ECOLOGICAL CHARACTER DESCRIPTION OF THE LAKE WARDEN SYSTEM RAMSAR SITE, ESPERANCE, WESTERN AUSTRALIA

A report by the Department of Environment and Conservation

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GLOSSARY

(Definitions from DEWHA, 2008).

Administrative authority	The agency within each contracting party charged by the national government with oversight of implementation of the Ramsar Convention within its territory. **http://www.ramsar.org/about/about_glossary.htm**
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, 2005b).
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).
Baseline	Condition at a starting point. For Ramsar wetlands it will usually be at the time of listing of a Ramsar site (Lambert & Elix, 2006).
Benchmark	A standard or point of reference. A predetermined state (based on the values that are sought to be protected) to be achieved or maintained (Lambert & Elix, 2006).
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, 2005a). 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, 2005b).
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 based largely on the one contained in Article 2 of the Convention on Biological Diversity (Ramsar Convention, 2005b).
Catchment	The total area draining into a river, reservoir, or other body of water (ANZECC and ARMCANZ, 2000a).
Change in ecological character	Is defined as the human induced adverse alteration of any ecosystem component, process, and/or ecosystem benefit/service (Ramsar Convention, 2005a).
Community	An assemblage of organisms characterised by a distinctive combination of species occupying a common environment and interacting with one another (ANZECC and ARMCANZ, 2000a).
Community composition	All the types of taxa present in a community (ANZECC and ARMCANZ, 2000a).

Community structure	All the types of taxa present in a community and their relative abundances (ANZECC and ARMCANZ, 2000a).
Conceptual model	Wetland conceptual models express ideas about components and processes deemed important for wetland ecosystems (Gross, 2003).
Contracting Parties	Are countries that are Member States to the Ramsar Convention on Wetlands; 159 as at June 2009. Membership in the Convention is open to all states that are members of the United Nations, one of the UN specialised agencies, or the International Atomic Energy Agency, or is a party to the Statute of the International Court of Justice. **http://www.ramsar.org/key_cp_e.htm**
Critical stage	Meaning stage of the lifecycle of wetland-dependant 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, 2005b).
Ecological Character	Is the 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 Millennium Ecosystem Assessment definition of ecosystem services as “the benefits that people receive from our ecosystems” (Ramsar Convention, 2005a). 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	Are 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, 2005b).
Ecosystems	Within the Millennium Ecosystem Assessment (2005a), ecosystems are described as the complex of living communities (including human communities) and nonliving environment (ecosystem components), interacting (through ecological processes) as a functional unit, which provides, inter alia, a variety of benefits to people (ecosystem services) (Ramsar Convention, 2005a).
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) (Ramsar Convention, 2005a).
Ecosystem processes	Dynamic forces within an ecosystem. They include all those processes that occur between organisms and within and between populations and communities, including interactions with the nonliving environment, that result in existing ecosystems and that bring about changes in ecosystems

	over time (Australian Heritage Commission, 2002). They may be physical, chemical or biological.
Ecosystem services	Are the benefits that people receive or obtain from an ecosystem. The components of ecosystem services are provisioning (e.g. food and water), regulating (e.g. flood control), cultural (e.g. spiritual, recreational) and supporting (e.g. nutrient cycling, ecological value) (Millennium Ecosystem Assessment, 2005b). See also "Benefits"
Limits of Acceptable Change	The variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland without indicating change in ecological character which may lead to a reduction or loss of the values for which the site was Ramsar listed (Phillips, 2006).
Monitoring	The collection of specific information for management purposes in response to hypothesis derived from assessment activities and the use of these monitoring results for implementing management (Ramsar Convention, 2002). Is based on surveillance and is the systematic collection of data or information over time in order to ascertain the extent of compliance with a predetermined standard or position (Hellawell, 1991).
Ramsar	Is a 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/about/about_glossary.htm**
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/about/about_glossary.htm**
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. **http://www.ramsar.org/index_very_key_docs.htm**
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/about/about_glossary.htm**
Ramsar List	The List of Wetlands of International Importance. **http://www.ramsar.org/about/about_glossary.htm**
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/about/about_glossary.htm
Wetlands	Are 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 types	As defined by the wetland classification system. **http://ramsar.org/ris/key_ris.htm#type**
Wise use of wetlands	Is the maintenance of their ecological character, achieved through the implementation of the ecosystem approaches [1], within the context of sustainable development [2] (Ramsar Convention, 2005a). 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 the OSPAR Commissions, Bremen, 25-26 June 2003). 2. The phrase "in the context of sustainable development" is intended to recognise 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.

ABBREVIATIONS

AASS	Actual Acid Sulfate Soils
AHD	Australian Height Datum
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
CALM	Department of Conservation and Land Management (now DEC)
CAMBA	China Australia Migratory Bird Agreement
CMS or Bonn	Convention on the Conservation of Migratory Species of Wild Animals
DAFWA	Department of Agriculture and Food Western Australia
DEC	Department of Environment and Conservation (Western Australia)
DEWHA	Department of Environment, Water, Heritage and the Arts (Commonwealth)
DoW	Department of Water (Western Australia)
ECD	Ecological Character Description
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
GIS	Geographical Information Systems
IBRA	Interim Biogeographic Regionalisation of Australia
IUCN	International Union for Conservation of Nature and Natural Resources
JAMBA	Japan Australia Migratory Bird Agreement
LAC	Limits of Acceptable Change
NRM	Natural Resource Management
PASS	Potential Acid Sulfate Soils
ROKAMBA	Republic of Korea Australia Migratory Bird Agreement
SWWMP	South West Wetlands Monitoring Programme

Photo: Ewans Lake (G. Daniel, 2008)

EXECUTIVE SUMMARY

The Lake Warden System Ramsar Site is located in Esperance, on the south coast of Western Australia and was designated as a Wetland of International Importance under the Ramsar Convention on the 7th January 1990. The Ramsar Convention formally, *The Convention on Wetlands of International Importance, especially as Waterfowl Habitat,* currently has 159 Contracting Parties as at 16th June 2009. The signatories of the treaty agree to cooperate on an international basis for the conservation and wise use of wetlands and their resources, which includes managing a Ramsar site to maintain its "ecological character".

The Ramsar Convention (2005a) defines ecological character as "*the combination of the ecosystem components, processes and benefits / services that characterise the wetlands at a given point in time".* Describing the ecological character (through an ecological character description [ECD]) of a wetland is crucial for identifying changes, or potential changes and provides a baseline or benchmark for future management and planning actions.

This report represents the first ECD for the Lake Warden System Ramsar Site and was prepared using the *National Framework and Guidance for Describing the Ecological Character of Australian Ramsar Wetlands: Module 2 of the National Guidelines for Ramsar Wetlands - Implementing the Ramsar Convention in Australia*. Australian Government Department of the Environment, Water, Heritage and the Arts, Canberra (see: DEWHA, 2008).

The objectives of this ECD are to:

- Provide an overall description of the Lake Warden System Ramsar Site;
- Describe the critical ecosystem components, processes, benefits and services of the Ramsar site;
- Describe any changes in ecosystem components, processes, benefits and services of the Ramsar site since listing and the current ecological character;

- Develop and provide conceptual models that describe the critical ecosystem components, processes, benefits and services of the Ramsar site;
- Identify threats to the ecological character of the site;
- Set limits of acceptable change for the critical ecosystem components and processes;
- Identify gaps in knowledge of the Lake Warden System Ramsar Site;
- Identify monitoring requirements for the Lake Warden System Ramsar Site; and
- Identify critical communication, education and public awareness messages that will enhance awareness and knowledge of the ecological values and threats of this system.

The Lake Warden System Ramsar Site is situated in the Esperance Sandplain Biogeographic Region which is within the South-West Coast Australian Drainage Division. The site is located in the Shire of Esperance, approximately 5 km north of the Esperance townsite and covers an area of 1,999 ha. The Lake Warden Catchment, north of the Ramsar site, is the major source of surface and groundwater.

The Ramsar site provides significant waterbird habitat and refuge, and waterbird species listed under the international migratory agreements CAMBA, JAMBA, ROKAMBA and CMS have been observed at the site. The Ramsar site is amongst the most important sites in south Western Australia for Chestnut Teal (*Anas castanea*) and the Hooded Plover (*Thinornis rubricollis*). Waterbird counts at the site indicate that both species have exceeded their respective 1% population thresholds (see: Wetlands International, 2006) “regularly”, as defined by the Ramsar Convention (Ramsar Convention, 2005b). Lake Warden has long been considered one of the most important sites along with Lake Gore (within the Lake Gore Ramsar Site) for Hooded Plover in the Esperance region (Newbey, 1996; Singor, 1999). The Hooded Plover is considered “Near Threatened” under the International Union for Conservation of Nature and Natural Resources (IUCN) Red List and in some regions it has become locally extinct (BirdLife International, 2006; Raines, 2002). The Hooded Plover is listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as “Marine” and is listed by the Western Australian Department of Environment and Conservation (DEC) as a Priority Four species (taxa in need of monitoring).

Other notable waterbird species recorded at the Ramsar site are the Cape Barren Goose (*Cereopsis novaehollandiae grisea*) and the Fairy Tern (*Sterna nereis*). The Cape Barren Goose recorded at the site is a rare subspecies and occurs largely on the islands of the Recherche Archipelago, however, it is occasionally recorded on the mainland. The Cape Barren Goose is listed as “Vulnerable” under the EPBC Act with approximately 650 individuals in the population (Wetlands International, 2006). The Fairy Tern is listed as “Vulnerable” under the IUCN Red List.

The Lake Warden System Ramsar Site currently meets the following three Ramsar Criteria:

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 considered to be unique in the South-West Coast Drainage Division. The wetlands within the site form a system of inter-connected lakes connected by channels. This system is distinctive as the lakes are highly variable in terms of their element and hydrochemical composition (Marimuthu et al., 2005).

Criterion 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.
Justification: The Ramsar site is considered to be a major dry season refuge for waterbirds in south-western Australia (Australian Nature Conservation Agency, 1996). Twenty five “Migratory” waterbirds recognised under the international migratory bird agreements CAMBA (23), JAMBA (22), ROKAMBA (19) and CMS (20) use the site as part of their annual migration.

Criterion 6: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.
Justification: The Lake Warden Ramsar Site until relatively recently, supported more than 1% of the global population of Hooded Plover (*Thinornis rubricollis* [1% last recorded in 2003]). The available data suggests that these population thresholds may again be met in the future.

The 1% population threshold is also met for the Chestnut Teal (*Anas castanea*). Regular counts exceeding the 1% population estimates (see: Wetlands International, 2006) have occurred at the site.

A summary of the critical ecosystem components, processes, benefits and services, and threats of the Lake Warden System Ramsar Site is provided in Table E1.

Table E1. Summary of the critical ecosystem components and processes of the Lake Warden System Ramsar Site, Esperance, Western Australia.

Critical ecosystem component/ process	Summary
Climate see: Section 2.4	• Mediterranean - warm, dry summers, cool wet winters • Evaporation exceeds rainfall most months with annual average rainfall approximately 620 mm and average annual evaporation rate 1,657 mm • During the years 1999, 2000, 2007 and 2009 Esperance has received unseasonal episodic rainfall events

	• January and February (summer) averaging approximately 26 ˚C. The lowest temperatures are experienced in July (winter) with an average of approximately 8 ˚C
Geomorphology	• The Ramsar site is situated between Quaternary dunes to the south and a granite escarpment to the north • The catchment is characterised by broad flat valley floors which gently undulate from 150 m AHD to 2 m AHD along the coastal plain • Wetlands are generally a series of broad, shallow basins with bathymetry not usually varying by more than 2 m
Hydrology	• The site consists of three distinct hydrological suites • Wetlands have a variable relationship with each other and local groundwater systems • Hydrological regime has provided habitats for a diversity of waterbirds i.e. wading to deeper feeding species
Water quality (physico-chemical)	• Salinity concentrations are saline to hypersaline depending on the wetland • Alkaline pH • Nutrient enriched
Physical Processes	• Sedimentation occurring at an accelerated rate since catchment clearing • Sedimentation has possible implications on the bathymetry and hydrological regimes of the wetlands within the Ramsar site
Wetland Soils	• Elevated nutrient concentrations – natural and anthropogenic sources • Moderate to high risk of potential acid sulfate soils
Biota	• Waterbirds - 73 species of waterbirds recorded - 42 EPBC Act listed species, 40 are listed as “Marine” species and 25 species are listed as “Migratory” and are included under the international migratory bird agreements CAMBA (23), JAMBA (22), ROKAMBA (19) and CMS (20) - Species exceeding 1% population thresholds: Chestnut Teal and Hooded Plover (listed as a Priority Four species by DEC and listed “Near Threatened” under the IUCN Red List) - Notable species recorded include Fairy Tern listed as “Threatened” under the IUCN Red List and the Cape Barren Goose listed as “Vulnerable” under the EPBC Act • Fish - Swan River Gobi, Hardy Head, Mullet and Black Bream have been recorded in the surrounding Esperance area • Aquatic invertebrates - Wetlands are variable in terms of species richness and composition due to differences in salinity concentrations - Marine influences • Flora - Vegetation forms part of the south coast “Macro-corridor”

	- Fringing vegetation is dependant on salinity concentrations of the wetland, although many are surrounded by *Melaleuca cuticularis* and some contain fringes of sedges and rushes. At Mullet Lake and to the east is a dominance of samphire species - Algal mats at most wetlands and algae species associated with eutrophication

Figure E1 conceptualises the interactions of the critical ecosystem components, processes, benefits and services that define the ecological character of the Lake Warden System Ramsar Site, along with the existing and potential threats.

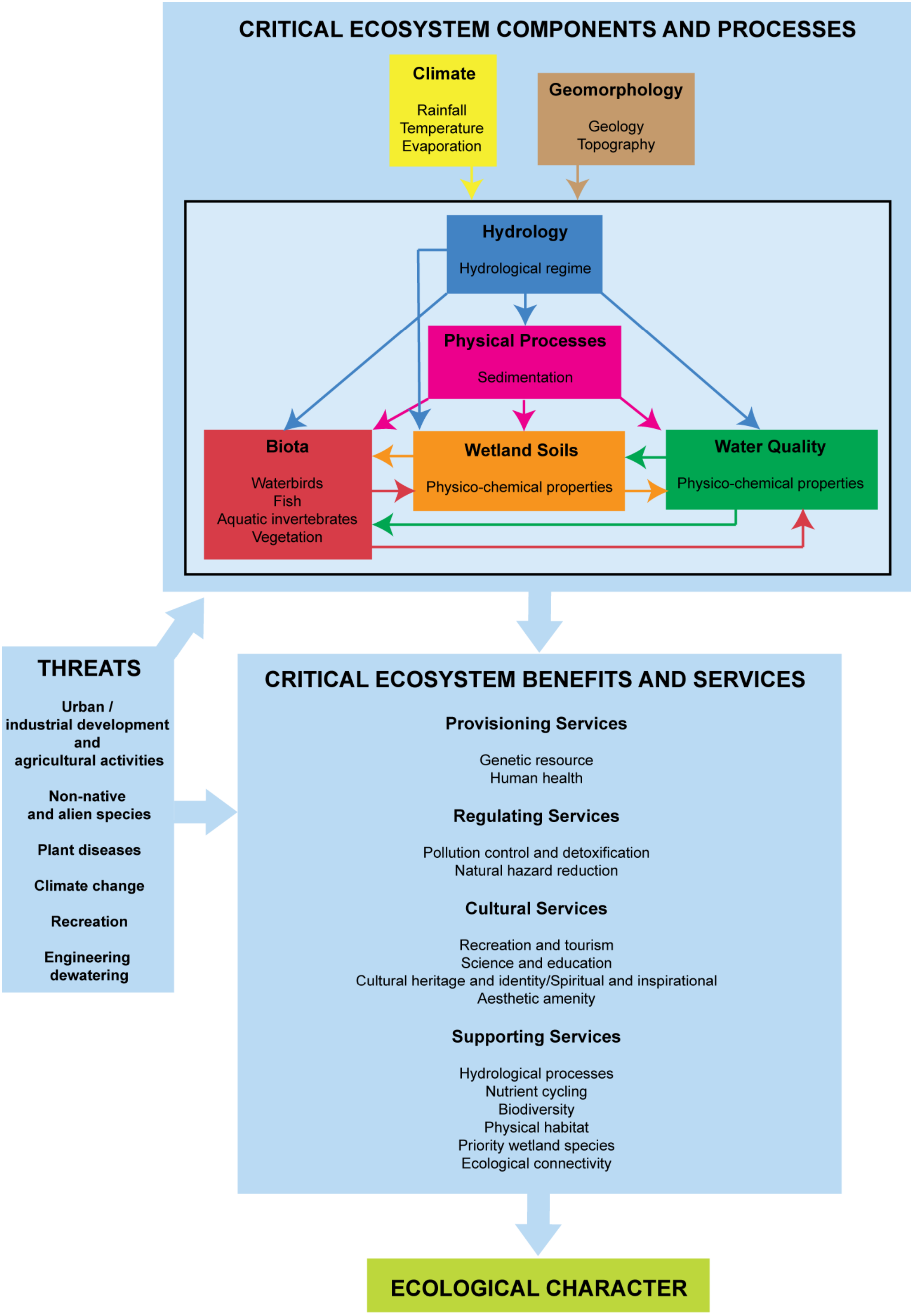


Figure E1. Conceptual model of the interaction of the critical ecosystem components, process, benefits and services of the Lake Warden System Ramsar Site , Esperance, Western Australia and the determination of ecological character. Threats influence changes in ecological character (adapted from DEWHA, 2008).

The Lake Warden Catchment is heavily cleared resulting in altered hydrological regimes and secondary salinity, which have in turn caused changes to the ecological character of the Lake Warden System Ramsar Site. Changes in ecological character of the Ramsar site have been identified prior to and since listing.

An altered hydrological regime is the overarching change to the ecological character of the Lake Warden System Ramsar Site. Increases in unseasonal, episodic rainfall events have exacerbated the affects of catchment clearing, resulting in an altered hydrological regime at the Ramsar site (i.e. increased extent and duration of inundation). It appears that changes to the hydrological regime have caused a reduction in exposed shore zone and wading habitat for waterbirds. The altered hydrological regime has also impacted on vegetation where the extent and duration of inundation has exceeded natural thresholds, resulting in death of riparian vegetation.

Due to the impacts of altered hydrology, in 1996 the Lake Warden Catchment was designated as a Natural Diversity Recovery Catchment under the State Salinity Action Plan and its successor the Salinity Strategy (Government of Western Australia, 1996, 2000). As a result, targeted revegetation within the Lake Warden Catchment and engineering dewatering of the Ramsar site to ameliorate the impacts of the altered hydrology within the catchment is currently in progress.

Limits of acceptable change (LAC) for the Lake Warden System Ramsar Site have been addressed in the ECD based on the requirements for the maintenance of the ecosystem critical components, processes, benefits and services which define the ecological character of the site. Adverse human induced changes outside these limits may constitute a change in ecological character. Management triggers have also been provided to land managers as an Annex to this report. Management trigger values are a precautionary alert purposely set below LAC so that an adaptive management response can occur prior to the LAC being reached. It is anticipated that LAC and management triggers are adapted and revised once more information is available and that the knowledge gaps outlined in the ECD are addressed.

Monitoring to support the ecological character and to address the knowledge gaps outlined have been identified in the ECD. These form the basis of future management and a monitoring programme for the Ramsar site.

1.0 INTRODUCTION

The Convention on Wetlands of International Importance, especially as Waterfowl Habitat, commonly referred to as The Ramsar Convention on Wetlands was signed in Ramsar, Iran in 1971 and came into force in 1975. The signatories of the treaty agree to cooperate on an international basis for the conservation and wise use of wetlands and their resources. The Ramsar Convention currently has 159 Contracting Parties and as at 16th June 2009, the treaty covered 1,847 wetland sites throughout the world. Australia has a total of 65 listed Ramsar sites covering approximately 7.5 million hectares (ha), 12 of which are located in Western Australia (see: Australian Government, 2008).

In addition to promoting the conservation and wise use of wetlands, Contracting Parties accept a number of other responsibilities, including managing a Ramsar site to maintain its "ecological character". Understanding and describing ecological character, and presenting this information in the form of an ecological character description (ECD), is an essential step in maintaining the ecological character of a Ramsar site. This report details the first ECD for the Lake Warden System Ramsar Site in Esperance, Western Australia.

1.1 SITE DETAILS

The Lake Warden System Ramsar Site is located in Esperance, on the south coast of Western Australia and was designated as a Wetland of International Importance under the Ramsar Convention on the 7th June 1990. Table 1 provides a summary of the details of the Lake Warden System Ramsar Site.

Table 1. Summary of the site details of the Lake Warden System Ramsar Site, Esperance, Western Australia.

Site Name	Lake Warden System Ramsar Site
Location in coordinates	Latitude 33º 47'S to 33º 50'S Longitude 121º 51'E to 122º 01'E
General location	The Lake Warden Ramsar Site is located on the south coast of Western Australia approximately 5 km north of the Esperance townsite.
Area	1,999 ha
Date of Ramsar site designation	7 June 1990
Ramsar Criteria met	Ramsar Criteria 1, 4 and 6
Management authority	Esperance District (based in Esperance) of the Department of Environment and Conservation.
Date the ECD applies	7 June 1990
Status of description	This report represents the first ECD of the site.
Date of compilation	February 2009
Name(s) of compiler(s)	Gareth Watkins of the Department of Environment and Conservation (DEC), all enquiries to Michael Coote, DEC, 17 Dick Perry Avenue, 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 Ramsar Information Sheet (RIS)	Lake Warden System Ramsar Site RIS compiled by the Western Australian Department of Conservation and Land Management (CALM) in 1990 and Roger Jaensch, Wetlands International - Oceania, on behalf of CALM, in 1998. Updated by CALM staff in 2000 and 2003. Updated by Gareth Watkins, DEC in 2009.
References to the management plan	A management plan including the Lake Warden System Ramsar Site (Esperance and Recherche Parks and Reserves Management Plan) is currently being prepared by DEC.

1.2 PURPOSE OF AN ECOLOGICAL CHARACTER DESCRIPTION

The Ramsar Convention (2005a) defines ecological character as follows:

"Ecological character is the combination of the ecosystem components, processes and benefits/ services that characterise the wetlands at a given point in time".

And a change in ecological character as:

"The human induced adverse alteration of any ecosystem component, process and or ecosystem benefit / service".

Wetland ecosystems, like all ecosystems, are dynamic and are therefore subject to "natural" variability. Changes in ecological character are recognised as the human-induced changes beyond "natural" variability. Human induced alteration to ecosystem components and processes are both direct and indirect and can vary in intensity. They include, though are not limited to: altered hydrological regimes; pollution (nutrients and other); secondary salinity; physical alteration and/or loss of habitat; and introduced flora and fauna.

Describing the ecological character of a wetland is crucial 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 *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides the legislation which helps ensure that the ecological character of Ramsar sites within Australia is maintained. This includes the environmental impact assessment (EIA) of any proposed actions that may impact on the ecological character of a Ramsar site.

When a Ramsar site is designated, a Ramsar Information Sheet (RIS) is prepared; however, this is insufficient in describing the ecological character of a site. To ensure a consistent approach in developing ECD's, the Australian Government, state and territory governments, have developed the *National Framework and Guidance for Describing the Ecological Character of Australian Ramsar Wetlands: Module 2 of the National Guidelines for Ramsar Wetlands - Implementing the Ramsar Convention in Australia*. Australian Government Department of the Environment, Water, Heritage and the Arts, Canberra.

(see: DEWHA, 2008). The Australian Government requires an ECD and a management plan to accompany 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 (Figure 1). McGrath (2006) outlines the purpose 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 (Commonwealth):
a) to describe and maintain the ecological character of declared Ramsar wetlands in Australia
b) to formulate and implement planning that promotes:
i) conservation of the wetland
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, to 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.

1.2.1 OBJECTIVES OF THE LAKE WARDEN SYSTEM RAMSAR SITE ECOLOGICAL CHARACTER DESCRIPTION

The objectives of this ECD are to:

- Provide an overall description of the Lake Warden System Ramsar Site ;
- Describe the critical ecosystem components, processes, benefits and services of the Ramsar site;
- Describe any changes in ecosystem components, processes, benefits and services of the Ramsar site since listing and the current ecological character;
- Develop and provide conceptual models that describe the critical ecosystem components, processes, benefits and services of the Ramsar site;
- Identify threats to the ecological character of the site;
- Set limits of acceptable change for the critical ecosystem components and processes;
- Identify gaps in knowledge of the Lake Warden System Ramsar Site;
- Identify monitoring requirements for the Lake Warden System Ramsar Site; and
- Identify critical communication, education and public awareness messages that will enhance awareness and knowledge of the ecological values and threats of this system.

Additionally, this ECD will provide an important reference in the development of the Esperance and Recherche Parks and Reserves Management Plan (Figure 1), which includes the Lake Warden System Ramsar Site. A draft of the management plan is currently being prepared by DEC.

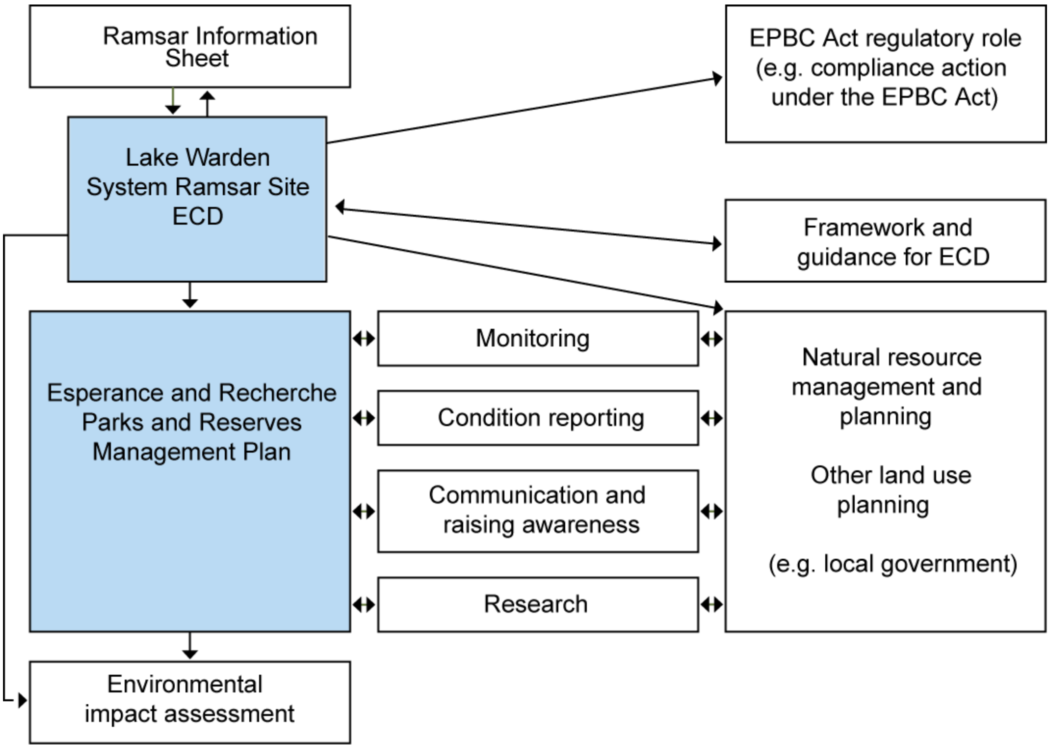


Figure 1. The relationship of the Lake Warden System Ramsar Site ecological character description with the Esperance and Recherche Parks and Reserves Management Plan, legislation and other documents (adapted from DEWHA, 2008).

1.3 RELEVANT TREATIES, LEGISLATION AND REGULATIONS

The following section details the treaties, legislation and regulations that are relevant to the Lake Warden System Ramsar Site. Additional state and local legislation that relate to a specific management perspective of the Lake Warden System Ramsar Site will be outlined in the Esperance and Recherche Parks and Reserves Management Plan.

1.3.1 INTERNATIONAL AGREEMENTS/CONVENTIONS

Ramsar convention

The Ramsar Convention formally, *The Convention on Wetlands of International Importance, especially as Waterfowl Habitat,* is an intergovernmental treaty first adopted in Ramsar, Iran in 1971, coming into force in 1975. Its signatories are committed to the conservation and wise use of wetlands and their resources. Nomination and selection of Ramsar listed wetlands is based on their level of international significance taking into consideration the 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 aims to conserve all migratory species (terrestrial, marine and avian) throughout their range and prevent them from becoming endangered.

JAMBA, CAMBA, ROKAMBA

Australia has three bilateral agreements that are relevant to the waterbird species that have been recorded at the Lake Warden System Ramsar Site. These agreements are for the conservation of migratory bird species.

JAMBA - *The 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;*

CAMBA - *The 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;* and

ROKAMBA - *The 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.*

1.3.2 NATIONAL LEGISLATION

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

The 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 (EPBC Act 1999 s16 (1)). An action that will have or is likely to have a significant impact on a Ramsar wetland is subject to environmental assessment and approval under the EPBC Act. An "action" includes a project, a development, an undertaking or an activity or series of activities **(http://www.environment.gov.au/epbc/index.html).**

The EPBC Act establishes a framework for managing Ramsar wetlands, through the Australian Ramsar Management Principles (EPBC Act 1999 s335), which are set out in Schedule 6 of the *Environment Protection and Biodiversity Conservation Regulations 2000*. These principles are intended to promote national standards of management, planning, environmental impact

assessment, community involvement, and monitoring, for all of Australia's Ramsar wetlands in a way that is consistent with Australia's obligations under the Ramsar Convention. Some matters protected under the EPBC Act are not protected under local or state/territory legislation, and as such, many migratory birds are not specifically protected under State legislation (though they are in Western Australia). All species listed under international treaties, JAMBA, CAMBA, ROKAMBA and CMS are covered by the Act. Threatened species and communities listed under the EPBC Act may also occur, or have habitat in the Ramsar site. The Regulations also cover matters relevant to the preparation of management plans, environmental assessment of actions that may affect the site, and the community consultation process
(http://www.environment.gov.au/epbc/matters/Ramsar.html).

1.3.3 WESTERN AUSTRALIA STATE LEGISLATION

Aboriginal Heritage Act 1972

This Act provides protection for Aboriginal sites (places and objects) which are significant in Aboriginal culture. Sites listed under the *Aboriginal Heritage Act 1972* occur in the Ramsar site and in the Esperance region.

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.

Environmental Protection (Clearing of Native Vegetation) Regulations 2004

Defines wetlands listed under the Ramsar Convention as environmentally sensitive areas. The clearing provisions of the *Environmental Protection Act 1986* prohibit clearing of native vegetation, unless a permit is granted by DEC or the clearing is for an exempt purpose. Exemptions do not apply in environmentally sensitive areas or within 50 metres of the boundary.

Conservation and Land Management Act 1984

This Act is administered by the Western Australian Department of Environment and Conservation (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.

Rights in Water Irrigation Act 1914

The Act provides for the management of water resources in Western Australia where a licence is required prior to any disturbance of a wetland and/or to take water from wetlands. New legislation is currently in preparation to replace the current Act in order to meet the requirements under the National Water Initiative signed by the Western Australian State Government in 2006.

Wildlife Conservation Act 1950

The Act provides for the protection and conservation of all wildlife (flora and fauna) in Western Australia. It provides the licensing framework for possessing and removal of flora and fauna and also offences and penalties in relation to the protection and conservation of flora and fauna.

2.0 DESCRIPTION OF THE LAKE WARDEN SYSTEM RAMSAR SITE

2.1 BACKGROUND

The Lake Warden System Ramsar Site is located on the south coast of Western Australia approximately 760 km south east of its capital, Perth. It is within the Shire of Esperance, approximately 5 km north of the Esperance Townsite and covers an area of 1,999 ha (Figure 2). The Lake Warden System Ramsar Site is situated in the South-West Coast Australian Drainage Division and lies within the Esperance Sandplain Biogeographic Region (IBRA). The Ramsar site extends over the majority of the Lake Warden Wetland System (LWWS) which encompasses 90 overflow satellite wetlands and the major lakes: Lake Warden, Pink Lake (excluded from the Ramsar site), Windabout Lake, Woody Lake, Lake Wheatfield, Ewans Lake, Station Lake and Mullet Lake (Figure 2).

The Lake Warden Catchment originates north of the Ramsar site and is the major source of water for the site, covering approximately 212,408 ha. Approximately 80 - 90% of the catchment has been cleared, with less than 5% of remnant vegetation remaining (Gee & Simons, 2002; Government of Western Australia, 1996; Pen, 1999). As a result of the threats arising from broad scale clearing of the catchment surrounding the Ramsar site (e.g. altered hydrology and secondary salinity), in 1996 the Lake Warden Catchment was designated as a Natural Diversity Recovery Catchment (NDRC) under the State Salinity Action Plan, and now its successor the Salinity Strategy (Government of Western Australia, 1996, 2000). Targeted revegetation within the Lake Warden Catchment and engineering dewatering of the LWWS to ameliorate the impacts of the altered hydrology within the catchment is currently in progress.

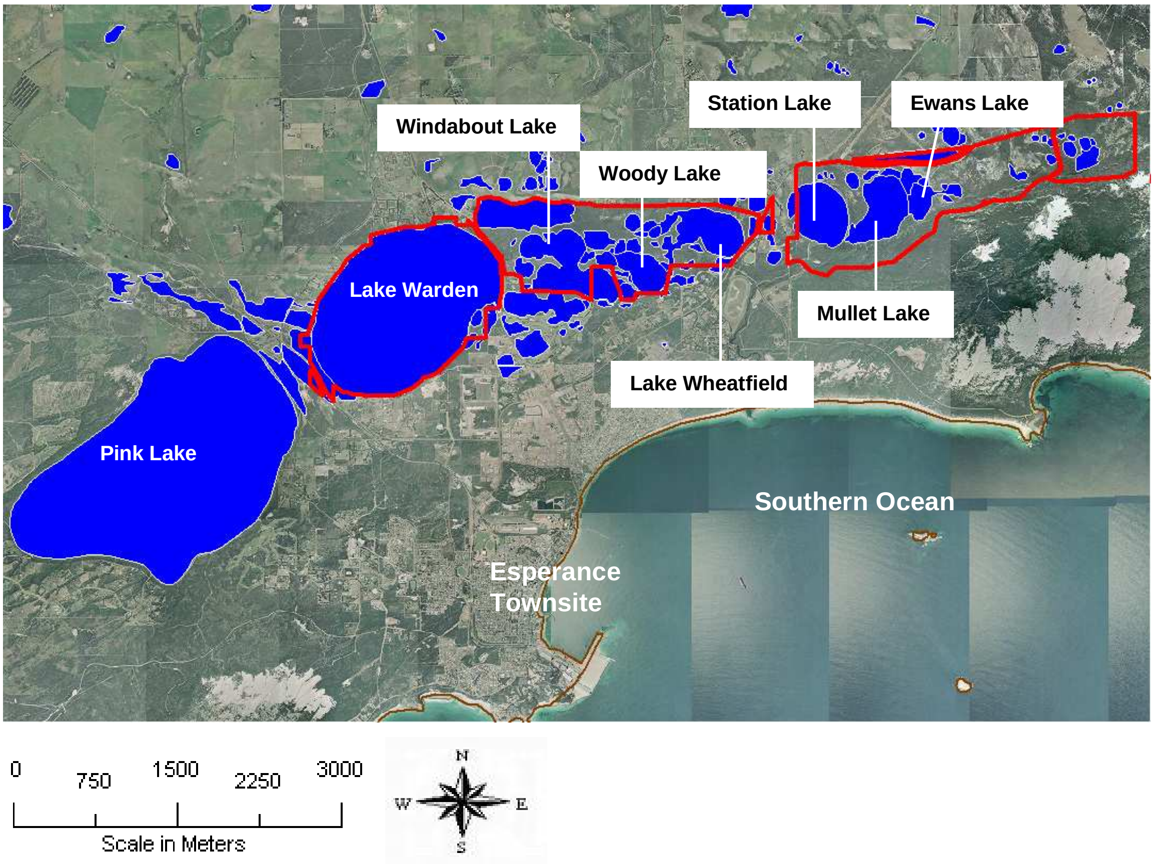


Figure 2. The Lake Warden System Ramsar Site in relation to Lake Warden Wetlands System, Esperance, Western Australia. Note: Ramsar boundary in red.

2.2 LAND TENURE AND LAND USE

The Lake Warden System Ramsar Site comprises of three Nature Reserves (Figure 3):

1. Lake Warden Nature Reserve 32257 (for purpose of Recreation and the Conservation of Flora and Fauna) which includes Lake Warden;
2. Woody Lake Nature Reserve 15231 (for purpose of Recreation and the Conservation of Flora and Fauna) which includes, Woody Lake, Lake Wheatfield and the northern section of Windabout Lake; and
3. Mullet Lake Nature Reserve 23825 (for the purpose of Conservation of Flora and Fauna) which includes, Mullet, Station and Ewans Lakes.

The land tenure surrounding the Ramsar site includes Nature Reserve, Crown Land and freehold land (Figure 3). The majority of the land use surrounding the Ramsar site is dedicated to agriculture of some form or another. Oats, wheat, barley, canola and lupins are the major crop types grown. Grazing for lamb, beef and wool production also takes place in the surrounding catchments. Some farm forestry and hobby farming also exists.

Mining and mineral exploration occurs on Pink Lake with a mining lease for the production of salt over the north east section of the lake (Figure 3). Residential, commercial and recreational purposes also form part of the surrounding land use.

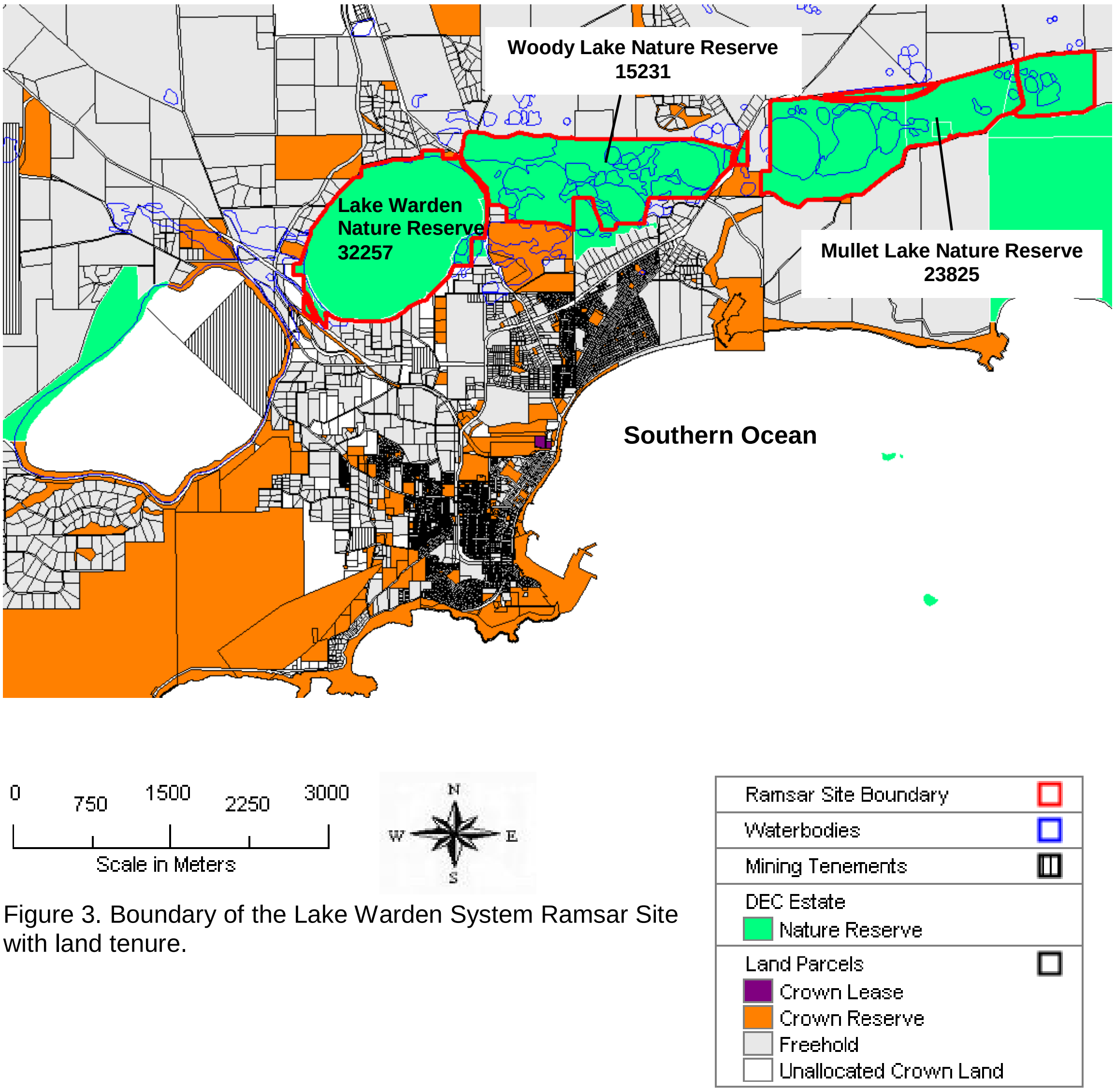


Figure 3. Boundary of the Lake Warden System Ramsar Site with land tenure.

2.4 CLIMATE

Climate is an important ecosystem component and driver of wetland ecology (see: Section 3.0). The climate of Esperance is Mediterranean, with warm dry summers (December to February) and cool, wet winters (June to August). This climatic pattern is the result of northwest cloud bands that originate in the Indian Ocean and account for 25% - 40% of the rainfall received by Esperance (Burgess, 2001; Water and Rivers Commission, 2002). Wet winter days are characterised by southerly winds from the Southern Ocean and summer is dominated by northerly winds. Temperatures are highest in January and February (summer) averaging approximately 26˚C (Figure 4). The lowest temperatures are experienced in July (winter) with an average of approximately 8˚C (Figure 4).

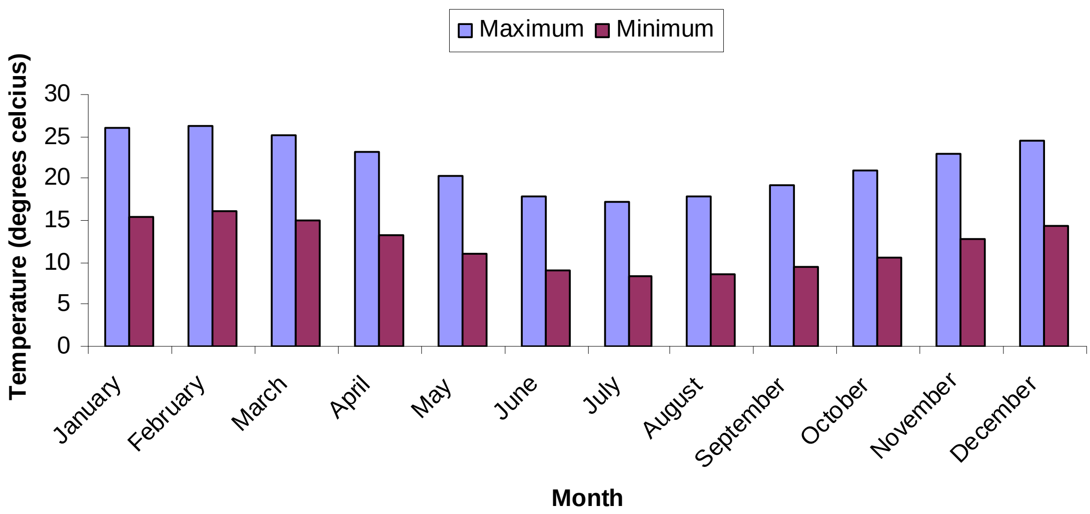


Figure 4. Mean maximum and minimum temperatures (1969 - 2008) for Esperance, Western Australia (data from Bureau of Meteorology, 2008).

The majority of the rainfall at Esperance falls between April and October, with the month of July receiving the most rainfall, averaging approximately 96 mm (Figure 5). The average annual evaporation rate at Esperance is approximately 1,657 mm (Bureau of Meteorology, 2008), with evaporation generally exceeding rainfall (Figure 5). From 1969 to 2008, the months of May, July and September have been the most variable in terms of rainfall (Figure 6). Annual average rainfall at Esperance is approximately 620 mm, although it has varied over the years ranging in the order of 400 mm to > 860 mm (Figure 7). The years 1971, 1989, 1992, 1999 and 2007 have been amongst the wettest years with approximately > 800 mm being recorded (Figure 7). The annual rainfall for the years 1983, 1991, 1994, 2002 and 2006 has been notably lower at < 500 mm (Figure 7). The annual rainfall varies from 350 mm in the upper catchments that surround the Ramsar site to 650 mm in the lower part of the catchments at the coast.

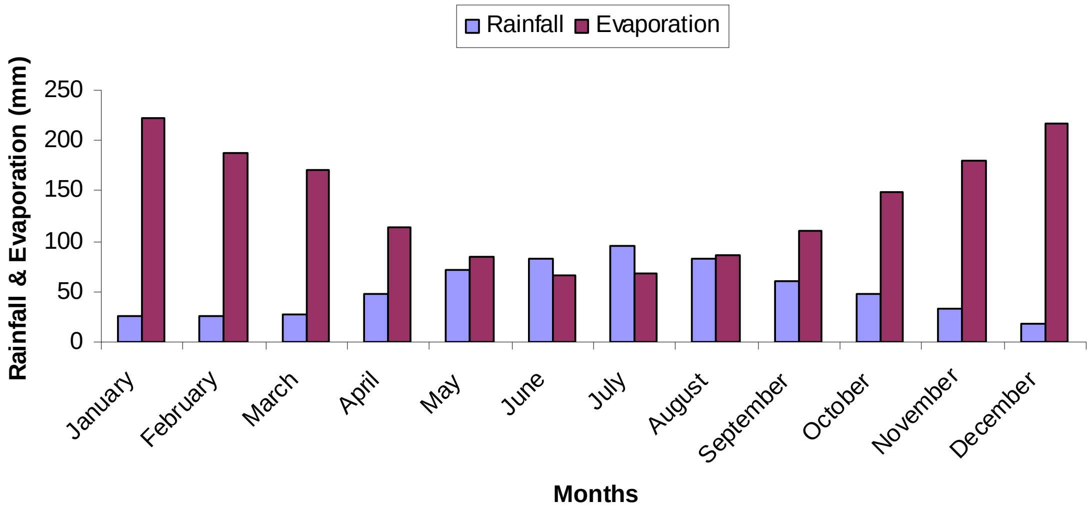


Figure 5. Average monthly rainfall and evaporation (1969 - 2008) for Esperance, Western Australia (data from Bureau of Meteorology, 2008).

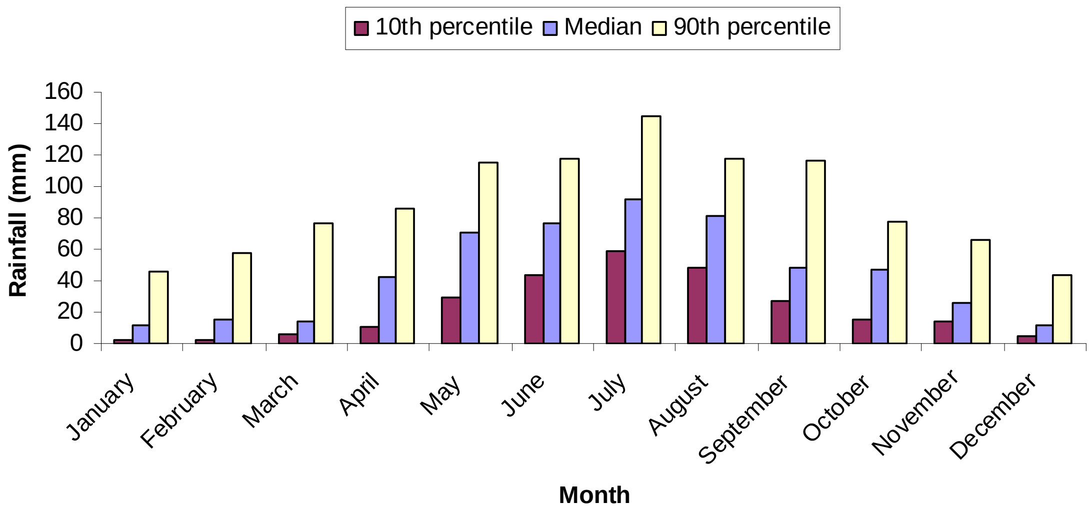


Figure 6. Median (10th and 90th percentile) monthly rainfall (1969 - 2008) for Esperance, Western Australia (data from Bureau of Meteorology, 2008).

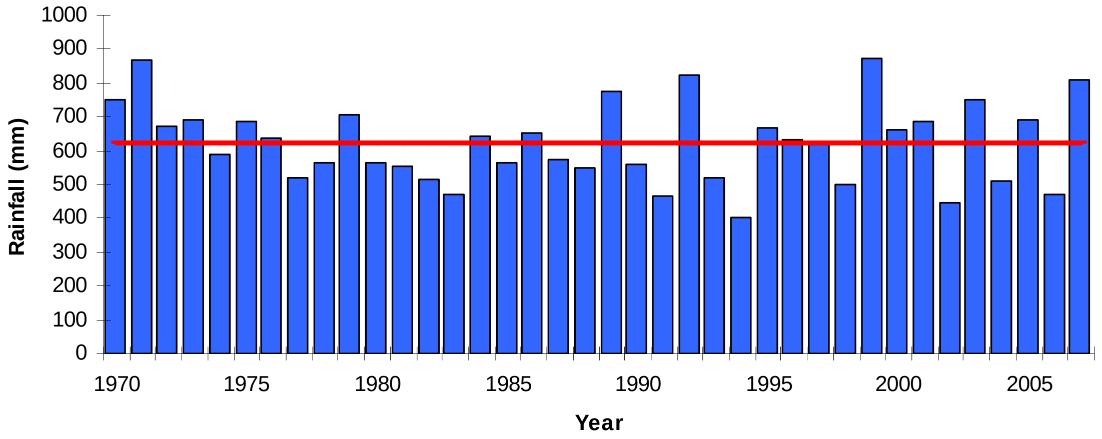


Figure 7. Annual rainfall (1970 - 2007) for Esperance, Western Australia together with long term average in red (data from Bureau of Meteorology, 2008).

