer Higbid provided valuable feedback throughout the development of this document.

GLOSSARY

Definitions of words associated with ecological character descriptions (DEWHA 2008).

Adverse conditions	Ecological conditions unusually hostile to the survival of plant or animal species, such as occur during severe weather like prolonged drought, flooding, cold, etc (Ramsar Convention 2005).
Assessment	The identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities (as defined by Ramsar Convention 2002, Resolution VIII.6).
Baseline	Condition at a starting point. For Ramsar wetlands it will usually be the time of listing of a Ramsar site.
Benchmark	A standard or point of reference (ANZECC and ARMCANZ 2000). A pre-determined state (based on the values which are sought to be protected) to be achieved or maintained.
Benefits	Benefits/services are defined in accordance with the Millennium Ecosystem Assessment definition of ecosystem services as "the benefits that people receive from ecosystems (Ramsar Convention 2005 Resolution IX.1 Annex A). See also “Ecosystem Services”.
Biogeographic region	A scientifically rigorous determination of regions as established using biological and physical parameters such as climate, soil type, vegetation cover, etc (Ramsar Convention 2005).
Biological diversity	The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species (genetic diversity), between species (species diversity), of ecosystems (ecosystem diversity), and of ecological processes. This definition is largely based on Article 2 of the Convention on Biological Diversity (Ramsar Convention 2005).
Catchment	The total area draining into a river, reservoir, or other body of water (ANZECC and ARMCANZ 2000).
Change in ecological character	Defined as the human-induced adverse alteration of any ecosystem component, process, and-or ecosystem benefit/service (Ramsar Convention 2005a, Resolution IX.1 Annex A).
Community	Assemblage of organisms characterised by a distinctive combination of species occupying a common environment and interacting with one another (ANZECC and ARMCANZ 2000).
Community Composition	All the types of taxa present in a community (ANZECC and ARMCANZ 2000).
Community Structure	All the types of taxa present in a community and their relative abundances (ANZECC and ARMCANZ 2000).
Conceptual model	Wetland conceptual models express ideas about components and processes deemed important for wetland ecosystems (Gross 2003)
Contracting Parties	Countries that are Member States to the Ramsar Convention on Wetlands; 159 as at July 2009. Membership in the Convention is open to all states that are members of the United Nations, one of the UN specialized agencies, or the

	International Atomic Energy Agency, or is a Party to the Statute of the International Court of Justice [http://www.ramsar.org].
Critical stage	Meaning stage of the life cycle of wetland-dependent species. Critical stages being those activities (breeding, migration stopovers, moulting etc.) which if interrupted or prevented from occurring may threaten long-term conservation of the species. (Ramsar Convention 2005).
Damplands	Seasonally waterlogged basin of variable size and shape (Semeniuk 1987).
Ecological character	Combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time. Within this context, ecosystem benefits are defined in accordance with the variety of benefits to people (Ecosystem Services). (Millennium definition of ecosystem services as "the benefits that people receive from ecosystems" (Ramsar Convention 2005, Resolution IX.1 Annex A). The phrase "at a given point in time" refers to Resolution VI.1 paragraph 2.1, which states that "It is essential that the ecological character of a site be described by the Contracting Party concerned at the time of designation for the Ramsar List, by completion of the Information Sheet on Ramsar Wetlands (as adopted by Recommendation IV. 7).
Ecological communities	Any naturally occurring group of species inhabiting a common environment, interacting with each other especially through food relationships and relatively independent of other groups. Ecological communities may be of varying sizes, and larger ones may contain smaller ones (Ramsar Convention 2005).
Ecosystems	The complex of living communities (including human communities) and non-living environment (Ecosystem Components) interacting (through Ecological Processes) as a functional unit which provides *inter alia* a variety of benefits to people (Ecosystem Services). (Millennium Ecosystem Assessment 2005).
Ecosystem components	Include the physical, chemical and biological parts of a wetland (from large scale to very small scale, e.g. habitat, species and genes) (Millennium Ecosystem Assessment 2005).
Ecosystem processes	Are the changes or reactions that occur naturally within wetland systems. They may be physical, chemical or biological. (Ramsar Convention 1996, Resolution VI.1 Annex A). They include all those processes that occur between organisms and within and between populations and communities, including interactions with the non-living environment, that result in existing ecosystems and bring about changes in ecosystems over time (Australian Heritage Commission 2002)
Ecosystem services	The benefits that people receive or obtain from an ecosystem. The components of ecosystem services are provisioning (e.g. food & water), regulating (e.g. flood control), cultural (e.g. spiritual, recreational), and supporting (e.g. nutrient cycling, ecological value). (Millennium Ecosystem Assessment 2005). See also “Benefits”.
Ecologically Sustainable Development	Development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends (ANZECC and ARMCANZ 2000).
Eutrophication	A natural process of accumulation of nutrients leading to increased plant growth in waterways, including wetlands. Exacerbated by runoff containing fertilizers and other high nutrient waste, resulting in algal blooms and deterioration of water quality (Water and Rivers Commission 2001).
Geomorphology	The study of water-shaped landforms (Gordon *et al.* 1999)

Hydrology	The study of water, its properties, distribution and utilisation above and below the earth's surface (Water and Rivers Commission 2001).
Indicator species	Species whose status provides information on the overall condition of the ecosystem and of other species in that ecosystem; taxa that are sensitive to environmental conditions and which can therefore be used to assess environmental quality (Ramsar Convention 2005).
Indigenous species	A species that originates and occurs naturally in a particular country (Ramsar Convention 2005).
Introduced (non-native) species	A species that does not originate or occur naturally in a particular country (Ramsar Convention 2005).
Limits of Acceptable Change	The variation that is considered acceptable in a particular component or process of the ecological character of the wetland without indicating change in ecological character which may lead to a reduction or loss of the criteria for which the site was Ramsar listed' (modified from definition adopted by Phillips 2006).
List of Wetlands of International Importance ("the Ramsar List")	The list of wetlands which have been designated by the Ramsar Contracting Party in which they reside as internationally important, according to one or more of the criteria that have been adopted by the Conference of the Parties [http://www.ramsar.org].
Macroinvertebrates	Aquatic invertebrates retained after sieving with a 0.25 mm mesh net. The main groups are worms, snails, arachnids, crustaceans and insects (Water and Rivers Commission 2001).
Macrophyte	Rooted aquatic plants (e.g. sedges), as opposed to phytoplankton and other small algae (Water and Rivers Commission 2001).
Monitoring	The collection of specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing management (Ramsar Convention 2002, Resolution VIII.6).
Ramsar	City in Iran, on the shores of the Caspian Sea, where the Convention on Wetlands was signed on 2 February 1971; thus the Convention's short title "Ramsar Convention on Wetlands" [http://www.ramsar.org].
Ramsar Criteria	Criteria for Identifying Wetlands of International Importance, used by Contracting Parties and advisory bodies to identify wetlands as qualifying for the Ramsar List on the basis of representativeness or uniqueness or of biodiversity values [http://www.ramsar.org].
Ramsar Convention	*Convention on Wetlands of International Importance, especially as Waterfowl Habitat*. Ramsar (Iran), 2 February 1971. UN Treaty Series No. 14583. As amended by the Paris Protocol, 3 December 1982, and Regina Amendments, 28 May 1987. The abbreviated names "Convention on Wetlands (Ramsar, Iran, 1971)" or "Ramsar Convention" are more commonly used [http://www.ramsar.org].
Ramsar Information Sheet (RIS)	The form upon which Contracting Parties record relevant data on proposed Wetlands of International Importance for inclusion in the Ramsar Database; covers identifying details like geographical coordinates and surface area, criteria for inclusion in the Ramsar List and wetland types present, hydrological, ecological, and socioeconomic issues among others, ownership and jurisdictions, and conservation measures taken and needed [http://www.ramsar.org].
Ramsar List	The List of Wetlands of International Importance [http://www.ramsar.org].

Ramsar Sites	Wetlands designated by the Contracting Parties for inclusion in the List of Wetlands of International Importance because they meet one or more of the Ramsar Criteria [http://www.ramsar.org].
Ramsar Sites Database	Repository of ecological, biological, socio-economic, and political data and maps with boundaries on all Ramsar sites, maintained by Wetlands International in Wageningen, the Netherlands, under contract to the Convention [http://www.ramsar.org].
Sumplands	Seasonally inundated basin of variable size and shape (Semeniuk 1987).
Wetlands	Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres (Ramsar Convention 1987).
Wetland Assessment	Identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities (Finlayson 2001; Ramsar Convention 2002)
Wetland Ecological Risk Assessment	A quantitative or qualitative evaluation of the actual or potential adverse effects of stressors on a wetland ecosystem
Wetland types	As defined by the Ramsar Convention's wetland classification system [http://www.ramsar.org].
Wise use of wetlands	The maintenance of their ecological character, achieved through the implementation of ecosystem approaches [1], within the context of sustainable development [2]" (Ramsar Convention 2005 Resolution IX.1 Annex A). 1. Including *inter alia* the Convention on Biological Diversity's "Ecosystem Approach" (CBD COP5 Decision V/6) and that applied by HELCOM and OSPAR (Declaration of the First Joint Ministerial Meeting of the Helsinki and OSPAR Commissions, Bremen, 25-26 June 2003). 2. The phrase "in the context of sustainable development" is intended to recognize that whilst some wetland development is inevitable and that many developments have important benefits to society, developments can be facilitated in sustainable ways by approaches elaborated under the Convention, and it is not appropriate to imply that 'development' is an objective for every wetland.

EXECUTIVE SUMMARY

The Muir-Byenup System Ramsar site is located 55 km east-south-east of Manjimup in the South-West Coast Australian Drainage Division of Western Australia, and covers an area of 10,631 hectares, of which approximately 7,000 hectares is wetland. Named wetlands in the site include; Lake Muir, Byenup Lagoon, Tordit-Gurrup Lagoon, Poorginup Swamp, Neeranup Swamp, Coorinup Swamp and Wimbalup Swamp. This Ecological Character Description (ECD) includes the current Ramsar listed site as well as the recent additions to Nature Reserve 31880, south of Tordit-Gurrup Lagoon and east of Coorinup Swamp.

Designation of the Muir-Byenup System Ramsar site occurred in 2001. The Ramsar Convention, ratified in 1975, provides the framework for the wise use of wetlands at local, regional, national and international levels. Wetlands of international importance are selected based on ecological, botanical, zoological, limnological and hydrological importance. Under the Ramsar Convention, Australia is obliged to promote the conservation of wetlands included in the list (interpreted as a commitment to protect the ecological character of listed sites), and as far as possible, the wise use of wetlands in Australia.

ECDs guide management planning and associated monitoring and evaluation. A Ramsar Information Sheet (RIS) is prepared at the time of listing, however, an ECD provides a more detailed description of the interactions between ecosystem components, processes and functions.

The specific objectives of this ECD are to provide a comprehensive description of the ecological character that:

1. Describes the critical ecosystem components, processes, benefits and services of the Muir-Byenup System Ramsar site at the time of listing;
2. Identifies changes to the critical components, processes, benefits and services of the site since the time of listing;
3. Develops a conceptual model that describes the ecological character of the site in terms of components, processes, benefits and services and their interactions;
4. Sets limits of acceptable change for the critical components, processes, benefits and services;
5. Identifies actual or likely threats to the components, processes or services of the site;
6. Identifies knowledge gaps and monitoring priorities for the Ramsar site;
7. Identifies any communication, education and public awareness messages.

The Muir-Byenup System Ramsar site is composed of partly inter-connected wetlands, ranging in size, salinity (saline to fresh), water permanence (permanent to seasonal) and substrate (peat and inorganic), in an internally-draining catchment. Byenup Lagoon, Tordit-Gurrup Lagoon, Poorginup Swamp, Geordinup Swamp and Neeranup Swamp are naturally freshwater wetlands, while Lake Muir and Coorinup Swamp are naturally occurring saline wetlands. Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp are peat based wetlands, which are rare in Western Australia (Department of Environment and Conservation 2008). These wetlands

strongly influence water quality and provide important habitat for native plants and animals (Department of Environment and Conservation 2008).

The Muir-Byenup System Ramsar site is highly diverse with at least 600 indigenous flora species recorded (Gibson and Keighery 1999). The Ramsar site provides significant waterbird habitat and refuge, and supports bird species listed under the EPBC Act and international migratory agreements. The Ramsar Site is considered a centre of endemism as it provides habitat for endemic freshwater fish fauna and supports a number of important endemic macroinvertebrate taxa.

The Muir-Byenup System Ramsar site meets the following criteria for listing as a wetland of international importance:

Criterion 1**:** *A wetland should be considered internationally important if it contains a representative, rare or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.*
The Ramsar site is an excellent example of a wetland complex in a relatively undisturbed condition in the South-West Coast Australian Drainage Division (Environment Australia 2001). The peat based wetlands within the site are rare in Western Australia (Department of Environment and Conservation 2008; Environment Australia 2001) and they are also recognised as the most outstanding example in south-western Australia (Wetland Research and Management 2005).

Criterion 2**:** *A wetland should be considered internationally important if it supports vulnerable, endangered or critically endangered species or threatened ecological communities.*
The Ramsar site supports a number of species listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Populations of three wetland dependent orchids *Caladenia christineae*, *Caladenia harringtoniae* and Tall Donkey Orchid (*Diuris drummondii*) occur on the margins of Lake Muir and elsewhere in the Ramsar site. These orchids are listed as Vulnerable under the EPBC Act and inhabit seasonally inundated areas or wetland margins.

The Ramsar site supports the freshwater fish species Balston's Pygmy Perch (*Nannatherina balstoni*), which is listed as Vulnerable under the EPBC Act. The Ramsar site also supports the Australasian Bittern (*Botaurus poiciloptilus*), which is listed as Endangered under the IUCN Red List. In Western Australia, the Australasian Bittern population is now much restricted, with the largest concentration thought to occur within the Ramsar site (IUCN 2008).

Criterion 3**:** *A wetland should be considered internationally important if it supports populations of plant and-or animal species important for maintaining the biological diversity of a particular biogeographic region.*
Peat and primary saline wetlands at the site support endemic species and populations of plant and animal species important for maintaining the biodiversity of the South-West Coast Australian Drainage Division.

The site includes 21 'priority taxa' listed by the Western Australian Department of Environment and Conservation, including endemic plant taxa *Eryngium* sp. Lake Muir and *Tribonanthes* sp. Lake Muir. *Astartea* sp. Lake Muir is also endemic to the site. The majority of the population of *Wurmbea* sp. Cranbrook also occurs at the Ramsar site.

The Muir-Byenup System Ramsar site supports six of the eight endemic south-western Australian freshwater fish species including; the Western Pygmy Perch (*Edelia vittata*), Balston's Pygmy Perch (*Nannatherina balstoni*), Nightfish (*Bostockia porosa*), Western Minnow (*Galaxias occidentalis*), Black-striped Minnow (*Galaxiella nigrostriata*) and Mud Minnow (*Galaxiella munda*). The Ramsar site also supports a number of important macroinvertebrate taxa, including 32 endemic taxa (Storey 1998).

Criterion 4: *A wetland should be considered internationally important if it supports plant and animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.*
The Muir-Byenup System Ramsar site supports thousands of Australian Shelducks (*Tadorna tadornoides*) during their moulting phase. The Ramsar site supports breeding of Little Bittern (*Ixobrychus minutus*), Spotless Crake *(Porzana tabuensis*), Australasian Bittern, Black Swan (*Cygnus atratus*) and Eurasian Coot (*Fulica atra*). The Ramsar site is also used as a drought refuge by tens of thousands of waterbirds and supports 10 species identified under international migratory agreements (CAMBA, JAMBA, ROKAMBA, and CMS).

Criterion 5: *A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.*
Up to 52,000 waterbirds (1989) have been counted at Lake Muir during periods of high water levels. Although there is no comprehensive data available on waterbird numbers since 1989, it is likely that the Ramsar site is still capable of regularly supporting more than 20,000 waterbirds as there has been no major change in water depth or salinity. Annual data on water depth, over a 25 year period, suggests that conditions were suitable for use by 20,000 waterbirds at least several times over this period.

Criterion 6: *A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or sub-species of waterbird.*
The Ramsar site supports at least five, and possibly up to 10, Australasian Bitterns, which exceeds the 1% population thresholds for south-western Australia (Wetlands International 2006). Although, no comprehensive counts have been made since 1991, there has been no major change in water quality or wetland vegetation at the site, suggesting that conditions remain suitable to support 1% of the south-western Australian population. The site also contains the core component of a wider suite of wetlands that constitutes one of the five remaining refuges for the south-western Australian population of Australasian Bitterns.

A summary of the ecological character of the Muir-Byenup System Ramsar site is provided in Table E1. Due to the complexity of the site, the ECD discusses Lake Muir and the Byenup Lagoon System separately. The Byenup Lagoon System includes Byenup Lagoon, Tordit-Gurrup Lagoon, and Neeranup, Mulgarnup and Poorginup Swamps (V & C Semeniuk Research Group 1997).

Table E1. Summary of the ecological character of the Muir-Byenup System Ramsar site

COMPONENT	SUMMARY DESCRIPTION
Geology	Tertiary alluvial flats (Lake Muir) and Tertiary plateau and flat (Byenup Lagoon System).
Hydrogeology	Fresh to saline groundwater Groundwater pH 5.2 to 6.3. Acidity is due to soluble metals. Potential acidity is present in the form of pyrite (metallic sulfide).
Lake Muir	
Hydrology	Major sink for groundwater and surface flows - internally draining. Naturally saline wetland - shallow evaporating basin (dry 9 years 1998-2008).
Water quality	Saline (0.58-96 ppt). pH 6.2-9.9. Lower pH is associated with low water levels.
Flora (habitat)	Salt tolerant macrophytes. Fringing vegetation includes; *Gahnia trifida* sedgelands, low shrublands (samphires) and wetland scrub. *Eucalyptus occidentalis* occurs at higher elevations. Notable flora includes wetland dependent orchids and endemic species.
Aquatic invertebrates	No information available.
Fish	No information available.
Frogs and reptiles	No comprehensive surveys. Likely to be rich in reptiles, including Oblong Tortoises (*Chelodina oblonga*) and Tiger Snakes (*Notechis ater*).
Mammals	Believed to contain many species found in adjacent Perup Forest including Woylies (*Bettongia pencillata*), Numbat (*Myrmecobius fasciatus*) and Chuditch (*Dasyurus geoffroii*). Also contains suitable habitat for Boodies (*Bettongia lesueur*), Dalgytes (*Macrostis lagotis*) and Water Rats (*Hydromys chrysogaster*).
Waterbirds	Up to 52,000 waterbirds (1989). Water depth data suggests suitable conditions to regularly support 20,000 waterbirds. 6 species listed under international migratory agreements. Used as a drought refuge by large numbers of waterbirds. Black Swans, Silver Gulls and Australasian Shoveler breed at Lake Muir.
Byenup Lagoon System	
Hydrology	Surface water area and depth varies seasonally. Coorinup Swamp acts as a shallow evaporating basin (primary saline lake). Byenup Lagoon permanent, other wetlands permanent or near permanent and minor swamps inundated/waterlogged in winter/spring. Areas of peat in Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp dry out seasonally.
Water quality	Poorginup Swamp fresh (0.1-1.6 ppt), other wetlands brackish to saline (Tordit-Gurrup 0.65-15.2 and Byenup 1.38-42.2 ppt). Poorginup Swamp acidic (pH 5-6.6), other wetlands pH 7-9. Higher nutrient concentrations related to low water levels and peat drying. Wetlands do not behave as eutrophic.
Flora (habitat)	Macrophytes include *Villarsia submersa* and *Schoenus natans.* Fringing vegetation includes; *Baumea* sedgelands and shrublands with Jarrah/Yate or *E. rudis* woodlands at higher elevations.
Aquatic invertebrates	DeHaan (1987) recorded 103 invertebrate taxa in Tordit-Gurrup Lagoon, Byenup Lagoon and Poorginup Swamp. Tordit-Gurrup Lagoon had the highest richness and Poorginup the lowest. Insects accounted for 73% of total invertebrates.

	11 Hydracarina taxa (watermites) (six in Poorginup swamp). Storey (1998) found 219 taxa, 32 endemic to south-western Australia (most in Poorginup Swamp). > 78 species of ostracods and copepods, with 6 ostracods and 1 cyclopoid only known in the Muir-Unicup area. New species within Rotifera and Cladocera families and 2 new dytiscids. *Hygrobia wattsii* sp. n (Byenup Lagoon) appears restricted to peat wetlands.
Fish	7 fish species, 6 endemic to south-west WA (Western Pygmy Perch, Balston's Pygmy Perch, Nightfish, Western Minnow, Black-stripe Minnow and Mud Minnow) and introduced Mosquitofish. Poorginup Swamp had the greatest number of native fish species. Balston's Pygmy Perch listed as Vulnerable (EPBC Act) Black-stripe and Mud Minnows listed as Lower Risk/near threatened (IUCN Red List, 2009).
Frogs and reptiles	No comprehensive surveys. Likely to be rich in reptiles, including Oblong Tortoises and Tiger Snakes.
Mammals	Believed to contain many species found in adjacent Perup Forest including Woylies, Numbat and Chuditch. Also contains suitable habitat for Boodies, Dalgytes and Water Rats.
Waterbirds	Tordit-Gurrup used as a drought refuge by large numbers of waterbirds. Open water important for Australian Shelduck in their moulting phase (over 12,000 in 1992). Non-vegetated beaches (Tordit-Gurrup and Byenup) provide habitat for waders, ducks and swans. Poorginup Swamp contains critical habitat for Australasian Bitterns (Endangered IUCN red list). Little Bittern, Spotless Crake, Australasian Bitterns, Black Swans and Eurasian Coots breed at the site. Local knowledge suggests Grebes, Swamp Harrier, Blue-billed Duck, Cormorants, Sea-eagles and Spoonbills also breed at the site (P. Taylor, pers. com.).

Since listing in 2001 some changes have been identified within the Byenup Lagoon System of the Ramsar site. The changes relate to aquatic invertebrate communities composition, distribution of some fish species and condition of fringing vegetation. These changes may be due to increased salinity levels, however, as mean annual salinity has not been statistically significantly different over the long term (1978-2008) the changes may be within natural variation. It should be noted that these changes may also be a result of sampling effort and further investigation is required. This ECD concludes that, based on available evidence, there has not been a change to the ecological character of the Ramsar site since the time of listing.

Major threatening activities, processes and impacts to the ecological character of the Muir-Byenup System Ramsar site identified in the ECD include:

- Secondary salinity;
- Disturbance of potential acid sulfate soils;
- Eutrophication;
- Grazing;
- Introduced species;
- Pathogens and pests;
- Inappropriate fire regimes; and,
- Illegal vehicle access.

In the absence of complete knowledge, conservative limits of acceptable change have been set, which can be reviewed in light of monitoring and additional information. Components and processes for which limits of acceptable change can be established are those where:

- Information is adequate to form a baseline against which change can be measured;
- Information is sufficient to characterise natural variability; and
- Management and monitoring can occur (Hale and Butcher 2007).

Where these criteria cannot be met, limits of acceptable change are set using a hierarchical approach. This approach uses key abiotic factors and primary response to abiotic conditions within the system to set limits for species and communities within the wetland system (Hale and Butcher 2007).

Key knowledge gaps that are required to fully describe the ecological character of the Muir-Byenup System Ramsar site are shown in Table E3.

Table E3. Key knowledge gaps of the Muir-Byenup System Ramsar site.

COMPONENT PROCESS	KNOWLEDGE GAP	RECOMMENDED ACTION
Hydrology	Understanding interactions between groundwater and wetlands. Effect of plantations on groundwater, salinity and acidity.	Continued investigations of bores and depth gauges located within the wetlands.
Water quality	Effect of surrounding land-uses (clearing and plantations) on water quality (salinity and acidity).	Continued monitoring of water quality sites.
Aquatic plants	Community composition, distribution and temporal patterns.	Community composition, distribution and temporal patterns.
Fringing vegetation	Community composition and distribution of fungal and non-vascular flora.	Community composition, distribution and temporal patterns.
	Vegetation response to salinity and acidity (groundwater and acid sulfate soils) Transects last done in 2001 (Froend and Loomes 2001). Permanent plots last measured 2002 (Gibson *et al.* 2004).	Continued monitoring of transects and quadrats within the Ramsar site.
Macroinvertebrates	Response of macroinvertebrates to salinisation, acidity and altered hydrology. Last sampled 2004 (Wetland Research and Management 2005).	Continued monitoring of sampling sites. Establish baseline information for Lake Muir.
Fish	Response of fish to salinisation, acidity and altered hydrology. Last sampled 2004 (Wetland Research and Management 2005). Determine distribution and migration patterns.	Continued monitoring of sampling sites. Establish baseline information for Lake Muir. Mechanisms of drought and salinity tolerance.
Waterbirds	Current waterbird data. Last comprehensive surveys undertaken 1992 (Halse *et al.* 1995).	Continued monitoring of sampling sites.

In addition to the required monitoring to address these knowledge gaps and set limits of acceptable change, the following processes and threats require further investigation:

1. Acid sulfate soils – High Priority
    - How to manage and dispose of acid groundwater (Hearn 2005).
    - Vegetation community robustness to acidity and aluminium toxicity.

2. Salinisation – High Priority
    - Vegetation community robustness to salinity and water removal by plantations.

3. *Phytophthora* – Medium Priority
    - Lack detailed *Phytophthora* mapping and limited available data on impacts on individual species and communities (McKenzie *et al.* 2002).
    - *Armillaria* mapping (Gibson and Keighery 2000).

TABLE OF CONTENTS

GLOSSARY .... **IV**

EXECUTIVE SUMMARY .... **VIII**

1. INTRODUCTION **1**

1.1 SITE DETAILS 1
1.2 PURPOSE OF ECOLOGICAL CHARACTER DESCRIPTIONS 1
1.3 OBJECTIVES OF THE ECOLOGICAL CHARACTER DESCRIPTION OF THE MUIR-BYENUP SYSTEM RAMSAR SITE 3
1.4 RELEVANT TREATIES, LEGISLATION OR REGULATIONS 3
1.4.1 International *4*
1.4.2 National legislation *4*
1.4.3 Western Australia State policy and legislation *5*
1.5 METHODOLOGY 6

2. OVERVIEW OF THE MUIR-BYENUP SYSTEM RAMSAR SITE **7**

2.1 LOCATION 7
2.2 LAND TENURE AND LAND USE 8
2.3 CLIMATE 9
2.4 WETLAND TYPES 11
2.5 RAMSAR CRITERIA 12
2.5.1 Current Ramsar Criteria *13*

3. MUIR-BYENUP SYSTEM RAMSAR SITE CRITICAL COMPONENTS AND PROCESSES **17**

3.1 WETLAND ECOLOGY DRIVERS 17
3.2 CRITICAL ECOSYSTEM COMPONENTS AND PROCESSES 17
3.2.1 Geology *21*
3.2.2 Hydrogeology *24*
3.2.3 Surface hydrology *25*
3.2.4 Water quality *32*
3.2.5 Phytoplankton and aquatic macrophytes *49*
3.2.6 Fringing vegetation *50*
3.2.7 Aquatic invertebrates *54*
3.2.8 Fish *58*
3.2.9 Frogs and reptiles *59*
3.2.10 Mammals *59*
3.2.11 Waterbirds *59*

4. SYSTEM SERVICES AND BENEFITS **64**

5. CHANGES IN THE ECOLOGICAL CHARACTER OF THE MUIR-BYENUP SYSTEM RAMSAR SITE: CURRENT STATE OF CRITICAL COMPONENTS AND PROCESSES **67**

5.1 CHANGES SINCE LISTING 67
5.1.1 Aquatic invertebrates *67*
5.1.2 Fish communities *68*
5.1.3 Fringing vegetation *68*

6. HOW THE MUIR-BYENUP SYSTEM RAMSAR SITE WORKS: INTERACTIONS BETWEEN COMPONENTS, PROCESSES, BENEFITS AND SERVICES **69**

7. THREATS TO THE ECOLOGICAL CHARACTER OF THE MUIR-BYENUP WETLAND **73**

7.1 SECONDARY SALINITY 73
7.2 DISTURBANCE OF POTENTIAL ACID SULFATE SOILS 75
7.3 EUTROPHICATION 76
7.4 GRAZING 76
7.5 INTRODUCED SPECIES 76
7.6 PATHOGENS AND PESTS 77
7.7 INAPPROPRIATE FIRE REGIMES 78

7.8 ILLEGAL VEHICLE ACCESS 78

8. LIMITS OF ACCEPTABLE CHANGE 79

9. SUMMARY OF KNOWLEDGE GAPS 85

10. RECOMMENDATIONS FOR MONITORING / RESEARCH 86

10.1 EXISTING MONITORING PROGRAMS 86
10.1.1 Historical and current monitoring in the Muir-Byenup System Ramsar site 86
10.2 MONITORING OF ECOLOGICAL CHARACTER 87

11. COMMUNICATION, EDUCATION AND PUBLIC AWARENESS 91

11.1 CURRENT CEPA 91
11.2 CEPA MESSAGES ARISING FROM THE ECD 91

12. REFERENCES 92

APPENDIX A: METHOD 98
APPENDIX B: VEGETATION DESCRIPTION OF THE MUIR-BYENUP SYSTEM RAMSAR SITE (GIBSON AND KEIGHERY 1999) 101
APPENDIX C: FISH 104
APPENDIX D: WATERBIRDS 105
APPENDIX E: MACROINVERTEBRATES AND WATER QUALITY TOLERANCES 111

1. INTRODUCTION

1.1 Site details

The Muir-Byenup System Ramsar site is located 55 km east-south-east of Manjimup in Western Australia. The Ramsar site is situated in the Jarrah Forest bioregion within the South-West Coast Australian Drainage Division and covers an area of 10,631 hectares, of which approximately 7,000 hectares is wetland. This Ecological Character Description (ECD) includes the current Ramsar listed site as well as recently acquired land by the Department of Environment and Conservation (DEC) south of Tordit-Gurrup Lagoon and east of Coorinup Swamp. Table 1 presents a summary of the Muir-Byenup System Ramsar site details.

Table 1. Muir-Byenup System Ramsar site details

Site name	Muir-Byenup System, Western Australia
Location in coordinates	Latitude: 34° 26' S to 34° 32' S Longitude: 116° 43' E to 116° 49' E
General location	Inland south-west of Western Australia. Shires: Manjimup and Cranbrook (local authorities). Biogeographic region: South-West Coast Australian Drainage Division, Jarrah Forest (IBRA). The Muir-Byenup System Ramsar site comprises the portion of Nature Reserve 31880, south of Muirs Highway. Named wetlands in the site include Lake Muir, Byenup Lagoon, Tordit-Gurrup Lagoon, Poorginup Swamp, Neeranup Swamp, Coorinup Swamp and Wimbalup Swamp.
Area	10,631 ha (of which approximately 7,000 ha is wetland)
Date of Ramsar site designation	05/01/2001
Ramsar/DIWA criteria met	Ramsar Criteria 1, 2, 3, 4, 5 and 6
Management authority	The Donnelly District (based in Pemberton) of the Warren Region, Western Australian Department of Environment and Conservation (formally Department of Conservation and Land Management).
Date the ECD applies	05/01/2001
Status of description	This is the first ecological character description for the site.
Date of compilation	September 2009
Name(s) of compiler(s)	Claire Farrell and Barbara Cook on behalf of Department of Environment and Conservation (DEC)
References to the Ramsar Information Sheet (RIS)	Roger Jaensch, Wetlands International – Oceania, on behalf of the Western Australian Department of Conservation & Land Management (DCLM) in 1998. Updated by DCLM staff in 2000 and 2003. Updated by Claire Farrell and Barbara Cook on behalf of DEC in September 2009. All enquiries should be directed to Michael Coote, DEC, 17 Dick Perry Ave, Technology Park, Kensington, WA 6983, Australia (Tel: +61-8-9219-8714; Fax: +61-8-9219-8750; email: michael.coote@dec.wa.gov.au)
References to the management plan	A management plan, which includes the Muir-Byenup System Ramsar site, is currently in preparation by DEC.

1.2 Purpose of ecological character descriptions

Ecological character is defined by the Ramsar Convention (2005) as "the combination of the ecosystem components, processes and benefits/services that characterise the wetlands at a given point in time". A change in ecological character is defined as "the human induced adverse alteration of any ecosystem component, process and or ecosystem benefit/service" (Ramsar Convention 2005).

Describing the ecological character of a wetland is important for identifying changes, or potential changes, and an ECD provides a baseline or benchmark for future management and planning actions. The implementation of a management plan along with an appropriate monitoring programme allows early recognition of changes to ecological character.

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) regulates actions that will have or are likely to have a significant impact on any matter of national environmental significance, which includes the ecological character of a Ramsar wetland. An action that will have or is likely to have a significant impact on a Ramsar wetland will require an environmental assessment and approval under the EPBC Act.

When a Ramsar site is designated, a Ramsar Information Sheet (RIS) is prepared, which provides a brief description of the ecological character of the Ramsar site. An Ecological Character Description provides a comprehensive description of the ecological character of the site. To ensure a consistent approach in developing ECDs, the Australian Government, state and territory governments, have developed the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands: Module 2 of the National Guidelines for Ramsar Wetlands-Implementing the Ramsar Convention in Australia* (Department of the Environment, Water, Heritage and the Arts 2008). The Australian Government requires an ECD and a management plan to accompany any new Ramsar site nominations.

An ECD is a central component to management, legislative compliance and other processes that promote the conservation and wise use of a Ramsar wetland. McGrath (2006) outlined the general aims of an ECD:

1. To assist in implementing Australia's obligations under the Ramsar Convention, as stated in Schedule 6 (Managing wetlands of international importance) of the *Environment Protection and Biodiversity Conservation Regulations* 2000 (Cwth);
    a. To describe and maintain the ecological character of declared Ramsar wetlands in Australia; and
    b. To formulate and implement planning that promotes
        i. Conservation of the wetland; and
        ii. Wise and sustainable use of the wetland for the benefit of humanity in a way that is compatible with maintenance of the natural properties of the ecosystem.

2. To assist in fulfilling Australia's obligation under the Ramsar Convention – "to arrange to be informed at the earliest possible time if the ecological character of any wetland in its territory and included in the Ramsar List has changed, is

changing or is likely to change as the result of technological developments, pollution or other human interference."

3. To supplement the description of the ecological character contained in the Ramsar Information Sheet submitted under the Ramsar Convention for each listed wetland and collectively form an official record of the ecological character of the site.

4. To assist the administration of the EPBC Act, particularly:
   a. To determine whether an action has, will have or is likely to have a significant impact on a declared Ramsar wetland in contravention of sections 16 and 17B of the EPBC Act; or
   b. To assess the impacts that actions referred to the Minister under part 7 of the EPBC Act have had, will have or are likely to have on a declared Ramsar wetland.

5. To assist any person considering taking an action that may impact on a declared Ramsar wetland whether to refer the action to the Minister under Part 7 of the EPBC Act for assessment and approval.

6. To inform members of the public who are interested generally in declared Ramsar wetlands to understand and value the wetlands.

1.3 Objectives of the Ecological Character Description of the Muir-Byenup System Ramsar Site

The specific objectives of this ECD are to provide a comprehensive description of the ecological character that:

1. Describes the critical ecosystem components, processes, benefits and services of the Muir-Byenup System Ramsar site at the time of listing;
2. Identifies changes to the critical components, processes, benefits and services of the Muir-Byenup System Ramsar site since the time of listing;
3. Develops a conceptual model that describes the ecological character of the Muir-Byenup System Ramsar site in terms of components, processes, benefits and services and their interactions;
4. Sets limits of acceptable change for the critical components, processes, benefits and services;
5. Identifies threats to the ecological character of the Ramsar site;
6. Identifies gaps in knowledge of the Ramsar site
7. Identifies monitoring priorities for the Ramsar site;
8. Identifies any communication, education and public awareness messages.

1.4 Relevant treaties, legislation or regulations

This section provides a brief outline of international, national and Western Australian legislation and policy relevant to the Muir-Byenup System Ramsar site.

1.4.1 International

Ramsar Convention

The *Convention on Wetlands of International Importance, especially as Waterfowl Habitat,* commonly known as the Ramsar Convention, was signed in Ramsar, Iran in 1971 and came into force in 1975. It provides the framework for local, regional and national actions, and international cooperation, for the conservation and wise use of wetlands. Wetlands of international importance are selected on the basis of their international significance in terms of ecology, botany, zoology, limnology and or hydrology.

Convention on the Conservation of Migratory Species of Wild Animals

The CMS or Bonn Convention is a multilateral, intergovernmental treaty which seeks to protect all migratory species (terrestrial, marine and avian) throughout their range.

Bilateral migratory bird agreements

Australia is signatory to three bilateral agreements for the conservation of migratory birds.

CAMBA – Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds in Danger of Extinction and their Environment 1986.

JAMBA – Agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds in Danger of Extinction and their Environment 1974.

ROKAMBA – Agreement between the Government of Australia and the Republic of Korea for the Protection of Migratory Birds in Danger of Extinction and their Environment 2006.

1.4.2 National legislation

The Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)

The EPBC Act regulates actions that have or are likely to have significant impacts on any matter of national environmental significance, including Ramsar wetlands (EPBC Act 1999 s16 (1)). Actions (including developments, undertakings or a series of activities) that have or are likely to have a significant impact on Ramsar wetlands will require approval under the EPBC Act.

The Australian Ramsar Management Principles are set out in the EPBC Regulations. These principles aim to promote national standards of management, planning, environmental impact assessment, community involvement and monitoring for all Australian Ramsar wetlands in a way that is consistent with obligations under the Ramsar Convention. All species listed under international treaties are covered by the Act, including JAMBA, CAMBA, ROKAMBA and CMS.

Australian Heritage Council Act 2003

The *Australian Heritage Council Act 2003* establishes the Australian Heritage Council, who advise the Australian Government on heritage list nominations under the EPBC Act and maintain the Register of the National Estate. The Muir-Byenup System Ramsar site is included within the Lake Muir Area site (9556), which is registered on the Register of the National Estate. The site is listed for its importance for rare, endangered or uncommon flora, undisturbed vegetation and wetland systems, and the high aesthetic value of its wetlands.

1.4.3 Western Australia State policy and legislation

Environmental Protection Act 1986

This Act is for the prevention, control and abatement of pollution; also for the prevention control and abatement of environmental harm; and for the conservation, preservation, protection, enhancement and management of the environment. The Act covers any matters that are incidental to or connected with any of these.

The clearing provisions under the EP Act (*Environmental Protection (Clearing of Native Vegetation) Regulations 2004*) identify Ramsar wetlands and the area within 50 metres of their boundary as “environmentally sensitive areas”. The clearing provisions of the Act prohibit clearing of native vegetation, unless a clearing permit is granted by DEC or the clearing is for an exempt purpose. The exemptions allow low impact day-to-day activities involving clearing to be undertaken in accordance with the Regulations. People who wish to clear native vegetation are required to obtain a permit if an exemption does not apply. Exemptions do not apply in “environmentally sensitive areas”.

Wetlands Conservation Policy for Western Australia 1997

This policy is administered by DEC, Department of Water and the Department of Planning. The policy is a statement of the Western Australian Government’s commitment to “identifying, maintaining and managing the State’s wetland resources, including the full range of wetland values, for the long-term benefit of the people of Western Australia”.

Conservation and Land Management Act 1984

This Act is administered by DEC and covers all public conservation lands managed by DEC including National Parks, State Forests and Nature Reserves. The Act provides for a better provision for the use, protection and management of certain public lands and the flora, fauna and waters within them.

Wildlife Conservation Act 1950

The *Wildlife Conservation Act 1950* is administered by DEC and provides for the protection and conservation of wildlife (fauna and flora) in Western Australia. It provides the licensing framework for the possession and removal of flora and fauna and also offences and penalties in relation to the protection and conservation of flora and fauna.

