Department of
Environment and Conservation
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Resource Condition Report for a Significant Western Australian Wetland

Lake Gregory (Paraku) System

2009

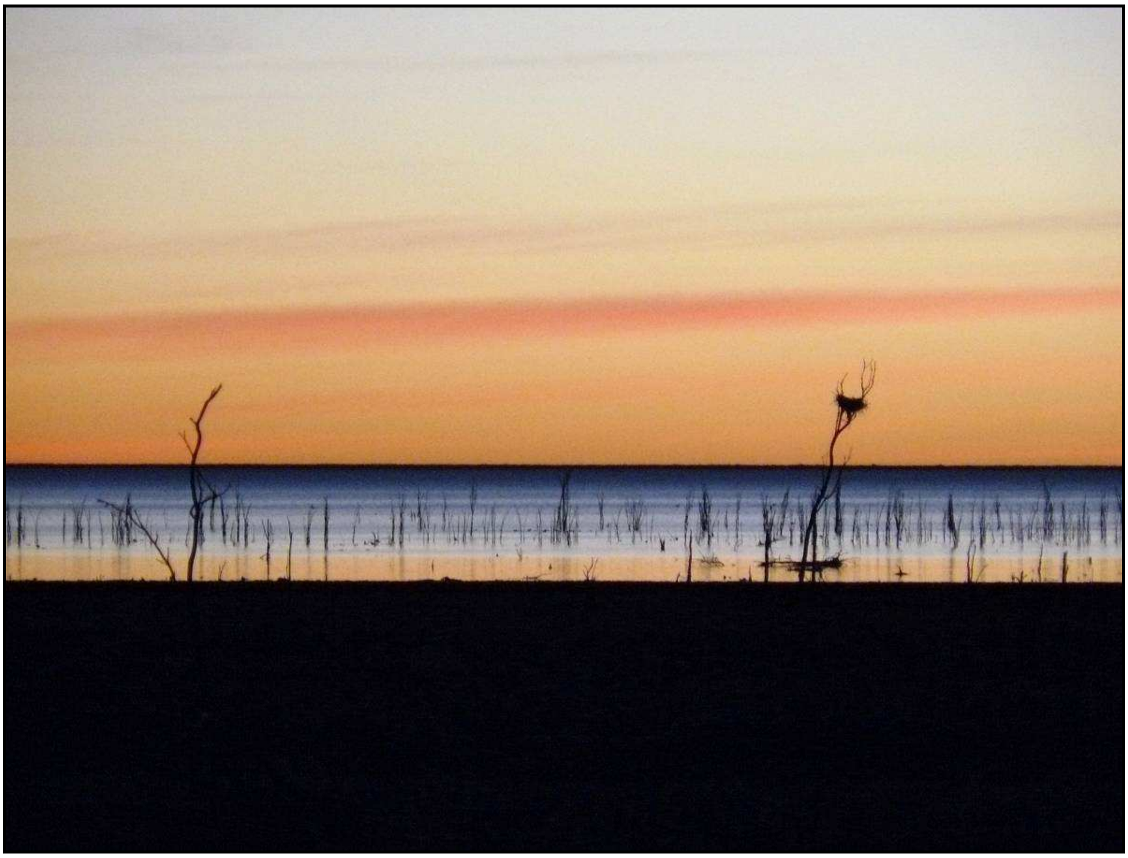

Figure 1 – Sunset over Lake Gregory.

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Contents

1. Introduction

This Resource Condition Report (RCR) was prepared by the Inland Aquatic Integrity Resource Condition Monitoring (IAI RCM) project. It describes the ecological character and condition of the Lake Gregory system, a very large group of episodic wetlands in the southern Kimberley. The Lake Gregory system includes a megascale lake (Mulan Lake), as well as several macroscale lakes (Bulbi, Yuinby, Guda, Rilya and Gillung) and sumps, all of which are connected by sinuous creeks in the delta of Sturt Creek.

The Lake Gregory system is of high significance to local Aboriginal people, who call the lake system Paraku and link it to human creation stories (pers. obs. 2008). When full, the lake system is an important breeding ground for many species of waterbird.

In the current report, the term 'Lake Gregory' will be used in reference to the broader wetland system, 'Mulan Lake' for the largest basin within that system and 'Paraku' for the Indigenous Protected Area (IPA). The current report considers aspects of the Lake Gregory system, but biological and water quality data were only collected on the eastern shore of Mulan Lake (Figures 2 and 3).

1.1. Site Code

Directory of Important Wetlands in Australia: WA096

Register of Nation Estate (Interim List) ID: 17244

Inland Aquatic Integrity Resource Condition Monitoring Project (DEC) RCM013

Transect code: RCM013-R1

RCM013-R2

RCM013-A2'

Aquatic invertebrates of Lake Gregory in relation to salinity and ionic composition (Halse et al. 1998b): Site 5

1.2. Purpose of Resource Condition Report

The objective of the RCR is to summarise all available ecological information relevant to Lake Gregory and describe the drivers of, and threats to, the system. This 'snapshot' of ecological character will provide context for future monitoring of the site and allow the effectiveness of management planning and actions to be gauged.

1.3. Relevant International Agreements and Legislation

The following is a summary of international agreements and legislation that are relevant to the management of Lake Gregory.

International Agreements

Migratory bird bilateral agreements and international conventions

Australia is party to a number of bilateral agreements, initiatives and conventions for the conservation of migratory birds that are relevant to Lake Gregory. The bilateral agreements are:

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 and their Environment, 1986;

ROKAMBA - The Agreement between the Government of Australia and the Republic of Korea for the Protection of Migratory Birds and their Environment, 2006;

The Bonn Convention on Migratory Species (CMS) **-** The Bonn Convention adopts a framework in which countries with jurisdiction over any part of the range of a particular species co-operate to prevent migratory species becoming endangered. For Australian purposes, many of the species are migratory birds.

Convention on Wetlands (Ramsar) - Australia a signatory to the Ramsar Convention, a intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. As Lake Gregory is proposed for listing under the Ramsar Convention, this convention may be relevant in the future.

National legislation

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

The EPBC Act is the Australian Government's central piece of environmental legislation. It provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places. These are defined in the Act as matters of national environmental significance.

There are seven matters of national environmental significance to which the EPBC Act applies. Two of these are relevant to Lake Gregory:

- nationally threatened species and ecological communities; and
- migratory species listed under international treaties JAMBA, CAMBA and CMS.

Lake Gregory is also a proposed Ramsar site and, if this listing is achieved, the site will be further protected under the EPBC Act as a wetland of international significance.

Indigenous Protected Areas

An Indigenous Protected Area (IPA) is an area of Indigenous-owned land or sea where traditional owners have entered into an agreement with the Australian Government to promote biodiversity and cultural resource conservation. An Indigenous Protected Area is governed by the continuing responsibilities of Aboriginal and Torres Strait Islander peoples to care for and protect lands and waters for present and future generations. Indigenous Protected Areas may include areas of land and waters over which Aboriginal and Torres Strait Islanders are custodians, and which shall be managed for cultural biodiversity and conservation, permitting customary sustainable resource use and sharing of benefit.

Paraku was declared an Indigenous Protected Area in September 2001 and was the first IPA to be declared in West Australia. The IPA, which covers an area of 434,000 hectares, is managed by the Tjurabalan Pastoral Company and the Traditional Owners, including the Walmajarri, Jaru and Kukatja peoples. The declaration of Paraku IPA in September 2001 was made under World Conservation Union (IUCN) *Category II – Protected Area managed mainly for ecosystem conservation and recreation* and *Category VI – Managed Resource Protected Area: Protected Area managed mainly for the sustainable use of natural ecosystems.*

Western Australian legislation

Wildlife Conservation Act 1950

This Act provides for the protection of wildlife. All fauna (animals native to Australia) in Western Australia are protected under section 14 and all flora (plants native to Western Australia) are protected under section 23 of the *Wildlife Conservation Act 1950*. The Act establishes licensing frameworks for the taking and possession of protected fauna, and establishes offences and penalties for interactions with fauna.

Aboriginal Heritage Act 1972

The purpose of this Act is to protect Aboriginal remains, relics and sites from undue interference, and to recognise the legitimate pursuit of Aboriginal customs and traditions. Under the Act, it is an offence for a person to excavate, destroy, damage or alter any Aboriginal site. The Act applies to all objects which are of sacred, ritual or ceremonial significance to persons of Aboriginal descent, or which are or were used for any purpose connected with the traditional cultural life of the Aboriginal people and the places where such objects are found. It also protects any sacred, ritual or ceremonial site which is of importance and special significance to persons of Aboriginal descent. Finally, the Act states that, where a representative body of persons of Aboriginal descent, who usually live subject to Aboriginal customary law, has an interest in a place, that place shall be available to that body for purposes sanctioned by the Aboriginal tradition relevant to that place.