Recent analysis of rainfall data from the south west of Western Australia indicates that there has been between a 5% to 10% increase in annual rainfall in the Esperance region (Figure 8). This is in contrast to the drier conditions experienced throughout the majority of the south west of Western Australia (Figure 8). During the years 1999, 2000, 2007 and 2009 Esperance has received unseasonal episodic rainfall events. In January 1999, over 107 mm of rain fell within a 24 hour period, contributing to the highest recorded monthly rainfall of 223.8 mm for Esperance (see: Bureau of Meteorology, 2008), and resulting in widespread flooding in the surrounding catchments. In March 2000, cyclone "Steve" delivered another extreme rainfall event causing flooding greater in magnitude than the previous year (Water and Rivers Commission, 2002). In January 2007, ex-tropical cyclone "Isobel" delivered a record 153 mm in a 24 hour period, again causing mass flooding and resulting in 196 mm of rainfall for the month (see: Bureau of Meteorology, 2008), well above the average generally expected for January. Widespread flooding occurred as a result of these events which also caused massive erosion in the catchments and impacted on the Esperance Townsite.

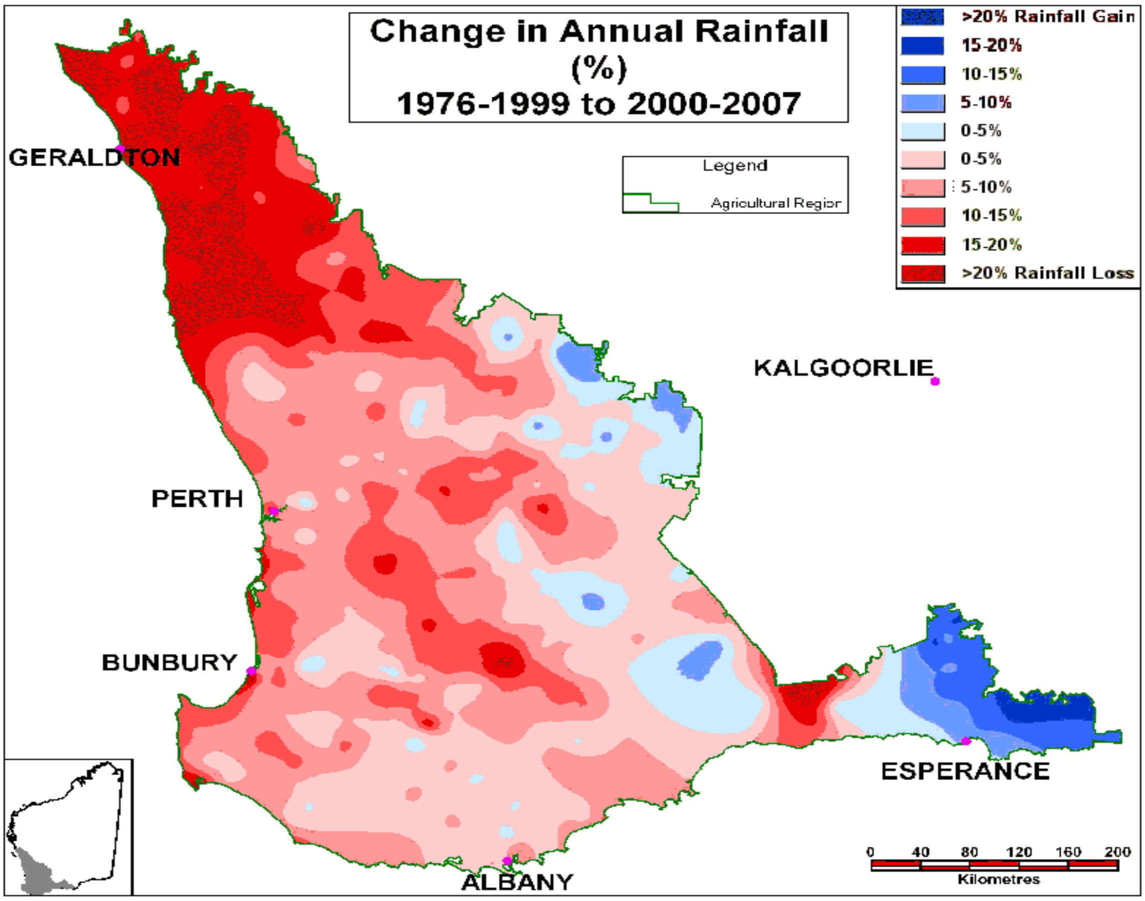


Figure 8. Rainfall in the south west of Western Australia comparing 1976 - 1999 with 2000 - 2007 (from George et al., 2008).

2.5 WETLAND TYPES

The Lake Warden System Ramsar Site contains the wetland types J, Q and R as recognised by the Ramsar classification system. The wetland types within the Ramsar site have not been formally mapped or classified into types. However, a review of the Ramsar Information Sheet (2003) and satellite imagery suggest that these wetland types exist at the Lake Warden System Ramsar Site. All of the wetlands on the site are of natural origin.

Marine /Coastal Wetlands

J - Coastal brackish/saline lagoons; brackish to saline lagoons with at least one relatively narrow connection.

Inland wetlands

Q - Permanent saline/brackish/ alkaline lakes.

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

The wetlands of the Ramsar site cover an area in the order of 1,450 ha and the major lakes cover the following approximate areas:

Lake Warden 652.2 ha
Windabout Lake 161.6 ha
Woody Lake 40.7 ha
Lake Wheatfield 88.3 ha
Station Lake 84.2 ha
Mullet Lake 76.5 ha
Ewans Lake 26.6 ha

The majority of the major lakes within the Ramsar site such as Warden, Woody, Wheatfield and Mullet are permanent (Q), with other wetlands (predominantly satellite wetlands) within the Ramsar site seasonal (R) to permanent (Q) (Figure 9). Ramsar wetland type J - coastal lagoon is connected to the Southern Ocean via Bandy Creek (Figure 9).

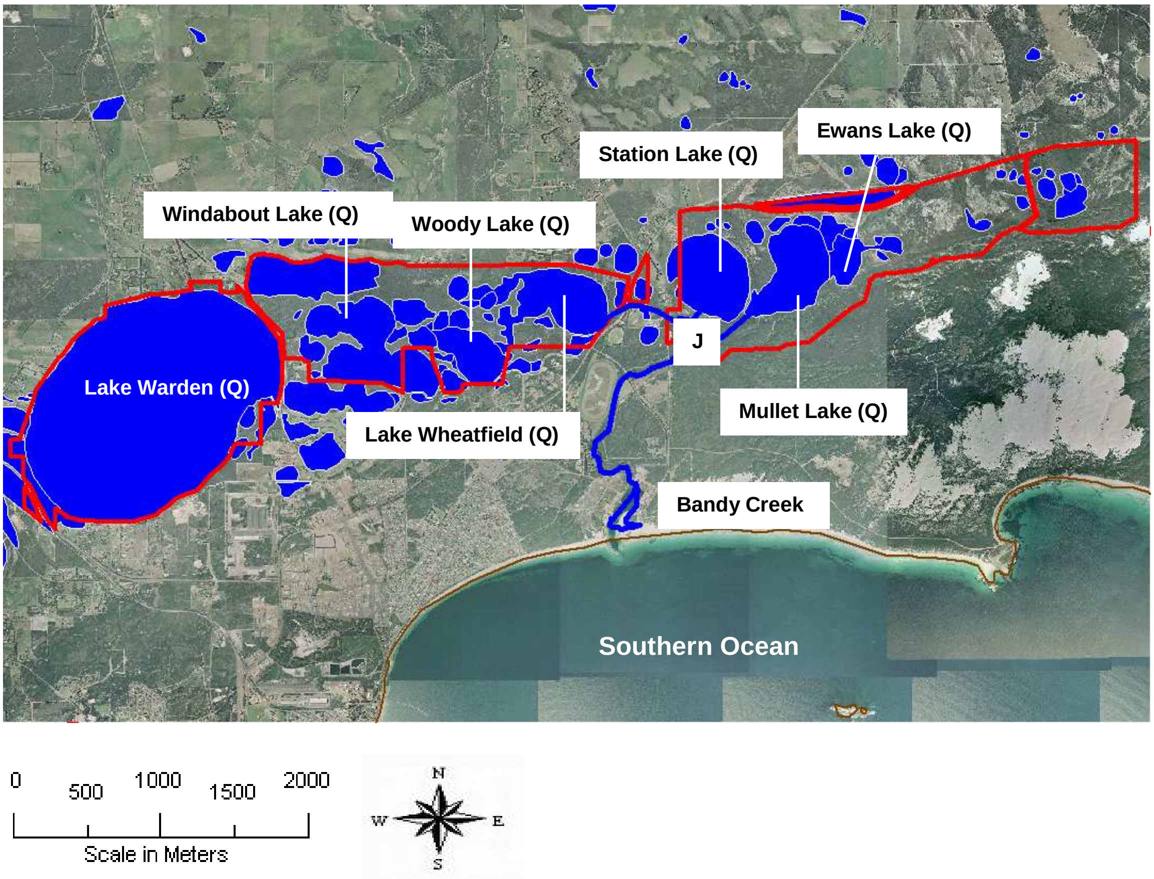


Figure 9. Wetland types at the Lake Warden System Ramsar Site. Note: Ramsar boundary in red.

2.6 RAMSAR CRITERIA

In order to be identified as a Wetland of International Importance a wetland must meet at least one of nine Ramsar Criteria (Ramsar Convention, 2005b).

2.6.1 RAMSAR CRITERIA UNDER WHICH THE SITE WAS DESIGNATED

At the time of nomination, there were thirteen Ramsar Criteria under which the Lake Warden System Ramsar Site could qualify for as a Wetland of International Importance (Table 2). When listed in June 1990 the site was considered to meet three of these Ramsar Criteria (1a, 3a and 3c [Table 2]).

Table 2. Ramsar Criteria for identifying Wetlands of International Importance at the time of listing. Note: Ramsar Criteria for which the Lake Warden System Ramsar Site was listed is highlighted in grey (from Ramsar Information Sheet, 2003).

Group 1.	
Criteria for representative or unique wetlands	**1a:** It is a particularly good representative example of a natural or near natural wetland, characteristic of the appropriate bioregion. **Justification:** The site is a good example of saline coastal lakes typical of the coast of Western Australia.
	1b: It is a particularly good representative example of a natural or near natural wetland, common to more than one bioregion.
	1c: It is a particularly good representative example of a wetland which plays a substantial hydrological, biological or ecological role in the natural functioning of a major river basin or coastal system, especially where it is located in a trans-border position.
	1d: It is an example of a specific type of wetland, rare or unusual in the appropriate biogeographical region.
Group 2.	
General criteria based on plants and animals	**2a:** It supports an appreciable assemblage of rare, vulnerable or endangered species or subspecies of plant or animal, or an appreciable number of individuals of any one or more of these species.
	2b: It is of special value for maintaining the genetic and ecological diversity of a region because of the quality and peculiarities of its flora and fauna.
	2c: It is of special value as the habitat of plants or animals at a critical stage of their biological cycle.
	2d: It is of special value for one or more endemic plant or animal species or communities.
Group 3.	
Specific criteria based on waterbirds	**3a:** It regularly supports 20,000 waterfowl. **Justification:** More than 30,000 waterbirds have been recorded using the Lake Warden System. The number of individual waterbirds that use the lake probably exceeds 20,000 regularly, and the annual data on water depth suggest that conditions are suitable for use by 20,000 waterbirds at least several times within a 25 year period; in the context of wetland availability in Western Australia this is considered sufficient evidence of regular use by 20,000 waterbirds.
	3b: It regularly supports substantial numbers of individuals from particular groups of waterfowl, indicative of wetland values, productivity or diversity.
	3c: Where data on populations are available, it regularly supports 1% of the individuals in a population of one species or subspecies of waterfowl. **Justification:** The Site supports more than 1% of the global population of Hooded Plover, *Thinornis rubricollis*. The global population of this species, which is restricted to southern Australia, is less than 10,500 individuals, while the Western Australian population numbers less than 6,000 individuals (Wetlands International, 2002). Over 240 have been recorded on one occasion at Lake Warden (February 1985), which constitutes 2.4% of the global population and 4% of the Western Australian population.
Group 4.	
Specific criteria based on fish	**4a:** 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.

	4b: 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.

2.6.2 CURRENT RAMSAR CRITERIA

Since the Lake Warden System Ramsar Site was listed, the Ramsar Criteria were further developed and revised, and the criteria were reduced to six. In 1996, two additional criteria were included (criteria 7 and 8) and a ninth criterion was added in 2005 after the 9th Meeting of the Conference of the Contracting Parties. Table 3 details the Ramsar Criteria currently met by the Lake Warden System Ramsar Site. During the preparation of this ECD an analysis of the historical and recent waterbird survey data was conducted in order to ascertain if the Lake Warden System Ramsar Site still meets the Ramsar Criteria that it was originally nominated for and whether any changes to waterbird species richness and abundance has occurred.

Analyses of the available data indicates that Ramsar Criteria 1, 4 and 6 are currently met by the Lake Warden System Ramsar Site with the addition of one waterbird species; the Chestnut Teal (*Anas castanea*) under Ramsar Criterion 6. Ramsar Criterion 5 (Ramsar Criterion 3a at the time of listing) is not considered to be currently met at the Lake Warden System Ramsar Site and its application at the time of nomination has been reassessed as part of this ECD. These conclusions are in consideration of the most recent global waterbird population estimates (see: Wetlands International, 2006) and the Ramsar guidelines for applying Ramsar Criteria 5 and 6 including the definition of "regularly" under these Criteria (see: Text Box 1). As part of the preparation of this ECD the RIS has also been updated to reflect these changes. Sub-section 2.6.2.1 provides a description of the assessment against each of the Ramsar Criteria.

Table 3. Current Ramsar Criteria for identifying Wetlands of International Importance (from Ramsar Convention, 2005b). Note: Ramsar Criteria for which Lake Warden System Ramsar Site currently meets is highlighted in grey.

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 considered to be unique in the South-West Coast Drainage Division. The wetlands within the site form a system of inter-connected lakes connected by channels. This system is distinctive as the lakes are highly variable in terms of their element and hydrochemical composition (Marimuthu et al., 2005).
Group B: Sites of international importance for conserving biological diversity	
Criteria based on species and ecological communities	**Criterion 2:** A wetland should be considered internationally important if it supports vulnerable, endangered or critically endangered species or threatened ecological communities.
	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 biographic region.
	Criterion 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions. **Justification:** The Ramsar site is considered to be a major dry season refuge for waterbirds in south-western Australia (Australian Nature Conservation Agency, 1996). Twenty five "Migratory" waterbird species recognised under the international migratory bird agreements CAMBA (23), JAMBA (22), ROKAMBA (19) and CMS (20) use the site as part of their annual migration. White Bellied Sea Eagle (*Haliaeetus leucogaster*), Cattle Egret (*Ardea ibis*), Great Egret (*Egretta alba*), Grey Plover (*Pluvialis squatarola*), White-winged Black Tern (*Chlidonias leucopterus*), Ruddy Turnstone (*Arenaria interpres*), Sharp-tailed Sandpiper (*Calidris acuminate*), Sanderling (*Calidris alba*), Red Knot (*Calidris canutus*), Curlew Sandpiper (*Calidris ferruginea*), Pectoral Sandpiper (*Calidris melanotos*), Red-necked Stint (*Calidris ruficollis*), Long-toed Stint (*Calidris subminuta*), Great Knot (*Calidris tenuirostris*), Broad-billed Sandpiper (*Limicola falcinellus*), Bar-tailed Godwit (*Limosa lapponica*), Black-tailed Godwit (*Limosa limosa*), Whimbrel (*Numenius phaeopus*), Common Sandpiper (*Tringa glareola*), Common Greenshank (*Tringa nebularia*), Marsh Sandpiper (*Tringa stagnatilis*), Terek Sandpiper (*Xenus cinereus*), Caspian Tern (*Sterna caspia*), Clamorous Reed-Warbler (*Acrocephalus stentoreus*), Glossy Ibis (*Plegadis falcinellus*).
Specific criteria based on waterbirds	**Criterion 5:** A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.
	Criterion 6: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird. **Justification:** The Lake Warden Ramsar Site until relatively recently, supported more than 1% of the global population of Hooded Plover (*Thinornis rubricollis* [1% last recorded in 2003]). The available data suggests that these population thresholds may again be met in the future. The 1% population threshold is also met for the Chestnut Teal (*Anas castanea*). Regular counts exceeding the 1% population estimates (see: Wetlands International, 2006) have occurred at the site.

	1. Hooded Plover 1% of the Western Australian population = 60 birds. Years exceeded with maximum count: 1982 = 65; 1983 = 72; 1984 = 99; 1985 = 240; 1986 = 77; 1987 = 75; 1988 = 539; 1995 = 146; 1996 = 272; 1997 = 230; 1998 = 607; 2003 = 60. 2. Chestnut Teal 1% of the South-west Australian population = 50 birds. Years exceeded with maximum count: 1981 = 300; 1982 = 100; 1985 = 153; 1991 = 948; 1992 = 1269; 1997 = 429; 1999 = 76; 2001 = 250; 2003 = 200; 2006 = 409; 2007 = 196; 2008 = 763.
Specific criteria based on fish	**Criterion 7:** 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: 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.
Specific criteria based on other taxa	**Criterion 9:** A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of wetland-dependant non-avian animal species

The definition of "regularly" under Strategic Framework and guidelines for the future development of the List of Wetlands of International Importance of the Convention on Wetlands (Ramsar, Iran,1971) Third edition, as adopted by Resolution VII.11 (COP7, 1999) and amended by Resolutions VII.13 (1999), VIII.11 and VIII.33 (COP8, 2002), and IX.1 Annexes A and B (COP9, 2005) (Ramsar Convention, 2005b):

Regularly (Ramsar Criteria 5 & 6) - as in supports regularly - a wetland regularly supports a population of a given size if:

i) the requisite number of birds is known to have occurred in two thirds of the seasons for which adequate data are available, the total number of seasons being not less than three; or

ii) the mean of the maxima of those seasons in which the site is internationally important, taken over at least five years, amounts to the required level (means based on three or four years may be quoted in provisional assessments only).

In establishing long-term "use" of a site by birds, natural variability in population levels should be considered especially in relation to the ecological needs of the populations present. Thus in some situations (e.g., sites of importance as drought or cold weather refuges or temporary wetlands in semi-arid or arid areas - which may be quite variable in extent between years), the simple arithmetical average number of birds using a site over several years may not adequately reflect the true ecological importance of the site. In these instances, a site may be of crucial importance at certain times ("ecological bottlenecks"), but hold lesser numbers at other times. In such situations, there is a need for interpretation of data from an appropriate time period in order to ensure that the importance of sites is accurately assessed.

In some instances, however, for species occurring in very remote areas or which are particularly rare, or where there are particular constraints on national capacity to undertake surveys, areas may be considered suitable on the basis of fewer counts. For some countries or sites where there is very little information, single counts can help establish the relative importance of the site for a species. **http://www.ramsar.org/key_guide_list2006_e.htm**.

Text Box 1. Definition of "regularly" in the application of Ramsar Criteria 5 and 6.

2.6.2.1 Assessment against each of the Ramsar Criteria for the Lake Warden System Ramsar Site

Criterion 1. This criterion was met at the time of listing of the Lake Warden System Ramsar Site and continues to be met.

The Ramsar site is considered to be unique in the South-West Coast Drainage Division. Although the wetlands are viewed as a consanguineous system as they are interconnected by a series of surface water channels, their association is variable. This leads to the formation of distinct hydrological suites within the LWWS delineated by their composition and their relationships with each other and local groundwater systems.

Criterion 2. This criterion is not met by the Lake Warden System Ramsar Site.

The Cape Barren Goose (*Cereopsis novaehollandiae grisea*) which is listed as “Vulnerable” under the EPBC Act and the Fairy Tern (*Sterna nereis*) which is listed as “Vulnerable” under the International Union for Conservation of Nature and Natural Resources (IUCN) Red List have both been recorded at the Ramsar site.

The Cape Barren Goose recorded at the site is a rare subspecies and occurs largely on the islands of the Recherche Archipelago. It has been recorded at Ewans Lake on one occasion (January 1982 [2]) and in the mid 80’s on five occasions where 2 to 8 individuals were recorded at Windabout Lake (Jaensch et al., 1988). Since this time 5 individuals were recorded at Windabout Lake in October 2006 and over 40 were recorded in February 2008 (Bennelongia, 2008a; Halse, 2007).

The Fairy Tern has been recorded at Lake Warden (7 occasions), Windabout Lake (2 occasions) and Station Lake (1 occasion) during the mid 1980’s (see: Jaensch et al., 1988). The Ramsar site is not considered important in supporting populations of Cape Barren Goose or Fairy Tern as the numbers recorded to date suggest that both are only occasional visitors.

Criterion 3. No species of flora or fauna are supported solely by the Lake Warden System Ramsar Site and therefore this criterion is not met.

Criterion 4. This criterion is met by the Lake Warden System Ramsar Site.

The Ramsar site provides a variety of permanent water habitats and during drought conditions it provides a refuge to waterbirds. In south-western Australia it is considered one of the major drought refuges for waterbirds (Australian Nature Conservation Agency, 1996).

Twenty five “Migratory” waterbird species as listed under the EPBC Act use the Ramsar site as part of their annual migration. These waterbirds are also listed under the international migratory bird agreements CAMBA (23), JAMBA (22), ROKAMBA (19) and CMS (20).

White Bellied Sea Eagle (*Haliaeetus leucogaster*), Cattle Egret (*Ardea ibis*), Great Egret (*Egretta alba*), Grey Plover (*Pluvialis squatarola*), White-winged Black Tern (*Chlidonias leucopterus*), Ruddy Turnstone (*Arenaria interpres*), Sharp-tailed Sandpiper (*Calidris acuminate*), Sanderling (*Calidris alba*), Red Knot (*Calidris canutus*), Curlew Sandpiper (*Calidris ferruginea*), Pectoral Sandpiper

(*Calidris melanotos*), Red-necked Stint (*Calidris ruficollis*), Long-toed Stint (*Calidris subminuta*), Great Knot (*Calidris tenuirostris*), Broad-billed Sandpiper (*Limicola falcinellus*), Bar-tailed Godwit (*Limosa lapponica*), Black-tailed Godwit (*Limosa limosa*), Whimbrel (*Numenius phaeopus*), Common Sandpiper (*Tringa glareola*), Common Greenshank (*Tringa nebularia*), Marsh Sandpiper (*Tringa stagnatilis*), Terek Sandpiper (*Xenus cinereus*), Caspian Tern (*Sterna caspia*), Clamorous Reed-Warbler (*Acrocephalus stentoreus*), Glossy Ibis (*Plegadis falcinellus*).

Criterion 5. The current interpretation of this criterion is not met by the Lake Warden System Ramsar Site.

This criterion was considered to be met at the time of nomination (criterion 3a at the time) and therefore at the time of listing of the Lake Warden System Ramsar Site. The original justification for Ramsar Criterion 5 provided in the 2003 RIS stated that "annual data on water depth suggest conditions are suitable for use by 20,000 waterbirds at least several times within a 25 year period" (Ramsar Information Sheet, 2003). Analysis of the waterbird data from 1981 to 2008 indicates that there have been no occasions where 20,000 or more waterbirds have been recorded at the site.

Historic waterbird surveys have been limited spatially and very few have surveyed all of the wetlands within the Ramsar site boundary simultaneously. This is most likely due to the constraints of the methods employed, as the surveys from 1981 - 2005 were mainly ground based. Aerial waterbird surveys (2006 - 2008) have recently been conducted and the entire Ramsar site was covered within a relatively short space of time (see: Bennelongia, 2008a; Bennelongia, 2008b; Halse, 2007). Future waterbird surveys conducted in this manner may provide sufficient justification to include this Ramsar Criterion. However, even the recent aerial surveys (2006 - 2008) did not record 20,000 or more waterbirds (see: Bennelongia, 2008a; Bennelongia, 2008b; Halse, 2007). Bennelongia (2009) acknowledge that it is unlikely that this current criterion is met "regularly" by the Ramsar site.

Criterion 6. This criterion was met at the time of listing of the Lake Warden System Ramsar Site and continues to be met.

At the time of listing, Hooded Plover (*Thinornis rubricollis*) counts regularly exceeded the 1% population threshold (Wetlands International, 2006). Although, the Hooded Plover counts last exceeded the 1% population thresholds in 2003, insufficient time has lapsed to suggest that this species will not meet the 1% population thresholds in the future.

An additional species, the Chestnut Teal (*Anas castanea*) now also meets Criterion 6. Chestnut Teal were not included as justification for this criterion at the time of listing, as population estimates for this species were not available. The latest global population estimates (see: Wetlands International, 2006), in comparison with historical and current waterbird surveys, indicate that the counts of Chestnut Teal exceed the 1% population threshold for this species "regularly".

1. Hooded Plover 1% of the Western Australian population = 60 birds.
   Years exceeded with maximum count:

1982 = 65	1986 = 77	1996 = 272
1983 = 72	1987 = 75	1997 = 230
1984 = 99	1988 = 539	1998 = 607
1985 = 240	1995 = 146	2003 = 60

2. Chestnut Teal 1% of the South-west Australian population = 50 birds.
   Years exceeded with maximum count:

1981 = 300	1992 = 1269	2003 = 200
1982 = 100	1997 = 429	2006 = 409
1985 = 153	1999 = 76	2007 = 196
1991 = 948	2001 = 250	2008 = 763

(see: Bennelongia, 2008a; Bennelongia, 2008b; Birds Australia, 2008b, 2009; Cale, 2008; Clarke et al., 2003; Halse, 2007; Halse et al., 1990; Halse et al., 1995; Halse et al., 1994; Jaensch et al., 1988).

Criterion 7, 8 & 9. These criteria are not considered to be applicable to the Lake Warden System Ramsar Site.

3.0 LAKE WARDEN SYSTEM RAMSAR SITE: CRITICAL ECOSYSTEM COMPONENTS, PROCESSES, BENEFITS AND SERVICES

3.1 CRITICAL ECOSYSTEM COMPONENTS AND PROCESSES

Ecosystem components and processes include the physical, chemical and biological parts of a wetland and include habitat, species and genes (Ramsar Convention, 2005a). Climate and geomorphology are overarching ecosystem components and processes as they strongly influence the ecology of wetlands (Mitsch & Gosselink, 2007). Climate and geomorphology affect other ecosystem components and processes such as the physico-chemical environment, wetland biota and hydrology (Mitsch & Gosselink, 2007). Collectively, ecosystem components and processes contribute in determining the ecological character of a wetland. Figure 10 provides an overview of ecosystem components and processes and their interactions.

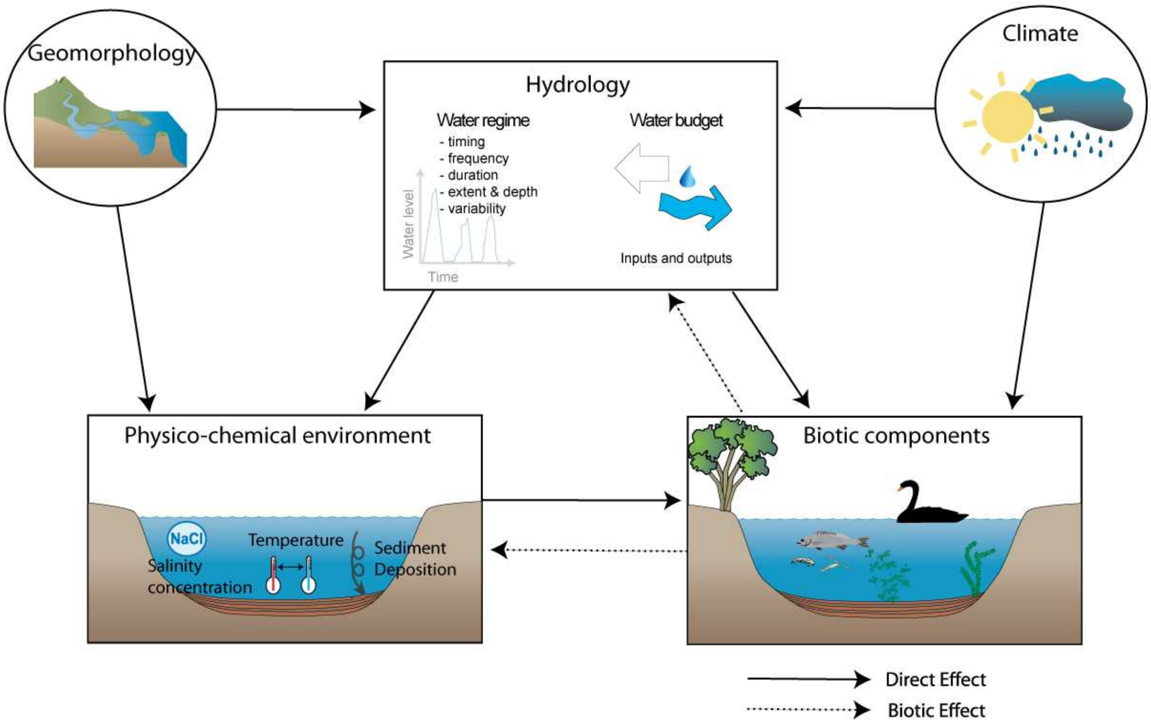


Figure 10. An overview of ecosystem components and processes and their interactions (adapted from DEWHA, 2008; Mitsch & Gosselink, 2007).

Alterations to any of the ecosystem components and processes may result in a change to the ecological character of a wetland system (see: Section 5.0 Changes to Ecological Character). This section will identify and describe the critical ecosystem components and processes that most strongly influence or determine the ecological character of the Lake Warden System Ramsar Site. Ideally, the critical ecosystem components and processes should be quantified so if changes do occur they are both measurable and comparable in the future. However, in some instances knowledge gaps exist and quantification is difficult (see: Section 7.0 Knowledge Gaps).

Identifying and describing critical ecosystem components and processes will contribute towards setting limits of acceptable change, determining knowledge gaps and recommending monitoring requirements for the Lake Warden System Ramsar Site, as detailed in later sections of this ECD. Any changes to the components and processes identified here will also be discussed in Section 5.0 Changes to Ecological Character.

Table 4. Summary of the critical ecosystem components and processes of the Lake Warden System Ramsar Site, Esperance, Western Australia.

Critical ecosystem component/ process	Summary
Climate see: Section 2.4	• Mediterranean - warm, dry summers, cool wet winters • Evaporation exceeds rainfall most months with annual average rainfall approximately 620 mm and average annual evaporation rate 1,657 mm • During the years 1999, 2000 and 2007 Esperance has received unseasonal episodic rainfall events • January and February (summer) averaging approximately 26 ˚C. The lowest temperatures are experienced in July (winter) with an average of approximately 8 ˚C
Geomorphology	• The Ramsar site is situated between Quaternary dunes to the south and a granite escarpment to the north • The catchment is characterised by broad flat valley floors which gently undulate from 150 m AHD to 2 m AHD along the coastal plain • Wetlands are generally a series of broad, shallow basins with bathymetry not usually varying by more than 2 m
Hydrology	• The site consists of three distinct hydrological suites • Wetlands have a variable relationship with each other and local groundwater systems • Hydrological regime has provided habitats for a diversity of waterbirds i.e. wading to deeper feeding species
Water quality (physico-chemical)	• Salinity concentrations are saline to hypersaline depending on the wetland • Alkaline pH • Nutrient enriched
Physical Processes	• Sedimentation occurring at an accelerated rate since catchment clearing • Sedimentation has possible implications on the bathymetry and hydrological regimes of the wetlands within the Ramsar site
Wetland Soils	• Elevated nutrient concentrations – natural and anthropogenic sources • Moderate to high risk of potential acid sulfate soils
Biota	• Waterbirds - 73 species of waterbirds recorded - 42 EPBC Act listed species, 40 are listed as “Marine” species and 25 species are listed as “Migratory” and are included under the international migratory bird agreements CAMBA (23), JAMBA (22), ROKAMBA (19) and CMS (20) - Species exceeding 1% population thresholds: Chestnut Teal and Hooded Plover (listed as a Priority Four species by DEC and listed “Near Threatened” under the IUCN Red List) - Notable species recorded include Fairy Tern listed as “Threatened” under the IUCN Red List and the Cape Barren Goose listed as “Vulnerable” under the EPBC Act

	• Fish - Swan River Gobi, Hardy Head, Mullet and Black Bream have been recorded in the area • Aquatic invertebrates - Wetlands are variable in terms of species richness and composition due to differences in salinity concentrations - Marine influences • Flora - Vegetation forms part of the south coast "Macro-corridor" - Fringing vegetation is dependant on salinity concentrations of the wetland, although many are surrounded by *Melaleuca cuticularis* and some contain fringes of sedges and rushes. At Mullet Lake and to the east is a dominance of samphire species - Algal mats at most wetlands and algae species associated with eutrophication

Rationale for selection of the critical ecosystem components and processes

The identification and description of the critical components and processes of the Lake Warden System Ramsar Site is based on the minimum requirements set by DEWHA (2008). The critical ecosystem components and processes have been selected on the basis that:

- They are important determinants of the site's unique character;
- They are important for supporting the Ramsar Criteria under which the site was listed;
- Changes to components and processes are likely to occur over short or medium time scales (<100 years); and
- Significant negative consequences will be the result of changes to the components and processes.

Climate and Geomorphology: Climate and geomorphology are the overarching ecosystem components (Mitsch & Gosselink, 2007), and should be considered as part of the critical components and processes of any ecosystem.

Hydrology: Hydrology is a fundamental determinant of the ecological character of this site. The hydrological regime directly influences biota including vegetation, waterbirds and invertebrates and is important in supporting the Ramsar Criteria for which the site was listed. Changes in the hydrological regime of the Ramsar site would have significant negative consequences for the ecological character of the site.

Water quality: Water quality is important in relation to the biotic composition of an ecosystem and is critical in any wetland. Changes in the water physico-chemical environment of Ramsar site will impact waterbirds, vegetation and aquatic invertebrates and may affect the ability of the Ramsar site to support the Ramsar Criteria for which it was listed.

Physical Processes: Sedimentation is an important process influencing the ecological character of the site. Sedimentation directly alters the bathymetry of the wetlands within the Ramsar site, which has subsequent impacts on components of the hydrological regime.

Wetland Soils: It is the physico-chemical attributes that make the wetland soils a critical component. The wetland soils affect water quality and also partly determine the vegetation of the site. Essentially a product of hydrology, geomorphology and climatic processes, as with water quality, wetland soils influence the biotic composition of the site.

Biota: The biotic components form the foodweb and are a critical determinant of the ecological character of the Ramsar site. As waterbirds are part of the foodweb, any changes to richness abundance and composition of waterbirds may affect the ability of the site to support the Ramsar Criteria for which it was originally nominated.

3.1.1 GEOMORPHOLOGY

Geomorphology is second to climate as one of the most important factors in the ecology of wetlands (Mitsch & Gosselink, 2007). The basement geology of the Esperance area is made up of Proterozoic rocks of the Albany - Fraser Orogen consisting of granite and gneisses formed approximately 2,300 – 1,800 million years ago (CALM, 1999; Short, 2000). This bedrock was overlain by Tertiary sediments of the Plantagenet Group during periods of sea level change approximately 40 million years ago (CALM, 1999; Short, 2000).

Approximately 30 million years ago during the Oligocene period, the Darling Plateau began to rise and the southern coastline tilted toward the south, forming the Ravensthorpe Ramp (Short, 2001). As a consequence, the older east - west flowing river systems were partly rejuvenated and began to flow in a southerly direction (Short, 2001). Over the past two million years during the Quaternary period, sediments consisting of sand and limestone have been deposited over the area (Short, 2000).

Topography

Along the coastal sandplain, the sediments deposited during the Quaternary period are at their thickest forming prominent sand dunes to the south of the Ramsar site (Reynolds & Marimuthu, 2007). The Ramsar site is situated between these sand dunes and a granite escarpment to the north.

The catchment originates approximately 50 km north of the Ramsar site, inland at a height of approximately 150 m Australian Height Datum [AHD] and gradually decreases in height towards the Southern Ocean, before reaching the granite escarpment that rises up to 60 m AHD (Marimuthu et al., 2005; Short et al., 2000). The escarpment gently falls to a narrow (approximately 10 km wide), undulating coastal sandplain ranging between 2 m AHD and 20 m AHD (Marimuthu et al., 2005; Short et al., 2000).

The bathymetry of each wetland within the Ramsar site, generally does not vary by more than 2 m. The majority of the wetlands within the Ramsar site can be described as a series of broad shallow basins, however, the degree in which the depth gradient changes is dependant on the wetland size. For example, Lake Warden is the largest lake within the Ramsar site (652 ha) with it's bathymetry ranging from approximately 2.5 m AHD to 5 m AHD and it is therefore a fairly broad, shallow basin. This means that a small flux in water level can influence the extent of inundation and therefore the area of exposed shore zone used by some waterbird species. Additional changes in the bathymetry from sedimentation may also increase the extent of inundation (see: Section 3.1.4 Physical Processes).

3.1.2 HYDROLOGY

The hydrology of a wetland is directly influenced by climate and geomorphology (Mitsch & Gosselink, 2007). Hydrology and particularly the hydrological regime of a wetland affects biodiversity through the direct modification of the physico-chemical environment (Mitsch & Gosselink, 2007).

The components of a hydrological regime include timing, frequency, duration, extent and depth, and variability (Boulton & Brock, 1999). The interactions of surface and groundwater contribute to the hydrological regime. Recording the water depth of a wetland on a seasonal basis assists in describing the hydrological characteristics or hydroperiod of a wetland. The hydroperiod (expressed in a hydrograph) represents the timing, frequency, duration and depth components of the hydrological regime. It is a major determinant of wetland processes and can vary, sometimes dramatically, both seasonally and annually (Mitsch & Gosselink, 2007).

Hydrological regime strongly influences the waterbird species composition of the Lake Warden System Ramsar Site. The water depth, along with the extent of inundation and the subsequent habitat created, is an important ecosystem component for the Ramsar site. In particular, it has been demonstrated that too much water within Lake Warden itself results in an increase in the extent and duration of inundation. Subsequently, wading waterbird habitat is impacted and waterbird species richness and abundance is reduced (Robertson & Massenbauer, 2005). Wading waterbirds generally require a habitat that is ≤ 0.5 m with studies indicating waterbird diversity increases at depths < 0.3 m (Colwell & Taft, 2000; Ehrhardt, 2001).

3.1.2.1 Hydrological setting

Four major catchments north of the site comprise the Lake Warden Catchment (Figure 11), which is the major source of water for the wetlands within the Ramsar site and covers approximately 212,408 ha (CALM, 2006):

1. Neridup Creek Catchment 81,305 ha;
2. Bandy Creek Catchment 73,463 ha;
3. Coramup Creek Catchment 39,480 ha; and
4. The Western Lakes Catchments which includes Melijinup, Buckenerup and Monjingup Creeks 18,160 ha.

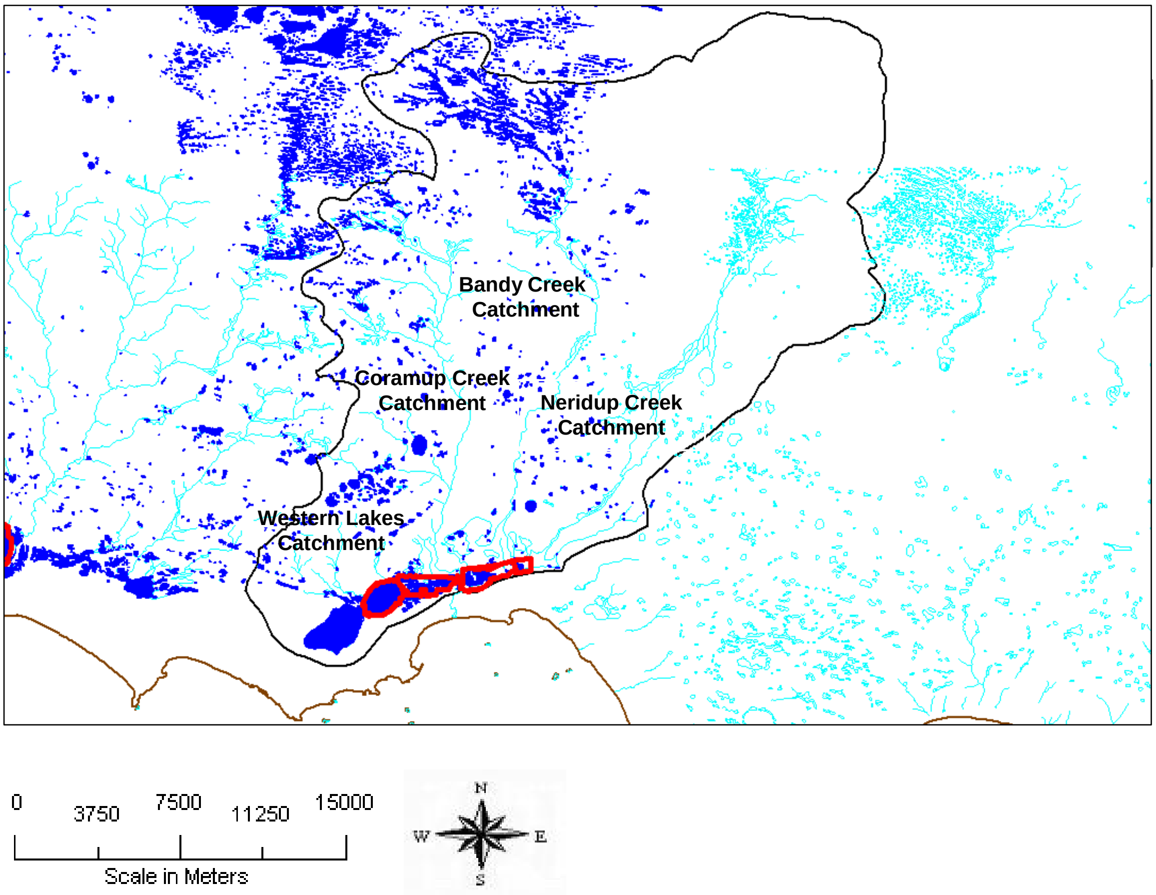


Figure 11. The Lake Warden Catchment, Esperance, Western Australia.

There are three main hydrogeological units within the Lake Warden Catchment, which form a two layer aquifer system: the Precambrian bedrock; the Tertiary sediments and the Quaternary sand and dunes. Short et al. (2000) describes this aquifer system:

1. Deep semi - confined/confined aquifer: comprising of weathered Precambrian basement rocks that are overlain by the Tertiary Werrilup aquifer. These two aquifers are hydraulically connected, with recharge occurring primarily on ridge zones into Precambrian basement rocks which then feed into the Tertiary Werrilup formation. The flow of groundwater in these systems is significant in the development of dryland salinity.
2. Shallow unconfined and perched aquifers: comprising of Tertiary Pallinup Siltstones and Quaternary sand sheets and dunes.

3.1.2.2 Surface and ground water interactions

The Coramup and Bandy Creek Catchments have an average annual flow of approximately 8,300 ML and 6,400 ML respectively (Pen, 1999). Coramup and Bandy Creek are perennial systems and deliver approximately 90% of the surface water that is received by the LWWS. However, the majority of the surface stream flow in these two systems is derived from groundwater baseflows, which maintains flows throughout the year (Marimuthu et al., 2005). During the summer period, the groundwater baseflows account for up to 70% of the flows within these creeks (Marimuthu et al., 2005). Conversely, Neridup Creek and components of the Western Lakes Catchment can be described as ephemeral, drying out periodically throughout the year (Marimuthu et al., 2005).

Up to 25% of the water balance of the LWWS is lost through evaporation and up to 15% is gained through precipitation (Marimuthu et al., submitted). The surface water inflow components account for up to 55% of the balance of the LWWS, which increases up to 80% during major rainfall events (Marimuthu et al., submitted). Groundwater input is effective at sustaining the lake levels within the LWWS, particularly during the summer period even though it is not a major water balance component (Marimuthu et al., submitted).

The wetlands of the LWWS act as a sink for the majority of the groundwater flow in the Lake Warden Catchment as the hydraulic head values are lower along the coastal plain. Therefore, groundwater flow is predominantly north to south although more localised flows (i.e. within the LWWS) travel northeast - southwest (Marimuthu et al., 2005). There is seasonal variability in the relationship between the wetlands of the LWWS and the local aquifers. In general, winter lake levels rise ahead of groundwater and recharge the surrounding aquifers (Marimuthu et al., submitted). Conversely, during summer, the lakes dry ahead of groundwater and the groundwater discharges into the lakes (Marimuthu et al., submitted).

The water bodies within the LWWS initially appear to be part of a single homogenous system as they form an organisation of wetlands interconnected by a series of channels, however, they show large variations in terms of isotopic composition and hydrochemistry (Marimuthu et al., 2005). The LWWS contains three distinct hydrological suites: the Western, Eastern and Central suite, which are distinguishable due to a lack of groundwater connection between them.

Eastern hydrological suite

The Eastern hydrological suite comprises of Ewans, Mullet and Station Lakes, which are generally lower than the surrounding groundwater table and are therefore predominantly groundwater fed (Marimuthu et al., 2005; Stevenson, 2007). However, the suite is also fed by surface water from

Bandy and Neridup Creeks (CALM, 2006). The surface water flow from Bandy and Neridup Creek converge east of Ewans Lake and travel east to west (from Ewans Lake into Mullet Lake and then into Station Lake via a braided channel network) with the outflow from one lake providing inflow for the next (CALM, 2006; Marimuthu et al., submitted). This interaction usually only occurs following high rainfall events (Marimuthu et al., submitted). The relationship between the wetlands and the creeks is dynamic and dependant on the flow within the Neridup and Bandy Creek Catchments. To the north of the Eastern hydrological suite is the large floodplain of the Neridup and Bandy Creek Catchments. During peak flow periods confluence of these catchments occurs and both systems contribute surface water flow to all wetlands within the Eastern hydrological suites to varying degrees.

Central hydrological suite

The Central hydrological suite comprises of Lake Wheatfield, Woody Lake, Windabout Lake and a few other unnamed smaller wetlands connected by a series of channels. Surface water from Coramup Creek enters this suite at Lake Wheatfield and the outflow from one lake provides the inflow for the next. Coramup Creek flows from east to west through Lake Wheatfield directly into Woody Lake via a well defined channel (CALM, 2006). Woody Lake then overflows into Windabout Lake, which in wetter years has overflowed into Lake Warden (CALM, 1999).

Lake Wheatfield can also overflow through culverts in Fisheries Road into Bandy Creek and then into the Southern Ocean (CALM, 2006).

The Central suite of wetlands are at similar elevations, generally higher than the surrounding groundwater levels and during winter and spring, they recharge groundwater (Marimuthu et al., 2005). Conversely, in summer, evapotranspiration lowers the water levels of the lakes in the Central suite below the surrounding groundwater levels and groundwater discharges into the lakes (Marimuthu et al., 2005).

Western hydrological suite

The Western hydrological suite comprises of Lake Warden and Pink Lake (not included in the Ramsar boundary). Lake Warden is fed by Melijinup Creek and the small ephemeral creeks, Monjinup and Buckeniup Creeks, and has no surface water connectivity with Pink Lake (CALM, 2006). Surface water flows and precipitation are strong determinants in the flux of water depth at Lake Warden (Marimuthu et al., submitted). Lake Warden receives a fairly constant volume of groundwater throughout the year and is described as a flowthrough lake (Marimuthu et al., 2005; Marimuthu et al., submitted). That is, Lake Warden is recharged by groundwater entering from the east and groundwater is recharged by Lake Warden on its western side.

Generally, the surface water gradient slopes toward Lake Warden from the Central hydrological suite and in wetter years has overflowed into Lake Warden. The surface water gradient can also reverse, when Coramup Creek flows into the Central hydrological suite are reduced. Thus Lake Warden can overflow into Windabout Lake, with surface water flow travelling west to east through Woody Lake and finally Windabout Lake.

The clearing of native vegetation for agriculture has altered the hydrological regime in the Lake Warden Catchment. The clearing of land for agriculture, along with encroaching urbanisation, has resulted in rising watertables and increased surface water runoff, directly impacting the wetlands within the Ramsar site (Halse & Massenbauer, 2005; Short, 2000). Hydrological modelling has indicated that if management of the catchment continues under the current trend, approximately 27% of the Lake Warden Catchment will be at risk from salinity by 2020, increasing to approximately 45% by 2050 (Short et al., 2000). More recent unseasonal episodic rainfall events such as those of 1999, 2000, 2007 and 2009 (see: Section 2.4 Climate), have exacerbated the effects of clearing and contributed to altered hydrological regimes within the Lake Warden Catchment (see: Section 5.0 Changes to Ecological Character).

Figure 12 and Figure 13 conceptualise the surface and groundwater interactions.