Aboriginal Heritage Act 1972

The *Aboriginal Heritage Act 1972* applies to the protection of places and objects which may be of importance and significance to people of Aboriginal descent in Western Australia. Under the Act it is an offence to damage sites, whether they are registered or not.

1.5 Methodology

The methodology used to develop the Muir-Byenup System Ramsar site ecological character description is based on the method provided in the *National Framework and Guidance for Describing the Ecological Character of Australian Ramsar wetlands* (Department of the Environment, Water, Heritage and the Arts 2008). A brief outline of the report is as follows:

1. Introduction to the description, including:
    a. Site details;
    b. Statement of purpose for description; and,
    c. Relevant legislation.
2. Site description, including:
    a. Site location;
    b. Maps images and photographs;
    c. Land tenure;
    d. Ramsar criteria met; and,
    e. Wetland types.
3. Ecological character description, including:
    a. Description of the critical ecosystem components, processes, benefits and services of the site which most strongly determine the ecological character of the site and the relationship between them;
    b. Conceptual model for the wetland; and
    c. Natural variability and limits of acceptable change for the critical components, processes and services of the site.
4. Changes to ecological character since listing
5. Actual or likely threats to the site
6. Summary of knowledge gaps
7. Recommendations for monitoring
8. Communication, education and public awareness messages

A more detailed description of the methodology and curriculum vitae of the ECD compilers can be found in Appendix A.

2. OVERVIEW OF THE MUIR-BYENUP SYSTEM RAMSAR SITE

2.1 Location

The Muir-Byenup System Ramsar site is located in the south-west of Western Australia, 55 km east-south-east of Manjimup (Figure 1), within the shires of Manjimup and Cranbrook. The Ramsar site is situated in the South-West Coast Australian Drainage Division and the Jarrah Forest IBRA bioregion.

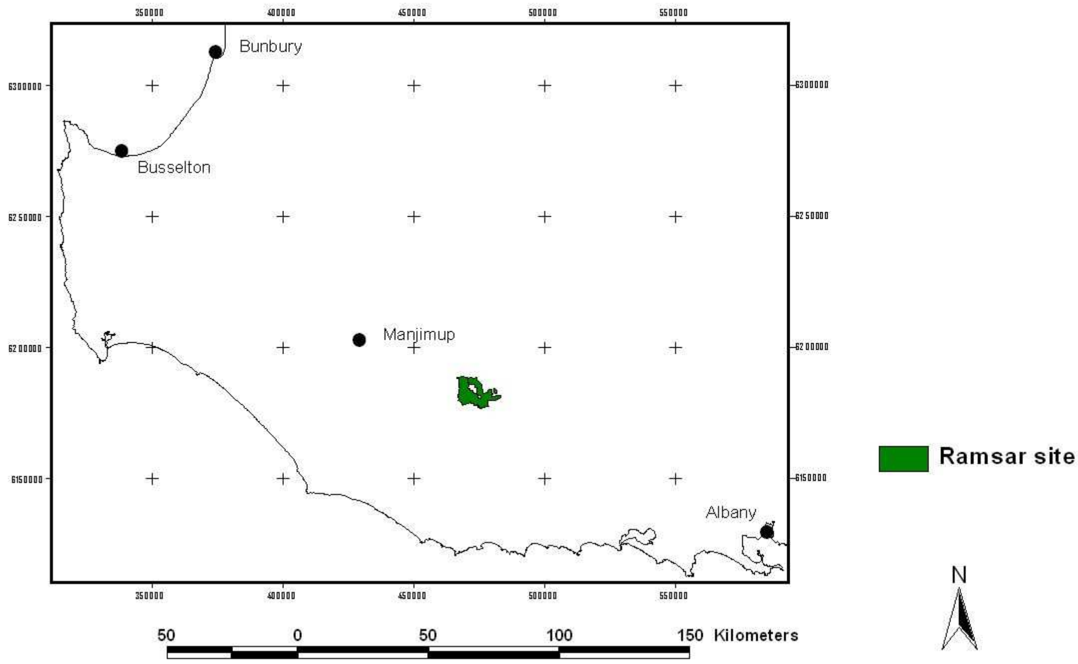

Figure 1. General location of the Muir-Byenup System Ramsar site.

The Muir-Byenup System Ramsar site is located within the Lake Muir-Unicup Wetland Complex Natural Diversity Recovery Catchment designated under the State Salinity Action Plan and its successor, the Salinity Strategy (Government of Western Australia 1996 and 2000). The Lake Muir-Unicup catchment covers approximately 694 km^2 and shares imprecise boundaries with the south-flowing drainages of the Tone, Deep and Frankland Rivers (Smith 2003). Figure 2 shows the location of named wetlands within the Ramsar site.

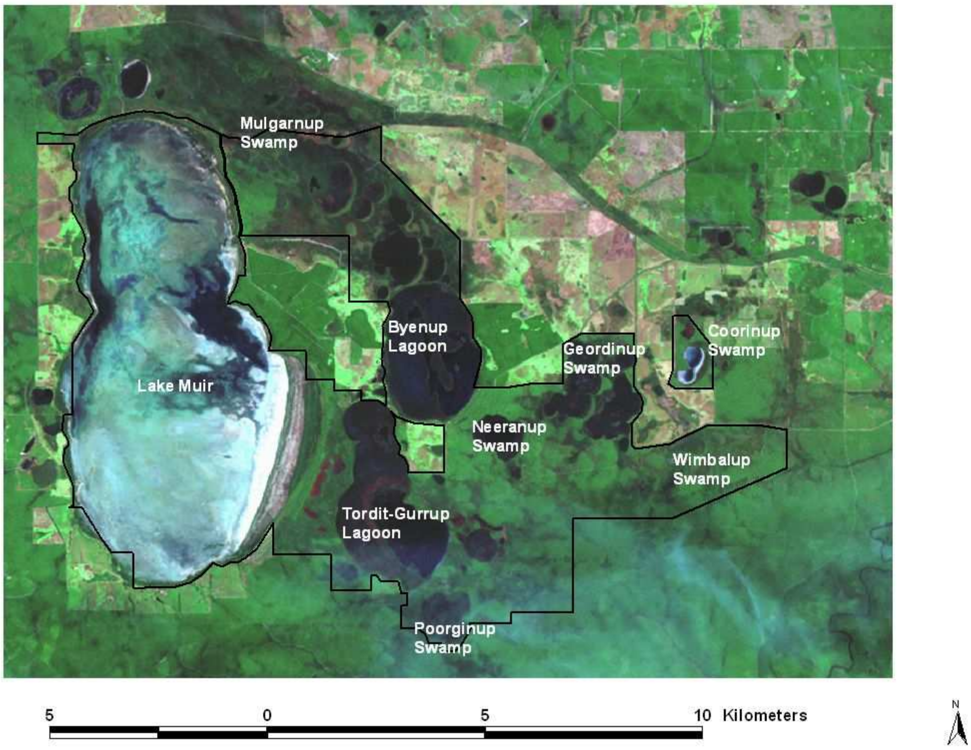

Figure 2. Landsat image of Muir-Byenup System Ramsar site showing individual named wetlands.

2.2 Land tenure and land use

The Muir-Byenup System Ramsar site includes the areas of Nature Reserve 31880 south of Muirs Highway. Nature Reserve 31880 is an "A" class reserve, which is vested in the Conservation Commission of Western Australia and managed by DEC for the purpose of 'water and conservation of flora and fauna'. Freehold land and gazetted road reserves are not included within the Ramsar site (Figure 3). The Ramsar site also does not currently include the recent additions to Nature Reserve 31880 along the western shoreline of Lake Muir. Recently acquired land south of Tordit-Gurrup Lagoon and east of Coorinup Swamp will also be added to the Nature Reserve (Lot 9247 on Plan 140779 and Lot 12565 on Plan 208115).

Surrounding land uses include agriculture, predominantly grazing and tree plantations on freehold land, and peat mining north of Lake Muir. The southern boundary of the Ramsar site adjoins the Lake Muir National Park. Previously, timber was also extracted from surrounding State Forest areas. Within the Ramsar site, land use is restricted to nature conservation, in line with the land tenure and purpose.

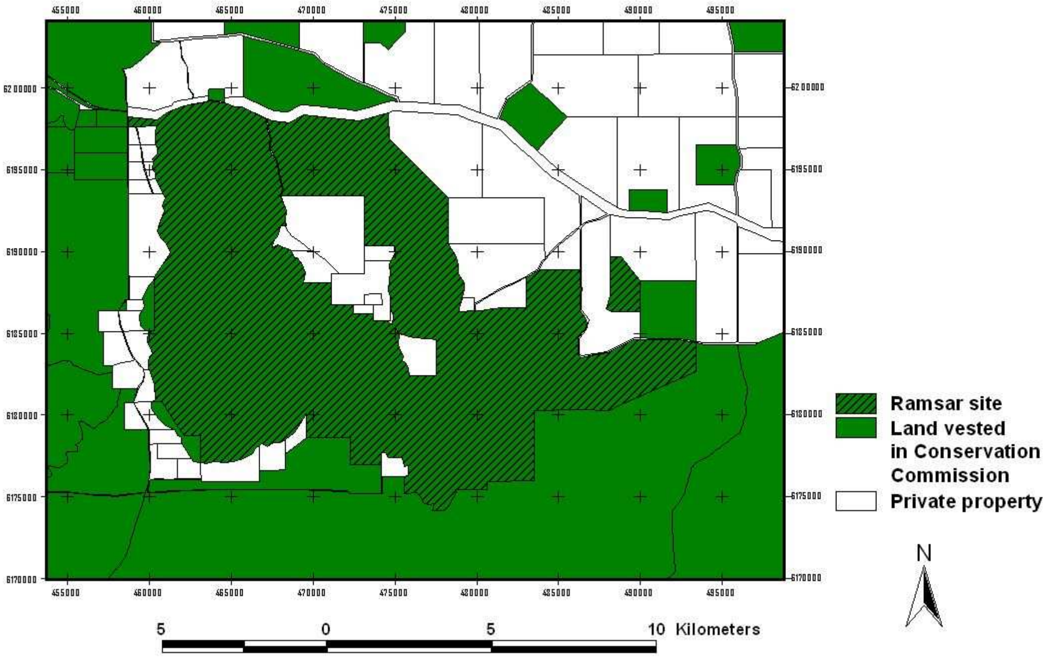

Figure 3. Land tenure within and adjacent to the Muir-Byenup System Ramsar site.

2.3 Climate

The Muir-Byenup System Ramsar site experiences a moderate Mediterranean climate of warm to hot, dry summers and cold, wet winters. Figure 4 shows the annual mean rainfall for the closest weather station to the Ramsar site, located 55 km to the west in Manjimup. Average annual rainfall decreases northeast across the region from 900 to 700 mm, with most rain falling between May and August (Figure 5) (Department of Conservation and Land Management 1998). Annual evaporation is approximately 1,300 mm. Mean monthly temperatures range from a maximum of 26°C in summer to a minimum of 5°C in winter (Figure 6) (Department of Conservation and Land Management 1998).

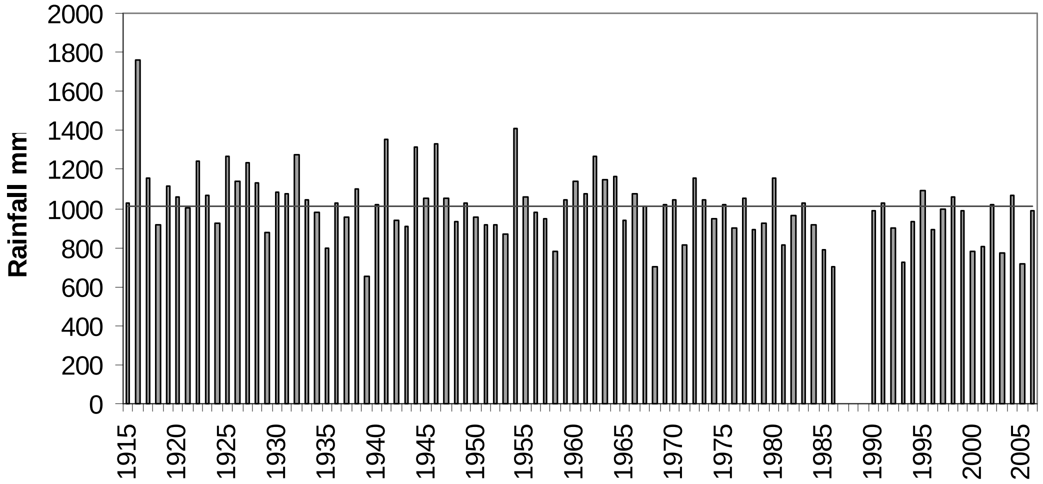

Figure 4. Manjimup annual rainfall 1916 to 2007 with long term mean indicated by the line (data from the Bureau of meteorology).

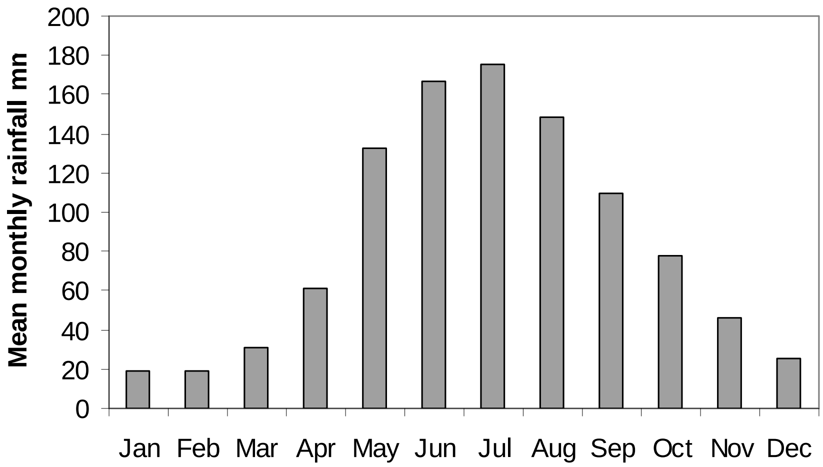

Figure 5. Mean monthly rainfall at Manjimup 1915 to 2008 (data from the Bureau of Meteorology).

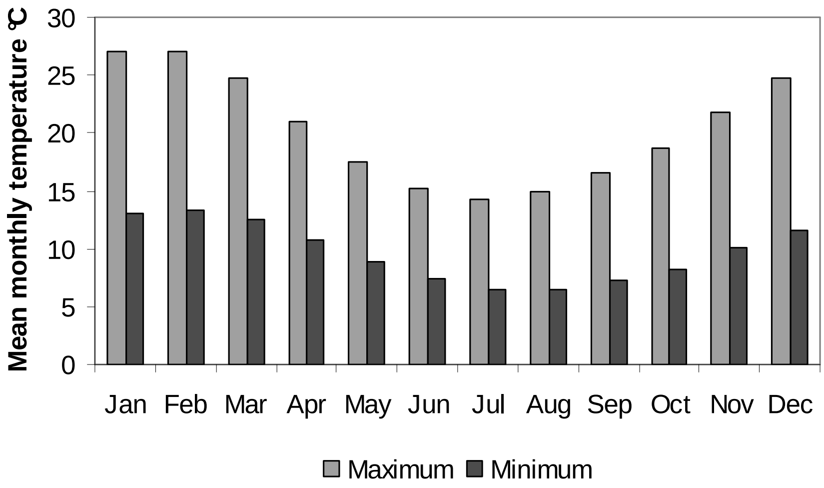

Figure 6. Mean maximum and minimum monthly temperatures at Manjimup 1936 to 2008 (data from the Bureau of Meteorology).

2.4 Wetland types

The Muir-Byenup System Ramsar site contains an unusual complex of natural wetlands, composed of partly inter-connected lakes and swamps, ranging in size (up to 4,600 ha), salinity (saline to fresh), water permanence (permanent to seasonal) and substrate (peat and inorganic), in an internally-draining catchment. The Ramsar site includes; a large lake (Lake Muir), smaller lakes and swamps (Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp) and interconnected flats. Wetland types consistent with the Ramsar wetland classification system have not been mapped or formally inventoried within the Muir-Byenup System Ramsar site. Within the Ramsar site multiple wetland types occur together, however, clear boundaries between wetland types are difficult to define. Due to the complexity of the site, this ECD discusses Lake Muir and the Byenup Lagoon System separately. The Byenup Lagoon System includes Byenup Lagoon, Tordit-Gurrup Lagoon, and Neeranup, Mulgarnup and Poorginup Swamps (V & C Semeniuk Research Group 1997).

Byenup Lagoon, Tordit-Gurrup Lagoon, Poorginup Swamp, Geordinup Swamp and Neeranup Swamp are naturally freshwater wetlands, while Lake Muir and Coorinup Swamp are naturally occurring saline wetlands. Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp are peat based wetlands, which are rare in Western Australia (Department of Environment and Conservation 2008).

Under the Ramsar wetland classification system there are seven main types of wetlands which have been identified within the Ramsar site, including:

Lake Muir:

- **R-Seasonal/intermittent saline/brackish/alkaline lakes and flats**.

Byenup Lagoon System:

- **O-Permanent freshwater lakes (> 8 ha);** includes large oxbow lakes
- **Tp-Permanent freshwater marshes/pools;** ponds (below 8 ha), marshes and swamps on inorganic soils, with emergent vegetation waterlogged for at least most of the growing season.
- **Ts-Seasonal/intermittent freshwater marshes/pools on inorganic soils;** includes sloughs, potholes, seasonally flooded meadows, sedge marshes.
- **U-Non-forested peatlands;** includes shrub or open bogs, swamps, fens.
- **W-Shrub-dominated wetlands;** shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils
- **Xf-Freshwater, tree-dominated wetlands;** includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils.

2.5 Ramsar Criteria

At the time of nomination, there were eight Ramsar Criteria against which the Muir-Byenup System could qualify for listing as a wetland of international importance. When listed in 2001, the Muir-Byenup System Ramsar site met four of these Criteria, as described in Table 2.

Table 2. Criteria for Identifying Wetlands of International Importance. Bold criteria refer to criteria relevant to the listing of the Muir-Byenup site (2001).

Number	Basis	Description
GROUP A: SITES CONTAINING REPRESENTATIVE, RARE OR UNIQUE WETLAND TYPES		
Criterion 1		A wetland should be considered internationally important if it contains a representative, rare or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.
GROUP B: SITES OF INTERNATIONAL IMPORTANCE FOR CONSERVING BIOLOGICAL DIVERSITY		
Criterion 2	**Species and ecological communities**	**A wetland should be considered internationally important if it supports vulnerable, endangered or critically endangered species or threatened ecological communities.** ***Justification*:** Three wetland-dependent orchids that are formally recognised as nationally vulnerable, and at least one other wetland plant species that may soon be so recognised, occur at the site in appreciable numbers. These plants mainly occur on seasonally inundated areas or wetland margins, which have been extensively cleared for agriculture elsewhere in South-Western Australia.
Criterion 3	Species and ecological communities	A wetland should be considered internationally important if it supports populations of plant and-or animal species important for maintaining the biological diversity of a particular biogeographic region.
Criterion 4	**Species and ecological communities**	**A wetland should be considered internationally important if it supports plant and animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.** ***Justification*:** The open lakes of the site regularly support moulting by thousands of Australian Shelducks; this is one of the most important moulting sites for Shelducks in South-western Australia. Lake Muir is used as a drought refuge by tens of thousands of waterbirds.
Criterion 5	**Waterbirds**	**A wetland should be considered internationally important if it**

		regularly supports 20,000 or more waterbirds. ***Justification*:** Up to 51,000 waterbirds have been counted at the site (at Lake Muir, when full). The annual data on water depth suggest conditions are suitable for use by 20,000 waterbirds at least several times within a 25 year period, which in the context of wetland availability in Western Australia is considered sufficient evidence of regular use by 20,000 waterbirds.
Criterion 6	**Waterbirds**	**A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or sub-species of waterbird.** ***Justification*:** At least five, possibly in the order of 10 Australasian Bitterns occur regularly and possibly breed in the sedge swamps of the site, which constitutes more than 1% of the South-Western Australian population. The site contains the core component of a wider suite of wetlands that constitutes one of the five remaining refuges for the South-Western Australian population of this globally threatened species.
Criterion 7	Fish	A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and-or populations that are representative of wetland benefits and-or values and thereby contributes to global biological diversity.
Criterion 8	Fish	A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and-or migration path on which fish stocks, either within the wetland or elsewhere, depend.

2.5.1 Current Ramsar Criteria

Since the Muir-Byenup Ramsar site was listed in 2001, the Ramsar Criteria have been further developed and revised. A ninth Criterion was added in 2005 after the 9th Meeting of the Conference of the Contracting Parties. During the preparation of this ECD an assessment of the Muir-Byenup System Ramsar site against each of the nine Ramsar Criteria was undertaken. Based on an analysis of the available data this assessment determined whether the Criteria for listing were still valid and whether any new criteria now applied. This analysis indicated that the original Ramsar Criteria still applied to the Ramsar site and the justification for each criterion has been revised. Two new criteria (1 and 3) have also been added.

The Muir-Byenup System Ramsar site, nominated in 2001, currently meets six of the nine Criteria for listing as an internationally important wetland, as described in Table 3.

Table 3. Criteria for Identifying Wetlands of International Importance. Bold criteria refer to criteria currently met by the Muir-Byenup System Ramsar site.

Number	Basis	Description
GROUP A: SITES CONTAINING REPRESENTATIVE, RARE OR UNIQUE WETLAND TYPES		
Criterion 1		**A wetland should be considered internationally important if it contains a representative, rare or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.** ***Justification*:** The Ramsar site is an excellent example of a wetland complex in a relatively undisturbed condition in the South-West Coast Australian Drainage Division (Environment Australia 2001). The peat based wetlands within the site are rare in Western Australia (Department of Environment and Conservation 2008; Environment Australia 2001) and they are also recognised as the most outstanding example in south-western Australia (Wetland Research and Management 2005).
GROUP B: SITES OF INTERNATIONAL IMPORTANCE FOR CONSERVING BIOLOGICAL DIVERSITY		
Criterion 2	**Species and ecological communities**	**A wetland should be considered internationally important if it supports vulnerable, endangered or critically endangered species or threatened ecological communities.** ***Justification*:** The Ramsar site supports a number of species listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Populations of three wetland dependent orchids *Caladenia christineae*, *Caladenia harringtoniae* and Tall Donkey Orchid (*Diuris drummondii)* occur on the margins of Lake Muir and elsewhere in the Ramsar site. These orchids are listed as Vulnerable under the EPBC Act and inhabit seasonally inundated areas or wetland margins. The Ramsar site supports the freshwater fish species Balston's Pygmy Perch (*Nannatherina balstoni*), which is listed as Vulnerable under the EPBC Act. The Ramsar site also supports the Australasian Bittern (*Botaurus poiciloptilus*), which is listed as Endangered under the IUCN Red List. In Western Australia, the Australasian Bittern population is now much restricted, with the largest concentration thought to occur within the Ramsar site (IUCN 2008).
Criterion 3	**Species and ecological communities**	**A wetland should be considered internationally important if it supports populations of plant and-or animal species important for maintaining the biological diversity of a particular biogeographic region.** ***Justification*:** Peat and primary saline wetlands at the site support endemic species and populations of plant and animal species important for maintaining the biodiversity of the South-West Coast Australian Drainage Division. The site includes 21 'priority taxa' listed by the Western Australian Department of Environment and Conservation, including endemic plant taxa *Eryngium* sp. Lake Muir and *Tribonanthes* sp. Lake Muir. *Astartea* sp. Lake Muir is also endemic to the site. The majority of the population of *Wurmbea* sp. Cranbrook also occurs at the Ramsar site. The Muir-Byenup System Ramsar site supports six of the eight endemic south-western Australian freshwater fish species including; the Western Pygmy Perch (*Edelia vittata*), Balston's Pygmy Perch (*Nannatherina balstoni*), Nightfish (*Bostockia porosa*), Western Minnow (*Galaxias*

		occidentalis), Black-striped Minnow (*Galaxiella nigrostriata*) and Mud Minnow (*Galaxiella munda*). The Ramsar site also supports a number of important macroinvertebrate taxa, including 32 endemic taxa (Storey (1998).
Criterion 4	**Species and ecological communities**	**A wetland should be considered internationally important if it supports plant and animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.** ***Justification*:** The Muir-Byenup System Ramsar site supports thousands of Australian Shelducks (*Tadorna tadornoides*) during their moulting phase. The Ramsar site supports breeding of Little Bittern (*Ixobrychus minutus*), Spotless Crake *(Porzana tabuensis*), Australasian Bittern, Black Swan (*Cygnus atratus*) and Eurasian Coot (*Fulica atra*). The Ramsar site is also used as a drought refuge by tens of thousands of waterbirds and supports 10 species identified under international migratory agreements (CAMBA, JAMBA, ROKAMBA and CMS).
Criterion 5	**Waterbirds**	**A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.** ***Justification*:** Up to 52,000 waterbirds (1989) have been counted at Lake Muir during periods of high water levels. Although there is no comprehensive data available on waterbird numbers since 1989, it is likely that the Ramsar site is still capable of regularly supporting more than 20,000 waterbirds as there has been no major change in water depth or salinity. Annual data on water depth, over a 25 year period, suggests that conditions were suitable for use by 20,000 waterbirds at least several times over this period.
Criterion 6	**Waterbirds**	**A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or sub-species of waterbird.** ***Justification*:** The Ramsar site supports at least five, and possibly up to 10, Australasian Bitterns, which exceeds the 1% population thresholds for south-western Australia (Wetlands International 2006). Although, no comprehensive counts have been made since 1991, there has been no major change in water quality or wetland vegetation at the site, suggesting that conditions remain suitable to support 1% of the south-western Australian population. The site also contains the core component of a wider suite of wetlands that constitutes one of the five remaining refuges for the south-western Australian population of Australasian Bitterns.
Criterion 7	Fish	A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and-or populations that are representative of wetland benefits and-or values and thereby contributes to global biological diversity.
Criterion 8	Fish	A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and-or migration path on which fish stocks, either within the wetland or elsewhere, depend.
Criterion 9	Other taxa	A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or sub-species of wetland-dependent non-avian animal species.

Additional criteria may also be applicable, however, at present there is insufficient data to adequately justify their inclusion. Criteria 7 and 8 could be considered, as the Muir-Byenup Ramsar site currently supports six of the eight endemic south-western Australian freshwater fish species including; the Western Pygmy Perch, Balston's Pygmy Perch, Nightfish, Western Minnow, Black-striped Minnow and Mud Minnow. However, further investigation is required to determine if the site meets the criteria in terms of supporting a significant proportion of indigenous fish species (population size) or life history stages and whether or not the site is important for fish stocks in terms of breeding and migration. Criterion 9 may also be applicable in terms of endemic macroinvertebrates, however, this will be dependent on obtaining reliable national population estimates.

3. MUIR-BYENUP SYSTEM RAMSAR SITE CRITICAL COMPONENTS AND PROCESSES

This section identifies, describes and where possible, quantifies the critical ecosystem components and processes of the site. These are the aspects of the wetland ecology which, if significantly altered, would result in a change of ecological character.

3.1 Wetland ecology drivers

Climate and geomorphology determine the location of a wetland within the landscape, the type of wetland and its' hydrological regime. The hydrological regime then influences wetland biota and the chemical processes and components. Figure 7 shows how the key drivers of wetland ecology, climate and geomorphology, interact with wetland hydrology and physical, chemical and biological components.

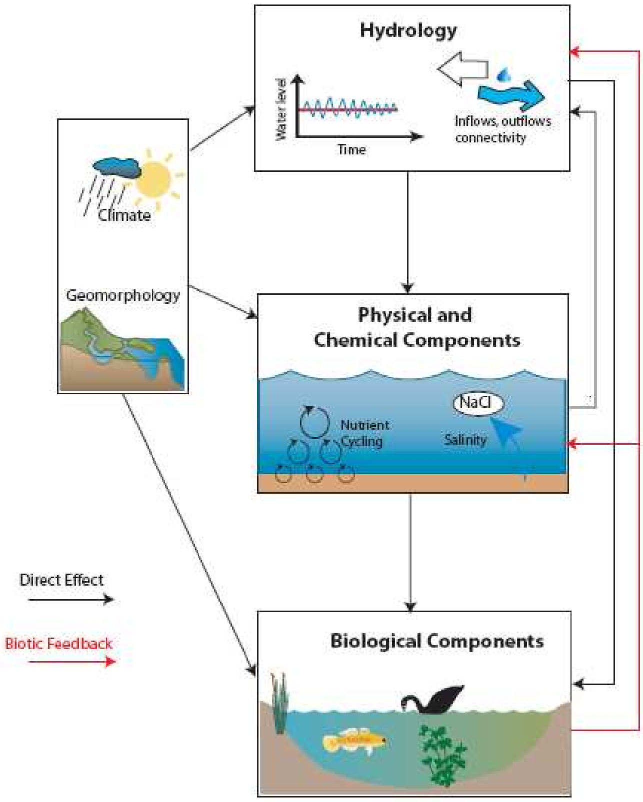

Figure 7. Conceptual model of wetland ecology (taken from Hale and Butcher 2007; adapted from Mitsch and Gosselink 2000)

3.2 Critical ecosystem components and processes

Table 4 presents a summary of the critical ecosystem components and processes of the Muir-Byenup System Ramsar site. These critical components and processes are discussed in detail in the following sub-sections. Due to the complexity of the site, components and processes, except for geomorphology and hydrogeology, are separated for Lake Muir and the Byenup Lagoon System (Byenup Lagoon, Tordit-Gurrup Lagoon, Neeranup, Mulgarnup and Poorginup Swamps).

The critical components and processes are quantified where possible to assist in understanding the natural variability of the Ramsar site. The identification of critical ecosystem components and processes also contributes to setting limits of acceptable change (Section 8), identification of knowledge gaps (Section 9) and monitoring requirements (Section 10).

The critical ecosystem components and processes for the Muir-Byenup System Ramsar site have been determined in accordance with the *National Framework and Guidance for Describing the Ecological Character of Australian Ramsar wetlands* (Department of the Environment, Water, Heritage and the Arts 2008). The critical components and processes have been identified as they:

- are important determinants of the site's unique character
- are important for supporting the Ramsar Criteria for which the site is listed
- are likely to change over short or medium time scales (<100 years)
- will cause significant negative consequences if change occurs.

Climate, geology and hydrogeology – are considered the overarching components that influence all aspects of the ecosystem.
Hydrology – directly influences the biota and habitat of the Ramsar site, including flora and fauna that support the listed Ramsar Criteria. Changes to the hydrological regime will have adverse consequences for the ecological character of the site.
Water quality – is important in providing suitable conditions for flora and fauna, including waterbirds, fish and macroinvertebrates that support the listed Ramsar Criteria.
Biota – form the foodweb and support the listed Ramsar Criteria. Changes to the biota and foodweb will have wide ranging impacts on the ecological character.

The interactions between the critical ecosystem components processes, benefits and services are provided in Section 6.

Table 4. Ecosystem components and processes of the Muir-Byenup System Ramsar site

COMPONENT	SUMMARY DESCRIPTION
Geology	Tertiary alluvial flats (Lake Muir) and Tertiary plateau and flat (Byenup Lagoon system).
Hydrogeology	Fresh to saline groundwater (0.5-90 ppt, dominated by $NaCl^-$) Soluble iron concentrations up to 100 mgL^{-1} in aquifers. Groundwater pH 5.2 to 6.3. Acidity is due to soluble metals. Potential acidity is present in the form of pyrite (metallic sulfide), identified in sedimentary and fractured or weathered bedrock aquifers.
Lake Muir	
Hydrology	Regionally, a major sink for groundwater and surface water flows and is almost exclusively internally draining. Inflow from artificial channels and Mulgarnup Swamp complex. Lake Muir (seasonal) is a naturally saline wetland and acts as a shallow evaporating basin (dry for 9 out of 10 years 1998-2008). Surface water area and depth varies seasonally.
Water quality	Saline (0.58-96 ppt). pH 6.2-9.9. Lower pH is associated with low water levels.
Flora (habitat)	Salt tolerant macrophytes: *Ruppia polycarpa*, *Lepilaena cylindrocarpa*

	Crassula helmsii, *Cotula coronopifolia*, *Triglochin procera* and *Zygnema* sp. Fringing vegetation includes; *Gahnia trifida* sedgelands, low shrublands (samphires), and wetland scrub (*Melaleuca viminea*, *M. cuticularis*, *M. rhaphiophylla* and *M. densa*). *Eucalyptus occidentalis* occurs at higher elevations. Notable flora includes wetland dependent orchids (*Caladenia christineae*, *Caladenia harringtoniae* and *Diuris drummondii)* and restricted species including *Lilaeopsis polyantha*.
Aquatic invertebrates	No information available.
Fish	No information available.
Frogs and reptiles	No comprehensive surveys. Likely to be rich in reptile fauna due to the presence of open woodland with sandy soils. The Oblong Tortoise (*Chelodina oblonga*) has been recorded at Tordit-Gurrup and is likely to be common throughout the wetlands. Tiger Snakes (*Notechis ater*) also occur (Department of Conservation and Land Management 1998). Also likely to be rich in frogs.
Mammals	Lake Muir is believed to contain many of the species found in the adjacent Perup Forest including Woylies (*Bettongia penicillata*), Numbat (*Myrmecobius fasciatus)* and Chuditch (*Dasyurus geoffroii*) (Department of Conservation and Land Management 1998). Lake Muir also contains suitable habitat for the Boodie (or Burrowing Bettong, *Bettongia lesueur*) and the Dalgyte (or Bilby, *Macrostis lagotis*) (Department of Conservation and Land Management 1998). It is also possible the semi-aquatic Water Rat (*Hydromys chrysogaster*) occurs here (Department of Conservation and Land Management 1998).
Waterbirds	Up to 52,000 waterbirds were counted on Lake Muir in March 1989, the most abundant species were Pacific Black Duck (*Anas superciliosa* up to 18,450), Grey Teal (*Anas gracilis* 16,000), and Eurasian Coot (*Fulica atra* 9,630). Six species of migratory shorebirds also use Lake Muir, including Red-necked Stints (*Calidris ruficollis* up to 517 in November 1985), which is listed as Migratory under the EPBC Act (CMS, CAMBA, JAMBA, and ROKAMBA). Water depth data suggests that conditions are suitable to regularly support 20,000 waterbirds. Lake Muir is used as a drought refuge by large numbers of waterbirds and for breeding by Black Swans, Silver Gulls and Australasian Shoveler.
Byenup Lagoon System	
Hydrology	Fresh to saline conditions (also seasonal cycles). Byenup Lagoon overflows when full into the area surrounding Mulgarnup Swamp, but bypasses the swamp itself. Mulgarnup and Poorginup Swamp join when flooded and overflow into Tordit-Gurrup Lagoon. Tordit-Gurrup Lagoon and Neeranup Swamp overflow into Byenup Lagoon. Surface water area and depth of wetlands varies seasonally, Coorinup Swamp acts as a shallow evaporating basin. However, Coorinup Swamp becomes fresh when flooded out and then re-saturates from sediments (primary saline lake). Byenup Lagoon is permanent, other wetlands are permanent or near permanent and minor swamps are inundated or waterlogged only in winter-spring. Areas of peat in Byenup, Tordit-Gurrup and Poorginup dry out seasonally.
Water quality	Poorginup Swamp is fresh (0.1-1.6 ppt), other wetlands range from brackish to saline with increased salinity in summer (Tordit-Gurrup Lagoon 0.65-15.2 and Byenup Lagoon 1.38-42.2 ppt). Poorginup Swamp is acidic (pH 5-6.6). Other wetlands pH 7-9. Nutrient concentrations are related to water levels and concentration effects, as well as drying out of peat. Wetlands do not behave as eutrophic.

Flora (habitat)	Macrophytes include *Villarsia submersa* and *Schoenus natans*. Fringing vegetation includes; *Baumea* sedgelands, *Melaleuca rhaphiophylla, M. lateritia* and *Astartea leptophylla, Taxandria juniperina* shrublands with Jarrah/Yate or *E. rudis* woodlands at higher elevations.
Aquatic invertebrates	DeHaan (1987) recorded 103 invertebrate taxa in Tordit-Gurrup Lagoon, Byenup Lagoon and Poorginup Swamp. Eight species were common between wetlands. Tordit-Gurrup Lagoon had the highest richness (60 species) and Poorginup the lowest (39 species) (DeHaan 1987). Insects accounted for 73% of total invertebrates. Species richness in Tordit-Gurrup and Byenup Lagoons decreases in April (low water levels and increased salinity). Species of interest include 11 Hydracarina taxa (watermites) (six in Poorginup Swamp); including *Pseudohydryphantes doegi, Acercella poorginup, Huitfeldtia* sp. and crustaceans *Cherax preissii* and *C. quinquecarinatus.* Storey (1998) found 219 taxa, 32 known to be endemic to south-western Australia. Greatest numbers of endemic species were found in Poorginup Swamp. At least 78 species of ostracods and copepods were recorded, with six ostracods and one cyclopoid only known in the Muir-Unicup area. New species were recorded within the Rotifera and Cladocera families and two new species of dytiscid water beetle, *Sternopriscus* sp. nov. and *Antiporus pennifoldae* were also found. *Hygrobia wattsii* sp. n (Coleoptera: Hygrobiidae) found in Byenup Lagoon appears to be restricted to peatland swamps/lakes and is likely to be impacted by drainage and increased salinity (Hendrich 2001).
Fish	7 fish species, including 6 endemic to south-west WA (Western Pygmy Perch, Balston's Pygmy Perch, Nightfish, Western Minnow, Black-stripe Minnow and Mud Minnow) and introduced Mosquitofish. Poorginup Swamp had the greatest number of native fish species (5) followed by Mulgarnup Swamp (4). Black-stripe Minnow and Mud Minnow (Poorginup Swamp) and Balston's Pygmy Perch (Mulgarnup Swamp) are restricted to south-west WA. Balston's Pygmy Perch is listed as Vulnerable under the EPBC Act, Black-stripe Minnow and Mud Minnow are listed as Lower Risk, near threatened (IUCN Red List, 2009).
Frogs and reptiles	No comprehensive surveys, likely to be rich in reptile fauna due to the presence of open woodland with sandy soils. The Oblong Tortoise has been recorded at Tordit-Gurrup and is likely to be common throughout the wetlands. Tiger Snakes also occur (Department of Conservation and Land Management 1998). Also likely to be rich in frogs.
Mammals	The Byenup Lagoon System is believed to contain many of the species found in the adjacent Perup Forest including Woylies, Numbat and Chuditch (Department of Conservation and Land Management 1998). The site also contains suitable habitat for the Boodie and Dalgyte and it is also possible the semi-aquatic Water Rat occurs (Department of Conservation and Land Management 1998).
Waterbirds	Tordit-Gurrup is used as a drought refuge by large numbers of waterbirds. Open water is important for Australian Shelduck in their moulting phase (over 12,000 in December 1992). Non-vegetated beaches of Tordit-Gurrup Lagoon and Byenup Lagoon provide habitat for waders, ducks and swans. Poorginup Swamp, and Byenup and Tordit-Gurrup Lagoons contain critical habitat for Australasian Bitterns. Little Bittern, Spotless Crake, Australasian Bitterns, Black Swans and Eurasian Coots breeding has been confirmed within the Byenup Lagoon System. Local knowledge suggests Grebes, Swamp Harrier, Blue-billed Duck, Cormorants, Sea-eagles and Spoonbills also breed at the site (P. Taylor, pers. com.).