Aboriginal Affairs Planning Authority Act 1972 (AAPA Act)

The AAPA Act repealed earlier Indigenous welfare legislation. It governs most Indigenous land-related matters and vests reserves in the Aboriginal Affairs Planning Authority, which promotes the well-being and economic advancement of Indigenous Australians. A visitor should always seek and gain permission to enter an Aboriginal community, and in the case of Aboriginal Reserve land, must do so by obtaining an entry permit. Under the AAPA Act, transit permits are required for any person visiting or passing through an Aboriginal reserve, unless he/she is:

- a person of Aboriginal descent;
- a member of either House of Parliament of the State or of the Commonwealth;
- a person exercising a function under the AAPA Act 1972 or otherwise acting in pursuance of a duty imposed by law; or
- a person authorised under the regulations of the AAPA Act 1972.

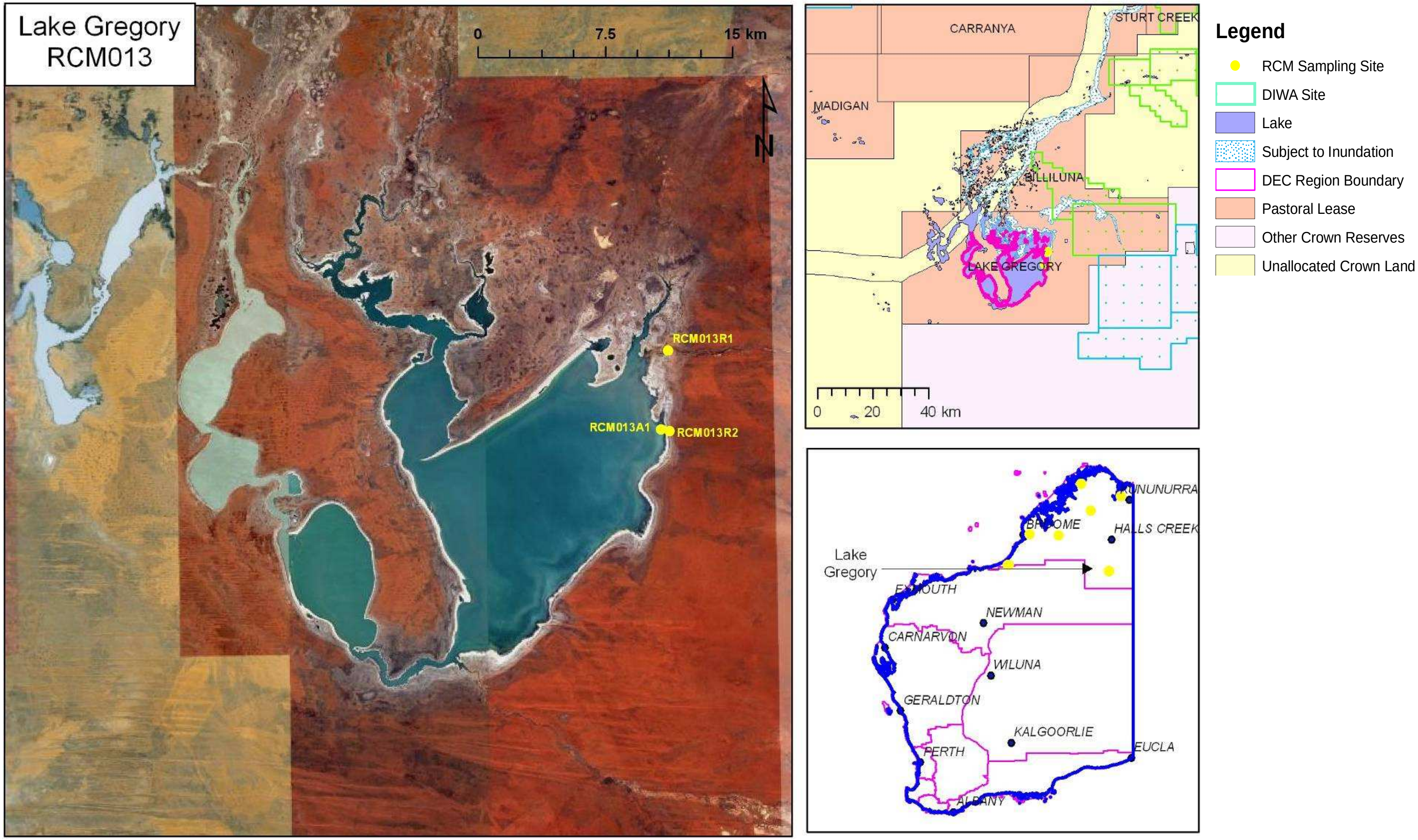


Figure 2 – Satellite imagery showing the location of the vegetation transects at Lake Gregory. Water quality and invertebrate samples were collected adjacent to the vegetation transects. The upper insert shows the location of the survey locations relative to the surrounding reserves, pastoral leases and mining tenements. The lower insert shows the location of Lake Gregory in relation to other IAI RCM survey sites in the Kimberly and the location of the lake system in WA.

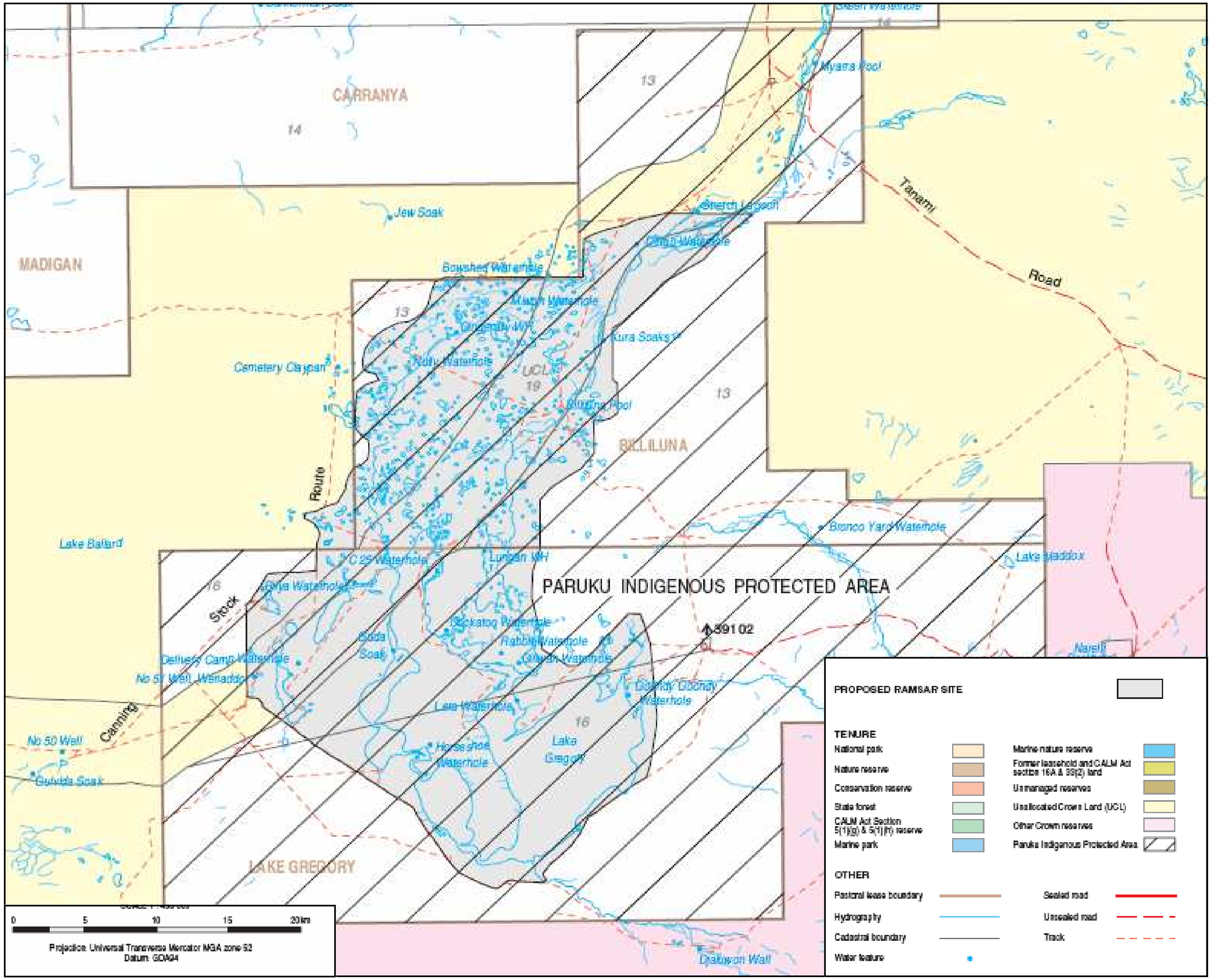


Figure 3 – The Lake Gregory System, showing the proposed Ramsar area.