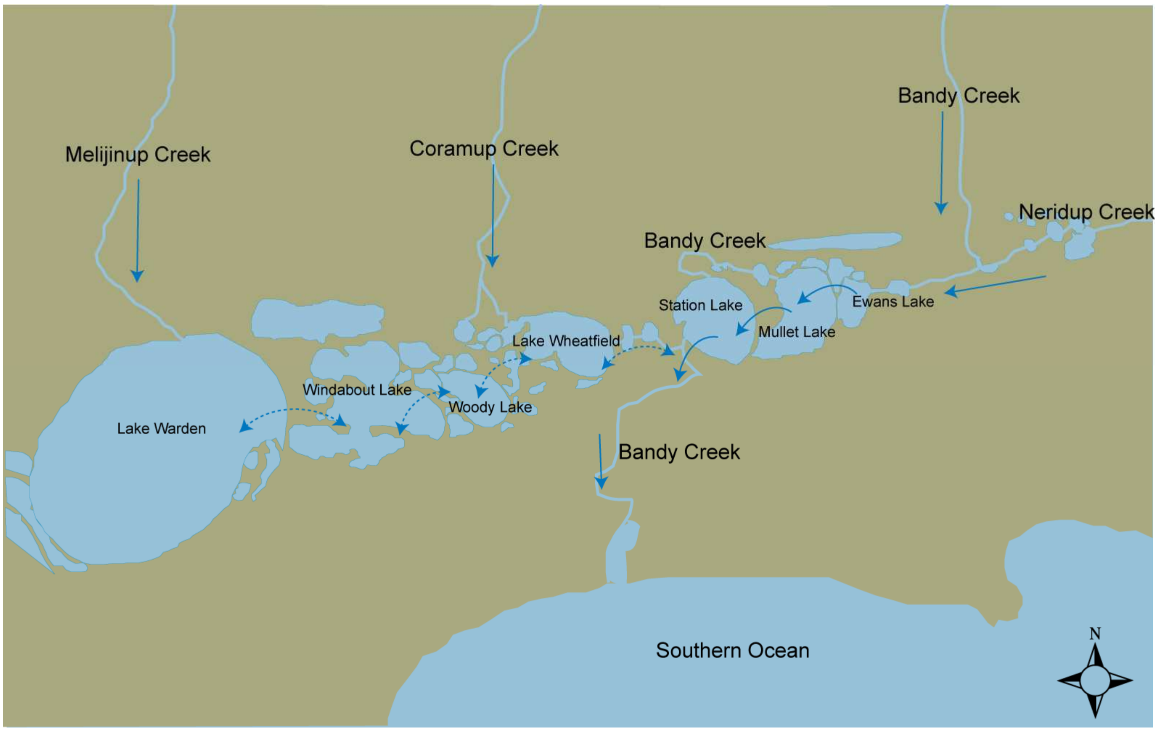


Figure 12. Conceptual surface water flows within the Lake Warden System Ramsar Site, Esperance, Western Australia.

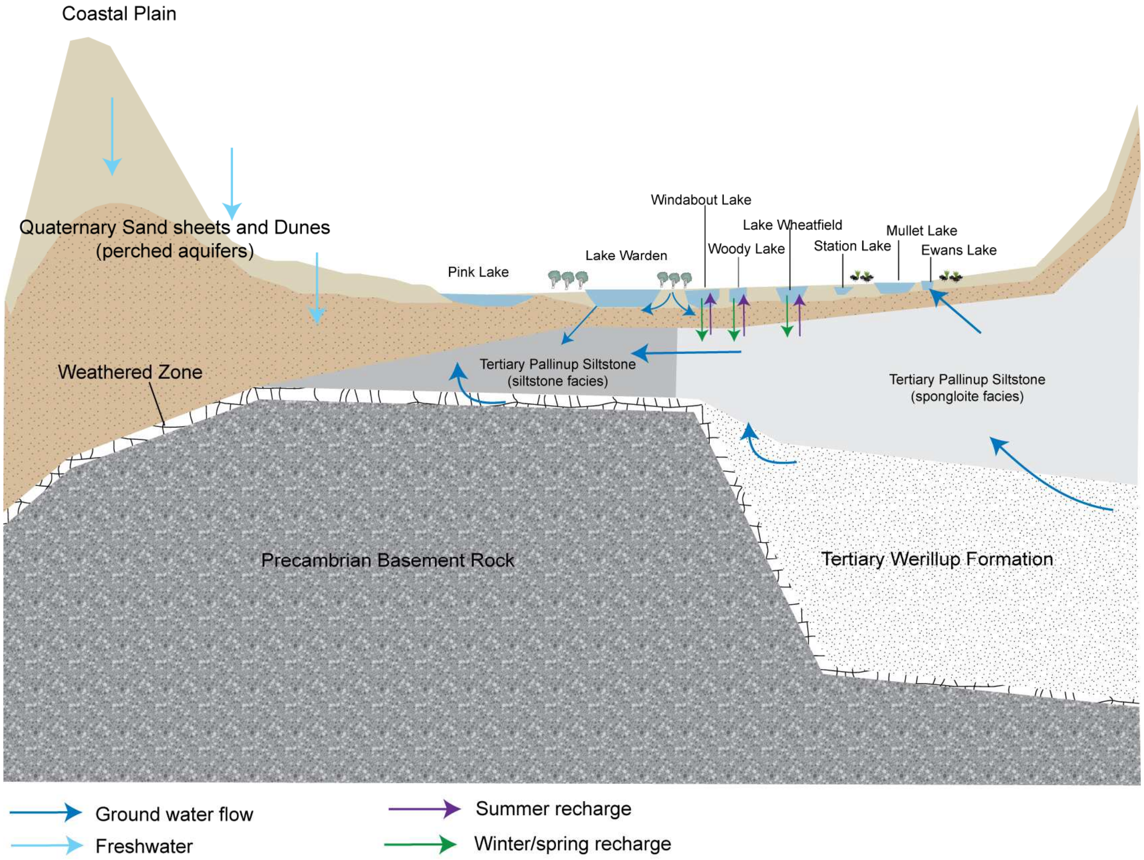


Figure 13. Conceptual groundwater model within the Lake Warden System Ramsar Site, Esperance, Western Australia (adapted from Marimuthu et al., 2005).

3.2.2.3 Hydrological regime of the major lakes within the Ramsar site

Water depth has been recorded since 1977 in selected wetlands (including the Lake Warden System Ramsar Site) of the south west of Western Australia by DEC, as part of the South West Wetland Monitoring Programme (SWWMP). Water depth has been recorded at various lakes within the Ramsar site from 1979 as part of the SWWMP (see: Lane, 2008). Initially, between 1979 and 1985 water depth was recorded every two months, then from the end of 1985 water depth was recorded biannually during September and November only (see: Lane, 2008). The SWWMP is still being undertaken at the time of writing. More recently, surveillance established under the Lake Warden Recovery Catchment Programme (LWRCP) began in 2002 and fortnightly depth records for the major lakes within the Ramsar site have been collected by DEC Esperance District Office (see: Department of Environment and Conservation, 2009b). Lane et al. (2004) applied statistical analysis to the data collected during September and November from 1979 - 2000 as part of the SWWMP.

The water levels within the wetlands of the Ramsar site are generally highest during the winter/spring period and are lowest during the summer/autumn period, with groundwater levels following the same pattern (Marimuthu et al., 2005). This trend is the typical pattern of water depth reflected in other wetlands of the south west of Western Australia (Halse & Jaensch, 1989). However, unseasonal episodic rainfall events have resulted in the highest water levels being recorded during summer months.

Eastern hydrological suite

The seasonal water depth of Station Lake has been recorded from 1980 to 1985 and then biannually (September and November) under the SWWMP (see: Lane, 2008). The water depth of Station Lake has also been recorded fortnightly since May 2002 along with Mullet Lake and Ewans Lake (since May 2003) under the LWRCP (see: Department of Environment and Conservation, 2009b).

Seasonal data for Station Lake indicates that prior to listing there were some distinct dry periods that occurred during the early to mid 80’s in the summer/autumn period (see: Lane, 2008). Post listing, drying has only been recorded during the summer/autumn period of 2005 and 2008 (see: Department of Environment and Conservation, 2009b). The highest recorded depth at Station Lake was in January 2007 at 1.73 m (see: Department of Environment and Conservation, 2009b) coinciding with the unseasonal episodic rainfall event resulting from ex-tropical cyclone “Isobel” (see: Section 2.4 Climate).

The September and November water depths for Station Lake have been used to illustrate long term trends (Figure 14). Between 1980 and 2008, the September and November water depths for Station Lake have remained relatively constant, mainly below 0.8 m, with a dry period shown in 1983 (Figure 14).

The mean (± standard deviation) water depth for September and November 1980 to 1989 (prior to listing) was 0.64 m (± 0.18) and 0.54 m (± 0.18) respectively (Figure 14). The mean (± standard deviation) water depth for September and November 1990 to 2008 (post listing) was 0.74 m (± 0.03) and 0.66 m (± 0.05) respectively (Figure 14). This indicates that post listing, the September and November mean water depths for Station Lake are slightly higher than prior to listing (approximately 10 - 20 cm) with less variability.

From 1980 to 2000 statistical analysis of the water depth trends (combined September and November records) of Station Lake indicate an annual rate of change of 0.011 m (Lane et al., 2004).

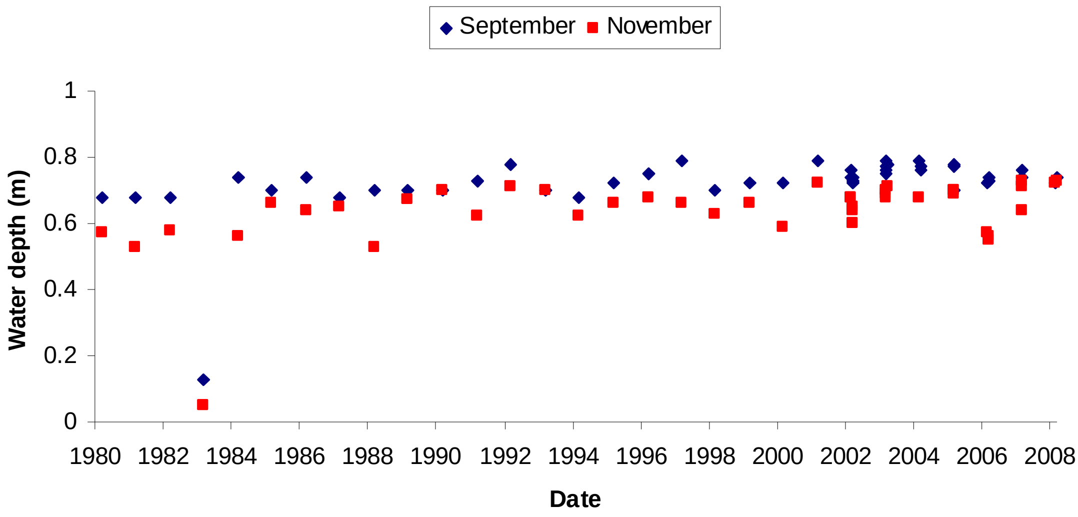


Figure 14. Biannual (September and November) water depths 1980 - 2008, for Station Lake, Lake Warden System Ramsar Site, Esperance, Western Australia (data from Department of Environment and Conservation, 2009b; Lane, 2008).

Post listing, the water depths for Ewans Lake have ranged between 0.61 m and 1.6 m, and the water depths for Mullet Lake have ranged between 0.48 m and 2.0 m (Figure 15). The highest water depths recorded for Ewans Lake and Mullet Lake also coincide with the unseasonal episodic rainfall event resulting from ex-tropical cyclone “Isobel” in January 2007 (see: Section 2.4 Climate).

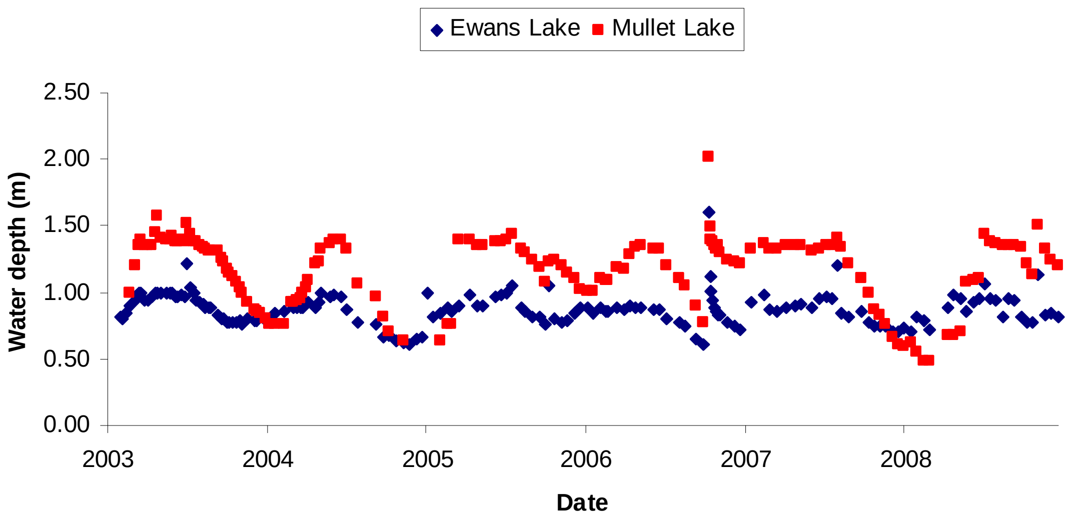


Figure 15. Water depths 2003 - 2009 for Ewans Lake and Mullet Lake, Lake Warden System Ramsar Site, Esperance, Western Australia (data from Department of Environment and Conservation, 2009b; Lane, 2008).

Central hydrological suite

The water depths of the wetlands within the Central hydrological suite have only been recorded post listing. Lake Wheatfield has been recorded as part of the SWWMP since 1999, mainly during September and November (see: Lane, 2008) and also part of the LWRCP since May 2002 (see: Department of Environment and Conservation, 2009b). Woody Lake and Windabout Lake water depths have also been recorded as part of the LWRCP, starting in May and June 2003 respectively (see: Department of Environment and Conservation, 2009b).

Lake Wheatfield depths have ranged from 0.75 m to 2.94 m over the period of 2000 to 2009 (Figure 16). Woody Lake and Windabout Lake depths have ranged from 1.02 m to 3.0 m and from 1.2 m to 2.66 m respectively (Figure 16). The highest water levels recorded for all three of these lakes occurred in January 2007 (Figure 16) and coincide with the unseasonal episodic rainfall event resulting from ex-tropical cyclone “Isobel” (see: Section 2.4 Climate).

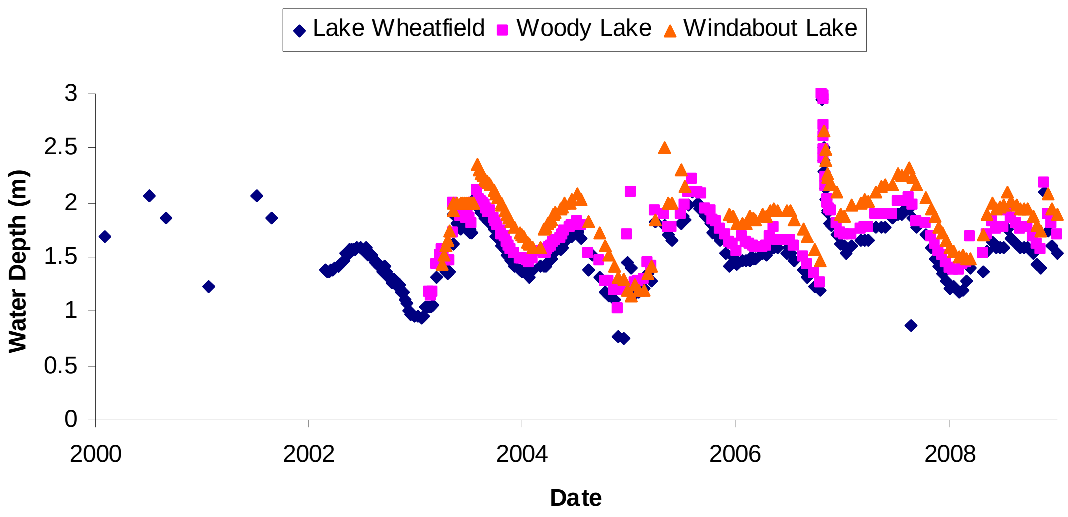


Figure 16. Water depths 2000 - 2009 for Lake Wheatfield, Woody Lake and Windabout, Lake Warden System Ramsar Site, Esperance, Western Australia (data from Department of Environment and Conservation, 2009b; Lane, 2008).

Western hydrological suite

The water depth of Lake Warden has been recorded since 1979 with seasonal recording of water depth ending in 1985 as part of the SWWMP (see: Lane, 2008). The water depth at Lake Warden is now recorded biannually (September and November) as part of the SWWMP and since June 2002 as part of the LWRCP (see: Department of Environment and Conservation, 2009b).

Seasonal water depth data indicates that from 1979 to 1984 (prior to listing) some dry periods were experienced at Lake Warden (see: Lane, 2008). Lake Warden now remains permanently inundated and does not dry (see: Department of Environment and Conservation, 2009b). The highest water depth was recorded in September 1989 at 2.9 m (Figure 17).

The September and November water depths for Lake Warden have been used to illustrate long term trends (Figure 17). The mean (± standard deviation) water depth for September and November 1979 to 1989 (prior to listing) was 1.09 m (± 0.72) and 0.98 m (± 0.75) respectively (Figure 17). The mean (± standard deviation) water depth for September and November 1990 to 2008 (post listing) was 2.02 m (± 0.52) and 2.04 m (± 0.57) respectively (Figure 17). This indicates that post listing, the September and November mean water depths at Lake Warden are less variable and have approximately doubled.

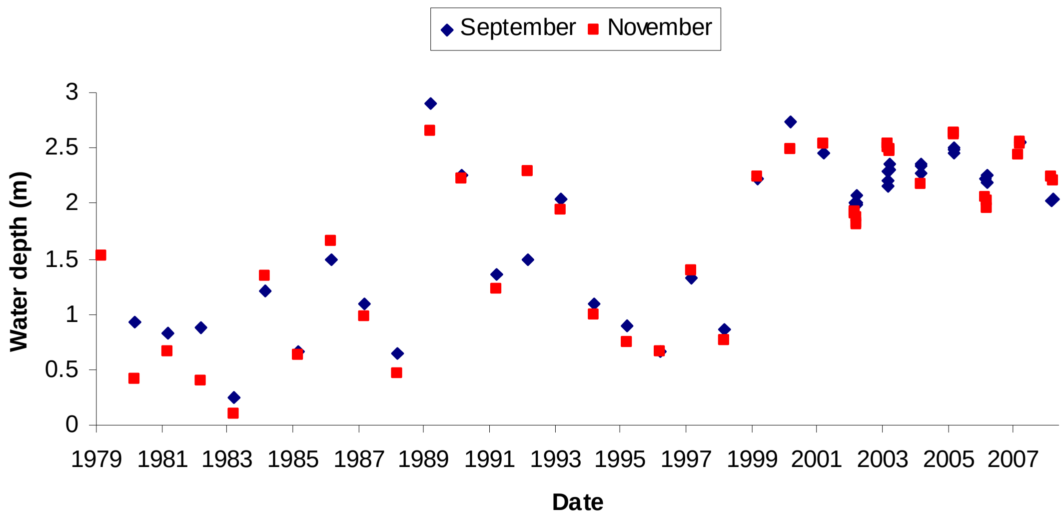


Figure 17**.** Biannual (September and November) water depths 1979 - 2008, for Lake Warden, Lake Warden System Ramsar Site, Esperance, Western Australia (data from Department of Environment and Conservation, 2009b; Lane, 2008).

Statistical analysis from 1977 - 2000 (September and November records) indicates a "highly significant" ($p<0.01$) increase in water levels at Lake Warden with no corresponding significant trend in annual rainfall over this period (Lane et al., 2004). The rate of change from 1977 - 2000 was calculated at 0.063 m per year (Lane et al., 2004). Massenbauer & Robertson (2005) suggest that the water depth of Lake Warden has increased by approximately 1 m since 1979. This increase in water depth has been attributed to catchment clearing and unseasonal episodic rainfall events resulting in flooding, namely during 1999, 2000, 2007 and 2009.

The waterbird and riparian values within the LWWS have been impacted by the altered hydrological regimes, resulting in increased extent and duration of inundation and loss of shore zone area (Massenbauer & Robertson, 2005; Massenbauer & Vogwill, 2007). Engineering intervention is currently underway to reduce the water levels of the Central hydrological suite via Lake Wheatfield and is also proposed for Lake Warden (see: Massenbauer & Vogwill, 2007; Maunsell/AECOM, 2008). This change in ecological character is discussed further in section 5.0 Changes in Ecological Character.

The current and optimum exposed shore zone area resulting from the extent of inundation have been calculated for Lake Warden using geographical information systems (GIS), bathymetry volume calculations, and historic and current lake depth data (see: Massenbauer, 2008; Robertson & Massenbauer, 2005). The conceptual optimum minimum and maximum exposed shore zone area for Lake Warden is 50 ha - 250 ha and is based on historical ranges (Massenbauer, 2008; Robertson & Massenbauer, 2005). During the current hydrological regime the minimum and maximum exposed shore zone area at Lake Warden has been reduced to 3 ha - 55 ha (Massenbauer, 2008; Robertson & Massenbauer, 2005). Thus the optimum minimum and maximum shore zone areas have been reduced by 47 ha and 195 ha respectively. Losses in exposed shore zone area have also been experienced in the lakes of the Central hydrological suite (Massenbauer, 2008; Robertson & Massenbauer, 2005). This change in ecological character is discussed further in section 5.0 Changes in Ecological Character.

3.2.2.4 Catchment trends

Prior to clearing of the Lake Warden Catchment, groundwater pressures were lower and there was an absence of shallow aquifers (Short, 2000; Short et al., 2000). Since clearing, groundwater levels within the Lake Warden Catchment have been rising rapidly, between 0.1 m and 0.3 m per year and in some cases up to 0.5 m per year (Short et al., 2000). However, some groundwater areas within the Lake Warden Catchment appear to be stagnant with little increase; these groundwater aquifers are close to full capacity and are unable to store any significant amounts of additional water (John Simons, Regional Hydrologist DAFWA, pers. comm., 2008).

The hydrograph from observation bores installed around the Ramsar site in 2001 to monitor groundwater influences, indicates a seasonal trend, with depth to groundwater increasing in the summer months and decreasing in the winter months (Figure 18).The groundwater data indicates that the majority of the groundwater surrounding the Ramsar site is less than 3.0 m from the surface (Figure 18). The groundwater levels recorded from these observation bores suggest that some of the aquifers surrounding the Ramsar site have reached full capacity (John Simons, Regional

Hydrologist DAFWA, pers. comm., 2008). Although seasonal fluctuations are apparent, the increases in depth to groundwater during summer months is most likely due to the effects of evapo-transpiration and evaporation (John Simons, Regional Hydrologist DAFWA, pers. comm., 2008).

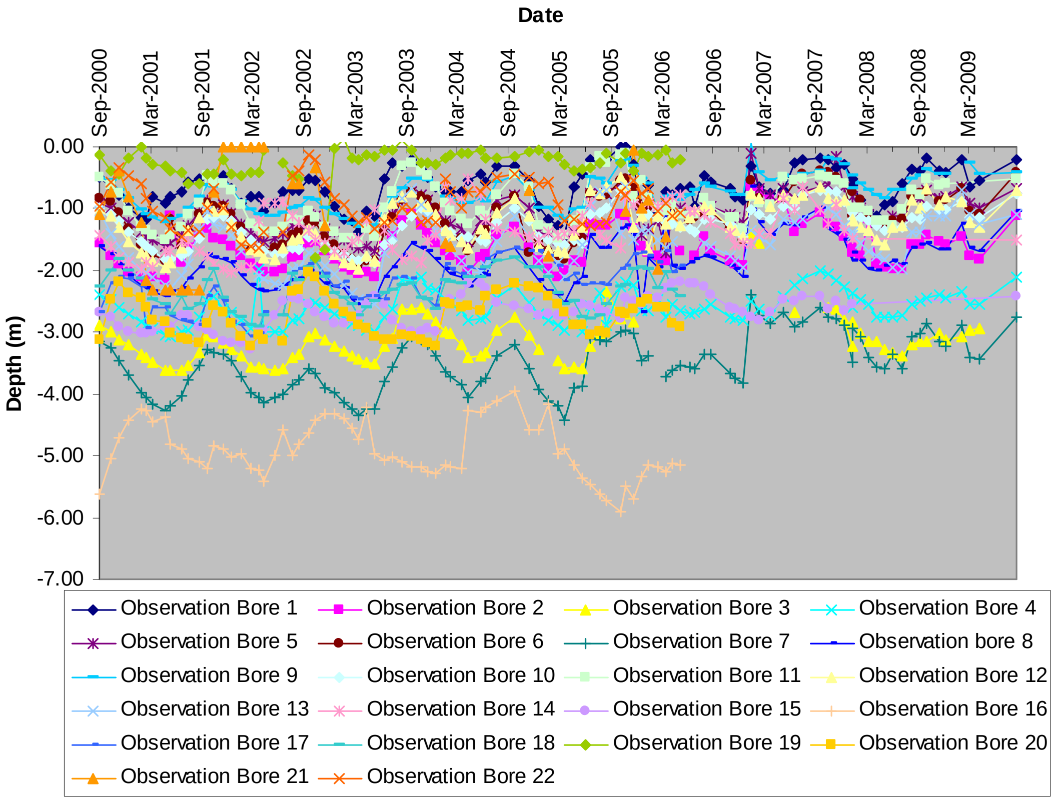


Figure 18. Depth to groundwater records September 2000 to April 2009 for observation bores located at the Lake Warden System Ramsar Site, Esperance, Western Australia (data from Department of Environment and Conservation, 2009b).

The consistently high groundwater levels reflect the current altered hydrological regime experienced by the Lake Warden System Ramsar Site and the surrounding catchments. As a result, soil pore spaces are saturated and waterlogging occurs, which increases surface water runoff and causes anaerobic conditions for the roots of vegetation. High groundwater levels and constant waterlogging also increases the incidence of secondary salinisation, which is a threatening processes at the site (Comer et al., 2001).

3.1.3 WATER QUALITY

The measurement of water quality involves sampling a suite of physico-chemical parameters such as pH, salinity, metal and nutrient concentrations, which aids in understanding the physical and chemical processes that occur in wetlands.

The SWWMP has recorded various water quality parameters for Station Lake, Lake Wheatfield and Lake Warden. The water quality parameters that have been recorded include, pH, salinity, nitrogen and phosphorus concentrations, and have been recorded in conjunction with water depth (see: Lane, 2008). As with water depth, the DEC Esperance District Office as part of LWRCP, began recording conductivity as a measure of salinity, and pH on a fortnightly basis at the major lakes within the Ramsar site (see: Department of Environment and Conservation, 2009b). A large range of physico-chemical data has also been recorded for Lake Wheatfield and Mullet Lake by DEC since 1997 under the Salinity Action Plan (see: Cale, 2008; Cale et al., 2004). Additional physico-chemical data from DoW is available for Station Lake, Lake Wheatfield and Lake Warden from 2006 to 2008 (May, 2008).

The spring data (September and November records) from the SWWMP is the most comprehensive data for illustrating trends (pre and post listing) in the salinity and nutrient concentrations (see: Lane, 2008). This long term data is only available for Station Lake and Lake Warden. The physico-chemical data for all other major lakes within the Ramsar site is only available after the time of listing.

3.1.3.1 Physico-chemical properties of the major lakes within the Ramsar site

For continuity, the lakes within the Ramsar site will be described (physico-chemically) as per the hydrological suite within which they fall.

3.1.3.1.1 Salinity concentrations

The salinity of a wetland can be influenced by geology, precipitation and evaporation. Salinity has a major affect on aquatic invertebrate species composition, with increasing salinities reducing aquatic invertebrate species richness (Blinn, 2004; Pinder et al., 2004). However, some saline wetlands are also amongst the most productive wetlands for plants, waterbirds, fish and invertebrates.

The salinity concentration of the major lakes within the Ramsar site has ranged from fresh to hypersaline. As with many other wetlands, the trend in salinity concentration within the lakes is relative to the water volume (i.e. lower water volume = higher salinity concentrations). This occurs usually during high flow events, with the strength of this relationship being variable between the lakes. Secondary salinisation caused by landscape clearing has also occurred within the surrounding catchments and also has the ability to affect the salinity concentrations of the wetlands within the Ramsar site (CALM, 1999; Massenbauer, 2007a).

Salinity classes differ in the literature, therefore for the purpose of this ECD, salinity concentrations have been grouped under the following:

- Freshwater ≤ 2 parts per thousand (ppt)
- Hyposaline/brackish > 2 ppt - 5 ppt
- Saline > 5 ppt - 35 ppt
- Hypersaline > 35 ppt

Eastern hydrological suite

Seasonal salinity data indicates that the salinity concentration at Station Lake has ranged from 5.7 ppt to a maximum of 297 ppt (see: Department of Environment and Conservation, 2009b; Lane, 2008). A strong inverse relationship between water depth and salinity has been noted at Station Lake with a dramatic increase in salinity observed as water levels approach zero metres (Lane et al., 2004). Figure 19 demonstrates this relationship where the maximum recorded salinity concentration of 297 ppt in November 1983 coincided with the lowest water depths recorded for Station Lake (see: Section 3.1.2 Hydrology).

Generally, the salinity concentration at Station Lake at the time of listing was saline and has remained relatively stable during September and November from 1980 to 2007 (Figure 19). Excluding the maximum outlier (297 ppt in 1983) the mean (± standard deviation) salinity concentrations for September and November from 1980 to 2007 were 13.07 (± 6.5) ppt and 17.05 (± 4.5) ppt respectively (see: Lane, 2008).

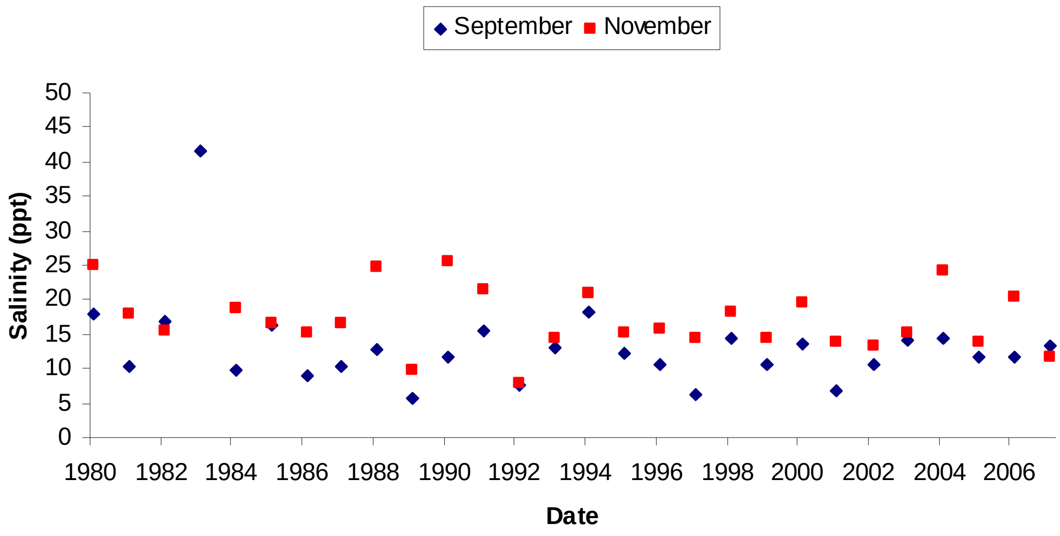


Figure 19. Biannual (September and November) salinity concentrations 1980 - 2008, for Station Lake, Lake Warden System Ramsar Site, Esperance, Western Australia (data from Lane, 2008).

The salinity of Ewans Lake from 2003 to 2009 (post listing) has ranged from approximately 5.3 ppt to 20.84 ppt indicating that it is saline (Figure 20). The mean (± standard deviation) salinity concentrations for Ewans Lake from 2003 to 2009 was 11.89 (± 3.06) ppt. The salinity concentrations for Mullet Lake over the same period have been more variable (± 12.08 ppt standard deviation) with a distinct increase in salinity concentration during summer and autumn months (lower water levels) that have ranged from saline to hypersaline (Figure 20). However, the mean salinity concentration (18.83 ppt) indicates that it is generally saline (see: Department of Environment and Conservation, 2009b).

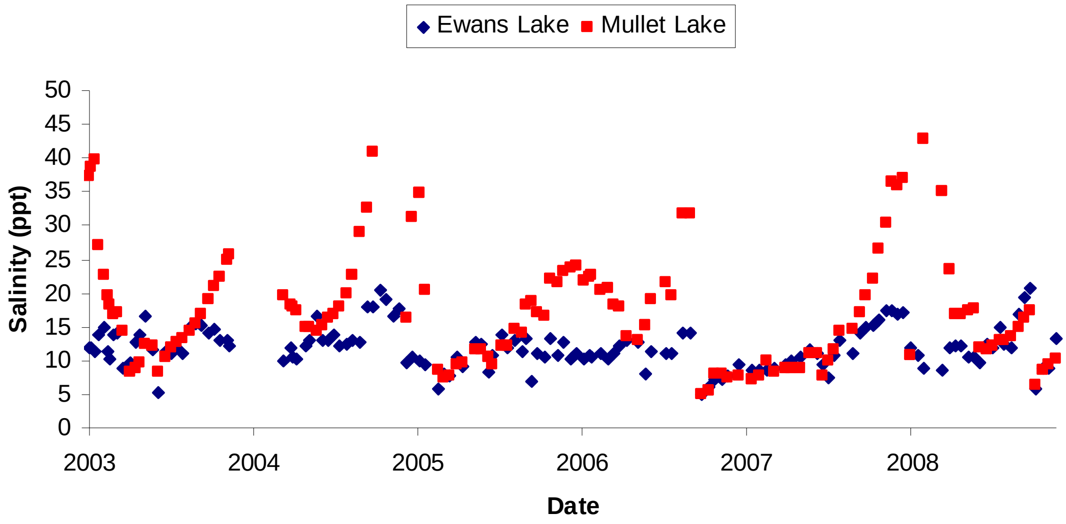


Figure 20. Salinity concentrations 2003 - 2009 for Ewans Lake and Mullet Lake, Lake Warden System Ramsar Site, Esperance, Western Australia (data from Department of Environment and Conservation, 2009b).

Central hydrological suite

The salinity concentrations recorded post listing for Lake Wheatfield, Woody Lake and Windabout Lake indicate that they are saline (Figure 21). Post listing, the mean (± standard deviation) salinity concentrations for Lake Wheatfield, Woody Lake and Windabout Lake were 6.86 (± 2.2) ppt, 7.37 (± 2.69) ppt and 10.82 (± 3.86) ppt respectively (see: Cale, 2008; Department of Environment and Conservation, 2009b; Lane, 2008).

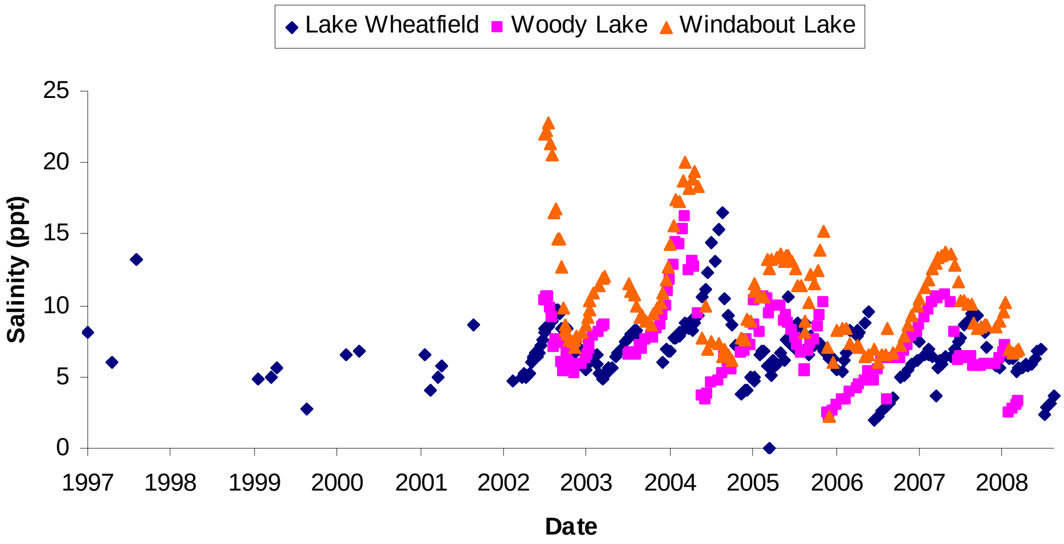


Figure 21. Salinity concentrations for Lake Wheatfield (1997 - 2009), Woody Lake and Mullet Lake, (2003 - 2009) Lake Warden System Ramsar Site, Esperance, Western Australia (data from Cale, 2008; Department of Environment and Conservation, 2009b; Lane, 2008).

Western hydrological suite

Seasonal salinity data indicates that the salinity concentration at Lake Warden has ranged from 15 ppt to a maximum of 369 ppt (see: Department of Environment and Conservation, 2009b; Lane, 2008). At the time of listing, the salinity for Lake Warden ranged from saline to hypersaline (Figure 22).

Prior to listing, the mean (± standard deviation) salinity concentrations for September and November were 79.39 (± 68.27) ppt and 72.89 (± 52.73) ppt respectively (see: Lane, 2008). Therefore, prior to listing average salinity concentrations were hypersaline and highly variable. Post listing salinity concentrations for September and November were less variable, and although lower, were still hypersaline. Post listing, the mean (± standard deviation) salinity concentrations for September and November were 42.75 (± 17.5) ppt and 54.60 (± 27.30) ppt respectively (see: Lane, 2008).

Lane et al. (2004) explains that the salinity concentration of Lake Warden has been variable (between saline and hypersaline) both intra-annually and inter-annually but no statistically significant changes in salinity between 1979 and 2000 were apparent. As Lake Warden's increase in water depth has been "highly significant" ($p<0.01$) over the same period, the salinity concentrations may have been diluted. It is anticipated that same-depth comparison of salinities may yield different results (Lane et al., 2004).

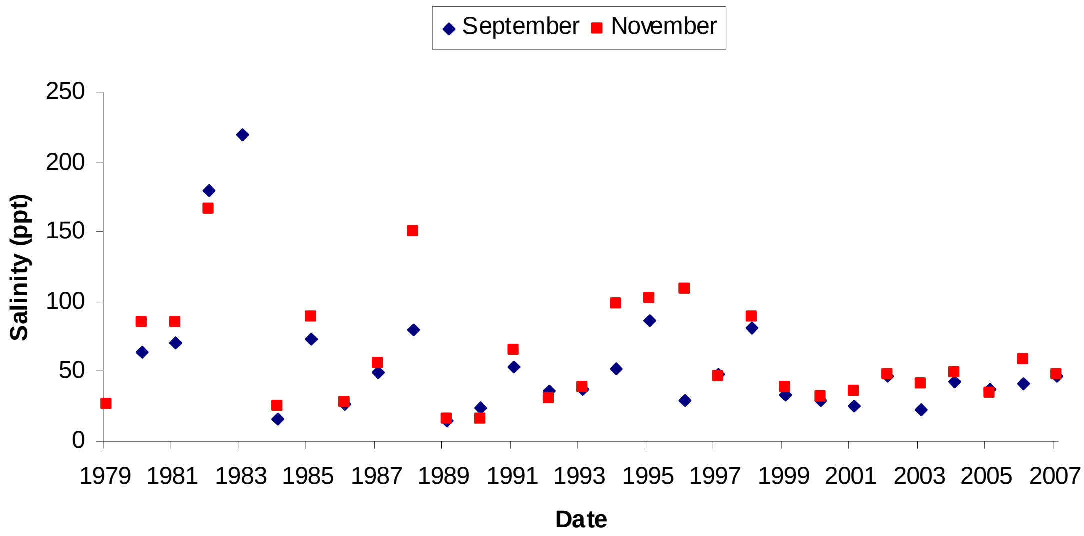


Figure 22. Biannual (September and November) salinity concentrations 1979 - 2007, for Lake Warden, Lake Warden System Ramsar Site, Esperance, Western Australia (data from Lane, 2008).

3.1.3.1.2 pH

Recording pH is important, apart from the information it provides in terms of alkalinity or acidity, pH fluctuations can also affect metal toxicity. For example, low pH or acidic conditions increase the solubility of metals which can increase their concentrations. Metals such as aluminium and iron have recognised negative impacts on fish resulting in kills (Sammut et al., 1995; Stephens & Ingram, 2006). Acidic conditions also provide a poor environment for vegetation and generally only a few fauna species such as mosquitoes can survive acidic water conditions. The pH conditions therefore have a strong influence on the composition of biota and any changes in pH could impact food webs.

The pH levels recorded at the major lakes within the Ramsar site from 1979 to 2009 indicate that they have been generally alkaline (i.e. pH > 7). A summary of the pH ranges within the Ramsar site is as follows:

Eastern hydrological suite

Station Lake 6.9 - 10.1

Ewans Lake and Mullet Lake 6.9 - 9.5

Central hydrological suite

Lake Wheatfield 6.7 - 9.6

Woody Lake 6.5 - 9.6

Windabout Lake 7.0 - 10.7

Western hydrological suite

Lake Warden 6.4 - 10.0

(data from Cale, 2008; Department of Environment and Conservation, 2009b; Lane, 2008).

3.1.3.1.3 Nutrient concentrations

The macronutrients nitrogen and phosphorus are often considered to be “limiting nutrients”, as excessive amounts of these nutrients (i.e. eutrophication) can cause a dramatic increase in algal growth within a wetland (Boulton & Brock, 1999). Conversely, a wetland that is oligotrophic or nutrient poor is less productive as it contains little nutrients to sustain an abundance of plant and animal life. Nutrient sources can be both natural (e.g. internal cycling of nutrients within an ecosystem) and artificial (usually anthropogenic sources e.g. fertilisers). Both natural and artificial sources have the potential to cause eutrophication.

The presence of algae, or in particular chlorophyll *a* concentrations, within the water are used as a surrogate indicator for nutrient pollution (ANZECC and ARMCANZ, 2000b). Excessive algal growth and subsequent death can reduce dissolved oxygen levels, increase turbidity and therefore affect the water quality. This causes distress to other biota, with invertebrates, fish and waterbirds impacted by low oxygen concentrations and the toxic affects of blooms or certain algal species (Balla, 1994). Algal blooms have occurred within the Ramsar site, with eutrophication caused by agricultural fertilisers considered a major threat (Australian Nature Conservation Agency, 1996; CALM, 1999, 2006). Algae species associated with eutrophication have been recorded at Lake Warden (Handley, 1991). The algal blooms have been associated with agricultural fertilisers applied on the surrounding catchments, however, waterbird populations could also be a contributing factor in eutrophication, as waterbird excrement has been found to promote eutrophication of water bodies (Mukherjee & Borad, 2001). Waterbird excrement could be a synergist to the diffuse nutrient input from the catchments surrounding the Ramsar site (Figure 23).

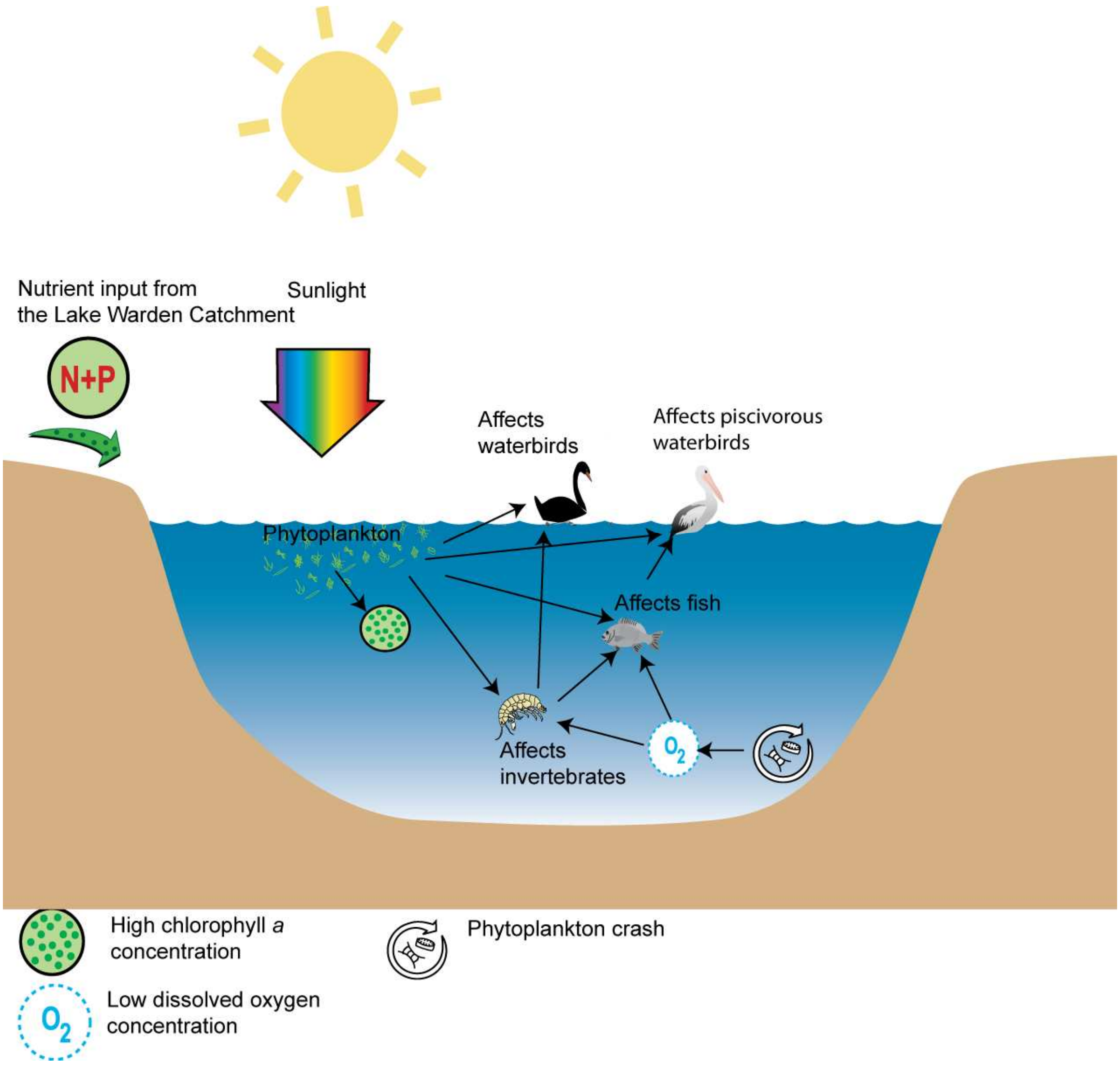


Figure 23. Conceptual model of the potential effect of nutrient enrichment combined with waterbird excrement at the Lake Warden System Ramsar Site, Esperance, Western Australia.

The concentrations of total phosphorus (TP), total nitrogen (TN), soluble reactive phosphorus (SRP) and total soluble nitrogen (TSN) have been recorded for Station Lake (from the Eastern hydrological suite), Lake Wheatfield (from the Central hydrological suite) and Lake Warden (from the Western hydrological suite). The TP and TN concentrations have been compared against ANZECC and ARMCANZ (2000b) guideline trigger values for wetlands of the south west of Western Australia. ANZECC and ARMCANZ (2000b) guideline trigger values are derived from freshwater ecosystems and therefore in this ECD they are used only as a general guide for comparison purposes.

The TP concentrations for Station Lake have been consistently below the ANZECC and ARMCANZ (2000b) guideline trigger values and the concentrations of Lake Wheatfield and Lake Warden (Figure 24). The concentrations for TP at Station Lake have ranged from 0.005 mg/L to 0.05 mg/L (Figure 24). The highest recorded TP concentration was at Lake Wheatfield in September 2002 with 0.24 mg/L (Figure 24). The majority of the TP concentrations at Lake Warden have been between 0.005 mg/L and 0.09 mg/L (Figure 24).

The TN concentrations for Station Lake have been mostly below the ANZECC and ARMCANZ (2000b) trigger values, ranging from 0.59 mg/L to 4.5 mg/L (Figure 25). The highest TN concentrations have been recorded at Lake Warden, all above the ANZECC and ARMCANZ (2000b) guideline trigger values, ranging from 2.6 mg/L to 8.2 mg/L (Figure 25). The TN concentrations for Lake Wheatfield have been mostly above the ANZECC and ARMCANZ (2000b) guideline trigger values, ranging from 0.56 mg/L to 3.4 mg/L (Figure 25).