3.2.1 Geology

Smith (2003) has summarised the geology of the Muir-Byenup System Ramsar site. The Ramsar site overlies the Proterozoic Albany-Fraser Orogen, between the Pemberton and Northcliffe Faults (Figure 8). The Northcliffe Fault divides the Albany-Fraser Orogen into the northern Biranup and southern Nornalup complexes. The Northcliffe and Pemberton faults are associated with an east-west trending shear zone between the Archaean Yilgarn Craton (north-east of the Ramsar site) and the Albany-Fraser Orogen.

In the Proterozoic Albany-Fraser Orogen, the northern Biranup Complex is an intensely deformed metamorphic belt of layered gneissic rocks, characterised by pronounced layering and high total magnetism (Myers 1995). The southern Nornalup Complex consists of granitic orthogneiss and paragneiss, which are less deformed than rocks in the Biranup Complex, intruded by a large volume of granite. These Proterozoic granitic rocks are also associated with migmatites. Mafic dykes are also present in the Albany-Fraser Orogen.

Cainozoic sediments overlie Precambian basement rocks in the area, many of which are associated with paleodrainages, active in the Jurassic-Cretaceous (213-65 million years ago (ma)), but possibly dating from the Permian (286-253 ma) (Smith 2003). In the late Eocene (42-<38 ma), prior to the Eocene marine transgression which extended Bremer Basin sediments northwards, these channels became clogged by mainly fluvial sediments of the Werillup Formation.

The Eocene transgression (Tuketja transgression) and subsequent regression (Late Tertiary <38 ma) may have been due to sea level changes resulting from global interruption of subduction and from plate edge stretch, rebound and sag, arising from separation from Antarctica. Sediments from the Pallinup Formation have been found east of Unicup Lake, however they have not been found in the Ramsar site, likely due to extensive erosion. Tuketja transgression left widespread thin sediments at up to 300 m AHD which formed various geological units through laterisation. As early as the Oligocene, southward tilting of the Ravensthorpe Ramp led to partial dissection by new, relatively short, south-flowing drainages.

Table 5 describes the origin, geologic and geomorphological characteristics and stratigraphy and soils of the Muir-Byenup System Ramsar site (V & C Semeniuk Research Group 1997).

Table 5. Wetland suites of the Muir-Byenup System Ramsar site (V & C Semeniuk Research Group 1997).

Muir Suite	
Geologic/geomorphic framework	Tertiary alluvial flats (Young Basin, isolated excavation structure in Old Basin)
Wetland description	Megascale sumpland (Lake Muir), sumplands, seasonal freshwater leptoscale to microscale creeks; vegetation bacataform (peripheral cover; mottled vegetation).
Stratigraphy	Underlain by a range of substrates. Eastern and northern sides of Lake Muir are underlain by cream sand overlying mottled grey/green sandy mud overlying mottled orange/yellow/grey mud overlying green muddy sand to a depth of 1 m. Sumpland margin on western side composed of grey clay underlain by a layer of white coarse sand to a depth of 1.5 m. Sediments underlying wetlands of the dune/swale sequence are alternately quartz sand and gravelly quartz with grains of $CaCO^3$. Creeks are underlain by a layer of humic sand overlying mottled orange/grey muddy sand overlying mottled sand with ferricrete nodules.
Origin of wetland	Lake Muir is a basin formed by geomorphic processes belonging to a former arid period. At the time of its initial formation, undulation in the plateau terrain in the area, intersected the regional saline water table, forming a wetland depression. This basin was enlarged by salt weathering of the margins, combined with aeolian deflation. The contact zone of the large basin with the older plateau surface underwent rill and creek erosion, resulting in drainage lines down the slope. Today the basin continues to be a window to the watertable.
Byenup Suite	
Geologic/geomorphic framework	Tertiary plateau and flat (Old Plateau and Old Basin)
Wetland description	Lakes, sumplands, damplands, flats and several small scale creeks. Microscale to macroscale wetland basins which are rounded, sub-rounded and ovoid, freshwater to hyposaline; vegetation varies from complete to patchy peripheral cover. Freshwater floodplains; vegetation maculiform (patchy cover; mottled vegetation).
Stratigraphy	Basins are underlain by peat or peaty sand over sand, or underlain by peat over black mud (clay) over sand, or underlain by peat or peaty sand over cream/orange mottled muddy sand (saprolite) with nodules of laterite. Floodplains underlain by either white sand over laterite or saprolite over laterite.
Origin of wetland	Many of the basins are surrounded by beach ridges indicating a period of aridity in the history of the wetlands.

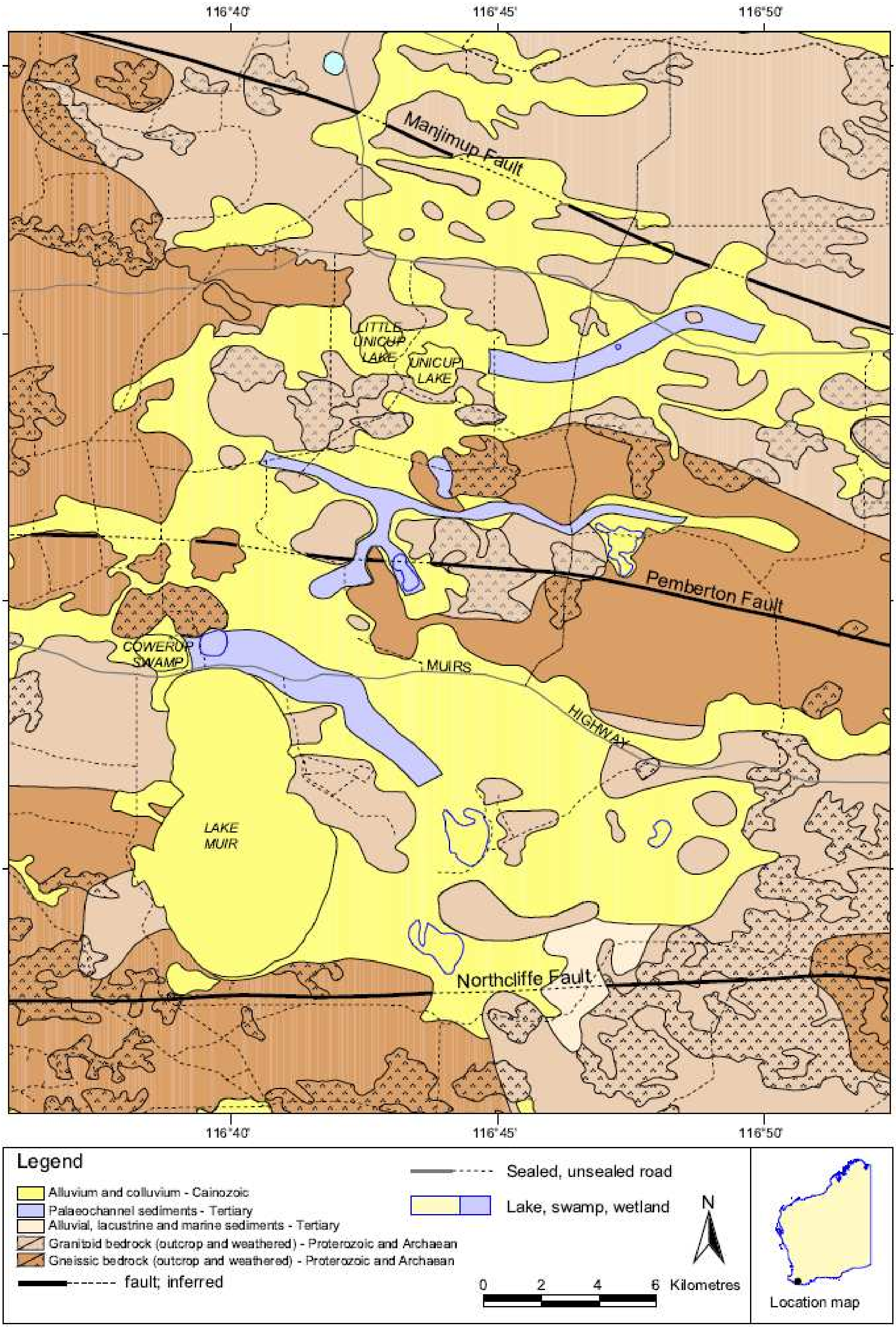

Figure 8. Hydrogeology of the Muir-Byenup System Ramsar site (Smith 2003).

3.2.2 Hydrogeology

This section presents results from a groundwater investigation program undertaken by DEC (unpublished, M. Smith, pers. com.).

Groundwater is present in two distinct hydrogeological settings in the Muir–Byenup wetland system. These are the hard rock Albany–Fraser Province, and the Late Eocene sediments of the Eucla Basin, which overlies the Albany–Fraser Province. The three aquifers are the thin surficial aquifer, the sedimentary aquifer and the fractured or weathered bedrock aquifer.

The unconfined surficial aquifer is comprised of Cainozoic alluvial, colluvial, and lacustrine sediments that overlie both the sedimentary aquifer and the fractured or weathered bedrock aquifer. Figure 9 shows a diagrammatic cross section of the Lake Muir paleochannel (after De Silva 2003) with typical stratigraphic profiles for the Muir-Byenup catchments (Smith 2003).

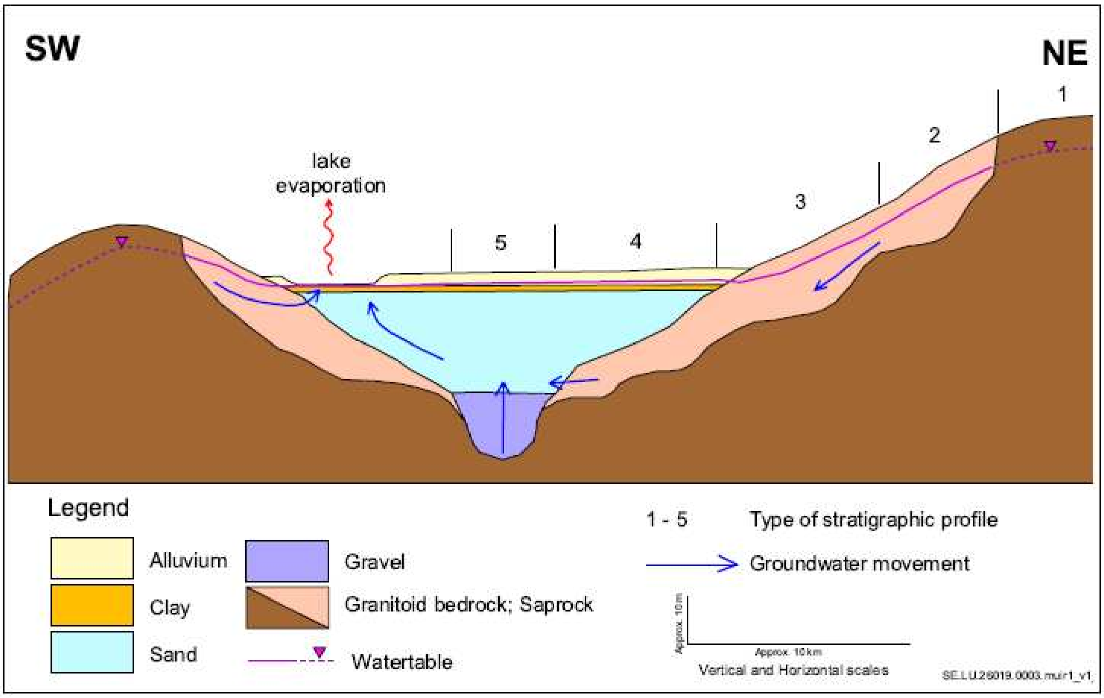

Figure 9. Diagrammatic cross section of the Lake Muir paleochannel (after De Silva 2003) with typical stratigraphic profiles for the Muir-Byenup catchments (Smith 2003).

The sedimentary aquifer is comprised of fluvial sediments correlated with the Late Eocene Werillup Formation. This aquifer is mostly confined by the surficial aquifer, but where exposed on the surface it is unconfined. The sediments consist of interbedded dark grey to black carbonaceous clays, carbonaceous silts and medium to coarse grained quartz sand.

The aquifer is laterally extensive in the catchment and is developed over fresh granite and gneiss. Within the valley and plains this aquifer is overlain by either the sedimentary or surficial aquifers. On the slope and crests of hills the aquifer tends to be the upper most aquifer and is capped by an *in situ* ferruginous duricrust (commonly referred to as laterite).

The Muir-Byenup System Ramsar site is part of a small internally draining groundwater basin and has groundwater TDS values ranging from 500 to 90,000 mgL^{-1} (0.5-90 ppt) (seawater ~35,000 mgL^{-1}, 35 ppt). The groundwater flow direction changes from southwest (in the north of the area) to west and northwest in the south of the area. Where the groundwater flows converge, the chain of wetlands exist. Groundwater is mostly discharged as evaporation through Lake Muir.

Groundwater in the catchment is marine in origin and this is reflected in the sedimentary aquifer where the water chemistry is dominated by sodium and chloride ions. In the aquifer, calcium and sodium ions make up about 80% of the major cations with magnesium making up the remaining 20%. Chloride is still the major anion. In all three aquifers nitrate is generally less than 2 mgL^{-1}. High levels of dissolved iron are present with the soluble iron concentrations ranging from below detection to about 100 mgL^{-1}.

The groundwater has mostly a net alkalinity, but groundwater with a net acidity (acidity-alkalinity) has been identified with pH values between 5.2 and 6.3. The acidity is due to soluble metals such as iron, manganese and at low pH, aluminium. Where this groundwater discharges on the surface, aluminium may precipitate as alunite and iron as jarosite or natrojarosite, and the pH values fall to between 2 and 4. Potential acidity is present in the form of pyrite (metallic sulfide) that has been identified in the sedimentary and bedrock aquifers.

3.2.3 Surface hydrology

The Lake Muir-Unicup catchment is approximately 694 km^2 and shares imprecise boundaries with the south-flowing drainages of the Tone, Deep and Frankland rivers (Smith 2003). Lake Muir, at approximately 41 km^2 is the largest surface waterbody in the catchment, and is almost exclusively internally draining (Smith 2003). Other wetlands overflow to downstream wetlands or waterways such as the Tone or Frankland rivers (Smith 2003). Water is derived from minor seasonal streams of up to 5 km long within a surface catchment that covers about 38,500 ha (Department of Conservation and Land Management 2003). There are also a number of constructed channels that drain adjacent farming land and divert runoff into wetlands or directly into the Tone River (Smith 2003).

Depending on rainfall, evaporation and groundwater connectivity, wetlands in the Muir-Unicup catchments are either; permanent or ephemeral, naturally fresh, naturally saline or seasonally alternating (Smith 2003). These wetlands can belong to groundwater systems overlying poorly conductive clays or they may be ‘windows’ to deeper regional aquifers, depending on their position in the landscape (Smith 2003).

The Lake Muir-Unicup catchment has been divided informally into a number of sub-catchments, including: Lake Muir, Unicup and Yarnup (Figure 10) (Smith 2003).

The Lake Muir catchment (370 km^2) is a large flat area of internal drainage consisting of small to very large permanent and intermittent lakes, swamps and floodplains (Smith 2003). Surface water flows for the Muir-Byenup System Ramsar site are shown in Figure 11. Lake Muir is a major sink for groundwater and surface water in the region (Smith 2003). Very infrequent overflow from Lake Muir drains southwest through swamps into the Deep River (Smith 2003). Inflow surface water is channelled into Lake Muir from the north and east. From the north, water enters via artificial channels associated with peat mining activities (Department of Conservation and Land Management 2003), which run beyond Red Lake through Cowerup Swamp (Smith 2003) (Figure 11). On the eastern side of Lake Muir, inflow enters at Mulgarnup Bridge fed by the Mulgarnup Swamp complex (Smith 2003) (Figure 11).

Flows into the Mulgarnup Swamp complex, from under the Muirs Highway, originate from three distinct sources; Pindicup Creek, Decampo Creek and Noobijup Creek (Smith 2003). The Mulgarnup Swamp complex is also fed by Byenup Lagoon, which overflows to the north annually when full (Smith 2003) (Figure 11), although Mulgarnup Swamp itself is bypassed (R. Hearn, pers. com.). Byenup Lagoon is fed by average to wet years overflow from southern Tordit-Gurrup Lagoon and Neeranup Swamp (Smith 2003) (Figure 11).

Byenup Lagoon, Tordit-Gurrup Lagoon, Poorginup Swamp, Geordinup Swamp and Neeranup Swamp are naturally freshwater wetlands, while Lake Muir and Coorinup Swamp are naturally occurring saline wetlands. Lake Muir and Coorinup Swamp act as shallow evaporating basins, drying up to salt pans in summer (Smith 2003). Coorinup Swamp is periodically freshened when flooded before it re-saturates with salts from the regolith (R. Hearn, pers. com.). Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp are peat swamps, formed by climatic conditions, very slow water movement and a shallow lake basin, and strongly influence water quality by providing an effective filter and buffering capacity (Department of Environment and Conservation 2008).

The Muir-Byenup System Ramsar site possibly contributes to the maintenance of groundwater in surrounding areas, however little is known on the interactions between shallow and deep groundwater systems and groundwater interactions with surface water systems (Department of Conservation and Land Management 2003). These are currently being investigated (Department of Conservation and Land Management 2003). Smith (2003) suggested that due to permeable lake floor sediments and/or large areal extent, wetlands in the Ramsar site were likely to have groundwater flow-through regimes, although some could exhibit seasonal discharge or recharge regimes.

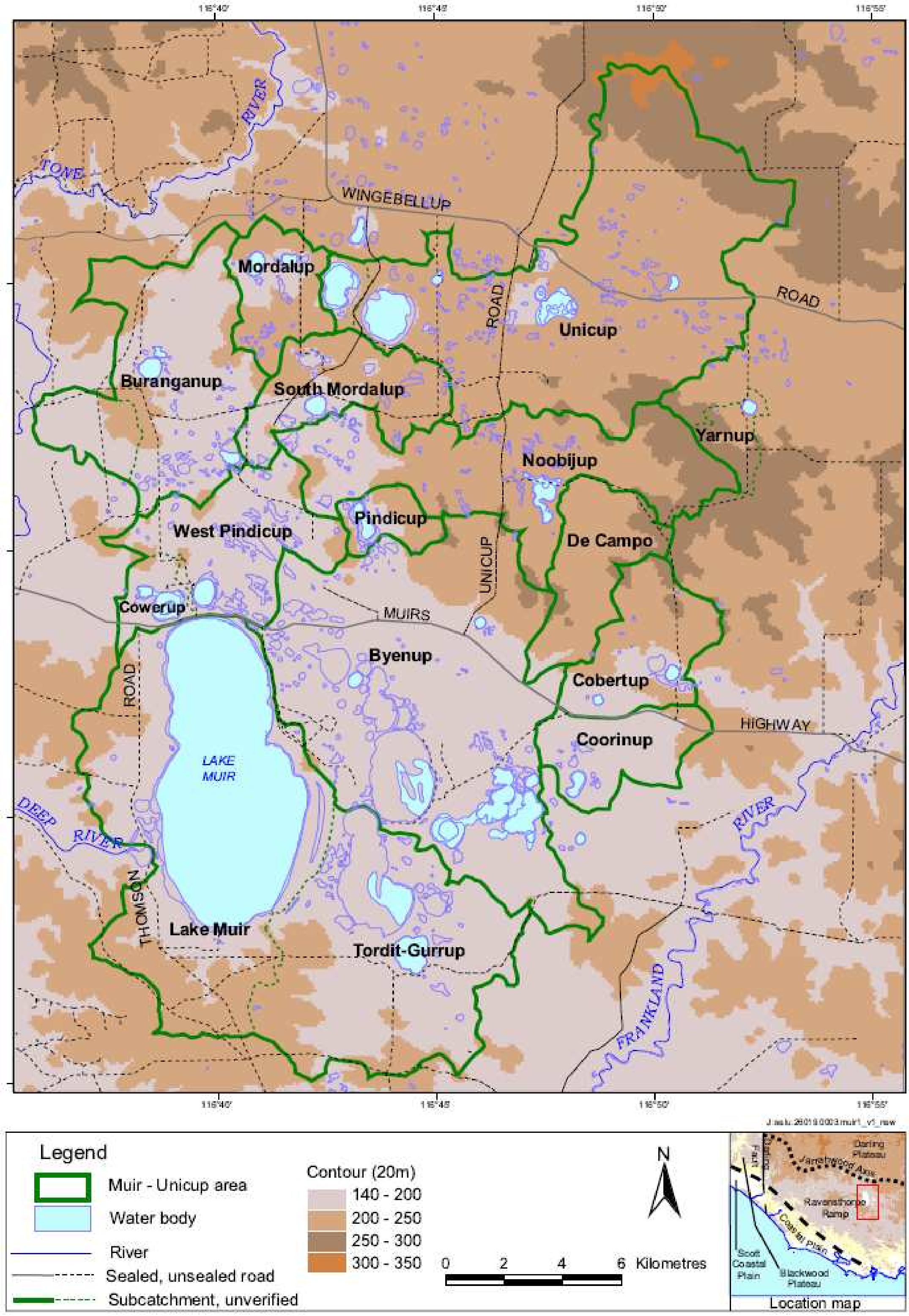

Figure 10. Muir-Unicup physiographic divisions, topography and subcatchments (Smith 2003).

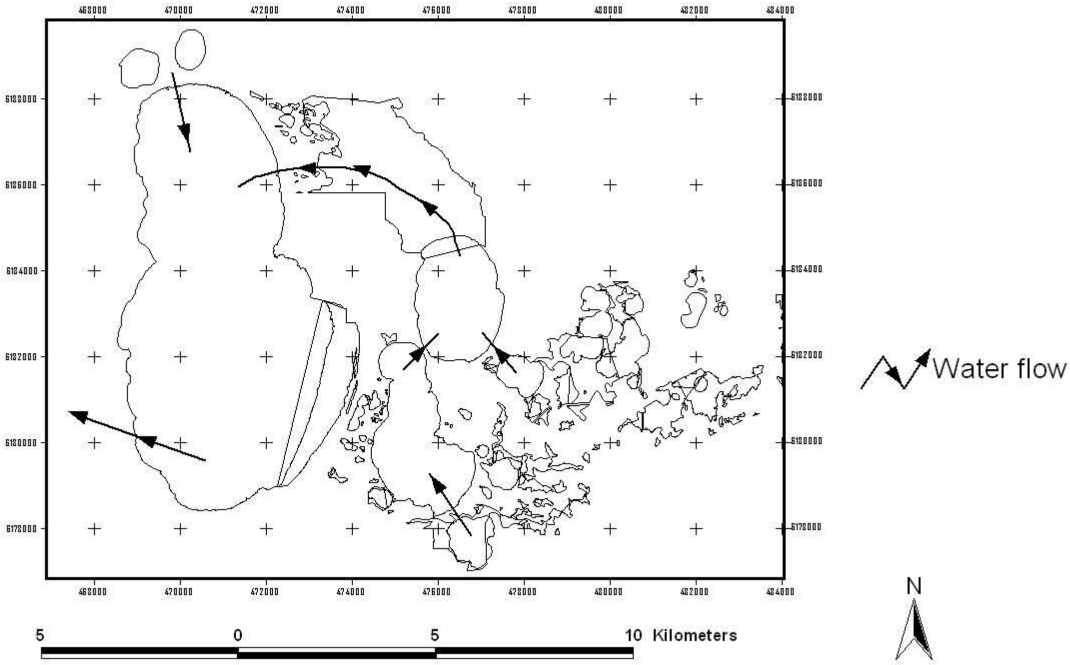

Figure 11. Surface water flows for the Muir-Byenup System Ramsar site.

Water levels

Surface water area and depth of wetlands in south-west Western Australia varies seasonally, with water levels rising in winter and spring and falling in summer and autumn (Lane and Munro 1982). Mean annual water depth data for the Muir-Byenup System Ramsar site have been obtained from the Department of Environment and Conservation (unpublished data from J. Lane, DEC 2008). This data is part of a monitoring program of wetlands in WA in which water quality parameters have been measured at least twice yearly for Lake Muir, Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp since the late 1970s. Mean annual data are presented up until 2008 to allow determination of trends since listing (2001) and in context with historical variation. Statistical analyses were also undertaken to determine significant differences between years (One-way ANOVA).

Lake Muir

Lake Muir is often dry in autumn (nine out of the 10 last years 1998-2008) (R. Hearn, pers. com.) and the maximum mean annual depth recorded since 1978 is 1.3 m (November 1988) (Department of Conservation and Land Management 2003) (Figure 12). Differences in mean annual depth between years were highly significant ($P<0.001$). Between 1988 and 2005 conditions were generally wetter and fringing vegetation communities were flooded at peak levels in 1988 but had not been flooded regularly since (Froend and Loomes 2001). However, there has been no significant change in mean annual water depth at Lake Muir since the time of listing (2001).

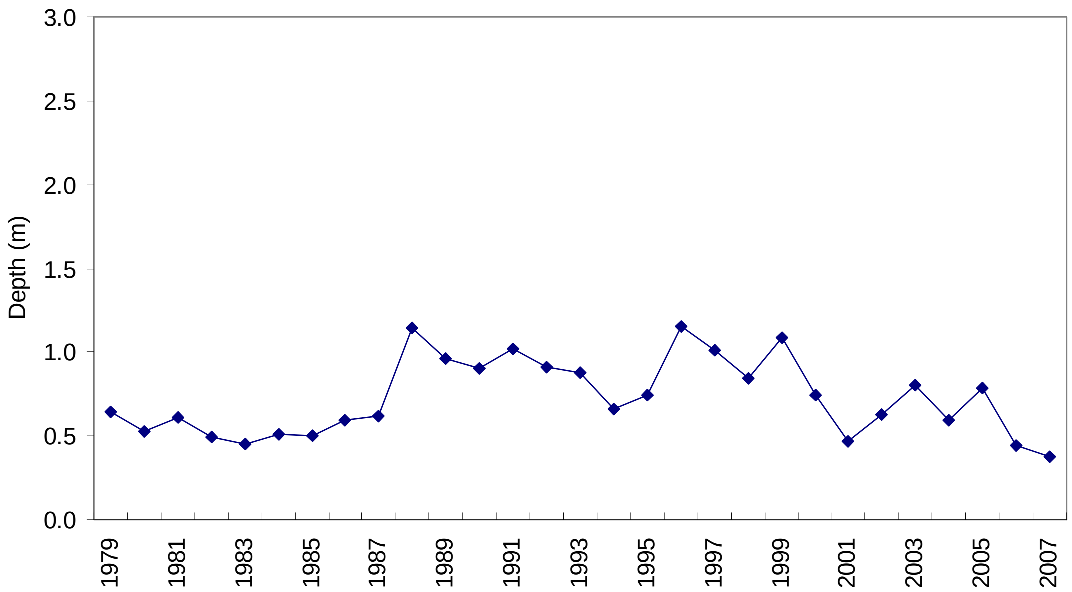

Figure 12. Mean annual depth for Lake Muir 1979 to 2008 (unpublished data from J. Lane, DEC 2008).

<u>Byenup Lagoon System</u>

In the Byenup Lagoon System, differences in mean annual water depth between years were significant for all three wetlands ($P<0.001$).

Byenup Lagoon is permanent (Department of Conservation and Land Management 2003) with water levels varying between 0.4-2.8 m (Figure 13). Peat in Byenup Lagoon, comprising one third of the total surface area, dries out in summer months when the watertable drops (DeHaan 1987). Depth in Byenup Lagoon was generally higher between 1989 and 2000 compared to the periods 1978-1988, and 2001-2007, with 1987 and 1988 having the lowest water depth (1.5 m) (Figure 13).

Tordit-Gurrup Lagoon has also never dried up during the period of records (Department of Conservation and Land Management 1998) with mean annual water depths ranging between 0.15-3.1 m. Peat in Tordit-Gurrup Lagoon, also about one third of the total surface area, dries out seasonally while open water remains, fluctuating between 1.7 to 2.9 m (DeHaan 1987). Water depths at Tordit-Gurrup Lagoon have remained relatively constant throughout 1977 to 2006, with the exception of drier years in 1987-88, 1995 and 2007 (Figure 13).

Historically, Poorginup Swamp, which is entirely filled with peat, dried out annually between March and May (DeHaan 1987). Artificial drains installed in the wetland adjacent to Poorginup Swamp have reduced water levels by 0.5-0.75 m, altering local hydrological systems and indirectly causing Poorginup Swamp to dry out more rapidly than other wetlands in the Ramsar site (R. Hearn, pers. com.). Mean annual water depths vary between 0-0.72 m and are significantly different between years, with lower depths in 1987 and 2007 (Figure 13).

Other wetlands are permanent or near permanent and minor swamps are inundated or waterlogged only in winter-spring (Department of Conservation and Land Management 2003).

Water depth for all three wetlands is highly variable between years, however, there has been no significant change in mean annual water depth since the time of listing (2001).

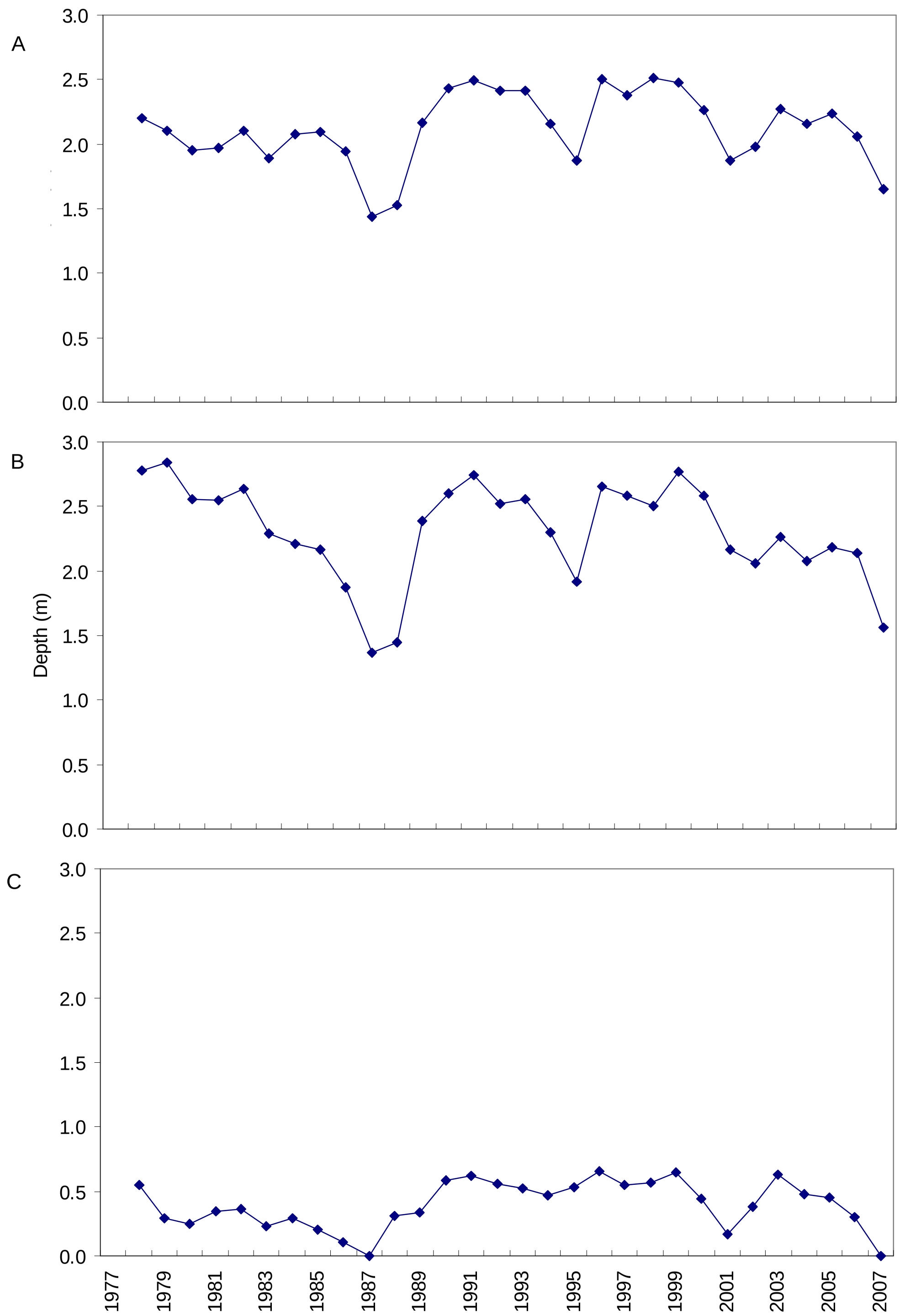

Figure 13. Mean annual water depth for Byenup Lagoon (A), Tordit-Gurrup Lagoon (B) and Poorginup Swamp (C) 1977 to 2008 (unpublished data from J. Lane, DEC 2008).

3.2.4 *Water quality*

Mean annual water quality data for the Muir-Byenup System Ramsar site have been obtained from the Department of Environment and Conservation (unpublished data from J. Lane, DEC 2008). This data is part of a monitoring program of wetlands in WA in which salinity and other surface water quality parameters have been measured at least twice yearly for Lake Muir, Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp since the late 1970s. Mean annual data are presented up until 2008 to allow determination of trends in water quality since listing (2001) and in context with historical variation. Trends for each parameter and any significant changes since listing are discussed. Statistical analyses were undertaken to determine significant differences between years (One-way ANOVA). Results from these analyses are also discussed for each parameter.

Seasonal water quality data for wetlands sampled within the Byenup Lagoon System by Wetland Research and Management in 1996/97 and 2003/04 are also discussed (Wetland Research and Management 2005). These results came out of a study aiming to assess the nature conservation values and physicochemistry of wetlands within the Lake Muir-Unicup Wetland Complex Natural Diversity Recovery Catchment.

ANZECC/ARMCANZ 2000 guidelines for protecting aquatic ecosystems in south-western Australia are shown in Table 6 and for salinity in Table 7. These guidelines are used within this ECD as a guide only and to provide context, as they are generally not applicable within the Muir-Byenup System Ramsar site. For naturally occurring saline wetlands such as Lake Muir and Coorinup Swamp (Smith 2003), and peat based wetlands in the Byenup Lagoon System, ANZECC guidelines for water quality are not appropriate due to the seasonal drying and concentration effects. For example, drying of peat releases nutrients, particularly organic nitrogen (DeHaan 1987). Indicator species such as fringing vegetation and macroinvertebrates may provide useful guidelines for water quality (see Section 7).

Table 6. Default trigger values for physical-chemistry stressors for slightly disturbed ecosystems, applicable to south-west Western Australia. TP = total phosphorus, FRP = filterable reactive phosphate, TN = total nitrogen, NOx = oxides of nitrogen, NH_4^+ = ammonia, DO = dissolved oxygen (ANZECC/ARMCANZ 2000).

Ecosystem Type	TP mgL^{-1}	FRP mgL^{-1}	TN mgL^{-1}	NOx mgL^{-1}	NH_4^+ mgL^{-1}	DO % saturation[2]		pH	
						Lower	Upper	Lower	Upper
Lakes and Reservoirs	0.01	0.005	0.35	0.01	0.01	90	No data	6.5	8.0
Wetlands	0.06	0.03	1.5	0.1	0.04	90	120	7.0	8.5

Table 7. Default trigger values for conductivity (EC, salinity) for slightly disturbed ecosystems in south-west Western Australia (ANZECC/ARMCANZ 2000).

Ecosystem type	Salinity		Explanatory notes
	μScm^{-1}	ppt*	
Lakes, reservoirs and wetlands	300-1500	0.16-0.82	Values at the lower end of the range are observed during seasonal rainfall events. Values even higher than 1,500 µS/cm are often found in saltwater lakes and marshes. Wetlands typically have conductivity values in the range of 500-1,500 µS/cm over winter. Higher values (>3,000) are often measured in summer due to evaporative losses.

*ppt was approximated using a conversion factor of 1 μScm^{-1} = 0.0005 ppt

Table 8 presents a summary of water quality ranges (minimum and maximum annual values for the period 1977-2008 for salinity, Total and soluble N and P, and pH) for all wetlands within the Muir-Byenup System Ramsar site (unpublished data from J. Lane, DEC 2008). Further discussion of each parameter follows in the sections below.

Table 8. Summary of water quality ranges (minimum and maximum annual values for the period 1979-2008) (depth, salinity, total and soluble N and P, and pH) for all wetlands within the Muir-Byenup System Ramsar site (unpublished data from J. Lane, DEC 2008).

Water quality parameter		Byenup Lagoon System		
	Lake Muir	Byenup Lagoon	Tordit-Gurrup Lagoon	Poorginup Swamp
Salinity (ppt)	0.58 - 96	1.38 - 42.2	0.65 - 15.2	0.1 - 1.6
Total N (mgL^{-1})	0.58 - 5.8	1.3 - 3.5	1 - 2.6	0.63 - 1.7
Soluble N (mgL^{-1})	0.4 - 4.7	0.96 - 3.3	0.77 - 2.2	0.47 - 1.4
Total P (mgL^{-1})	0.005 - 0.65	0.005 - 0.11	0.005 - 0.02	0.005 - 0.36
Soluble P (mgL^{-1})	0.005 - 0.1	0.005 - 0.07	0.005 - 0.09	0.005 - 0.11
pH	6.2 - 9.9	6.8 - 9.3	6.9 - 9.3	4.6 - 8.3

Salinity

Lake Muir

Lake Muir is a naturally occurring saline wetland acting as a shallow evaporating basin (Smith 2003). Mean annual salinity is presented for Lake Muir from 1979 to 2008 (unpublished data from J. Lane, DEC 2008) (Figure 14). Salinity (ppt) ranged from 0.58 to 96 ppt. Differences in salinity between years were not statistically significant, and there is unlikely to have been any change in ecological character due to changes in hydrology from surrounding land uses.

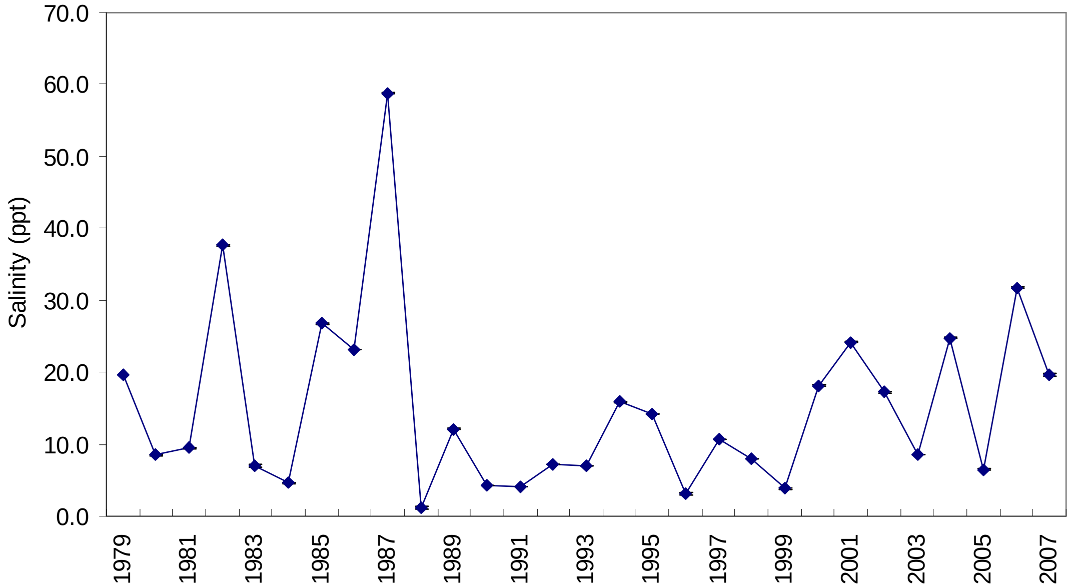

Figure 14. Mean annual surface water salinity for Lake Muir 1979 to 2008 (unpublished data from J. Lane, DEC 2008).