2. Overview of Lake Gregory

2.1. Location and Cadastral Information

Lake Gregory lies 200 m above sea level, 220 km south of Halls Creek near the junction of the Great Sandy and Tanami Deserts in Western Australia's Kimberley region. The system includes an area of about 400 km^2 that is subject to regular flooding within a very large (approximately 5,000 km^2) paleolake bed.

Lake Gregory straddles Billiluna and Lake Gregory ex-pastoral leases, which together comprise the Paraku IPA. The nearest community is Mulan (population of 200), approximately 8 km to the east, from where the IPA is administered (Balgo-Kutjungka Catholic Parish 2007). Paraku is home to Walmajarri, Jaru and Kukatja peoples, who are the area's traditional owners (DEWHA 2008).

The area surrounding Lake Gregory forms part of the Billiluna and Lake Gregory pastoral leases. A request by the former Department of Fisheries and Fauna (now Department of Environment and Conservation) to convert this area to Conservation Estate was denied by the then Department of Lands and Surveys in 1961 (Halse 1990). The area known as Paraku was declared an IPA in September 2001 under IUCN Category II - Protected Area managed mainly for ecosystem conservation and recreation, and Category VI - Managed Resource Protected Area: Protected Area managed mainly for the sustainable use of natural ecosystems (DEWHA 2008). The conditions of the IPA allow the Tjurabalan pastoral company to run cattle on the ex-pastoral leases. A 'plain language management plan' has been developed to assist in minimising the impacts of these pastoral activities and tourism at the lake (Paraku IPA 2004).

Access to Lake Gregory should not occur without the permission of the IPA managers at Mulan. A road leads from Mulan to the main campsite on the eastern side of the lake.

2.2. IBRA Region

Lake Gregory lies at the far southwest extremity of the Tanami subregion of the Tanami Interim Biogeographic Regionalisation of Australia (IBRA) region. The Tanami subregion is mainly red Quaternary sandplains overlying Permian and Proterozoic strata that are exposed locally as hills and ranges. The sandplains support mixed shrub steppes of *Hakea* spp., desert bloodwoods, *Acacia* spp. and *Grevillea* spp. over soft spinifex (*Triodia pungens*) hummock grasslands. Wattle scrub over soft spinifex (*T. pungens*) hummock grass communities occur on the ranges.

Alluvial and lacustrine calcareous deposits occur throughout the subregion. In the north they are associated with Sturt Creek drainage, and support ribbon grass (*Chrysopogon* spp.) and Flinders grass (*Iseilema* spp.) short grasslands, often as savannas with river red gum (*Eucalyptus camaldulensis*) (Graham 2001).

2.3. Climate

The data presented in this section is from the Bureau of Meteorology weather station at Balgo Hills, approximately 50 km east of Lake Gregory (Bureau of Meteorology 2009).

Lake Gregory experiences a semi-arid climate with a monsoonal influence. It receives a mean annual rainfall of 348.1 mm with almost 80% of that falling between November and March (Figure 4). Most rainfall is associated with the passage of tropical cyclones; the absence of these cyclones can lead to drought conditions. Cyclones can result in additional deluge, with as much as 120 mm of rain recorded in a single day. Annual evaporation averages 3,212 mm. Mean maxima/minima temperatures are 38.7ºC/25.2ºC in January and 26.5ºC/12.3ºC in July.

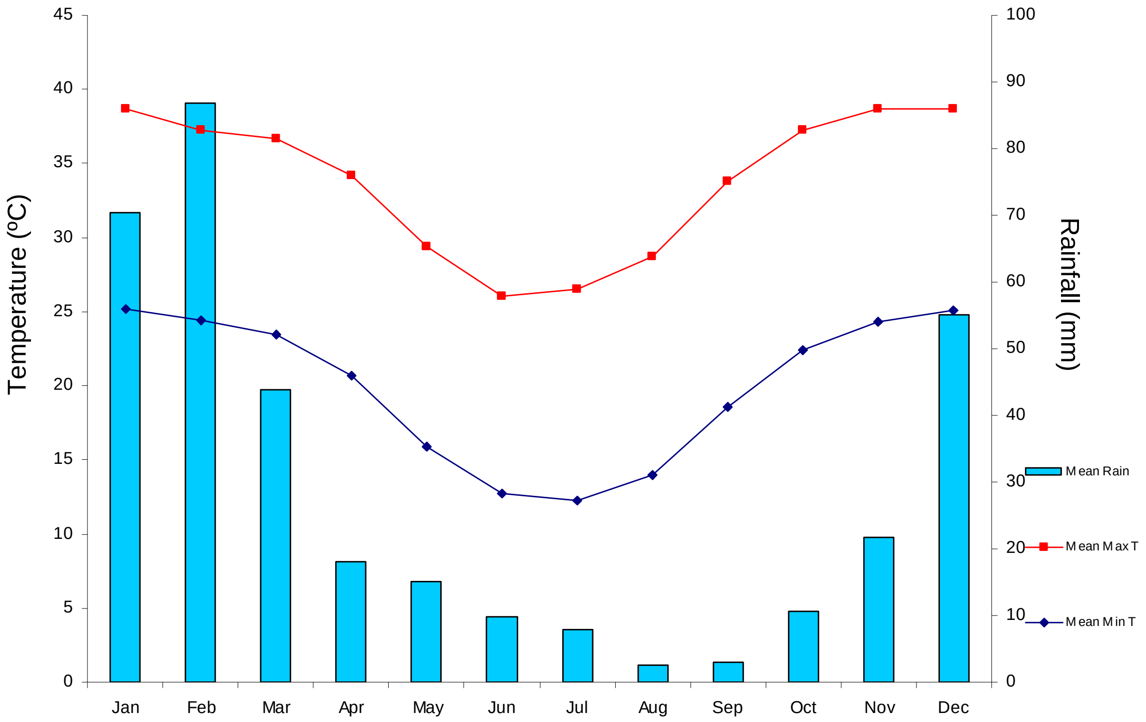


Figure 4 – Climatic averages for Balgo Hills, 50 km east of Lake Gregory.

In the twelve months preceding the IAI RCM survey of Lake Gregory, Balgo Hills received 264.5 mm of rain. The majority of this (148 mm) fell in February, with only 6.8 mm falling between the end of February and the 26th of May, when Lake Gregory was surveyed. The water regime of Lake Gregory is strongly influenced by rainfall in the catchment of Sturt Creek (see section 3.2 for more information).

2.4. Wetland Type

The *Directory of Important Wetlands in Australia* (Environment Australia 2001) describes the Lake Gregory System as comprising three main wetland types:

- Permanent saline/brackish lakes (type B7)
- Seasonal/intermittent saline lakes (type B8)
- Seasonal and irregular rivers and streams (type B2)

Mulan Lake, where surveys for this report were conducted, is a permanent saline/brackish lake.

2.5. *Directory of Important Wetlands in Australia* Criteria

The Lake Gregory System is currently identified as a wetland of national importance under criteria 1, 2, 3, 4 and 6 of the *Directory of Important Wetlands in Australia* (DIWA). These criteria are as follows:

1. It is a good example of a wetland type occurring within a biogeographic region in Australia.
2. It is a wetland that plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex.
3. It is a wetland that is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail.

4. The wetland supports 1% or more of the national populations of any native plant or animal taxa.

6. The wetland is of outstanding historical or cultural significance.

These criteria recognise that the system is a major breeding area for waterbirds, especially cormorants and terns. Surveys have recorded as many as 600,000 birds belonging to 59 different species. Lake Gregory supports the largest breeding colony of Little Black Cormorant (*Phalacrocorax sulcirostris*) in Australia. It is also a major drought or non-breeding refuge area for waterbirds, especially waterfowl, notably Eurasian Coot (*Fulica atra*). The system supports more than 1% of the national population of Masked Lapwing (*Vanellus miles*), Oriental Plover (*Charadrius veredus*), Marsh Sandpiper (*Tringa stagnatilis*), and Sharp-tailed Sandpiper (*Calidris acuminata*). This means the system plays an important role in supporting waterbird populations at regional and national levels. At times, Lake Gregory is a major migration stopover area for shorebirds, notably Oriental Plover.

The area also has scientific historical value, as it has been regularly surveyed for waterbirds from the time of the early explorer Carnegie's visit in 1856. A major integrated research program by former Department of Conservation and Land Management (CALM, now DEC), Museum of Victoria, University of Adelaide and University of WA studied the palaeohistory, limnology and waterbirds of the system. This began in 1989 and finished in 1995.

The Lake Gregory system is recognised as one of the best examples of a large brackish system, with inland (terminal) drainage lakes in Australia which has regular inflow and is near-permanent. It has been identified as meeting four Ramsar Criteria for listing as a Wetland of International Importance. Ramsar listing requires the support of the local land managers; negotiations to achieve this are continuing.