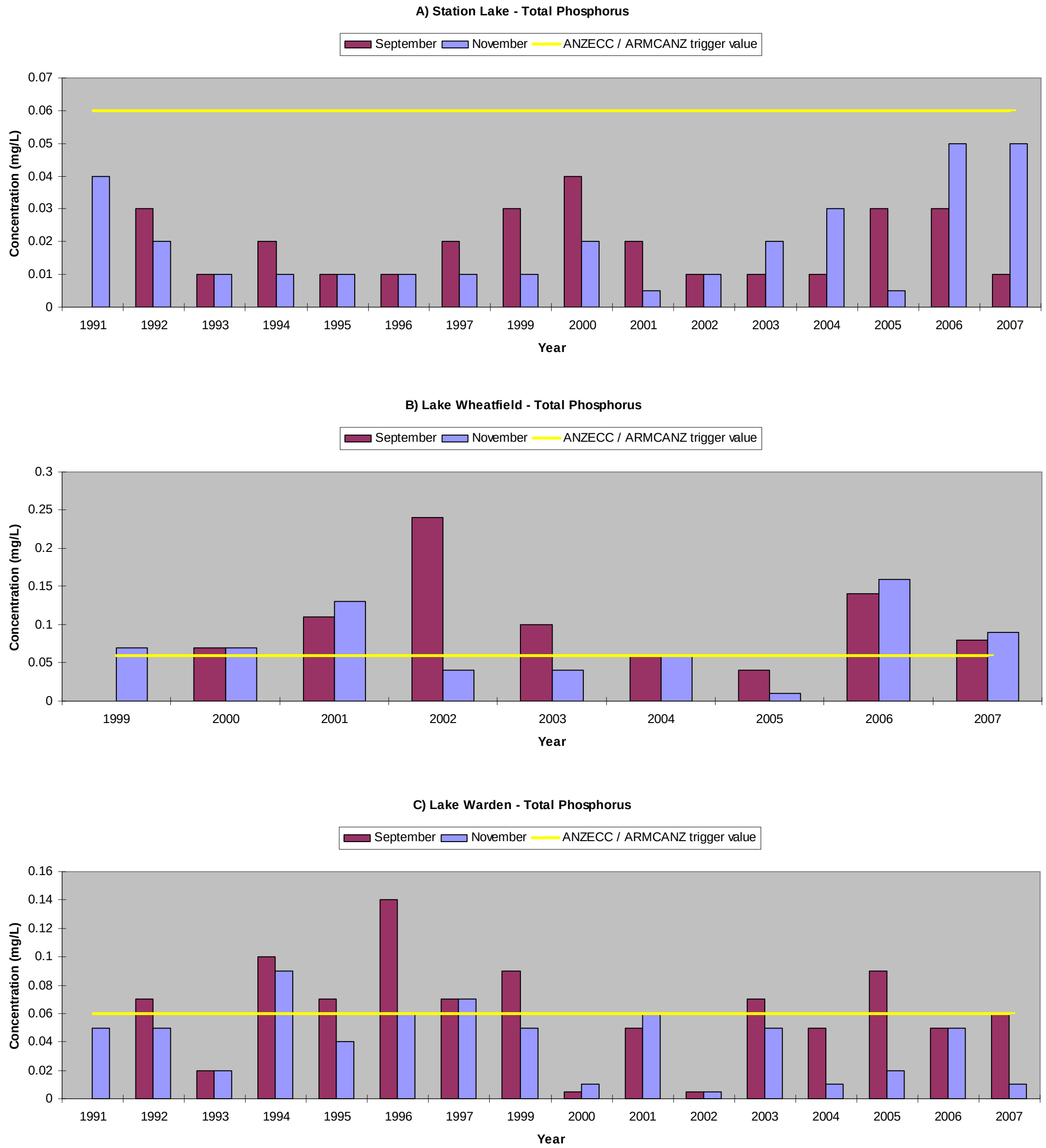


Figure 24. Total phosphorus concentrations (September and November records) together with ANZECC and ARMCANZ trigger values for A) Station Lake 1991 - 2007, B) Lake Wheatfield 1999 - 2007 and C) Lake Warden Lake 1991 - 2007 of the Lake Warden System Ramsar Site, Esperance, Western Australia (data from Lane, 2008). Note: Zero value indicates no record was taken.

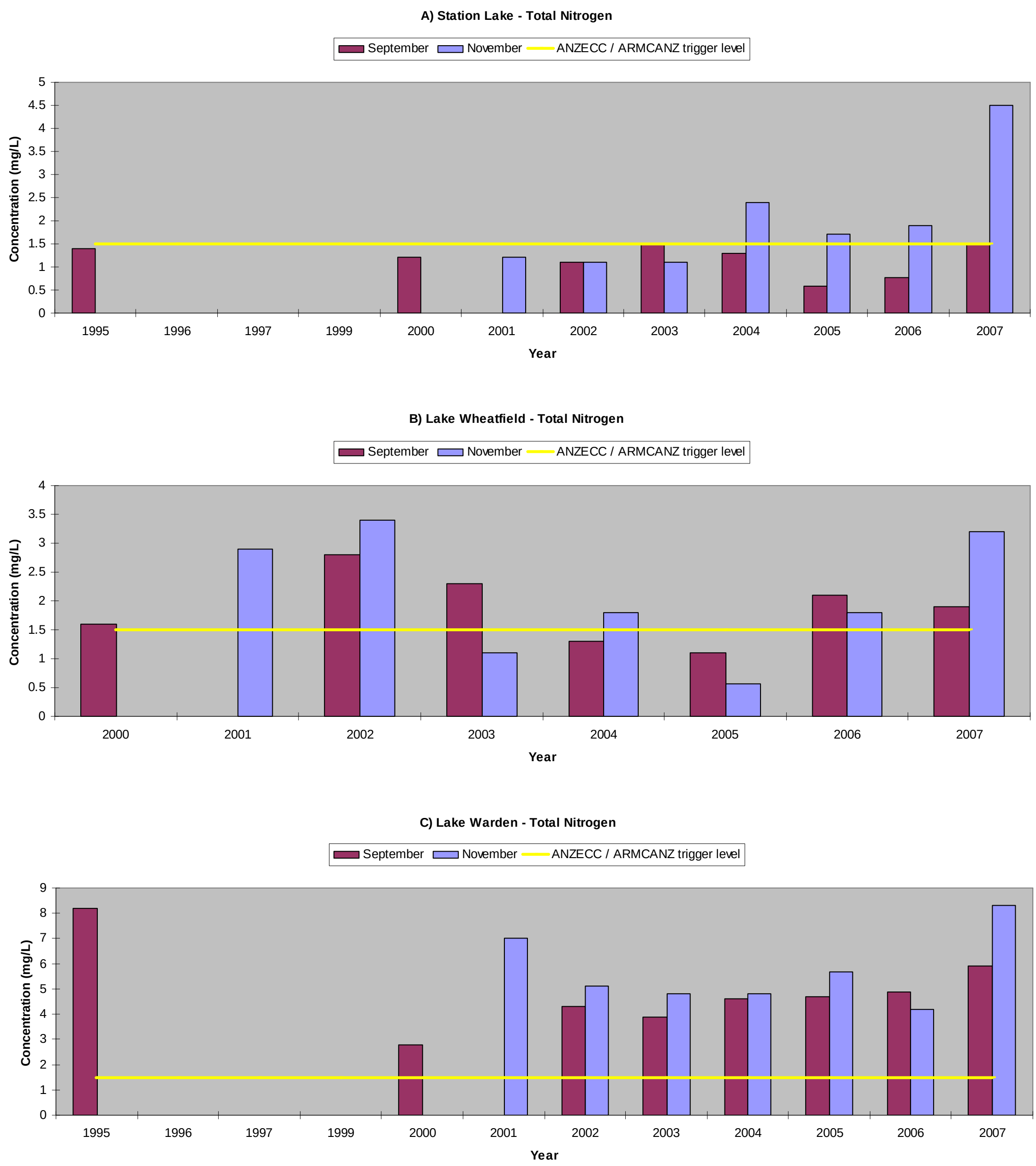


Figure 25. Total nitrogen concentrations (September and November records) together with ANZECC and ARMCANZ trigger values for A) Station Lake 1995 - 2007, B) Lake Wheatfield 2000 - 2007 and C) Lake Warden Lake 1995 - 2007 of the Lake Warden System Ramsar Site, Esperance, Western Australia (data from Lane, 2008). Note: Zero value indicates no record was taken.

There are no ANZECC and ARMCANZ guideline trigger values for SRP or TSN for wetlands in the south west of Western Australia. Recording SRP and TSN concentrations gives an indication of the bioavailability of these nutrients. The SRP concentrations have been similar for Station Lake, Lake

Wheatfield and Lake Warden mainly ranging from 0.005 mg/L - 0.07 mg/L, with the exception of the outlier at Station Lake in September 1991 at 0.16 mg/L (Figure 26). With longer term SRP concentrations for Station Lake and Lake Warden there is a notable reduction in the concentration of SRP between 2000 and 2007 for both of these lakes (Figure 26).

The TSN concentration for Station Lake and Lake Wheatfield have been similar, ranging from 0.48 mg/L to 4.5 mg/L and 0.56 mg/L to 3.4 mg/L respectively (Figure 27). The TSN concentrations have been the highest at Lake Warden, ranging from 0.93 mg/L to 7.6 mg/L (Figure 27).

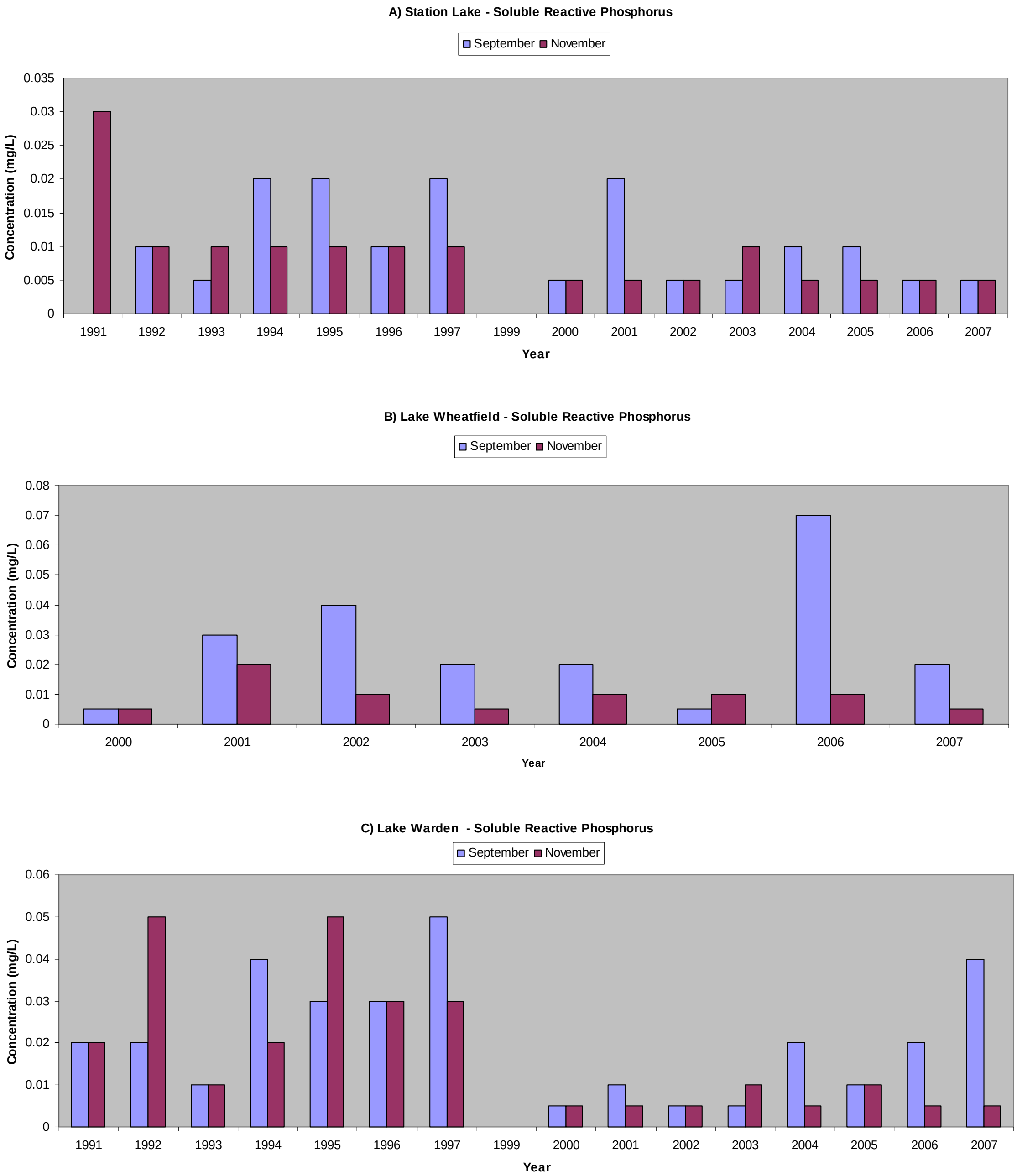


Figure 26. Soluble reactive phosphorus concentrations (September and November records) for A) Station Lake 1991 - 2007, B) Lake Wheatfield 2000 - 2007 and C) Lake Warden Lake 1991 - 2007 of the Lake Warden System Ramsar Site, Esperance, Western Australia (data from Lane, 2008). Note: Zero value indicates no record was taken.

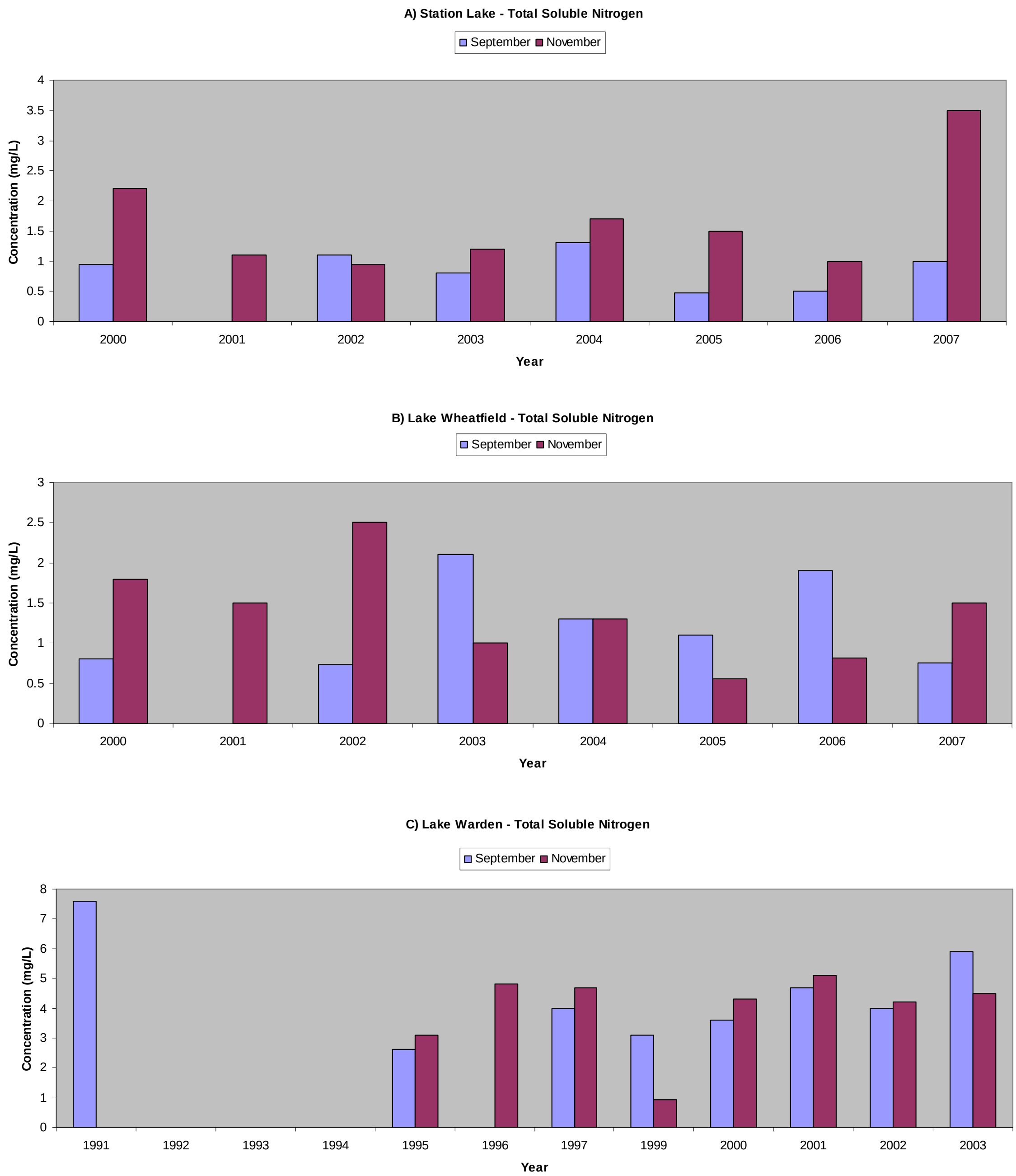


Figure 27. Total soluble nitrogen concentrations (September and November records) for A) Station Lake 2000 - 2007, B) Lake Wheatfield 2000 - 2007 and C) Lake Warden Lake 1991 - 2007 of the Lake Warden System Ramsar Site, Esperance, Western Australia (data from Lane, 2008). Note: Zero value indicates no record was taken.

In comparison to the ANZECC and ARMCANZ (2000b) guideline trigger values, nutrient concentrations recorded at some of the lakes within the Ramsar site appear elevated. However, these are guidelines only and the values recorded to date may reflect the Ramsar site's natural variability, particularly as core samples from Lake Warden, Lake Wheatfield and Station Lake suggest eutrophication began naturally approximately 600 years ago (Wilson, 2004). Nutrient concentrations only reflect the capacity of the wetland to increase plant biomass, with temperature, light and the ratio of nutrients also being limiting factors. The apparent elevated levels of nutrients recorded at the Ramsar site are only a problem if they adversely affect the wetland, for example in the regular occurrence of algal blooms. Nutrient loads, chlorophyll *a* and the frequency of algal blooms are additional measurements that are required to ascertain if there is a nutrient problem within the Ramsar site.

3.1.3.2 Catchment surface and groundwater physico-chemical properties

3.1.3.2.1 Salinity concentrations

The salinity concentrations of Bandy Creek and Coramup Creek generally range from brackish to saline (Pen, 1999). Salinity concentrations generally decrease down the catchment toward the coastal plain. The same pattern is observed in the groundwater, as salinity concentrations increase further inland, with the freshest groundwater found within the coastal plain. The salinity of the groundwater also affects the salinity levels within the lakes (Marimuthu et al., submitted). Observation bores installed in 2001 indicate that the groundwater in the vicinity of the Ramsar site ranges from fresh to saline (Department of Environment and Conservation, 2009b). To a large extent, the groundwater in the Tertiary palaeochannels in the Esperance region often contains hypersaline water (Steve Appleyard, Hydrogeologist, DEC, pers. comm., 2008). To the west of the Esperance Townsite toward the coast, a freshwater aquifer (salinity concentration <1 ppt) supplies the town with its freshwater supply (CALM, 1999).

3.1.3.2.2 pH

The pH of the water entering the Ramsar site from Coramup and Bandy Creeks is alkaline (>7) with recent average pH records for both creeks at approximately 8.1 (May, 2008). Data from observation bores at the Ramsar site, indicates that the groundwater in the vicinity of the site has pH ranging from 5.4 to 8.6 (Figure 28). The pH of the wetlands within the Ramsar site is generally alkaline (see: Section 3.1.3.1 Physico-chemical properties of the major lakes within the Ramsar site) and the available data suggests that the Ramsar site has not been affected by acidity. The wetlands within the Ramsar site have considerable buffering and acid neutralising capacity (Maunsell/AECOM, 2008), which reduces the threat of surface and groundwater acidity. Surface and groundwater acidity is a threat in other catchments in the Esperance region such as the Dalyup Catchment, which is the major hydrological input for the Lake Gore Ramsar Site (Department of Environment and Conservation, 2009a). The possible source of this acidity is from Tertiary palaeochannels which are often acidic and with rising groundwater tables it is possible that this acidic groundwater is discharging to surface drainages (Department of Environment and Conservation, 2009a).

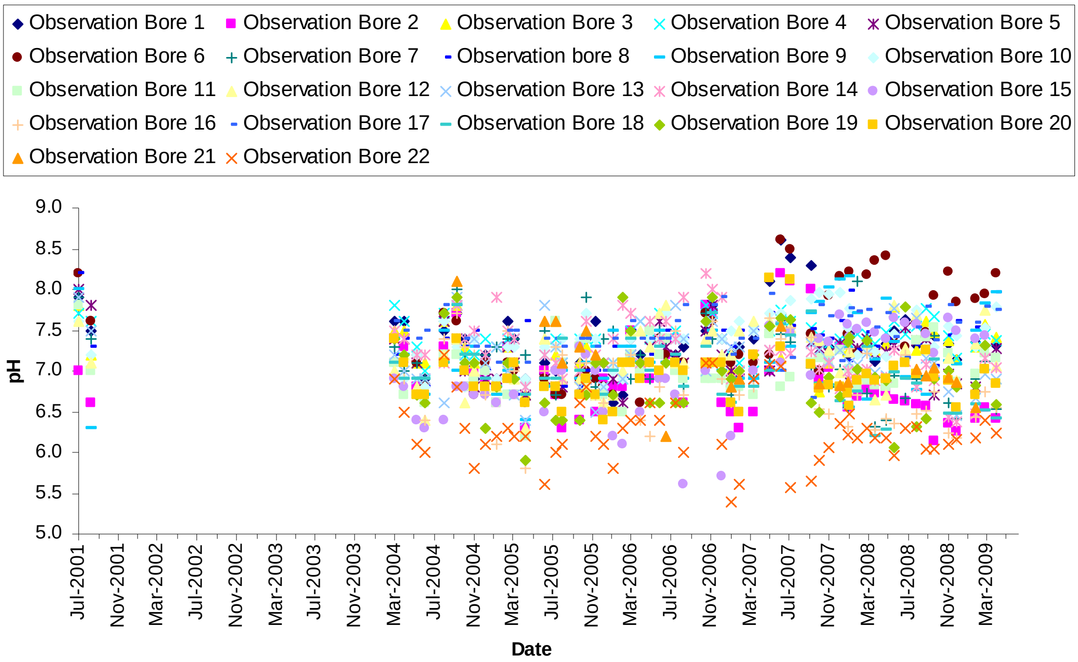


Figure 28. Recorded pH from July 2001 to April 2009 for observation bores located at the Lake Warden System Ramsar Site, Esperance, Western Australia (data from Department of Environment and Conservation, 2009b).

3.1.3.2.3 Nutrient concentrations

Nutrient load estimates indicate that Coramup and Bandy Creeks deliver the highest loads of TN into the Ramsar site annually (Table 5). The highest loads of TP come from Coramup and Neridup Creeks (Table 5). As nutrient loads are variable and dependant upon flow and volume of water, regular quantification in terms of nutrient loads that are entering from surrounding catchments is required.

High nutrient loads do not necessarily equate to high nutrient concentrations as concentration is dependant upon water volume. For example, surveillance of the Bandy and Coramup Creek Catchments from 2006 to 2008 indicates that mean TN and TP concentrations for Bandy and Coramup Creeks are similar. The mean TN concentrations for Bandy and Coramup Creeks were 1.07 mg/L and 1.10 mg/L respectively (May, 2008). The mean TP concentrations for Bandy and Coramup Creeks were 0.006 mg/L and 0.007 mg/L respectively (May, 2008). Although, Coramup

Creek generally delivers higher nutrient loads than Bandy Creek (Table 5), Coramup Creek also delivers higher volumes of water than Bandy Creek, hence nutrient concentrations are similar.

Table 5. Estimations of annual nutrient load contributions into the Lake Warden System Ramsar Site, Esperance, Western Australia (data from Janicke, 2004).

Creek	Total Nitrogen (%)	Total Phosphorus (%)
Coramup	49	33
Bandy	25	17
Neridup	18	44
Melijinup	8	6

3.1.4 PHYSICAL PROCESSES

Sedimentation

The land uses within the catchments that feed the Ramsar site have resulted in large scale clearing of native vegetation. This absence of vegetation has reduced the catchments ability to entrap resources, resulting in increased surface water runoff and sediment transportation. These sediments subsequently make their way into the wetlands of the Ramsar site, depositing greater sediment loads than what would be expected in a vegetated catchment. Whilst there is no quantification in the amount of sediment received by the Ramsar site on an annual basis, rates of sediment accumulation have increased in some of the wetlands markedly.

Sedimentation rates have been documented at Lake Wheatfield, Lake Warden and Station Lake (Wilson, 2004). The rates of sediment accumulation has increased 5 to 10 times in Lake Wheatfield and Lake Warden since widespread clearing of the catchments (Wilson, 2004). Station Lake has had a 10 to 20 times increase in sedimentation rates (Wilson, 2004). The source of the sediment is from the upper catchment, bare saline drainage lines and incised stream lines (CALM, 2006).

Further investigation on sediment loads and its affect on bathymetry need to be undertaken, in particular the spatial differences throughout the wetlands of the Ramsar site.

3.1.5 WETLAND SOILS

The majority of the Ramsar site lies within the Gore land system which is characterised by alkaline grey sandy duplex soils, pale deep sands and saline wet soils (CALM, 1999; Short, 2000). Much of the soils in the Esperance area have been described as having extremely low concentrations of nitrogen, phosphorus and potassium (McArthur, 1991).

Sediment core descriptions are available for Lake Warden, Lake Wheatfield and Station Lake. The lithology of the Lake Warden sediments are described as comprising of a massive sand unit which is intersected by well defined marl/sand bands (Wilson, 2004). This pattern continued throughout the 105 cm sediment core taken at the time of the study. The Lake Wheatfield core comprised of a dark organic rich ooze (0 - 24 cm) that overlaid a pale organic clay (24 - 100 cm) (Wilson, 2004). The Station Lake core comprised of a massive marl unit (0 - 92 cm) overlain with a massive white sand unit (92 - 110 cm) (Wilson, 2004).

Core samples also indicate that eutrophication of Lake Warden, Lake Wheatfield and Station Lake began approximately 600 years ago and continues to the present date (Wilson, 2004). However, within the sediments of these lakes there was a marked increase in phosphorus between 9.5 - 11.5 cm (Wilson, 2004). This increase occurs at the same depth as *Pinus* spp. pollen was found, indicating the beginning of European land use practices around the 1950's and coinciding with superphosphate application within the surrounding catchment (Wilson, 2004).

The soils of the Gore land system have been recognised with a high probability of having potential acid sulfate soils (PASS) (Massenbauer, 2007a). However, if PASS are identified and remain undisturbed, they should not cause any adverse environmental conditions i.e. becoming actual acid sulfate soils (AASS) (see: Text Box 2).

Recent analysis indicates some high to moderate risk areas of acid sulfate soils within the Ramsar site, namely at Lake Warden and Lake Wheatfield (Figure 29). However, this analysis was spatially limited and did not include all areas of the Ramsar site (Figure 29).

The formation of AASS produces sulfuric acid, with the soil and surrounding waterways becoming acidic. While acidity alone may affect biota, acidic conditions also promote the release of metals from the sediments including potentially lethal quantities of heavy metals. Section 4.0 explains the threat of acid sulfate soils on the ecological character of the Lake Warden System Ramsar Site.

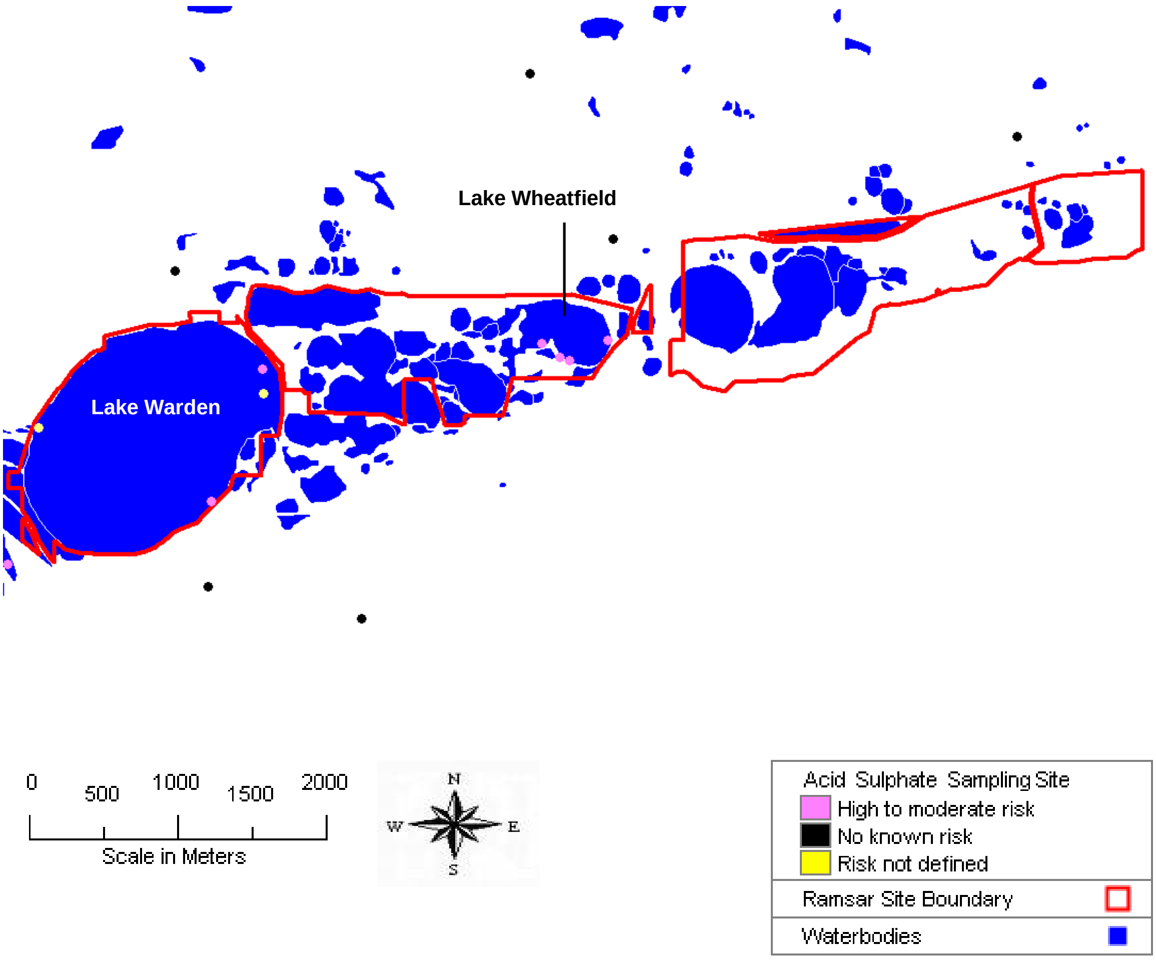


Figure 29. Risk areas for acid sulfate soils in the Lake Warden System Ramsar Site and wider area (GIS data from Galloway & Clarendon, 2009)

Acid sulfate soils

Acid sulfate soils (ASS) are naturally occurring soils and sediments containing iron sulfides, most commonly pyrite. When ASS are exposed to air the iron sulfides in the soil react with oxygen and water to produce a variety of iron compounds and sulfuric acid. Initially a chemical reaction, the process is accelerated by soil bacteria. The resulting acid can release other substances, including heavy metals, from the soil and into the surrounding environment.

Potential acid sulfate soils

ASS which have not been oxidised by exposure to air are known as potential acid sulfate soils (PASS). While contained in a layer of waterlogged soil, the iron sulfides in the soil are stable and the surrounding soil pH is often weakly acid to weakly alkaline.

Potential acid sulfate soils:

- often have a pH close to neutral (6.5 - 7.5)
- contain unoxidised iron sulfides
- are usually soft, sticky and saturated with water
- are usually gel-like muds but can include wet sands and gravels
- have the potential to produce acid if exposed to oxygen.

Actual acid sulfate soils

When PASS are disturbed or exposed to oxygen, the iron sulfides are oxidised to produce sulfuric acid and the soil becomes strongly acidic (usually below pH 4). These soils are then called actual acid sulfate soils (AASS) - that is, they are already acidic.

Actual acid sulfate soils:

- have a pH of less than 4
- contain oxidised iron sulfides
- vary in texture
- often contain jarosite (a yellow mottle produced as a by-product of the oxidation process).

How are acid sulfate soils formed?

Although some ASS were formed millions of years ago and occur in ancient marine rocks, those of most concern were formed after the last major sea level rise - within the past 10,000 years (Holocene period). When the sea level rose and flooded the land, sulfate in the seawater mixed with land sediments containing iron oxides and organic matter. The resulting chemical reaction produced large quantities of iron sulfides in the waterlogged sediments. When exposed to air, these sulfides oxidise to produce sulfuric acid, hence the name acid sulfate soils.

Text Box 2. Acid sulfate soils (from Department of Environment and Conservation, 2008a).

3.1.6 BIOTA

3.1.6.1 Waterbirds

The diversity, abundance and distribution of waterbirds is dependant upon the habitat characteristics of a wetland. This includes the availability, distribution and density of food; size, shape and physico-chemical characteristics of the waterbody; and the availability of suitable sites for breeding and nesting (Goodsell, 1990; Halse et al., 1993; Wiens, 1989). Diversity and abundance of waterbirds may also change due to migration flux, birth and death rates.

Waterbird behaviour and functional morphology dictates which habitats birds occupy. For example, waterbirds occupy different water depths (habitats) within a wetland in order to satisfy their dietary requirements. Waterbirds are limited to certain habitats within a waterbody due to the size and function of their body parts such as the size and shape of their bill (Elner et al., 2005). Changes in habitat characteristics may affect the diversity and abundance of waterbird species that are able to use a wetland area. For example, seasonal changes such as the differences between summer and winter rainfall, affecting water depth.

Waterbirds occupy a series of guilds, which are groupings where the individuals share similar ecological requirements or have similar behaviours. Jaensch (2002) describes a series of waterbird guilds and this information has been combined with a literature review by Cowcher (2005) to organise the waterbird species recorded at the Lake Warden System Ramsar Site into waterbird guilds and other ecological requirements (see: Appendix B).

Describing the ecological requirements of the waterbirds recorded at the Lake Warden System Ramsar Site is an essential component of the ECD. If environmental conditions change outside of these requirements the resulting habitat may no longer be suitable for all of the waterbird species that have been recorded at the Ramsar site. These ecological requirements therefore contribute to setting the limits of acceptable change for the Lake Warden System Ramsar Site (see: Section 6.0 Limits of Acceptable Change).

Waterbird surveys at the Lake Warden System Ramsar Site have been conducted as part of various DEC projects (formerly Department of Conservation and Land Management [CALM]). Surveys include the CALM Water Birds in Nature Reserves Project; CALM Annual Waterfowl Counts and other CALM Aquatic Projects and were undertaken during 1981 - 1992 and 1998. The initial surveys (July 1981 - May 1988) under the CALM Water Birds in Nature Reserves Project were conducted by the Royal Australasian Ornithologists Union (see: Jaensch et al., 1988). From

November 1988 to March 1992 the Annual Waterfowl Counts in South-west Western Australia Project was conducted by CALM staff, however, these surveys only recorded waterfowl, namely ducks, swans and coots (see: Halse et al., 1992; Halse et al., 1990; Halse et al., 1995; Halse et al., 1994). DEC, through the Salinity Strategy, the Salinity Action Plan Wheatbelt Wetlands Monitoring Programme, began monitoring waterbirds in 1997 (see: Cale, 2008; Cale et al., 2004). Only the waterbirds at Lake Wheatfield have been recorded under this programme.

Various waterbird surveys have also been conducted by Birds Australia, including specific Hooded Plover surveys during 1994 - 1998, 2001 - 2003 and 2008 as part of the Hooded Plover Project (see: Newbey, 1996; Singor, 1999). In February 2004, Clarke et al. (2003) undertook a waterbird census in the Esperance region which included some of the wetlands within the Ramsar site.

Past surveys have used on-ground methods of waterbird surveillance such as from the shore or from boats. As the Lake Warden System Ramsar Site is vast, employing these methods has meant that waterbird surveys have been limited spatially and very few wetlands within the Ramsar site have been able to be recorded simultaneously, on the same day. Bennelongia Environmental Consultants have recently conducted aerial surveys in spring of 2006 and 2007 and in the summer of 2008 (see: Bennelongia, 2008a; Bennelongia, 2008b; Halse, 2007). These aerial surveys have increased the spatial area of surveillance and have been able to cover the whole Ramsar site during one survey. It is acknowledged that cryptic species and diving waterbirds, are missed during aerial surveys (Bennelongia, 2008a, 2008b; Halse, 2007), however, aerial surveys are useful for understanding the abundances of waterbirds using the Ramsar site at any one time and aid in the application of Ramsar Criteria 5 (see: Ramsar Convention, 2005b).

Figure 30 depicts all of the wetlands that have been surveyed within the Lake Warden System Ramsar Site. The North Windabout Complex, Gun Club Suite, Merivale Road Wetlands and the Bandy Creek Pans Complex are additional wetlands that have only been named and surveyed during the later aerial surveys (see: Bennelongia, 2008a; Bennelongia, 2008b; Halse, 2007).

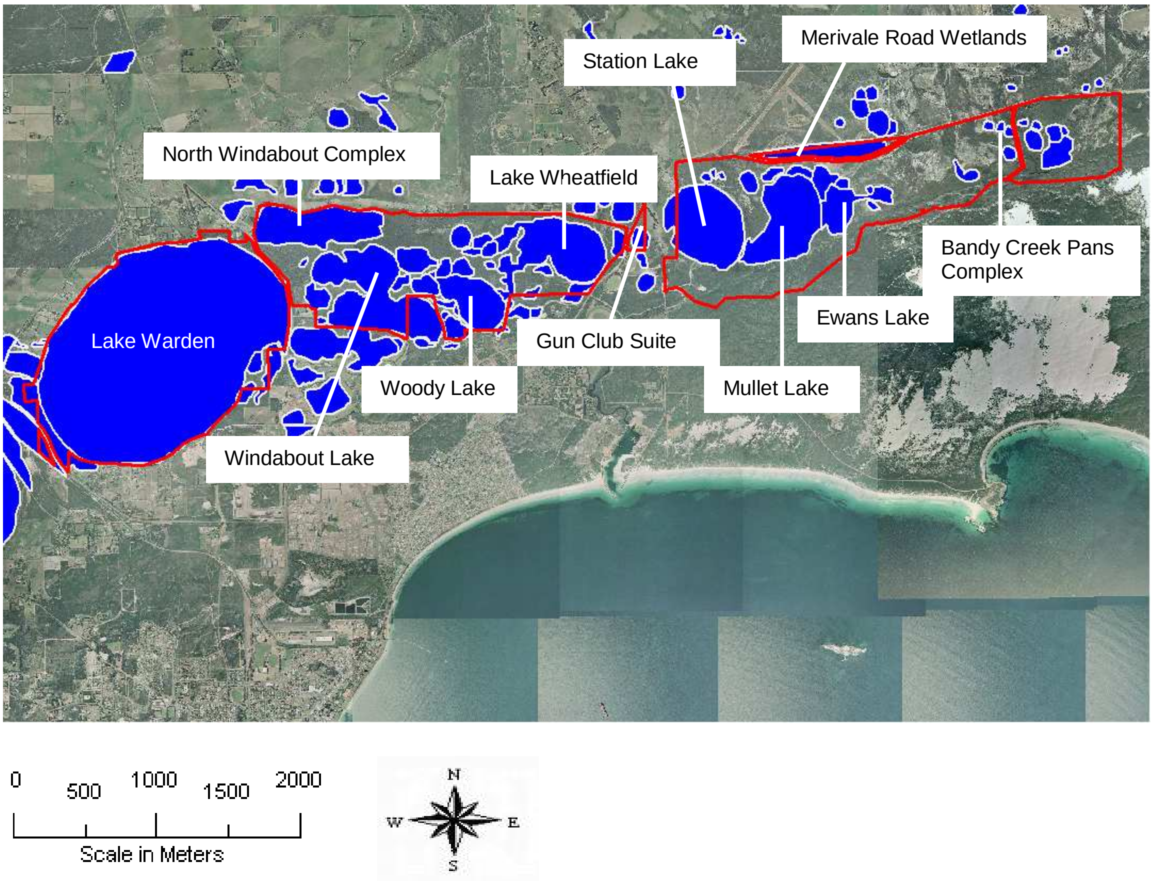


Figure 30. Location of waterbird surveys at the Lake Warden System Ramsar Site. Note: Ramsar boundary in red.

3.1.6.1.1 Species diversity and abundance

Waterbird surveys at the Ramsar site have resulted in a total of 73 waterbird species being recorded (Table 6). For comparison, at the Lake Gore Ramsar Site also in the Esperance region 53 species have been recorded (Department of Environment and Conservation, 2009a). The 73 waterbird species recorded at the Ramsar site includes 42 EPBC Act listed species, 40 are listed as “Marine” species and 25 species are listed as “Migratory” and are included under the international migratory bird agreements CAMBA (23), JAMBA (22), ROKAMBA (19) and CMS (20) (Appendix B, Table B1). One species (Cape Barren Goose *Cereopsis novaehollandiae grisea*) is listed as “Vulnerable” under the EPBC Act.

A total of 4 species listed under the International Union for Conservation of Nature and Natural Resources (IUCN) Red List have been recorded at the site, 3 species “Near threatened” (Black-tailed Godwit [*Limosa limosa*], Darter [*Anhinga melanogaster*] and Hooded Plover [*Thinornis rubricollis*]) and 1 species listed as "Vulnerable" (Fairy Tern [*Sterna nereis*]).

Table 6. Number of waterbird species recorded at the Lake Warden System Ramsar Site, Esperance, Western Australia, together with their feeding requirements (feeding requirements from Cowcher, 2005).

Waterbird group	Families	Feeding requirements	No of species
Ducks and allies	Anatidae	Dryland to deep water > 1 m. Omnivores including plant/algae material, fish and invertebrates	13
Grebes	Podicipedidae	Deep open water > 1 m feeding on mainly fish but also insects and some vegetation	3
Pelicans, Cormorants, Darters	Anhingidae, Pelecanidae, Phalacrocoracidae	Deep open water > 1 m feeding on fish and invertebrates	6
Herons, Egrets, Ibises, Spoonbills	Ardeidae, Threskiornithidae	Shallow/wading or on mudflats feeding on a range of animals (invertebrates, reptiles and fish)	10
Hawks, Eagles	Accipitridae	Feeds on dryland to deep open water on a variety of animals including waterbirds and fish	2
Crakes, Rails, Water Hens, Coots	Rallidae	Shallow/wading or on mudflats with Coots using deeper open water > 1 m. Omnivores including plant/algae material, fish and invertebrates	5
Shorebirds	Charadriidae, Recurvirostridae, Scolopacidae	Shallow/wading or on mudflats feeding on mainly fish and invertebrates and some vegetation	27
Gulls and Terns	Laridae, Sternidae	Gulls use a wide range of habitats and are omnivorous, feeding opportunistically. Terns feed over permanent, open waters eating mainly fish but also invertebrates	6
Old World Warblers	Sylviidae	Shorefeeder insects and similar prey	1
Total			**73**

The waterbirds recorded at the site have been grouped into four different guilds to illustrate their habitat feeding requirements (Figure 31 and Appendix B, Table B1). Feeding requirements have been based on the maximum depth required for feeding, however, some waterbirds may occupy or feed within any habitat up to their maximum feeding depth. Typically, the majority (approximately 60%) of the waterbird species that have utilised the Lake Warden System Ramsar Site are shallow feeders or waders that generally require a habitat that is ≤ 0.5 m in depth and they may also rely on an exposed shore zone (Figure 31 and Appendix B, Table B1). Approximately 27% of the species utilising the Lake Warden System Ramsar Site are deep feeders and require a habitat ≥ 1 m (Figure 31 and Appendix B, Table B1). The remaining 13% is occupied by shore and aerial feeders (Figure 31 and Appendix B, Table B1).

Of the 42 species listed under the EPBC Act, 28 species occupy waterbird feeding Guild 2 indicating they are shallow feeding or wading waterbirds, which may also rely on an exposed shore zone (Figure 31 and Appendix B, Table B1). These 28 species (21 of which are migratory [CAMBA, JAMBA, ROKAMBA and CMS]) represent approximately 38% of all the waterbirds recorded at Ramsar site and comprise approximately 64% of waterbird feeding Guild 2.

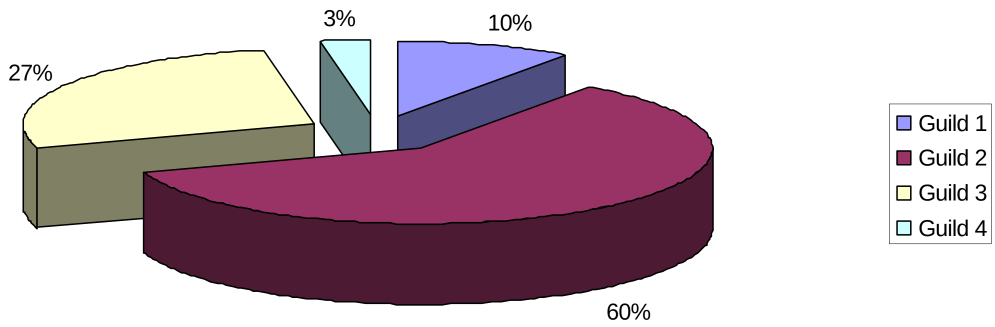


Figure 31. An illustration of the general percentage composition of the waterbird feeding guilds of the Lake Warden System Ramsar Site, Esperance, Western Australia. Note: Guild 1 - Shore: Majority of feeding is on dry land; Guild 2 - Wading birds and shallow feeders: Feeding in water that is ≤ 0.5 m. Birds within this group may also feed within wet mud and guild 1; Guild 3 - Deep feeders: Requiring a water depth that is ≥ 1 m but can also occupy guilds 1 and 2; Guild 4 - Aerial feeders: Birds of prey (guild information adapted from Cowcher, 2005; Jaensch, 2002).

The identification of waterbird feeding guilds indicates that the Ramsar site offers a diversity of feeding habitats (water depths) and has been particularly important to wading and shallow feeding species, some of which are protected under the EPBC Act. In order for these species to continue using the site, it is essential that the diversity of waterbird feeding habitats is maintained.

Figure 32 depicts the highest waterbird counts for the Lake Warden System Ramsar Site. As the Ramsar site covers a vast area, some of the on-ground waterbird surveys of the entire site (i.e. from 1981 - 2005) took place over multiple days. In this case, to represent the data in this ECD the waterbird abundances from individual wetlands over the survey period were combined. This approach may lead to estimation errors in waterbird numbers. Some waterbirds may have been counted on multiple occasions if they moved between wetlands during the survey period resulting in over estimation, conversely, under estimation could also occur as flocks of waterbirds may have moved from unsurveyed wetlands to wetlands already surveyed.

The highest number (abundance) of waterbirds counted at the Lake Warden System Ramsar Site was in November 1982 with 19,561 individuals (Figure 32). At the time of listing, the annual water depth data of the Ramsar site was considered an indication that conditions would be suitable for use by 20,000 waterbirds at least several times within a 25 year period (Ramsar Information Sheet, 2003). Additionally, the Ramsar Information Sheet (2003) states that more than 30,000 waterbirds were recorded using the Ramsar site over a four year period from 1981 to 1985. Analysis of 27 years of waterbird data indicates that on no occasion has the Lake Warden System Ramsar Site exceeded 20,000 waterbirds (Figure 32).

As described in Section 2.6, it is not considered that the Lake Warden System Ramsar Site originally met or currently meets Ramsar Criterion 5. In particular, the application of the Ramsar definition of "regularly" discounts Criterion 5 being supported at the Ramsar site. However, it should be noted that survey effort (i.e. the number of wetlands surveyed) can affect the abundance recorded, with fewer wetlands surveyed generally resulting in lower abundances (see: Figure 32). Future waterbird surveys that incorporate the entire Ramsar site may provide justification to support Ramsar Criterion 5.

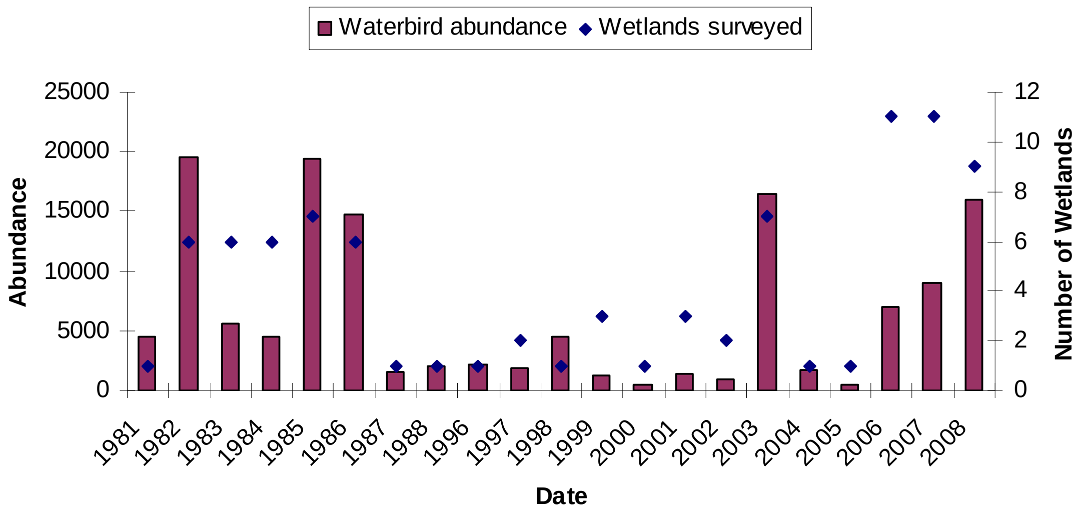


Figure 32. Highest waterbird counts for the Lake Warden System Ramsar Site 1981 - 1988 and 1996 - 2008, Esperance, Western Australia compared with the number of wetlands surveyed (data from Bennelongia, 2008a; Bennelongia, 2008b; Birds Australia, 2008; Cale, 2008; Cale et al., 2004; Clarke & Lane, 2003; Halse, 2007; Jaensch et al., 1988). Note: does not include annual waterfowl count data November 1988 - March 1992.

Two species have been recorded at the Ramsar site exceeding their respective 1% population thresholds (see: Wetlands International, 2006 for population thresholds), including:

1. Chestnut Teal, *Anas castanea* (Anatidae) 1% of the South-west Australian population = 50 birds.
2. Hooded Plover, *Thinornis rubricollis* (Charadriidae) 1% of the Western Australian population = 60 birds.

At the time of listing, only the Hooded Plover was considered to support Ramsar Criterion 6 (Ramsar Criterion 3c at the time of listing). At this time there were no population estimates for the Chestnut Teal. The latest waterbird population estimates (see: Wetlands International, 2006) and the waterbirds surveys from the Ramsar site indicate that the Chestnut Teal have also exceeded the 1% population thresholds “regularly”, as defined by the Ramsar Convention (Ramsar Convention, 2005b). Table 7 details the waterbird surveys that have taken place since 1981 and the number of times the Chestnut Teal and the Hooded Plover have exceeded the 1% population thresholds.