<u>Byenup Lagoon System</u>
Coorinup Swamp is a naturally occurring saline wetland acting as a shallow evaporating basin (Smith 2003). Byenup Lagoon, Tordit-Gurrup Lagoon, Poorginup Swamp, Geordinup Swamp and Neeranup Swamp are naturally freshwater wetlands (R. Hearn, pers. com.). Byenup Lagoon is mostly fresh on the western margins where *Baumea* grows, while the open water ranges from brackish to saline (R. Hearn, pers. com.). Salinisation of Byenup Lagoon has been attributed to secondary salinity (Storey 1998) but may also be part of natural salt-cycles (R. Hearn, pers. com.). Tordit-Gurrup Lagoon is not as saline as Byenup Lagoon, due in part to a lack of clearing in the surrounding catchment (R. Hearn, pers. com.). Geordinup and Neeranup Swamps were both degraded due to redirection from the north of stream flow (DeCampo Creek) for several years (R. Hearn, pers. com.).

Seasonal salinity (ppt) for wetlands sampled within the Byenup Lagoon System in 1996/97 and 2003/04 are presented in Table 9 and Table 10, respectively (Wetland Research and Management 2005).

Table 9. Mean seasonal salinity (ppt) for wetlands sampled within the Byenup Lagoon System 1996/97 (Wetland Research and Management 2005).

Wetland	Spring	Summer	Autumn
Poorginup Swamp	0.19	0.29	0.42
Tordit-Gurrup Lagoon	1.0	1.13	1.31
Mulgarnup Swamp	1.09	1.73	3.14
Byenup Lagoon	2.19	3.58	4.37
N end of Byenup Lagoon	1.08	3.03	4.92
Geordinup Swamp	1.25	2.96	4.8

Table 10. Mean seasonal salinity (ppt) results for wetlands sampled within the Byenup Lagoon System 2003/04 (Wetland Research and Management 2005).

Wetland	Spring	Summer	Autumn
Poorginup Swamp	0.17	0.27	0.49
Tordit-Gurrup Lagoon	1.54	1.93	2.58
Mulgarnup Swamp	1.51	2.81	5.39
Byenup Lagoon	4.67	5.84	8.12
N end of Byenup Lagoon	1.34	2.67	6.66
Geordinup Swamp	1.44	2.66	6.04

Upper limits of ANZECC/ARMCANZ (2000) trigger values (Table 7) were exceeded in all seasons for all wetlands except Poorginup Swamp in both 1996/97 (Table 9) 2003/04 (Table 10). Increased salinity levels were most apparent in summer and autumn months, but could not solely be attributed to lower water levels in wetlands during 2003/04 compared with 1996/97 (Wetland Research and Management 2005). Based on salinity categories defined by the Department of Environment (2003) Byenup Lagoon was saline (3-35 ppt), Poorginup Swamp was fresh (<1 ppt) during summer, autumn and spring, while other Byenup Lagoon System wetlands were brackish (1-3 ppt) in spring and summer, and saline in autumn during both sampling periods.

Mean annual salinity are presented for Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp, 1979 to 2008 (Figure 15) (unpublished data from J. Lane, DEC 2008). Salinity (ppt) ranged from 1.38-42.2 at Byenup Lagoon, 0.65-15.2 at Tordit-Gurrup Lagoon and 0.1-1.6 at Poorginup Swamp. Salinity levels between years were only significantly different in Poorginup Swamp ($P<0.001$) and were associated with lower water depths in 1987 and 2007 (Figure 15).

For all three wetlands, mean annual salinity data is highly variable and there has been no significant change since the time of listing (2001). Due to the high natural variability in these wetlands the ANZECC guidelines are not considered appropriate.

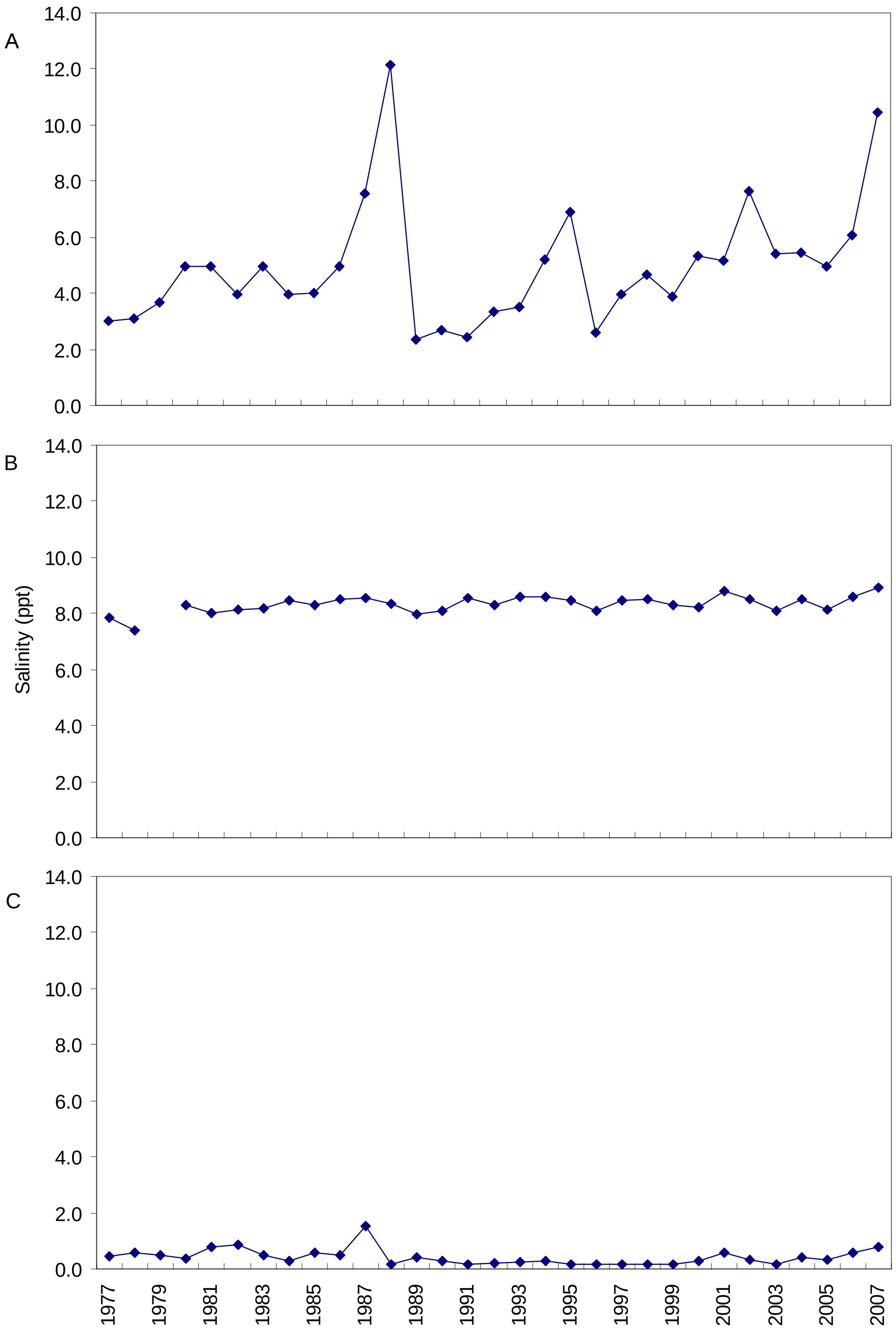

Figure 15. Mean annual surface water salinity for Byenup Lagoon (A), Tordit-Gurrup Lagoon (B) and Poorginup Swamp (C) 1977 to 2008 (unpublished data from J. Lane, DEC 2008).

Nutrients

Lake Muir

Mean annual surface water nutrient concentrations are presented for Lake Muir from 1979 to 2008 (Figure 16 and Figure 17) (unpublished data from J. Lane, DEC 2008). Total N and soluble N ranged from 0.58-5.8 and 0.4-4.7 mgL^{-1}, respectively. Total P and soluble P ranged from 0.005-0.65 and 0.005-0.1 mgL^{-1}, respectively. Mean annual total and soluble N and P were not significantly different between years for Lake Muir and there are no apparent trends. ANZECC guidelines are not appropriate to for Lake Muir and baseline data for phytoplankton biomass or macroinvertebrate composition may be more useful guidelines.

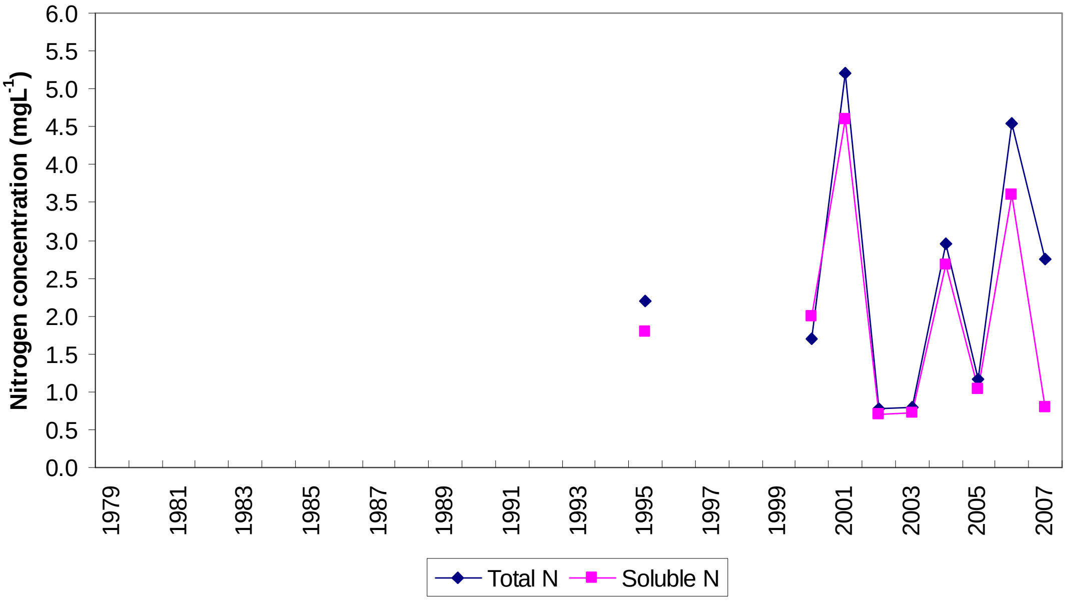

Figure 16. Mean annual nitrogen concentrations (mgL^{-1}) for Lake Muir 1979 to 2008 (unpublished data from J. Lane, DEC 2008).

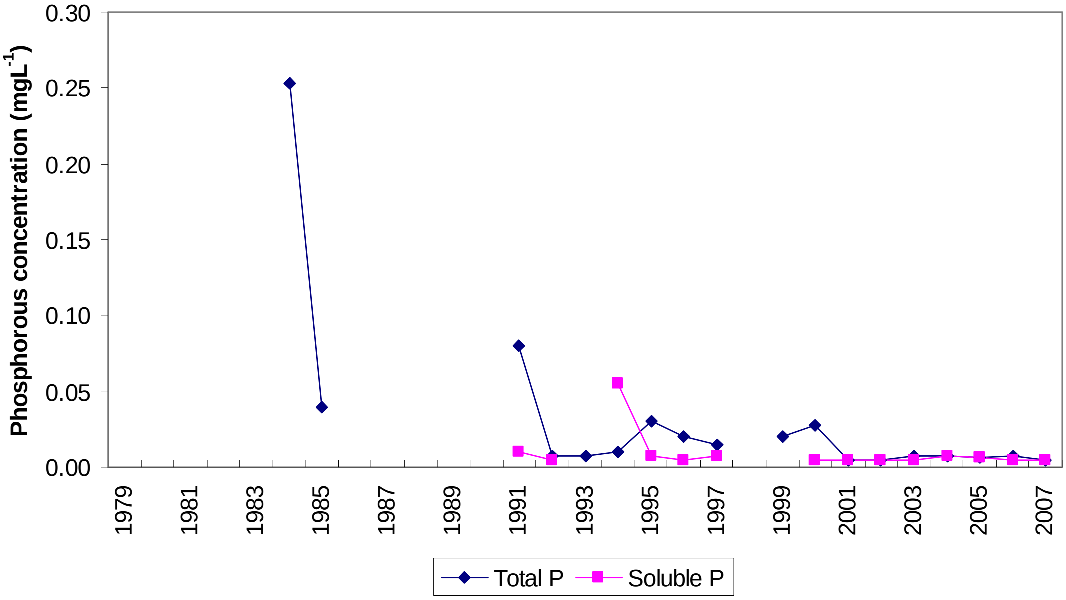

Figure 17. Mean annual phosphorous concentrations (mgL^{-1}) for Lake Muir 1979 to 2008 (unpublished data from J. Lane, DEC 2008).

Byenup Lagoon System

Table 11 and Table 12 show seasonal total nitrogen and total phosphorus concentrations in surface waters of the Byenup Lagoon System wetlands measured in 1996/97 and 2003/04, respectively (Wetland Research and Management 2005).

Table 11. Mean seasonal surface water nutrient concentrations (total N and total P; mgL^{-1}) for wetlands sampled within the Byenup Lagoon System 1996/97 (Wetland Research and Management 2005).

Wetland	Spring		Summer		Autumn	
	Total N	Total P	Total N	Total P	Total N	Total P
Poorginup Swamp	1.7	0.01	1.7	0.01	1.4	<0.01
Tordit-Gurrup Lagoon	1.8	<0.01	1.8	0.01	2.0	<0.01
Mulgarnup Swamp	1.7	<0.01	1.9	<0.01	2.2	<0.01
Byenup Lagoon	1.8	<0.01	1.9	0.01	2.7	<0.01
N end of Byenup Lagoon	1.6	<0.01	2.7	<0.01	4.0	0.01
Geordinup Swamp	1.3	0.01	1.6	<0.01	2.6	<0.01

Table 12. Mean seasonal surface water nutrient concentrations (total N and total P) for wetlands sampled within the Byenup Lagoon System 2003/04 (Wetland Research and Management 2005).

Wetland	Spring		Summer		Autumn	
	Total N	Total P	Total N	Total P	Total N	Total P
Poorginup Swamp	1.5	<0.01	2	<0.01	1.9	<0.01
Tordit-Gurrup Lagoon	1.8	<0.01	1.9	<0.01	1.2	<0.01
Mulgarnup Swamp	2.1	<0.01	3.6	<0.01	5.5	<0.01
Byenup Lagoon	2.8	<0.01	2.7	<0.01	1.7	<0.01
N end of Byenup Lagoon	1.6	<0.01	2.3	<0.01	3.9	<0.01
Geordinup Swamp	5.5	<0.01	5.5	<0.01	10	<0.01

Seasonal patterns for surface water total nitrogen and total phosphorous were similar between the 1996/97 and 2003/04 sampling periods. In 1996/97, total nitrogen concentrations were found to be consistently high at most sites and seasons, except for Geordinup Swamp in spring and Poorginup Swamp in autumn. In 2003/04, total N concentrations were high in all seasons and at all sites, except Tordit-Gurrup in autumn and Poorginup Swamp in spring. Phosphorous was limited at all sampling times in all wetlands (Wetland Research and Management 2005). Algal growth within the Ramsar site is likely to be minimised by limited phosphorus availability and by coloured wetlands (TCU >300) such as Poorginup and Mulgarnup Swamps, due to reduced light penetration (Wetland Research and Management 2005).

Historically, Byenup Lagoon has experienced algal blooms due to nutrient enrichment (Department of Conservation and Land Management 1998). However, Storey (1998) found that although nitrogen levels were relatively high in 1996/97 the wetlands did not behave as eutrophic and had no algal blooms. This may be due to the fact that phytoplankton activity is phosphorus limited in Tordit-Gurrup and Byenup Lagoons, with increased chlorophyll *a* concentrations in July (winter) when total phosphorus is high (DeHaan 1987).

Seasonal patterns of nutrient concentrations in Tordit-Gurrup Lagoon and Byenup Lagoon were also monitored by DeHaan between 1985 and 1986 (DeHaan 1987). Total nitrogen levels in Tordit-Gurrup peaked in April (5,800 μgL^{-1}) and decreased in July (mean 3,300 ± 550 μgL^{-1}). Total nitrogen in Byenup Lagoon remained stable throughout the year (2,900-3,900 μgL^{-1}) (DeHaan 1987). Organic nitrogen was responsible for these patterns of total nitrogen (DeHaan 1987). Total phosphorus increased throughout the year as water volumes were reduced and organic phosphorus accounted for most of the total phosphorus (DeHaan 1987). Nutrient levels in these lagoons were seasonal, relating to water levels and concentration effects. Drying of peat also releases nutrients, particularly organic nitrogen (DeHaan 1987).

Mean annual surface water nutrient concentration data are presented for Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp, 1979 to 2008 (Figure 18 and 19) (unpublished data from J. Lane, DEC 2008).

In Byenup Lagoon, total N and soluble N ranged from 1.3-3.5 and 0.96-3.3 mgL^{-1}, respectively, across all years. Total P and soluble P ranged from 0.005-0.11 and 0.005-0.07 mgL^{-1}, respectively. Differences in mean annual total and soluble N were not significant, however differences in mean annual P between years were significant. Total P was significantly higher in 1991 and 1995 compared to all other years ($P=0.005$) (Figure 18). Soluble P was significantly higher in 1994 compared to all other years ($P<0.001$) (Figure 18).

In Tordit-Gurrup Lagoon total N and soluble N ranged from 1-2.6 and 0.77-2.2 mgL^{-1}, respectively, across all years. Total P and soluble P ranged from 0.005-0.02 and 0.005-0.09 mgL^{-1}, respectively. Only differences in mean annual soluble P between years were significant (P <0.001), with increased soluble P in 1994 compared to all other years. This also followed the pattern for soluble P in Byenup Lagoon (Figure 19).

In Poorginup Swamp, total N and soluble N ranged across all years from 0.63-1.7 and 0.47-1.4 mgL^{-1}, respectively. Mean annual total N was significantly lower in 2000, compared with 1995, 2001, 2004, 2005 and 2006 (P=0.005). Mean annual soluble N was lower in 2007 compared to 1995 and 2006, when TN was highest (P=0.008) (Figure 18). Total P and soluble P ranged from 0.005-0.36 and 0.005-0.11 mgL^{-1}, respectively. Mean annual total P was significantly higher in 1985 (0.36 mgL^{-1}) compared to all other years (P<0.001). Mean annual soluble P was significantly higher in 1995 compared to all other years (0.11) (P<0.001).

There were no significant differences in total N between years for Byenup Lagoon and Tordit-Gurrup Lagoon. However, total N concentrations in Poorginup Swamp were higher in 1995, 2001, and 2004-06, relating to lower water levels and concentration effects (DeHaan 1987). Drying of peat also releases nutrients, particularly organic nitrogen (DeHaan 1987). As these wetlands do not behave as eutrophic (Storey 1998) limits of acceptable change could use algal blooms as a surrogate measure.

For all three wetlands there has been no significant change in mean annual water nutrient concentrations (TN, SN, TP and SP) since the time of listing (2001).

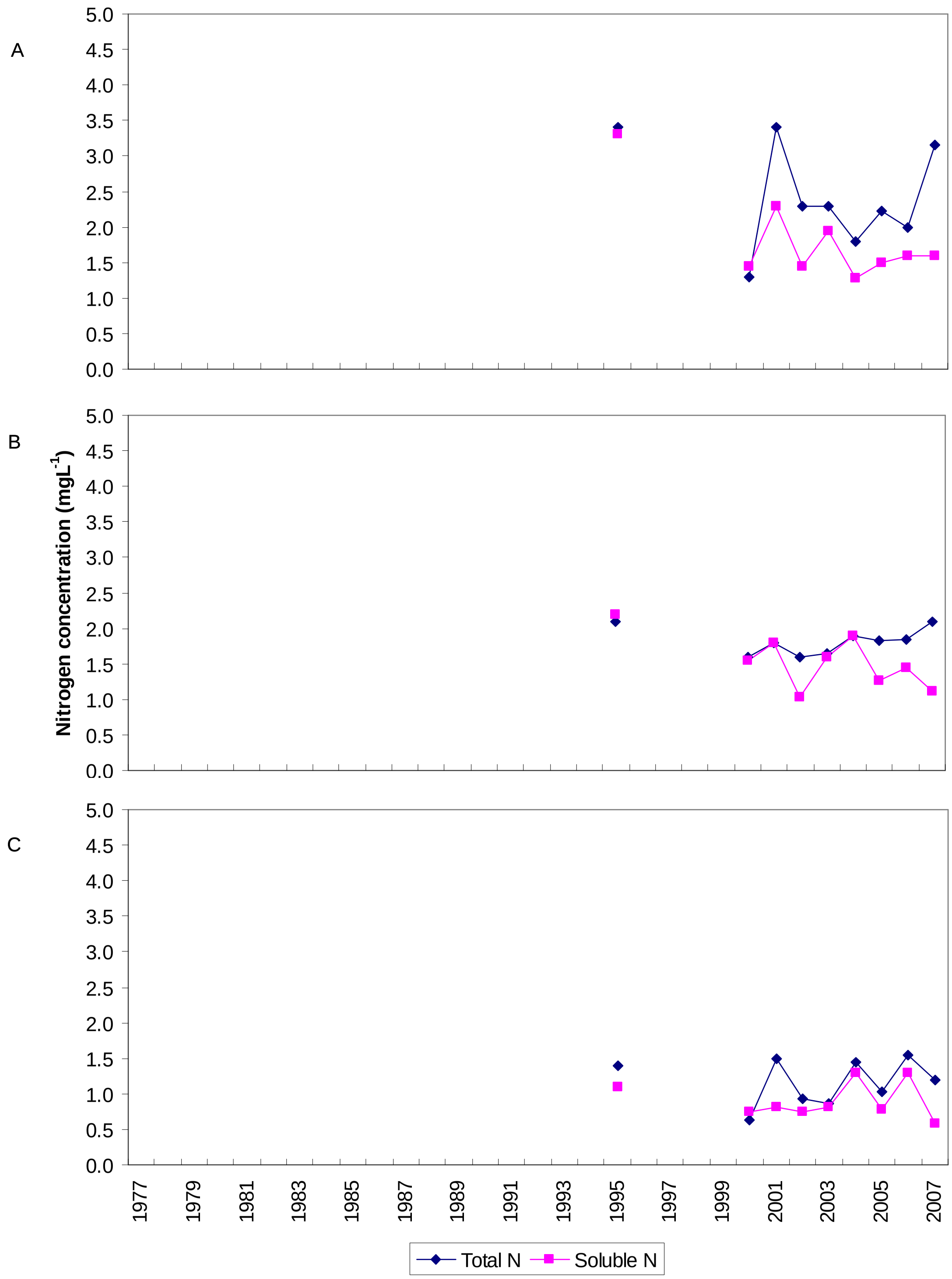

Figure 18. Mean annual nitrogen concentrations (mgL^{-1}) for Byenup Lagoon (A), Tordit-Gurrup Lagoon (B) and Poorginup Swamp (C) 1977 to 2008 (unpublished data from J. Lane, DEC 2008).

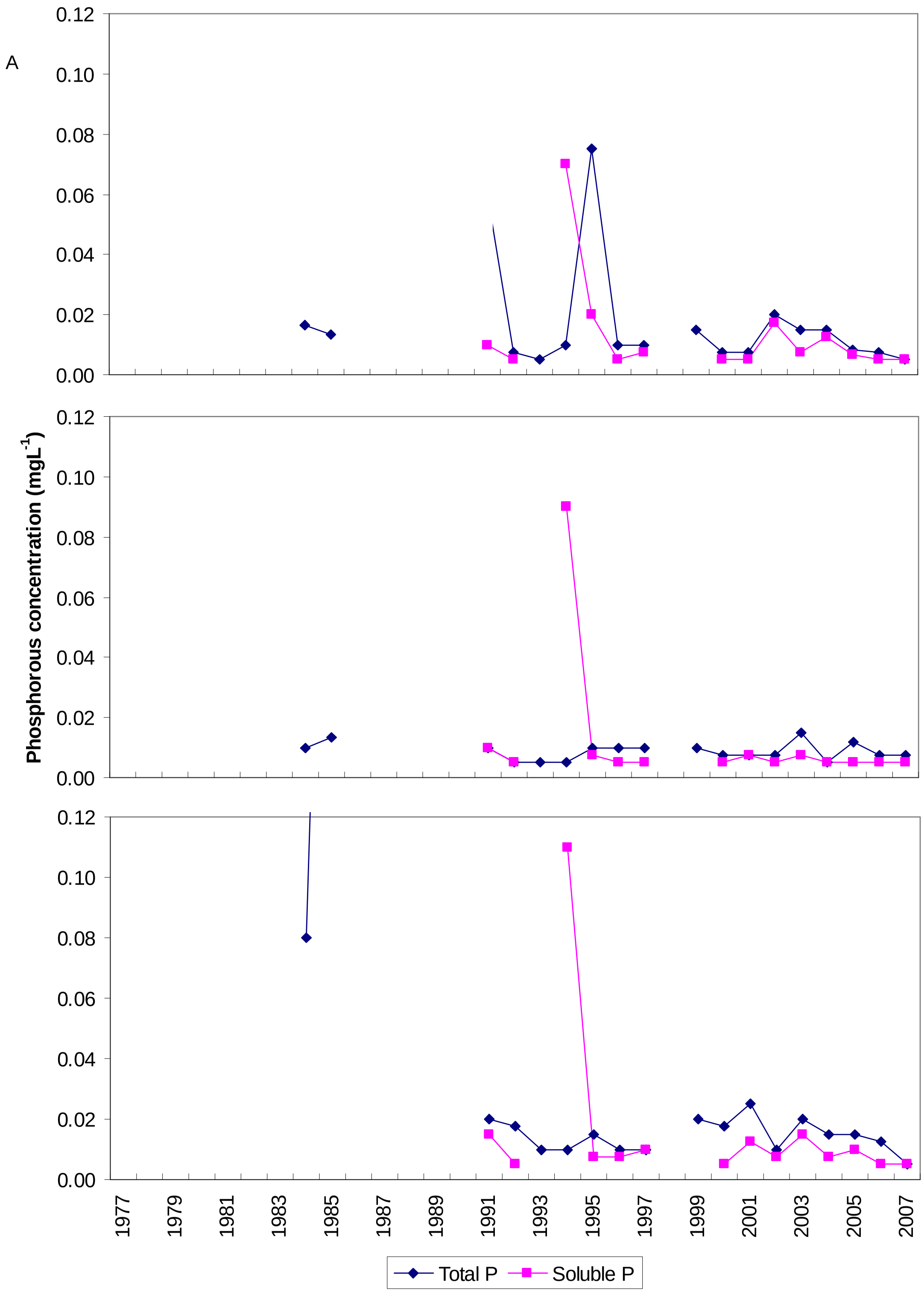

Figure 19. Mean annual phosphorous concentrations (mgL^{-1}) for Byenup Lagoon (A), Tordit-Gurrup Lagoon (B) and Poorginup Swamp (C) 1977 to 2008 (unpublished data from J. Lane, DEC 2008).

Colour and Turbidity

Lake Muir

No information available.

Byenup Lagoon System

Seasonal colour (TCU) and turbidity (NTU) for Byenup Lagoon System wetlands are shown in Table 13 and Table 14. Wetlands above 300 TCUs are considered 'coloured' (Wetland Research and Management 2005) and include; Mulgarnup Swamp during spring, summer and autumn; and Poorginup Swamp in summer and autumn. This was consistent between sampling periods and there has been no significant change since listing. Dark stained waters are probably due to the presence of dissolved organic compounds (such as gilvin) from the underlying peat substrate of these wetlands (Pusey and Edward 1990).

Table 13. Mean seasonal results for colour (TCU) and turbidity (NTU) for wetlands sampled within the Byenup Lagoon System 1996/97 (Wetland Research and Management 2005).

Wetland	Spring		Summer		Autumn	
	Colour TCU	Turbidity NTU	Colour TCU	Turbidity NTU	Colour TCU	Turbidity NTU
Poorginup Swamp	180	1.9	390	1.1	350	3.8
Tordit-Gurrup Lagoon	68	1.6	81	0.9	38	0.9
Mulgarnup Swamp	310	2.7	530	1.0	460	1.5
Byenup Lagoon	21	2.0	42	1.2	31	2.0
N end of Byenup Lagoon	68	1.3	140	1.3	150	2.5
Geordinup Swamp	99	0.8	74	1.1	84	3.1

Table 14. Mean seasonal results for colour (TCU) and turbidity (NTU) for wetlands sampled within the Byenup Lagoon System 2003/04 (Wetland Research and Management 2005).

Wetland	Spring		Summer		Autumn	
	Colour TCU	Turbidity NTU	Colour TCU	Turbidity NTU	Colour TCU	Turbidity NTU
Poorginup Swamp	290	54	370	0.7	340	45
Tordit-Gurrup Lagoon	47	0	25	0	15	22
Mulgarnup Swamp	420	17	680	18	730	22
Byenup Lagoon	33	0	38	0	27	16
N end of Byenup Lagoon	160	62	170	5.8	110	7.3
Geordinup Swamp	260	14	200	4.7	160	5.8

Horwitz (1994) measured surface chlorophyll *a* and gilvin in Poorginup Swamp and found these to be 8.75 mgL^{-1} and 46.1 Abs/m, respectively. Increased chlorophyll *a* concentrations are not considered to be related to transparency in acid peat flats in south-western Australia (Pusey and Edward 1990).

Dissolved Oxygen

Lake Muir

No information available.

Byenup Lagoon System

Seasonal results for dissolved oxygen (DO), sampled within Byenup Lagoon System wetlands between 1996/97 and 2003/04, are presented in Table 15 and Table 16 respectively (Wetland Research and Management 2005). In 1996/97, DO values did not meet the acceptable range (DO 90-120%) for ANZECC/ARMCANZ guidelines in Poorginup Swamp (all seasons), Byenup Lagoon (summer and autumn), north end of Byenup Lagoon (autumn) and in Geordinup Swamp (top of water column in summer). In 2003/04, DO values exceeded the acceptable range (DO 90-120%) for ANZECC/ARMCANZ guidelines in all wetlands for all seasons, except for Byenup Lagoon in summer. This contrasts with results from 1996/97 where, with the exception of Poorginup Swamp, lower DO concentrations were generally recorded during summer and autumn (Byenup Lagoon (summer and autumn), north end of Byenup Lagoon (autumn) and in Geordinup Swamp (top of water column in summer).

However, the ANZECC/ARMCANZ guidelines are probably unsuitable for determining acceptable limits for DO in peat wetlands of the Byenup Lagoon System as lower DO is a result of the breakdown of organic matter to form peat by bacteria and benthic invertebrates. This is particularly noticeable in summer when decomposition rates and microbial activity are higher and can result in anoxia (Wetland Research and Management 2005). Anoxic conditions can result in localised extinction of aquatic fauna and also mobilise nutrients and heavy metals from sediments, reducing water quality (Wetland Research and Management 2005). More appropriate guidelines, using macroinvertebrate indicators, are discussed in Section 8.

Table 15. Mean seasonal results for dissolved oxygen (%DO) within Byenup Lagoon System wetlands 1996/97, sampled at the top and bottom of the water column (Wetland Research and Management 2005).

Wetland	Spring		Summer		Autumn	
	DO% top	DO% bottom	DO% top	DO% bottom	DO% top	DO% bottom
Poorginup Swamp	54	42	35	23	75	51
Tordit-Gurrup Lagoon	90	90	98	98	91	89
Mulgarnup Swamp	51	48	35	18	53	53
Byenup Lagoon	80	78	127	135	99	99
N end of Byenup Lagoon	50	43	68	60	101	101
Geordinup Swamp	65	49	111	74	88	82

Table 16. Mean seasonal results for dissolved oxygen (%DO) within Byenup Lagoon System wetlands 2003/04, sampled at the top and bottom of the water column (Wetland Research and Management 2005). (-) indicates missing data.

Wetland	Spring		Summer		Autumn	
	DO% top	DO% bottom	DO% top	DO% bottom	DO% top	DO% bottom
Poorginup Swamp	39.9	17	35	24.8	84	-
Tordit-Gurrup Lagoon	82.3	82	85.8	-	80.7	80.3
Mulgarnup Swamp	32.2	4.3	41.5	-	44	-
Byenup Lagoon	64.9	65	84	91.4	77.7	-
N end of Byenup Lagoon	53	29.5	29.8	-	73.9	-
Geordinup Swamp	32.1	29.8	12.3	-	41.6	-

pH

Lake Muir

Mean annual pH data are presented for Lake Muir from 1977 to 2008 (Figure 20) (unpublished data from J. Lane, DEC 2008). Levels of pH at Lake Muir ranged from 6.2 to 9.9 and were significantly different between years ($P<0.001$). Levels of mean annual pH were more elevated between 1989 and 2004 than between 1982 and 1988, and 2005-2006 (Figure 20). Lower pH levels from 1982-1988 seem to be related to lower water depths (Figure 12) and rainfall (Figure 5) and therefore maybe a reflection of groundwater pH levels (5.2-6.3) or of acid water inflows (pH 3.68-6.73) from Cowerup Swamp via Red Lake and artificial channels (see Section 7 on threats to ecological character). There are no apparent trends in the pH of Lake Muir and there have been no changes since the time of listing (2001).

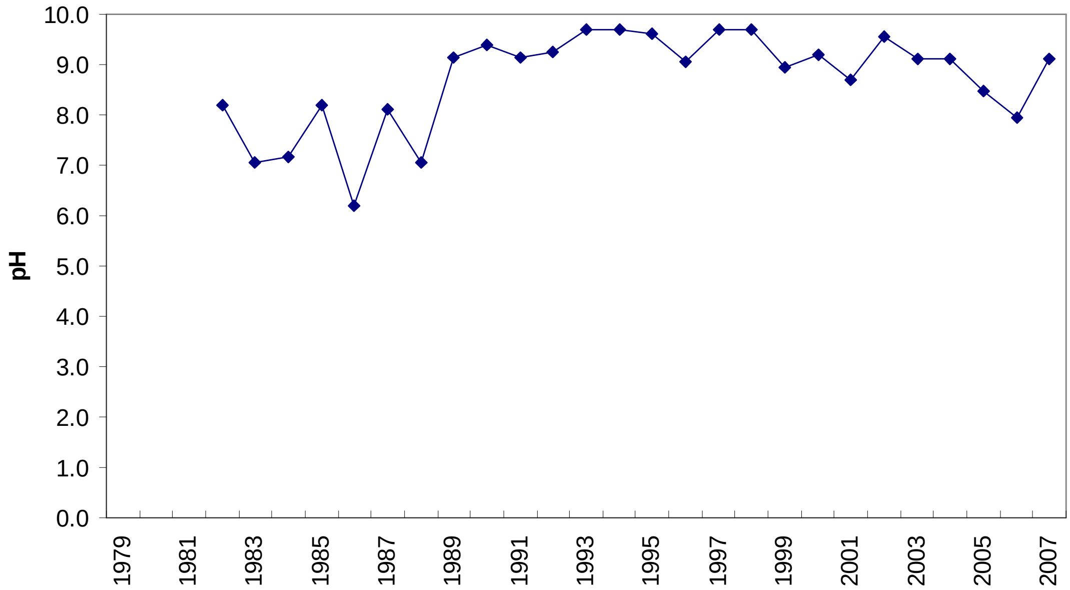

Figure 20. Mean annual pH values for Lake Muir 1982 to 2008 (unpublished data from J. Lane, DEC 2008).

Byenup Lagoon System

Climatic conditions, very slow water movement and a shallow lake basin has resulted in the accumulation of peat deposits in Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp (DeHaan 1987). Peat is formed by partially decomposed organic matter and associated inorganic minerals that are accumulated in a saturated water environment (DeHaan 1987). Levels of pH in peat wetlands, such as Poorginup Swamp, Tordit-Gurrup and Byenup Lagoons range between 4.5-8 depending on calcium availability (DeHaan 1987). Bicarbonate ions buffer pH in natural waters with pH ranging between 6 and 8. In peat based wetlands, in the absence of bicarbonate, organic acids leach from peat resulting in acidity (Pusey and Edward 1990). Peat may also contribute significantly to acidity in south-western Australian peat flats due to leaching of organic compounds from submerged leaf-litter (Pusey and Edward 1990). Acidity in these wetlands is seasonal with leaching occurring during rainfall events (Pusey and Edward 1990).

The presence of water is also critical for the development and maintenance of anaerobic peat environments (DeHaan 1987). Freshwater peat wetlands in the Muir-Byenup System Ramsar site, dominated by *Baumea* and *Melaleuca* communities, contain high concentrations of iron pyrite due to bacterial and chemical activity in the substrate (R. Hearn, pers. com.). Acidification of these potential acid sulfate soils occurs under aerobic conditions, due to draining or disturbance, when iron oxidises and reacts with sulfide in the presence of water to form sulfuric acid (DeHaan 1987).

Of the three peat wetlands in the Byenup Lagoon System, only Poorginup Swamp is acidic. Tordit-Gurrup and Byenup Lagoons are both slightly alkaline, fluctuating from pH 6 to 9, and vary little from year to year (DeHaan 1987). Levels of pH in Poorginup Swamp are also constant and acidic (pH 5-6.6) (DeHaan 1987). DeHaan (1987) suggested that lower pH in Poorginup may be due to acidification of acid sulfate soils during annual drying of peat and slow drainage reducing the capacity for dilution. ANZECC/ARMCANZ guidelines for pH 7-8.5 in wetlands are therefore inappropriate for the peat based wetlands within the Byenup Lagoon System.

Table 17 and Table 18 show seasonal pH results for wetlands sampled within the Byenup Lagoon System during 1996/97 and 2003/04 (Wetland Research and Management 2005). In 1996/97, low pH values were recorded in Poorginup Swamp, Tordit-Gurrup Lagoon (spring only), Mulgarnup Swamp, north end of Byenup Lagoon (spring and summer) and Geordinup Swamp (spring). In 2003/04, low pH values were recorded in Poorginup Swamp, Tordit-Gurrup Lagoon (summer only) and Mulgarnup Swamp (in autumn).

Table 17. Mean seasonal pH results for wetlands sampled within the Byenup Lagoon System 1996/97 (Wetland Research and Management 2005).

Wetland	Spring	Summer	Autumn
Poorginup Swamp	6.2	5.64	6.04
Tordit-Gurrup Lagoon	6.76	7.63	7.88
Mulgarnup Swamp	6.24	6.33	6.77
Byenup Lagoon	8.01	8.16	8.6
N end of Byenup Lagoon	6.13	6.77	7.5
Geordinup Swamp	5.91	7.26	7.8

Table 18. Mean seasonal pH results for wetlands sampled within the Byenup Lagoon System 2003/04 (Wetland Research and Management 2005).

Wetland	Spring	Summer	Autumn
Poorginup Swamp	6.41	6.31	6.0
Tordit-Gurrup Lagoon	8.71	9.06	8.49
Mulgarnup Swamp	7.18	7.01	6.88
Byenup Lagoon	8.36	8.55	8.45
N end of Byenup Lagoon	6.82	7.17	7.12
Geordinup Swamp	7.09	7.11	7.37

Mean annual pH data from 1977 to 2008, are presented for Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp (Figure 21) (unpublished data from J. Lane, DEC 2008). Levels of pH ranged from 6.8 to 9.3 at Byenup Lagoon, 6.9 to 9.3 at Tordit-Gurrup Lagoon and 4.6 to 8.3 at Poorginup Swamp. Levels of pH were not significantly different between years for Byenup and Tordit-Gurrup Lagoons, however, pH levels between years were significantly different in Poorginup Swamp (P=0.012). In Poorginup Swamp pH levels were significantly lower in 1981, 1987, 2001 and 2007 and generally corresponded with lower water depths (Figure 13).

Overall, there are no apparent trends in the levels of pH in the Byenup Lagoon System and there have been no changes since the time of listing (2001).