The Lake Gregory system incorporates a number of sites that are sacred to the local Aboriginal people. Local creation stories refer to the first people emerging from the lake.

2.6. Values of Lake Gregory

Values are the internal principles that guide the behaviour of an individual or group. Value systems determine the importance people place on the natural environment and how they view their place within it. Divergent values may result in people pursuing different objectives in relation to nature conservation, having different reasons for desiring a commonly agreed outcome, or favouring different mechanisms to achieve this outcome. Because of this, it is important to be explicit about the values that are driving conservation activities at a wetland.

The Conceptual Framework for Managing Natural Biodiversity in the Western Australian Wheatbelt (Wallace 2003) identified eight reasons that humans value natural biodiversity:

a. Consumptive use

Consumptive use is gaining benefit from products derived from the natural environment, without these products going through a market place; for example, the collection and personal use of firewood or 'bushtucker'. Lake Gregory (Paraku) has traditionally been an important source of resources for the Kukatja, Jaru and Walmajarri people. This is illustrated in the 'plain language management plan' (Paraku IPA 2004), which refers to the need for local people to hunt and fish around the lake. A chief concern of the local people, discussed in that plan, is the continuation of traditional knowledge and practices in the area.

b. Productive use

Productive use values are derived from market transactions involving products derived from the natural environment. The same firewood that is collected for personal use may be exchanged for money or another commodity. Lake Gregory lies within an active pastoral lease and the management plan for the area refers to ambitions to increase the intensity of pastoral operations.

c. Opportunities for future use

Not all uses of the natural environment may be apparent at present. The potential for future benefit from the natural environment is maximised by maintaining the greatest possible biodiversity. Every lost taxa or ecosystem represents lost opportunities. Lake Gregory may support endemic or rare taxa. Such unique features would increase the potential for future opportunities to present.

d. Ecosystem services

There are many naturally occurring phenomena that bring enormous benefit to mankind. For instance, plants generate oxygen, insects pollinate food crops and wetlands mitigate floods by regulating water flows. The term ‘ecosystem services’, is used as a broad umbrella to cover the myriad of benefits delivered, directly or indirectly, to humankind by healthy ecosystems. Lake Gregory is a large system of regional significance. It delivers considerable ecosystem services, including the provision of habitat for large numbers of water birds.

e. Amenity

Amenity describes features of the natural environment that make life more pleasant for people. For instance, pleasant views and shade or wind shelter from a stand of trees. Lake Gregory undeniably has significant amenity value for local people and tourists alike.

f. Scientific and educational uses

Parts of the natural environment that remain relatively unmodified by human activity represent great educational opportunities. Such sites allow us to learn about the changes that have occurred to the natural world. They are also ‘control’ sites that allow us to benchmark other, altered habitats. Lake Gregory has been a site of scientific exploration for a century and half, and this long record makes it a highly valuable study site.

g. Recreation

Many recreational activities rely on the natural environment (bird watching, canoeing, wildflower tourism, etc.) or are greatly enhanced by it (hiking, cycling, horse riding, photography, etc.). Recreation may deliver economic benefit derived from tourism and also delivers spiritual and physical health benefits to the recreator. Lake Gregory is a popular location for bird-watching and, positioned at one end of the Canning Stock Route, is relatively heavily utilised by tourists. Local people also enjoy the recreational opportunities afforded by the lake.

h. Spiritual/philosophical values

People’s spiritual and philosophical reasons for valuing natural environment are numerous and diverse. One commonly cited is the ‘sense of place’ that people derive from elements of their environment. This is evident in many Aboriginal and rural Australians, who strongly identify themselves with their natural environment. Many people also believe that nature has inherent value or a right to exist that is independent of any benefit delivered to humans. A sense of spiritual well-being may, therefore, be derived from the knowledge of healthy environments, even if the individual has no contact with them. Lake Gregory is of cultural significance to the local Aboriginal people, being linked to creation stories.

The intent of nature conservation is usually to maintain the ecosystem service values, opportunity values and scientific and educational values at a given site. Doing so is likely to have positive effects on the amenity values, recreational values and spiritual/philosophical values to which the site’s natural environment contributes. Consumptive and productive uses of the natural environment are not usually considered, as these are often incompatible with nature conservation. That said, Lake Gregory has been described as an important source of resources for local Aboriginal people and may be esteemed by them for its consumptive values. These conflicting value sets should be considered when attempting to implement conservation management at the site.

3. Critical Components and Processes of the Ecology of Lake Gregory

The objective of the Lake Gregory Resource Condition Report (RCR) is to identify, describe and quantify the components and processes that drive the wetland ecosystem. These components and processes determine the site's ecological character and are the variables that should be addressed in any ongoing monitoring.

Climate and geomorphology are the most important drivers of wetland ecosystems. Between them, these factors determine the position of a wetland in the landscape and the type and hydrological regime of that wetland. In turn, a wetland's position, type and hydrology exert a strong influence on its biota and biochemical properties and processes.

A summary of Lake Gregory's critical ecosystem components is presented in Table 1. This is followed by a detailed description of the results of the Inland Aquatic Integrity Resource Condition Monitoring (IAI RCM) 2008 survey as well as findings from previous studies conducted at Lake Gregory.

Table 1 – Summary of critical ecosystem components at Lake Gregory.

Component	**Summary description**
Geomorphology	Megascale irregular lake situated in the Canning Basin on alluvial and lacustrine sediments
Hydrology	Several interconnected waterbodies, fed primarily by Sturt Creek; water decants through the system into its largest basin, Mulan Lake, which accumulates salts; Mulan Lake is near-permanent
Water Quality	Moderately saline (3.1g/L), poikilohaline, alkaline, moderate nitrogen, low phosphorus
Benthic Plants	*Najas marina* and *Myriophyllum verrucosum* with occasional emergent *Acacia* sp.
Riparian Vegetation	Low open-woodland or low open-forest, and low shrubland (samphire), which occur in zoniform arrangement
Invertebrates	Total of 88 taxa recorded at sample point and 182 known from Lake Gregory, making it one of the most species rich wetlands in arid Australia
Fish	None seen
Waterbirds	80 species, 20 under treaties, 21 breeding; Lake Gregory is the most important inland wetland in Australia in terms of waterbird numbers (up to an estimated 600,000 recorded)
Terrestrial Vertebrates	None recorded by the IAI RCM survey, but at least 33 species of reptile, 11 species of mammal and 3 species of amphibian have been recorded in the general area.

3.1. Geology and Soils

Lake Gregory is situated in the northeast Canning Basin, within the Gregory sub-basin. It is underlain by up to 16,000 m of sedimentary rocks, ranging in age from Ordovician to mid-Triassic. These are covered by a veneer of alluvium and lacustrine sediments believed to attain a maximum thickness of around 30 m. The bed of the lake is clay with local development of salt and gypsum pans (Allen 1990).

Sturt Creek is believed to form the headwaters of a large paleoriver, which once flowed westward to the Indian Ocean. A change to a more arid climate in the late Tertiary is thought to have resulted in the river becoming choked with sediments and, ultimately, covered by sand dunes (Allen 1990).

Sediments at the IAI RCM survey location were clayey-sand with small amounts of gravel.

3.2. Hydrology

The Lake Gregory System consists of several interconnected waterbodies, fed primarily by Sturt Creek. The creek flows north to south as a single channel until just south of Halls Creek. From that point, it breaks into an anastomosing channel system. The lake chain consists of a series of shallow interconnected basins, fed by two main tributaries of Sturt Creek. The western tributary feeds into Rillya, Kurdu, Yuenbi and Bulbi Lakes. The eastern tributary discharges through Leira waterhole into the largest basin, Mulan Lake. Water decants through the system during the evaporative phase, due to slight differences in elevation of the basins. This causes salts to be concentrated in the deepest part of the system, namely eastern Mulan Lake.

The major catchment area of the lake is in the southeast Kimberley, where Sturt Creek originates. Sturt Creek has been estimated to have a catchment area of around 65,000 km^2. Mulan Lake may remain full for several years following stream flow events. There is also a local catchment area to the east, which is drained by Salt Pan Creek and Djaluwon Creek (Allen 1990).

An unconfined aquifer is thought to extend across the broad Lake Gregory area, within the alluvium and uppermost Permian and Triassic sediments. The depth to the water table varies from about 3 to 20 m, depending on the topography. Groundwater flow probably approximates surface topography, with groundwater discharging by evaporation and evapotranspiration around Mulan Lake. Groundwater is generally brackish, tending to saline closer to Mulan Lake.

Sandstones within the Ordovician to Mid Triassic sediments contain confined aquifers. Believed to be brackish to saline, the direction of flow in these is unknown. It is unlikely that the confined aquifers interact with surface water in Lake Gregory. However, the unconfined aquifer is known to do so. Evidence of this is the absence of a salt crust on the lake in its dry phase. Salts are thought to leach into the unconfined aquifer before being discharged from the system via the paleochannel (Allen 1990).