The Hooded Plover is considered “Near Threatened” under the International Union for Conservation of Nature and Natural Resources (IUCN) Red List and in some regions it has become locally extinct (BirdLife International, 2006; Raines, 2002). The Hooded Plover is listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as “Marine” and is listed by the Western Australian Department of Environment and Conservation (DEC) as a Priority Four species (taxa in need of monitoring). The main food source of Hooded Plover is considered to be the molluscs, *Coxiella* spp. (Singor, 1999; Weston & Elgar, 2000). The most important wetlands within the Ramsar site for Hooded Plover have been (in order of greatest abundance) Lake Warden, Station Lake and to a lesser extent Ewans Lake. The north-east section of Lake Warden has been used as a loafing site for large numbers of Hooded Plover when not inundated (Jaensch et al., 1988). The exposed shoreline and bed of Station Lake have also been considered to be important feeding, loafing and possibly breeding areas for large numbers of Hooded Plover (Jaensch et al., 1988).

The highest count of Hooded Plover occurred at Lake Warden in March 1998 where 607 individuals were recorded (Singor, 1999). Lake Warden has long been considered one of the most important sites, along with Lake Gore (within the Lake Gore Ramsar Site), for Hooded Plover in the Esperance region (Newbey, 1996; Singor, 1999). The Hooded Plover has only been recorded exceeding the species 1% population threshold 5 times since listing in 1990 (Table 7). The Hooded Plover require a wading habitat including an exposed shore zone It has been acknowledged that an altered hydrological regime at Lake Warden is a potential threat to the Hooded Plover’s habitat, as lake levels and the extent and duration of inundation increases, thus decreasing the wading habitat and shore zone (Clarke & Lane, 2003). Lake Warden and Station Lake have certainly supported higher numbers of Hooded Plovers in the past, when water levels were lower (Bennelongia, 2008b).

Table 7. Waterbirds recorded at the Lake Warden System Ramsar Site that have exceeded the 1% population thresholds (see: Wetlands International, 2006). Note: X denotes the species was recorded exceeding the 1% population threshold; N.S: no survey undertaken.

Year	Chestnut Teal	Hooded Plover
1981	X	
1982	X	X
1983		X
1984		X
1985	X	X
1986		X
1987		X
1988		X
1989		N.S
1990		
1991	X	N.S
1992	X	N.S
1993	N.S	N.S
1994	N.S	
1995	N.S	X
1996		X
1997	X	X
1998		X
1999	X	
2000		
2001	X	
2002		
2003	X	X
2004		N.S
2005		
2006	X	
2007	X	
2008	X	

The apparent reduction in the numbers of Hooded Plover over time could be attributed to a lack of suitable habitat. In the Esperance area, a number of lakes provide suitable habitat for Hooded Plover. For example, it has been noted that Carbul, Gidong and Kubitch Lakes which are adjacent to the Lake Gore Ramsar Site have also been important sites for Hooded Plover (see: Jaensch et al., 1988). Jaensch et al. (1988) explains that it is likely that Hooded Plovers congregate at any one of these wetlands (i.e. Gore, Carbul, Gidong and Kubitch) at any given time, depending on which ever has the most suitable water level.

The altered hydrological regime and a subsequent loss of habitat (see: Section 3.1.2 Hydrology) may have reduced Hooded Plover numbers at the Ramsar site. However, this is a cryptic species and could be missed due to a reduction in survey effort or different survey methods. Weston & Elgar (2000) conducted a 14 day intensive survey of Hooded Plover at nearby Lake Gore and highlighted how variability in waterbird numbers can be attributed to species behaviour influenced by time of day and weather (Weston & Elgar, 2000). They found significant differences in Hooded Plover numbers. On some days the counts were relatively constant; other days there were higher numbers in the midday as opposed to evening; and on some days Hooded Plover numbers were higher in the morning and evening while lower at midday. Cryptic species such as the Hooded Plover and also diving waterbirds, are difficult to detect during aerial surveys (Bennelongia, 2008a, 2008b; Halse, 2007). It is therefore sensible to conduct targeted Hooded Plover surveys, such as those conducted by Birds Australia during 1994 - 1998, 2001 - 2003 and 2008 as part of the Hooded Plover Project (see: Newbey, 1996; Singor, 1999).

The most significant wetlands for Chestnut Teal within the Ramsar site (in order) have been Lake Wheatfield, Lake Warden, Windabout Lake and Mullet Lake (see: Bennelongia, 2008a; Bennelongia, 2008b; Birds Australia, 2008; Cale, 2008; Cale et al., 2004; Halse, 2007; Halse et al., 1992; Halse et al., 1990; Halse et al., 1995; Halse et al., 1994; Jaensch et al., 1988). The highest count of Chestnut Teal for the Ramsar site was in March 1992 (1,269) where Mullet Lake, Lake Wheatfield, Lake Warden and Woody Lake were surveyed at the same time as part of the Annual Waterfowl Counts (see: Halse et al., 1995). This count is significant and in comparison with the most recent waterbird estimates (see: Wetlands International, 2006) represents approximately 25% of the current South-west Australian population. Additionally, counts of Chestnut Teal may also be under estimated at the Ramsar site as females of this species resemble Grey Teal (*Anas gibberifrons*) and may be misidentified during a survey (David Cale, Technical Officer, DEC, pers. comm., 2008).

Other notable waterbird species recorded at the Ramsar site are the Cape Barren Goose and the Fairy Tern. The Cape Barren Goose recorded at the site is a rare subspecies which occurs largely on the islands of the Recherche Archipelago, however, it is occasionally recorded on the mainland. The Cape Barren Goose is listed as “Vulnerable” under the EPBC Act with approximately 650 individuals in the population (see: Wetlands International, 2006). It has been recorded at Ewans Lake on one occasion (January 1982 [2]) and in the mid 80’s on five occasions where 2 to 8 individuals were recorded at Windabout Lake (Jaensch et al., 1988). Since this time, 5 individuals were recorded at Windabout Lake in October 2006 and over 40 were recorded in February 2008 (Bennelongia, 2008a; Halse, 2007). At the time of the large count in February 2008 it was thought that a particularly warm summer had caused large numbers of Cape Barren Geese to move off the islands of the Recherche Archipelago to the mainland to feed (Bennelongia, 2008a). Large numbers (between 40 - 50) of Cape Barren Geese have been observed feeding on the grass of the Esperance Golf Club, which is south of Windabout Lake and adjacent to the Ramsar site. The 1% population threshold for this species is 7 (see: Wetlands International, 2006) and although numbers recorded at Windabout Lake have exceeded this, it is not considered to be occurring “regularly” as defined by Ramsar (Ramsar Convention, 2005b).

The Fairy Tern, which is listed as “Vulnerable” under the IUCN Red List, was recorded at Lake Warden (7 occasions), Windabout Lake (2 occasions) and Station Lake (1 occasion) during the mid 1980’s (see: Jaensch et al., 1988). The Ramsar site is not considered important in supporting populations of Cape Barren Goose or Fairy Tern as the numbers recorded to date suggest that both are only occasional visitors.

The waterbirds of the Ramsar site will be described by Nature Reserve, consistent with surveys:

1. The Lake Warden Nature Reserve 32257, which includes Lake Warden;
2. Woody Lake Nature Reserve 15231, which includes Woody Lake, Lake Wheatfield and the northern section of Windabout Lake. The North Windabout Complex and the Gun Club Suite are also included in this Reserve; and
3. Mullet Lake Nature Reserve 23825, which includes Mullet, Station and Ewans Lakes. This Reserve also includes the Merivale Road Wetlands and the Bandy Creek Pans Complex.

Lake Warden Nature Reserve

The most abundant waterbird species at Lake Warden have been (in order) the Banded Stilt (highest count 10,000 in September 1982), Black Swan (highest count 5,000 in May 2003), Australian Shelduck (highest count 5,500 in November 1982) and Musk Duck (highest count 2,000 in May 2003).

During the early to mid 1980’s large numbers of Banded Stilt were recorded (Figure 33), some exceeding 1% of the South-west Australian population threshold of 2,400 birds (see: Wetlands

International, 2006). It should be noted that the periods in the 1980's when Banded Stilt were recorded exceeding the 1% population threshold coincided with the lowest water levels recorded at Lake Warden (see: Section 3.1.2 Hydrology). As Banded Stilt are waders they generally prefer a shallower habitat for feeding.

Large numbers of Banded Stilt were last recorded at Lake Warden in 1998 (Figure 33), coinciding with the last time significant numbers were recorded at the nearby Lake Gore Ramsar Site, also in the Esperance region (see: Department of Environment and Conservation, 2009a). The Lake Gore Ramsar Site has undergone similar changes in hydrological regime to Lake Warden (i.e. increases in depth, extent and duration of inundation) and at this site higher water levels have been implicated in observed reductions in Banded Stilt (see: Department of Environment and Conservation, 2009a). The reduction in Banded Stilts recorded at Lake Gore is likely due to higher water levels and loss of suitable habitat (Department of Environment and Conservation, 2009a). The altered hydrological regime may also be responsible for a reduction in Banded Stilt numbers at Lake Warden.

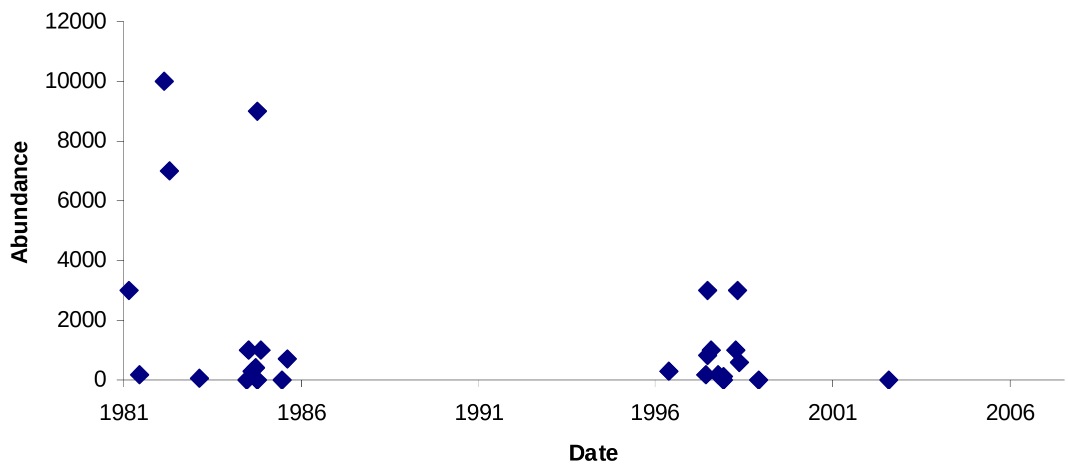


Figure 33. Abundance of Banded Stilt from counts at Lake Warden 1981 - 2008 (data from Bennelongia, 2008a; Bennelongia, 2008b; Birds Australia, 2008; Clarke & Lane, 2003; Halse, 2007; Jaensch et al., 1988).

Recent waterbird surveys during October (spring) 2006 and 2007 suggest that the suitability of Lake Warden for waterbirds has declined due to increasing water depths (Bennelongia, 2008b; Halse, 2007). During these surveys, water depth exceeded 2.0 m and shorelines were submerged, providing no habitat for shorebirds (Bennelongia, 2008b). Other waterbirds that require a deeper feeding habitat such as the Australian Shelduck and the Black Swan also appeared to be finding that the depth of Lake Warden was too great for feeding and were using habitats more suitable within the Ramsar site and beyond (Bennelongia, 2008b).

Robertson & Massenbauer (2005) describe that the depth of Lake Warden has exceeded its optimal range for waterbird diversity. The waterbird data indicates a significant decrease in waterbird richness and abundance with increasing water depths, and notable collapses in waterbird numbers above 1.4 m (3.74 m AHD). Historically, greater abundance of waterbirds has been recorded during the spring period (Jaensch et al., 1988), however, since listing, average water depths for Lake Warden in spring are exceeding 2.0 m (see: Section 3.2.2.3 Hydrological regime of the major lakes within the Ramsar site).

The conceptual optimum hydrological thresholds for waterbirds at Lake Warden and other lakes within the Ramsar site have been calculated using GIS, bathymetry volume calculations, waterbird habitat preference literature, and historic and current lake depth data (see: Massenbauer, 2008; Robertson & Massenbauer, 2005). During the current hydrological regime, the optimum minimum and maximum shore zone areas at Lake Warden have been reduced by 47 ha and 195 ha respectively (Massenbauer, 2008; Robertson & Massenbauer, 2005). Thus the maximum habitat area available for wading waterbirds has reduced from 290 ha to 20 ha, and for diving waterbirds it has increased (Figure 34). To maintain waterbird diversity, the exposed shore zone around Lake Warden should be between a minimum of 50 ha and a maximum of 250 ha, equating to a depth range between 0.3 m (2.64 m AHD) and 1.4 m (3.74 m AHD) (Figure 34). A beach area to the north-east of the lake is considered important habitat for Hooded Plover when exposed, however, when inundated, the reduced shore zone area does not provide adequate habitat for this species (Jaensch et al., 1988). This change in ecological character is discussed further in Section 5.0 Changes to Ecological Character.

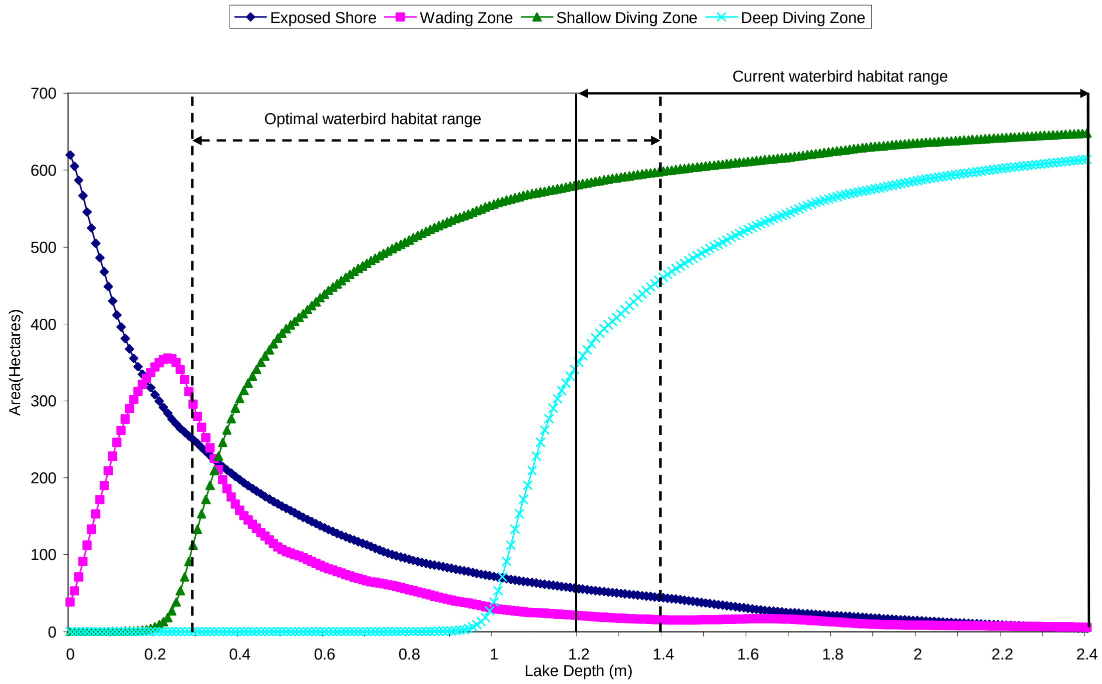


Figure 34. Area of conceptual waterbird habitat zones in relation to water depth for Lake Warden, Esperance, Western Australia (from Massenbauer, 2008; Robertson & Massenbauer, 2005).

Woody Lake Nature Reserve

The most abundant waterbird species within the Woody Lake Nature Reserve have been (in order) the Grey Teal (highest count 5,500 at Windabout Lake in May 1985), Eurasian Coot (highest count 900 at Windabout Lake in February 2003), Pacific Black Duck (highest count 882 at Windabout Lake in February 2008) and the Black Swan (highest count 1,881 at Windabout Lake in February 2003). Clarke et al. (2003) identified Windabout Lake as an important drought refuge, with consistently high counts of individual species recorded during summer.

Since 1982, Lake Wheatfield has recorded overall higher abundances of Eurasian Coot and Pacific Black Duck. The waterbird monitoring as part of the Salinity Action Plan Wheatbelt Wetlands Monitoring Programme, indicates a significant increase ($p<0.01$) in waterbird abundance as water levels decline and salinity concentration increases at Lake Wheatfield (Department of Environment and Conservation, 2006). However, historical waterbird counts indicate one of the dominant species recorded at Lake Wheatfield are diving waterbirds, owing to the wetlands naturally deeper bathymetry (Department of Environment and Conservation, 2006; Robertson & Massenbauer, 2005).

Lake Wheatfield has provided important breeding habitat, with the colonial waterbirds such as Yellow-billed Spoonbill and Little Black Cormorant using the extensive stands of *Melaleuca* spp. in the south of the lake for nesting sites (Cale et al., 2004; Halse, 2007). Other species that have utilised Lake Wheatfield for breeding include the Australian Shoveler, Darter, Great Crested Grebe, Grey Teal, Pacific Black Duck, Pink-eared Duck, Straw-necked Ibis and the White-faced Heron (Department of Environment and Conservation, 2006; Jaensch et al., 1988).

As with Lake Warden, the conceptual optimum hydrological thresholds for waterbirds at Lake Wheatfield have also been determined. The reduction in waterbird richness with depth is not significant for Lake Wheatfield, owing to its naturally deeper bathymetry and its subsequent attraction to diving waterbirds (Robertson & Massenbauer, 2005). Nonetheless, optimal depth ranges have been set for Lake Wheatfield along with dewatering targets, which will be addressed in Section 4.0 Threats and Section 6.0 Limits of Acceptable Change.

White-faced Herons have also been recorded breeding in the fringing trees of Woody and Windabout Lakes (Jaensch et al., 1988). Additionally, Pacific Black Ducks have also been recorded breeding at Woody Lake (Jaensch et al., 1988).

Mullet Lake Nature Reserve

Within the Ramsar site, Station Lake is important for Hooded Plover exceeded only by Lake Warden. Station Lake has an extensive exposed shore zone on its eastern side, which is an important area for feeding, loafing and probably breeding of Hooded Plover (Jaensch et al., 1988). The highest count of Hooded Plover at Station Lake was 99 in February 1984 (Jaensch et al., 1988). Station Lake is also important for species recognised under the international migratory bird agreements CAMBA, JAMBA, ROKAMBA and CMS.

The most abundant waterbird species within the Mullet Lake Nature Reserve have been (in order) the Australian Shelduck (highest count 1,695 at Ewans Lake in March 1991), Black Swan (highest count 2,000 at Mullet Lake in January 1986), Banded Stilt (highest count 3,510 at Mullet Lake in February 2008) and Grey Teal (highest count 1,795 at Mullet Lake in March 1992).

The waterbird data in this ECD is from (Bennelongia, 2008a, 2008b; Birds Australia, 2008, 2009; Cale, 2008; Cale et al., 2004; Clarke & Lane, 2003; Halse, 2007; Halse et al., 1992; Halse et al., 1990; Halse et al., 1995; Halse et al., 1994; Jaensch et al., 1988).

3.1.6.2 Fish

Fish satisfy the dietary requirements of many different waterbird groups, particularly the deeper feeding species such as gulls, terns, grebes, pelicans and cormorants, which are piscivores (see: Appendix B, Table B2).

There is little reference to the presence of fish at the Lake Warden System Ramsar Site although the area has been used for fishing by Indigenous peoples of the Esperance area (see: Section 3.2.3 Cultural Services). Black Bream are often fished for in the lakes of the Ramsar site and have been recorded in Bandy Creek (Hodgkin & Clark, 1989). Black Bream is considered to be an estuarine species, although land locked populations do occur in Western Australia, including nearby Lake Gore and the Dalyup River (Norriss et al., 2002).

Other species of fish such as the Swan River Gobi (*Pseudogobius olorum*) and the Hardyhead (*Leptatherina wallacei*) have also been recorded at Bandy Creek (Hodgkin & Clark, 1989). These species may also exist throughout the Ramsar site, particularly the Swan River Gobi as it known to occur at Lake Wheatfield (David Cale, Technical Officer DEC, pers. comm., 2009). A species of possibly Mullet (*Aldrichetta* sp.) or Hardyhead (*Atherinosoma* sp.) have been recorded at Lake Warden (Australian Nature Conservation Agency, 1996).

It is unclear if the fish populations at the Ramsar site are stable and how fluctuations in water quality affect them. Changes in fish populations may also impact the waterbirds using the Ramsar site. Further monitoring is required to identify the fish species within the Ramsar site.

3.1.6.3 Aquatic invertebrates

Aquatic invertebrates are responsible for a significant proportion of secondary production (Davis & Christidis, 1997) and are a vital driver in wetland ecology, providing food sources to other biota such as fish and waterbirds. Aquatic invertebrates form two interconnected food chains: a grazing and a detrital food chain (Davis & Christidis, 1997). The organisms in the detrital food chain feed on dead and decaying plant and animal material and are essential in the process of decomposition and the elemental cycling of plant and animal material (Davis & Christidis, 1997). The grazing food chain comprises of organisms that feed directly upon primary producers within the ecosystem such as the macrophytes and phytoplankton. Figure 35 details the grazing and detrital food chains of invertebrates in wetland ecosystems.

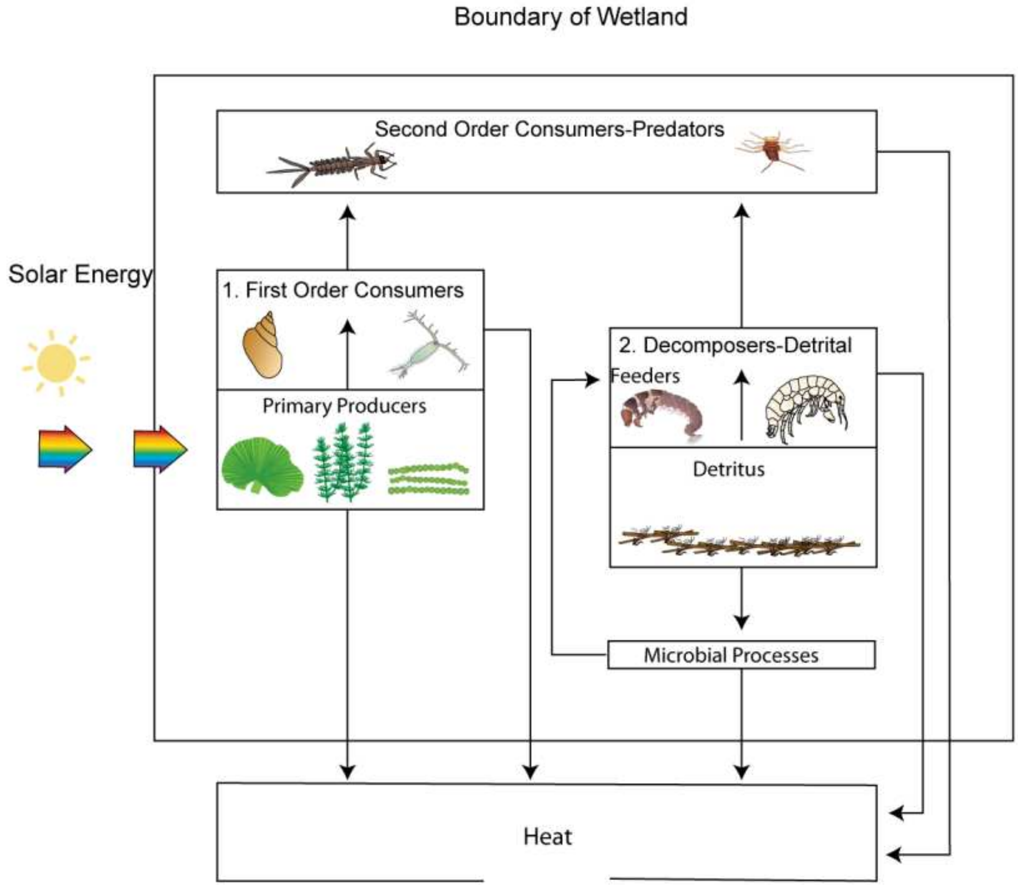


Figure 35. Grazing and detrital invertebrate food chains; Note: 1. Grazing food chain; 2. Detrital food chain; (from Davis & Christidis, 1997).

Invertebrates form functional feeding groups (Table 8) based on their feeding habits and can occupy either or both the detrital and grazing food chains.

Table 8. General examples of invertebrate functional feeding groups (adapted from Boulton & Brock, 1999).

Feeding Group	Food / Diet	Examples
Shredders	Feed on organic material mainly coarse particulate matter	Leptocerid caddisflies, some crustaceans (e.g. *Cherax* spp.) and some amphipods (*Austrochiltonia*)
Collectors	Deposited fine particulate matter	Oligochaete worms, some chironomid larvae (*Chironomous* spp.), many mayflies, stoneflies and caddisflies
Collectors - filter feeders	Suspended fine particulate matter	Some chironomid larvae (*Tanytarsus* spp.), water fleas (Cladocera), seed shrimps (Ostracods), black fly larvae (Simuliidae) and copepods
Scrapers	Graze on periphytic algae	Snails, some mayflies and caddisflies
Macrophyte piercers	Feeding off living plants and algae cells	Microcaddisflies (Hydroptilidae)
Predators	Feed off other invertebrates	Dragonflies and damselflies, some caddisflies, most aquatic bugs (Hemiptera) and beetles (Coleoptera)

Invertebrate studies of the Lake Warden System Ramsar Site have mostly taken place after listing. The only study on invertebrates prior to listing was in spring 1981 and included Mullet Lake and Lake Warden (see: Brock & Shiel, 1983). Another earlier study of the aquatic invertebrates of the Ramsar site took place just after listing, in the winter and summer months of 1991 (see: Handley, 1991). Included in this study were Station Lake, Mullet Lake, Woody Lake, Windabout Lake, Lake Wheatfield and Lake Warden.

As part of the Salinity Strategy, the Salinity Action Plan Wheatbelt Wetlands Monitoring Programme which began in 1997 also included monitoring of aquatic invertebrates at Lake Wheatfield during spring (see: Cale et al., 2004). Raw data from this monitoring is available up until 2008, however, this ECD only includes data from 1997 and 1999 as the remaining data is yet to be finalised. Also part of the Salinity Strategy, a biological survey of wetlands in the wheatbelt of the south west of Western Australian took place between 1997 and 2000 in late winter and spring (see: Pinder et al., 2004) and included Mullet Lake.

Other aquatic invertebrate sampling has taken place recently in spring of 2006 and 2007 at Lake Warden, Lake Wheatfield, Ewans Lake and Station Lake. This survey was initially implemented for benchmarking and ongoing monitoring of the macro and micro-invertebrate assemblages within these wetlands as part of the recovery plan for the Lake Warden Catchment (see: Cook & Farrell, 2008; Cook et al., 2007).

At Lake Wheatfield, 52 species of invertebrates were recorded in 1997 and 73 in 1999 (Cale et al., 2004). Insects were found to be the most dominant group during both of these monitoring years (Cale et al., 2004). In 1997 and 1999, insects comprised of 46% (24 species) and 40% (29 species) of the taxa collected at Lake Wheatfield respectively (Cale et al., 2004). Next highly represented were crustaceans with 18 species (34%) collected in 1997 and 17 species (23%) collected in 1999 (Cale et al., 2004). A greater number (15 species) of rotifers were collected in 1999 than in 1997 (3 species) (Cale et al., 2004). During these sampling occasions it was found that the invertebrate assemblages of Lake Wheatfield include a significant component with marine affinities, including species such as the amphipod *Melita kauerti*, the copepod *Gladioferans imparipens,* the decapod *Paleomonetes australis* and the isopod *Exosphaeroma* sp. (Cale et al., 2004). However, there was a strong negative relationship between invertebrate species richness and salinity (Cale et al., 2004). In general, in non marine saline aquatic environments such as Lake Wheatfield, as the salinity level increases, aquatic invertebrate species richness declines (Blinn, 2004; Boulton & Brock, 1999; Pinder et al., 2004). In 2006 and 2007, the invertebrates recorded for Lake Wheatfield were also dominated by insects with total species richness being 29 and 20 respectively (2008; Cook et al., 2007). The invertebrate species richness recorded by Cook & Farrell (2008) and Cook et al. (2008; 2007) was therefore much lower than that recorded by Cale et al. (2004).

In comparison to Lake Warden, Ewans Lake and Station Lake, the invertebrate assemblages at Lake Wheatfield were distinct and had the most diversity (Cook & Farrell, 2008; Cook et al., 2007).

Lake Warden had the lowest invertebrate species richness in 2006 and 2007 with 8 and 15 species recorded respectively (Cook & Farrell, 2008; Cook et al., 2007). This could be attributed to the higher salinity concentrations of Lake Warden in comparison to other lakes within the Ramsar site (Cook & Farrell, 2008). The aquatic invertebrate assemblages of Lake Warden were dominated by the crustaceans: copepods and ostracods (Cook & Farrell, 2008; Cook et al., 2007). In particular, Lake Warden was dominated by calanoid copepods, which generally feed on detritus and phytoplankton and are an important food source for higher trophic level predators such as fish and waterbirds. Calanoid copepods were also recorded in high abundances at Lake Wheatfield, Ewans Lake and Station Lake (Cook & Farrell, 2008; Cook et al., 2007).

After Lake Wheatfield, Station Lake and Ewans Lake recorded the next highest invertebrate species richness (Cook & Farrell, 2008; Cook et al., 2007). Station Lake and Ewans Lake were most similar in terms of invertebrates assemblages and were dominated by ostracod crustaceans (Cook &

Farrell, 2008; Cook et al., 2007). Pinder et al. (2004) recorded 42 species at Mullet Lake with crustaceans (ostracods) and insects recorded as the dominant groups.

Insects from the order Odonata have been recorded at Lake Wheatfield, Mullet Lake, Station Lake and Ewans Lake (see: Cale et al., 2004; Cook & Farrell, 2008; Cook et al., 2007; Pinder et al., 2004). The presence of larval Odonata within wetlands is often considered an indicator of a healthy aquatic environment as they generally respond negatively to eutrophication (Boulton & Brock, 1999). Species of Odonata have not been recorded at Lake Warden (see: Cook & Farrell, 2008; Cook et al., 2007) and although this lake has been known to be naturally eutrophic and has also been influenced further by anthropogenic eutrophication (see: CALM, 2006; Handley, 1991; Wilson, 2004) the absence of species of Odonata could be due to the higher salinity concentrations of Lake Warden. For example, Lake Wheatfield has a lower salinity concentrations, and although it is also naturally eutrophic (see: Wilson, 2004) species of Odonata have been recorded (see: Cook & Farrell, 2008; Cook et al., 2007).

Lake Wheatfield, in comparison to Lake Warden, Station Lake and Ewans Lake, had more taxa present that are best able to adapt to eutrophic conditions (see: Cale et al., 2004; Cook & Farrell, 2008; Cook et al., 2007; Wilson, 2004). This includes the cladocerans, *Daphnia* spp.; the ostracod *Candonocypris* sp.; the dipterans from the Chironominae family, *Chironomus* spp., *Polypidelum nubifer* and *Kiefferulus intertinctus* and the hemipteran, *Micronecta robusta* (see: Cale et al., 2004; Cook & Farrell, 2008; Cook et al., 2007; Wilson, 2004).

Species from the *Coxiella* genus have been recorded at Lake Wheatfield, Lake Warden, Station Lake, Ewans Lake and Mullet Lake within the Ramsar site (see: Cale et al., 2004; Cook & Farrell, 2008; Cook et al., 2007; Handley, 1991; Pinder et al., 2004). These species are able to survive environmental extremes (i.e. salinity and drying) and can reproduce repeatedly during optimum conditions (Williams & Mellor, 1991). These molluscs are considered as an important food source for the Hooded Plover as they have been observed foraging on them. The shells of these molluscs have also been found in the faeces and stomach contents of Hooded Plover at nearby Lake Gore and other wetlands (Singor, 1999; Weston & Elgar, 2000). High abundances of Hooded Plover have previously been associated with Lake Warden (Jaensch et al., 1988) along with dense beds of *Coxiella striata* (Handley, 1991). Recent monitoring of aquatic invertebrates in 2006 and 2007 at the Ramsar site indicate that *Coxiella* sp. was in low abundances at Lake Warden (Cook & Farrell, 2008; Cook et al., 2007). However, at Station Lake and Ewans Lake greater abundances of *Coxiella* sp. were recorded (Cook & Farrell, 2008; Cook et al., 2007). After Lake Warden, Station Lake and then Ewans Lake have been considered to be important habitats for Hooded Plover (see: Section 3.1.6.1 Waterbirds).

Lake Warden has supported higher numbers of Hooded Plover in the past (Bennelongia, 2008b; Clarke & Lane, 2003) and it has been acknowledged that the altered hydrological regime at Lake Warden is a potential threat to the Hooded Plover's habitat. It is plausible that altered hydrological regimes and lower abundances of *Coxiella* sp. at Lake Warden have synergistically caused a reduction in Hooded Plover numbers.

The invertebrate survey which took place at Mullet Lake and Lake Warden prior to listing in 1981, recorded lower species richness with 8 and 3 species respectively. Although, species are similar to those recorded post listing, an Australian native species of brine shrimp (*Parartemia* sp.) was recorded at Lake Warden which has not been recorded since (see: Brock & Shiel, 1983). Brine shrimp are an important food source for fish and waterbirds and could have been impacted due to changing salinity and hydrological conditions at Lake Warden.

Comprehensive and regular monitoring of the Ramsar site's invertebrates is required to correctly interpret the existing data.

3.1.6.4 Flora

3.1.6.4.1 Vegetation communities

The Lake Warden System Ramsar Site is located in the South-West Botanical Province within the Fanny's Cove Vegetation System. The Fanny's Cove Vegetation System occupies a narrow plain on top of the young Quaternary sands, silts and clays between the sea and the older sandplains of the Esperance System to the north. The coastal dune vegetation is dominated by *Scaevola crassifolia* which occurs in front of the mallee *Eucalyptus angulosa* with an understorey of *Melaleuca pentagona* (Beard, 1973). Further inland there are thickets of tall *Acacia*, *Melaleuca* or scrub heath dominated by *Banksia speciosa* (Beard, 1973). *Eucalyptus platypus* forms thickets in the depressions between the dunes (Beard, 1973).

The vegetation of the Ramsar site and surrounds, forms part of the south coast "macro-corridor" which is a near continuous strip of native coastal vegetation along the south coast between Albany and Esperance in Western Australia. This corridor is providing an important potential migratory and gene pool pathway (CALM, 1999).

Fringing vegetation of the wetlands within the Ramsar site is dependant upon salinity. The majority of the wetlands within the Ramsar site are surrounded by *Melaleuca cuticularis* or other *Melaleuca* spp. (CALM, 1999). Other dominant species include *Calothamnus quadrifidus* and *Acacia cyclops* (CALM, 1999). Some wetlands within the Ramsar site contain fringes of rushes and sedges such as

Baumea juncea, *Juncus kraussii,* and *Ficinia nodosa*. *Gahnia trifida* are also found around the shore zone.

Two major studies have been conducted to describe the vegetation within the Ramsar site. In December 1987 to February 1988 (prior to listing, but probably reflecting the character at the time of listing) a survey of 106 wetlands in the south west of Western Australia was conducted, with the aim of obtaining baseline wetland vegetation data (see: Halse et al., 1993). Within the Ramsar site, Lake Warden and Station Lake were included in this survey. The second study was undertaken as part of the State Salinity Action Plan, where the vegetation of Lake Wheatfield was described between 1997 and 2000 (post listing) (see: Franke et al., 2001; Ogden & Froend, 1998).

The vegetation of some of the wetlands within the Ramsar site are described by Nature Reserve, as follows:

Lake Warden Nature Reserve

Lake Warden is saline and has been described as being surrounded by a belt of samphire species; *Sarcocornia quinqueflora, Halosarcia pergranulata, H. lepidosperma* and sporadic clumps of *Chenopodium glaucum* (Halse et al., 1993). In 1987/1988 samphire species covered approximately 60% of the area with 50% cover (Halse et al., 1993).

The sedges *Ficinia nodosa*, *Schoenus brevifolius* and *Juncus* sp. also occurred around the high water mark (Halse et al., 1993). *Melaleuca cuticularis* occurred on and above the high water mark as a discontinuous fringe with *Acacia* sp. at the back of this zone (Halse et al., 1993; Jaensch et al., 1988). In the early 1980's, Jaensch et al. (1988) described the fringing paperbarks to be living. In 1987/1988 dead trees constituted 30% of the area and had 20% canopy cover, although no indication is given as to the species that were dead (Halse et al., 1993). It is likely that the fringing *M. cuticularis* is what was described as dead in this instance, and some decline has occurred throughout the 1980's.

Lake Warden has provided important habitat to waterbirds with the *M. cuticularis* along the northern shore being described as providing cover and roosting habitat for cormorants, ducks, grebes, herons and egrets (Clarke & Lane, 2003). The vegetation also provides ideal habitat for the Rufous Night Heron (Clarke & Lane, 2003).

Woody Lake Nature Reserve

The vegetation descriptions for Woody Lake and Windabout Lake are limited, with both described as having similar vegetation of a narrow fringe of dying *Melaleuca* spp. and *Juncea* spp. (Clarke & Lane, 2003).

Vegetation surveys in 1997 and 2000 (post listing) described the vegetation to the north, east and southern areas of Lake Wheatfield as consisting of a woodland of *Banksia speciosa* with an understorey of *Darwinia diosmoides* and an unidentified Myrtaceae species (Franke et al., 2001; Ogden & Froend, 1998). A *M. cuticularis* woodland was described in the littoral zone of the wetland, along with sedges including *Ficinia nodosa* and *Baumea juncea* (Franke et al., 2001; Ogden & Froend, 1998). The northern side of the lake was dominated by *M. cuticularis*, *Spyridium globulosum* and *S. quinqueflora,* which were present at lower elevations (Franke et al., 2001; Ogden & Froend, 1998). Also along the northern side of the lake (near the outflow channel) were stands of *M. brevifolia* (Franke et al., 2001; Ogden & Froend, 1998).

At the time of these surveys of Lake Wheatfield, increasing salinity concentrations and water logging were causing the decline in condition of the *M. cuticularis* in the littoral zone (Franke et al., 2001; Ogden & Froend, 1998). As a result, no recruitment of this species was recorded in either survey (Franke et al., 2001; Ogden & Froend, 1998). It is anticipated that if salinity and waterlogging continue, recruitment of *M. cuticularis* will be further impacted and adversely affect the sustainability of this community (Franke et al., 2001). Other vegetation appeared to be unaffected by salinity, however, an area *B. speciosa* to the north of the lake appeared to be affected by *Phytophthora cinnamomi* (Franke et al., 2001; Ogden & Froend, 1998). From 1997 to 2000, it was apparent that understorey diversity had significantly declined and weed invasion had increased, which was attributed to recreational activities such as fishing (Franke et al., 2001; Ogden & Froend, 1998).

The dead stands of *Melaleuca* spp. surrounding Lake Wheatfield provides important habitat including roosting and nesting for cormorants, egrets, ibis, spoonbills and herons (Bennelongia, 2008b; Cale et al., 2004; Clarke & Lane, 2003). The open water and the overhanging vegetation around the lake also provides important loafing and roosting sites for large numbers of ducks such as Musk Ducks and Blue Billed Ducks (Clarke & Lane, 2003; Jaensch et al., 1988).

Mullet Lake Nature Reserve

On the eastern side of Station Lake is a low ridge that has a distinct band of vegetation associated with it. On top of the ridge *M. cuticularis* and an unidentified *Melaleuca* sp. have been recorded along with an understorey of shrub species consisting of *Schoenus* sp. and *G. trifida* (Halse et al., 1993). A low shrubland exists on the ridge slopes and was described as consisting of *Suaeda* *australis*, *H. synocarpa*, *S. quinquefloria*, *Sclerostegia moniliformus*, *Schoenus* sp. and *G. trifida* (Halse et al., 1993). Surrounding the ridge is marshland consisting of samphire species and beyond is a *Melaleuca* /*Acacia* woodland (Halse et al., 1993).

Prior to listing, a narrow fringe of unidentified dead trees was described as being present around the northern end of the lake, constituting 2% of the area and 1% of the canopy cover (Halse et al., 1993). Also prior to listing, samphires constituted a large percentage (70%) of the wetland vegetation with 40% canopy cover (Halse et al., 1993). Shrubs averaging 1.5 m in height, covered 10% of the area with 60% living and 40% dead canopy cover (Halse et al., 1993).

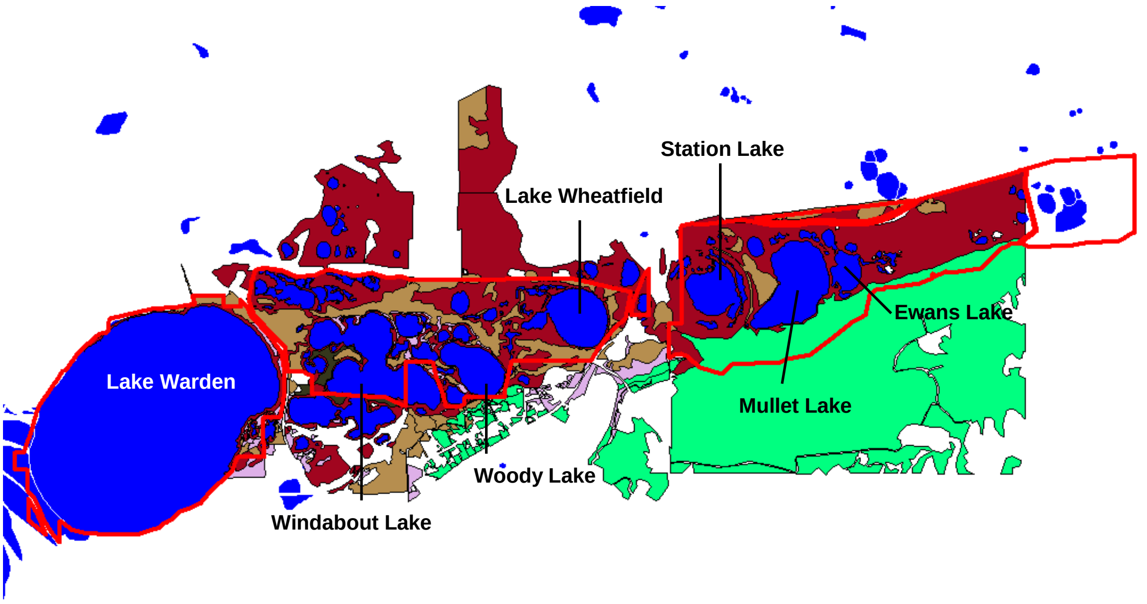
The vegetation of Ewans Lake was described more recently in 2008 (post listing) as part of the Resource Condition Monitoring Project (see: Department of Environment and Conservation, 2008b). The upper vegetative stratum was described as consisting of *Juncus kraussii* subsp. *australiensis* and *Tecticornia* sp. along with other rushes and samphires (Department of Environment and Conservation, 2008b). The understorey was dominated by *S. quinqueflora*, *Suaeda australis* and *Hemichroa pentandra* low shrubland (65.1% cover, < 0.4 m tall) (Department of Environment and Conservation, 2008b). Isolated individuals of *M. cuticularis* and *M. brevifolia* (approximately up to 4 m) were also observed scattered along the shoreline and at the time appeared to be in good health (Department of Environment and Conservation, 2008b).

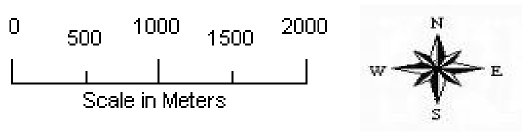
Some isolated plants of *Parapholis incurva* (a weed species) were recorded, however, overall the community condition was considered “natural” (Department of Environment and Conservation, 2008b). The species *Hemichroa pentandra* is represented by only four herbarium records from Western Australia, namely from Rottnest Island and the Kimberley region (Department of Environment and Conservation, 2008b). The recording of this species at Ewans Lake in Esperance represents a substantial range extension for the species (Department of Environment and Conservation, 2008b).

The description of the vegetation at Mullet Lake is limited, however, it is adjacent to Ewans Lake and has similar species present, broadly described as an open lake with a samphire fringe (Pinder et al., 2004).

In addition to these, in 2004 Massenbauer (2007b) surveyed and broadly mapped a total of five community types for parts of the Lake Warden area and including *Banksia* Woodland; *Eucalyptus* Woodland; *Nuytsia* Mixed Heath; *Acacia* Coastal Shrubland and *Melaleuca* Woodland (Figure 36). The survey and mapping were undertaken using Digital Multi-Spectral Imaging (DMSI) combined with ground truthing to identify vegetation types and monitor vegetation condition. In 2007, the survey was repeated and vegetation change over the three years was determined by comparing the DMSI data and a vegetation change detection image was produced. Vegetation change was determined as a measure of change in plant cell density.

Melaleuca woodland is the dominant vegetation type immediately surrounding the wetlands within the Ramsar site, consisting mainly of *M. cuticularis* and *M. brevifolia* (Figure 36). On-ground observations indicate that the *Melaleuca* woodland is the predominant vegetation type in decline, affected by increases in the timing and extent of inundation of saline water. Approximately 603 ha of *Melaleuca* woodland has been mapped in the Lake Warden area and the DMSI analysis indicates that at 2007, 187 ha (31%) of *Melaleuca* woodland was already dead and 198 ha (33%) was in further decline (Department of Environment and Conservation, 2007b). However, it must be understood this analysis extends beyond the boundary of the Ramsar site and does not give a true quantitative evaluation of dead and declining vegetation within the Ramsar site. Nonetheless, ground observations combined with this data would suggest that vegetation is being affected by an altered hydrological regime.





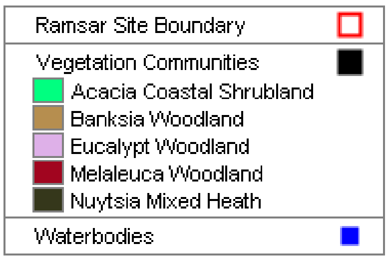


Figure 36. Lake Warden vegetation communities, Esperance, Western Australia (data from Department of Environment and Conservation, 2007b). Note: Eastern Melaleuca woodland near Ewans Lake consists of mainly open rush and samphires with isolated patches of Melaleuca woodland.

3.1.6.4.2 Aquatic flora

Aquatic flora are primary producers and are an important food source to both invertebrates and waterbirds. Aquatic flora provide feeding and structural habitat for waterbirds, aquatic invertebrates and fish.

The aquatic flora (phytoplankton and macrophytes) for Lake Warden, Woody Lake, Wheatfield Lake, Windabout Lake and Station Lake was described in the summer and winter months in 1991 and 1992/1993 (see: Handley, 1991, 2003). The lakes were described as containing characteristic aquatic flora that are dominated by diatoms and cyanobacteria (Handley, 1991). Approximately 100 taxa were identified from six phylum: Bacillariophyta (diatoms); Cyanophyta (cyanobacteria); Dynophyta (dinoflagellates); Euglenophyta (flagellates), Chlorophyta (green algae) and Charophyta (stoneworts) (Handley, 1991, 2003). Winter months recorded higher biodiversity than the summer months, however, the results were not statistically significant (Handley, 1991). The lake contained macrophyte flora that are common to the south west of Western Australia such as *Lamprothamnium papulosum*, *Lepilaena preissii* and *Ruppia polycarpa* (Handley, 1991).

Algal composition of Lake Warden deviated from the other lakes (Wheatfield, Woody, Mullet) and was dominated by the macrophyte *Lamprothamnium papulosum* (Handley, 2003). The algae species *Martyana martyi* was also present and is widespread in eutrophic waters (Handley, 2003).

The algal floral community of Mullet Lake reflects a degree of marine influence because of the connection to Bandy Creek, which terminates at the Southern ocean. Algal species such as *Mastogloia halophila, Mastogloia reimeri, Bracysira aponina* have been common (Handley, 2003). As salinity decreased in the winter, the algal community shifted from diatom dominated to cyanobacteria species *Aphanocapsa elachista* and *Gomphosphaeria aponina* (Handley, 2003).

Algal mats were also recorded at Lake Warden, Woody Lake and Mullet Lake (Handley, 1991, 2003). Taxa from the phyla Bacillariophyta, Charophyta, Chlorophyta and Cyanophyta made up the algal mats at Woody Lake (Handley, 1991, 2003). Bacillariophyta and Chlorophyta phyla were represented in the algal mats of Lake Warden and Mullet Lake was dominated cyanobacteria (Handley, 1991, 2003).

3.2 CRITICAL ECOSYSTEM BENEFITS AND SERVICES

As well as describing the critical components and processes of an ecosystem it is important to also understand the benefits and services they provide. Ecosystem benefits and services are defined by the Millennium Ecosystem Assessment as *"the benefits that people receive from ecosystems"* (Ramsar Convention, 2005a). Ecosystem benefits are both tangible and intangible and can be in the form of economic, social, health and cultural benefits.

Ecosystem benefits and services are derived directly from the ecosystem components and processes as a result of the interaction between them (Figure 37). There is therefore a correlation between the preservation of the ecosystem components and processes and the continuation of the benefits people receive from them. This focus is particularly prevalent in the Ramsar sites of developing countries, where the preservation of the critical ecosystem components and processes is directly related to the livelihood and health of people. This forms part of the reason why some Ramsar sites in developing countries have been nominated in the first instance. The recognition of link between critical ecosystem benefits and services and the benefits and services they provide to people helps drive more sustainable practices. This sub-section provides a description of the critical benefits and services provided by the ecosystem of the Lake Warden System Ramsar Site and the rationale for their identification.