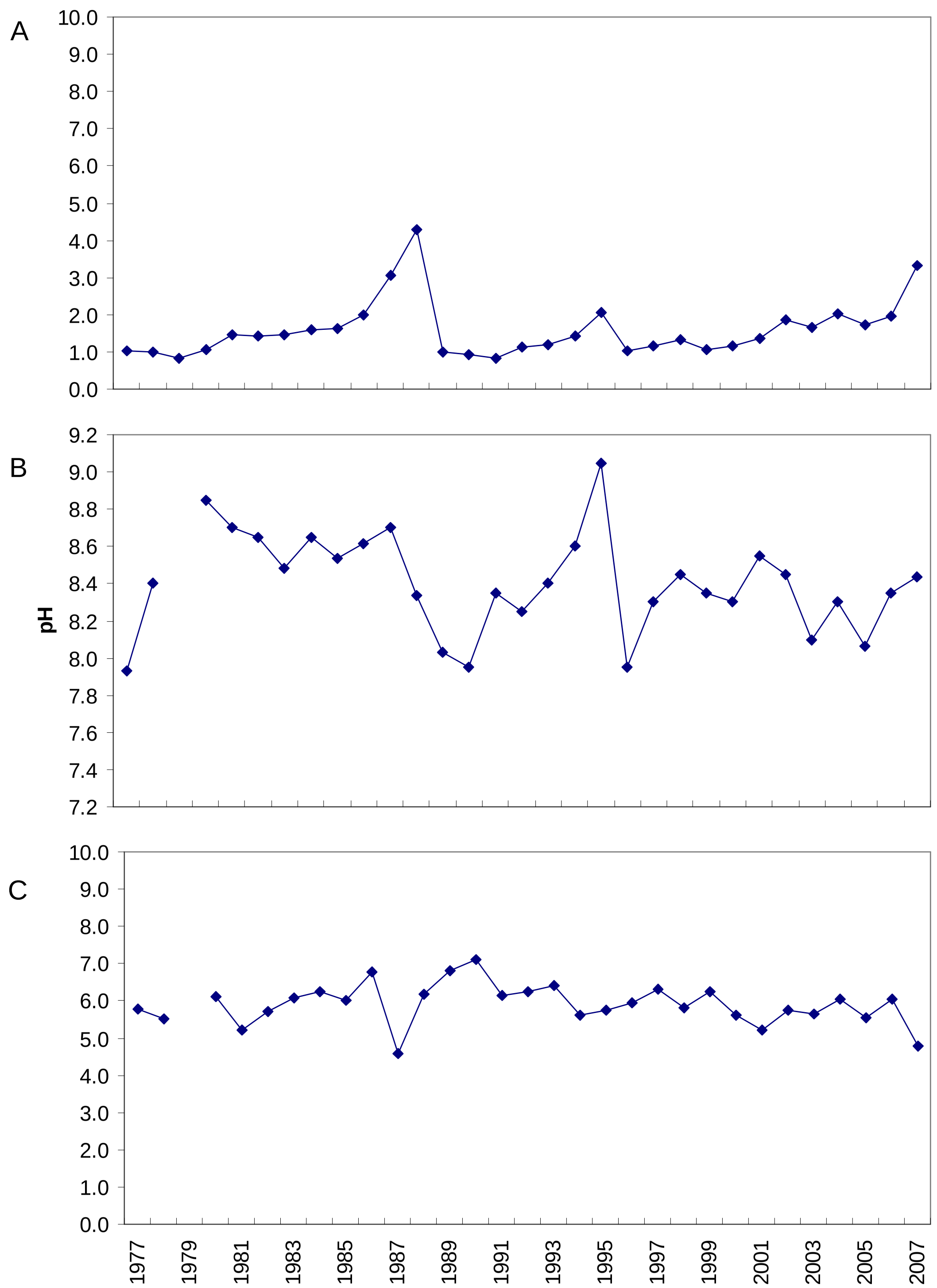

Figure 21. Mean annual pH values for Byenup Lagoon (A), Tordit-Gurrup Lagoon (B) and Poorginup Swamp (C) 1977 to 2008 (unpublished data from J. Lane, DEC 2008).

3.2.5 Phytoplankton and aquatic macrophytes

Lake Muir

Aquatic macrophytes found in Lake Muir include *Ruppia polycarpa, Lepilaena cylindrocarpa, Crassula helmsii, Cotula coronopifolia, Triglochin procera* and *Zygnema* sp. (Brock and Shiel 1983). The stonewort *Lamprothamnium* sp. also occurs in the free water of Lake Muir but dies from desiccation as the lake dries out in summer (Environmental Resources of Australia Pty Ltd and Cladium Mining Pty Ltd 1971).

Brock and Lane (1983) assessed the distribution of aquatic macrophytes in naturally saline wetlands of south-western Australia and found that *Ruppia*, *Lepilaena* and *Lamprothamnium* species were tolerant of both salinity fluctuation and drying. These species are able to tolerate adverse conditions as they complete their life-cycles within a few months (Brock and Lane 1983). In south-western Australian wetlands, only *Ruppia*, *Lamprothamnium* and *Lepilaena* were found where salinity exceeded 5 ppt TDS (Brock and Shiel 1983). The salinity ranges of submerged macrophyte species found within the Muir-Byenup System Ramsar site are shown in (Table 19).

Table 19. Salinity ranges of submerged macrophyte species recorded within the Muir-Byenup System Ramsar site (adapted from Brock and Lane 1983).

Species	Location within the Muir-Byenup System Ramsar site	Salinity range of species (ppt)	Salinity range at site (ppt)
Ruppia polycarpa	Lake Muir	1.4 - 125	0.58 - 96
Lepilaena cylindrocarpa	Lake Muir	2 - 27	0.58 - 96
Utricularia sp.	Byenup Lagoon System	0.8 - 2.5	1.38 - 42.2
Lamprothamnium papulosum	Lake Muir	9 - 125	0.58 - 96
Chara fibrosa	Byenup Lagoon System	5 - 9	1.38 - 42.2

Byenup Lagoon System

Phytoplankton activity is phosphorus limited in Tordit-Gurrup and Byenup Lagoons, with increased chlorophyll *a* concentrations in July when total phosphorus is high (DeHaan 1987).

Stoneworts (*Chara* sp., *C. fibrosa* and *C. preissii*) occur as sub-surface meadows in freshwater wetlands of the Byenup Lagoon System (Environmental Resources of Australia Pty Ltd and Cladium Mining Pty Ltd 1971).

Notable aquatic macrophytic flora include *Schoenus natans*, an aquatic sedge which was previously listed as Declared Rare Flora under the *Wildlife Conservation Act 1950*, but has been de-listed due to a large population within the Ramsar site and several populations in nearby Nature Reserves. Previously it was believed to be restricted to the Swan Coastal Plain. Both *S. natans* and *Villarsia* spp. are widespread in wetlands during early spring, giving way to herbs as wetlands dry (Gibson and Keighery 2000). *Villarsia submersa* is an uncommon aquatic herb occurring within the Ramsar site (Pen 1997).

Montia australasica, Utricularia spp. and mats of floating native grasses have been found in Byenup Lagoon (Hendrich 2001).

3.2.6 Fringing vegetation

The Muir-Byenup System Ramsar site is highly diverse; a total of 649 indigenous flora have been recorded in Nature Reserve 31880, with at least 600 species within the Ramsar site (Gibson and Keighery 1999). This diversity is probably due to complexes of soil types and hydrological patterns, which are found over short distances and are reflected in vegetation patterning (Gibson and Keighery 1999). In particular, vegetation patterning at the site is related to inundation, groundwater and fire history (Gibson and Keighery 1999). Structural vegetation mapping at the site has defined a complex mosaic of over 30 vegetation types (Gibson and Keighery 1999).

At a regional mapping scale, the site falls into Beard's Kwornicup vegetation system (Gibson and Keighery 1999). The Kwornicup system is characterised by a poorly drained swampy plain between the headwaters of the Kent, Hay and Gordon Rivers (Gibson and Keighery 1999). Vegetation in this system is a mosaic of *Eucalyptus marginata/Corymbia calophylla* forests, paperbark low forest and reed swamps, with *E. decipiens* occurring on sandy swampy sites as either the dominant or understorey species (Gibson and Keighery 1999). Sandy swamps may also have dense stands of *Melaleuca cuticularis* grading into reed swamps, while clay swamps usually have stands of *E. occidentalis* with *M. cuticularis* and *M. violacea* understorey (Gibson and Keighery 1999). Thirty-one vegetation units have been mapped in the Nature Reserve, with predominately wet heaths and scrubs in the northern section of the site, and eucalypt woodland in the south (Gibson and Keighery 1999). See Appendix B for the vegetation description of the Muir-Byenup System Ramsar site (Gibson and Keighery 1999).

Noteworthy flora at the site (Table 20) includes three species of wetland dependent orchids; *Caladenia christineae*, *Caladenia harringtoniae* and *Diuris drummondii*, which occur on the margins of Lake Muir and elsewhere in the site (Gibson and Keighery 1999). These orchids are listed as Vulnerable under the EPBC Act. 21 other DEC listed 'priority taxa' are also found within site, including:

- *Stylidium rhipidium* and *Wurmbea* sp. Cranbrook, found in winter-wet swamps, which are poorly known and may be declared rare at a State level (Department of Conservation and Land Management 2003).
- *Eryngium* sp. Lake Muir, which appears to be endemic to winter-wet clay flats of Lake Muir and is currently known only from the Ramsar site (Department of Conservation and Land Management 2003).
- *Euphrasia scabra,* which has been recommended for national listing as critically endangered, as the two populations at the site are the only known extant populations in Western Australia (Department of Conservation and Land Management 2003).
- *Caladenia lodgeana*, a species previously known from a few restricted populations in the Augusta area (Department of Conservation and Land Management 2003).

- *Lilaeopsis polyantha*, with the State's only known population found in fringing vegetation surrounding Lake Muir (Department of Conservation and Land Management 2003).
- *Tribonanthes* sp. Lake Muir, a previously unrecognised taxon, endemic to winter-wet clay flats of the Ramsar site and nearby Nature Reserves.

Table 20. Notable flora within the Muir-Byenup System Ramsar site.

Information taken from FloraBase (Department of Environment and Conservation and Western Australian Herbarium 2008).

Species	EPBC Act listing	Wildlife Conservation Act and DEC priority listing	Habitat	Description
Caladenia christineae	Vulnerable	Declared rare	Margins of winter-wet flats, swamps and freshwater lakes.	Tuberous perennial herb, 0.25-0.4 m high, flowering Sept-Nov.
Caladenia harringtoniae	Vulnerable	Declared rare	Winter-wet flats, margins of lakes, creek lines and granite outcrops.	Tuberous perennial herb, 0.2-0.4 m high, flowering Oct-Nov.
Caladenia lodgeana		Priority two		Tuberous perennial herb, flowering Oct.
Diuris drummondii	Vulnerable	Declared rare	Low-lying depressions and swamps.	Tuberous perennial herb, 0.5-1.05 m high, flowering Nov-Jan.
Eryngium sp. Lake Muir		Priority one	Black peaty, silty soils, winter-wet swamps.	Near prostrate herb, flowering Jan.
Euphrasia scabra		Priority two		Erect annual herb, 0.15-0.5 cm high, flowering Oct.
Lilaeopsis polyantha		Priority two	Sandy mud, lake margins.	Rhizomatous perennial herb, 0.02-0.25 m high, flowering Nov.
Stylidium rhipidium		Priority three	Wet creek flats, swamps and granite outcrops.	Slender annual herb, 0.05 cm high, flowering Oct-Nov.
Tribonanthes sp. Lake Muir		Priority three	Brown clay over clay, winter-wet flats.	Tuberous perennial herb, flowering Oct.
Wurmbea sp. Cranbrook		Priority two	Valley floors.	Cormous perennial herb, 0.25 cm high, flowering Sept.

Lake Muir

The vegetation structure of Lake Muir is shown in Table 21. The margins of Lake Muir support a narrow zone of open-scrub, sedgeland and low shrubland (Department of Conservation and Land Management 2003). Wetland scrub is dominated by tall tea-tree shrubs *Melaleuca viminea* and *M. cuticularis*, with *M. rhaphiophylla* also present. Low shrublands are dominated by samphires; *Sarcocornia quinqueflora* and *Tecticornia* *lepidosperma*. Other plants near the lake margins include *Lepidosperma effusum*, *Gahnia trifida*, *Schoenus submicrostachyus* and *Wilsonia backhousei*.

Table 21. Vegetation structure of Lake Muir (Halse 1993).

Vegetation	Height m	% Area	% cover
Samphires	0.2	80	30
Sedges	0.6	20	20
Shrubs	0.6	20	2
Trees	4.0	20	10

Two vegetation transects were measured through fringing and emergent vegetation by Froend and Loomes (2001). Along transect 1, vegetation communities changed sequentially from the lake margin; samphire flats, *M. cuticularis* woodland over *Gahnia trifida* flats, *Gahnia* sedgeland and *M. rhaphiophylla*. In this transect, hydrological data indicated that only the samphire flats and *M. cuticularis* communities had been inundated since 1979. These communities were flooded at peak levels in 1988 but had not been flooded regularly (Froend and Loomes 2001).

In lower lying transect 2, vegetation communities changed sequentially from the lake margin; samphire flats, *M. cuticularis* complex, *M. cuticularis* woodland over *G. trifida* sedgeland and Yate (*Eucalyptus occidentalis*) woodland (Froend and Loomes 2001). Hydrological data indicated that samphires were inundated during most years and the *M. cuticularis* complex was completely flooded in 1988, but again, flooding events were not frequent (Froend and Loomes 2001).

Within the Ramsar site, freshwater adapted fringing and emergent trees such as *Melaleuca* species and *Eucalyptus rudis*, with salinity thresholds of 5-10 ppt, may be affected by increased salinity (Wetland Research and Management 2005). *M. cuticularis* found on the fringes of Lake Muir has been found to tolerate up to 29 ppt (Carter *et al*. 2006).

Byenup Lagoon System

Wetlands within the Ramsar site support extensive sedgelands and fringing or scattered areas of low-closed forest or closed-scrub, with open-heathland over open-sedgeland on the wet flats. Sedgelands are dominated by *Baumea articulata* which are also associated with *Baumea* spp. and *Triglochin huegelii*.

B. articulata characterises the peat swamps of the Muir-Byenup System Ramsar site and is responsible for the thick peat deposits in these wetlands (Wetland Research and Management 2005). *Baumea* also provides critical habitat for Bitterns and Balston's Pygmy Perch. *B. articulata* is a salt sensitive species (threshold of approximately 3 ppt). Within *Baumea* peat wetlands at the site, salinity ranges between 0.1 and 42.2 ppt, which may indicate that it is seasonally tolerant of increased salinity.

At Poorginup Swamp, *Meeboldina scariosa*, *B. vaginalis* and *G. trifida* also occur. The dominant wetland tree in these freshwater lakes and swamps is *M. rhaphiophylla*, with *M.*

lateritia, *Astartea leptophylla*, *A. scoparia* and *Taxandria juniperina* also occurring in some wetlands.

Morphological characteristics and vegetation cover of wetlands within the Byenup Lagoon System measured by Wetland Research and Management (2005) are shown in Table 22.

Table 22. Morphological characteristics and vegetation cover of the Byenup Lagoon System wetlands (adapted from Wetland Research and Management 2005)

Wetland	Open water %	Sedges/rushes %	Melaleuca %	Macrophyte %
Poorginup Swamp	35	50	15	0
Tordit-Gurrup Lagoon	45	54	1	20
Mulgarnup Swamp	0	71	29	0
Byenup Lagoon	25	72	3	1
N end of Byenup Lagoon	0	90	10	0
Geordinup Swamp	15	84	1	0

Although species composition varies little between Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp, the extent of fringing vegetation does differ (DeHaan 1987). Poorginup Swamp is entirely surrounded by vegetation while some clearing for pastures has occurred around Tordit-Gurrup Lagoon, and almost all of the fringing forest vegetation around Byenup Lagoon has been cleared (DeHaan 1987).

Vegetation structure of Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp is shown in Table 23. At Byenup Lagoon, vegetation transects were measured through fringing and emergent vegetation by Froend and Loomes (2001). In transect 1, vegetation communities changed sequentially from *Baumea* sedgeland, *M. rhaphiophylla* forest to Jarrah (*Eucalyptus marginata*)/Yate woodland (Froend and Loomes 2001). *Samolus junceus* open herbs are also associated with *B. articulata* sedges on black peaty sands at Byenup Lagoon (Gibson and Keighery 1999). In this transect, hydrological data indicated that *Baumea* sedgeland and *M. rhaphiophylla* were flooded annually along with the lower half of the Jarrah/Yate woodland (Froend and Loomes 2001). In the steeper elevational gradient of transect 2, the Jarrah/Yate woodland was absent (Froend and Loomes 2001). *Baumea* sedgeland and *M. rhaphiophylla* are not annually flooded in this transect (Froend and Loomes 2001).

In North Byenup Lagoon, emergent *E. rudis* open woodland occurs over *M. rhaphiopylla* low woodland, *Acacia cyclops* and *M. densa* open scrub, and *B. juncea* and *Lepidosperma longitudinale* dense tall sedges on black peat soils (Gibson and Keighery 1999).

Table 23. Vegetation structure of Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp (Halse 1993).

Vegetation	Height	% Area	% cover
Byenup Lagoon			
Sedges	2.0	95	100
Sedges	1.0	5	100
Trees	5	5	50
Tordit-Gurrup Lagoon			
Sedges	1.0	85	100
Sedges	2.0	15	100
Trees	4.0	5	5
Poorginup Swamp			
Sedges	1.5	100	100
Sedges	2.5	20	30
Trees	4.0	20	2
Trees	8.0	10	60

Three vegetation communities were identified at Tordit-Gurrup Lagoon: closed *Baumea* sedgeland, *M. rhaphiophylla* woodland and Jarrah/Marri (*Corymbia calophylla*) woodland (Froend and Loomes 2001). *B. juncea* open low sedges occur on gentle washline slopes of yellow sand and coffee rock at Tordit-Gurrup Lagoon (Gibson and Keighery 1999). Hydrological data indicated that *Baumea* sedgeland is frequently inundated, *M. rhaphiophylla* woodland is dry except for peak flooding events and the Jarrah/Marri woodland does not experience flooding (Froend and Loomes 2001).

At Poorginup Swamp, open *Baumea* sedgeland occurred across the 30 m of the transect closest to the wetland and *M. rhaphiophylla* forest dominated the remaining 30 m (Froend and Loomes 2001). Hydrological data indicated that *Baumea* sedgeland is frequently inundated and only the lower parts of *M. rhaphiophylla* forest are flooded (Froend and Loomes 2001). Emergent *Astartea leptophylla* open scrub also occurs with *B. articulata* and *Meeboldina scariosa* tall sedges on black clayey peat soils at Poorginup Swamp (Gibson and Keighery 1999).

In Geordinup Swamp, *E. rudis* and *M. rhaphiophylla* open low woodland occurs over *Meeboldina tephrina* tall sedges on flat, brown sandy soils, or *B. articulata* tall sedges occur on black peat soils (Gibson and Keighery 1999).

3.2.7 Aquatic invertebrates

Lake Muir

Aquatic invertebrate surveys have not been undertaken in Lake Muir.

Byenup Lagoon system

South-western Australian aquatic fauna is highly endemic but depauperate in richness (Horwitz 1997), possibly due to: great age and stability of the landscape; strong climatic gradients; high diversity of aquatic habitats within the region; adaptation to salinity and aridity; and genetic isolation from eastern Australia (Pinder *et al.* 2004). Kay *et al.*

(2001) found that macroinvertebrates in south-western Australia were able to tolerate a broad range of environmental conditions (see Appendix E).

Rainfall influences macroinvertebrate biota in south-west WA by regulating water quality through dilution and flushing, and by determining the quantity and permanence of surface water (Kay *et al.* 2001). In south-west WA, macroinvertebrate family richness has been found to increase with increasing rainfall and decrease with increasing salinity (Kay *et al.* 2001). The environmental variables which influence family distribution and structure of aquatic macroinvertebrate communities in the agricultural zone is shown in Figure 22 (Kay *et al.* 2001).

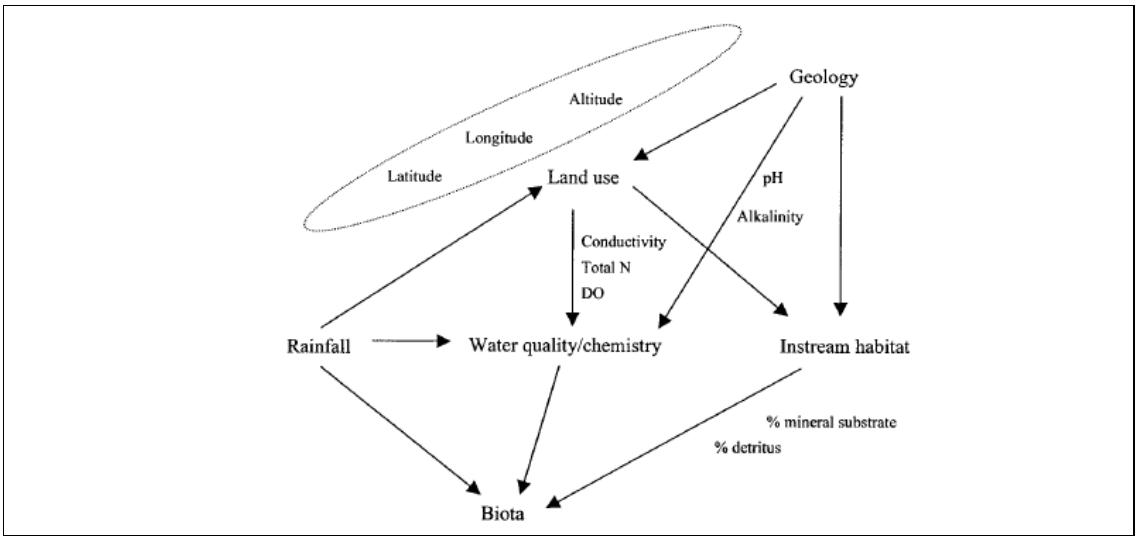

Figure 22. Environmental variables which influence family distribution and structure of aquatic macroinvertebrate communities in the agricultural zone (Kay *et al.* 2001)

Peat wetlands in the Byenup Lagoon System are essential for maintaining the endemic macroinvertebrate and fish communities. Peat wetlands are important habitat for invertebrates, as peat remains wet and provides refuge for invertebrates even in dry times (Department of Conservation and Land Management 1998). According to Camp *et al.* (1981) in terms of aquatic fauna, the two most important hydrologic characteristics of peat wetlands are:

1. Watertable height – affects water levels; and,
2. Quantity and timing of runoff events – influences water levels in receiving waters.

DeHaan (1987) described the aquatic invertebrates of the Byenup Lagoon System and found that species richness varied seasonally at Tordit-Gurrup Lagoon, Byenup Lagoon and Poorginup Swamp. Species richness in Tordit-Gurrup and Byenup Lagoons decreased in April when water levels were low and salinity levels increased. In December, Tordit-Gurrup Lagoon was dominated by coleopterans, hemipterans, dipterans and trichopterans. In April, dipterans and trichopterans were still dominant, but Coleoptera and Hemiptera were replaced by Mollusca. Coleoptera and Diptera dominated Byenup Lagoon in December, while April composition was dominated by Mollusca, Decapods and Diptera. Molluscs, dipterans, tricopterans and crustaceans are more salt tolerant taxa. In fresher Poorginup Swamp, Hydracarina were the most dominant, although Coleoptera and Diptera were also found in high numbers.

DeHaan (1987) recorded 103 invertebrate taxa in Tordit-Gurrup Lagoon, Byenup Lagoon and Poorginup Swamp. Of these, only eight species were common between the three wetlands. Tordit-Gurrup Lagoon had the highest richness, with 60 species, and Poorginup Swamp the lowest with 39 species. The class Insecta accounted for 73% of the total invertebrate fauna, consistent with lower salinity levels of the three wetlands. Of particular interest zoogeographically, due to their restricted distributions, were 11 Hydracarina taxa (watermites), six of which were recorded in Poorginup Swamp, including *Pseudohydryphantes doegi* and the Poorginup Swamp watermite (*Acercella poorginup*), both of which are listed by DEC as Priority 2 species. *Huitfeldtia* sp. was also recorded at the site, and is the second known species in its genus; the other occurring in northern Europe and Canada (DeHaan 1987). De Haan (1987) recorded the crustaceans *Cherax preissii* and *C. quinquecarinatus* within the site and Horwitz (1994) also found *Cherax preissii* at Poorginup Swamp. Crustaceans become more prevalent as salinity increases in wetlands (Kay *et al.* 2001).

Storey (1998) also surveyed macroinvertebrate communities within the Ramsar site at; Byenup Lagoon, Tordit-Gurrup Lagoon, Mulgarnup Swamp, Geordinup Swamp and Poorginup Swamp. A total of 219 taxa were recorded, with 32 known to be endemic to south-western Australia (Storey 1998). The greatest numbers of endemic species were recorded in Poorginup Swamp. Horwitz (1994) also found a high number of endemics in Poorginup Swamp relative to other shrublands and peat wetlands in south-western Australia. Overall the site contained a rich and diverse fauna. At least 78 species of ostracods and copepods were recorded at the site, with six ostracods and one cyclopoid only known in the Muir-Unicup area (Department of Conservation and Land Management 2003). New species were recorded within the Rotifera and Cladocera families. Within Rotifera there were 11 new records for Western Australia, one new record for Australia and one new species not yet described. Within the Cladocera there were two new species and a second recorded of a new undescribed genus (Department of Conservation and Land Management 2003). South-western Australia has more endemic cladocerans than any other region and it is likely that taxonomic revision of the Cladocera will reveal other new taxa in the Muir-Unicup area (Department of Conservation and Land Management 2003).

Two new species of dytiscid water beetle, *Sternopriscus* sp. nov. and *Antiporus pennifoldae* were also recorded at the site (Storey 1998). *Sternopriscus* sp. nov. was widespread throughout the Muir-Unicup catchment, while *Antiporus pennifoldae* was recorded at Poorginup Swamp and one other location (Storey 1998). Watts and Pinder also found a new species of dytiscid in the Muir-Byenup area (Kodjinup Swamp, outside of the Ramsar site).

Hygrobia wattsii sp. n (Coleoptera: Hygrobiidae) was recorded in Byenup Lagoon and appears to be restricted to peatland swamps and lakes, and is the sixth species in this genus identified globally, and the fourth species identified in Australia (Hendrich 2001). *Hygrobia wattsii* sp. n is a relict species, which is likely to be impacted by swamp drainage and increased salinity (Hendrich 2001).

Wetland Research and Management (2005) identified some changes in macroinvertebrate communities in the Byenup Lagoon System between the two sampling periods of 1996/97 and 2003/04 including: altered community structure in Byenup Lagoon and Poorginup Swamp; reduced macroinvertebrate species diversity in Byenup Lagoon, Tordit-Gurrup and Poorginup Swamp (Table 23); and fewer south-west and locally restricted endemic species in Byenup Lagoon, Poorginup Swamp and Mulgarnup Swamp (Table 24 and 25). These changes are discussed in detail in Section 5.

Table 23. Species richness for Byenup Lagoon System wetlands 1996/97 and 2003/04 (Wetland Research and Management 2005).

Wetlands	No. taxa 1996/97	No. taxa 2003/04
Poorginup Swamp	68	58
Tordit-Gurrup Lagoon	56	34
Mulgarnup Swamp	51	50
Byenup Lagoon	59	38
N end of Byenup Lagoon	56	57
Geordinup Swamp	65	68

Table 24. Total number of south-west Australian endemic species for Byenup Lagoon System wetlands 1996/97 and 2003/04 (Wetland Research and Management 2005).

Wetlands	No. endemics 1996/97	No. endemics 2003/04
Poorginup Swamp	16	12
N end of Byenup Lagoon	11	11
Mulgarnup Swamp	11	9
Byenup Lagoon	10	4
Geordinup Swamp	9	8
Tordit-Gurrup Lagoon	8	3

Table 25. Number of south-west Australian endemic species with restricted distributions in Byenup Lagoon System wetlands for 1996/97 and 2003/04 (Wetland Research and Management 2005).

Wetlands	No. restricted 1996/97	No. restricted 2003/04
Mulgarnup Swamp	4	1
Poorginup Swamp	2	1
Byenup Lagoon	2	1
N end of Byenup Lagoon	2	3
Geordinup Swamp	2	1
Tordit-Gurrup Lagoon	1	1

3.2.8 Fish

Lake Muir

Fish surveys have not been undertaken in Lake Muir.

Byenup Lagoon System

Seven freshwater fish species, including six endemic to south-west WA and one introduced species, the Mosquitofish (*Gambusia holbrooki*), have been recorded in the Byenup Lagoon system (Storey 1998). In 1996/97, surveys were undertaken at; Byenup Lagoon, Tordit-Gurrup Lagoon, Mulgarnup Swamp, Geordinup Swamp and Poorginup Swamp (Storey 1998). The native fish species identified during this survey included: Western Pygmy Perch (*Edelia vittata*), Balston's Pygmy Perch (*Nannatherina balstoni*), Nightfish (*Bostockia porosa*), Western Minnow (*Galaxias occidentalis*), Black-stripe Minnow (*Galaxiella nigrostriata*), and the Mud Minnow (*Galaxiella munda*) (Storey 1998). Balston's Pygmy Perch is listed as Vulnerable under the EPBC Act, Black-stripe Minnow and Mud Minnow are listed as Lower Risk/near threatened on the IUCN Red List (2009). All six endemic fish species found in the Byenup Lagoon System require freshwater, although Western Minnow and Western Pygmy Perch are tolerant of brackish conditions (FishBase 2009). Fish species tolerant of acidic conditions include: Balston's Pygmy Perch (as low as pH 3); Black-stripe Minnow (pH 4.5-6.5) and Mud Minnow (pH 3-6) (FishBase 2009).

Poorginup Swamp had the greatest number of native fish species (five), followed by Mulgarnup Swamp (four). Black-stripe Minnow and Mud Minnow were only found at Poorginup Swamp and Balston's Pygmy Perch was only found at Mulgarnup Swamp within the Ramsar site (Storey 1998). These three fish species are scarce, with distributions restricted to the south-western coasts of Western Australia (Storey 1998). Information on fish habitat preferences can be found in Appendix C.

Additional surveys in 2003/04 found temporal changes in fish communities, including the absence of several species, since sampling in 1996/97 (Wetland Research and Management 2005). The fish species not recorded in the 2003/04 sampling in the Byenup Lagoon System include; Western Pygmy Perch, Balston's Pygmy Perch, Nightfish and Western Minnow from Mulgarnup Swamp; and, Nightfish from Byenup Lagoon (Wetland Research and Management 2005). These changes may be a result of sampling effort or seasonality and may not be permanent, as Nightfish and Balston's Pygmy Perch were recorded again within the Ramsar site at Myalgelup Swamp (between Tordit-Gurrup Lagoon and Poorginup Swamp) in 2008 (R. Hearn, pers. com.). These changes are discussed in detail in Section 5.

Anecdotal reports indicate that the native Freshwater Cobbler (*Tandanus bostocki*) and introduced Redfin Perch (*Perca fluviatilis*) were present in the area (R. Hearn, pers. com.), however, further investigation is required to confirm these reports.

3.2.9 Frogs and reptiles

No systematic surveys have been undertaken in the Muir-Byenup System Ramsar site. The Ramsar site is likely to be rich in reptile fauna due to the presence of open woodland with sandy soils. The Oblong Tortoise (*Chelodina oblonga*) has been recorded at Tordit-Gurrup and is likely to be common throughout the wetlands. Tiger Snakes (*Notechis ater*) also occur (Department of Conservation and Land Management 1998). Observations indicate that some frog species are abundant in certain wetlands (R. Hearn pers. com.).

3.2.10 Mammals

The Muir-Byenup System Ramsar site is believed to contain many of the mammal species found in the adjacent Perup Forest including; Woylies (*Bettongia penicillata*), Numbat (*Myrmecobius fasciatus*) and Chuditch (*Dasyurus geoffroii*) (Department of Conservation and Land Management 1998). The site also contains suitable habitat for the Boodie (or Burrowing Bettong, *Bettongia lesueur*) and the Dalgyte (or Bilby, *Macrostis lagotis*) (Department of Conservation and Land Management 1998). It is also possible that the semi-aquatic Water Rat (*Hydromys chrysogaster*) occurs in the Muir-Byenup System Ramsar site (Department of Conservation and Land Management 1998).

3.2.11 Waterbirds

49 waterbird species have been recorded within the Muir-Byenup System Ramsar site, and 10 of these species are listed under international migratory bird agreements (see Table D1, Appendix D) (Department of Conservation and Land Management 1998). Waterbirds were surveyed annually between 1981 and 1991 (Halse *et al.* 1990; Halse *et al.* 1995; Halse *et al.* 1992; Jaensch and Vervest 1988), however, there have been no comprehensive waterbird surveys since. Recently (December 2008 to September 2009), waterbirds have been surveyed at Lake Muir, Byenup Lagoon and Tordit-Gurrup Lagoon by Peter Taylor (Birding South West), however this data has not yet been analysed.

Baumea/peat freshwater wetlands and saline wetlands are the main habitat for waterbirds within the Muir-Byenup System Ramsar site. The number of waterbirds inhabiting these wetlands is strongly influenced by local and regional water availability and varies from year to year (Department of Conservation and Land Management 1998).

Lane and Munro (1982) studied waterfowl breeding in south-west Western Australia and identified that nest construction and egg-laying commences as early as June and continues through to November/December. Peak nesting activity for most species occurs during August and September with breeding during spring and early summer, at peak water levels and when food is most abundant. Ducklings are commonly seen from September to November and better than average rainfall results in high numbers of young.

Following breeding, all species of ducks and swans are flightless for a month or so while feathers are shed and new feathers grow (moulting) (Department of Conservation and Land Management 1998). During this period, large numbers of birds may congregate on undisturbed waters (Department of Conservation and Land Management 1998). The

Muir-Byenup System Ramsar site is one of the most important moulting sites for Australian Shelduck in south-west WA (Department of Conservation and Land Management 2003).

Waterbird feeding strategies are used to classify the waterbirds that use the Ramsar site into broad groups including:

- Ducks and allies (Anatidae) – ducks and swans. Feed on both plant and animal material and require fresh drinking water.
- Grebes (Podicipedidae) – diving waterbirds that feed mainly on animals, including fish, and are associated with both fresh and saline wetlands.
- Pelicans (Pelicanidae), cormorants (Phalacrocoracidae), darters (Anhingidae) – piscivorous waterbirds (fish eating), although they also eat invertebrates such as crustaceans, typically feed in water <1 m.
- Herons and egrets (Ardeidae), ibises and spoonbills (Threskiornithidae) – forage in the shallows feeding on fish and invertebrates.
- Hawks and eagles (Accipitridae) – raptors that eat fish and waterbirds, and nest in wetlands.
- Crakes, rails, coots and waterhens (Rallidae) – forage on open water by diving (coots) or in the shallows and amongst inundated vegetation, feed on plants and animals.
- Shorebirds (Scolopacidae, Recurvirostridae, Charadriidae) – forage in the shallows and on exposed mud flats for benthic and other invertebrates.
- Gulls and terns (Laridae) – feed mainly on animals, especially fish, both in the shallows and in water >1 m deep, some are omnivorous scavengers.

Table 26 shows the number of breeding species and maximum bird numbers for monitored wetlands in the Muir-Byenup System Ramsar site related to salinity, permanence, water depth and phosphorus concentrations (Halse *et al.* 1993). Jaensch (2002) developed a series of guilds that group waterbirds based on common ecological requirements or behaviour patterns. Waterbirds recorded in the Muir-Byenup System Ramsar site have been grouped according to these guilds (Appendix D), which includes:

- Feeding habitats (Table D2)
- Dietary preferences (Table D3)
- Nesting sites (Table D4)
- Other behaviour (Table D5)

Table 26. Environmental variables (September 1981-85) associated with waterbirds in the Muir-Byenup System Ramsar site (Halse *et al.* 1993).

Wetland	Salinity MgL^{-1} (class)	Veg. type	Perm	Depth m	pH	P MgL^{-1}	Size ha	No. of sp.	No. breed-ing sp.	High-est count
Byenup	3.0 (2)	Extensive sedges	P	2.4	8.1	0.02	572	31	5	838
Tordit-Gurrup	1.1 (1)	Extensive sedges	P	2.7	7.7	0.01	686	14	0	12036
Poorginup	0.38 (1)	Extensive sedges	S	0.6	6.1	0.15	50	2	0	11
Lake Muir	6.5 (2)	Samphire	S	0.3	7.4	0.2	4600	17	1	3012

Note: salinity classes: (1) fresh TDS ≤ 3 ppt; (2) brackish TDS < 10 ppt. P denotes permanent, S denotes seasonal.

Discussion in the ECD focuses on wetland dependent birds, however, the site also supports non-wetland dependent birds, including; Muir's Corella (*Cacatua pastinator pastinator*), Baudin's Black-Cockatoo (*Calyptorhynchus baudinii*) and Forest Red-tailed Black-Cockatoo (*Calyptorhynchus banksii naso*), which are listed as Vulnerable under the EPBC Act. The site also supports Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) which is listed as Endangered under the EPBC Act.

Lake Muir

Diversity and abundance

The number of waterbird species recorded within Lake Muir (1981-91) and information on feeding and foraging are shown in Table 27. More detailed information on waterbird feeding habitat guilds can be found in Appendix D, Table D2.

Table 27. Number of waterbird species recorded within Lake Muir in the Muir-Byenup System Ramsar site (1981-1991). Ramsar site total includes the Byenup Lagoon System.

Waterbird group	Typical feeding and foraging information	No. spp.	Ramsar site total
Ducks and allies	Shallow or deep water open foragers, vegetarian (Black Swan) or omnivorous with diet including leaves, seeds and invertebrates	7	11
Herons, Ibis, Egrets, Bitterns and Spoonbills	Shallow water or mudflats, feeding mainly on fish and invertebrates	2	7
Hawks and Eagles	Shallow open or vegetated water, feed on fish and occasionally waterbirds and carrion	1	1
Crakes, Rails, Coots and Waterhens	Coots in open water, others in shallow water with or without vegetation	2	4
Shorebirds	Shallow water mudflats, feeding mainly on fish and invertebrates	8	8
Gulls and terns	Terns over open water feeding on fish, gulls opportunistic feeders in a wide range of habitats	2	3

Up to 52,000 waterbirds were recorded on Lake Muir in March 1989, and the most abundant species were Pacific Black Duck (*Anas superciliosa* 18,450), Grey Teal (*Anas gracilis* 16,000), and Eurasian Coot (*Fulica atra* 9,630) (Department of Conservation and

Land Management 1998). Migratory shorebirds also use Lake Muir, such as Red-necked Stints (*Calidris ruficollis* 517 in November 1985) (Department of Conservation and Land Management 2003). Open water areas in Lake Muir have been observed to be especially important for feeding and moulting of waders during the final stages of drying through evaporation (R. Hearn, pers. com.), and are regularly used in spring for the moulting of thousands of Australian Shelduck (Department of Conservation and Land Management 2003).

Lake Muir is used as a drought refuge by large numbers of waterbirds. In March 1989, 51,600 waterbirds were recorded on Lake Muir (Department of Conservation and Land Management 2003). While this was an unusually high density due to high winter rainfall, depth data suggests that Lake Muir is capable of supporting more than 20,000 waterbirds regularly (Department of Conservation and Land Management 2003).