3.3. Water Quality

The various basins within the Lake Gregory System lie on a slight downhill gradient. This allows water to be decanted as it passes through evaporative phases. Therefore, water chemistry varies through the system, as salts are concentrated in lower lying basins.

A Museum of Victoria study documented variations in water chemistry between basins on two visits in 1978 and 1981 (Allen 1990). The findings of that study showed a difference of almost four pH units between Mulan (pH 11.04) and Bulbi (pH 7.3). Concentrations of various ions were significantly greater in Bulbi than in Mulan (Ca^{2+} 2x, Mg^{2+} 1.5x, Na^+ 2x, SO_4^{2-} 4x, etc.). Naturally, there is also a large degree of variation between years, with ionic concentrations in the water bodies much diluted when the system is full.

At the time of the IAI RCM survey, no water depth or extent measurements were taken. However, observations of the water level in relation to the shoreline indicated that Mulan Lake was over half full. Table 2 shows the water chemistry measurements taken in Mulan Lake during the IAI RCM survey. It is difficult to draw meaningful comparisons with previous findings without knowing the relative water levels, but the results from the IAI RCM study are similar to those found during the 1981 Victorian Museum survey.

Numerous points in different parts of the Lake Gregory System were also sampled for aquatic invertebrates and water quality by Halse et al. (1998b) between 1989 and 1993. ‘Site 5’ in Halse et al. (1998B) is located very close to a IAI RCM sampling site (a location known as “Handover”) and is used in Table 2 for comparison. Other than salinity, which varies according to depth, water chemistry appears to have been quite stable at Mulan Lake over the last 20 years. It is alkaline, with moderate concentrations of nitrogen (though not enriched) and low phosphorus and it is NaCl dominated. Halse et al. (1989) recognised six groups of water chemistry samples based on order of ionic dominance. The RCM013 sample in May 2008 fits into category 'Aa' (strong NaCl dominance (83.5%) with calcium to carbonates ratio <1). Ionic ratios vary with salinity at this lake, even at low salinities.

Table 2 – Water quality parameters as measured on the eastern shore of Mulan Lake (site 5 of Halse et al. 1998).

	Halse et al. Oct 1989	**Halse et al. May 1991**	**Halse et al. Aug 1993**	**IAI RCM Survey May 2008**
pH	9.5	8.3	9.7	8.96
Alkalinity (mg/L)	-	50	35	190
TDS (g/L)	25.1	0.38	0.46	3.1
Turbidity (NTU)	-	18	26	9.2
Colour (TCU)	-	-	-	2
Total nitrogen (µg/L)	-	-	-	930
Total phosphorus (µg/L)	-	-	-	20
Total soluble nitrogen (µg/L)	-	470	460	430
Total soluble phosphorus (µg/L)	-	5	10	5
Chlorophyll (µg/L)	-	-	1	4.5
Na (mg/L)	8,450	97	131	1,090
Mg (mg/L)	421	9	9	61.4
Ca (mg/L)	47	23	16	36.4
K (mg/L)	548	11	14	93.9
Cl (mg/L)	13,300	146	198	1,670
SO_4 (mg/L)	2,200	46	51	264
HCO_3 (mg/L)	180	61	43	226
CO_3 (mg/L)	58	1	1	3

3.4. Benthic Plants

A vegetation transect of 50 m, composed of eight 5 m x 5 m quadrats, was established at Mulan Lake (Figure 1). Only two species of aquatic plant were collected, as well as some emergent *Acacia* spp. (Table 3). The two aquatic plant species were also previously collected by Handasyde (2006). When the lake dries, these plants dry to form a vegetative mat on the dry lake bed (Handasyde 2006). Photographs of Lake Gregory sometimes show extensive algal blooms, probably *Cladophora* sp. (Marchant and Halse 1990).

Shrubs of samphire (*Halosarcia indica* subsp. *leiostachya*), *Acacia victoriae* and juvenile smooth-barked coolibah (*Eucalyptus victrix*) have also been recorded as sometimes present in the aquatic zone (Handasyde 2006).

Table 3 – Aquatic vegetation transect RCM013-A1 at Mulan Lake.

Species	Quadrat (m) / % layer cover							
	0-5	**5-10**	**10-15**	**15-20**	**30-35**	**35-40**	**40-45**	**45-50**
Najas marina	30	30	20	20	20	20	20	20
Myriophyllum verrucosum	0	0	40	40	40	40	40	40
Acacia sp.	1	1	2	2	5	5	5	5

Note: No plants were recorded in the 20 – 30 m section of the transect

Figure 5 – Aquatic vegetation transect, looking back to the eastern shore of Mulan Lake.

3.5. Riparian Vegetation

The vegetation of the Lake Gregory System consists primarily of low open-woodland or low open-forest, and low shrubland (samphire), which occur in zoniform arrangement (Jaensch 1993). The principal tree is Wirimangurru (*Acacia maconochieana*). Some *Eucalyptus camaldulensis*, *E. microtheca*, *Acacia holosericea* and *A. striata* occur along the creeks. *Melaleuca glomerata* and *M. lasiandra* form a shrub layer over the grasses *Eulalia fulva* and *Cenchrus ciliarus*. The riparian vegetation includes wide bands of samphire composed of *Tecticornia halocnemoides* subsp. *tenuis* and *T. indica* subsp*. leiostachya*, *Cressa cretica*, *Eragrostis dielsii*, *Stemodia floribunda*, *Sida rohlenae* and *Swainsona* sp. (Marchant and Halse 1990; Jaensch 1993).

Two 40 m transects, comprised of eight consecutive 5 m x 5 m quadrats, were established within the riparian vegetation of Mulan Lake. The first of these (RCM013-R1) was located near Salt Pan Creek, in the northeast corner of Mulan Lake (Table 4, Figure 6). The second (RCM013-R2), was further down the lake's shore, to the south of the Creek (Table 5, Figure 7).

Couch grass (*Cynodon dactylon*) was recorded at transect RCM013-R2 had an overall coverage of about 10% of the transect area. Note*, Cenchrus ciliarus* (Buffel Grass) is also a weed species known to occur in the area but was not recorded in the transect.

There has been a long-term decline in extent of living trees in the Lake Gregory System. Most are now dead, having been killed by prolonged inundation, notably the 1982/83 flood (Jaensch 1993). This flooding event was considered to have been the highest for possibly 20 years. River red gum (*Eucalyptus camaldulensis)* thought to have been about 20 years old at the time of this flooding died as a result of long inundation, as too did smooth-barked coolibah and the extensive stands of Wirimangurru acacia growing around the lake margins (Handasyde 2006).

Table 4 – Riparian vegetation transect RCM013-R1 at Mulan Lake.

Species	Quadrat (m) / % layer cover							
	0-5	**5-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**
Tecticornia indica subsp. *leiostachya*	20	15	10	5	5	10	40	40
Tecticornia halocnemoides subsp. *tenuis*	5	25	30	35	20	50	20	20
Abutilon otocarpum	5	1	0	0	0	0	0	0
Sida fibulifera	10	1	0	0	0	0	0	0
Eragrostis falcata	1	5	1	5	1	0	1	0
Acacia victoriae subsp. *victoriae*	1	0	0	0	0	0	0	0
Stemodia florulenta	0	0	0	1	0	0	0	0
Sida rohlenae subsp. *rohlenae*	0	0	0	1	0	0	0	0
Glinus oppositifolius	1	1	1	1	0	0	0	0
* *Cynodon dactylon*	5	5	10	20	20	10	5	0
Bare ground	60	50	50	20	40	30	30	30
Fallen timber	0	0	0	30	15	10	0	0

* Introduced species

Figure 6 – Riparian vegetation transect RCM013-R1 at Mulan Lake (near Salt Pan Creek).

Table 5 – Riparian vegetation transect RCM013-R2 at Mulan Lake.

Species	Quadrat (m) / % layer cover							
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40
Acacia victoriae subsp. *victoriae*	0	0	10	10	25	10	0	0
Eragrostis falcata	50	50	40	40	40	30	30	40
Abutilon otocarpum	0	0	0	0	0	5	5	0
Bare ground	40	40	40	30	20	30	25	50
Dead plants	5	5	5	15	10	15	15	5

Figure 7 – Riparian vegetation of transect RCM013-R2 at Mulan Lake.

3.6. Aquatic Invertebrates

Aquatic invertebrate surveys were conducted at various locations of the Lake Gregory System between 1989 and 1993 (Halse et al. 1998b). ‘Site 5’ (Halse et al 1998b) is located very close to the IAI RCM invertebrate sampling site (a location known as “Handover”) and is used in Table 6 for comparison. Invertebrate richness at the large and hydrologically complex Lake Gregory varies enormously according to the salinity at the time and in relation to differences in ionic composition between different parts of the wetland (Halse et al. 1998b). The number of macroinvertebrate families and species recorded in 2008 equals or exceeds the number recorded in this part of the wetland previously and brings the total species list for this area to eighty-eight taxa. The total for the lake now stands at 182 (of which only eight were not collected by Halse et al. (1998b). The lake was noted as one of the most species-rich in arid Australia (Halse et al. 1998b).