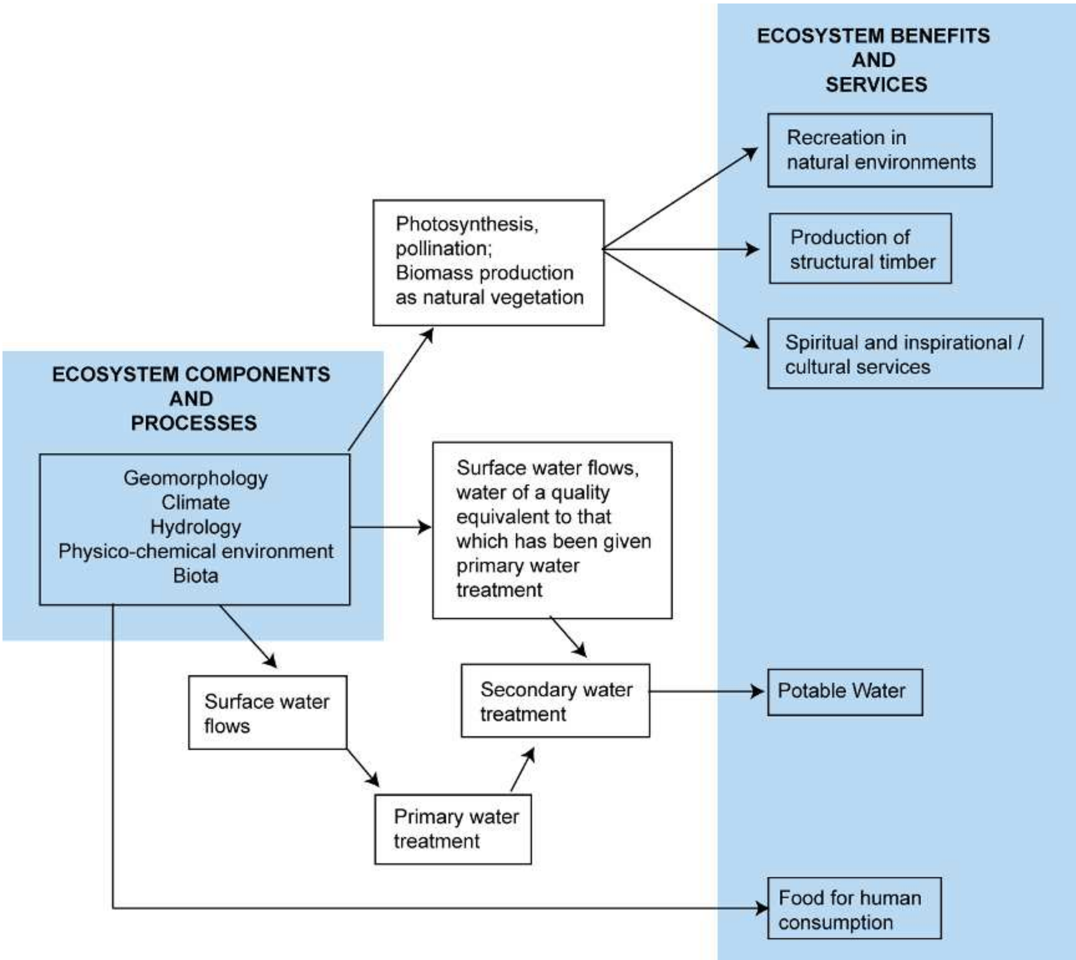


Figure 37. Conceptual model of wetland ecosystem components and processes and ecosystem pathways in delivering ecosystem benefits and services (adapted from Wallace, 2007).

The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005a, 2005b) identifies four main categories of ecosystem benefits and services:

1. ***Provisioning services –*** *the products obtained from the ecosystem such as food, fuel and freshwater;*
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.*

Rationale for selection of the critical ecosystem benefits and services

The identification and description of the critical benefits and services of the Lake Warden System Ramsar Site is based on the minimum requirements set by DEWHA (2008). The critical ecosystem benefits and services have been selected on the basis that:

- They are important determinants of the site's unique character;
- They are important for supporting the Ramsar Criteria under which the site was listed;
- Changes to the benefits and services are likely to occur over short or medium time scales (<100 years); and
- Significant negative consequences will be the result of changes to the benefits and services.

The critical ecosystem benefits and services are related to the critical ecosystem components and processes of the Lake Warden System Ramsar Site (see: Section 3.1 Critical Ecosystem Components and Processes). They also illustrate the values of the Lake Warden System Ramsar across multiple audiences and not just from an ecological perspective.

Table 9 provides a summary of the critical ecosystem benefits and services of the Lake Warden System Ramsar Site.

Table 9. Critical ecosystem benefits and services for the Lake Warden System Ramsar Site, Esperance, Western Australia.

Category	Description
Provisioning Services *The material products provided directly from wetland ecosystems including food, fresh water, fibre, fuel, biochemical's and genetic material.*	
Genetic resource	Plausible but not yet confirmed.
Human health	Provides an environment conducive to the continuation of human physical and mental health.
Regulating Services *The material benefits obtained from the regulation of wetland ecosystem processes.*	
Pollution control and detoxification	The site is a sink for excess nutrients, sediments and saline water discharges from the surrounding catchments
Natural hazard reduction	The wetlands within the Ramsar site have a role in flood mitigation providing protection to the Esperance township and properties surrounding the site.
Cultural Services *The benefits people obtain through spiritual and Inspirational, enrichment recreation, education and aesthetic experiences.*	
Recreation and tourism	Highly valuable tourism resource providing various recreational activities.
Science and education	Long term recording of water depth and quality. Opportunities for science based management of threatening processes.
Cultural heritage and identity/ Spiritual and inspirational	Indigenous people have an historical affinity with some of the lakes within the Ramsar site. The site also has European heritage values and provides "sense of place".
Aesthetic amenity	Provides scenic values to residents and visitors which are in addition to others in the scenically rich area.
Supporting Services *Those services necessary for the production of all other ecosystem services including soil formation and nutrient cycling.*	
Hydrological processes	The lakes within the Ramsar site store surface water and to varying degrees recharge local groundwater aquifers.
Nutrient cycling	The Ramsar site has a role in nutrient cycling although the scale at which this occurs is unknown.
Biodiversity	Supports 1% of the population of two waterbird species and a diversity of aquatic invertebrates.
Physical habitat	Provides varied waterbird feeding habitats (wading to deep diving) and is a drought refuge during summer periods. Vegetation within the site provides important breeding and roosting habitat for waterbirds. Habitat varies within the Ramsar site from wetland to terrestrial, offering habitat for wetland and terrestrial dependant species.
Priority wetland species	Supports the Hooded Plover which has a current management plan and is listed by DEC as a Priority Four species (taxa in need of monitoring). The Hooded Plover is also listed as "Near Threatened" under the IUCN Red List and as "Marine" under the EPBC Act. Forty two waterbird species listed under the EPBC Act have been recorded at the Ramsar site which includes waterbirds listed under CAMBA, JAMBA, ROKAMBA and CMS.
Ecological connectivity	Forms part of an interconnected habitat of wetlands for waterbirds and other wildlife in the Esperance region.

3.2.1 PROVISIONING SERVICES

Genetic resource

The Lake Warden System Ramsar Site, like other ecosystems, contains genetic resources that require conserving in order to provide provisioning, regulating, cultural and supporting services in the future. Although, not confirmed it is plausible that if any genetic resource at the Lake Warden System Ramsar Site was lost that it would affect the ecosystem functioning in a way that would discontinue the provision of other benefits and services.

Human health

Human health both physically and mentally is attributed partly to the health of the environment. It is evident that a relationship exists between the decline in human health and a decline in environmental health. Dryland salinity illustrates such a relationship, which has been attributed to multiple human health problems such as: respiratory health problems through increases in wind-borne dust; increases in the threat and incidence of the Ross River virus by altering the ecology of the mosquito-borne disease; and a decline in mental health (Jardine, 2007).

The health of an ecosystem such as the Lake Warden System Ramsar Site and the surrounding catchments is therefore also important to human health. Although the contribution to human health that the Lake Warden System Ramsar Site provides is difficult to quantify, it is nonetheless a valid benefit and service to people.

3.2.2 REGULATING SERVICES

Pollution control and detoxification

The Lake Warden catchment has long standing issues, many of which are associated with the clearing of deep rooted vegetation to make way for agriculture. The result is that the wetlands within the Ramsar site act as a sink for excess nutrients, sediments and saline water discharges from the catchment. Pollution is recognised as a threatening processes at the Ramsar site (see: Comer et al., 2001), and the site therefore has a monetary benefit in supplying this regulating service. Particularly, as some of the saline water discharges are the result of the installation of deep drains on farms to alleviate problems associated with excessive rises in groundwater.

Natural hazard reduction

The clearing of native vegetation for agriculture has altered the hydrological regime in the Lake Warden catchment. This has resulted in rising watertables and increased surface water runoff, directly impacting on the wetlands within the Ramsar site (Halse & Massenbauer, 2005; Short, 2000). As a result, when the affects on an already cleared catchment are combined with exacerbating unseasonal episodic rainfall events such as those in 1999, 2000, 2007 and 2009 (see Section 2.4 Climate), flooding occurs. The wetlands within the Ramsar site have a role in flood mitigation, providing protection to the Esperance township and properties surrounding the site. Although, the flood of 2007 was severe and the Esperance region was declared a Natural Disaster Zone, it is anticipated that the impact of flooding events such as these would be more severe if the wetlands within the Ramsar site were not providing this benefit/service.

3.2.3 CULTURAL SERVICES

Recreation and tourism

The Ramsar site offers numerous nature based recreational and tourism values such as bushwalking, bird watching and picnicking. Bushwalking trails with interpretive signage exist around Woody Lake and Lake Wheatfield. Bird hides are located on Lake Wheatfield to enhance this experience for visitors who enjoy bird watching. It is also used by the Esperance Bird Observers Group who are an active community group and have been involved in many waterbird surveys at the site.

Some active water based recreational activities occur within the Ramsar site including, fishing, canoeing, windsurfing, sailing and water skiing. Water skiing is a seasonal activity occurring when water levels are deep enough. Woody Lake is currently gazetted as the water ski area within the Ramsar site and it is anticipated that this activity will continue, although the engineering dewatering management activities to reduce water levels may impact on this type of recreational use. This will be discussed further in Section 4.0 Threats to Ecological Character.

Canoeing currently occurs at all the major wetlands within the Ramsar site and some of the deeper satellite wetlands, along the canoe trail between Woody Lake and Lake Wheatfield. Windsurfing and sailing sometimes also occurs at Lake Warden, Lake Wheatfield and Windabout Lake (CALM, 1999).

Science and education

Long term recording of water depth and water quality have occurred at lakes within the Ramsar site (see: Section 3.1 Critical Ecosystem Components and Processes) and it has historically been used as an education tool for local schools (Ribbons of Blue Programme). Educational values are also supported by interpretive signage at the Ramsar site, which explains the ecological aspects and threatening processes of the site. The Ramsar site is also part of the Esperance Hooded Plover Management Region (see: Raines, 2002).

This site also has threatening processes associated with catchment land use and catchment clearing, providing an opportunity to apply science based management to alleviate these threats. Currently, engineering dewatering is occurring at Lake Wheatfield (see: Massenbauer & Vogwill, 2007; Maunsell/AECOM, 2008) to alleviate the threat of excess water within the Ramsar site. The lessons learned from this can be then be applied to other similarly affected ecosystems.

Cultural heritage and identity/Spiritual and inspirational

The Esperance Lakes Nature Reserves, which include the Lake Warden System Ramsar Site are listed on the Register of the National Estate and are significant not only in terms of the biodiversity present but also due to cultural heritage.

The Ramsar site also provides a "sense of place" for the community, contributing to wellbeing and spiritual values. Aboriginal people have an historical connection with the lakes of the Lake Warden System and Bandy Creek (CALM, 1999). The Lake Warden area is regarded as a important area for food gathering and fishing by Indigenous people (Henry Dabb, South Coast NRM, pers. comm., 2008). Four Aboriginal sites listed with the Department of Indigenous Affairs occur within the Ramsar boundary (Figure 38) and a total of 8 occur within the wider Esperance area.

- Lake Warden - Site No 20607 has mythological significance for the Rainbow Serpent the "Waugal";
- Bandy (Barndi Creek) - Site No 22938 mythological and historical (camping and hunting) significance;
- Bandy (Barndi Creek) - Site No 1713 has Aboriginal significance as a camping and hunting place; and
- Mullet Lake - Site No 1638 has Aboriginal significance as a camping and hunting place.

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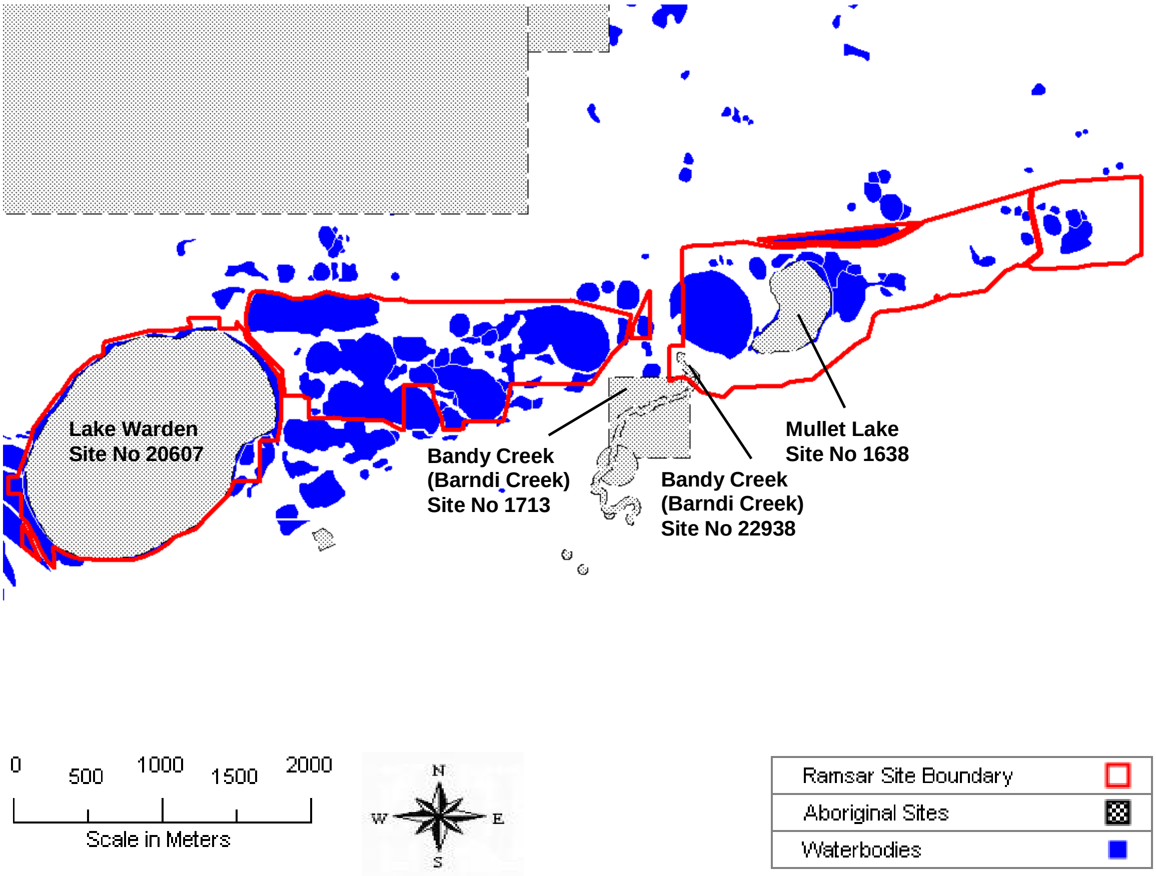


Figure 38. Aboriginal Sites within and surrounding the Lake Warden System Ramsar Site, Esperance, Western Australia.

Esperance Bay was named after the French ship *Espérance* that took shelter there in December 1792, with the town of Esperance later named in 1893 (CALM, 1999). The Dempster brothers ran sheep through the majority of the Esperance area from the 1860's and were the original European settlers of the region (CALM, 1999). Remnants of their woolshed are located in the Woody Lake Nature Reserve within the Lake Warden System Ramsar Site (CALM, 1999). Early clearing of vegetation for farming and the installation of infrastructure such as roads, is associated with these early settlements.

Prior to listing as a Ramsar Site, Woody Lake and Mullet Lake Nature Reserves were managed as game reserves, where selected species of waterbirds were taken for sport (CALM, 1999). The last open season on these reserves was the season of 1989-1990 after which the two reserves were included as part of the Ramsar Site (CALM, 1999).

Aesthetic amenity

The Esperance area is a scenically rich area known internationally and nationally for its pristine beaches and coastline. The Lake Warden System Ramsar Site provides additional scenic and aesthetic values to the Esperance region.

3.2.4 SUPPORTING SERVICES

Hydrological processes

The lakes within the Ramsar site store surface water and therefore provide a drought refuge to waterbirds during the summer months. The wetlands in the Ramsar site recharge local groundwater aquifers to varying degrees, although in general, winter lake levels rise ahead of groundwater and recharge the surrounding aquifers.

Nutrient cycling

Ecosystems have a role to play in the cycling of chemical elements from the abiotic parts of the environment into organic components. The details, such as nutrient loads and internal loading, are unknown for the Lake Warden System Ramsar Site.

Biodiversity

The lakes within the Ramsar site are varied in terms of their physico-chemical attributes, which in turn equates to diversity in aquatic invertebrates. The lakes within the Ramsar site are distinct in terms of their assemblages of aquatic invertebrates. The site has also supported on a regular basis 1% or more of the population of Chestnut Teal and the Hooded Plover (see: Wetlands International, 2006).

Physical habitat

The site provides a variety of habitats from wetland to terrestrial, supporting aquatic as well as terrestrial species. In particular, there are important sites such as the north-east section of Lake Warden where large numbers of loafing Hooded Plover have been recorded (Jaensch et al., 1988).

The vegetation surrounding the lakes within the Ramsar site provides nesting and roosting habitat for many species of waterbirds. The vegetation surrounding Lake Wheatfield in particular is attractive to large numbers of colonial waterbirds.

The Ramsar site is a drought refuge in summer for many waterbirds and also provides various waterbird feeding habitats from wading to deeper feeding conditions.

Priority wetland species

The site supports the Hooded Plover, which has a current management plan aimed at conserving the species and its habitat (see: Raines, 2002). The Hooded Plover is listed by DEC as a Priority Four species (taxa in need of monitoring) and is considered as "Near Threatened" under the IUCN Red List and "Marine" under the EPBC Act. Forty two waterbird species listed under the EPBC Act have been recorded at the site: 40 species are listed as "Marine", 25 species are listed as "Migratory" and are included under the international migratory bird agreements CAMBA (23), JAMBA (22), ROKAMBA (19) and CMS (20).

Ecological connectivity

Within the Esperance region there are multiple wetlands providing habitat to waterbird species. The Lake Warden System Ramsar Site forms part of this interconnected habitat of wetlands for waterbirds and other wildlife in the Esperance region. The site is part of the south coast "macro-corridor" which is a near continuous strip of native coastal vegetation along the south coast between Albany and Esperance in Western Australia. These corridors allow for movement of flora and fauna and connect various habitat types.

4.0 THREATS TO ECOLOGICAL CHARACTER

This section identifies actual or likely threats to the ecological character of the Lake Warden System Ramsar Site. Table 10 provides a summary of the threats to the critical ecosystem components, processes, benefits and services at the Lake Warden System Ramsar Site. It is anticipated that any threatening process acting on the critical ecosystem components and processes at the Lake Warden System Ramsar Site will result in a reduced capacity of the site to provide critical ecosystem benefits and services. The threats also have the ability to cause a change in ecological character which will be explored in Section 5.0 Changes to Ecological Character.

Table 10. Threats to the critical ecosystem components, processes, benefits and services of the Lake Warden System Ramsar Site, Esperance, Western Australia.

Actual or likely threat or threatening activities	Potential and/or actual impact(s) to wetland components, processes, benefits and services	Likelihood	Timing of threat
Urban / industrial development and agricultural activities • Clearing of native vegetation • Livestock grazing • General cropping and agricultural activities • General infrastructure • Urban encroachment	• Altered hydrological regime - timing, frequency and extent of inundation • Introduction and establishment of weeds and feral animals • Increased salinisation (secondary salinisation) through changed hydrology (Short et al., 2000) • Pollution - nutrient, sediment and salinity (Comer et al., 2001) • Reduction in waterbird habitat area • Reduction in extent and condition of native vegetation • Altered fire regimes • Changes to water and sediment chemistry • Disturbance of potential acid sulfate soils • Increased fragmentation, loss of remnants and lack of recruitment	Certain/high	Immediate - long term

Actual or likely threat or threatening activities	Potential and/or actual impact(s) to wetland components, processes, benefits and services	Likelihood	Timing of threat
	• Reduction in the capacity for the site to provide provisioning, regulating, cultural and supporting services		
Non native and alien species	• Competition with native flora and fauna reducing habitat area and condition • Loss of native species • Reduction in the capacity for the site to provide provisioning, regulating, cultural and supporting services	Certain/high	Immediate
Plant diseases • *Phytophthora cinnamomi* • *Armillaria luteobubalina*	• Vegetation death • Alteration of plant communities • Loss of fauna habitats	Certain/high	Immediate
Climate change • Changes in rainfall, temperature and wind regimes • Increases in extreme episodic events	• Altered catchment hydrological regimes - timing, magnitude and frequency of flows into the Ramsar site • Altered hydrological regime i.e. timing, frequency and extent of inundation • Changes to flora and fauna distribution and condition • Increased non-native flora and fauna species • Increases in sedimentation • Reduction in the capacity for the site to provide provisioning, regulating, cultural and supporting services	High	Medium to long term (5 years to decades)
Recreation	• Introduction and establishment of weeds • Spread of alien and non-native species such as weeds • Spread of *Phytophthora cinnamomi* and other plant diseases • Destruction of flora and fauna habitat • Increased fire risk • Direct impacts on flora and fauna (e.g. by vehicles and trampling, impacting vegetation and waterbird, loafing, roosting and breeding sites) • Reduction in the capacity for	High	Immediate to long term (decades)

Actual or likely threat or threatening activities	Potential and/or actual impact(s) to wetland components, processes, benefits and services	Likelihood	Timing of threat
	the site to provide provisioning, regulating, cultural and supporting services		
Engineering dewatering • Lake Wheatfield and Lake Warden	• Clearing of native vegetation • Disturbance of fauna habitats • Spread of alien and non-native species such as weeds • Spread of *Phytophthora cinnamomi* and other plant diseases • Change in lake chemistry and seasonality • Exposure of PASS – acidity and heavy metal risk • Reduction in the capacity for the site to provide provisioning, regulating, cultural and supporting services	Low	Medium to long term (5 years to decades)

4.1 URBAN / INDUSTRIAL DEVELOPMENT AND AGRICULTURAL ACTIVITIES

4.1.1 ALTERED HYDROLOGY

Many of the threats to the Ramsar site are driven by catchment activities. Clearing for agriculture, along with encroaching urbanisation, have resulted in altered catchment hydrology causing rising groundwater levels, increased surface water runoff and prolonged inundation of wetlands areas. Other threats associated with altered hydrology include secondary salinity, erosion, waterlogging, sedimentation and eutrophication. Approximately 8% of agricultural land in Esperance is affected by secondary salinity and under current recharge rates, approximately 27% of the Lake Warden Catchment will be at risk from salinity by 2020, increasing to approximately 45% by 2050 (Short et al., 2000). Agricultural production has been reduced or lost in lower areas due to waterlogging, salinity, eutrophication and siltation following clearing (Massenbauer, 2007a).

The hydrological changes in the Lake Warden Catchment have in turn altered the hydrological regime of the wetlands within the Ramsar site. The threats facing the Ramsar site and the Lake Warden Catchment as a whole, has seen the catchment designated as a NDRC since 1996 (Government of Western Australia, 2000).

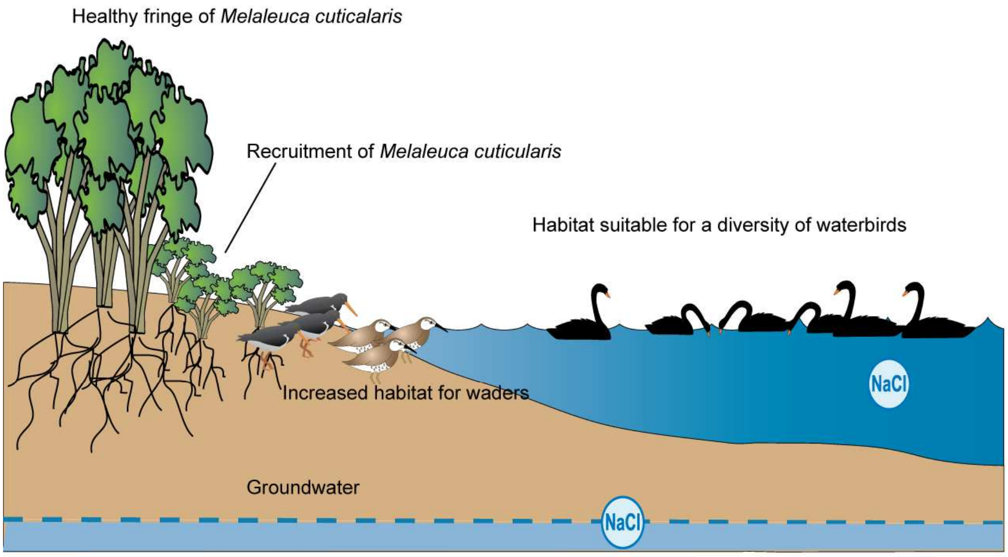
Threat to flora and fauna

The waterbird and riparian vegetation values of the LWWS are under immediate threat from rising water tables and excessive inundation (Massenbauer & Vogwill, 2007). The altered hydrological regime in the catchment has resulted in increases in the water depth and the extent and duration of inundation at many of the wetlands within the Ramsar site, particularly Lake Warden. The hydrological changes have been implicated in the death and decline of some components of the riparian vegetation of the Ramsar site (Comer et al., 2001). The decline and death of vegetation has been mainly associated with *Melaleuca cuticularis,* which fringes many of the lakes of the Ramsar site (see: Department of Environment and Conservation, 2007b; Franke et al., 2001; Ogden & Froend, 1998). The threats to vegetation also include soil waterlogging and increased inputs of saline to hypersaline water. *M. cuticularis* is tolerant of waterlogging and has been recorded withstanding salinities of up to 42 ppt (Carter et al., 2006; Froend & van der moezel, 1996). However, prolonged flooding deprives tree roots of oxygen and *M. cuticularis* are likely to die if they do not dry out every 1 to 2 years (Froend et al., 1987).

The altered hydrological regime experienced at the Ramsar site is also reducing waterbird habitat diversity, particularly wading waterbird habitat such as that suitable for the Hooded Plover (Clarke & Lane, 2003; Massenbauer, 2008; Robertson & Massenbauer, 2005).

Figure 39 conceptualises changes in the hydrological regime of Lake Warden and its affects on fringing riparian vegetation and waterbird species composition.

A) Unaltered hydrological regime



B) Altered hydrological regime

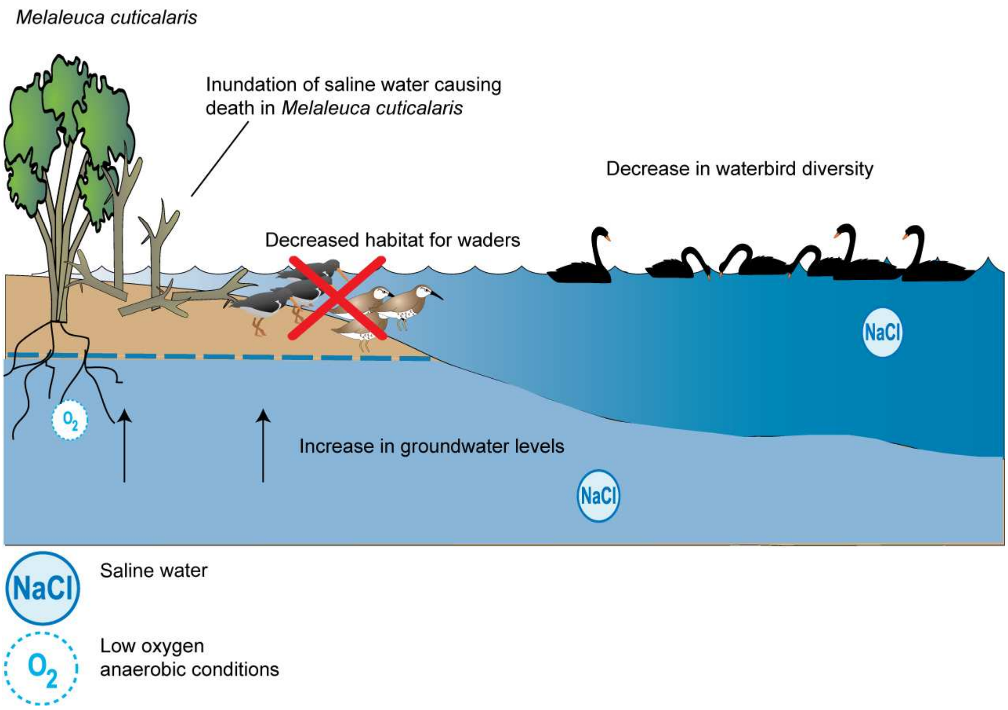


Figure 39. Conceptual changes in hydrological regime at Lake Warden, Lake Warden System Ramsar Site, Esperance, Western Australia. A) Unaltered hydrological regime suitable habit for a diversity of waterbirds and healthy fringe of riparian vegetation; B) Altered hydrological regime resulting in a reduced diversity of waterbird habitats; and death of fringing riparian vegetation from low oxygen conditions and prolonged inundation of saline water.

4.1.2 POLLUTION

Pollution is recognised as a threatening process to the Lake Warden System Ramsar Site (Comer et al., 2001) in the form of nutrients, sediments and saline water discharges from surrounding agricultural land and urban uses (CALM, 2006).

Although Wilson (2004) suggests Lake Wheatfield, Lake Warden and Station Lake are naturally eutrophic, anthropogenic sources of nutrients are present and pose a threat to the Ramsar site. Analysis of sediment cores taken in Lake Wheatfield, Lake Warden and Station Lake have shown elevated nutrient levels occurring from the 1950's, coinciding with the beginning of agriculture and application of fertiliser in the catchment (Wilson, 2004). There have also been anecdotal reports of algal blooms occurring at the Ramsar site and algal species associated with eutrophication have also been recorded (see: Handley, 1991). In addition, the levels of TP and TN recorded at the Ramsar site are high when compared with ANZECC and ARMCANZ (2000b), suggesting that nutrient enrichment is a potential threat.

Other recognised potential sources of nutrients include the meat works in the Lake Warden Catchment and the irrigation of areas in the vicinity of the Ramsar site with treated, diluted sewage. The meat works irrigate treated wastewater from the processing and rendering plant onto pastured areas. The Esperance Shire irrigates the Esperance Golf Course, Esperance Turf Club and the Newtown Football Club oval with treated, diluted sewage. These areas are all in the vicinity of the Ramsar site. The irrigation of treated diluted sewage has the ability to impact the site as it is a source of nutrients and provides additional water to a system already being impacted by increases in water volumes.

Sedimentation rates have been documented at Lake Wheatfield, Lake Warden and Station Lake (Wilson, 2004). The rate of sediment accumulation has increased 5 to 20 times in Lake Wheatfield, Lake Warden and Station Lake since widespread clearing of the catchments (Wilson, 2004). Sedimentation can directly smother vegetation and faunal habitat, however, the increased sedimentation rates mainly pose a threat to the ecological character of the Ramsar site by altering wetland bathymetry, making them shallower. This displaces water and increases the extent of inundation, while reducing the amount of exposed shore zone and wading waterbird habitat. In addition, wetland vegetation becomes inundated and nutrient cycles can become disrupted.

4.1.3 ALTERED FIRE REGIMES

Fire and fire suppression are a potential threat to the ecological character of the site due to the land use surrounding the Ramsar site. Agriculture has the potential to increase the occurrence of fire due to the use of agricultural machinery and the growth of annual crops which provide dry fuel during summer periods. To protect human life, infrastructure and businesses in urban environments, fire is also suppressed. Fire is a naturally occurring form of disturbance in Australia and is essential for seed germination, dispersal and nutrient recycling within ecosystems (Australian Academy of Science, 1981). Depending on the intensity, disturbances such as fire can be associated with high species richness and diversity (Beard et al., 2000; Kimmins, 2004; Morrison, 2002). However, this is also dependant upon other factors such as fire frequency and timing (Morrison, 2002). Fire suppression leads to a build up of fuel and the ensuing fire may then burn too intense for flora and fauna to recover.

Another issue associated with fire is the introduction of weeds and weed infestation. Disturbance through fire provides the opportunity for weeds to replace the native species of the Lake Warden System Ramsar Site. Fire can also cause hydrological changes through the removal of vegetation. Other threats resulting from fire include the attraction of feral animals to an area to feed on new growth that results post fire (Nikki Cowcher, Fire Operations Officer, DEC, pers. comm., 2008). For example, after a fire there is often a concentration and abundance of rabbits, which causes erosion and changes vegetation structure; rabbits will also attract foxes which may predate on native species (Nikki Cowcher, Fire Operations Officer, DEC, pers. comm., 2008).

Most of the vegetation within the Ramsar site has remained unburned for at least 30 years (CALM, 1999). Australian flora relies on different methods of recovery post fire; some species are able to resprout from epicormic buds and some are obligate seeders. Therefore, some species can withstand more regular fires, for example resprouters such as Eucalypt species, can withstand more regular fires than obligate seeders. Although seeder species such as Acacias respond quickly and positively post fire, another fire occurring before the new generation has set seed may completely remove the species from the ecosystem. It is these sorts of balances between intensity and frequency of fire that are difficult to maintain during prescribed burns. However, what is clear is that many of Australia’s native flora relies on fire or components of fire for regeneration to occur. For example, *Banksia* spp. rely on a combination of heat and smoke chemicals for seed to disperse and germinate (Dixon et al., 2001; Rokich et al., 2002). Some stands of *Banksia speciosa* within the Ramsar site appear to be in a state of collapse, most likely due to infrequent burns and fire may be required to regenerate these areas (CALM, 1999).

The fire management strategy for the Ramsar site will be covered in the Esperance and Recherche Parks and Reserves Management Plan which is currently in preparation.

4.1.4 ACID SULFATE SOILS

The soils of the Gore system have a high probability of having PASS (Massenbauer, 2007a) and these soils may exist within the Ramsar site (see: Section 3.1.5 Wetland Soils). The activities in the surrounding catchment may disturb and expose these PASS.

Acidity and heavy metal risk

Exposure of PASS, which leads to AASS, presents an acid and heavy metal risk to the ecological character of the Ramsar site which may result in:

- Increasing anoxia of benthic sediments due to the formation of iron monosulphide black oozes (MBO) caused by increasing sulfate inputs into the Ramsar site. This could reduce the biodiversity and abundance of benthic macroinvertebrates;
- Increased eutrophication and associated algal blooms linked to increasing MBO formation and sulfate inputs. These factors cause phosphorus to be released from benthic sediments into the water column in wetlands. An increase in the frequency of algal blooms in the wetland are a threat to fauna (i.e. death) due to cyanobacterial toxins;
- Increasing soluble aluminium due to acid drainage entering the wetland. Aluminium is extremely toxic to macroinvertebrates, which are likely to form the base of local food webs that support waterbird populations in the wetland. Elevated levels of metal concentrations such as aluminium and iron have been recognised to result in fish kills (Sammut et al., 1995; Stephens & Ingram, 2006). Additionally, increased levels of readily soluble aluminium may cause aluminium toxicity in the fringing vegetation of the wetlands; and
- Increasing levels of heavy metals in the benthic sediments of the wetlands due to inputs from acid saline drainage. The heavy metal of most concern in the catchment is likely to be lead, due to its abundance in leachate from granitic rocks and due to the risk of this metal bioaccumulating in organisms and being biomagnified through local food webs (Steve Appleyard, Hydrogeologist, DEC, pers. comm., 2008).

Figure 40 conceptualises the threat of acidity to the Ramsar site.

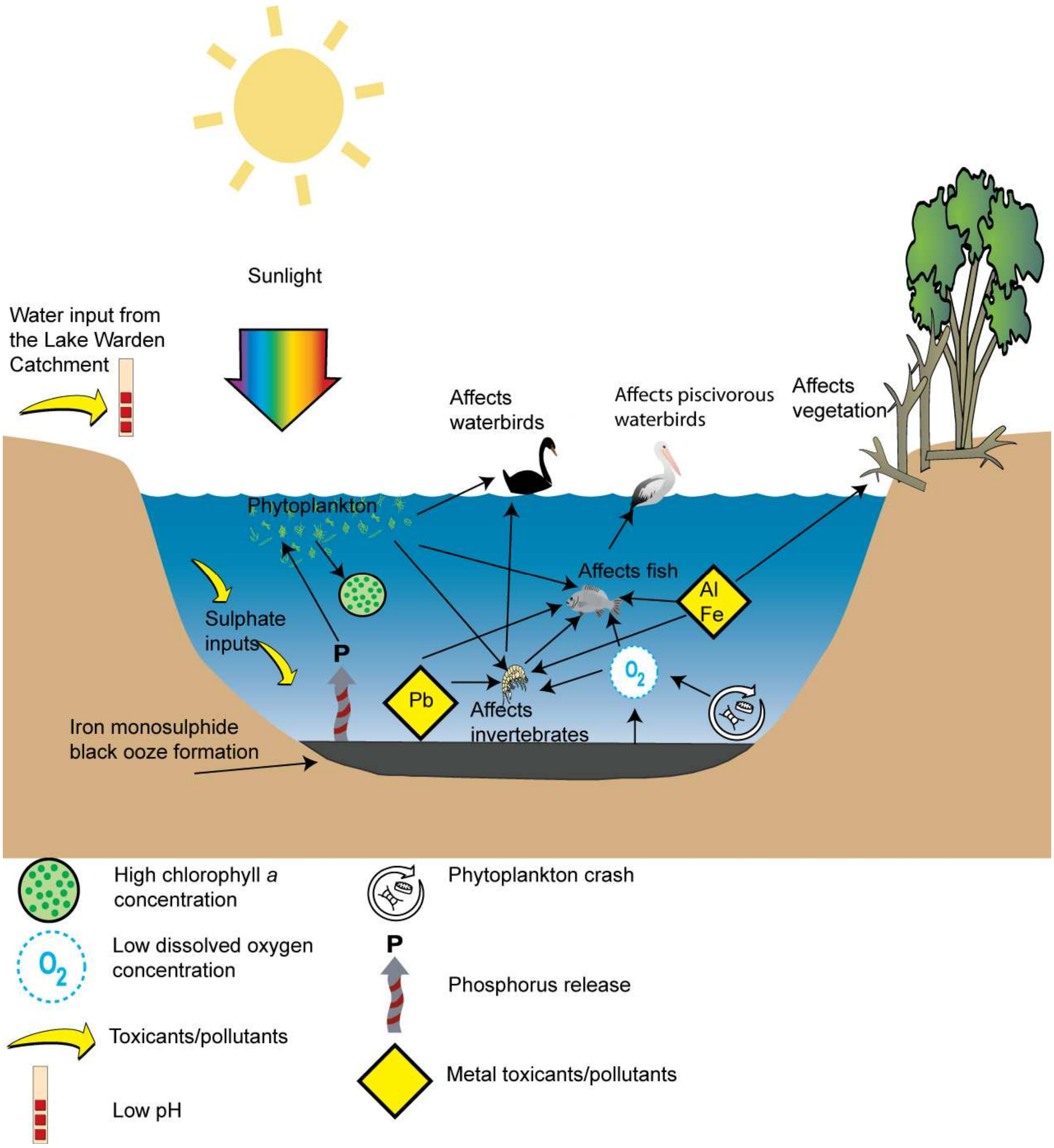


Figure 40. Conceptual model of the potential acidity threat to the Lake Warden System Ramsar Site, Esperance, Western Australia.

4.1.5 OTHER THREATS

Other threats arising from urban / industrial development and agricultural activities are based around the infrastructure and associated behaviours related to human development. Urban development in particular has encroached to the edge of the Ramsar boundary.

Activities incompatible with the purpose of the Nature Reserves such as driving of off-road vehicles (motorcycles and cars), horse riding, shooting, timber cutting, rubbish dumping and the extraction of soil and sand material have occurred within the Ramsar site (CALM, 1999). All of these activities pose direct and indirect threats on the ecological character of the Ramsar site. Off-road vehicle use is particularly concentrated within the Mullet Lake Nature Reserve. The shore zone on the eastern side of Station Lake is for the most part impacted by off-road vehicles. It has been observed that motor vehicles are impacting on waterbird habitat and the samphire vegetation on this portion of the lake. Of particular concern is the disturbance of Hooded Plover and other waterbirds nesting, feeding and loafing habitat at Station Lake. Historical waterbird counts in the mid 80's (see: Jaensch et al., 1988) also highlight this threat, indicating that if the shore zone on the eastern side of Station Lake is frequently disturbed by motor vehicles the area may become unsuitable for Hooded Plovers. It is understood that policing this activity has been extremely difficult.

Historical waterbird counts in the mid 80's (see: Jaensch et al., 1988) also indicate that vehicles are frequently driven over the north-east section of Lake Warden, which is also important habitat for Hooded Plover and other loafing waterbirds.

The Nature Reserves and wetlands within the Ramsar site are also impacted by infrastructure. For example, telephone and powerlines, roads, railway and drainage systems exist in and around reserves, in particular the Lake Warden and Woody Lake Nature Reserves (CALM, 1999). Roads and the Coolgardie to Esperance railway in between Pink Lake and Lake Warden pose a threat due to inherent dangers such as chemical spills from vehicles (CALM, 1999).

4.2 NON-NATIVE AND ALIEN SPECIES

The Esperance Sand Plain Biogeographic Region is host to some of the typical exotic mammal species found in the Wheatbelt region of Western Australia including, the house mouse (*Mus domesticus)*, black rat (*Rattus rattus)*, red fox (*Vulpes vulpes)*, cat (*Felis catus)* and the European rabbit (*Oryctolagus cuniculus)* (Australian Government, 2007). Domestic and feral cats are a problem particularly where residential areas border the reserves (CALM, 1999). These feral animals compete for resources and directly predate upon native fauna.

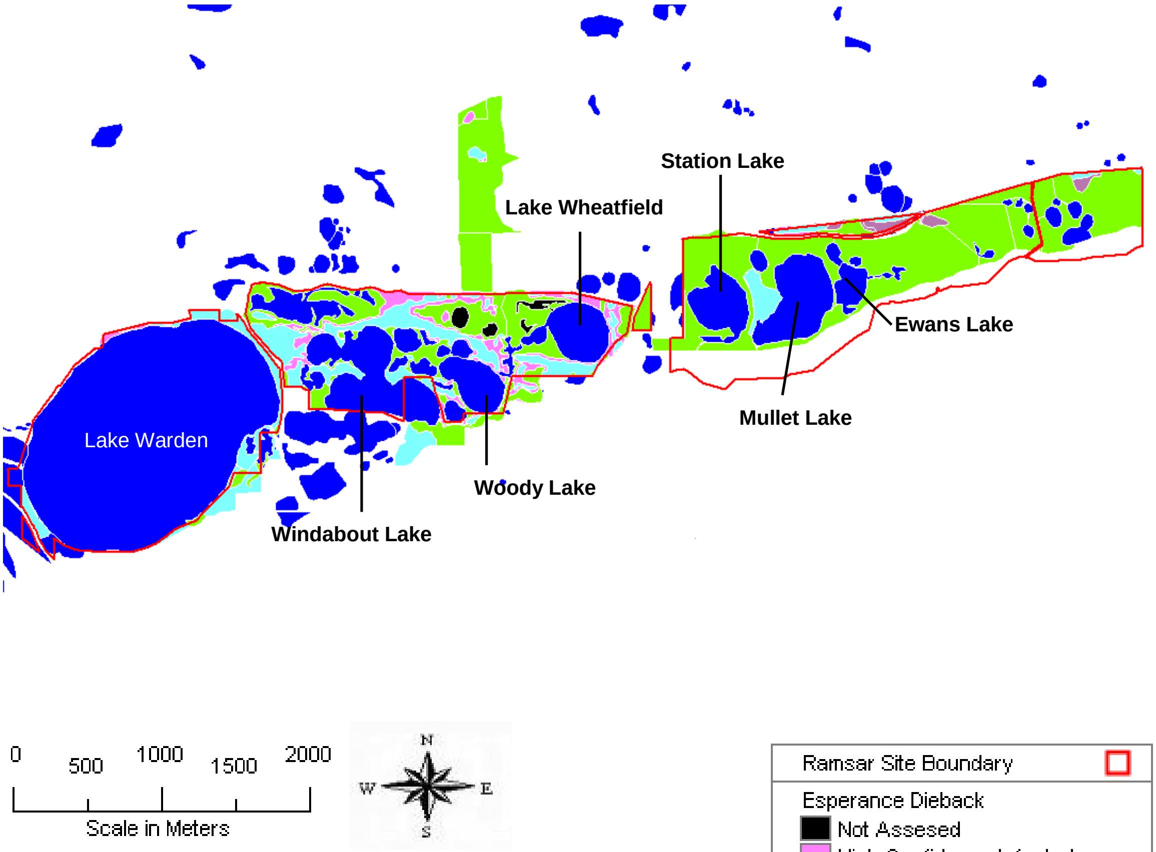
Major weed species such as Pattersons Curse (*Echium plantagineum*), South African Boxthorn (*Lycium ferocissimum*), Victorian Tea Tree (*Leptospermum laevigatum*), Bridal Creeper (*Myrsiphyllum asparagoides*) and Blackberry (*Rubus fruticosus*) have been recorded either within the Ramsar site or in surrounding areas (CALM, 1999). Bridal Creeper and the Victorian Tea Tree are considered to be of significant threat to the Lake Warden System Ramsar Site (Comer et al., 2001).

4.3 PLANT DISEASES

Another threat to the ecological character of the Lake Warden System Ramsar Site is *Phytophthora cinnamomi*, which causes *Phytophthora* Dieback. *Phytophthora* is a pathogen introduced into Australia that kills plants by destroying root systems, leaving the plants unable to uptake nutrients and water. *Phytophthora* is a microscopic water mould that travels from plant to plant via soil, water or through root-to-root contact, and once established it can never be eradicated (Department of Environment and Conservation, 2007a). Symptoms of infection include crown decline and death of vegetation, which can often be sudden.

Phytophthora Dieback can cause the collapse of whole ecosystems, and fauna such as waterbirds, will lose their source of food and habitat (Department of Environment and Conservation, 2007a). *Phytophthora* Dieback can also decrease biodiversity, for example resulting in the dominance of *Phytophthora* Dieback resistant species such as grasses (Department of Environment and Conservation, 2007a).

Figure 41 represents the *Phytophthora* Dieback mapping at the Ramsar site which indicates infestation, particularly around Lake Wheatfield, Woody Lake and Windabout Lake.



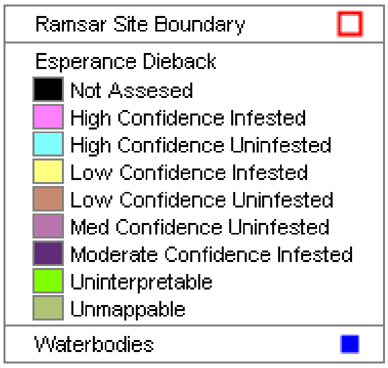


Figure 41. Confidence ranking of *Phytophthora cinnamomi* infestation at the Lake Warden System Ramsar Site, Esperance Western Australia (data from Department of Environment and Conservation, 2009c).

Armillaria luteobubalina is a native soil borne fungus with infection usually occurring from contact of roots and stems (Shearer & Tippett, 1988). The fungus attacks the woody parts of plants causing rot (Shearer & Tippett, 1988) and eventually killing vegetation, which can look very similar to the effects of *Phytophthora* Dieback. This fungus has been recorded within the Ramsar site although the threat is believed not to be as significant as *Phytophthora* Dieback (CALM, 1999).

4.4 CLIMATE CHANGE

Human induced climate change is a threat to the ecological character of the Lake Warden System Ramsar Site. There has been a noted reduction in winter rainfall throughout much of the south west of Western Australia (Indian Ocean Climate Initiative, 2004), which may impact hydrological regimes. However, the Esperance Region has experienced an increase in rainfall and unseasonal, episodic rainfall and flooding events (see: Section 2.4 Climate). Although these are not confirmed climate change events, they have affected hydrological regimes. Climate change is a broad issue and controlling it is beyond the management scope for the site. However, the implications of climate change on the ecological character of the Lake Warden System Ramsar Site need to be understood in order to effectively manage the site.

The Indian Ocean Climate Initiative (2002) states that the following changes have already occurred to the climate in the south west of Western Australia:

- Winter rainfall in the south west of Western Australia has decreased substantially since the mid-20th century. This has altered the perceptions of regional climate even though a similar, albeit less severe, dry sequence was experienced earlier in the century;
- The recent rainfall decrease was only observed in early winter (May - July) rainfall; late winter (August - October) rainfall has actually increased, although by a smaller amount;
- The winter rainfall sharply and suddenly decreased in the mid-1970s by about 15 - 20%. It was not a gradual decline but more of a switching into an alternative rainfall regime;
- The reduction in winter rainfall resulted in an even sharper fall in stream flow in the south west; and
- Temperatures, both day-time and night-time, have increased gradually but substantially over the last 50 years, particularly in winter and autumn.

4.5 RECREATION

Recreation has been identified as a critical ecosystem benefit/service, however, inappropriate recreational activities may adversely affect the site's ecological character. The Ramsar site hosts passive and active forms of recreation from bird watching to water skiing. One of the more threatening recreational activities within the Ramsar site is water skiing, as it includes the use of a motorised boat which can impact on waterbirds and other fauna. Additionally, it could pose a danger to other recreational users of the site. Woody Lake is gazetted as a water ski area within the Woody Lake Nature Reserve (15231). Alternative water skiing areas will be discussed in the Esperance and Recherche Parks and Reserves Management Plan.