Breeding

Nests and broods of Black Swans and Australasian Shovelers were recorded at Lake Muir in 1989-1991 (Halse *et al.* 1994; Halse *et al.* 1990; Halse *et al.* 1995; Halse *et al.* 1992). Silver Gulls (*Larus novaehollandiae*) also breed at the lake (Department of Conservation and Land Management 2003). Nesting requirements of waterbirds found breeding at Lake Muir are shown in Table 28.

Table 28. Requirements of waterbirds recorded breeding at Lake Muir (adapted from Jaensch 2002).

Species	Breeding behaviour nesting sites
Australasian Shoveler	Limited dispersal in first year away from nest (Sutton *et al.* 2002).
Black Swan	Nest mound built in open water, on an island or in swamp vegetation. Requires minimum water depth of 30-50 cm until cygnets are independent. First flight at approximately 8 weeks.
Silver Gull	Nest on ground surface (Gillham 1961).

Byenup Lagoon system

Diversity and abundance

The number of confirmed waterbird species found within Byenup Lagoon, Tordit-Gurrup Lagoon, Poorginup Swamp and Neeranup Swamp (1981-91 and 2008-09) and feeding and foraging information is presented in Table 29. More detailed information on waterbird feeding habitat guilds can be found in Appendix D, Table D2.

Byenup Lagoon is used as a drought refuge by large numbers of waterbirds. Open water in smaller lakes, such as Tordit-Gurrup Lagoon are important for Australian Shelduck moulting, with over 12,000 recorded in December 1992 (Department of Conservation and Land Management 1998). During 1992, Lake Muir was too shallow to be used by birds for moulting due to lower than average rainfall (Department of Conservation and Land Management 1998).

Non-vegetated beaches on the eastern side of Tordit-Gurrup Lagoon and Byenup Lagoon provide habitat for waders, ducks and swans (R. Hearn, pers. com.). Tordit-Gurrup

Lagoon supports more waterbird species than Byenup Lagoon due to its larger beach expanse and greater variety of habitats (R. Hearn, pers. com.).

Poorginup Swamp provides important habitat for Australasian Bitterns in the Muir-Byenup System Ramsar site (R. Hearn, pers. com.).

Table 29. Number of waterbird species recorded within the Byenup Lagoon System in the Muir-Byenup System Ramsar site (1981-1991). Ramsar site total includes Lake Muir (1981-91).

Waterbird group	Typical feeding and foraging information	Byenup Lagoon	Tordit-Gurrup Lagoon	Poorginup Swamp	Neeranup Swamp	Ramsar site total
Ducks and allies	Shallow or deep water open foragers, vegetarian (Black Swan) or omnivorous, with diet including leaves, seeds and invertebrates	10	7	1	5	11
Grebes	Deeper open waters, feeding mainly on fish	4	1	0	2	4
Pelicans, Cormorants and Darters	Deeper open waters, feeding mainly on fish	5	6	0	2	5
Herons, Ibis, Egrets, Bitterns and Spoonbills	Shallow water or mudflats, feeding mainly on animals (fish and invertebrates)	7	5	0	4	7
Hawks and Eagles	Shallow open or vegetated water, feed on fish and occasionally waterbirds and carrion	1	1	0	1	1
Crakes, Rails, Coots and Waterhens	Coots in open water, others in shallow water with or without vegetation	4	2	1	4	4
Shorebirds	Shallow water mudflats, feeding mainly on animals (fish and invertebrates)	11	6	0	4	14
Gulls and terns	Terns over open water feeding on fish, gulls opportunistic feeders in a wide range of habitats	3	1	0	1	3

Breeding

Baumea communities in freshwater lakes, including Tordit-Gurrup and Byenup Lagoons and Poorginup Swamp, provide habitat for breeding pairs of Little Bittern (*Ixobrychus minutus*) and Spotless Crake *(Porzana tabuensis*) (Department of Conservation and Land Management 2003). These sedge dominated wetlands also provide important habitat for the Australasian Bittern (Department of Conservation and Land Management 2003), which is listed as Endangered at the global level under the IUCN Red List (2008). Possibly ten Australasian Bitterns, are supported by these wetlands, and behaviour suggests that breeding occurs at the site (Department of Conservation and Land Management 2003). The latest south-western population estimate for the Australasian Bittern is 500 birds (Wetlands International 2006), therefore the Ramsar site exceeds the

1% population threshold for this species. The Muir-Byenup System Ramsar site is one of the five remaining refuges for the south-western Australian population of Australasian Bitterns.

Nests and broods of Black Swans (Byenup Lagoon) and Eurasian Coots (Byenup Lagoon and Tordit-Gurrup) were recorded in 1989-1991 (Halse et al. 1994; Halse et al. 1990; Halse et al. 1995; Halse et al. 1992). Local knowledge also suggests that Swamp Harriers, Blue-billed Ducks, Cormorants, Sea Eagles, Spoonbills and Grebes also breed in the Byenup Lagoon System (P. Taylor, pers. com.). Table 30 presents the nesting requirements of Australasian Bitterns, Black Swans and Eurasian Coots.

Table 30. Requirements of waterbirds recorded breeding at the Byenup Lagoon System (Department of Environment 2000; Jaensch 2002).

Species	Breeding behaviour nesting sites
Australasian Bittern	Tall and short sedges, well constructed cup-shaped nests.
Black Swan	Nest mound built in open water, on an island or in swamp vegetation, requires minimum water depth of 30-50 cm until cygnets are independent, first flight at approximately 8 weeks.
Eurasian Coot	Nests in or over open water in vegetation (shrubs, trees, sedges) or in a partly floating mound, young leave nest soon after hatching, but are dependent on adults for approximately 5 weeks.

4. SYSTEM SERVICES AND BENEFITS

Ecosystem benefits and services are defined as the "benefits that people receive from ecosystems" (Ramsar Convention 2005, Resolution IX.1 Annex A), including direct benefits such as food and water provision, and indirect ecological benefits.

There are four main categories of ecosystem services defined by the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005):

1. *Provisioning services* – the products obtained from the ecosystem such as food, fuel and fresh water;
2. *Regulating services* – the benefits obtained from the regulation of ecosystem processes such as climate regulation, water regulation and natural hazard regulation;
3. *Cultural services* – the benefits people obtain through spiritual enrichment, recreation, education and aesthetics; and,
4. *Supporting services* – the services necessary for the production of all other ecosystem services such as water cycling, nutrient cycling and habitat for biota. These services will generally have an indirect benefit to humans or a direct benefit over a long period of time.

The critical ecosystem services and benefits for the Muir-Byenup System Ramsar site have been determined in accordance with the *National Framework and Guidance for Describing the Ecological Character of Australian Ramsar wetlands* (Department of the Environment, Water, Heritage and the Arts 2008). The critical services and benefits have been identified as they:

- are important determinants of the site's unique character
- are important for supporting the Ramsar Criteria for which the site is listed
- are likely to change over short or medium time scales (<100 years)
- will cause significant negative consequences if change occurs.

Table 31 outlines the critical ecosystem benefits and services for the Muir-Byenup System Ramsar site. The interactions between theses ecosystem benefits and services and ecological processes and components are discussed in Section 6.

Table 31. Ecosystem benefits and services for the Muir-Byenup System Ramsar site.

CATEGORY	DESCRIPTION
PROVISIONING SERVICE – PRODUCTS OBTAINED FROM THE ECOSYSTEM SUCH AS FOOD AND FRESH WATER	
Wetland products	No commercial products are obtained from the site
REGULATING SERVICES – BENEFITS OBTAINED FROM THE REGULATION OF ECOSYSTEM PROCESSES SUCH AS CLIMATE REGULATION, WATER REGULATION AND NATURAL HAZARD REGULATION	
Pollution control and detoxification	Wetlands act as sinks for sediment and nutrients from the catchment (DeHaan 1987).
Climate regulation	Plausible but not documented.
Flood control	The site acts as a receiver of drainage water from the surrounding floodplain.
CULTURAL SERVICES – BENEFITS PEOPLE OBTAIN THROUGH SPIRITUAL ENRICHMENT, RECREATION, EDUCATION AND AESTHETICS	
Recreation and tourism	The bird observatory on Muirs Highway is used for passive nature study/appreciation activities such as bird watching, photography, landscape painting, drawing and writing.
Spiritual and inspirational	The wetlands are spiritually significant for the Noongar people and at least one Aboriginal site occurs within the Muir-Byenup System Ramsar site. The Mulgarnup Swamp complex is known to be an important site for Aboriginal women (R. Hearn pers. com.).
	European historical sites also exist within the Ramsar site
	The Ramsar site is included within the Lake Muir Area site (9556), which is registered on the Register of the National Estate.
Scientific and educational	The Muir-Byenup System Ramsar site has been monitored for several decades. Peat wetlands, rare in Western Australia, and primary saline wetlands are found within the Ramsar site and support scientifically important flora and fauna. The Ramsar site is also of interest for scientific research of past climatic regimes (peat record). Pollen and charcoal fossil records from Byenup Lagoon peat profiles have provided insights into Holocene vegetation and fire history (Dodson and Lu 2000). Analysis of lignite obtained during drilling investigations have also contributed to understanding late Eocene history of the area (Milne 2003).
	An information bay and interpretive facility at Lake Muir provides conservation education. Education also occurs through the Perup Forest Ecology Centre.

SUPPORTING SERVICES – SERVICES NECESSARY FOR THE PRODUCTION OF ALL OTHER ECOSYSTEM SERVICES SUCH AS WATER CYCLING, NUTRIENT CYCLING AND HABITAT FOR BIOTA. THESE SERVICES WILL GENERALLY HAVE AN INDIRECT BENEFIT TO HUMANS OR A DIRECT BENEFIT OVER A LONG PERIOD OF TIME	
Biodiversity	As evidenced by the listing of the site as a wetland of international importance. Biodiversity values include: • Supporting a wide range of ecological communities; • Supporting a number of regionally, nationally and internationally threatened species; • Supporting a high diversity of species (flora and fauna); and, • Supporting an important representative of a rare habitat (peat wetlands) • Supporting numerous short range endemic species.
Nutrient cycling	The Ramsar site plays a role in the recycling of nutrients from the surrounding catchment.
	Carbon sequestration – data deficient but plausible.
Habitat	Habitat types that are important for the ecological character of the Ramsar site include: • Open water – key biota: fish, macroinvertebrates, waterbirds (foraging); • Mudflats – key biota: macroinvertebrates, waders; • Peat wetlands – key biota: macroinvertebrates, waterbirds (foraging); • *Baumea* sedgeland – key biota: fish, macroinvertebrates, waterbirds (nesting, foraging and protection from predators); • *Gahnia* sedgeland – key biota: waterbirds; • Samphire – key biota: waterbirds (foraging, nesting, roosting and protection from predators); • *Melaleuca* communities – key biota: waterbirds (nesting and roosting); • *Eucalyptus* woodlands – key biota: waterbirds (nesting and roosting).

5. CHANGES IN THE ECOLOGICAL CHARACTER OF THE MUIR-BYENUP SYSTEM RAMSAR SITE: CURRENT STATE OF CRITICAL COMPONENTS AND PROCESSES

5.1 Changes since listing

The Muir-Byenup System Ramsar site was first listed under the Ramsar Convention as a wetland of international importance in 2001. The available data indicates that there have been some changes to aquatic macroinvertebrate communities composition and distribution of some fish species in the Byenup Lagoon System, since the time of listing. Some changes have also been noted in the condition and extent of fringing vegetation. As well as being important for maintaining the ecological character of the site, these components also contain species which support the listed Ramsar Criteria. It should be noted that these changes may be a result of sampling effort (i.e. only two surveys have been conducted for macroinvertebrates and fish, in 1996/97 and 2003/04) and further investigation is required to confirm the changes. Based on available evidence, it is considered that there has not been a change to the ecological character of the Ramsar site since the time of listing.

5.1.1 Aquatic invertebrates

Wetland Research and Management (2005) identified some changes in macroinvertebrate communities in the Byenup Lagoon System wetlands between the two sampling periods of 1996/97 and 2003/04 including: altered community structure in Byenup Lagoon and Poorginup Swamp; reduced macroinvertebrate species diversity in Byenup Lagoon, Tordit-Gurrup and Poorginup Swamp; and fewer south-west and locally restricted endemic species in Byenup Lagoon, Poorginup Swamp and Mulgarnup Swamp.

Increased salinity levels from 1996/97 to 2003/04 has been correlated with reduced macroinvertebrate species diversity in Byenup Lagoon, Tordit-Gurrup and Poorginup Swamp (Wetland Research and Management 2005). However, as differences in mean annual salinity between the years from 1978-2008 were not statistically significant, these changes may not be permanent. Overall, fewer south-west and locally endemic species were recorded in 2003/04 than in the 1996/97 surveys (Wetland Research and Management 2005). The north end of Byenup Lagoon was the only wetland area sampled where a decrease in the number of south-west endemics and restricted south-west endemics was not observed between the two sampling periods (Wetland Research and Management 2005). However, in all other Byenup Lagoon System wetlands, either the same number of restricted endemics (Tordit-Gurrup Lagoon) or reduced numbers (Byenup Lagoon, Poorginup Swamp and Mulgarnup Swamp) were recorded (Wetland Research and Management 2005).

Frequency of taxa collected between 1996/97 and 2003/04 during summer and autumn also differed, with reduced frequencies of species in 2003/04 (Wetland Research and Management 2005). Species which were found to have a reduced frequency of occurrence in autumn included chironomids (*Paramerina levidensis*, *Limnophyes pullulus* and *Tanytarsus* sp.) and odonata (*Procordulia affinis* and *Austrothemis* *nigrescens*) (Wetland Research and Management 2005). These changes were possibly due to elevated salinities and nutrient levels in Byenup Lagoon System wetlands during autumn 2003/04 compared with 1996/97 (Wetland Research and Management 2005). Species which increased in frequency of occurrence in autumn included Hydracarina (*Limnochares australica*), a chironomid (*Procladius villosimanus*), ceratopogonids, tabanids, a zygopteran (*Austrolestes analis*), and dytiscid beetles (*Megaporus solidus* and *Sternopriscus* sp.) (Wetland Research and Management 2005). Kay *et al.* (2001) measured salinity tolerances associated with macroinvertebrates in south-western Australia and found that chironomid and Hydracarina families were generally salt-tolerant.

5.1.2 Fish communities

Temporal changes in fish communities have been identified in the Byenup Lagoon System wetlands between the sampling periods of 1996/97 and 2003/04 (Wetland Research and Management 2005). Fish species recorded in 1996/97 but absent in 2003/04 included: Western Pygmy Perch, Balston's Pygmy Perch, Nightfish and Western Minnow from Mulgarnup Swamp; and Nightfish from Byenup Lagoon (Wetland Research and Management 2005). As these wetlands are permanent the changes may be related to water quality, particularly increased salinity levels from 1996/97 to 2003/04. However, as differences in mean annual salinity over the long term (1978-2008) were not significant it is possible that these changes are temporary and within natural variation. Wetland Research and Management (2005) recognise that increased salinity of wetlands within the Muir-Byenup System Ramsar site may result in the loss of salt-sensitive fish larvae and juveniles. However, the absence of certain species could also be influenced by fish breeding season and whether juvenile fish are present during high salinity seasons (autumn) (Wetland Research and Management 2005).

Disappearance of fish, may also be due to drought conditions and failure of fish to recolonise wetlands during more favourable conditions (R. Hearn, pers. com.). Temporal changes in fish distributions will need to be monitored in the longer term as Balston's Pygmy Perch and Nightfish were observed in Myalgelup (Road) Swamp (Site 44) in 2008 (R. Hearn, pers. com.). Recolonisation of Balston's Pygmy Perch in 2008 may have been due to its ability to aestivate in damp bottom sediments during periods of drought (FishBase 2009).

5.1.3 Fringing vegetation

Since the time of listing (2001), Storey found that *Baumea* sedgeland health and density had substantially increased in Geordinup Swamp in 2003/04 relative to 1996/97 (Wetland Research and Management 2005). However, large areas of *B. articulata* in Yarnup and Unicup wetlands, north of the Byenup Lagoon System, had been degraded since 1996/97 (Wetland Research and Management 2005). Gibson and Keighery (1999) also observed *Baumea* sedgeland decline at Byenup Lagoon from 1980 to 1995, through comparison of aerial photographs. These changes could be related to increased salinity levels over that period, however, changes in *Baumea* in West Kodjinup Nature Reserve were likely due to fire damage (Wetland Research and Management 2005).

6. HOW THE MUIR-BYENUP SYSTEM RAMSAR SITE WORKS: INTERACTIONS BETWEEN COMPONENTS, PROCESSES, BENEFITS AND SERVICES

Table 32 presents a summary of the interactions between the components and processes, and the services and benefits for the Muir-Byenup System Ramsar site. For each service and benefit, the following associations have been identified:

- Location within the Muir-Byenup System Ramsar site for which the service and benefit applies;
- Components and processes that are directly responsible for the provision of the service and benefit;
- Influencing biotic components and processes that are indirectly related to the service and benefit by supporting or impacting on direct components and processes;
- Influencing abiotic components and processes that affect the service and benefit;
- Threatening activities that are or have potential to affect components and processes that provide service and benefit.

Table 32. Muir-Byenup System Ramsar site benefits and services, and components and processes (adapted from Hale and Butcher 2007)

BENEFIT/SERVICE	DIRECT COMPONENTS	INFLUENCING BIOTIC COMPONENTS	ABIOTIC COMPONENTS	THREATS AND THREATENING ACTIVITIES
Pollution control	Nutrient concentrations in water and sediment (entire Ramsar site).	Phytoplankton and macrophyte biomass.	Nutrient concentrations. Denitrification. DO concentrations. Nutrient storage and release from sediments.	Increased catchment nutrient loads from fertiliser inputs leading to eutrophication. Any actions that disturb drainage flows and interactions between wetlands.
Cultural services: Recreation and tourism Spiritual and inspirational Scientific and educational	Waterbird populations. Aboriginal sites. Rare flora and fauna. Peat pollen record (entire Ramsar site).	Habitat extent (saline and peat wetlands) and distribution. Primary production (balance between productivity and eutrophication).	Hydrology Water quality: Nutrients Dissolved oxygen Water clarity Salinity pH	Increased catchment nutrient loads from fertiliser inputs leading to eutrophication. Dryland salinity. Disturbance of acid sulfate soils. Any actions that disturb hydrology (drainage, groundwater extraction).
Ecological service: Supports an important representative of a rare habitat	Byenup Lagoon System peat wetlands. Primary saline wetlands (Lake Muir and Coorinup Swamp).	Vegetation, waterbird, fish and macroinvertebrate communities.	Hydrology Water quality: Nutrients Dissolved oxygen Water clarity Salinity pH	

Ecological service: Supports a high diversity of species (flora and fauna)	Byenup Lagoon System peat wetlands and naturally saline Lake Muir.	Vegetation, waterbirds, fish and macroinvertebrate communities.	Hydrology Water quality: Nutrients Dissolved oxygen Water clarity Salinity pH	
Ecological service: Supports a number of regionally, nationally and internationally threatened species (flora and fauna)	Waterbirds, flora and fish.	Habitat diversity and extent	Hydrology Water quality: Nutrients Dissolved oxygen Water clarity Salinity pH	
Ecological service: Regularly supports 20,000 or more waterbirds	Waterbirds	Macrophytes Phytoplankton Macroinvertebrates Habitat extent and distribution Primary production	Hydrology Water quality: Nutrients Dissolved oxygen Water clarity Salinity pH	Increased catchment nutrient loads from fertiliser inputs leading to eutrophication. Dryland salinity. Disturbance of acid sulfate soils. Disturbance of birds and nests. Introduced predators. Any actions that disturb hydrology (drainage, groundwater extraction).
Ecological service: Supports plant and-or animal species at a critical stage in their lifecycles, or provides refuge during adverse conditions	Waterbirds (Australasian Bittern, Australian Shelduck moulting, migratory shorebirds, breeding of 6 species).	Macrophytes Phytoplankton Macroinvertebrates Habitat extent and distribution	Hydrology Water quality: Nutrients Dissolved oxygen Water clarity Salinity pH	
Ecological service: Regularly supports 1% of the individuals in a population of one species or subspecies of waterbirds	Australasian Bitterns	Macrophytes Phytoplankton Macroinvertebrates Habitat extent and distribution	Hydrology Water quality: Nutrients Dissolved oxygen Water clarity Salinity pH	

The interactions between the critical components and processes, and services and benefits determine the ecological character of the Muir-Byenup System Ramsar site. Conceptual models have been provided to illustrate the ecological character of Lake Muir (Figure 23) and the Byenup Lagoon System (Figure 24). These models also show the species and communities that support the listing criteria of the Muir-Byenup Ramsar System Ramsar site including; flora, waterbirds, fish and macroinvertebrates.

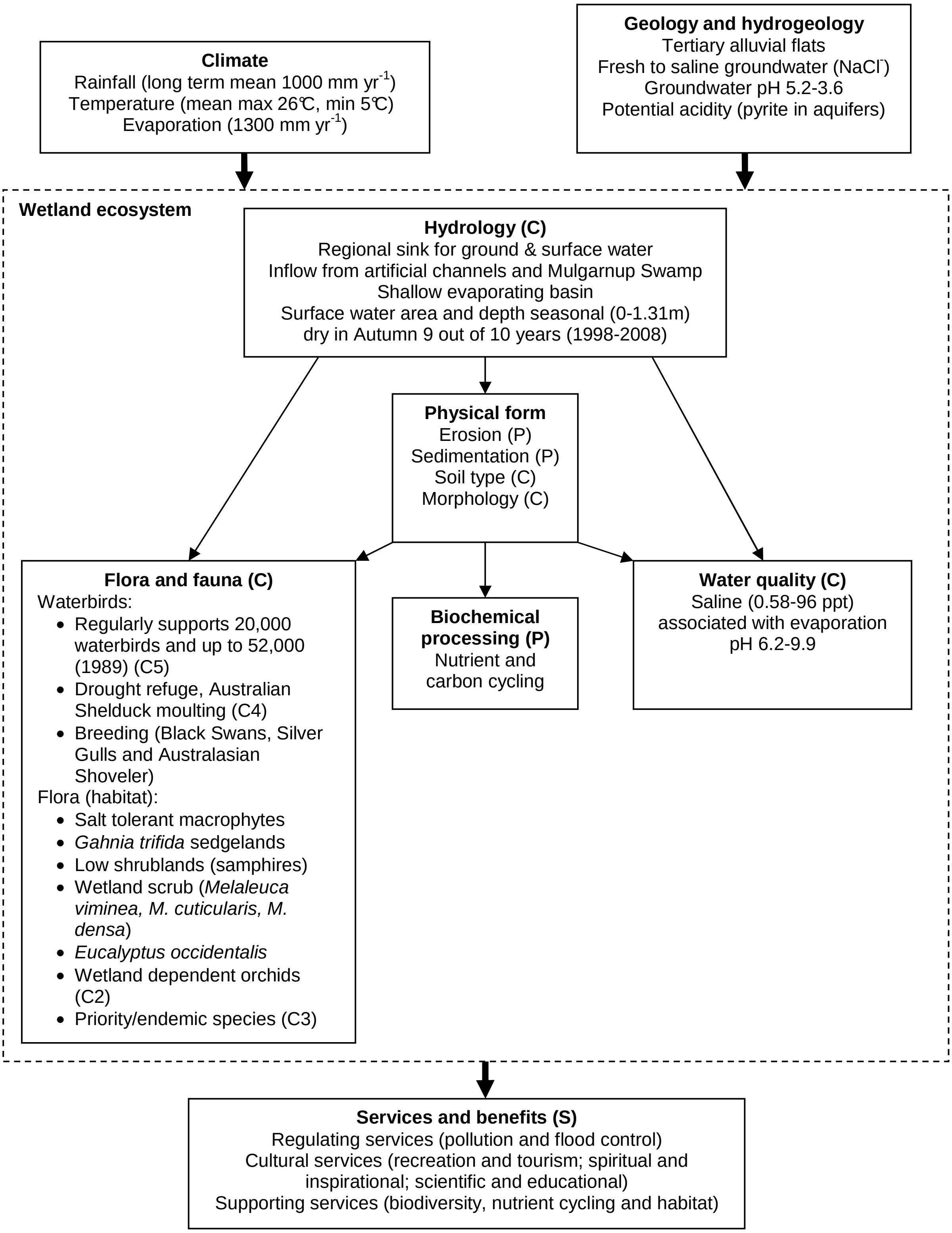

Figure 23. Conceptual model of the Lake Muir System showing the critical components (C), processes (P) and services (S) for maintaining ecological character . C1 etc. denote Ramsar criteria met.

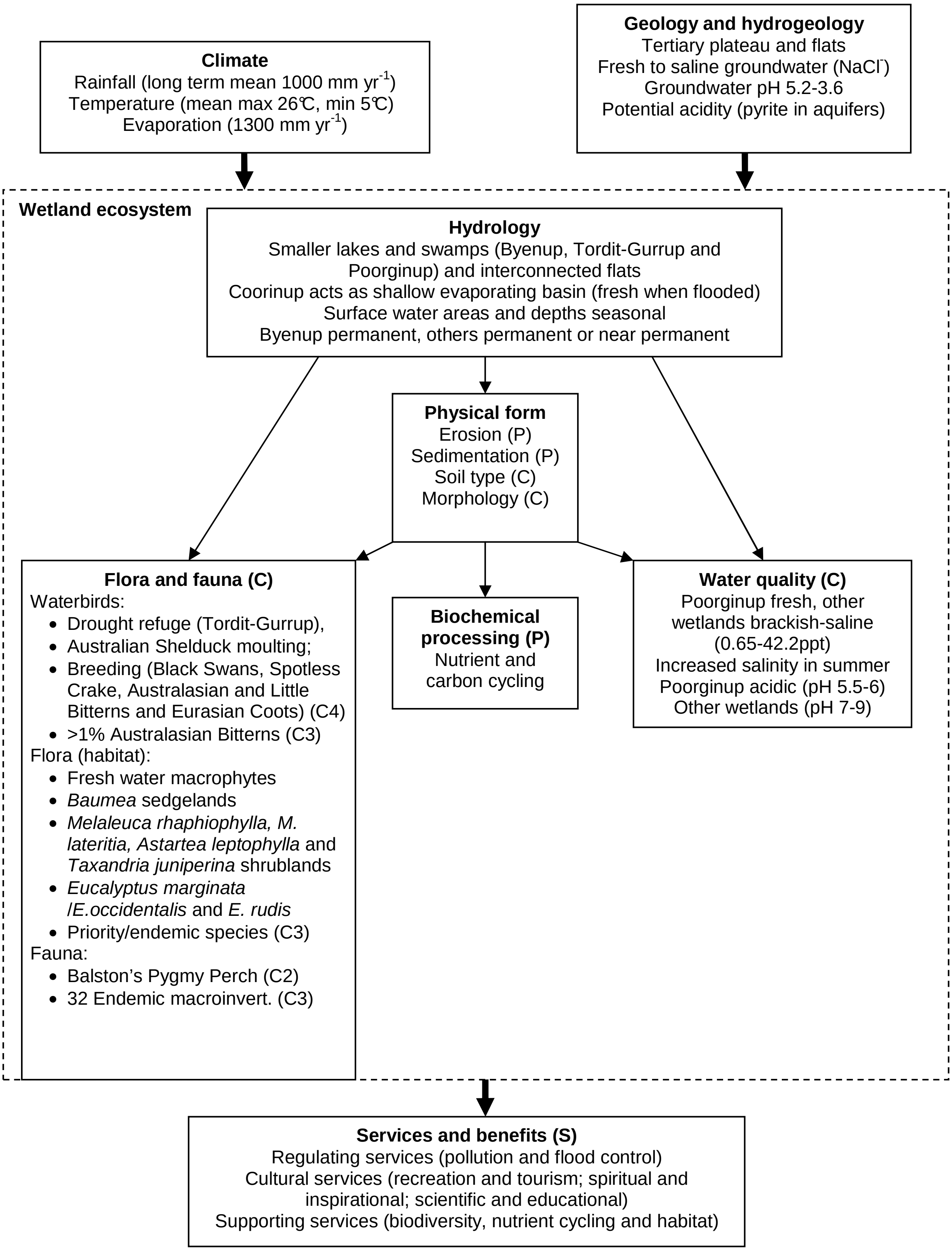

Figure 24. Conceptual model of the Byenup Lagoon System showing the critical components (C), processes (P) and services (S) for maintaining ecological character . C1 etc. denote Ramsar criteria met.

7. THREATS TO THE ECOLOGICAL CHARACTER OF THE MUIR-BYENUP WETLAND

Threatening processes identified in the Muir-Byenup System Ramsar site include:

- Secondary salinity;
- Disturbance of potential acid sulfate soils;
- Eutrophication;
- Grazing;
- Introduced species;
- Pathogens and pests;
- Inappropriate fire regimes; and,
- Illegal vehicle access.

7.1 Secondary salinity

Wetlands, due to their low position in the landscape, are considered to be one of the first habitats to be impacted by rising groundwater and salinity (Gibson *et al.* 2004). Secondary salinisation has been identified as a major threat to the conservation values (Gibson and Keighery 1999) and the ecology of the Muir-Byenup peat wetlands (Wetland Research and Management 2005).

Land clearing for agriculture is the major cause of land and water secondary salinisation in south-western Australia. In the Lake Muir catchment during the 1960s and 70s, more than 20,000 hectares were cleared for pasture and horticultural crops (Clews 1999). Replacing deep-rooted perennial vegetation with shallow-rooted annual crops and pastures, alters the water balance, causing rising watertables and mobilisation and concentration through evaporation of ancient salts in the soil profile (Smith 2003). Wetland systems can become saline through increased salt-laden runoff, and rising saline watertables (Smith 2003). These processes can also lead to intermittent wetlands or swamps becoming permanently inundated or waterlogged (Smith 2003).

Salinisation due to shallow water levels, varies from no risk to high risk within the Ramsar site depending on geology, topography and rainfall (Smith 2003). Wetlands on broad flats, such as Lake Muir, and wetlands adjacent to cleared land, have the highest risk of land salinisation due to poor drainage and the presence of shallow saline groundwater (Smith 2003). However, it is still unclear as to the extent to which saline water has been released by land clearing into the surface waters of the Ramsar site (R. Hearn, pers. com.). Drainage works also contribute to salinisation of wetlands (Gibson *et al.* 2004).

In 1996, the Lake Muir-Unicup Wetland Complex was nominated as a high-priority catchment for recovery under the State Salinity Action Plan and its successor, the Salinity Strategy (Government of Western Australia 1996 and 2000). While a recovery catchment plan has not been written to date, recovery actions have included reforestation and revegetation through tree plantations and perennial crops and pastures (Clews 1999). However, plantations may also be responsible for increased salinity of wetlands. Water use by plantations reduces freshwater runoff to wetlands and valley floor groundwater recharge, and may be responsible for lowering water levels in the Ramsar site by reducing dilution and flushing effects, which results in an increase in surface water salinities. Plantation harvesting may also lead to salinisation of wetlands by saline groundwater intrusion through lake floors associated with rising regional watertables (R. Hearn, pers. com.). Long-term data indicates that there have been no significant changes in salinity between years for all monitored wetlands except for Poorginup Swamp. Increased salinisation in some years in Poorginup Swamp was related to low water levels during the 1980s and there was no evidence for increased salinisation in the last 10 years.

In naturally saline wetlands in south-western Australia, salinity levels do not appear to affect vegetation species richness (Halse 1993). However, secondary salinisation does reduce vegetation species richness and composition, principally from increased salinity levels and waterlogging (Halse 1993). Peat based *Baumea* wetlands are very narrowly distributed and are threatened by increased salinity (Department of Conservation and Land Management 1998). Gibson and Keighery (1999) observed *Baumea* sedgeland decline at Byenup Lagoon through comparison of aerial photography from 1980 to 1995. This decline coincided with an eight year peak in salinity levels in the lagoon (Gibson and Keighery 2000). Increased salinity of peat based wetlands has also been found to be negatively correlated with both aquatic invertebrate species richness and waterbird richness (Cale *et al.* 2004). Effects of salinity on aquatic macrophytes are also likely to have adverse effects on aquatic invertebrates, fish and waterbirds, through removal of food sources and habitat (Hart *et al.* 1991).

Increasing salinisation is likely to have direct and indirect impacts on waterbirds within the Ramsar site (Wetland Research and Management 2005). Hart *et al.* (1991) found that the salinity tolerance of waterbirds varies greatly between species. Most waterbirds require freshwater to drink and there is evidence of low breeding success above 3,000 mgL^{-1} (3 ppt). Indirectly, increased salinities are likely to affect waterbirds through loss of habitat for feeding, nesting and food source (e.g. changes in invertebrate composition), vegetation degradation and death (Wetland Research and Management 2005).

Salinisation dramatically alters the composition and richness of freshwater aquatic invertebrate communities, with salt-sensitive species gradually replaced by salt-tolerant or halophyllic species (Pinder *et al.* 2004). Salinised communities are relatively homogenous compared with naturally saline or freshwater wetlands (Pinder *et al.* 2004). Naturally saline wetlands are also threatened by dryland salinity due to altered hydrology (increased streamflow and wetland inundation, changed vegetation and formation of new wetlands) and water chemistry (changed ionic composition) (Pinder *et al.* 2004). DeHaan (1987) suggested that increased salinity in the Byenup Lagoon System would alter macroinvertebrate community structure, with crustaceans becoming more dominant than insect taxa. This will also adversely impact on fish species such as Balston's Pygmy Perch whose larvae feed on Cladocera (FishBase 2009).

Naturally saline wetlands, such as Lake Muir are also affected, as plants and animals cannot tolerate the increased hydroperiod and altered salinity regime associated with secondary salinity (Cramer and Hobbs 2002). Increased salinity is likely to adversely impact the ecological character of the Ramsar site through changes in macroinvertebrate and fish composition, and subsequent impacts on waterbirds through loss of food source.

7.2 Disturbance of potential acid sulfate soils

Increased acidity may impact the ecological character of the Muir-Byenup System Ramsar site, by altering macroinvertebrate and fish composition, and reducing food for waterbirds. Disturbance of potential acid sulfate soils should be investigated prior to activities such as drainage (Smith 2003). Lower water levels in wetlands may expose peat to oxidation, causing acidification of naturally occurring acid sulfate soils. Potential acid sulfate soils within the Ramsar site are also exacerbated by disturbance of peat wetlands by feral animals, illegal vehicle use and horses (McKenzie *et al.* 2002).

The Ramsar site is adjacent to a peat mining area (McKenzie *et al.* 2002). Wetlands north of Lake Muir, including Red Lake and Cowerup Swamp, have been subject to peat mining and drainage activities (Department of Conservation and Land Management 2003). Cowerup Swamp has been mined for peat, and acidic water drains (pH 3.68-6.73) (DeHaan 1987) via artificial drainage channels and Red Lake, into Lake Muir (R. Hearn, pers. com.). Currently, Lake Muir has sufficient buffering capacity due to high levels of carbonates from snail shells. Closure of this drain would return anoxic conditions to Cowerup Swamp and help re-establish peat communities (R. Hearn, pers. com.).

Artificial drains installed in the wetland adjacent to Poorginup Swamp have reduced water levels by 0.5-0.75 m, altering local hydrological systems and indirectly causing Poorginup Swamp to dry out more rapidly than other wetlands in the Ramsar site (R. Hearn, pers. com.). In addition to changes in hydrologic properties, drainage of peat wetlands can also cause subsidence from erosion, shrinkage, oxidation, compression and compaction of the peat surface (DeHaan 1987). Oxidation occurs either by the acceleration of aerobic decomposition or by fire losses, which can be spontaneous in drained peat (DeHaan 1987). Subsidence increases surface runoff and potentially reduces groundwater recharge (DeHaan 1987).

Acidity of wetlands may also occur following plantation harvesting from acid and ferrous ion rich groundwater intrusion via rising water tables (R. Hearn, pers. com.).

DeHaan (1987) suggested that low pH in the Byenup Lagoon System was likely to reduce macroinvertebrate species richness, diversity and abundance. Increased acidity has been shown to detrimentally affect macroinvertebrate diversity (Petrin *et al.* 2007) with depauperate communities in south-western Australian wheatbelt lakes where pH was less than 4 (Pinder *et al.* 2004). Stewart *et al.* (2009) suggests that pH levels of about 5 indicate a level for concern in south-western Australia. Macrophytes and algae are also known to be sensitive to acidification (Farmer 1990) and loss of these species would further impact on macroinvertebrates in the Byenup Lagoon System.

7.3 Eutrophication

Increased nutrient levels, nitrogen and phosphorus concentrations and availability, can directly influence aquatic ecosystems through toxicity or indirectly via excessive plant growth and eutrophication (Wetland Research and Management 2005). Nutrients enter the Ramsar site from the release of phosphorus via drainage associated with mining activities and agriculture (DeHaan 1987). Historically, Byenup Lagoon has experienced algal blooms due to nutrient enrichment (Department of Conservation and Land Management 1998). Excessive nitrogen and phosphorous may have changed invertebrate composition (R. Hearn, pers. com.) and therefore increased nutrient concentrations are likely to adversely impact the ecological character. Changes in macroinvertebrate composition will also impact on fish and waterbirds through reduction of food source.

7.4 Grazing

Currently, areas of the Ramsar site are being used by neighbouring landholders to graze cattle. Cattle adversely impacts wetlands through trampling, vegetation degradation, soil erosion and degradation of water quality (Horwitz 1994). Grazing was found to have a detrimental impact on emergent and fringing plant species in a study of wetlands in nature reserves of south-western Australia (Halse 1993). Domestic cattle also cause degradation of aquatic macrophytes, which results in reduction of the number of invertebrate species (Halse 1993).

Grazing in the Muir-Byenup System Ramsar site has resulted in increased weed diversity in the Jarrah/Yate woodlands and *E. rudis* woodlands (Gibson and Keighery 2000). Grazing may impact the ecological character of the Ramsar site by altering waterbird and aquatic fauna habitat, and result in the loss of wetland dependent orchids and priority endemic floral species.

7.5 Introduced species

Feral animals have caused land degradation and weed invasion (Department of Conservation and Land Management 1998) in wetland areas and watering points throughout the Muir-Byenup System Ramsar site. Feral animals are likely to adversely impact the ecological character of the Ramsar site by altering habitat for waterbirds and aquatic fauna, and reducing the extent of key flora species. Introduced animals known to occur in the Ramsar site, include:

- Fox (*Vulpes vulpes*)
- Red deer and Fallow deer (*Cervus elaphus, Dama dama*)
- Cat (*Felis catus*)
- Dog (*Canis familiaris familiaris*)
- Pig (*Sus scrofa*)
- Rabbit (*Oryctolagus cuniculus*)
- Horse (*Equus asinus*)
- House mouse (*Mus musculus*)
- Black rat (*Rattus rattus*)
- Honeybee (*Apis mellifera*)

- Laughing Kookaburra (*Dacelo novaeguineae*)
- Mosquitofish (*Gambusia holbrooki*)

Foxes pose direct threats to waterbirds through predation. Horses, deer and pigs also pose direct threats to waterbirds through habitat destruction. Horses and pigs can also spread *Phytophthora* (Department of Conservation and Land Management 1998). Vegetation around wetlands and the presence of water make the wetlands highly suitable for feral pigs, which are difficult to eradicate (Department of Conservation and Land Management 1998). Deer also exacerbate acid sulfate soils in *Baumea* sedgelands by oxygenating peat and mobilising acid groundwater, and cause tree death through ringbarking (R. Hearn, pers. com.). Methods of control include baiting and trapping programs and opportunistic shooting of foxes, cats, dogs and pigs (Department of Conservation and Land Management 1998).

The Laughing Kookaburra is not native to Western Australia and was introduced from the eastern states in 1896, however, it is protected under the *Wildlife Conservation Act 1950* (Department of Conservation and Land Management 1998). Mosquitofish have also been recorded in the Ramsar site (Wetland Research and Management 2005). Redfin Perch (*Perca fluviatilis*) were introduced to the Ramsar site as part of the acclimatisation program and may still persist in the area (R. Hearn, pers. com.) More investigation is required to determine whether Redfin Perch are a threat.