In the spring of 1989 the lake was saline, whereas in 1991 and 1993 the lake was fresh (<1 g/L) after significant rains in the catchment in winter 1991 and winter 1993. These salinity changes explain the large increase in invertebrate diversity between 1989 and 1991. The lake was only slightly brackish in 2008 (3.1 g/L) and richness was as high as when fresh. However, there are likely to have been fewer microinvertebrate species in 2008 compared to 1991 and 1993, as many of those are particularly salt-sensitive, especially the rotifers.

Table 6 – Aquatic invertebrate richness as sampled on the eastern shore of Mulan Lake (site 5 of Halse et al. 1998b).

Diversity measure	Halse et al. Oct 1989	Halse et al. May 1991	Halse et al. Aug 1993	RCM Survey May 2008
Total invertebrate species richness	6	29	48	-
Macroinvertebrate species richness	2	18	25	28
Total invertebrate family richness	6	17	25	-
Macroinvertebrate family richness	2	11	15	15

3.7. Fish

No fish were observed during the IAI RCM survey in 2008. However, Spangled Perch (*Leiopotherapon unicolour*) are abundant in the system (S. Halse pers. comm. in Jaensch 1993). While some traditional owners recall catching catfish in the system until the 1960s, these no longer occur at Lake Gregory (Kimberley Land Council 1999).

3.8. Waterbirds

Lake Gregory has been described as the most important inland wetland in Australia, in terms of supporting large numbers of waterbirds. The estimate of 650,000 individuals at the site in 1988 is the second largest number of waterbirds recorded anywhere in Australia (Halse et al. 1998a). Twenty-one species have been observed breeding within the Lake Gregory System and a total of eighty species of waterbird have been recorded there. Twenty of these are protected under international migratory agreements (see section 1.3).

Mulan Lake, and the greater Lake Gregory system, supports the Freckled Duck – Australia's rarest duck (Halse et al. 1998a). A count of 898 Freckled Ducks in 1986 (Jaensch and Vervest 1990) and 333 in 1995 (Halse et al. 1998a) suggest Lake Gregory is the most important site for Freckled Ducks in Western Australia. Other rare birds recorded at the wetlands include a Painted Snipe and Long-toed Stints.

The Lake Gregory system supports more than 1% of the national population of Masked Lapwing, Oriental Plover, Marsh Sandpiper and Sharp-tailed Sandpiper.

Seventeen species, with up to 100 individuals, were observed at Lake Mulan during the IAI RCM survey in 2008. All of these species have previously been recorded within the Lake Gregory System. A complete list of waterbirds observed at Lake Gregory between 1977 and 2008 is provided in Table 10 (Appendix 2).

3.9. Terrestrial Vertebrates

Feral horses were observed in the vicinity of Mulan Lake during the IAI RCM survey in 2008. No evidence of other terrestrial vertebrates was observed.

At least thirty-three species of reptile, eleven species of mammal and three species of amphibian have been recorded within a 40 km radius of the IAI RCM survey location.

4. Interactions Between Ecological Components At Mulan Lake

An appreciation of the interactions between the elements of a wetland ecosystem is essential to understanding the condition of the system. Although components of a wetland are often monitored and managed as discrete entities, they exist as nodes in a complex ecological web. Documenting the full extent of the interactions that occur at a wetland would be impractical. However, it is essential to identify key interactions that define the system's ecological character.

Hale and Butcher (2007) justified the equivalence of Ramsar nomination criteria and primary determinants of ecological character. Accordingly, the primary determinants of ecological character at Lake Gregory are:

- The characteristics that make the site a good example of a system of large, brackish, inland (terminal) drainage lakes in Australia which has regular inflow and is near-permanent.
- The contribution the site makes to the ecological or hydrological functioning of the wetland system/complex, and the characteristics that make the lake attractive as a major migration stopover area for shorebirds, notably Oriental Plover.
- The animal taxa that utilise the site as habitat at a vulnerable stage in their life cycles, or as a refuge when adverse conditions such as drought prevail; and the characteristics of the site that allow it to support these populations. Notably, the characteristics that make the site a major breeding area, and a major drought or non-breeding refuge area for waterbirds (Figure 8).
- Little Black Cormorants, of which the largest breeding colony in Australia is supported by the site.
- Masked Lapwings, Oriental Plovers, Marsh Sandpipers and Sharp-tailed Sandpipers, of which the system supports more than 1% of the national population.
- The site's outstanding historical and cultural significance.

More specifically, the primary determinants of the ecological character of Mulan Lake are:

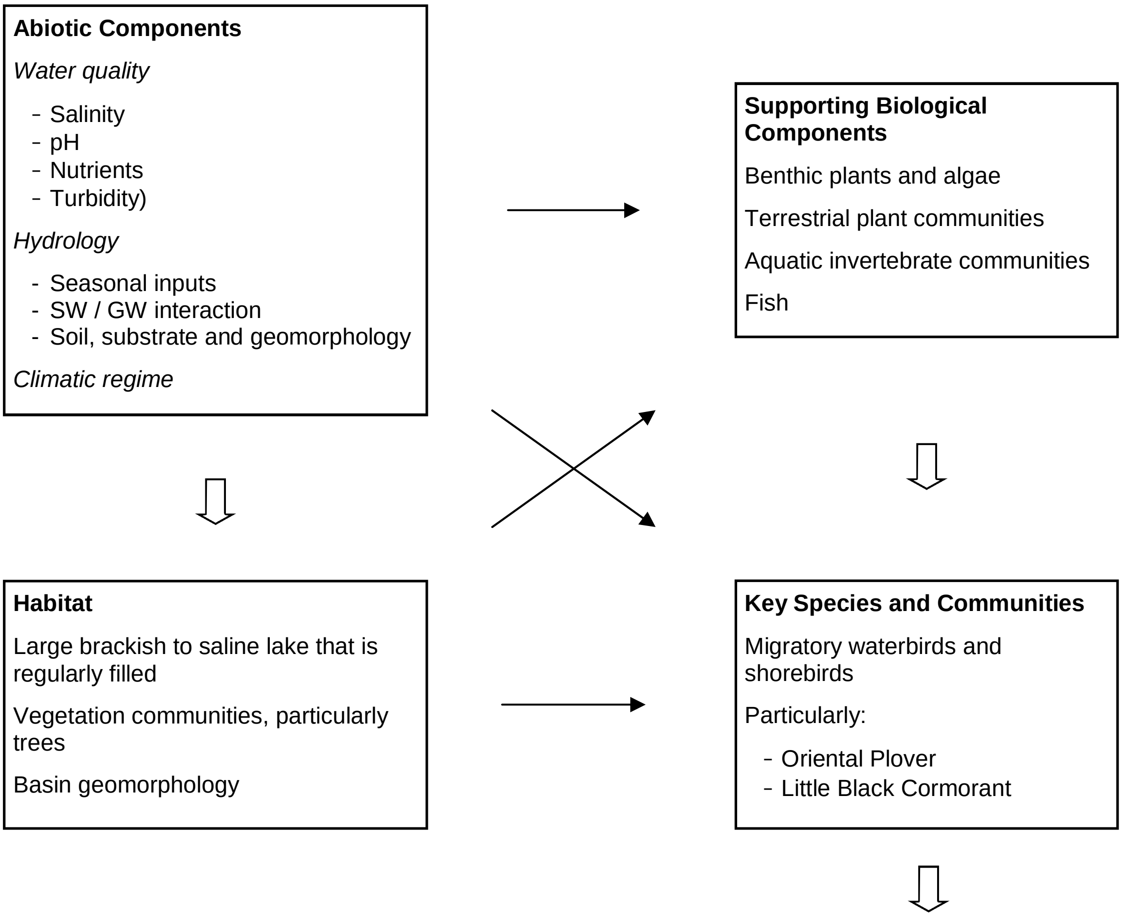
- Climate and hydrology, particularly regular inflow from reliable tropical rain in the catchment of Sturt Creek and the movement of water through the wetland chain.
- Interaction between surface and groundwater at Mulan Lake that results in the system's unique chemical properties.
- Habitat for waterbirds and shorebirds, particularly nesting sites (trees), and food sources (algae, benthic plants, aquatic invertebrates and fish).

Mulan Lake is a particularly important component of the Lake Gregory system because it is the largest of the system's basins, it retains water for the longest period of time and (due to its size) and it probably has the greatest degree of interaction with the unconfined aquifer. As such, Mulan Lake provides the greatest area of habitat for flora and fauna, functions as a drought refuge, and plays an important role in determining the chemical properties of the system.