Visitors to the Ramsar site may inadvertently spread weeds and *Phytophthora* Dieback. In addition, fishing occurs on all lakes and is thought to have particular impacts on vegetation (and therefore waterbird habitat) as fishermen pursue secluded fishing spots. The impacts of recreational activities (official and unofficial) at the Lake Warden System Ramsar Site have not been quantified and they remain potential impacts to the ecological character of the site.

Monaghan & Beale (2004) identify that human disturbance of waterbirds may reduce reproductive success by affecting behaviour or causing stress related behavioural changes, and may even delay breeding. For instance, it has been documented that human disturbance of Hooded Plovers, while they are away from the nest, results in a negative incubation response (Michael & Mark, 2007). Human disturbance decreases nest attendance substantially more than any other source of disturbance.

4.6 ENGINEERING DEWATERING

To ameliorate the threats associated with the altered hydrological regime within the Lake Warden Catchment and the Ramsar site, revegetation of the catchment and engineering dewatering of the LWWS have been identified as essential (Massenbauer & Vogwill, 2007). Some revegetation of the Lake Warden Catchment has already taken place, with these and future revegetation efforts focused on the planting of deep rooted perennial vegetation.

The engineering component to reduce the threats associated with an altered hydrological regime will take place in two stages:

Stage 1. Draining of water from Lake Wheatfield using a gravity-fed pipe system and disposing the water into Bandy Creek, 900 metres away.
Stage 2. Pumping water from Lake Warden and disposing via a pipeline into Esperance Bay, approximately 6.9 km away.

Volume ranges for Lake Warden, Lake Windabout, Woody Lake and Lake Wheatfield have been set in order to provide recovery of waterbird abundance and richness, and vegetation condition (see: Massenbauer, 2008; Robertson & Massenbauer, 2005).

Stage 1 aims to initially dewater between 1.2 and 2.4 GL of water from the Central hydrological suite of the Ramsar site via Lake Wheatfield (see: Massenbauer, 2008; Robertson & Massenbauer, 2005). Stage 2 aims to initially dewater 6-9 GL of water from the Western hydrological suite via Lake Warden (see: Massenbauer, 2008; Robertson & Massenbauer, 2005). These initial dewatering targets will reduce the volume of water to depth ranges appropriate for the recovery of waterbirds and vegetation condition. Ongoing dewatering to ensure that these depths are maintained will also need to occur.

DEC's management objective for the LWWS is to "recover the existing (2003) waterbird species richness and abundance and its living assemblages to a near natural condition[1] by the year 2030" (Massenbauer & Vogwill, 2007). At the time of writing, Stage 1 dewatering of the central suite via Lake Wheatfield had commenced.

The overall aim of the engineering dewatering should result in improving, conserving and maintaining the ecological character of the site. However, there are also inherent threats with this intervention to the ecological character of the Ramsar site which are outlined in the initial environmental impact assessment for the proposal (see: Maunsell/AECOM, 2008).

The main threats from lowering the water levels at the lakes are (from Maunsell/AECOM, 2008):

- Excessive dewatering, altering the natural seasonal trends and water quality; lowering water levels will increase local groundwater inflows with possible changes to the chemistry and / or seasonality of the lakes.
- Acidity from oxidation of acid sulfate soils; lowering water levels may cause the oxidation of potential acid sulfate soils present in Lake Warden and Lake Wheatfield (see: Section 4.1.4 Acid Sulfate Soils). This may generate some acidity and possibly heavy metal and phosphorus release and other impacts associated with the oxidation of acid sulfate soils (see: Section 4.1.4 Acid Sulfate Soils).

These threats are being monitored under the dewatering process and management actions are in place to ensure the ecological character of the site is not impacted.

The dewatering of the Central hydrological suite of the Ramsar site via Lake Wheatfield will impact on the water skiing activities at Woody Lake, which is used by Esperance Water Ski Club (EWSC) members and the Western Australian Water Ski Association (WAWSA). The legal water skiing depth for EWSC members is 1.8 m and for WAWSA members 1.4 m (Maunsell/AECOM, 2008). Prior to dewatering, Woody Lake was only suitable for water skiing 25% of the time by EWSC members and 76% of the time by WAWSA members (Maunsell/AECOM, 2008). It is anticipated that the volume of water removed from the Central hydrological suite during engineering dewatering will result in WAWSA members restricted ski period extending from 24% to 35% - 40% of the time (Maunsell/AECOM, 2008). Alternative water skiing areas will be discussed in the Esperance and Recherche Parks and Reserves Management Plan.

[1] Natural condition is benchmarked at early 1980's waterbird survey counts and hydrology records.

5.0 CHANGES TO ECOLOGICAL CHARACTER

This section describes the current ecological character of the Lake Warden System Ramsar Site and identifies any changes in ecological character. Although positive and negative changes can occur in ecological condition, a change in ecological character is defined by Ramsar Convention (2005a) as:

"The human induced adverse alteration of any ecosystem component, process and or ecosystem benefit/ service".

An ECD should identify any changes in a Ramsar site's ecological character since the time of listing (DEWHA, 2008). However, it should be recognised that a change in ecological character since listing may also reflect changes that began prior to listing. This section will discuss changes in ecological character prior to and since listing.

At the time of listing in June 1990, the Lake Warden System Ramsar Site was already experiencing changes resulting from the threatening processes described in section 4.0. Comer et al. (2001) has acknowledged that the Lake Warden System Ramsar Site, is in fair condition with a declining trend.

Some changes can be easily identified (e.g. death and decline of riparian vegetation), however, other changes may not be immediately apparent and may take decades to show an observable response. Determining if the changes to critical ecosystem components, processes, benefits and services are human induced and constitute a change in ecological character, is difficult. Cause and effect relationships are not always obvious and there are often multiple influences occurring simultaneously. As such, a precautionary approach will be used when identifying changes to ecological character. If precaution is not used further adverse changes may result whilst additional evidence is being obtained.

5.1 INTERACTION BETWEEN THE CRITICAL ECOSYSTEM COMPONENTS, PROCESSES, BENEFITS, SERVICES AND THREATS

The interaction of the critical ecosystem components, processes, benefits and services determine the ecological character of the Lake Warden System Ramsar Site. Threatening activities can have direct influences on critical ecosystem components, processes, benefits and services and therefore influence and cause changes to the ecological character of the Lake Warden System Ramsar Site.

There are interactions between the critical ecosystem components and processes, with climate and geomorphology the overarching drivers. It is important to understand that these critical ecosystem components and processes provide the critical ecosystem benefits and services of the Lake Warden System Ramsar Site. They are inextricably linked and negative changes in the critical ecosystem components and processes may affect the capacity of the site to deliver critical ecosystem benefits and services, thus resulting in a change in ecological character. Figure 42 conceptualises the interaction between the critical ecosystem components, processes benefits, services and threats.

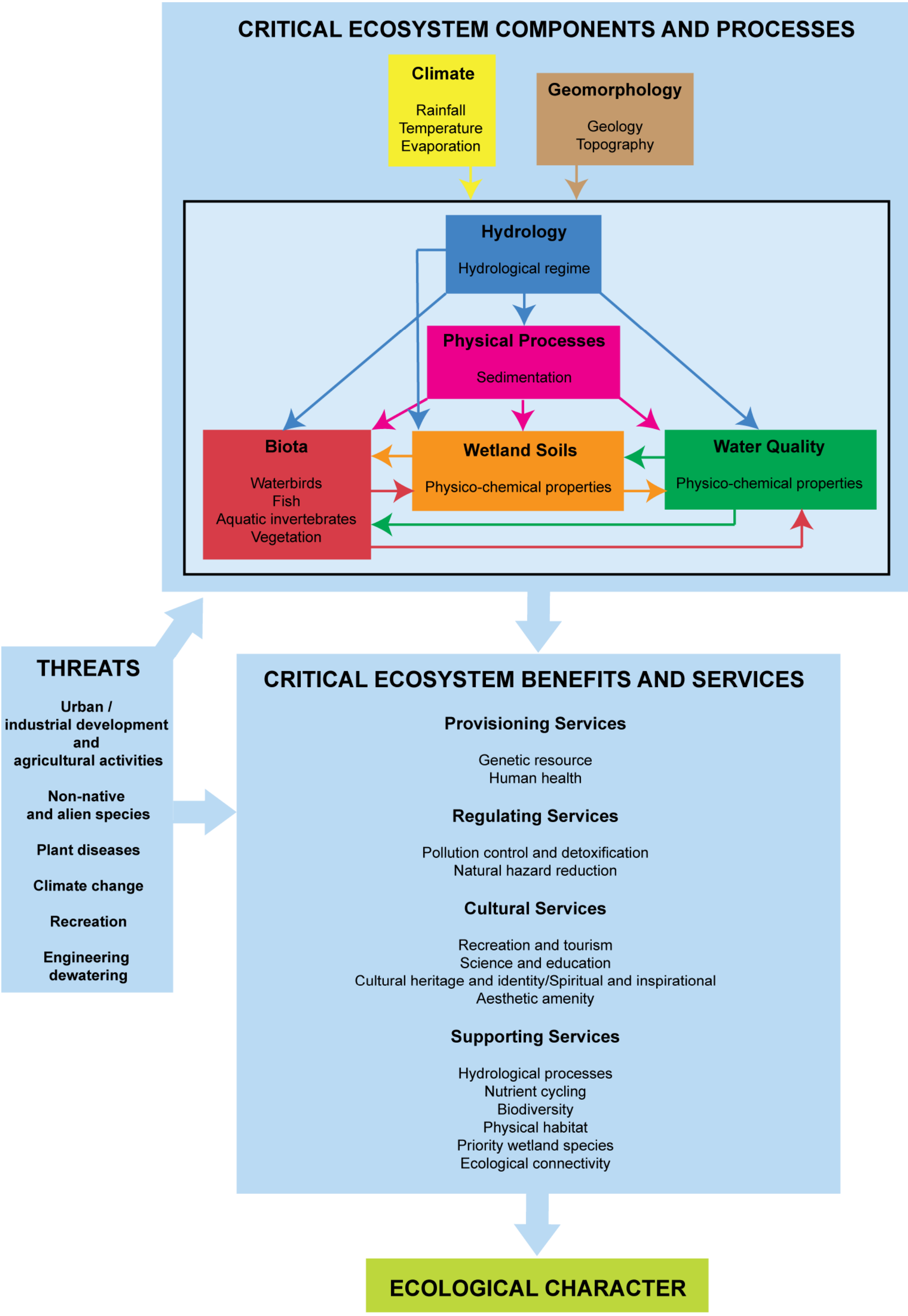


Figure 42. Conceptual model of the interaction of the critical ecosystem components, process, benefits and services of the Lake Warden System Ramsar Site , Esperance, Western Australia and the determination of ecological character. Threats influence changes in ecological character (adapted from DEWHA, 2008).

5.2 CHANGES TO CRITICAL ECOSYSTEM COMPONENTS AND PROCESSES

The Lake Warden System Ramsar Site was listed under the Ramsar Convention in 1990. The available data indicates that prior to and at the time of listing, changes to the ecological character of the site were occurring. These changes have continued since the time of listing. The limited data available means that some of the changes since the time of listing are not able to be fully quantified.

These changes in ecological character are adverse and considered human induced as a result of catchment clearing prior to listing. Increases in unseasonal, episodic rainfall events have exacerbated the affects of catchment clearing, resulting in an altered hydrological regime at the Ramsar site (i.e. increased extent and duration of inundation). It appears that changes to the hydrological regime have caused adverse changes to waterbird habitat and the vegetation of the Lake Warden System Ramsar Site.

It is anticipated that further changes to the ecological character of the Lake Warden System Ramsar Site may occur as a hydrological equilibrium has not been reached. This statement does not take into consideration the benefits of catchment revegetation and current engineering dewatering, which may ameliorate the impacts of the altered hydrological regime.

The following is a summary of the environmental variances and consequential changes to the ecological character of the Lake Warden System Ramsar Site:

Climate

- A 5% to 10% increase in annual rainfall in the Esperance region comparing 1976 - 1999 to 2000 - 2007 data (George et al., 2008); and
- An increase in unseasonal, episodic rainfall events resulting in floods in 1999, 2000, 2007 and 2009.

Hydrology

- Since clearing, groundwater levels within the Lake Warden Catchment have been rising rapidly, between 0.1 m and 0.3 m per year and in some cases up to 0.5 m per year (Short et al., 2000). Some groundwater aquifers surrounding the site are close to full capacity (John Simons, Regional Hydrologist DAFWA, pers. comm., 2008);
- Statistical analysis indicates a "highly significant" ($p<0.01$) increase in water levels at Lake Warden from 1977 - 2000 (September and November records) (Lane et al., 2004). The rate of change from 1977 - 2000 was calculated at 0.063 m per year (Lane et al., 2004).

Massenbauer & Robertson (2005) suggests that the water depth of Lake Warden has increased by approximately 1 m since 1979. Furthermore, post listing the September and November mean water depths at Lake Warden are less variable and have approximately doubled from 1.09 m and 0.98 m (prior to listing) to 2.02 m and 2.04 m respectively;

- Modelling indicates that the optimum minimum and maximum exposed shore zone area to maintain waterbird diversity at Lake Warden has been reduced from 50 ha - 250 ha in the early 1980s, to 3 ha - 55 ha in 2005 due to an altered hydrological regime (Massenbauer, 2008; Robertson & Massenbauer, 2005). The optimum maximum areas for wading waterbirds has reduced from 290 ha to 20 ha and for deep diving birds it has increased from 590 ha to 614 ha (Massenbauer, 2008; Robertson & Massenbauer, 2005). This equates to a reduction of up to 270 ha of wading waterbird habitat and a gain of up to 24 ha in habitat for deep diving waterbirds, depending on water depth and the subsequent area of inundation;
- The loss of shore zone area within the Central hydrological suite are less definitive, however dewatering targets indicate that there is up to 2.4 GL of excess water within this system when compared with the water volumes required for optimum waterbird richness and abundance (Massenbauer, 2008; Robertson & Massenbauer, 2005); and
- Sedimentation rates have increased 5 to 10 times in Lake Wheatfield and Lake Warden and at Station Lake they have increased 10 to 20 times since clearing of the Lake Warden Catchment occurred (Wilson, 2004).

Vegetation

- *Melaleuca cuticularis* fringing Lake Warden has been declining since the 1980's;
- From 1997 to 2000, increasing salinity concentrations and waterlogging at Lake Wheatfield caused the decline in condition of *M. cuticularis* in the littoral zone (Franke et al., 2001; Ogden & Froend, 1998). Recruitment of *M. cuticularis* at Lake Wheatfield has also been impacted by salinity and waterlogging, which threatens the sustainability of this community (Franke et al., 2001);
- The understorey flora diversity at Lake Wheatfield has significantly declined and weed invasion has increased between 1997 and 2000 (Franke et al., 2001); and
- *Melaleuca* woodland is in decline within the Ramsar site and beyond, through increases in the timing and extent of inundation of saline water. At 2007, the majority of *Melaleuca* woodland was either dead or declining (Department of Environment and Conservation, 2007b), however, the area within the Ramsar site has not been quantified.

5.3 CHANGES TO CRITICAL ECOSYSTEM BENEFITS AND SERVICES

Critical ecosystem benefits and services are not easily quantifiable and it is therefore difficult to measure changes. However, the changes identified in the critical ecosystem components and processes are likely to result in changes to the critical ecosystem benefits and services. This relates to the provisioning, regulating, cultural and supporting services provided by the Lake Warden System Ramsar Site.

There has been a change in the physical habitat of the Ramsar site, which is a supporting service and constitutes a change in ecological character (see: Section 3.2 Critical Ecosystem Benefits and Services). The hydrological changes have reduced the diversity of waterbird habitat and the vegetation which they rely on. These changes to physical habitat constitute a change in ecological character.

It is anticipated that if threatening processes continue, other critical ecosystem benefits and services will undergo adverse changes that would constitute a change in ecological character. Specifically it is likely that the following critical ecosystem benefits and services will undergo adverse changes:

- **Human health** - Physical and mental health may be affected caused by factors such as further degradation to land (e.g. increases in secondary salinisation);
- **Pollution control and detoxification -** Further pressures on the Lake Warden System Ramsar Site to receive pollution from the surrounding catchment may result in a collapse of the system. The system's capacity to deal with pollution will therefore be diminished and catchments, along with agriculture, will be affected;
- **Natural hazard reduction** - If hydrological changes continue in the catchment it is anticipated that the capacity of the Ramsar site to provide flood mitigation will diminish with time. This will negatively impact the Esperance township, infrastructure and properties surrounding the site;
- **Recreation and tourism -** Bird watching experiences could be diminished, particularly if a reduction in waterbird species richness occurs. Other recreation activities are likely to be affected and as the site is a highly valuable tourism resource, revenue from these activities will be impacted;
- **Aesthetic amenity** - If further vegetation deaths occur, visual amenity will be reduced. Visual amenity may also be reduced if pollution threats continue, resulting in an increase in algal blooms;

- **Biodiversity -** The habitats of the Ramsar site contribute to the biodiversity it attracts, particularly in relation to waterbird habitat. If the condition of these habitats is impacted biodiversity may be reduced;
- **Priority wetland species -** A reduction in waterbird habitat has already occurred and this may affect the CAMBA, JAMBA, ROKAMBA and CMS species that visit the Ramsar site during stages of their lifecycle. The majority of these waterbird species require a wading habitat (see: Section 3.1.6.1 Waterbirds). A reduction in Hooded Plover numbers and the regularity with which they use the site may also occur; and
- **Ecological connectivity -** If vegetation of the Ramsar site continues to decline it may become fragmented, which will reduce the site's ability to provide corridors of connectivity with other vegetation within the Esperance region.

6.0 LIMITS OF ACCEPTABLE CHANGE

Limits of acceptable change (LAC) are defined by Phillips: (2006) 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 (Figure 43). *In most cases, change is considered in a negative context, leading to a reduction in the values for which the site was listed".*

LAC was originally conceived to deal with the issues of recreation carrying capacity in forested wilderness areas in the United States (Stankey et al., 1985), but has since been adopted by the Ramsar Convention (and in other contexts) to describe, identify and set limits within which change can be tolerated. Phillips (2006), explains that the limits of acceptable change should be set outside of natural variability (Figure 43).

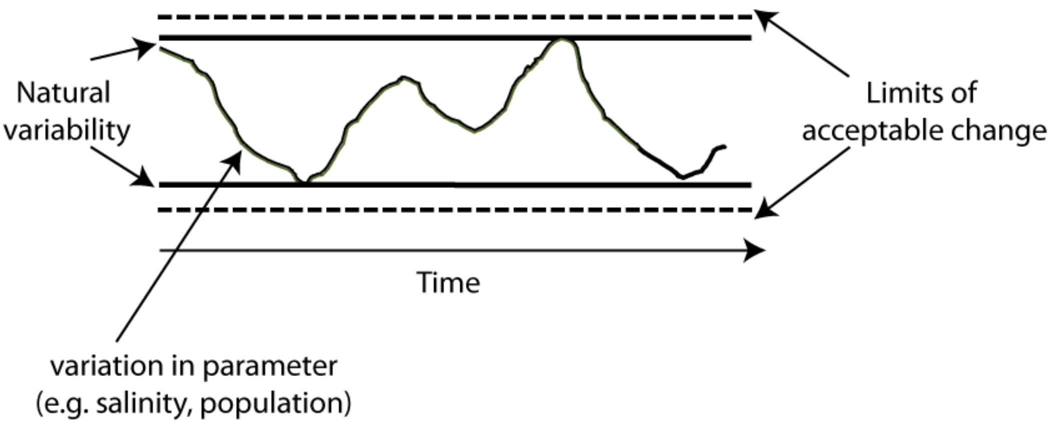


Figure 43. Natural variability and the limits of acceptable change (from Phillips, 2006).

Hale & Butcher (2007) explain that it is insufficient to set limits of acceptable change outside the extreme values of natural variability (i.e. based on maximum and minimum values), as these values alone fail to detect the full possible variability of any parameter (Figure 44). However, it is impossible to determine all the potential parameter variations outside of natural variability as this would involve knowing all the changes to parameters as a result of anthropogenic influences. In these instances the precautionary principle must be applied. There are multiple definitions of the precautionary principle although in essence a precautionary approach should be adopted where there is a lack of full scientific knowledge and there is a potential threat of serious or irreversible negative effects on environmental, human, animal and plant health.

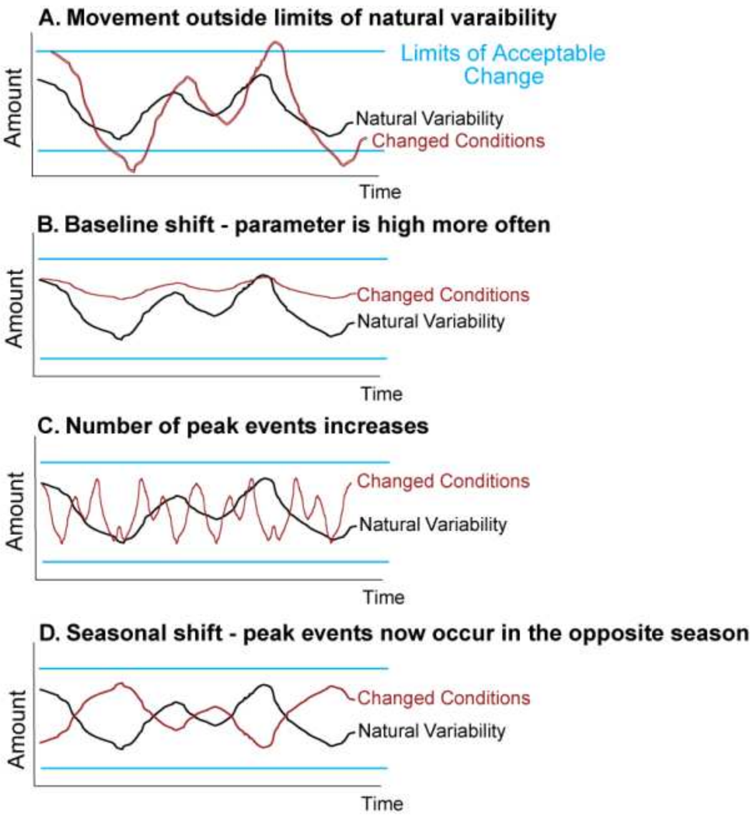


Figure 44. Illustration on setting limits of acceptable change based on maximum and minimum values outside of natural variability. A) This will only capture a change in maximum and minimum values; (B - D) Situations that involve shifts in baseline values; an increase in the number of peak events or a seasonal shift will not be captured (from Hale & Butcher, 2007).

Ideally, quantitative information should be used to determine limits of acceptable change (Davis & Brock, 2008), however, this information is often not available. Qualitative information can be used, however, careful use of language or clearly defined definitions must be provided as they could be open to interpretation.

The LAC for the Lake Warden System Ramsar Site have been based on the requirements for the maintenance of the critical ecosystem components, processes, benefits and services that define the ecological character of the site. For example, the LAC for water physico-chemical parameters (e.g. pH and salinity) have been based on the requirements of the other critical ecosystem components and processes, such as waterbirds. This in turn aids in the continuation of critical ecosystem benefits and services such as recreational bird watching. The LAC have also been based on information that has previously been recorded at the site such as water physico-chemical parameters and waterbird species richness and abundance.

As discussed in section 5.0, the Lake Warden System Ramsar Site was already on a downward trajectory in terms of ecological character at the time of listing, due to a changing hydrological regime. LAC should be set for the ecological character of the site at the time of listing, however, LAC based at this time are likely to have already been exceeded. In consideration of this, two sets of LAC have been included in this ECD. The first LAC aim to represent the ecological character of the site at the time of listing and are in consideration of the current engineering dewatering targets. The first LAC are set under the assumption that waterbird richness and abundance and vegetation condition are the biological indicators for the ecological character of the Ramsar site and indirectly represent the historical hydrological regime of the site. The second LAC are based on accepting a new hydrological regime and are set under the assumption that the engineering dewatering will not be successful. The second LAC provide an alternative should the engineering dewatering programme fail and it is envisaged they will be used to detect any further changes in the ecological character of the site.

Where a lack of knowledge exists, the precautionary principle has been applied in setting the LAC for the Lake Warden System Ramsar Site. Knowledge gaps have been outlined in section 7.0 where little comprehensive information is available. Table 11 details the LAC for the Lake Warden System Ramsar Site and it is recommended that they are considered in management planning and monitoring for the site.

In the management and monitoring of the site, LAC are ideally combined with management trigger values. Management trigger values are a precautionary alert purposely set below LAC so that an adaptive management response can occur prior to the LAC being reached. This ultimately aids in ensuring that a change in ecological character does not occur. It is not the purpose of an ECD to include management actions therefore management trigger values will be provided separately to land managers as an Annex to this report.

Table 11. Limits of acceptable change and management triggers for the Lake Warden System Ramsar Site, Esperance, Western Australia.

Ecological components and processes	Baseline condition/ ecological requirements	1. Limits of acceptable change (for optimum waterbird habitat)	2. Limits of acceptable change (new hydrological regime)
Abiotic components			
HYDROLOGY **Western hydrological suite - Lake Warden hydrological regime**	The current depth range for Lake Warden is approximately 1.2 m to 2.5 m. The optimum depth range for waterbird species richness and abundance is 0.3 m to 1.4 m (250 ha - 50 ha of exposed shore zone (Massenbauer, 2008; Robertson & Massenbauer, 2005).	Seasonal drying i.e. < 0.5 m during summer / autumn period annually. At all other times the depth of Lake Warden should not exceed 1.4 m and/or the exposed shore zone should not fall below 50 ha.* These limits are in accordance with the engineering dewatering of Lake Warden (see: Maunsell/AECOM, 2008). *It should be acknowledged that extreme flooding events will exceed this level for a short period of time.	Catchment has not reached a hydrological equilibrium; therefore LAC can not be set. Interim limits - no further increase in water depth of Lake Warden i.e. water depth must remain below 2.5 m.
HYDROLOGY **Central hydrological suite - Windabout Lake, Woody Lake and Lake Wheatfield**	The optimum depth range at Lake Wheatfield for optimum waterbird species richness and abundance and vegetation condition within the Central hydrological suite is 0.8 m to 1.6 m (Massenbauer, 2008; Robertson & Massenbauer, 2005).	Seasonal drying i.e. < 1.0 m during summer / autumn period annually at Lake Wheatfield. At all other times the depth of Lake Wheatfield should not exceed 1.6 m.* These limits are in accordance with the engineering dewatering of Lake Wheatfield (see: Maunsell/AECOM, 2008). *It should be acknowledged that extreme flooding events will exceed this level for a short period of time.	Catchment has not reached a hydrological equilibrium; therefore LAC can not be set. Interim limits - no further increase in water depth of Lake Wheatfield i.e. water depth must remain below 1.7 m.
HYDROLOGY **Eastern hydrological suite - Station Lake, Mullet Lake and**	Station Lake has undergone distinct dry periods, mainly prior to listing when the lake dried out completely. Station Lake water depths have ranged between 0 m and 1.73 m. For optimum waterbird abundance and	Seasonal drying i.e. 0 m during the summer / autumn period in 1 out of every 3 years. At all other times the depth of Station Lake should not exceed 0.8 m.*	Catchment has not reached a hydrological equilibrium; therefore LAC can not be set. Interim limits - no further increase in water depth of Station Lake i.e. water

Ecological components and processes	Baseline condition/ ecological requirements	1. Limits of acceptable change (for optimum waterbird habitat)	2. Limits of acceptable change (new hydrological regime)
Ewans Lake	richness the depth of Station Lake should remain < 0.8 m (Massenbauer, 2008; Robertson & Massenbauer, 2005). There is insufficient baseline information for Mullet Lake and Ewans Lake.	*It should be acknowledged that extreme flooding events will exceed this level for a short period of time.	depth must remain below 0.8 m.
WATER QUALITY - SALINITY **Western hydrological suite - Lake Warden**	Salinity concentrations at Lake Warden have ranged from approximately 15 ppt to 369 ppt (see: Department of Environment and Conservation, 2009b; Lane, 2008). Waterbirds observed at Lake Warden have been recorded at a range of salinity concentrations from < 2 - > 35 ppt (see: Appendix B).	Lake Warden median summer salinities 100 ppt.	Lake Warden median summer salinities 100 ppt.
WATER QUALITY - SALINITY **Central hydrological suite - Windabout Lake, Woody Lake and Lake Wheatfield**	Salinity concentrations at Windabout Lake have ranged from approximately 6 ppt to 22 ppt (see: Department of Environment and Conservation, 2009b; Lane, 2008). Salinity concentrations at Woody Lake have ranged from approximately 2 ppt to 16 ppt (see: Department of Environment and Conservation, 2009b; Lane, 2008). Salinity concentrations at Lake Wheatfield have ranged from approximately 2 ppt to 15 ppt (see: Department of Environment and Conservation, 2009b; Lane, 2008). Waterbirds observed at lakes of the Central hydrological suite have been recorded at a range of salinity	Windabout Lake median summer salinity concentration 10 ppt. Woody Lake median summer salinity concentration 7 ppt. Lake Wheatfield median summer salinity concentration 9 ppt.	Windabout Lake median summer salinity concentration 10 ppt. Woody Lake median summer salinity concentration 7 ppt. Lake Wheatfield median summer salinity concentration 9 ppt.

Ecological components and processes	Baseline condition/ ecological requirements	1. Limits of acceptable change (for optimum waterbird habitat)	2. Limits of acceptable change (new hydrological regime)
	concentrations from < 2 - > 35 ppt (see: Appendix B).		
WATER QUALITY - SALINITY **Eastern hydrological suite - Station Lake, Mullet Lake and Ewans Lake**	Salinity concentrations at Station Lake have ranged from approximately 5 ppt to 297 ppt (see: Department of Environment and Conservation, 2009b; Lane, 2008). Salinity concentrations at Mullet Lake have ranged from approximately 5 ppt to 67 ppt (see: Department of Environment and Conservation, 2009b; Lane, 2008). Salinity concentrations at Ewans Lake have ranged from approximately 5 ppt to 20 ppt (see: Department of Environment and Conservation, 2009b; Lane, 2008). Waterbirds observed at lakes of the Eastern hydrological suite have been recorded at a range of salinity concentrations from < 2 - > 35 ppt (see: Appendix B)	Station Lake median summer salinity concentration 20 ppt. Mullet Lake median summer salinity concentration 25 ppt. Ewans Lake median summer salinity concentration 15 ppt.	Station Lake median summer salinity concentration 20 ppt. Mullet Lake median summer salinity concentration 25 ppt. Ewans Lake median summer salinity concentration 15 ppt.
WATER QUALITY **pH**	**Western hydrological suite** Lake Warden 6.4 - 10.0 **Eastern hydrological suite** Station Lake 6.9 - 10.1 Ewans Lake and Mullet Lake 6.9 - 9.5 **Central hydrological suite** Lake Wheatfield 6.7 - 9.6 Woody Lake 6.5 - 9.6 Windabout Lake 7.0 - 10.7 (data from Cale, 2008; Department of Environment and Conservation,	The minimum pH value must not fall below 6.5 and the maximum pH value must not be greater than 11.	The minimum pH value must not fall below 6.5 and the maximum pH value must not be greater than 11.

Ecological components and processes	Baseline condition/ ecological requirements	1. Limits of acceptable change (for optimum waterbird habitat)	2. Limits of acceptable change (new hydrological regime)
	2009b; Lane, 2008). Waterbirds observed at the Ramsar site have been recorded at average pH values between 5 and 8.7 (minimum 1.9 and maximum 11.5 see: Appendix B).		
WATER QUALITY **Nutrient status of wetlands**	September and November TP concentrations at: • Station Lake have ranged from 0.005 mg/L to 0.05 mg/L • Lake Wheatfield have ranged from 0.01 mg/L to 0.24 mg/L • Lake Warden have ranged from 0.005 mg/L to 0.14 mg/L September and November TN concentrations at: • Station Lake have ranged from 0.59 mg/L to 4.5 mg/L • Lake Wheatfield have ranged from 0.56 mg/L to 3.4 mg/L • Lake Warden have ranged from 2.6 mg/L to 8.2 mg/L September and November SRP concentrations at: • Station Lake have ranged from 0.005 mg/L to 0.05 mg/L • Lake Wheatfield have ranged from 0.005 mg/L to 0.07 mg/L • Lake Warden have ranged from 0.005 mg/L to 0.05 mg/L September and November TSN concentrations at: • Station Lake have ranged from 0.48 mg/L to 4.5 mg/L • Lake Wheatfield have ranged	Insufficient data at this time.	Insufficient data at this time.

Ecological components and processes	Baseline condition/ ecological requirements	1. Limits of acceptable change (for optimum waterbird habitat)	2. Limits of acceptable change (new hydrological regime)
	from 0.56 mg/L to 3.4 mg/L • Lake Warden have ranged from 0.93 mg/L to 7.6 mg/L (data from: Lane, 2008) Baseline information is not sufficient to derive seasonal trends and is limited spatially to Station Lake, Lake Wheatfield and Lake Warden. It is also not conclusive if these concentrations represent natural variability and/or pose a threat to the ecological character of the site. Using them as a baseline may reflect adverse environmental conditions. Nutrient loads are also unknown.		
WATER QUALITY **Chlorophyll *a* status of the wetlands**	Baseline information is insufficient at this stage as to what concentrations of chlorophyll *a* represent natural baseline conditions of the wetlands.	Insufficient data at this time.	Insufficient data at this time.
WATER QUALITY **Metal status of wetlands**	The metal status of the wetlands is unknown. Baseline information is insufficient at this stage.	Baseline must be identified before limits can be set.	Baseline must be identified before limits can be set.
PHYSICAL PROCESSES **Sedimentation rates within the wetlands**	Sedimentation rates have increased 5 to 10 times in Lake Wheatfield and Lake Warden, at Station Lake they have increased 10 to 20 times since clearing of the Lake Warden Catchment (Wilson, 2004). Information on spatial variability of sedimentation within the wetlands is unknown. Sedimentation and its actual affects on altering the bathymetry and aspects of the hydrological regime of the wetlands	Baseline must be identified before limits can be set.	Sediment rates are the result of catchment clearing and the subsequent hydrological regime. LAC can not be set until a hydrological equilibrium is reached. Interim limit - of no further increase in sedimentation rates.

Ecological components and processes	Baseline condition/ ecological requirements	1. Limits of acceptable change (for optimum waterbird habitat)	2. Limits of acceptable change (new hydrological regime)
	are also limited.		
Biotic components			
BIOTA **Waterbird diversity and abundance**	The site has supported > 1% of the South-west Australian population of the Chestnut Teal. The site has supported > 1% of the Western Australian Population of Hooded Plover. A total of 73 species of waterbirds have been recorded at the site, 42 species listed under the EPBC Act : 40 "Marine", 25 "Migratory" species listed under international migratory agreements CAMBA, JAMBA, ROKAMBA and CMS. Waterbird use of the Lake Warden System Ramsar Site is highly variable. At the regional scale it is strongly influenced by changes in wetland availability in the South-west of Australia. At the local scale it is influenced by changes in water levels in the lakes, as this determines habitat availability.	The Ramsar Site supports: • > 1% of the South-west Australian population of Chestnut Teal in at least 2 out of 3 years • > 1% of the Western Australian population of the Hooded Plover in at least 2 out of 5 years • All 25 EPBC listed "Migratory" waterbird species listed under international migratory agreements CAMBA, JAMBA, ROKAMBA and CMS previously recorded at the site over a 2 year period These LAC are set under the assumption that environmental conditions external to the site remain stable and regular waterbird surveys are conducted.	It is anticipated that the waterbird species composition, richness and abundance experienced historically will continue only if appropriate aquatic habitats are provided by the hydrological regime. As hydrological equilibrium has not been reached LAC can not be set, however the following will serve as interim limits as they will still indicate a change in ecological character. The Ramsar Site supports: • > 1% of the South-west Australian population of Chestnut Teal in at least 2 out of 3 years • > 1% of the Western Australian population of the Hooded Plover in at least 2 out of 5 years • All 25 EPBC listed "Migratory" waterbird species listed under international migratory agreements CAMBA, JAMBA, ROKAMBA and CMS previously recorded at the site over a 2 year period
BIOTA **Fish**	Black Bream exist in the wetlands of the Ramsar site. Swan River Gobi (*Pseudogobius olorum*) and the Hardyhead (*Leptatherina wallacei*) have also been recorded at Bandy Creek (Hodgkin & Clark, 1989).	Baseline must be identified before limits can be set.	Baseline must be identified before limits can be set.

Ecological components and processes	Baseline condition/ ecological requirements	1. Limits of acceptable change (for optimum waterbird habitat)	2. Limits of acceptable change (new hydrological regime)
	A species of possibly Mullet (*Aldrichetta* sp.) or Hardyhead (*Atherinosoma* sp.) have been recorded at Lake Warden (Australian Nature Conservation Agency, 1996). There is no current information to the actual existence or continued existence of any of these fish species at the Ramsar site, apart from Black Bream		
BIOTA **Aquatic invertebrates**	The invertebrate species composition within the wetlands of the Ramsar site has been variable, dependant on differences in water quality i.e. salinity and levels of eutrophication. As many of the aquatic invertebrate species found at the site are halotolerant or halophytes, species richness and abundance may change depending on fluctuations in seasonal salinity, the degree to which this occurs is unknown. Molluscs belonging to the *Coxiella* genus have been recorded at the site and are considered an important food source for the Hooded Plover.	Insufficient information available at this time, although no changes in the presence of *Coxiella* spp. should occur.	Insufficient information available at this time, although no changes in the presence of *Coxiella* spp. should occur.
BIOTA **Vegetation**	Some vegetation within the Ramsar site is in decline, notably the Melaleuca woodland. This vegetation type consists of mainly *Melaleuca cuticularis*, which forms the fringing vegetation of many of the wetlands within the Ramsar site. However, vegetation condition within the Ramsar site has not been quantified.	Baseline must be identified before limits can be set.	Baseline must be identified before limits can be set.

7.0 KNOWLEDGE GAPS

The Ramsar site is part of the Lake Warden Natural Resource Recovery Catchment and as such resources have been dedicated to understanding the site, particularly hydrological aspects. However, there are also numerous knowledge gaps identified for the Lake Warden System Ramsar Site (Table 12). To fully describe and set limits of acceptable change for the critical ecological components and processes, these knowledge gaps should be addressed. Initially, surveillance of some of the identified knowledge gaps will have to take place. Once the critical ecological components and processes are better understood, management triggers and limits of acceptable change can be "tightened" for some parameters and assigned for others. These predetermined levels can then be used in monitoring of the wetland.

Ideally, it would be beneficial to investigate all of the knowledge gaps for this site, however, resources are often limited and therefore the knowledge gaps that are important for describing and maintaining the ecological character should be prioritised.

Table 12. Summary of knowledge gaps and recommended actions for the Lake Warden System Ramsar Site, Esperance, Western Australia.

Overarching component/process/ benefit/service	Specific component /process	Identified knowledge gaps	Recommended action
Hydrology	Extent, depth and timing of inundation Seasonal hydrological regime	The conceptual optimum ranges in extent and depth of inundation for waterbird abundance and richness is known for the wetlands in the Ramsar site (see: Robertson & Massenbauer, 2005). However, knowledge pertaining to the optimum seasonal hydrological regime for biodiversity is required.	Comprehensive research on the ecological water requirements for optimum biodiversity at the site. Continue with Robertson & Massenbauer (2005) depth and volume calculations to ascertain optimum seasonal hydrological regime for biodiversity.
Water quality	Water physico-chemical properties	Analysis of the wetlands physico-chemical properties has been limited to salinity, TN, TP, FRP and TSN concentrations and pH.	Regular water surveillance/monitoring on a complete suite of physico-chemical parameters including metals, salinity and nutrient loads should be investigated in addition to concentrations.
Physical processes	Sedimentation	Preliminary assessment of the rates of sedimentation has been limited to Lake Wheatfield, Lake Warden and Station Lake, and is spatially limited within those wetlands. Sedimentation and its affects on bathymetry are also limited and temporal changes are unknown. Knowledge on the sediment loads entering the Ramsar site is limited.	Investigate and monitor spatial sedimentation rates at Lake Wheatfield, Lake Warden and Station Lake, and model the affects on bathymetry. Monitor sediment loads from the catchment and correlate with creek flows.
Wetland soil quality	Geochemical cycling between sediments and water column	Mineralogy and geochemistry of lake sediments and surrounding soils. Bioavailability of nutrients and metals.	Establish sediment and soil quality monitoring within the major wetlands of the Ramsar site that will measure the bioavailability of nutrients and metals to flora and fauna.
	Acid sulfate soils	The mapping of acid sulfate soils within the Ramsar site has been spatially limited to areas of Lake Warden and Lake Wheatfield that will be disturbed by the engineering dewatering.	Investigate and extend the mapping of the presence of potential acid sulfate soils throughout the Ramsar site.
Biota	Waterbirds	No uniform methodology in waterbird surveys. No temporally consistent waterbird surveys.	Implement an appropriate waterbird survey method for recording maximum abundance and species richness. Implement an appropriate waterbird survey

Overarching component/process/ benefit/service	Specific component /process	Identified knowledge gaps	Recommended action
			regime. This will ensure that the Ramsar site is surveyed with uniform frequency at appropriate times of the year, recording the maximum abundance and species richness.
	Fish	No recent fish surveys.	Fish surveillance/monitoring taking into account different seasons and changes in salinity.
	Aquatic invertebrates	Long term monitoring of aquatic invertebrates has been limited to Lake Wheatfield.	Aquatic invertebrate surveillance/monitoring taking into account different seasons and changes in salinity concentrations in all of the major wetlands of the Ramsar site.
	Vegetation	Current condition and extent of vegetation last recorded in 2007. Quantification of vegetation condition within the Ramsar site only is required. No regular mapping or monitoring of the extent, distribution and condition of the vegetation communities within the Ramsar site.	Update the extent and distribution of vegetation communities within the Ramsar site as conducted by Department of Environment and Conservation (2007b). Ongoing monitoring of vegetation condition at the Ramsar site.
	Non-native and alien species Weeds	No regular weed mapping.	Undertake regular weed mapping at the Lake Warden System Ramsar Site to ascertain rate of spread.
	Phytoplankton	Species composition and abundance has not been monitored on a regular basis.	Monitor chlorophyll *a* (biomass of phytoplankton), algae (phytoplankton cell count and composition) and macro algae.
Regulating Service	Pollution control and detoxification Natural hazard reduction	Monetary benefits of the Lake Warden System Ramsar Site in providing these regulating services.	Investigation and quantification of the economic value of the site as an ecosystem in providing these regulating services.
Cultural Service	Recreation and tourism Aesthetic amenity	Monetary benefits of the Lake Warden System Ramsar Site in providing these regulating services.	Investigation and quantification of the economic value of the site as an ecosystem in providing these cultural services.

Overarching component/process/ benefit/service	Specific component /process	Identified knowledge gaps	Recommended action
		Quantified impacts of recreation.	Quantify the impacts of recreation.
Supporting Service	Nutrient cycling	The Ramsar site has a role in nutrient cycling although the scale at which this occurs is unknown.	Investigation and quantification of the role the Ramsar site has in nutrient cycling.

8.0 SURVEILLANCE AND MONITORING REQUIREMENTS

The aim of this section is not to develop a monitoring programme, rather to highlight what aspects of the ecological character or which threats require observation. This section is not exhaustive and further studies into the site may identify additional monitoring requirements.

It is important that actual "monitoring" occurs so that the collection of data is driven and comparable with pre-determined objectives or standards. *"It appears that Australian agencies have been actively undertaking surveillance and not monitoring"* (Finlayson & Mitchell, 1999). The differentiation between these two important processes (monitoring and surveillance) must be understood by land managers so that appropriate adaptive management outcomes are the result for the Lake Warden System Ramsar Site and other managed areas.

The difference between survey, surveillance and monitoring is outlined by Hellawell (1991):

*"**Survey** is an exercise in which a set of qualitative observations are made but without any preconception of what the findings ought to be.*
***Surveillance** is a time series of surveys to ascertain the extent of variability and/or range of values for particular parameters.*
***Monitoring** is based on surveillance and is the systematic collection of data or information over time in order to ascertain the extent of compliance with a predetermined standard or position".*

A comprehensive monitoring programme for the Lake Warden System Ramsar Site will assist in detecting changes in the critical ecosystem components, processes, benefits and services, prior to irrevocable changes in the ecological character of the site. Table 13 details the monitoring requirements of the Lake Warden System Ramsar Site. The monitoring requirements have been given a relative priority ranking, so that funding for monitoring can be distributed accordingly. However, it is preferable that as many of the components and processes identified for monitoring are recorded simultaneously. This allows for a greater understanding of trends and any relationships between components and processes.

Table 13. Surveillance and monitoring requirements of the Lake Warden System Ramsar Site, Esperance, Western Australia.

Overarching Component/ process	Specific component/ process	Requirement & Objective	Indicator	Frequency	Priority
Hydrology	Surface water flows of the major creeks	Monitor to detect change against predetermined standards/levels.	• Flows (m^3/s)	Monthly	High
	Groundwater	Monitor to detect change against predetermined standards/levels.	• Depth to groundwater at installed observation bores and piezometers	Monthly	High
	Water depth at all major wetlands	Monitor to obtain greater understanding of seasonal variation and to detect change against predetermined standards/levels.	• Water depth at depth gauge	Monthly	High
Water quality	Water physico-chemical properties at all major wetlands	Monitor to establish baseline information and to detect change against predetermined standards/levels. Determine bioavailability. This is depending on the parameter, some baseline information is already available.	• pH • Salinity loads and concentration • Nutrient loads and concentration: TN, TP, FRP, TSN, NH_4 and No_x • Dissolved oxygen • Chlorophyll *a* (biomass of phytoplankton) • Algae (phytoplankton cell count), macro algae • Metals including heavy metals • Faecal coliform bacteria (human use values present)	Monthly to bi-annually depending on the parameter.	Medium
	Water physico-chemical properties of the major creeks Catchment inputs	Monitor to establish baseline information and to detect change against predetermined standards/levels. This is depending on the parameter, some baseline	• pH • Salinity loads and concentration • Nutrient loads and concentration: TN, TP, FRP, TSN, NH_4 and No_x	Monthly to bi-annually depending on the parameter.	High

Overarching Component/ process	Specific component/ process	Requirement & Objective	Indicator	Frequency	Priority
		information is already available.	• Metals including heavy metals		
Physical processes	Sedimentation at Lake Warden, Lake Wheatfield and Station Lake	Monitor to detect change in the sediment levels and rates against predetermined standards/levels.	• Rates per year	Annually	Medium
Wetland soil quality	Geochemical cycling between sediments and water column	Monitor to establish baseline information and to detect change against predetermined standards/levels. Determine bioavailability.	• A range of physico-chemical parameters to be determined	Every 5 years	Medium
Biota	Waterbirds	Monitor to detect change against predetermined standards/levels. Monitor waterbirds at all of the major wetlands within the Ramsar site simultaneously.	• Richness and abundance • Breeding observations: number of breeding pairs, number of nests	This needs to be determined as outlined in Section 7.0 knowledge Gaps. At least on an annual basis.	High
	Fish	Monitor to establish baseline information and to detect change against predetermined standards/levels.	• Richness and abundance	Seasonally	Medium
	Aquatic invertebrates	Monitor to detect change against predetermined standards/levels.	• Richness and abundance of families	Seasonally	Medium
	Vegetation	Monitor to detect change against predetermined standards/levels.	• Mapping the extent, distribution and condition of the vegetation communities	Every 3 years	High
	Phytophthora Dieback	Monitor to detect change against predetermined standards/levels.	• Re check *Phytophthora* Dieback boundaries	Every 3 years (see: Department of Environment and Conservation, 2009c)	Medium

Overarching Component/ process	Specific component/ process	Requirement & Objective	Indicator	Frequency	Priority
	Non-native and alien species Weeds	Monitor to establish baseline information and to detect change against predetermined standards/levels.	• Weed mapping	Every 3 years	Medium

Photo: (J. Higbid, 2008)

9.0 COMMUNICATION, EDUCATION AND PUBLIC AWARENESS

This section identifies important communication, education and public awareness messages for the Lake Warden System Ramsar Site. Under the Ramsar Convention a programme of Communication, Education and Public Awareness 2003 - 2008 was established. The programme is aimed to raise public awareness into the values and functions of wetlands. These are achieved through coordinated international and national public awareness campaigns. To aid this, Australia has established the Wetland Communication, Education and Public Awareness (CEPA) National Action Plan 2001 - 2005.

Current CEPA for the Lake Warden System Ramsar Site includes:

- A 3.6 km long interpretive walking trail in the Woody Lake Nature Reserve, which consists of 1.5 km of raised timber boardwalks and 2.1 km of surfaced trail. The Kepwari Walk Trail has 20 information panels along the way and has been installed to educate visitors and to protect native vegetation from *Phytophthora* Dieback. As part of the trail, two bird hides have been installed at Lake Wheatfield where visitors can observe waterbirds. DEC have produced a brochure of the Kepwari Trail which is available at the Esperance District Office;

Photo: (J. Higbid, 2008)

- Signs indicating the system's Recovery Catchment and Ramsar Wetland status have been erected around the site;
- South Coast NRM Inc. have produced a fact sheet on the Lake Warden Catchment Project which summarises the aims of the project and achievements to date;
- DEC has prepared a Lake Warden student curriculum package for upper primary and lower secondary school students;
- Birds Australia has produced a Hooded Plover Management Plan, which includes the Esperance region. The plan itself details specific threats to wetlands and Hooded Plovers. It also includes specific strategies for the Esperance region for management and conservation; and
- Department of Agriculture and Food WA have a range of advisory services that provide information about a range of catchment management issues including salinity and weed/pest management. They are also able to aid in cost benefit analysis for fertiliser application rates to prevent over application.