Exotic weeds (*Watsonia*, Cape Tulip, east coast wattles, exotic grasses, blue gums, various clovers and their allies) are found within the Ramsar site. A *Watsonia* population has also been found north of the Ramsar site (corms were spread by bulldozers) which needs eradication (R. Hearn, pers. com.).

Typha orientalis populations have been found in Tordit-Gurrup Lagoon and in Geordinup Swamp. Both of these populations are being managed by spraying programs (since 2006) and seed removal (R. Hearn, pers. com.). Grazing of seedlings by kangaroos and flooding early in their life-cycle also helps eradication (R. Hearn, pers. com.). *Typha* on private properties and reserves north of the Ramsar site are also being managed to reduce the risk of spreading (R. Hearn, pers. com.).

7.6 Pathogens and pests

Pathogens are likely to adversely impact the ecological character, by affecting key flora species. Dieback, caused by *Phytophthora cinnamomi*, is identified as one of the major threats to the conservation values of the Muir-Byenup System Ramsar site (Gibson and Keighery 1999). Dieback hazard of low-lying areas of the Ramsar site is moderate to high (Gibson and Keighery 2000) and *Phytophthora* spread has been correlated with drainage and road works (Gibson and Keighery 1999). Horses and pigs can also spread *Phytophthora* (Department of Conservation and Land Management 1998). *Phytophthora* currently affects *Banksia ilicifolia* woodlands along the Muirs Highway (Gibson and Keighery 2000). *Phytophthora* is likely to change the composition of sand-plain communities through selectively targeting Proteaceae and Epacridaceae families (R. Hearn, pers. com.). However, as *Phytophthora* spread is compounded by rising watertables (McKenzie *et al.* 2002) it is difficult to separate the effects from salinity or acidity (R. Hearn, pers. com.).

Armillaria luteobubalina is an indigenous species of mushroom-producing fungus which causes infection by root-root contact and occasionally by aerial spore dispersal (Department of Conservation and Land Management 1998). Proteaceae, Myrtaceae, Papilionaceae, Epacridaceae and Mimosaceae are the most susceptible families (Department of Conservation and Land Management 1998). *Armillaria* is common in eastern Jarrah and Wandoo forests (Department of Conservation and Land Management 1998) and in the Ramsar site has infected part of the *Melaleuca preissiana – Kunzea sulphurea* woodland north of Poorginup Swamp (Gibson and Keighery 2000).

Insect attacks by Marri Spitfire (*Perga* sp., family Pergidae) have caused defoliation and death of Marri trees in the south-east part of the Ramsar site (R. Hearn, pers. com.). This is likely to affect the balance of Jarrah and Marri communities and may also result in Jarrah deaths due to changed hydrology, as Jarrah is intolerant of inundation (R. Hearn, pers. com.).

Pathogens and pests can alter vegetation composition, impacting the ecological character of the Ramsar site by changing waterbird and aquatic fauna habitat.

7.7 Inappropriate fire regimes

Lake Muir Nature Reserve has had a history of numerous wildfires, with most fires originating from adjacent farmland (Department of Conservation and Land Management 1998). The last significant fire in the peat wetlands (Tordit-Gurrup Lagoon) occurred in 1988, as a result of burning off in adjacent private property (Department of Conservation and Land Management 1998).

Fires have resulted in a depauperate understorey in forested areas east of Tordit-Gurrup Lagoon and south-east of Byenup Lagoon. In particular, the removal of litter and nitrogen fixing *Acacia* species and Papillionaceae families from the understorey has reduced ecosystem health (R. Hearn, pers. com.). Inappropriate burning regimes (such as frequent lethal or infrequent intense fire regimes) can have a range of impacts on sensitive flora and fauna species and can also result in the destruction of peat and retardation of regeneration of wetland shrub thickets, which are important for waterbird breeding (Department of Conservation and Land Management 2003).

7.8 Illegal vehicle access

Illegal vehicle access has resulted in the degradation of some wetland shorelines, including Lake Muir (Department of Conservation and Land Management 1998). Impacts from vehicles may threaten key flora species and degrade waterbird and aquatic fauna habitat.

8. LIMITS OF ACCEPTABLE CHANGE

Limits of acceptable change are linked to the natural variability of parameters from which limits are set. Both temporal and spatial variability occurs in wetland processes and components, however the limits of acceptable change should go beyond the levels of natural variability (Figure 25). Phillips (2006) defined the limits of acceptable change as:

"…the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland. This may include population measures, hectares covered by a particular wetland type, the range of certain water quality parameter, etc. The inference is that if the particular measure or parameter moves outside the 'limits of acceptable change' this may indicate a change in ecological character that could lead to a reduction or loss of the values for which the site was Ramsar listed. In most cases, change is considered in a negative context, leading to a reduction in the values for which a site was listed".

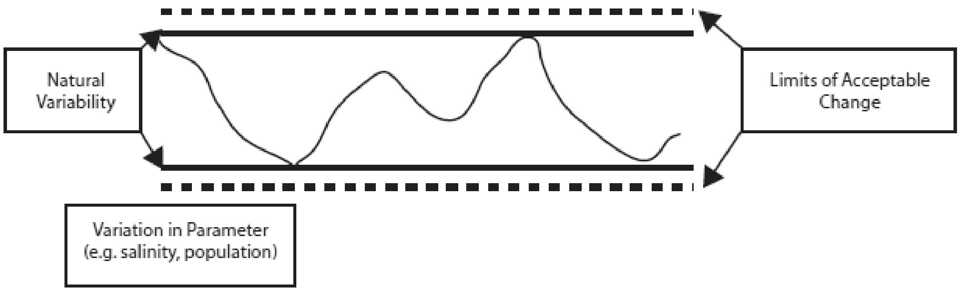

Figure 25. Example of natural variation and limits of ecological change (Phillips 2006).

In the absence of complete knowledge, conservative limits of acceptable change are set, which can be reviewed in light of monitoring and additional information. Components and processes for which limits of acceptable change can be established are those where:

- Information is adequate to form a baseline against which change can be measured;
- Information is sufficient to characterise natural variability; and
- Management and monitoring can occur (Hale and Butcher 2007).

Where these criteria cannot be met, limits of acceptable change are set using a hierarchical approach (Hale and Butcher 2007). This approach uses key abiotic factors and primary responses to abiotic conditions (supporting biological components and habitat) to set limits for species and communities within the wetland system (Hale and Butcher 2007) (Figure 26). The limits of acceptable change for Lake Muir are shown in Table 33 and for the Byenup Lagoon System in Table 34.

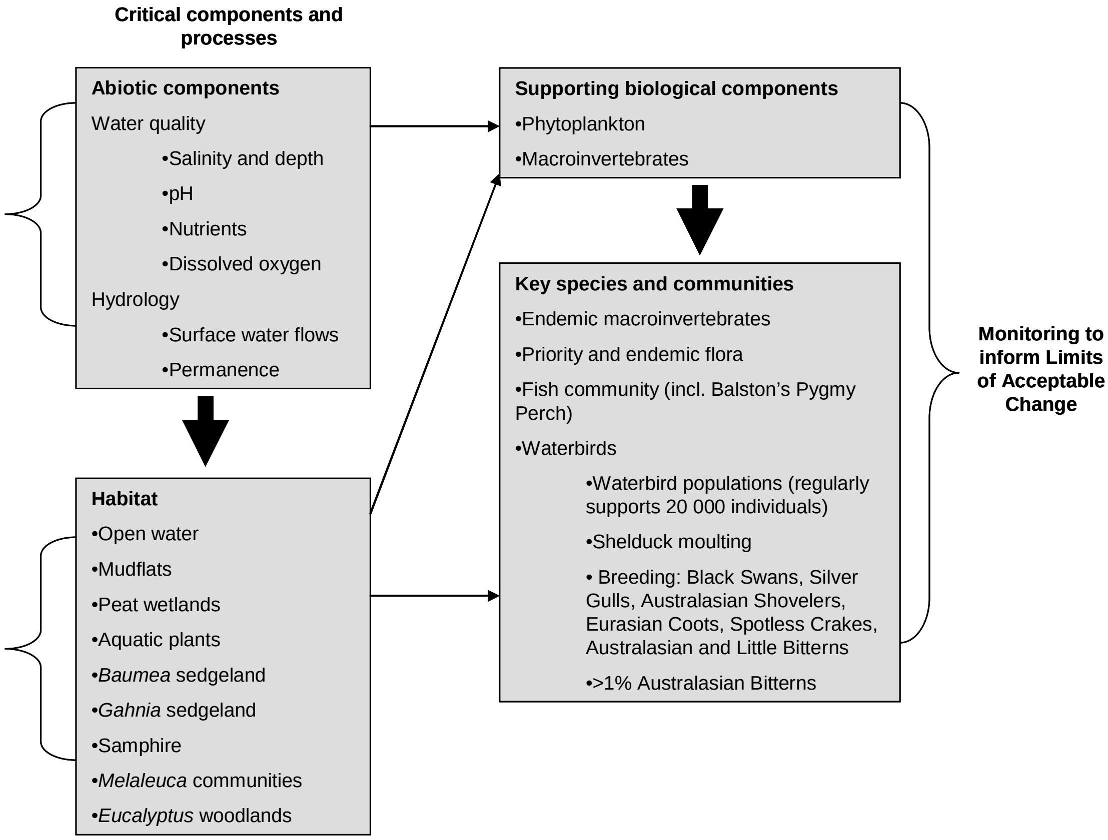

Figure 26. Hierarchical system for setting limits of acceptable change in the Muir-Byenup System Ramsar site (adapted from Hale and Butcher 2007).

As ANZECC/ARMCANZ (2000) guidelines for water quality do not seem to be appropriate for the Muir-Byenup System Ramsar site (see Section 3.2.4 for further information), limits of acceptable change have been based on historical variation and changes in composition or presence/absence of key species (e.g. macroinvertebrates) dependent on maintenance of current water quality conditions. These species are also important for maintaining the ecological character of the Ramsar site.

Table 33. Limits of acceptable change for Lake Muir

COMPONENT	BASELINE SUPPORTING EVIDENCE	LIMIT OF ACCEPTABLE CHANGE
Abiotic components		
Depth	Depth ranges from 0 - 1.31 m. Depth was significantly different between years during drier conditions 1979-87 and 2006-07. Peak water levels occurred in 1988.	Depth < 1.31 m.
Salinity	Salinity ranges from 0.58 - 96 ppt and differences in salinity were not significantly different between years. Some waterbirds require fresh drinking water (<3 ppt) (Hart *et al.* 1991), however this is provided nearby in the Byenup Lagoon System.	Salinity < 125 ppt.

	Salinity tolerances of macrophytes occurring in Lake Muir range up to 125 ppt for *Ruppia polycarpa* and *Lamprothamnium* sp (Brock and Lane 1983).	
pH	Baseline conditions indicate pH typically between 6.2 and 9.9 and mean annual pH is 8.64. Levels of pH were significantly different between years.	In the absence of baseline data for surrogates such as macroinvertebrate diversity, maximum pH levels should not exceed 9.9.
Nutrients	Baseline conditions indicate total N typically 0.58-5.8 and soluble N 0.4-4.7 mgL^{-1}. Total P 0.005-0.65 and soluble P 0.005-0.01 mgL^{-1}. Total and soluble N and P were not significantly different between years.	In the absence of baseline data for surrogates such as phytoplankton biomass or macroinvertebrate composition, no limits of acceptable change can be set.
Supporting biological components and habitat		
Phytoplankton	Current extent and biomass unknown. No records of algal blooms in Lake Muir	Presence of algal blooms.
Macrophytes	Current extent and biomass unknown. Species include: *Ruppia polycarpa*, *Lepilaena cylindrocarpa* *Crassula helmsii*, *Cotula coronopifolia*, *Triglochin procera* and *Zygnema* sp. *Lamprothamnium* sp.	Baseline must be set before limits can be set.
Samphire	Current extent and biomass = 80% area and 30% cover.	Maintain current extent of samphire.
Gahnia sedgeland	Current extent and biomass = 20% area and 20% cover.	Maintain current extent of *Gahnia* sedgeland.
Fringing shrubs and trees	Fringing vegetation includes; wetland scrub (*Melaleuca viminea, M. cuticularis, M. rhaphiophylla* and *M. densa*). *Eucalyptus occidentalis* occurs at increased elevations. Notable flora includes wetland dependent orchids. Current extent and biomass (shrub) = 20% area and 2% cover. Current extent and biomass (tree) = 20% area and 10% cover.	Maintain current extent of fringing vegetation, including EPBC listed wetland dependent orchids.
Key species and communities		
Macroinvertebrates	No data for baseline.	Baseline must be set before limits can be set.
Fish	No data for baseline.	Baseline must be set before limits can be set.
Waterbirds	Regularly supports 20,000 waterbirds Up to 52,000 waterbirds were recorded on Lake Muir in March 1989, the most abundant species were Pacific Black Duck (up to 18,450), Grey Teal (16,000), and Eurasian Coot (9,630) Migratory shorebirds also use Lake Muir, including Red-necked Stints (up to 517 in November 1985) and Silver Gulls (up to 700). Lake Muir is used as a drought refuge by large numbers of waterbirds. Lake Muir is used for breeding by Black Swans, Silver Gulls and Australasian Shoveler. As waterbird data have not been collected since 1992, it is recommended that the limit of acceptable change is revised as more data becomes available.	Regularly support >20,000 waterbirds (in accordance with the Ramsar definition of ‘regularly’). Maintain presence of waterbirds including; Pacific Black Duck, Grey Teal, and Eurasian Coot and migratory shorebirds including; Red-necked Stints and Silver Gulls. Breeding by Black Swans, Silver Gulls and Australasian Shoveler.

Table 34. Limits of acceptable change for Byenup Lagoon system.

COMPONENT	BASELINE SUPPORTING EVIDENCE	LIMIT OF ACCEPTABLE CHANGE
Abiotic components		
Depth	Depth ranged from 0.4-2.8 at Byenup Lagoon, with increased water levels between 1989 and 2000. Depth ranged from 0.15-3.1 at Tordit-Gurrup, with water levels relatively constant 1977-2006, except for lower water levels in 1987-88, 1995 and 2007. Depth ranged between 0-0.72 at Poorginup Swamp with lowest water levels in 1982 and 1987	Wetlands should not dry out to avoid acidification of acid sulfate soils and to maintain macroinvertebrate communities.
Salinity	Salinity concentrations peak in autumn. Salinity (ppt) ranges from 0.65-15.2 (Tordit-Gurrup), 1.38-42.2 (Byenup) and 0.1-1.6 (Poorginup). Salinity was not significantly different at Byenup or Tordit-Gurrup, however, salinity was higher at Poorginup Swamp in 1982 and 1987 and was related to low water levels. Some waterbirds require fresh drinking water (<3 ppt) (Hart *et al.* 1991). Macroinvertebrates and aquatic macrophytes are likely to be adversely affected by salinities 1-3 ppt (Hart *et al.* 1991). However ostracods and cladocera are likely to be more sensitive. Watermite tolerances range from 4.9-12.9 (Kay *et al.* 2001) and *Baumea* is 3 ppt (Wetland Research and Management 2005). Currently Insecta make up 73% of invertebrate composition, increased salinity is likely to increase dominance of crustaceans (DeHaan 1987), making this a useful surrogate measure.	>73% class Insecta in macroinvertebrate composition.
pH	Baseline conditions indicate pH typically between 6.8-9.3 for Tordit-Gurrup and Byenup Swamp 4.6-8.3 for Poorginup Swamp. There was no significant difference in pH for Tordit-Gurrup or Byenup Lagoon. However, in Poorginup Swamp pH was significantly lower in 1981, 1987, 2001 and 2007 compared with other years. Lower pH in 1987 and 2007 corresponded with reduced water levels. Low pH in Poorginup Swamp may be due to acidification of acid sulfate soils.	Maintain the presence of peat wetland endemic macroinvertebrates, including; watermites (*Acercella poorginup*, *Pseudohydryphantes doegi*, *Huitfeldtia* sp.), crustaceans (*Cherax preissii* and *C. quinquecarinatus*) and *Hygrobia wattssii* (Byenup Lagoon).
Nutrients	Current baseline suggests peaks in Total N in autumn. However wetlands do not behave as eutrophic. Phosphorous is limited in all seasons. Baseline conditions for Byenup and Tordit-Gurrup indicate total N typically 1-3.5 and soluble N 0.77-3.3 mgL^{-1}. Values for Poorginup Swamp TN 0.63-1.7 and SN 0.47-1.4 mgL^{-1}. Total P 0.005-0.11 and soluble P 0.005-0.07 in Byenup Lagoon. TP 0.005-0.02 and SP 0.005-0.09 in Tordit-Gurrup. TP 0.005-0.36 and SP 0.005-0.11 in Poorginup Swamp. In this system nutrient levels are seasonal, related to lower water levels and	As these wetlands do not behave as eutrophic (Storey 1998) the presence of algal blooms can be used as an interim limit.

	concentration effects. Drying of peat also releases nutrients (DeHaan 1987). Historically, algal blooms have occurred in Byenup Lagoon due to high nutrient concentrations.	
Supporting biological components and habitat		
Phytoplankton	Increased chlorophyll *a* concentrations in July when total P is high. Current extent and biomass unknown.	Baseline must be set before limits can be set.
Macrophytes	Macrophyte cover = 20% Tordit-Gurrup, 1% Byenup Lagoon. Macrophytes are absent from Poorginup Swamp. *Baumea articulata*, *Montia australasica*, *Utricularia* spp. and mats of floating native grasses have been found in Byenup Lagoon. Notable aquatic macrophytic flora include *Schoenus natans*, (previously listed as a Declared Rare Flora) and *Villarsia submersa*. Both *S. natans* and *Villarsia* spp. are widespread during early spring, giving way to herbs as wetlands dry.	Maintain current extent of macrophytes.
Baumea sedgeland	Current % extent = 95% Byenup Lagoon and Tordit-Gurrup; and 100% Poorginup Swamp, with 100% cover.	Maintain current extent of *Baumea* sedgeland.
Fringing shrubs and trees	Fringing vegetation includes; *Melaleuca rhaphiophylla, M. lateritia* and *Astartea fascicularis, Agonis juniperina* shrublands with Jarrah/Yate or *E. rudis* woodlands at higher elevations. Current % extent of *Melaleuca* spp. = 5% Byenup Lagoon and Tordit-Gurrup; and 20% Poorginup Swamp.	Maintain current extent of fringing vegetation.
Key species and communities.		
Macroinvertebrates	DeHaan (1987) recorded 103 invertebrate taxa in Tordit-Gurrup Lagoon, Byenup Lagoon and Poorginup Swamp. Tordit-Gurrup Lagoon had the highest richness Poorginup the lowest. Class Insecta accounted for 73% of total invertebrates. Species richness in Tordit-Gurrup and Byenup lagoons decreases in April (low water levels and increased salinity). Species of interest include 11 watermites (six in Poorginup swamp); crustaceans. Storey (1998) found 219 taxa, 32 endemic to south-western Australia (most in Poorginup Swamp). At least 78 species of ostracods and copepods, six ostracods and one cyclopoid restricted to Muir-Unicup area. New species of Rotifera and Cladocera families and two dytiscid water beetles. *Hygrobia wattsii* sp. n appears to be restricted to peatland swamps/lakes	Maintain the endemic macroinvertebrate taxa, including: watermites (*Acercella poorginup*, *Pseudohydryphantes doegi*, *Huitfeldtia* sp.), crustaceans (*Cherax preissii* and *C. quinquecarinatu)* and *Hygrobia wattssii*
Fish	6 fish species endemic to south-west WA (Western Pygmy Perch, Nightfish, Balston's Pygmy Perch, Western Minnow, Black-striped Minnow and Mud Minnow). Poorginup Swamp had the greatest number of native fish species (5) followed by Mulgarnup Swamp (4). Black-striped Minnow and Mud Minnow (Poorginup Swamp) and Balston's	Insufficient information to set baseline. As an interim limit maintain the EPBC listed Balston's Pygmy Perch.

	Pygmy Perch (Mulgarnup Swamp) are restricted to south-west WA.	
Waterbirds	Tordit-Gurrup is used as a drought refuge by large numbers of waterbirds. Open water is important for Australian Shelduck moulting (over 12,000, December 1992). Non-vegetated beaches of Tordit-Gurrup Lagoon and Byenup Lagoon provide habitat for waders, ducks and swans Poorginup Swamp has been found to be significant for Australasian Bittern. Supports breeding of Little Bittern, Spotless Crake, globally threatened Australasian Bitterns, Black Swans and Eurasian Coots. As waterbird data have not been collected since 1992, limits of acceptable change should be revised as more data becomes available.	Support breeding of Little Bittern, Spotless Crake, globally threatened Australasian Bitterns, Black Swans and Eurasian Coots. Maintain presence and abundance of Australian Shelducks. Maintain the 1% population threshold (5 birds) for Australasian Bittern.

9. SUMMARY OF KNOWLEDGE GAPS

Table 35 summarises key knowledge gaps and recommended actions for maintaining the ecological character of the Muir-Byenup System Ramsar site. Key knowledge gaps include understanding the interactions between components and processes where data is insufficient or lacking. More detail on monitoring of knowledge gaps is provided in Table 36.

Table 35. Knowledge gaps and recommended actions

COMPONENT PROCESS	KNOWLEDGE GAP	RECOMMENDED ACTION
Hydrology	Understanding of interactions between groundwater and wetlands. Effect of plantations on groundwater levels, salinity and acidity. Water depth, salinity and pH important to maintain key species, supporting biological components and habitat at the Ramsar site.	Continued investigations of bores and depth gauges located within the wetlands.
Water quality	Effect of surrounding land-uses (clearing and plantations) on water quality (salinity and acidity). Maintenance of current water quality important to maintain key species, supporting biological components and habitat at the Ramsar site.	Continued monitoring of water quality sites.
Aquatic plants	Community composition, distribution and temporal patterns. Aquatic plants important to maintain key species including macroinvertebrates and waterbirds through provision of food and habitat. Knowledge of distributions and abundances will also assist in setting limits of acceptable change for nutrient concentrations.	Community composition, distribution and temporal patterns of the Ramsar site.
Fringing vegetation	Community composition and distribution of fungal and non-vascular flora.	Community composition, distribution and temporal patterns of the Ramsar site.
	Vegetation response to salinity and acidity (groundwater and acid sulfate soils). Transects near wetlands last monitored in 2001 (Froend and Loomes 2001) and permanent plots last measured 2002 (Gibson *et al.* 2004). Vegetation includes key flora which meet Ramsar criteria and habitat for waterbirds. Response of vegetation to salinity and acidity will also assist in setting limits of acceptable change.	Continued monitoring of transects and quadrats within the Ramsar site.
Macroinvertebrates	Response of macroinvertebrates to salinisation, acidity and altered hydrology. Last sampled 2004 (Wetland Research and Management 2005). Macroinvertebrate communities include key species which meet Ramsar criteria and provide food for waterbirds. Response of macroinvertebrates to salinity and acidity will also assist in setting limits of acceptable change.	Continued monitoring of sampling sites. Also, need to establish baseline information for Lake Muir.
Fish	Response of fish to salinisation, acidity and	Continued monitoring of

	altered hydrology. Last sampled 2004 (Wetland Research and Management 2005). Includes key species (Balston's Pygmy Perch, Mud Minnow and Black-stripe Minnow) which meet Ramsar criteria and provide food for waterbirds. Response of macroinvertebrates to salinity and acidity will also assist in setting limits of acceptable change. Lack understanding of distribution and migration patterns.	sampling sites. Also, need to establish baseline information for Lake Muir. Research of fish lifecycles, mechanisms for drought avoidance and salt tolerance to determine fish community resilience. Determine distribution and migration patterns.
Waterbirds	Current waterbird data. Last comprehensive surveys undertaken 1992 (Halse *et al.* 1995). Waterbirds are critical for meeting Ramsar criteria and monitoring will also assist in setting limits of acceptable change.	Continued monitoring of sampling sites.

Data is also lacking for the following:

- Systematic mammal surveys – The Muir-Byenup Nature Reserve are believed to contain many of the mammal species found in the adjacent Perup Forest, including; Woylies, Numbat and Chuditch (Department of Conservation and Land Management 1998). The Nature Reserve also contains suitable habitat for the Boodie (or Burrowing Bettong,) and the Dalgyte (or Bilby) (Department of Conservation and Land Management 1998). It is also possible the semi-aquatic Water Rat occurs in the Muir-Byenup System Ramsar site (Department of Conservation and Land Management 1998).
- Reptile or amphibian fauna – The Ramsar site is likely to be rich in reptile fauna due to the presence of open woodland with sandy soils. The Oblong Tortoise has been recorded at Tordit-Gurrup and is likely to be common throughout the wetlands. Tiger Snakes also occur (Department of Conservation and Land Management 1998).

10. RECOMMENDATIONS FOR MONITORING / RESEARCH

10.1 Existing monitoring programs

10.1.1 Historical and current monitoring in the Muir-Byenup System Ramsar site

Paleontological studies

Core samples have been taken from the bed of Lake Muir (Churchill 1968) and Byenup Lagoon (Dodson and Lu 2000) for paleontological (fossil pollen) studies.

DEC water quality, depth and salinity

Depth, salinity and other surface water quality parameters have been measured at least twice yearly for Lake Muir, Byenup Lagoon, Tordit-Gurrup Lagoon and Poorginup Swamp by the Department of Environment and Conservation since the late 1970s.

Geology and hydrogeology

Magnetic and radiometric survey data have been collected to improve geological knowledge of the area (Chakravartula and Street 2000). Recently, airborne electromagnetic survey data has been acquired and borehole geophysical logging undertaken. Geological logging of boreholes was undertaken at the time of drilling and records are due for publication in the near future (R. Hearn, pers. com.). Limnological surveys, analysis and mapping are also being done to improve knowledge of groundwater and surface systems (Department of Conservation and Land Management 2003).

A hydrogeological study is ongoing within the Muir-Unicup catchment. This study aims to improve knowledge of groundwater and surface water systems and gain an understanding of salinity and acid sulfate soils (Smith 2003).

Waterbirds

Waterbirds were surveyed annually between 1981 and 1991. These surveys focused on wetland use by Bitterns and ducks (Halse *et al.* 1990; Halse *et al.* 1995; Halse *et al.* 1992; Jaensch and Vervest 1988). Waterbird surveys at Lake Muir, Byenup Lagoon and Tordit-Gurrup Lagoon were also undertaken from December 2008 to September 2009 by Peter Taylor (data to be analysed).

Flora and fauna

Intensive surveys of flora and fauna were conducted with funding from Environment Australia Biodiversity Group (Natural Heritage Trust) and the Western Australian Government (Salinity Action Plan). Reports on fish, aquatic macroinvertebrates, physiochemistry (Storey 1998), flora and vegetation (Gibson and Keighery 1999) were prepared. These were resurveyed in 2003 and 2004 (Gibson *et al.* 2004; Wetland Research and Management 2005).

Aquatic macroinvertebrates and physiochemistry have also been surveyed by DeHaan (1987) and Horwitz (1997). Other small collections of aquatic invertebrates have been made by the WA Museum (Harvey 1987; 1996) and Curtin University students (Department of Conservation and Land Management 1998).

Vegetation monitoring plots and transects have been installed at Tordit-Gurrup Lagoon, Mulgarnup Swamp, Byenup Lagoon, Geordinup Lagoon, Poorginup Swamp, Lake Muir and two other locations within the Ramsar site (Gibson and Keighery 1999). At six of the monitoring points within the Ramsar site, the relationships between water level, salinity and emergent/fringing vegetation was studied in 2001 (Froend and Loomes 2001) and 2003.

10.2 Monitoring of ecological character

Table 36 outlines the recommended monitoring of the Muir-Byenup System Ramsar site to identify any changes, or potential changes, in ecological character. Priorities have been given to each monitoring component to assist with distribution of available funds.

Detailed monitoring program design is beyond the scope of an ECD, however, the Ramsar framework for monitoring wetlands should be used as a guide for developing monitoring programs at the site (Annexure to Resolution VI.1: available at http://www.ramsar.org). The framework includes:

- **Problems/issues** – State clearly and unambiguously – State the known extent and most likely cause – Identify the baseline or reference situation.
- **Objective** – Provides the basis for collecting the information – Must be attainable and achievable within a reasonable time period.
- **Hypothesis** – Assumption against which the objectives are tested – Underpins the objective and can be tested.
- **Methods and variables** – Specific for the problem and provide the information to test the hypothesis – Able to detect the presence and assess the significance of any change – Identify or clarify the cause of the change.
- **Feasibility/cost** – Determine whether or not monitoring can be done regularly, effectively and continually – Assess factors that influence the sampling programme (availability of trained personnel; access to sampling sites; availability and reliability of specialist equipment; means of analysing and interpreting the data; usefulness of the data and information; means of reporting in a timely manner) – Determine if the costs of data acquisition and analysis are within the existing budget.
- **Pilot study** – Time to test and fine-tune the method and specialist equipment – Assess the training needs for staff involved – Confirm the means of analysing and interpreting data.
- **Sampling** – Staff should be trained in all sampling methods – All samples should be documented (date and location; name of staff; sampling methods; equipment used; means of storage or transport; all changes to the methods) – samples should be processed within a timely period and all data documented – (date and location; name of staff; processing methods; equipment used; and all changes to the protocols) – Sampling and data analysis should be done by rigorous and tested methods.
- **Reporting** – Interpret and report all results in a timely and cost effective manner – The report should be concise and indicate whether or not the hypothesis has been supported – The report should contain recommendations for management action, including further monitoring.

Table 36. Recommended monitoring actions to maintain the ecological character of the Muir-Byenup System Ramsar site.

COMPONENT /PROCESS	PURPOSE	INDICATOR	LOCATIONS	FREQ.	PRIORITY
Lake Muir					
Hydrology	Detection of change	Lake and aquifer levels	Historical bores	Weekly	High
Water quality	Detection of change	pH, salinity, DO, total and soluble nutrients, chlorophyll *a*	Historical water quality sites	Weekly (spring/summer) and monthly (winter)	High

Phytoplankton	Establishment of baseline and then detection of change	Identification and enumeration	Historical water quality sites	Weekly (spring/summer) and monthly (winter)	Medium
Aquatic plants	Establishment of baseline and then detection of change	Distribution, composition and biomass	Across the lake	Seasonally	Medium
Fringing vegetation (habitat)	Detection of change	Extent and condition	At historical transects (Froend and Loomes 2001) and permanent plots (Gibson and Keighery 1999)	2-5 years	High
Invertebrates	Establishment of baseline and then detection of change	Composition and abundance (protocol of Storey 1996)	Historical water quality sites	Annually in spring	High
Fish	Establishment of baseline and then detection of change	Composition and abundance (protocol of Storey 1996)	Historical water quality sites	Annually	High
Waterbirds	Establishment of baseline and detection of change	Ground surveys of species and abundance. Targeted surveys of breeding (e.g. Jaensch and Vervest 1988)	Historical sampling sites (e.g. Jaensch and Vervest 1988)	Bi-annual surveys. Weekly within critical periods for species specific information	High
Frogs	Establishment of baseline and then detection of change	Composition and abundance	Lake margins	Annually	Low
Mammals	Establishment of baseline and then detection of change	Composition and abundance	Lake margins	Annually	Low
Feral animals and weeds	Establishment of baseline and then detection of change	Composition, distribution and abundance	Across the wetland areas	Seasonally	High
Byenup Lagoon system					
Hydrology	Detection of change	Lake and aquifer levels	Historical bores	Weekly	High
Water quality	Detection of change	pH, salinity, DO, total and dissolved nutrients, chlorophyll *a*	Historical water quality sites	Weekly (spring/summer) and monthly (winter)	High
Phytoplankton	Establishment of baseline and then detection of change	Identification and enumeration	Historical water quality sites	Weekly (spring/summer) and monthly (winter)	Medium
Aquatic plants	Establishment of baseline and then detection of change	Distribution, composition and biomass	Across the wetlands	Seasonally	Medium

Fringing vegetation	Detection of change	Extent and condition	At historical transects (Froend and Loomes 2001) and permanent plots (Gibson and Keighery 1999)	2-5 years	High
Invertebrates	Detection of change	Composition and abundance (protocol of Storey 1996)	Historical sampling sites	Annually in spring	High
Fish	Detection of change	Composition, abundance and migration patterns (protocol of Storey 1996)	Historical sampling sites (Storey 1998)	Annually	High
Waterbirds	Establishment of baseline and detection of change	Ground surveys of species and abundance. Targeted surveys of breeding (e.g. Jaensch and Vervest 1988)	Historical sampling sites (e.g. Jaensch and Vervest 1988)	Bi-annual surveys. Weekly within critical periods for species specific information	High
Frogs	Establishment of baseline and then detection of change	Composition	Across the wetland areas	Seasonally	Low
Mammals	Establishment of baseline and then detection of change	Composition and abundance	Across the wetland areas	Bi-annual surveys	Low
Feral animals and weeds	Establishment of baseline and then detection of change	Composition, distribution and abundance	Across the wetland areas	Seasonally	High

In addition to the recommended monitoring detailed above, there are a number of knowledge gaps which also need further investigation, including:

1. Acid sulfate soils – High Priority
   - How to manage and dispose of acid groundwater (Hearn 2005).
   - Vegetation community robustness to acidity and aluminium toxicity.
2. Salinisation – High Priority
   - Vegetation community robustness to salinity and water removal by plantations.
3. *Phytophthora* – High Priority
   - Lack detailed *Phytophthora* mapping and limited available data on impacts on individual species and communities (McKenzie *et al.* 2002).
   - *Armillaria* mapping (Gibson and Keighery 2000).

11. COMMUNICATION, EDUCATION AND PUBLIC AWARENESS

Within the Ramsar Convention, the Outreach Programme 1999-2002, calls upon nations to raise awareness of wetland values and functions throughout the world. In Australia, a national plan has been developed to bring together all levels of government, statutory authorities, community, industry and conservation groups to develop and implement wetland communication, education and public awareness (CEPA).

11.1 Current CEPA

The Lake Muir observatory on the Muirs Highway is a regionally important and popular nature-based tourism site, with an estimated 15,000 visitors in 2006-07 (Department of Environment and Conservation 2008). The Lake Muir observatory provides opportunities for visitor education and interpretation of wetland and fauna conservation through signage displays (Department of Environment and Conservation 2008). Opportunities for passive nature study and appreciation activities are provided by the elevated boardwalk and the viewing platform with panoramic views of Lake Muir. Recreational activities include; bird watching, photography, landscape painting, drawing and writing.

11.2 CEPA messages arising from the ECD

Possible communication and education messages arising from identification of the ecological character of the Ramsar site and the current threatening processes outlined in this ECD include:

- International significance of the Muir-Byenup System Ramsar site.
- Hydrological processes within the Ramsar site, including interactions between wetlands.
- Importance of Lake Muir as an example of a relatively undisturbed primary saline wetland.
- Peat formation and acidification processes of the Byenup Lagoon System wetlands.
- The importance of *Baumea* sedgelands for Australasian Bitterns
- Ecological relationships between water quality and flora and fauna found within the Ramsar site.
- The impact of threatening processes such as salinity, acid sulfate soils, *Phytophthora* and land use (eutrophication) on biodiversity values (waterbirds, vegetation and macroinvertebrates) of the Muir Byenup System Ramsar site.

12. REFERENCES

ANZECC/ARMCANZ (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Available at: http://www.mincos.gov.au/publications/australian_and_new_zealand_guidelines_for_fresh_and_marine_water_quality.

Brock M, Lane J (1983) The aquatic macrophyte flora of saline wetlands in Western Australia in relation to salinity and permanence. *Hydrobiologia* **105**, 63-76.

Brock M, Shiel R (1983) The composition of aquatic communities in saline wetlands in Western Australia. *Hydrobiologia* **105**, 77-84.

Cale D, Halse S, Walker C (2004) Wetland monitoring in the wheatbelt of south-west Western Australia: Site descriptions, waterbird, aquatic invertebrate and groundwater data. *Conservation Science Western Australia* **5**, 20-135.

Camp Dresser, McKee Inc. (1981) Effect of peat mining on fish and other aquatic organisms in the upper midwest. *Environmental Sciences Division. Milwaukee, Wisconsin. For US Fish and Wildlife Service. Twin Cities, Minnesota.*

Carter JL, Colmer TD, Veneklaas EJ (2006) Variable tolerance of wetland tree species to combined salinity and waterlogging is related to regulation of ion uptake and production of organic solutes. *New Phytologist* **169**, 123-134.

Chakravartula P, Street G (2000) Hydrogeological interpretation of airborne geophysical data Lake Muir Unicup Catchment. Agraria Limited, Western Australia.

Churchill D (1968) The distribution and prehistory of *Eucalyptus diversicolor* F. Muell., *E. marginata* Donn. Ex Sm., and *E. calophylla* R.Br. in relation to rainfall. *Australian Journal of Botany* **16**, 125-151.

Clews M (1999) Saving the swamps. *Landscope* **14**.

Cramer V, Hobbs R (2002) Ecological consequences of altered hydrological regimes in fragmented ecosystems in southern Australia: Impacts and possible management strategies. *Austral Ecology* **27**, 546-564.

De Silva J (2003) Hydrogeology of the Pemberton-Irwin Inlet 1:250 000 sheet, Western Australia, Water and Rivers Commission, 1:250 000 Hydrogeological Series.

DeHaan M (1987) The possible effects of peat mining on aquatic invertebrates in the Lake Muir wetlands, Western Australia. BSc Honours thesis, Murdoch University, Perth.

Department of Conservation and Land Management (1998) Perup Forest, Lake Muir Reserve, Unicup Nature Reserve draft management plan. Department of Conservation and Land Management, NPNCA, Lands and Forest Commission, Perth (unpublished).

Department of Conservation and Land Management (2003) Information sheet on Ramsar wetlands (RIS); Muir-Byenup System, Western Australia.

Department of Environment (2000) The action plan for Australian birds 2000: Recovery outline Australasian Bittern. Available at: www.environment.gov.au/biodiversity/threatened/publications/action/birds2000/pubs/austr-bittern.pdf

Department of Environment and Conservation (2008) Parks and reserves of the Lake Muir, Perup, Kingston, Tone and Unicup area. Issues paper, November 2008.

Department of Environment and Conservation, Western Australian Herbarium (2008) FloraBase: The Western Australian Flora. Available at: http://florabase.calm.wa.gov.au/.

Department of the Environment W, Heritage and the Arts (2008) National framework and guidance for describing the ecological character of Australia's Ramsar wetlands. Module 2 of the National Guidelines for Ramsar Wetlands - Implementing the Ramsar Convention in Australia. Department of the Environment, Water, Heritage and the Arts, Canberra.

Dodson JR, Lu JJ (2000) A late holocene vegetation and environment record from Byenup Lagoon, South-western Australia. *Australian Geographer* **31**, 41-54.

Environment Australia (2001) A directory of important wetlands in Australia (3rd edition). Environment Australia.

Environmental Resources of Australia Pty Ltd, Cladium Mining Pty Ltd (1971) The environmental effect of proposed peat removal from lagoons in the Lake Muir area, WA: A report to Cladium Mining Pty Ltd.

Farmer AM (1990) The effects of lake acidification on aquatic macrophytes - a review. *Environmental Pollution* **65**, 219-240.

Finlayson C (2001) Wetland inventory, assessment and monitoring: Practical techniques and identification of major issues - introduction and review of past recommendations. In 'Wetland inventory, assessment and monitoring: Practical techniques and identification of major issues. Proceedings of workshop 4, 2nd International Conference on Wetlands and Development. Dakar, Senegal. 8-14 November 1998. Supervising Scientist Report 161, Supervising Scientist, Darwin'. (Eds C Finlayson, N Davidson, N Stevenson).