Section 4 of this RCR considers the ecological character of Mulan Lake. Figure 9 attempts to specify the primary determinants of the ecological character of Mulan Lake and the biological components that support them. Table 7 summarises the interactions between key components and processes at Mulan Lake. The table lists the components that are directly responsible for the provision of each service or benefit of the wetland and the biotic and abiotic factors that support or impact these components. Also listed, are the key threats that may affect the components or processes. This information assists in the identification of the primary determinants of ecological character.

Figure 8 – Birds roosting in recently inundated trees following a flood event. Such trees are an important habitat component for visiting waterbirds.

Primary Determinants of Ecological Character



Reasons for the nomination of Mulan Lake as a wetland of National significance

- Major part of a system of large, brackish, inland (terminal) drainage lakes in Australia, which has regular inflow and is near-permanent.
- Contributes to the ecological or hydrological functioning a major wetland system.
- A major breeding area for waterbirds, especially cormorants and terns.
- A major drought or non-breeding refuge area for waterbirds, especially waterfowl.
- A major migration stopover area for shorebirds, notably Oriental Plover (*Charadrius veredus*).
- Supports the largest breeding colony of Little Black Cormorant (*Phalacrocorax sulcirostris*) in Australia.
- Supports more than 1% of the national population of several species of waterbird.

Figure 9 – Schematic depiction of the interactions between critical components of the Mulan Lake ecosystem.

Table 7 – The relationship between the services and benefits delivered by Mulan Lake, and the key components and processes that support them.

Benefit or Service	Component	Factors Influencing Component		Threats and Threatening Activities
		Biotic	Abiotic	
Consumptive Value Traditional food, medicines and materials	Plants and animals	Plant pollinators Animal food sources	Hydrological regime Water quality Fire regime Climatic factors Habitat requirements	Grazing by cattle and introduced pest animals Changed fire regimes Altered hydrology due to climate change or catchment perturbation Weeds Sedimentation due to catchment disturbance Feral predators
Productive Value Pastoralism	Cattle	Fodder	Hydrological regime Water quality Fire regime Climatic factors	Overexploitation Competition from feral animals
Opportunity Value Potential future use of unique flora and fauna	Endemic flora, fungi, algae Endemic fauna	Plant pollinators Food sources	Habitat extent and distribution Hydrological regime Fire regime Water quality	Grazing by cattle and introduced pest animals Alteration to hydrology due to climate change or catchment perturbation Inappropriate fire regimes Weeds Predation of fauna
Ecosystem Service Value It is a good example of a wetland type occurring within a biogeographic region in Australia	Major part of a system of large, brackish, inland drainage lakes, which has regular inflow and is near-permanent, and contributes to the ecological or hydrological functioning of that system		Hydrological regime, particularly regular inflow from Sturt Creek and outflow from paleochannel Climatic factors Water quality System geomorphology	Alteration to hydrology due to climate change or catchment perturbation Erosion leading to wetland infill

Benefit or Service	Component	Factors Influencing Component		Threats and Threatening Activities
		Biotic	Abiotic	
Ecosystem Service Value It is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail The wetland supports 1% or more of the national populations of any native plant or animal taxa	Waterbirds that utilise the lake as a breeding area and/or drought or non-breeding refuge Largest breeding colony of Little Black Cormorant in Australia Shorebirds, notably Oriental Plover, that use the wetland as a major migration stopover	Invertebrate populations (food source) Phytoplankton (food source) Benthic plant biomass Vegetation communities, particularly trees	Soils and sediments Nutrient concentrations Water salinity and pH Hydrological regime Climatic regime Fire regime	Grazing by cattle and introduced pests Alteration to hydrology due to climate change or catchment perturbation Inappropriate fire regimes Excessive nutrient inputs from stock Weeds Predation of fauna Loss of migratory bird populations due to offsite factors Tourism
Recreational Value Bird watching Bush walking Camping Photography	Landscape amenity Waterbird populations Vegetation communities Significant flora Significant fauna	Invertebrate populations (food source) Phytoplankton (food source) Benthic plant biomass Vegetation communities Plant pollinators	Soils and sedments Hydrological regime Nutrient concentrations Water salinity and pH Climatic regime Fire regime	Grazing by cattle and introduced pests Alteration to hydrology due to climate change or catchment perturbation Inappropriate fire regimes Excessive nutrient inputs from stock. Weeds Predation of fauna Loss of migratory bird populations due to offsite factors Tourism
Spiritual Value The wetland is of cultural significance to local Aboriginal people	Geomorphology of lake and surrounds, particularly historical sites of human occupation around previous lake shoreline Native flora and fauna communities	Flora and fauna populations Pollinators and food sources for above	Soils and sediments Hydrology Water quality	Grazing by cattle and introduced pests Alteration to hydrology due to climate change or catchment perturbation Inappropriate fire regimes Excessive nutrient inputs from stock Weeds Predation of fauna Loss of migratory bird populations due to offsite factors Tourism

4.1. Primary Determinants of Ecological Character

The ecology of Mulan Lake is primarily determined by the geomorphology and hydrology of the system, and the effect these have on water chemistry.

4.1.1. Hydrology

Mulan Lake is unique in that it is an arid zone lake that receives regular fresh water inflows from Sturt Creek. Its semi-permanent nature makes it an important water source in an otherwise dry landscape. It supports large populations of birds and exerts a strong influence on surrounding vegetation.

Another important element of the lake's hydrology is the groundwater and surface water interaction that occurs. This interaction allows salt to be removed from the system, via paleochannel flow. This is critical to the system's water chemistry, allowing it to remain brackish rather than increasing in salinity over time. The relatively low concentration of salts in the water encourages rich and diverse benthic plant and aquatic invertebrate communities that are an important food source for waterbirds. It also allows *Eucalyptus* and *Acacia* species to persist around the lake margins; these are an important component of the habitat of migratory birds.

4.1.2. Geomorphology and Substrate

The geomorphology of the Lake Gregory System causes its constituent basins to develop unique water chemistry, and ensures that Mulan Lake generally retains water through periods of aridity. Two factors are important: the topographic distribution of basins that causes a 'decantation' effect, and the size and shape of Mulan Lake.

The basins within the Lake Gregory system lie at successively lower elevations along the flow line. This allows less dense salt-rich water to be 'decanted' through these basins during the system's drying phase. Mulan Lake, at the bottom of the system, receives the bulk of the salt load, while the other basins remain relatively fresh. The groundwater interaction that occurs beneath Mulan Lake allows salt to be exported from the system via a paleochannel. This prevents the accumulation of salt in the lake and allows it to retain relatively good water quality.

The export of salt from the system can occur because Mulan Lake, where groundwater interaction is greatest, is at the bottom of the chain. It is also possible because of the nature of the soils beneath that lake. If no groundwater interaction occurred, salt would accumulate in the system until the lake became hypersaline, like many lakes in the arid zone of WA.

The effectiveness of Mulan Lake as a drought refuge and stopover for migratory birds is also related to its large size and depth. The volume of water stored in the lake is so great that it rarely dries out entirely, even if rainfall in the catchment is insufficient.

4.1.3. Water Quality

The relatively fresh water in Mulan Lake supports a much greater richness and diversity of aquatic flora and fauna than an equivalent saline system. This rich food source, combined with the availability of suitable nesting sites, make the lake an important place for birds. Mulan Lake is a refuge for birds in times of drought, an important breeding ground and a stopover for migratory species on international flyways.

Figure 10 – Dead trees in a long-inundated area of Mulan Lake continue to play an important role in the provision of habitat for birds.

5. Threats to the Ecology of Lake Gregory

The ambition for management at Mulan Lake is to maintain those elements of the ecology that resulted in its recognition as a wetland of national significance. The critical components of the ecology are the geomorphologic and hydrologic factors that make the lake an important area for waterbirds and shorebirds. Little Black Cormorants, Oriental Plover and terns have been specifically highlighted as important visitors to the system.

Threats to Mulan Lake must be considered in relation to their likelihood of causing failure of the aforementioned management goal for the lake. An assessment is made of the probability that goal failure will result due to the impacts of each threatening process identified at the site, or potentially acting there. The results of this assessment are presented in Table 8. In summary, failure to achieve the management goal for Mulan Lake is most likely to result from impacts of pastoral activities, alteration to natural fire regimes, and/or feral horses. The level of threat to the site is high, particularly if plans to intensify pastoral operations come to fruition.

Cattle and horses have a number of detrimental impacts on Mulan Lake. Grazing removes native ground cover, providing a niche for weed establishment and allowing soil erosion to occur.

Erosion is also facilitated by soil disturbance from hoofed animals. Disturbed and overgrazed areas are more likely to be eroded, leading to increased rates of sedimentation in the lake and increases turbidity. Deposition of sediments is a serious issue, as it alters the geomorphology of wetlands and so changes their character.