The following CEPA activities are suggested for Lake Warden System Ramsar Site and are based on the information derived during the preparation of this ECD:

- The State Government funded Ribbons of Blue programme aims to increase awareness and understanding about local water quality through engaging school groups in sampling wetlands throughout the state. Esperance Senior High School was involved in the Ribbons of Blue programme and students sampled water quality at the wetlands within the Ramsar site for a number of years but this is no longer occurring. This important conservation and education tool could be reintroduced in the region;
- Interpretive signage at the site, consistent with the Ramsar guidelines for signs, to highlight the international significance of the site;
- Importance of wetlands - with particular emphasis on the Ramsar site and the waterbird species that visit;
- Effect of disturbance on waterbirds - community education to identify waterbird habitat and minimise disturbance;
- Provisioning Service (Human Health) - the recognition that the Ramsar Site contributes to human health in the Esperance area; and
- Increase awareness of the statutory protection mechanisms for Ramsar wetlands under Commonwealth and Western Australian legislation and the associated referral processes.

REFERENCES

ANZECC and ARMCANZ. (2000a). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Vol. 1). National Water Quality Management Strategy, Australian and New Zealand Environment and Conservation Council / Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

ANZECC and ARMCANZ. (2000b). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Vol. 2). National Water Quality Management Strategy, Australian and New Zealand Environment and Conservation Council / Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Australian Academy of Science. (1981). *Fire and the Australian Biota*. Australian Academy of Science, Canberra.

Australian Government. (2007). Australian National Resource Atlas - Biodiversity Assessment - Esperance Sandplains Retrieved June, 2008, from http://www.anra.gov.au/topics/vegetation/assessment/wa/ibra-esperance-plains.html

Australian Government. (2008). Australia's Ramsar sites. Retrieved April, 2008, from http://www.environment.gov.au/water/publications/environmental/wetlands/pubs/ramsar.pdf

Australian Heritage Commission. (2002). *Australian Natural Heritage Charter for conservation of places of natural heritage significance* (2 ed.). Australian Heritage Commission, Canberra.

Australian Nature Conservation Agency. (1996). *A Directory of Important Wetlands in Australia Second Edition*. ANCA, Canberra.

Balla, S. (1994). *Wetlands of the Swan Coastal Plain: Their Nature and Management* (Vol. 1). Water Authority of Western Australia and the Western Australia Department of Environmental Protection, Perth.

Beard, J. S. (1973). *The vegetation of the Esperance and Malcolm areas Western Australia: maps and explanatory memoir 1:250,000 Series*. Vegmap Publications, Perth, Western Australia.

Beard, J. S., Chapman, A. R., & Gioia, P. (2000). Species richness and endemism in the Western Australian flora. *Journal of Biogeography, 27*(6), 1257-1268.

Bennelongia. (2008a). *Waterbird monitoring of the Lake Warden and Lake Gore Wetland Systems, February 2008 (prepared for Esperance Regional Forum)*. Report 2008/26. Bennelongia Pty Ltd, Jolimont.

Bennelongia. (2008b). *Waterbird monitoring of the Lake Warden and Lake Gore Wetland Systems, October 2007 (prepared for SCRIPT and the Department of Environment and Conservation)*. Report 2008/18. Bennelongia Pty Ltd, Jolimont.

Bennelongia. (2009). *Waterbird monitoring of the Lake Warden and Lake Gore Wetland Systems, November 2008 (prepared for Esperance Regional Forum)*. Report 2009/64. Bennelongia Pty Ltd, Jolimont.

BirdLife International. (2006). Thinornis rubricollis. *2007 IUCN Red List of Threatened Species* Retrieved June 2008, from www.iucnredlist.org

Birds Australia. (2008). Birds Australia raw data for waterbird surveys at the Lake Warden System Ramsar Site 1996 - 2003. Birds Australia.

Birds Australia. (2009). Birds Australia raw data for Hooded Plover surveys at the Lake Warden System Ramsar Site 1990, 1994-1998, 2001-2003, 2005 and 2008. Birds Australia.

Blinn, D. D. (2004). Diatom and micro-invertebrate communities and environmental determinants in the western Australian wheatbelt: a response to salinisation. *Hydrobiologia, 528*(1-3), 229-248.

Boulton, A., & Brock, M. (1999). *Australian Freshwater Ecology*. Gleneagles Publishing, Adelaide, Australia.

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

Bureau of Meteorology. (2008). *Monthly climate statistics 1969-2008 for Esperance Station 009789*. Bureau of Meteorology, Western Australia.

Burgess, P. (2001). Climate. In *Dalyup Catchment 2000*. Department of Agriculture, Western Australia.

Cale, D. J. (2008). Salinity Action Plan Wheatbelt Wetlands Monitoring Programme and Wheatbelt Biological survey raw data set. Department of Environment and Conservation.

Cale, D. J., Halse, S. A., & Walker, C. D. (2004). Wetland monitoring in the Wheatbelt of south-west Western Australia: site descriptions, waterbird, aquatic invertebrate and groundwater data. *Conservation Science Western Australia 5*(1), 20-135.

CALM. (1999). *Esperance Lakes Nature Reserves Management Plan 1999-2009 Management Plan Number 39*. National Parks and Nature Conservation Authority, Perth, Western Australia.

CALM. (2006). *The Lake Warden Natural Diversity Recovery Catchment, Recovery Plan 2005-2030, Preliminary Draft*. Department of Conservation and Land Management, Western Australia.

Carter, J. L., Colmer, T. D., & Veneklaas, E. J. (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*(1), 123-134.

Clarke, A. G., & Lane, J. A. K. (2003). *A Waterbird Census of Selected Wetlands along the coastal margins of the Esperance district, Feb-Mar 2003*. Western Australian Department of Conservation and Land Management.

Colwell, M. A., & Taft, O. W. (2000). Waterbird communities in managed wetlands varying in water depth. *Waterbirds, 23*(1), 45-55.

Comer, S., Gilfillan, S., Barrett, S., Grant, M., Tiedemann, K., & Andersen, L. (2001). Esperance 2 (ESP2 - Recherche subregion). In J. E. May & N. L. McKenzie (Eds.), *Biodiversity Audit of Western Australia's Biogeographical Subregions in 2002*. Department of Conservation and Land Management, Western Australia.

Cook, B. A., & Farrell, C. (2008). *Lake Warden Wetlands System: Monitoring of Aquatic Invertebrates in 2007*. Centre of Excellence in Natural Resource Management, University of Western Australia, Perth, Western Australia.

Cook, B. A., Macgregor, C. J., & Janicke, B. G. (2007). *Lake Warden Wetlands System: Monitoring of Aquatic Invertebrates in 2006*. Centre of Excellence in Natural Resource Management, University of Western Australia, Perth, Western Australia.

Cowcher, N. (2005). *Esperance Lake's Nature Reserves waterbird ecology*. Department of Environment and Conservation, Esperance, Western Australia.

Davis, J., & Christidis, F. (1997). A Guide to Wetland Invertebrates of Southwest Australia. *West Australian Museum*.

Davis, J. A., & Brock, M. (2008). Detecting unacceptable change in the ecological character of Ramsar wetlands. *Ecological Management & Restoration, 9*(1), 26-32.

Department of Environment and Conservation. (2006). *Lake Wheatfield leaflet*. Prepared by David Cale and Stuart Halse. Department of Environment and Conservation, Woodvale, Western Australia.

Department of Environment and Conservation. (2007a). *Phytophthora Dieback Atlas - From the bush to your back fence: What you need to know*. Department of Environment and Conservation, Perth.

Department of Environment and Conservation. (2007b). *Unpublished Vegetation Community and Change Analysis of Remote sensing Imagery 2004 - 2007*. Conducted by T. Massenbauer, Department of Environment and Conservation, Esperance, Western Australia.

Department of Environment and Conservation. (2008a). Acid Sulfate Soils: Fact sheet 1. Retrieved October, 2008, from http://www.dec.wa.gov.au/management-and-protection/acid-sulfate-soils/fact-sheets.html

Department of Environment and Conservation. (2008b). *Resource Condition Report for Significant Western Australian Wetlands: Ewans Lake*. Department of Environment and Conservation, Perth, Australia. In Preparation.

Department of Environment and Conservation. (2009a). *Ecological Character Description of the Lake Gore Ramsar Site, Esperance, Western Australia: A Report by the Department of Environment and Conservation*. Prepared By G.Watkins, Department of Environment and Conservation, Perth, Western Australia.

Department of Environment and Conservation. (2009b). Esperance District Office raw physico-chemical data 2001 - 2009 for the Lake Warden wetlands. Department of Environment and Conservation.

Department of Environment and Conservation. (2009c). *Phytopthora cinnamomi* mapping in the Esperance region Prepared by G. Freebury, Department of Environment and Conservation. Unpublished.

DEWHA. (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*. Australian Government Department of the Environment, Water, Heritage and the Arts, Canberra.

Dixon, A. K., Meney, A. K., Sivasithamparam, A. K., & Tieu, A. A. (2001). The interaction of heat and smoke in the release of seed dormancy in seven species from southwestern Western Australia. *Annals of botany, 88*(2), 259-265.

Ehrhardt, E. (2001). *Using GIS to Inventory Shallow Habitat within a Dynamic Floodplain Wetland Complex*. Paper presented at the 21st ESRI International User Conference.

Elner, R. W., Beninger, P. G., Jackson, D. L., & Potter, T. M. (2005). Evidence of a new feeding mode in western sandpiper (*Calidris mauri*) and dunlin (*Calidris alpina*) based on bill and tongue morphology and ultrastructure. *Marine biology, 146*(6), 1223.

Finlayson, C. M., & Mitchell, D. S. (1999). Australian wetlands: the monitoring challenge. *Wetlands Ecology and Management, 7*, 105-112.

Franke, B., Gurner, R., & Froend, R. (2001). *Wetland vegetation monitoring 2000/2001 (Salinity Action Plan): Prepared for the Department of Conservation and Land Management*. Edith Cowan University, Centre for Ecosystem Management, Perth, Western Australia.

Froend, R. H., Heddle, E. M., Bell, D. T., & McComb, A. J. (1987). Effects of waterlogging and salinity on the vegetation of Lake Toolibin, Western Australia. *Australian Journal of Ecology, 12*, 281-298.

Froend, R. H., & van der moezel, P. G. (1996). The impact of prolonged flooding on the vegetation of Coomalbidgup swamp, Western Australia. *Journal of the Royal Society of Western Australia, 77*, 15-22.

Galloway, P., & Clarendon, S. (2009). *Esperance area acid sulfate soil risk mapping. Resource Management Technical Report (in press)*. Department of Agriculture and Food, Perth, W.A.

Gee, S. T., & Simons, J. A. (2002). *Catchments of the Esperance Region of Western Australia*. Department of Agriculture, Esperance, Western Australia.

George, R. J., Speed, R. J., Simons, J. A., Smith, R. H., Ferdowsian, R., Raper, G. P., et al. (2008). *Long-term groundwater trends and their impact on the future extent of dryland salinity in Western Australia in a variable climate*. Paper presented at the International Salinity Forum 2008.

Goodsell, J. T. (1990). Distribution of Waterbird Broods Relative to Wetland Salinity and pH in South-Western Australia. *Wildlife Research, 17*(3), 219-229.

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.

Gross, J. E. (2003). Developing Conceptual Models for Monitoring Programs. Retrieved April, 2008, from http://science.nature.nps.gov/im/monitor/docs/Conceptual_Modelling.pdf

Hale, J., & Butcher, R. (2007). *Ecological Character Description of the Peel-Yalgorup Ramsar Site, Report to the Department of Environment and Conservation and the Peel Harvey Catchment*, Perth, Western Australia.

Halse, S. A. (2007). *A Waterbird Census of the Lake Warden and Lake Gore Wetland Systems, October 2006*. Science Division, Department of Environment and Conservation, Western Australia.

Halse, S. A., & Jaensch, R. P. (1989). Breeding seasons of waterbirds in South-western Australia - the importance of rainfall. *Emu, 89*, 232-249.

Halse, S. A., Jaensch, R. P., & Munro, D. R. (1992). *Annual waterfowl counts in south-Western Australia - 1989-1990: Technical Report No.29*. Department of Environment and Conservation, Western Australia.

Halse, S. A., Jaensch, R. P., Munro, D. R., & Pearson, G. B. (1990). *Annual Waterfowl Counts in south-Western Australia - 1988/89: Technical Report No. 25*. Department of Conservation and Land Management, Western Australia.

Halse, S. A., & Massenbauer, T. (2005). Incorporating research results into wetland management: Lessons from recovery catchments in saline landscapes. *Hydrobiologia*(522), 33-44.

Halse, S. A., Pearson, G. B., & Patrick, S. (1993). *Vegetation of depth-gauged wetlands in nature reserves of the south-west of Western Australia: Technical Report No. 30*. Department of Conservation and Land Management, Western Australia.

Halse, S. A., Pearson, G. B., & Vervest, R. M. (1995). Annual waterfowl count in south-west Western Australia - 1991/92. *CALM Science 2*(1), 1-24.

Halse, S. A., Vervest, R. M., Pearson, G. B., Yung, F. H., & Fuller, P. J. (1994). Annual waterfowl counts in the south-west Western Australia - 1990/91. *CALM Science, 1*(2), 107-129.

Handley, M. A. (1991). *The biota of inland salt lakes of the Kambalda region and coastal salt lakes of Esperance, Western Australia - a comparitive study.* Unpublished Honours, Curtin University of Technology, Perth, Western Australia.

Handley, M. A. (2003). *The Distribution Pattern of Algal Flora in Saline Lakes in Kambalda and Esperance, Western Australia.* Unpublished Master of Science, Curtin University of Technology, Perth, Western Australia.

Hellawell, J. M. (1991). Development of a rationale for monitoring In B. F. Goldsmith (Ed.), *Monitoring for Conservation and Ecology* (pp. 1-14). Chapman and Hall, London.

Hodgkin, E. P., & Clark, R. (1989). *Estuaries and Coastal Lagoons of South Western Australia, Stokes Inlet and Other Estauries of the Shire of Esperance*. Environmental Protection Authority, Estaurine Stidies Series No.5.

Indian Ocean Climate Initiative. (2002). *Climate variability and change in south west Western Australia*. Published by Indian Ocean Climate Initiative Panel, Perth, Western Australia.

Indian Ocean Climate Initiative. (2004). How has our rainfall changed? The south west. Retrieved August 2005, from http://www.ioci.org.au/publications/pdf/IOCI_Notes_Series2.pdf

Jaensch, R. P. (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. P., Vervest, R. M., & Hewish, M. J. (1988). *Waterbirds in Nature Reserves of south-Western Australia 1981-1985: Reserve counts*. Royal Australasian Ornithologists Union, Western Australia.

Janicke, S. (2004). *Esperance Lakes catchment hydrographic and water quality review – June 1997 to August 2004*. Department of Environment. Unpublished.

Jardine, A. A. (2007). Dryland salinity and ecosystem distress syndrome: Human health implications. *Ecohealth, 4*(1), 10-17.

Kimmins, J. P. (2004). *Forest Ecology*. Macmillan Publishing, Sydney.

Lambert, J., & Elix, J. (2006). *Workshop Report - Ecological Character Description for Ramsar Wetlands*. Prepared for the Commonwealth Department of the Environment and Heritage. Unpublished, Community Solutions, Fairlight, Sydney.

Lane, J. A. K. (2008). Lake Warden Wetlands depth, pH, salinity, phosphorus and nitrogen raw data set 1979 - 2007 for the South West Wetland Monitoring Program. Department of Environment and Conservation.

Lane, J. A. K., Pearson, G. B., Clarke, A. G., Winchcombe, Y. C., & Munro, D. R. (2004). *Depths and salinities of wetlands in south-Western Australia: 1977-2000*. Department of Conservation and Land Management, Perth, Western Australia.

Marimuthu, S., Reynolds, D. A., & Le Gal La Salle, C. (2005). A field study of the hydraulic, geochemical and stable isotope relationship in a coastal wetlands system. *Journal of Hydrology* (315), 93-116.

Marimuthu, S., Reynolds, D. A., & Le Gal La Salle, C. (submitted). Detailed water balance approaches in a coastal wetlands system. *Journal of Hydrological Processes*.

Massenbauer, A. (2007a). *Esperance Lakes catchment appraisal 2007. Resource Management Technical Report 316*. Esperance Catchment Support Team, Department of Agriculture and Food, Western Australia.

Massenbauer, T. (2007b). Vegetation Community and Change Analysis Maps of the the Lake Warden Wetland System Department of Environment and Conservation. Unpublished.

Massenbauer, T. (2008). Lake Gore and Lake Warden raw waterbird habitat data. Department of Environment and Conservation.

Massenbauer, T., & Robertson, D. (2005). *Developing a Land Management Decision Support System for the Lake Warden Catchment.* Paper presented at the Natural Resource Management, Denmark, Western Australia.

Massenbauer, T., & Vogwill, R. (2007). *Lake Warden Wetland System Engineering Scoping Proposal*. Department of Environment and Conservation.

Maunsell/AECOM. (2008). *Lake Warden Wetland System (LWWS), Esperance: Initial Environmental Assessment*. Department of Environment and Conservation, Perth, Western Australia.

May, S. (2008). *Esperance Area Waterway Quality Report*. Department of Water, Albany, Western Australia.

McArthur, W. M. (1991). *Reference soils of south-western Australia*. Department of Agriculture, Western Australia.

McGrath, C. (2006). *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*. Department of the Environment and Heritage, Canberra. Unpublished.

Michael, A. W., & Mark, A. E. (2007). Responses of Incubating Hooded Plovers (*Thinornis rubricollis*) to Disturbance. *Journal of Coastal Research, 23*(3), 569.

Millennium Ecosystem Assessment. (2005a). *Ecosystem services and human wellbeing: Wetlands and water: Synthesis 2005: Millennium Ecosystem Assessment report to the Ramsar convention* World Resources Institute http://www.milllenniumassessment.org/en/products.aspx., Washington D.C.

Millennium Ecosystem Assessment. (2005b). *Ecosystems and human wellbeing - synthesis: Millennium Ecosystem Assessment report to the Ramsar convention*. World Resources Institute http://www.milllenniumassessment.org/en/products.aspx., Washington D.C.

Mitsch, W. J., & Gosselink, J. G. (2007). *Wetlands* (4 ed.). John Wiley and Sons, Inc, New Jersey.

Monaghan, C. P., & Beale, C. C. (2004). Human disturbance: people as predation-free predators? *The Journal of applied ecology, 41*(2), 335-343.

Morrison, D. A. D. A. (2002). Effects of fire intensity on plant species composition of sandstone communities in the Sydney region. *Austral ecology, 27*(4), 433.

Mukherjee, A., & Borad, C. K. (2001). Effects of waterbirds on water quality. *Hydrobiologia* (464), 201–205.

Newbey, B. J. (1996). *Report on the Hooded Plover Project: Supplement to Western Australian Bird Notes 76.* Royal Australian Ornithologist Union (WA Group), Western Australia.

Norriss, J. V., Tregonning, J. E., Lenanton, R. C. J., & Sarre, G. A. (2002). *Biological synopsis of the black bream Acanthopagrus butcheri (Munro)(Teleostei: Sparidae) in Western Australia with reference to information from other southern states. Fisheries Research Report No. 93*. Department of Fisheries, Western Australia, Western Australia.

Ogden, G., & Froend, R. (1998). *Salinity Action Plan: Wetland vegetation monitoring , 1997/1998, for the Department of Environment and Conservation*. Edith Cowan University, Centre for Ecosystem Management, Perth, Western Australia.

Pen, L. J. (1999). *Managing our rivers: a guide to the nature and management of the streams of south-west Western Australia* Water and Rivers Commission, East Perth, Western Australia

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: Ashmoore Reed National Nature Reserve, the Coral Sea Reserves (Coringa-Herald and Lihou reefs and Cays), and Elizabeth and Middleton Reefs Marine National Nature Reserve*. Mainstream Environmental Consulting Pty Ltd, Waramanga ACT.

Pinder, A. M., Halse, S. A., McRae, J. M., & Shiel, R. J. (2004). Aquatic invertebrate assemblages of wetlands and rivers in the wheatbelt region of Western Australia. *Records of the Western Australian Museum, Supplement No. 67*, 7-37.

Raines, J. (2002). *Hooded Plover management plan (2002-2012) Western Australia: Western Australia Bird Notes, Supplement No.7, July 2002*. Birds Australia, Perth, Western Australia.

Ramsar Convention. (1987). Convention on Wetlands of International Importance especially as Waterfowl Habitat. Retrieved April, 2008, from http://www.ramsar.org/key_conv_e.htm

Ramsar Convention. (2002). Resolution VIII.6 A Framework for Wetland Inventory. Retrieved April, 2008, from http://www.ramsar.org/res/key_res_viii_06_e.htm

Ramsar Convention. (2005a). *Resolution IX.1 Annex A. A Conceptual Framework for the wise use of wetlands and the maintenance of their ecological character.* Paper presented at the 9th Meeting of the Conference of the Parties to the Convention on Wetlands (Ramsar, Iran, 1971) “Wetlands and water: supporting life, sustaining livelihoods”, Kampala, Uganda.

Ramsar Convention. (2005b). Strategic Framework and Guidelines for the Future Development of the List of Wetlands of International Importance of the Convention on Wetlands (Ramsar, Iran,1971) Third edition, as adopted by Resolution VII.11 (COP7, 1999) and amended by Resolutions VII.13 (1999), VIII.11 and VIII.33 (COP8, 2002), and IX.1 Annexes A and B (COP9, 2005). Retrieved April, 2008, from http://www.ramsar.org/key_guide_list2006_e.htm

Ramsar Information Sheet. (2003). *Lake Warden System*. Department of Environment and Conservation, Busselton, Western Australia.

Reynolds, D. A., & Marimuthu, S. (2007). Deuterium composition and flow path analysis as additional calibration targets to calibrate groundwater flow simulation in a coastal wetlands system. *Hydrogeology journal, 15*(3), 515-535.

Robertson, D., & Massenbauer, T. (2005). *Applying hydrological thresholds to wetland management for waterbirds, using bathymetric surveys and GIS.* Paper presented at the MODSIM, Melbourne.

Rokich, D. P., Dixon, K. W., Sivasithamparam, K., & Meney, K. A. (2002). Smoke, Mulch, and Seed Broadcasting Effects on Woodland Restoration in Western Australia. *Restoration Ecology, 10*(2), 185-194.

Sammut, J., Melville, M. D., Callinan, R. B., & Fraser, G. C. (1995). Estuarine acidification: Impacts on aquatic biota of draining acid sulfate soils. *Australian Geographical Studies, 33*(1), 89-100.

Shearer, B. L., & Tippett, J. T. (1988). Distribution and impact of *Armillaria luteobubalina* in the *Eucalyptus marginata* Forest of South-western Australia. *Australian Journal of Botany, 36*, 433-445.

Short, R. (2000). *A conceptual hydrogeological model for the Lake Warden recovery catchments, Esperance WA*. Agriculture Western Australia, Esperance, Western Australia.

Short, R. (2001). Geological History. In *Dalyup Catchment 2000.* Department of Agriculture, Western Australia.

Short, R., Salama, R., Pollock, D., Hatton, T., Bond, W., Paydar, Z., et al. (2000). *Assessment of Salinity Managment Options for Lake Warden Catchments, Esperance, WA: Groundwater and Crop Water Balance Modelling*. CSIRO, Western Australia.

Singor, M. (1999). *Hooded Plover Report No.2 1996-1999: Supplement to Western Australian Bird Notes 90*. Birds Australia, Western Australia.

Stankey, G., H, Cole, D., N, Lucas, R., C, Petersen, M., E, & Frissell, S., S. (1985). *The Limits of Acceptable Change (LAC) system for wilderness planning. Gen. Tech. Rep. INT-176*. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Stephens, F. J., & Ingram, M. (2006). Two cases of fish mortality in low pH, aluminium rich water. *Journal of Fish Diseases, 29*(12), 765-770.

Stevenson, M. (2007). *Modelling the surface-groundwater interaction in Esperance, Western Australia using a groundwater flow model.* University of Stuttgart, Stuttgart.

Wallace, K. J. (2007). Classification of ecosystem services: Problems and solutions. *Biological Conservation, 139*, 235-246.

Water and Rivers Commission. (2002). *Dalyup and West Dalyup Rivers Action Plan: Water Resource Management Series, No WRM 34*. Water and Rivers Commission Western Australia.

Weston, M. A., & Elgar, M. (2000). The effect of a major rainfall event on hooded plovers on a salt-lake in Western Australia. *EMU, 100*, 64-69.

Wetlands International. (2002). *Waterbird population estimates - Third Edition. Wetlands International Global Series No.12* Wetlands International, Wageningen, The Netherlands.

Wetlands International. (2006). *Waterbird population estimates - Fourth Edition*, Wetlands International, Wageningen, The Netherlands.

Wiens, J. A. (1989). *The ecology of bird communities*. Cambridge University Press, Cambridge.

Williams, W. D., & Mellor, M. W. (1991). Ecology of coxiella (mollusca, gastropoda, prosobranchia), A snail endemic to Australian salt lakes. *Palaeogeography, palaeoclimatology, palaeoecology, 84*(1-4), 339-355.

Wilson, B. (2004). *A preliminary assessment of the recent environmental history of the Lake Warden wetlands - Esperance Western Australia: A technical report for the Department of Conservation and Land Management* School of Earth and Geographical Sciences, University of Western Australia.

APPENDICES

APPENDIX A: METHODS

The Lake Warden System Ramsar Site ECD was prepared by undertaking:

1. Desktop study

The Lake Warden System Ramsar Site ECD was prepared, based on a desktop study of the site using existing information. A literature review was undertaken by the author to compile information pertaining to the Ramsar Site. Raw data was also compiled and some statistical analysis was performed.

2. Site visit

A site visit was conducted for familiarisation with the ecosystem components, processes, benefits and services of the site.

3. Consultation

Consultation and liaison with a wide range of stakeholders including various state government Department representatives and other external stakeholders such as community members. The technical advisory group (TAG) met in Esperance and a public forum was also conducted. The TAG was formed specifically to provide technical advice on the ecosystem components, processes, benefits and services of the site.

4. Draft Documents

The ECD was developed in accordance with the requirements detailed in 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*. Australian Government Department of the Environment, Water, Heritage and the Arts, Canberra (see: DEWHA, 2008).

A draft ECD for the Lake Warden System Ramsar Site was prepared and the Ramsar Information Sheet (RIS) was updated, based on the 12 step process described in the national framework and guidance (Table A1). Please note the ECD has not necessarily been presented in this order.

Table A1. Twelve key steps in the preparation of the draft ECD and RIS for the Lake Warden System Ramsar Site, Esperance, Western Australia (after DEWHA, 2008).

Step	Outline of tasks performed
1. Introduction to the description	A summary of the site and a statement to the purpose of describing ecological character and the objectives of the ECD was provided. This included legislation that is relevant to the site.
2. Describe the site	A more detailed description of the Ramsar Site including location, climate, maps, tenure and wetland types was provided. This step also involved detailing the Ramsar Criteria applicable to the site.
3. Identify and describe the critical components and services	All possible components, processes, benefits and services of the Ramsar Site were identified. The critical ecosystem components, processes, benefits and services of the Ramsar Site were then identified and described.
4. Develop a conceptual model for the wetland	A series of control and stressor models were developed for the ECD. These were developed by the author using particular information in relation to the site and inferred ecological knowledge. Control models were included to depict the interaction of the critical ecosystem, components, benefits and services of the site. Stressor models were used to depict the effect of threatening processes on critical ecosystem components, processes, benefits and services of the site.
5. Set limits of acceptable change	Limits of Acceptable Change were set for the critical ecosystem components and processes where possible.
6. Identify threats of the site	The actual or likely threats to the Ramsar Site were identified and the affect on the critical ecosystem components, processes, benefits and services were identified. This was performed using information derived from steps 3-5 and other contextual information.
7. Describe the changes to ecological character	The interaction between the critical ecosystem components, processes, benefits, services and threats were described. Changes in the ecological character of the Ramsar Site were described and quantified where possible.
8. Summarise the knowledge gaps	Knowledge gaps regarding the Ramsar Site were highlighted along with recommended actions. Knowledge gaps were identified using information derived from steps 3-7.
9. Identify site monitoring needs	The monitoring requirements for the Ramsar Site were described based on maintaining the ecological character of the site. Monitoring requirements were identified using information derived from steps 3-8.
10. Identify communication and education messages	Important communication, education and public awareness messages applicable to the Ramsar Site were described. They were identified during the preparation of the ECD.
11. Compile the description of the ecological character	The information was compiled and a draft ecological character description of the site was prepared.
12. Prepare or update the RIS	The RIS was updated using the information derived from the preparation of the draft ECD.

5. Final Documents

A draft version of the ECD and RIS were prepared and submitted to the TAG and the Department of Environment, Water Heritage and the Arts (DEWHA) for review. The final ECD and RIS documents were prepared after incorporating the comments from the TAG and DEWHA.

APPENDIX B WATERBIRDS

Table B1. Waterbirds recorded for the Lake Warden System Ramsar Site, Esperance Western Australia 1981 - 2008 with feeding guilds. Note: X: Denotes species present; Guild 1 - Shore: Majority of feeding is on dry land; Guild 2 - Wading birds and shallow feeders: Feeding in water that is ≤ 0.5m. Birds within this group may also feed within wet mud and guild 1; Guild 3 - Deep feeders: Requiring a water depth that is ≥ 1m but can also occupy guilds 1 and 2; Guild 4 - Aerial feeders: Birds of prey (guild information adapted from Cowcher, 2005; Jaensch, 2002).

Key:
EPBC Act Status: "Migratory" B - CMS species, C - CAMBA species, J - JAMBA species, R - ROKAMBA species
"Marine" - M

IUCN Red List Status: "Near Threatened" - RNT
"Vulnerable" - RV

Scientific name	Common name	Guild 1.	Guild 2.	Guild 3.	Guild 4.
ACCIPITRIDAE					
Circus aeriginosus	Marsh Harrier **M**				X
Haliaeetus leucogaster	White Bellied Sea Eagle **C**				X
ANATIDAE					
Anas castanea	Chestnut Teal		X		
Anas gibberifrons	Grey Teal		X		
Anas rhynchotis	Australasian Shoveler		X		
Anas superciliosa	Pacific Black Duck		X		
Aythya australis	Hardhead			X	
Biziura lobata	Musk Duck			X	
Cereopsis novaehollandiae grisea	Cape Barren Goose **M;V**	X			
Chenonetta jubata	Australian Wood Duck		X		
Cygnus atratus	Black Swan			X	

Melacorhynchus membranaceus	Pink-eared Duck		X		
Oxyura australis	Blue-billed Duck			X	
Stictonetta naevosa	Freckled Duck			X	
Tadorna tadornoides	Australian Shelduck		X		
ANHINGIDAE					
Anhinga melanogaster	Darter **RNT**			X	
ARDEIDAE					
Ardea ibis	Cattle Egret **CJ;M**		X		
Ardea novaehollandiae	White-faced Heron		X		
Ardea pacifica	White-necked Heron		X		
Egretta alba	Great Egret **CJ;M**		X		
Egretta garzetta	Little Egret **M**		X		
Nycticorax caledonicus	Nankeen Night Heron **M**		X		
CHARADRIIDAE					
Charadrius ruficapillus	Red-capped Plover **M**		X		
Elseyornis melanops	Black-fronted Dotterel		X		
Erythrogonys cinctus	Red-kneed Dotterel		X		
Thinornis rubricollis	Hooded Plover **M.RNT**		X		
Pluvialis squatarola	Grey Plover **BCJR;M**		X		
Vanellus miles	Masked Lapwing		X		
Vanellus tricolor	Banded Lapwing		X		
LARIDAE					

Chlidonias hybridus	Whiskered Tern **M**			X	
Chlidonias leucopterus	White-winged Black Tern **CJR;M**			X	
Larus novaehollandiae	Silver Gull **M**	X			
Sterna nereis	Fairy Tern **M.RV**			X	
Sterna nilotica	Gull Billed Tern **M**			X	
PELECANIDAE					
Pelecanus conspicillatus	Australian Pelican **M**			X	
PODICIPEDIDAE					
Podiceps cristatus	Great Crested Grebe			X	
Poliocephalus poliocephalus	Hoary-headed Grebe			X	
Tachybaptus novaehollandiae	Australasian Grebe			X	
PHALACROCORACIDAE					
Phalacrocorax carbo	Great Cormorant			X	
Phalacrocorax melanoleucos	Little Pied Cormorant			X	
Phalacrocorax sulcirostris	Little Black Cormorant			X	
Phalacrocorax varius	Pied Cormorant			X	
RALLIDAE					
Fulica atra	Eurasian Coot			X	
Gallinula ventralis	Black-tailed Native Hen	X			
Porphyrio porphyrio	Purple Swamp Hen	X			
Porzana fluminea	Australian Spotted Crake		X		
Porzana tabuensis	Spotless Crake **M**	X			

RECURVIROSTRIDAE					
Cladorhynchus leucocephalus	Banded Stilt		X		
Himantopus himantopus	Black-winged Stilt **M**		X		
Recurvirostra novaehollandiae	Red-necked Avocet **M**		X		
SCOLOPACIDAE					
Arenaria interpres	Ruddy Turnstone **BCJR;M**		X		
Calidris acuminata	Sharp-tailed Sandpiper **BCJR;M**		X		
Calidris alba	Sanderling **BCJR;M**		X		
Calidris canutus	Red Knot **BCJR;M**		X		
Calidris ferruginea	Curlew Sandpiper **BCJR;M**		X		
Calidris melanotos	Pectoral Sandpiper **BJR;M**		X		
Calidris ruficollis	Red-necked Stint **BCJR;M**		X		
Calidris subminuta	Long-toed Stint **BCJR;M**		X		
Calidris tenuirostris	Great Knot **BCJR;M**		X		
Limicola falcinellus	Broad-billed Sandpiper **BCJR;M**		X		
Limosa lapponica	Bar-tailed Godwit **BCJR;M**		X		
Limosa limosa	Black-tailed Godwit **BCJR;M.RNT**		X		
Numenius phaeopus	Whimbrel **BCJR;M**		X		
Tringa glareola	Common Sandpiper **BCJR;M**		X		
Tringa nebularia	Common Greenshank **BCJR;M**		X		
Tringa stagnatilis	Marsh Sandpiper **BCJR;M**		X		
Xenus cinereus	Terek Sandpiper **BCJR;M**		X		

STERNIDAE					
Sterna caspia	Caspian Tern **CJ;M**			X	
SYLVIIDAE					
Acrocephalus stentoreus	Clamorous Reed-Warbler **B;M**	X			
THRESKIORNITHIDAE					
Platalea flavipes	Yellow-billed Spoonbill		X		
Plegadis falcinellus	Glossy Ibis **BC;M**		X		
Threskiornis molucca	Australian White Ibis **M**		X		
Threskiornis spinicollis	Straw Necked Ibis **M**	X			

Table B2. General waterbird dietary guilds. Note: X denotes mainly eaten; O denotes occasionally may be eaten (adapted from: Hale & Butcher, 2007)

	Plants and Animals	Mainly Plants	Mainly Animals	Fish	Freshwater crayfish
Ducks, Geese, Swans					
Australasian Shoveler	X				
Australian Shelduck	X				
Australian Wood Duck	X				
Black Swan		X			
Blue-billed Duck	X				
Cape Barren Goose		X			
Chestnut Teal	X				X
Freckled Duck	X				
Grey Teal	X				X
Hardhead	X			O	X
Musk Duck	X			O	X
Pacific Black Duck	X				X
Pink-eared Duck	X				X
Grebes					
Australasian Grebe			X	X	
Great Crested Grebe		O	X	X	
Hoary-headed Grebe			X	X	
Pelicans, Cormorants, 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
Pied Cormorant			X	X	X
Herons, Ibis, Egrets, Spoonbills					
Australian White Ibis			X	X	X
Cattle Egret			X	X	X
Glossy Ibis			X	O	X
Great Egret			X	X	X
Little Egret			X	X	X
Nankeen Night Heron			X	X	X
White-faced Heron			X	X	X
White-necked Heron			X	X	X
Yellow-billed Spoonbill			X	X	X
Straw Necked Ibis			X	X	X
Hawks, Eagles, Falcons					
Marsh Harrier			X	X	
White Bellied Sea Eagle			X	X	
Crakes, Rails, Water Hens, Coots					

	Plants and Animals	Mainly Plants	Mainly Animals	Fish	Freshwater crayfish
Australian Spotted Crake	X				
Black-tailed Native Hen	X				
Eurasian Coot	X				
Purple Swamp Hen	X			X	
Spotless Crake	X				
Shorebirds					
Banded Lapwing	X				
Banded Stilt	X			O	
Bar-tailed Godwit	X		X		
Black-fronted Dotterel	X				
Black-tailed Godwit		O	X		
Black-winged Stilt		O	X	O	
Broad-billed Sandpiper			X		X
Common Greenshank	X				
Common Sandpiper	X				
Curlew Sandpiper			X		X
Great Knot			X		
Grey Plover			X		
Hooded Plover			X		X
Long-toed Stint			X		
Masked Lapwing			X		
Marsh Sandpiper			X		
Pectoral Sandpiper	X				
Red Knot			X		
Red-capped Plover	X				
Red-kneed Dotterel	X				
Red-necked Avocet		O	X	O	
Red-necked Stint	X				
Ruddy Turnstone			X		
Sanderling	X		X		
Sharp-tailed Sandpiper	X				
Terek Sandpiper			X		
Whimbrel			X		
Gulls and terns					
Caspian Tern			X	X	
Fairy Tern			X	X	
Gull-billed Tern			X	X	X
Silver Gull	X			X	X
Whiskered Tern			X	X	
White-winged Black Tern			X		

	Plants and Animals	Mainly Plants	Mainly Animals	Fish	Freshwater crayfish
Old World Warblers					
Clamorous Reed-Warbler			X		

Table B3. Preferred waterbird water quality requirements (salinity and pH where available). Note: Figures in parenthesis are averages; * can cope with saline water if there is fresh water available; # not unusual for feeding at both acidic and non-acidic hypersaline waters (from Cowcher, 2005).

	Salinity (ppt)	pH
Ducks, Geese, Swans		
Australasian Shoveler	0.97 - 22.2 (9.25)	6.2 - 10 (8.4)
Australian Shelduck*#	0.35 - 57.0 (12.0)	4.8 - 9.8 (8.2)
Australian Wood Duck	0.14 - 9.5 (3.54)	7.0 - 9.6 (8.1)
Black Swan*	0.4 - 43.5 (9.65)	6.2 - 10.2 (8.2)
Blue-billed Duck	0.65 - 6.4 (1.72)	6.7 - 9.1 (8.6)
Cape Barren Goose	5	
Chestnut Teal	≤ 2 - 35	> 7
Freckled Duck	7.7 - 9.0 (8.3)	1.9 - 11.5 (6.34)
Grey Teal*#	0.12 - 37.65 (6.9)	6.2 - 10.1 (8.2)
Hardhead	0.4 - 4.9 (2.32)	6.4 - 9.0 (8.1)
Musk Duck	0.1 - 11.4 (2.74)	6.4 - 9.1 (8.3)
Pacific Black Duck*	0.2 - 14.6 (2.85)	6.7 - 10 (8.0)
Pink-eared Duck	0.14 - 17.0 (5.23)	6.7 - 10 (8.3)
Grebes		
Australasian Grebe	0.73 - 9.95 (4.04)	7.1 - 10.1 (8.1)
Great Crested Grebe	0.65 - 8.32 (3.47)	7.7 - 11.0 (8.7)
Hoary-headed Grebe	0.73 - 9.87 (4.57)	6.8 - 10.0 (8.4)
Pelicans, Cormorants, Darters		
Australian Pelican	> 2 - > 35	
Darter	1.67 - 7.3 (4.83)	7.0 - 10 (7.7)
Great Cormorant	0.96 - 4.7 (2.82)	7.3 - 8.1 (7.6)
Little Black Cormorant	0.87 - 17.2 (3.64)	6.2 - 9.0 (7.4)
Little Pied Cormorant	0.71 - 17.2 (5.77)	5.7 - 10.0 (7.9)
Pied Cormorant	> 2 - 35	
Herons, Ibis, Egrets, Spoonbills		
Australian White Ibis	≤ 2 - 5	
Cattle Egret		
Glossy Ibis		
Great Egret	1.5 - 10.2 (3.82)	7.0-8.1 (7.4)
Little Egret		
Nankeen Night Heron	0.8 - 10.2 (2.96)	7.0 - 9.0 (7.5)
White-faced Heron	0.14 - 25.8 (3.29)	6.0 - 9.1 (7.8)

	Salinity (ppt)	pH
White-necked Heron	≤ 2	
Yellow-billed Spoonbill	0.81 - 7.45 (2.42)	6.2 - 7.7 (7.2)
Straw Necked Ibis	0.81 - 2 (1.324)	6.2 - 7.0 (6.9)
Hawks, Eagles, Falcons		
Marsh Harrier		
White Bellied Sea Eagle		
Crakes, Rails, Water Hens, Coots		
Australian Spotted Crake	≤ 2	
Black-tailed Native Hen		>7
Eurasian Coot	0.17 - 32.1 (6.15)	6.2 - 10.2 (8.5)
Purple Swamp Hen	0.33 - 4.1 (1.6)	6.8 - 10.2 (8.3)
Spotless Crake		
Shorebirds		
Banded Lapwing		
Banded Stilt	10 - 25	> 7
Bar-tailed Godwit	≤ 2 - 35	
Black-fronted Dotterel	≤ 2 - 35	
Black-tailed Godwit	≤ 2 - 5	
Black-winged Stilt	0.127 - 21.52 (7.89)	6.8 - 10.1 (8.6)
Broad-billed Sandpiper	> 2 - 35	
Common Greenshank	> 2 - 5	
Common Sandpiper	> 2 - 5	> 7
Curlew Sandpiper	≤ 2 - 35	
Great Knot	≤ 2 - 35	
Grey Plover		
Hooded Plover	≤ 2 - > 35	
Long-toed Stint		
Masked Lapwing		
Marsh Sandpiper	≤ 2 - 5	
Pectoral Sandpiper	≤ 2 - 35	
Red Knot	≤ 2 - 35	
Red-capped Plover	35	
Red-kneed Dotterel		
Red-necked Avocet	114.0 - 344.0 (191.67)	2.8 - 8.6 (5.0)
Red-necked Stint	≤ 2 - 35	
Ruddy Turnstone	> 2 - 35	
Sanderling	≤ 2 - 5	
Sharp-tailed Sandpiper		
Terek Sandpiper		
Whimbrel	> 2 - 35	
Gulls and Terns		
Caspian Tern	> 2 - 35	
Fairy Tern	> 2 - 35	

	Salinity (ppt)	pH
Gull-billed Tern	> 2 - 35	
Silver Gull	35	
Whiskered Tern	> 2 - 35	
White-winged Black Tern	> 2 - 35	
Old World Warblers		
Clamorous Reed-Warbler	≤ 2	

APPENDIX C: AQUATIC INVERTEBRATES

Table C1. Aquatic invertebrates recorded at the Lake Warden System Ramsar Site (data from Brock & Shiel, 1983; Cale et al., 2004; Cook & Farrell, 2008; Cook et al., 2007; Handley, 1991; Pinder et al., 2004) .

Taxa	Taxa
Acarina	*Procladius paludicola*
Hydrachnidae	*Procladius villosimanus*
Koenikea verrucosa	Sciomyzidae
Mesostigmata	Stratiomyidae
Oribatida	*Tanytarsus fuscithorax/semibarbitarsus*
Pezidae	*Tanytarsus* sp. A (nr. K10)
Trombidioidea	**Gastropoda**
Amphipoda	*Coxiella glabra*
Austrochiltonia subtenuis	*Coxiella* sp.
Melita kauerti	*Coxiella striata*
Tallitridae	Planorbid gastropod
Annelida	**Hemiptera**
Dero digitata	*Anisops hackeri*
Enchytraeidae	*Hebrus* sp.
Oligochaeta	*Micronecta robusta*
Paranais litoralis	Notonectidae sp. F
Tubificidae	*Saldula* sp.
Arachnida	**Hydrazoa**
Araneae	*Cordylophora* sp.
Eylais sp.	Turbellaria
Hydryphantes meridianus	Nematoda
Oribatidae	**Isopoda**
unidentified trombidioids	*Exospaeroma* sp.
Arthropoda	Haloniscus sp.
Parartemia sp.	Sphaeromatidae sp.
Bivalvia	Haloniscus sp.
Pisidium sp.	Sphaeromatidae sp.
Cladocera	**Lepidoptera**
Alona sp.	Lepidoptera sp. 3
Daphnia carinata	Nymphulinae sp. 12
Collembola	Nymphulinae sp. 40
Hypogastruridae	**Odonata**
Coleoptera	*Austrolestes annulosus*
Antiporus gilberti	*Austrolestes analis*
Berosus discolor	*Austrolestes aridus*
Berosus sp.	*Austrolestes io*
Dytiscids	*Hemicordulia tau*
Gymnocthebius sp. 1	Zygoptera juveniles

Hydrophilidae	**Ostracoda**
Lancetes lanceolatus	*Alboa worooa*
Necterosoma penicilatus	*Australocypris insularis*
Necterosoma sp.	*Cabonocypris* sp. ('Kondinin')
Paroster niger	*Candonocypris* sp.
Staphylinidae	*Cypricercus* sp.
Sternopriscus multimaculatus	Cyprididae
Terebrionidae	*Cyprideis australiensis*
Copepoda	*Cyprinotus edwardi*
Apocyclops dengizicus	*Diacypris* n. sp. 581
Calanoida sp.	*Diacypris spinosa*
Cletocamptus aff *deitersi*	*Ilyocyprisus autraliensis*
Cyclopoida	*Kennethia cristata*
Gladioferens imparipens	*Leptocythere lacustris*
Halicyclops sp. 1 (nr *ambiguus*)	*Mytilocypris ambiguosa*
Harpacticoida	*Mytilocypris tasmanica chapmani*
Metacyclops sp. 442	*Newnhamia fenestra*
Mesochra baylyi	Ostracoda sp. 3
Mesochra sp.	Ostracoda sp. (elongate)
Mesocyclops brooksi	*Platycypris baueri* Herbst, 1956
Nitocra reducta	*Reticypris clava*
Onychocamptus bengalensis	*Reticyprus walbu*
Decapoda	*Sarscypridopsis aculeata*
Palaemonetes australis	**Rotifera**
Diptera	*Brachionus* sp.
Aedes (Ochlerotatus) camptorhynchus	*Brachionus rotundiformis*
Brachycera	*Colurella adriatica*
Ceratopogonidae	*Colurella* sp.
Chironomus aff. *alternans*	*Hexarthra fennica*
Chironomus occidentalis	*Hexarthra* sp.
Cladopelma curtivalva	*Keratella procurva*
Cladotanytarsus sp. A	*Keratella quadrata*
Clinohelea sp.	*Lecane ludwigii*
Cryptochironomus griseidorsum	*Lecane luna*
Culicoides sp.	*Lecane* sp.
Dicrotendipes pseudoconjunctus	*Macrotrachela* sp. a
Dicrotendipes sp. A (D. Edwards V47)	Philodinidae
Dolichopodidae	*Synchaeta* sp.
Empididae	*Testudinella patina*
Ephydridae	*Trichocerca* sp.
Kiefferulus intertinctus	**Trichoptera**
Monohelea sp.	*Ecnomus pansus/turgidus*
Muscidae	*Notalina spira*
Nilobezzia sp. 2	*Oecetis* sp.

Paralimnophyes pullulus	*Symphitoneuria wheeleri*
Polypedilum nr. *convexum*	*Triplectides australis*
Polypedilum nubifer	

APPENDIX D: NATIVE VEGETATION

Table D1. Native vegetation recorded at Lake Wheatfield in the Lake Warden System Ramsar Site, Esperance, Western Australia (data from Franke et al., 2001; Ogden & Froend, 1998).

Atriplex prostrata	*Leucopogan revoltus*
Baumea juncea	*Melaleuca brevifolia*
Chenopodium glaucum	*Nuytsia floribunda*
Dampiera linearis	*Paspalum vaginatum*
Darwinia diosmoides	*Sarcocornia quinqueflora*
Gahnia trifida	*Samolosis* sp.
Ficinia nodosa	*Scholtzia* sp.
Juncus krausii	*Sueda australis*
Labichea lanceolata	*Syridium* sp.
Leucopogan parvifloris	*Xanthosia rotundifolia*

Table D2. Native vegetation recorded at Ewans Lake in the Lake Warden System Ramsar Site, Esperance, Western Australia (data from Department of Environment and Conservation, 2008b).

Apium annuum	*Samolus repens* var. *repens*
Apium prostratum var. *prostratum*	*Sarcocornia quinqueflora*
Hemichroa pentandra	*Sporobolus virginicus*
Juncus kraussii subsp. *australiensis*	*Suaeda australis*
Melaleuca brevifolia	*Tecticornia* sp.
Melaleuca cuticularis	*Triglochin striata*
Puccinellia stricta	

Table D3. Native vegetation recorded at Lake Warden in the Lake Warden System Ramsar Site, Esperance, Western Australia (data from Halse et al., 1993)..

Acacia sp.	*Ficinia nodosa*
Chenopodium glaucum	*Melaleuca cuticularis*
Halosarcia pergranulata	*Sarcocornia quinqueflora*
Halosarcia lepidosperma	*Schoenus brevifolius*

Table D4. Native vegetation recorded at Station Lake in the Lake Warden System Ramsar Site, Esperance, Western Australia (data from Halse et al., 1993)..

Acacia sp.	*Melaleuca cuticularis*
Chenopodium glaucum	*Sarcocornia quinqueflora*
Gahnia trifida	*Schoenus brevifolius*
Halosarcia pergranulata	*Schoenus* sp.
Halosarcia lepidosperma	*Sclerostegia moniliformus*
Halosarcia synocarpa	*Suaeda australis*
Ficinia nodosa	