Froend RH, Loomes R (2001) Relationships between water level, salinity and the emergent and fringing vegetation of Byenup Muir Wetlands. Unpublished report prepared by Froend Bowen & Associates for the Department of Conservation and Land Management, Perth.

Gibson N, Keighery G (1999) Assessment of the nature conservation values of the Byenup-Muir peat swamp system, south western Australia: Flora and vegetation. Unpublished report for Environment Australia prepared by the WA Department of Conservation and land management.

Gibson N, Keighery G (2000) Flora and vegetation of the Byenup-Muir reserve system, south-west Western Australia. *CALMScience* **3**, 323-402.

Gibson N, Keighery G, Lane J (2004) Five years monitoring of the Lake Muir-Unicup wetland system, south-western Australia. *Journal of the Royal Society of Western Australia* **87**, 29-33.

Gillham M (1961) Alteration of the breeding habitat by sea birds and seals in Western Australia. *Journal of Ecology* **49**, 289-300

Government of Western Australia (1996) Western Australian Salinity Action Plan. Government of Western Australia, Perth, Western Australia.

Government of Western Australia (2000) Natural Resource Management in Western Australia, The Salinity Strategy. Government of Western Australia, Perth, Western Australia.

Hale J (2008) Ecological character description of the Ord River Floodplain Ramsar site. Draft report to the Department of Environment and Conservation, Perth, Western Australia.

Hale J, Butcher R (2007) Ecological character description of the Peel-Yalgorup Ramsar site. Draft report to the Department of Environment and Conservation and the Peel-Harvey Catchment Council. Perth, Western Australia.

Hall L, Krausman P, Morrison M (1997) The habitat concept and a plea for standard terminology. *Wildlife Society Bulletin* **25**, 173-182.

Halse S (1993) Vegetation of depth-gauged wetlands in nature reserves in south-west Western Australia. Western Australia Department of Conservation and Land Management, Technical report 30.

Halse S, Vervest R, Pearson G, Yung F, Fuller P (1994) Annual waterfowl counts in south-western Australia: 1990/91. *CALMScience* **1**, 107-129.

Halse S, Williams M, Jaensch R, Lane J (1993) Wetland characteristics and waterbird use of wetlands in south-western Australia. *Wildlife Research* **20**, 103-126.

Halse SA, Jaensch R, Munro DR, Pearson GB (1990) Annual waterfowl counts in south-west Western Australia: 1988/89. *Technical Report. Perth, Department of Conservation and Land Management*.

Halse SA, Pearson GB, Vervest RM, Yung FH (1995) Annual waterfowl counts in south-west Western Australia - 1991/92. *CALM Science* **2**, 1-24.

Halse SA, Vervest RM, Munro DR, Pearson GB, Yung FH (1992) Annual waterfowl counts in south-west Western Australia: 1989/90. *Technical Report. Perth, Department of Conservation and Land Management*.

Hart B, Bailey P, Edwards R, Hortle K, James K, McMahon A, Meredith C, Swadling K (1991) A review of the salt sensitivity of the Australian freshwater biota. *Hydrobiologia* **210**, 105-144.

Harvey M (1987) New and little known species of the water-mite genera Tartarophyas, Pseudohydryphantes and Cyclohydryphantes from Australia (Chelicerata; Actenidida; Hydrantidae). *Memoirs of the Museum of Victoria* **48**, 107-122.

Harvey M (1996) A review of the watermite family Pionidae in Australia (Acarina; Hygrobatoidea). *Records of the Western Australian Museum* **17**, 361-393.

Hearn R (2005) The Lake Muir-Unicup system. *Proceedings of the Royal Society of Western Australia* **October**, 2-3.

Hendrich L (2001) A new species of *Hygrobia* LATREILLE, from peatlands of south-western Australia (Coleoptera: Hygrobiidae). *Koleopterologische Rundschau* **71**, 17-25.

Horwitz P (1994) Patterns of endemism in the freshwater fauna of the far southern peatlands and shrublands of southwestern Australia. *Environmental Management Commissioned Research Report 1994-04. Prepared for the Australian Heritage Commission and the Heritage Council of Western Australia.*

Horwitz P (1997) Comparative endemism and richness of the aquatic invertebrate fauna in peatlands and shrublands of far south-western Australia. *Memoirs of the museum of Victoria* **56**, 313-321.

IUCN (2008) The 2008 review of the IUCN Red List of Threatened Species. Available at: www.iucn.org/redlist.

Jaensch R (2002) Ecological requirements and guilds of waterbirds recorded at the Menindee Lakes system, NSW, Report to Biosis Research and the NSW Department of Land and Water Conservation, Wetlands International, Oceanica.

Jaensch R, Vervest R (1988) Waterbirds in the eastern Muir wetlands 1986-1987. Royal Australasian Ornithologists Union Report No. 47.

Kay WR, Halse S, Scanlon M, Smith M (2001) Distribution and environmental tolerance of aquatic macroinvertebrate families in the agricultural zone of southwestern Australia. *Journal of the North American Benthological Society* **20**, 182-199.

Lane J, Munro DR (1982) 1981 review of rainfall and wetlands in the south-west of Western Australia. *Department of Fisheries and Wildlife, Western Australia. Report no. 56*.

McGrath C (2006) Unpublished legal review of the framework for describing the ecological character of Ramsar wetlands to support implementation of the EPBC Act. Report to the Department of the Environment and Heritage.

McKenzie N, May J, McKenna S (2002) Bioregional summary of the 2002 biodiversity audit for Western Australia. Department of Conservation and Land Management, Western Australia.

Millennium Ecosystem Assessment (2005) Millennium Ecosystem Assessment.

Milne LA (2003) Palynology report: Palynological analysis of three samples from Borehole 14: ME/BP61. Unpublished report to the Water and Rivers Commission, Perth.

Mitsch W, Gosselink J (2000) 'Wetlands Third Edition.' (John Wiley & Sons: New York).

Myers J (1995) Explanatory notes on geology of the Albany 1:1 000 000 sheet. Western Australia Geological Survey.

Pen L (1997) A systematic overview of environmental values of the wetlands, rivers and estuaries of the Busselton-Walpole Region. Western Australia Water and Rivers Commission, Water Resource Allocation and Planning Report Series WRAP 7.

Petrin Z, Laudon H, Malmqvist B (2007) Does freshwater macroinvertebrate diversity along a pH-gradient reflect adaptation to low pH? *Freshwater Biology* **52**, 2172-2183.

Phillips B (2006) Critique of the framework for describing the ecological character of Ramsar wetlands (Department of Sustainability and Environment, Victoria, 2005) based on its application at three Ramsar sites: Ashmore Reed National Nature Reserve, the Coral Sea Reserves (Coringa-Herald and Lihou Reeds and Cays) and Elizabeth and Middleton Reeds National Nature Reserve. Mainstream Environmental Consulting Pty Ltd, Waramanga ACT.

Pinder A, Halse S, McRae J, Shiel R (2004) Aquatic invertebrate assemblages of wetlands and rivers in the wheatbelt region of Western Australia. *Records of the Western Australian Museum Supplement* **67**, 7-37.

Pusey B, Edward D (1990) Limnology of the southern acid peat flats, South-western Australia. *Journal of the Royal Society of Western Australia* **73**, 29-46.

Ramsar Convention (1987).

Ramsar Convention (2002).

Ramsar Convention (2005).

Semeniuk CA (1987) Wetlands of the Darling System - a geomorphic approach to habitat classification. *Journal of the Royal Society of Western Australia* **69**, 95-112.

Smith R (2003) Hydrogeology of the Muir-Unicup catchments. Water and Rivers Commission, Salinity and Land Use Impacts Reports SLUI 22, Perth.

Stewart B, Strehlow K, Davis J (2009) Impacts of deep open drains on water quality and biodiversity of receiving waterways in the Wheatbelt of Western Australia. *Hydrobiologia* **619**, 103-118.

Storey A (1998) Assessment of the nature conservation values of the Byenup-Muir peat swamp system, southwestern Australia: Physio-chemistry, aquatic macroinvertebrates and fishes. UWA Wetland Research and Management Group, prepared for CALM.

Sutton R, Cheyne J, Neilson J, Williams M (2002) Recoveries of Australasian Shoveler (*Anas rhynchotis*) banded as ducklings in southern New Zealand. *Notornis* **49**, 209-217.

V & C Semeniuk Research Group (1997) Mapping and classification of wetlands from Augusta to Walpole in the South West of Western Australia. Western Australia Water and Rivers Commission, Water Resource Technical Series No. WRT 12.

Water and Rivers Commission (2001) Water facts 16: Living wetlands - an introduction to wetlands. Government of Western Australia.

Wetland Research and Management (2005) Reassessment of the nature conservation values of the Byenup-Muir peat swamp system. Draft report prepared for the Department of Conservation and Land Management, Western Australia

Wetlands International (2006) Waterbird population estimates - Fourth edition, Wetlands International, Wageningen, Netherlands.

Appendix A: Method

The method for compiling the Muir-Byenup System Ramsar site ECD was as follows:

Task 1: Review and compilation of available data

Claire Farrell undertook a thorough review of existing information on the Muir-Byenup System Ramsar site. Data reviewed included published and unpublished sources. This process also included a field tour of the Ramsar site with Roger Hearn, regional ecologist with DEC. Water quality data was also sourced from Jim Lane, DEC for analysis.

Task 2: Development of a draft ECD

Table A1 (adapted from Hale 2008) details the steps undertaken to complete the ECD. These steps are consistent with the *National Framework and Guidance for Describing the Ecological Character of Australian Ramsar Wetlands* (DEWHA 2008)

Table A1: Steps taken to complete the Muir-Byenup System Ramsar site ECD

Steps	Activities
1. Document introductory details	Prepared basic details including: site details, purpose and legislation
2. Describe the site	Based on the Ramsar RIS and the literature review the site (location, tenure, Ramsar criteria, and wetland types) was described. New criteria met since time of listing were also added.
3. Identify and describe the critical components, processes and services	Critical components, processes and services responsible for determining ecological character were identified.
4. Develop a conceptual model of the system	Conceptual models were developed for both Lake Muir and Byenup Lagoon System to show critical components and processes for maintaining ecological character at the site. These models also showed key species and communities that support the Ramsar Criteria. These include: aquatic and fringing flora; waterbirds and macroinvertebrates.
5. Set limits of acceptable change	Limits of acceptable change were set for critical components and processes for maintaining ecological character at the Muir-Byenup System Ramsar site
6. Identify threats to the site	Both actual and potential threats were identified.
7. Describe changes to ecological character since listing	This section described any changes to the ecological character of the site that have occurred since listing in 2001.
8. Summarise knowledge gaps	Knowledge gaps were identified for ecological character and management of the site.
9. Identify site monitoring needs	Monitoring needs were developed based on knowledge gaps, threats and limits of acceptable change.
10. Identify communication, education and public awareness messages	Broad communication, education and public awareness messages included key points from components, processes and services, threatening processes and what makes the site unique.

Task 3: Stakeholder engagement and consultation
DEC formed a Technical Advisory Group (TAG) specifically for the Muir-Byenup System Ramsar site ECD. This group was comprised of the following stakeholders:

Mr Roger Hearn, Department of Environment and Conservation, Manjimup
Mr Paul Roberts, Department of Environment and Conservation, Manjimup
Ms Jennifer Higbid, Department of Environment and Conservation, Perth
Ms Margaret Smith, Curtin University, Perth
Dr Peter Taylor, Birding South West, Manjimup
Ms Emily Lewis, Warren Catchments Council
Ms Lee Fontanini, Warren Catchments Council

The TAG met in Manjimup 16 December 2008 to discuss and review the components, processes, services and benefits of the Ramsar site as outlined in the draft ECD. Threats and limits of acceptable change were also discussed.

A community presentation of the ECD and management planning process was also presented on 16 December 2008.

Task 4: Revision of the Ramsar Information Sheet (RIS)
Following completion of the draft ECD and stakeholder engagement and consultation the RIS was revised to include new information and new criteria met since listing.

Task 5: Finalising the ECD and RIS
The draft ECD and RIS were reviewed by DEC, the TAG and the Department of Environment, Water, Heritage and the Arts (DEWHA). All feedback and comments were integrated into revised documents.

Consultant team

Dr Barbara Cook (team leader)
Dr Barbara Cook is an aquatic taxonomist and ecologist with over 25 years of experience in aquatic ecosystems, and is a lecturer in restoration ecology at the University of Western Australia (UWA). Barbara has authored many papers on the biodiversity and water quality of waterways and wetlands in the south-west of WA, and has experience in monitoring environmental and biological parameters in Ramsar sites.

Dr Claire Farrell
Dr Claire Farrell is an experienced botanist and ecologist who recently completed her PhD on the sustainability of salt-land rehabilitation in the agricultural wheatbelt of WA. She has also had extensive experience in a range of ecosystems, including; rehabilitated jarrah forests; forest remnants in plantations; semi-arid rangelands; wetlands and sub-tropical rainforests. Claire has a broad understanding of aquatic ecology, including macrophytes, fringing vegetation and macroinvertebrates. Most recently Claire has been involved in a wide range of water-based projects including; waterway management prioritisation frameworks; sediment and nutrient retention basins and buffer strips;

macroinvertebrate diversity in saline drains, and effects of timber mill effluent on macroinvertebrate diversity. Claire also lectures at UWA in restoration ecology.

Dr Peter Speldewinde

Dr Speldewinde has extensive experience in database development and management and he has developed relational databases for Geographic Information Systems (GIS). His experience in GIS ranges from farm planning for Landcare through to modelling potential habitat locations for endangered species. He has recently completed a PhD incorporating spatial analysis of the effects of environmental degradation on human health using Bayesian spatial modelling techniques, a component of which involved the analysis of health risks to the Aboriginal and Torres Strait Islander population in Western Australia (PhD title-Ecosystem health: the relationship between dryland salinity and human health).

Appendix B: Vegetation description of the Muir-Byenup System Ramsar site (Gibson and Keighery 1999).

1. Jarrah-Marri forest and woodland on laterite and lateritic gravels cover a small area in the south-eastern corner of the reserve. The understorey is typically diverse in shrubs, herbs and grasses. Typical understorey shrubs include *Hibbertia* spp., *Leucopogon* spp. and peas such as *Bossiaea* spp., *Daviesia* spp. and *Gompholobium* spp.
2. Jarrah-Marri open woodland on sandy soils occurs widely in the southern half of the reserve, common understorey species include *Hibbertia racemosa*, *Hibbertia subvaginata*, *Astroloma baxteri*, *Leucopogon* spp., *Phyllanthus calycinus*, *Acacia pulchella* and *Jacksonia furcellata*. There is generally a very rich and diverse herb layer and orchids are numerous early in the spring. Toward the northern part of the reserve this vegetation unit is replaced by Jarrah-Yate woodlands (unit 4).
3. Jarrah-Marri woodland over *Agonis* scrub occurs along seasonally-wet drainage lines and in the swales between the dunes to the east of Lake Muir. Typically the *Agonis* scrub is very dense with little or no other understorey.
4. Jarrah-Yate woodland occurs on the large dune bordering the eastern side of Lake Muir and sandy flats in the northern part of the reserve. Elsewhere on the reserve it is replaced by vegetation unit 3. Both units have very similar composition. Where Jarrah-Yate community has been grazed, weed diversity is high.
5. Jarrah woodland over *Hakea oleifolia* heath occurs on the red dunes to the east of Poorginup Swamp. This soil unit was not seen elsewhere on the reserve.
6. *Eucalyptus decipiens* woodland, similar to those occurring in Galamup and Cobertup Nature Reserves, is found in a small area on the wet clayey flats north of the Muirs Highway. *Allocasuarina lehmanniana, Allocasuarina microstachya, Leucopogon australis, Darwinia vestita* and *Aotus intermedia* are common components of the understorey. There is also a rich and diverse herb and sedge layer.
7. *Eucalyptus rudis* woodland occurs in small patches on wet flats and small rises. The understorey is typical of seasonally-inundated situations and includes *Anigozanthos flavidus, Taxandria parviceps, Kunzea ericifolia, Viminaria juncea, Hakea ceratophylla* and *Hakea varia*. Orchids were common in this unit early spring.
8. *Eucalyptus rudis* woodland on sand dunes occurs on the eastern side of most of the basin wetlands. These woodlands tended to be quite weedy reflecting a history of past grazing. *E. rudis* woodland is replaced by Yate woodland (vegetation unit 31) on the fringing dunes of Lake Muir, understorey composition is essentially similar.
9. *Banksia ilicifolia* woodland occurs in small patches along and to the north of the Muirs Highway. Extensive areas of dieback are apparent. In dieback free areas a diverse understorey of peas, epacrids and Myrtaceae is present. *Schoenus* spp. and *Mesomelaena tetragona* are also common.
10. *Melaleuca cuticularis* complex. The wet flats in the northern half of the reserve are mostly covered by *Melaleuca* shrublands and/or woodlands in a complex mosaic. One of the most variable is the *Melaleuca cuticularis* complex, which

ranges from woodland to very open woodland to wet heath with occasional *Melaleuca cuticularis* trees. Understorey is also variable apparently related to period of inundation, but generally includes *Astartea* spp., *Melaleuca densa, Hypocalymma angustifolium, Hakea varia, Harperia lateriflora* and *Meeboldina cana.* The Lake Muir endemic *Eryngium* sp. Lake Muir is also found in this unit.

11. *Melaleuca cuticularis* woodland over *Gahnia* sedgeland is a distinct unit occurring on the flats along the edge of Lake Muir. This unit is quite species poor.
12. *Melaleuca cuticularis* woodland over wet heath forms a distinct unit in the south-eastern part of the reserve. The substrate is generally clayey and this unit has a very rich and diverse annual herb layer. The Asteraceae, Centrolepidaceae, Cyperaceae, Orchidaceae, Stylidiaceae are well represented. Common perennial taxa include *Melaleuca* spp., *Kunzea micrantha* and the rushes *Apodasmia ceramophila, Meeboldina coangustata* and *Meeboldina cana.*
13. *Melaleuca preissiana-Kunzea sulphurea* woodland occurs as a small unit on drainage lines on the southern boundary of the reserve.
14. *Melaleuca preissiana* woodland over wet heath occurs extensively north of the Muirs Highway. The understorey is variable and in the wettest sites is generally dominated by *Pericalymma ellipticum*. On drier sites the understorey is diverse with peas and Myrtaceae dominating.
15. *Melaleuca rhaphiophylla* forest forms dense stands around basin wetlands and in the wettest parts of the flats. The understorey is generally dominated by *Lepidosperma* spp. and *Baumea* spp. but where the canopy is more open a variety of shrubs such as *Hypocalymma angustifolium, Pericalymma ellipticum, Callistachys lanceolata, Banksia littoralis, Hakea sulcata* become common.
16. *Melaleuca–Kunzea* scrub occurs on the clay flats near Wimbalup Swamp, dominant *Melaleuca* spp. include *M. viminalis, M. densa, M. spathulata.* The annual herb layer is again very diverse with an aquatic flora (*Schoenus natans* and *Villarsia submersa*) giving way to a sequence of annual Asteraceae, Centrolepidaceae, Cyperaceae and Stylidiaceae as the wetlands dry.
17. *Melaleuca densa-M. viminea* heath was a widespread unit in the northern area of the reserve occupying both sandy and sandy clay substrates. These areas are winter-wet and dry slowly in late spring and early summer. Aquatic taxa such as *Schoenus natans* and *Villarsia submersa* are widespread in early spring giving way to herbs as the wetlands dry. It was in this community that *Euphrasia scabra* was found. Two large populations were located and more populations may occur.
18. *Melaleuca densa-M. viminea* thicket can develop on long-inundated sites where diversity drops as the canopy closes over.
19. *Mixed Melaleuca* heath occurs in low lying flats in the southern half of the reserve. Composition is variable: *Sphaerolobium vimineum, Eutaxia virgata, Hakea ceratophylla, Aotus intermedia* and *Calothamnus lateralis* are common. On small rises this unit integrades with the sandy Jarrah unit (unit 2). In the wettest areas it gives way to the wet heath (unit 21) often dominated by *Pericalymma ellipticum.* Units 17, 18 and 19 occupy similar positions in the landscape and may reflect differences in fire age and/or period of winter inundation.

20. *Hakea prostrata* heath is a very small unit in Lake Muir but has essentially the same species composition to that of the same unit in Galamup Nature Reserve.
21. Wet heath occupies very wet sandy sites and is generally dominated by *Pericalymma ellipticum* and *Lepidosperma longitudinale.* On more clayey substrates this community grades into the *Melaleuca* shrublands (units 16-19). This is most common in the northern part of the reserve.
22. *Gahnia* sedgeland occurs in the shallow swales along the edge of Lake Muir. This community is very species poor, being dominated by *Gahnia trifida*. This unit grades into unit 11.
23. Open *Baumea* sedgeland occupies basin wetlands. In the deeper water *Baumea articulata* is the sole dominant, closer to the shore *B. juncea* and *B. arthrophylla* occur. Around the edge of these wetlands taxa such as *Utricularia australis, Cotula coronopifolia, Centrolepis polygyna, Juncus bufonius, Villarsia albiflora* and *Microtis atrata* can also be found.
24. Closed *Baumea* sedgeland occupies basin wetlands and is essentially similar to unit 23, however, the *Baumea articulata* tends to be denser.
25. Dying *Baumea* sedgeland. The *Baumea articulata* in Byenup Lagoon appears to be dying on the aerial photography taken on the 23rd October 1995 (WA3619-5051). This photo shows most of the sedgeland to be bright orange in colour, generally indicative of stress. Recent aerial inspection found a recovery of the sedgeland but that the sedgeland now appears more open than in 1995. It is not clear as to the cause of this apparent decline but it does coincide with an 8-year peak in salinity levels in the Lagoon (JAK Lane, personal communication).
26. Riparian vegetation (not mapped). Incised creek lines had a narrow but distinctive vegetation unit associated with them: this unit was too small to map. The overstorey was *Agonis* or *Callistachys* with a dense shrub layer of *Gastrolobium melanopetalum.* The poorly collected orchid *Gastrodia lacista* was found in these habitats.
27. Samphire flats occur along the shore of Lake Muir between the shore and the *Gahnia* sedgeland. Common species include *Tecticornia indica, Tecticornia leptoclada, Sarcocornia quinqueflora, Suaeda australis* and *Wilsonia backhousei.*
28. Cleared land occurs on a portion of the reserve north-west of Byenup Lagoon. This area is largely covered by pasture grasses and weeds, although some revegetation of the shrub and tree layer is occurring. A block of private land west of Poorginup Swamp has previously been cleared, but is also slowly revegetating.
29. *Armillaria* affected shrubland. Part of the *Melaleuca preissiana-Kunzea sulphurea* woodland north of Poorginup Swamp appears to be affected by canker, possibly *Armillaria*. This needs further investigation.
30. Open water occurs on most of the larger basin wetlands.
31. Yate woodland on sand dunes replaces the more widespread fringing *E. rudis* woodland (unit 8) on the eastern shore of Lake Muir.

Appendix C: Fish

Table C1. Native fish species recorded in the Muir-Byenup Ramsar site. Information from FishBase (www.fishbase.org). All species breed in freshwater. Byenup Lagoon System includes Byenup Lagoon, Tordit-Gurrup Lagoon, Mulgarnup Swamp, Geordinup Swamp and Poorginup Swamp.

Family	Species	Common name	Habitat	Listing		Occurrence
				IUCN	EPBC	
Percichthyidae	*Edelia vittata*	Western Pygmy Perch	Benthopelagic Freshwater			Byenup Lagoon System
	Nannatherina balstoni	Balston's Pygmy Perch	Benthopelagic Freshwater		V	Mulgarnup Swamp
	Bostockia porosa	Nightfish	Demersal Potamodromous Freshwater			Byenup Lagoon System
Galaxiidae	*Galaxias occidentalis*	Western Minnow	Benthopelagic Freshwater			Byenup Lagoon System
	Galaxiella nigrostriata	Black-stripe Minnow	Demersal, Freshwater	LR, NT		Poorginup Swamp
	Galaxiella munda	Mud Minnow	Benthopelagic Freshwater	LR, NT		Poorginup Swamp

Notes: LR = lower risk; NR = near threatened; V = vulnerable.

Appendix D: Waterbirds

Table D1: Waterbird species present in the Ramsar site.
Note that only species considered to be wetland dependent are included.
Key: X = species present.
Migratory (CAMBA, JAMBA, ROKAMBA, CMS) and IUCN Red List Status

	Listed species	Lake Muir	Byenup Lagoon	Tordit-Gurrup Lagoon	Neeranup Swamp	Poorginup Swamp
Waterfowl						
Musk Duck			X	X	X	
Black Swan		X	X	X		
Australian Shelduck		X	X	X		
Australian Wood Duck			X			
Pink-eared Duck			X			
Australasian Shoveler		X	X			
Grey Teal		X	X	X		
Chestnut Teal			X			
Pacific Black Duck		X	X	X	X	X
Hardhead		X				
Blue-billed Duck			X	X	X	
Grebes						
Australasian Grebe			X	X		
Hoary-headed Grebe			X			
Great Crested Grebe			X	X	X	
Pelicans, Cormorants and Darters						
Australasian Darter			X	X		
Little Pied Cormorant			X	X	X	
Great Cormorant			X	X		
Little Black Cormorant		X	X	X		
Australian Pelican			X	X		
Herons, Ibis, Egrets, Bitterns and Spoonbills						
Australasian Bittern	IUCN Endangered		X	X	X	
Little Bittern			X	X		X
White-necked Heron			X			
Eastern Great Egret	CAMBA JAMBA		X	X	X	
White-faced Heron		X	X	X	X	
Little Egret		X				
Australian White Ibis			X	X	X	
Straw-necked Ibis			X			
Yellow-billed Spoonbill			X	X	X	
Hawks, Eagles and Falcons						
White-bellied Sea-Eagle	CAMBA	X		X		
Swamp Harrier		X	X	X		
Crakes, Rails, Waterhens and Coots						
Purple Swamphen			X	X	X	X
Spotless Crake			X		X	

Eurasian Coot		X	X	X	X	
Shorebirds						
Black-winged Stilt		X	X		X	
Red-necked Avocet				X		
Banded Stilt			X			
Grey Plover	CAMBA JAMBA CMS ROKAMBA	X				
Red-capped Plover		X	X	X		
Black-fronted Dotterel			X	X	X	
Common Sandpiper	CAMBA JAMBA ROKAMBA CMS		X			
Common Greenshank	CAMBA JAMBA ROKAMBA CMS	X	X	X		
Red-necked Stint	CAMBA JAMBA ROKAMBA CMS	X	X	X		
Long-toed Stint	CAMBA JAMBA ROKAMBA CMS			X		
Sharp-tailed Sandpiper	CAMBA JAMBA ROKAMBA CMS	X	X			
Curlew Sandpiper	CAMBA JAMBA ROKAMBA CMS	X	X			
Gulls and Terns						
Whiskered Tern		X	X	X		
Silver Gull		X	X	X	X	
Clamorous Reed Warbler	CMS		X	X	X	
Little Grassbird			X	X	X	

Table D2: Waterbird feeding habitat guilds.
Data refer to principal or commonly used habitats for feeding. Birds may roost or loaf in certain habitats but not feed there (Hale and Butcher 2007).

	F1 dense inundated vegetation	**F2 Shallows (<0.5 m) &/or mud**	**F3 Deepwater (>1 m)**	**F4 Away from wetland habitats**	**F5 Saline water**	**F6 Fresh water**
Waterfowl						
Musk Duck			X		X	X
Black Swan		X	X	X	X	X
Australian Shelduck		X		X		

Australian Wood Duck				X		
Pink-eared Duck		X	X		X	X
Australasian Shoveler		X	X			X
Grey Teal		X	X		X	X
Chestnut Teal		X	X		X	X
Pacific Black Duck		X	X	X	X	X
Hardhead		X	X			X
Blue-billed Duck			X			X
Grebes						
Australasian Grebe		X	X			X
Hoary-headed Grebe		X	X		X	X
Great Crested Grebe			X		X	X
Pelicans, Cormorants and Darters						
Australasian Darter			X		X	X
Little Pied Cormorant		X	X		X	X
Great Cormorant			X		X	X
Little Black Cormorant			X		X	X
Australian Pelican			X		X	X
Herons, Ibis, Egrets, Bitterns and Spoonbills						
Australasian Bittern	X	X				X
Little Bittern	X	X				
White-necked Heron		X				X
Eastern Great Egret		X		X	X	X
White-faced Heron		X		X	X	X
Little Egret		X			X	X
Australian White Ibis		X		X	X	X
Straw-necked Ibis		X		X		X
Yellow-billed Spoonbill		X			X	X
Hawks, Eagles and Falcons						
White-bellied Sea-Eagle		X	X	X	X	X
Swamp Harrier	X	X		X		X
Crakes, Rails, Waterhens and Coots						
Purple Swamphen	X	X		X		X
Spotless Crake	X	X		X		X
Eurasian Coot		X	X		X	X
Shorebirds						
Black-winged Stilt		X			X	X
Banded Stilt		X	X		X	
Grey Plover		X			X	
Red-capped Plover		X		X	X	X
Black-fronted Dotterel		X		X		X
Common Sandpiper		X			X	X
Common Greenshank		X			X	X
Red-necked Stint		X			X	X
Sharp-tailed Sandpiper		X			X	X
Curlew Sandpiper		X			X	X
Gulls and Terns						
Whiskered Tern		X	X		X	X
Silver Gull		X	X	X	X	X

Table D3: Waterbird dietary guilds.
O = Occasionally may eat this item (some records from gut analyses); not scored in total.
Note that information on diets of waterbirds is incomplete, best known for certain groups, poorly known for others and not necessarily based on studies from this Ramsar site (Hale and Butcher 2007).

	D1 Plants and animals	**D2 Mainly plants**	**D3 Mainly plants**	**D4 Fish**	**D5 Freshwater crayfish**
Waterfowl					
Musk Duck	X			O	X
Black Swan		X			
Australian Shelduck	X				
Australian Wood Duck	X				
Pink-eared Duck	X				X
Australasian Shoveler	X				
Grey Teal	X				
Chestnut Teal	X				X
Pacific Black Duck	X				X
Hardhead	X			O	X
Blue-billed Duck	X				
Grebes					
Australasian Grebe			X	X	
Hoary-headed Grebe			X	X	
Great Crested Grebe		O	X	X	
Pelicans, Cormorants and Darters					
Australian Pelican			X	X	X
Darter	X			X	
Great Cormorant			X	X	X
Little Black Cormorant			X	X	X
Little Pied Cormorant			X	X	X
Herons, Ibis, Egrets, Bitterns and Spoonbills					
Australasian Bittern			X	X	X
Little Bittern				X	
White-necked Heron			X	X	X
Eastern Great Egret			X	X	X
White-faced Heron			X	X	X
Little Egret			X	X	X
Australian White Ibis			X	X	X
Straw-necked Ibis			X		X
Yellow-billed Spoonbill			X	X	X
Hawks, Eagles and Falcons					
White-bellied Sea-Eagle			X	X	
Swamp Harrier			X	X	
Crakes, Rails, Waterhens and Coots					
Purple Swamphen				X	Possibly
Spotless Crake	X				
Eurasian Coot	X				
Shorebirds					
Black-winged Stilt		O	X	O	
Banded Stilt	X			O	
Grey Plover			X		
Red-capped Plover	X				

Black-fronted Dotterel	X				
Common Sandpiper	X				
Common Greenshank	X				
Red-necked Stint	X				
Sharp-tailed Sandpiper	X				
Curlew Sandpiper			X		X
Gulls and Terns					
Whiskered Tern			X	X	
Silver Gull	X			X	X

Table D4: Waterbird nesting guilds.

	N1 Inundated dead trees	**N2 Inundated live trees**	**N3 In/under Inundated shrubs or low vegetation**	**N4 Ground next to water or island inlet**	**N5 Away from wetlands**	**N6 Mainly in colonies (in Aust.)**
Waterfowl						
Musk Duck			X			
Black Swan	X		X	X		O
Aust. Wood Duck	X	X			X	
Grey Teal	X	X	X	X		
Pacific Black Duck	X	X	X	X	X	
Grebes						
Great Crested Grebe			X			O
Pelicans, Cormorants and Darters						
Australasian Darter	X	X				X
Little Pied Cormorant	X	X				X
Little Black Cormorant	X	X				X
Australian Pelican				X		X
Herons, Ibis, Egrets, Bitterns and Spoonbills						
Australasian Bittern			X			
Little Bittern			X			
Crakes, Rails, Waterhens and Coots						
Purple Swamphen			X			
Spotless Crake			X			
Eurasian Coot	X	X	X	X		O
Shorebirds						
Banded Stilt				X		X
Black-fronted Dotterel				X	X	

Table D5: Waterbird guilds: other critical life stages or habits

	B1 Flightless at times each year due to moulting	**B2 Uses daily communal roost or loafing sites**
Waterfowl		
Musk Duck	X	Seasonal aggregations on open water
Black Swan	X	X Seasonal aggregations on open water
Australian Shelduck	X	X Seasonal aggregations on open water

Australian Wood Duck	X	X
Pink-eared Duck	X	X
Australasian Shoveler	X	X
Grey Teal	X	X
Chestnut Teal	X	X
Pacific Black Duck	X	X
Hardhead	X	Seasonal aggregations on open water
Blue-billed Duck	X	Seasonal aggregations on open water
Grebes		
Australasian Grebe	X	Seasonal aggregations on open water
Hoary-headed Grebe	X	Seasonal aggregations on open water
Great Crested Grebe	X	Seasonal aggregations on open water
Pelicans, Cormorants and Darters		
Australasian Darter		X
Little Pied Cormorant		X
Great Cormorant		X
Little Black Cormorant		X
Australian Pelican		X
Herons, Ibis, Egrets, Bitterns and Spoonbills		
Australasian Bittern		X
White-necked Heron		X
Eastern Great Egret		X
White-faced Heron		X
Little Egret		X
Australian White Ibis		X
Straw-necked Ibis		X
Yellow-billed Spoonbill		X
Hawks, Eagles and Falcons		
White-bellied Sea-Eagle		
Swamp Harrier		
Crakes, Rails, Waterhens and Coots		
Purple Swamphen	X	X
Spotless Crake	X	
Eurasian Coot	X	X Seasonal aggregations on open water
Shorebirds		
Black-winged Stilt		X
Banded Stilt		X
Grey Plover		X
Red-capped Plover		X
Black-fronted Dotterel		
Common Sandpiper		X
Common Greenshank		X
Red-necked Stint		X
Sharp-tailed Sandpiper		X
Curlew Sandpiper		X
Gulls and Terns		
Whiskered Tern		X
Silver Gull		X

Appendix E: Macroinvertebrates and water quality tolerances

Table E1. Ranges of water chemistry variables for the 30 most common aquatic macroinvertebrate families collected in south-western Australia during spring 1997. Limits of detection for colour, total N and total P were 5 TCU, 0.02 mg/L, and 0.01 mg/L, respectively. DO = dissolved oxygen (Kay et al. 2001).

Family group	Families	*n*	pH	Conductivity (mS/cm)	Color (TCU)	Alkalinity (mg/L $CaCo_3$)	Turbidity (NTU)	Total N (mg/L)	Total P (mg/L)	Avg. DO (% saturation)
1	Aeshnidae	32	5.9–9.3	0.2–30.2	<5–230	8–290	1–66	0.05–1.70	<0.01–0.13	20–180
	Palaemonidae	39	6.1–8.8	0.2–34.1	8–190	13–350	1–22	0.16–1.70	<0.01–0.20	28–174
	Parastacidae	43	5.9–8.8	0.1–29.2	<5–500	10–280	1–66	0.08–3.90	<0.01–0.36	20–146
	Perthiidae	26	5.4–9.0	0.2–7.6	<5–210	8–120	2–66	0.05–1.10	<0.01–0.13	20–132
	Scirtidae	28	5.9–12.9	0.1–36.7	<5–400	10–230	1–66	0.08–2.60	<0.01–0.25	20–148
3	Baetidae	20	6.9–8.7	0.2–19.6	<5–120	8–300	2–32	0.5–2.60	<0.01–0.37	84–132
	Caenidae	46	6.4–9.0	0.1–18.6	<5–320	10–300	1–32	0.10–2.60	<0.01–0.37	31–142
	Gyrinidae	26	6.4–9.0	0.3–18.6	<5–120	20–280	1–32	0.30–2.60	<0.01–0.37	66–142
	Libellulidae	30	6.4–9.3	0.4–30.2	<5–320	18–290	1–30	0.31–17.0	<0.01–9.00	20–279
	Simuliidae	55	5.9–12.9	0.2–14.8	<5–400	8–290	1–32	0.5–2.60	<0.01–0.37	42–180
	Tipulidae	43	5.4–12.9	0.2–192.0	<5–400	8–290	1–290	0.08–2.60	<0.01–0.25	62–180
4	Acarina	93	4.6–12.9	0.1–33.6	<5–500	3–490	1–120	0.05–25.0	<0.01–5.40	0–236
	Ceinidae	115	4.9–12.9	0.1–69.1	<5–400	8–490	1–42	0.25–25.0	<0.01–5.40	0–279
	Ceratopogonidae	143	4.6–12.9	0.1–192.0	<5–400	3–490	1–290	0.08–25.0	<0.01–9.00	0–279
	Chironominae	166	4.6–12.9	0.1–192.0	<5–400	3–490	1–290	0.05–25.0	<0.01–9.00	0–279
	Coenagrionidae	36	6.7–9.3	0.2–30.2	<5–190	10–300	1–22	0.09–25.0	<0.01–5.40	0–236
	Corduliidae	83	5.3–12.9	0.1–33.6	<5–320	8–300	1–66	0.05–17.0	<0.01–9.00	0–279
	Corixidae	56	6.1–12.9	0.2–23.1	<5–230	10–290	2–32	0.10–17.0	<0.01–9.00	4–279
	Dytiscidae	163	4.9–12.9	0.1–192.0	<5–500	8–490	1–120	0.05–25.0	<0.10–9.00	0–279
	Hydrophilidae	107	6.1–12.9	0.1–192.0	<5–320	10–320	1–120	0.09–25.0	<0.01–5.40	0–279
	Leptoceridae	117	4.9–12.9	0.1–69.1	<5–320	8–490	1–120	0.05–25.0	<0.01–9.00	0–180
	Notonectidae	41	5.3–9.3	0.1–26.9	<5–230	13–290	2–23	0.38–17.0	<0.01–9.00	4–279
	Oligochaeta	117	5.4–12.9	0.1–69.1	<5–400	8–490	1–290	0.05–25.0	<0.01–9.00	0–236
	Orthocladiinae	115	4.6–12.9	0.1–74.4	<5–500	3–490	1–290	0.05–25.0	<0.01–5.40	0–250
	Tanypodinae	141	5.3–12.9	0.1–192.0	<5–400	8–490	1–290	0.05–25.0	<0.01–9.00	0–279
5	Culicidae	56	4.6–9.3	0.1–192.0	<5–500	3–370	1–290	0.10–17.0	<0.01–9.00	4–279
	Dolichopodidae	21	4.6–9.1	1.1–192.0	<5–300	3–490	1–42	0.38–2.00	<0.01–0.18	4–167
	Ephydridae	39	4.6–9.3	0.6–69.1	<5–300	3–370	1–290	0.25–25.0	<0.10–5.40	0–279
	Hydraenidae	24	5.3–9.0	0.4–192.0	<5–180	13–260	1–66	0.29–1.90	<0.01–0.11	20–279
	Lestidae	33	5.3–9.3	3.4–36.7	5–230	13–300	1–66	0.31–25.0	<0.01–5.40	0–279