Heavy grazing pressure will also kill larger plants, particularly when combined with excessive nutrient inputs from animal waste. Germinants and regenerating plants are highly susceptible to grazing, as they tend to be more palatable to stock. This is of particular concern when riparian and fringing vegetation is recovering following flooding events. The loss of a generation of young plants to grazing can prevent the system from rebounding after such a disturbance.

It is imperative that cattle be excluded from areas near the lakeshore. Although prime grazing land, the fragility of this area and its importance to the lake ecology necessitate its protection from grazing. A suitable compromise is to pump water to paddocks that are maintained away from the lake margins. Feral horses also need to be removed from the lake, where they are causing damage to vegetation and soil structure.

Altered fire regimes are a major threat to biodiversity across the Kimberley region. The Environmental Protection Authority recently released an issues paper that details the current and future impacts of changes to the natural frequency and intensity of wildfire in that region (Russell-Smith 2005). That paper found that the season of burning has changed during the period of European occupation of the region. Aboriginal burning in the Kimberley occurred throughout the dry season, whereas today, most fires occur at the end of the dry season. Late dry season fires in the Kimberley today have major impacts across all land use and industry sectors. In particular, fire-sensitive vegetation in the Kimberley is being severely impacted by intense late dry season fires. It is likely that fires in recent times have had a major impact on small to medium sized animals such as bandicoots. Together with the effects of grazing on grass species and seed availability, fires may also have a major impact on many birds. Late dry season fires can also have significant impacts on soil loss, loss of nitrogen in smoke, increased greenhouse gas emissions, and impacts on air quality and human health.

In the context of Mulan Lake, fire has the potential to facilitate the establishment of weed species, expose soils to erosion, cause the loss of fire-sensitive flora taxa and negatively impact on fauna. It is very difficult to manage fire in the Kimberley. Native perennial grasses accumulate biomass very rapidly, meaning that prescribed burning is largely ineffective in establishing buffers to limit the spread of fires. The Paraku management plan discusses the interest of local people in participating in fire management, but does not provide detail about how this will be achieved. Any fire control measures would need to be maintained annually to ensure their continued effectiveness.

Wetlands are highly productive environments, but are also easily disturbed. Fires, pest animals, stock and human activities may all disturb native vegetation and create the niche required for exotic plants to become established. Weed propagules are introduced via the vectors of inflowing water, grazing stock, exotic animals, visiting waterbirds or wind. Once established, the productivity of the ecosystem often allows weed populations to flourish and exclude native plants. An additional problem is the difficulty in implementing weed control in wetland environments. The fragility of the system and fluxes of water usually make chemical weed control inappropriate. Mechanical control is often complicated by difficulty in accessing infestations.

Several weed species have been identified as being potentially problematic at Mulan Lake. Buffel grass (*Cenchrus ciliaris*), wild gooseberry (*Physalis angulata*) and kapok bush (*Aerva javanica*) are presently found there (Handasyde 2006). Of these, buffel grass is of particular concern due to its ability to exclude other plants from a location. Neem (*Azadirachta indica*), which is planted as a shade tree in Mulan Community, has a proven ability to invade wetland areas in the Kimberley. This threat must be carefully monitored to ensure Neem does not spread. Parkinsonia *(Parkinsonia aculeata*) is known to occur on properties upstream of Lake Gregory and control of these infestations will be important. The size and remoteness of the Lake Gregory System will make weed removal difficult, meaning that exclusion of new weed species is a far preferable option.

Table 8 – Threat assessment for Mulan Lake.

An estimate is provided of the perceived likelihood of goal failure resulting from the impacts of each identified threat category.

Goal: to maintain those components of the ecology, geomorphology and hydrology that provide habitat for waterbird and shore bird populations.

Threat category	Management issue	Probability that threat will cause goal failure with:		Assumptions underlying initial probability assessment and explanatory notes
		Existing management	Extra management	
Altered biogeochemical processes	Hydrological processes, particularly salinity	0	0	There is no evidence of increasing salt loads in the system nor of any hydrological perturbation.
	Erosion and sedimentation	.01	0	Overgrazing of land in the Sturt Creek catchment could potentially result in excessive erosion and infilling of the Lake Gregory system. Due to the large size of the system, this is unlikely to become a major management issue in the foreseeable future.
	Carbon cycle and climate change	0	0	Changes to rainfall are expected to be fairly minor in the Kimberley, perhaps as little as 1% over the next 50 years (CSIRO Undated). Such a small change is unlikely to have any impact on Mulan Lake.
Impacts of introduced plants and animals	Environmental weeds	.05	0	Only one species of introduced plant was found during the RCM survey of Mulan Lake. Previous work has referred to the presence of Buffel grass, Wild gooseberry and kapok bush. There is also potential for Neem trees to invade the lake margins. *Parkinsonia* is known to occur on properties upstream of Lake Gregory and control of these infestations will be important.
	Herbivory, wallowing and trampling by introduced species	.1	.1	Mulan Lake supports a large population of feral horses. These are doing considerable damage to both soil structure and vegetation. Removal of feral horses should be a priority for management of the area.
Impacts of problem native species	Overgrazing by native species	0	0	No impacts evident.
Impacts of disease	Plant pathogens	0	0	No impacts evident.
Detrimental regimes of physical disturbance events	Fire regimes	.2	.1	Increasing frequency and intensity of late season wildfires are having deleterious impacts on ecosystems across the Kimberley. Such fires facilitate the establishment of exotic grasses and other weeds. They also create the potential for erosion of soils with the next rainfall event. Management of fire in the Kimberley is difficult because of the size and remoteness of the region and the fast return rate of native annuals. Fire management should be an achievable goal for specific sites, however.

Threat category	Management issue	Probability that threat will cause goal failure with:		Assumptions underlying initial probability assessment and explanatory notes
		Existing management	Extra management	
	Drought	.05	.05	Rainfall projections for the Kimberley show that climate change may result in longer periods of drought, interspersed with severe storms and heavy rainfall (CSIRO Undated). The impacts of this on the ecology and geomorphology of Mulan Lake are difficult to predict. It is possible that it may lead to some alteration to the hydrology of the system.
	Flood	.02	.02	Vegetation at Mulan Lake is adapted to periodic inundation. Although flood events cause extensive plant death, these individuals are replaced by new recruits when floodwaters recede. Some deleterious impacts may be observed on the ecology of Mulan Lake if climate change results in more frequent or more severe flooding events.
Impacts of pollution	Herbicide, pesticide or fertiliser use and direct impacts	0	0	No agricultural operations occur in the lake's catchment.
Impacts of competing land uses	Recreation management	.01	0	Recreational usage of Mulan Lake is currently low impact. However, anecdotal evidence suggests that the area is receiving increasing visitation. Some visitor management has been put in place to preserve the environment.
	Nutrient enrichment of the water body	.01	0	Nutrient enrichment is not currently a problem. The exclusion of stock will ensure that it does not become one.
	Urban and industrial development	0	0	None likely.
	Productive uses	0.3	0.1	Cattle raised by the Billiluna and Lake Gregory Pastoral operations are causing considerable degradation of vegetation and soil structure. It is concerning that the Paraku management plan proposes a tripling of cattle numbers. If not managed very carefully, this will have a devastating impact on Mulan Lake and the rest of the system. Cattle need to be excluded from the lake margins and care should be taken that grazing in the catchment does not cause excessive soil erosion.
	Illegal activities	0.0	0.0	No evidence of any threat.
	Mines and quarries	0.0	0.0	Lake Gregory has been explored for mineral potential with negative results.
Insufficient ecological resources to maintain viable populations	Habitat, genetic exchange	0.01	0.01	Mulan Lake is within an extensive area of natural or near-natural environment. Populations are likely to self-supporting in this setting.

6. Knowledge Gaps and Recommendations for Future Monitoring

Lake Gregory is a fairly well understood system. There have been a number of studies conducted, covering aspects from hydrology to anthropology. Ongoing monitoring will be needed to ensure compliance with DIWA (and potentially Ramsar) criteria, but what is most urgently required is better management. Monitoring is also required as a tool to determine the effectiveness of management actions.

In line with the recommendations of the Paraku Management Plan, members of the Mulan community have established photo-monitoring points in stock exclosures on the eastern side of Mulan Lake. These are certain to unequivocally demonstrate the deleterious impact of stock and horses (Figure 11) on the vegetation of the lake. Some further work may be required to prove the impact of vegetation decline on the overall resource condition. However, any perceived uncertainty regarding the relationship between pastoral activity in the area and waterbird usage of the lake should not delay the implementation of more appropriate management. Other threats to the system pale compared to that posed by grazing, particularly if the proposed increase in cattle numbers eventuates.

Management planning would benefit from more regular measurement of water levels and inundation extent in the basins of the system. Sedimentation rates in the basins should also be monitored as this will provide early warning of the need to undertake catchment modification or change land management practices within the catchment of Sturt Creek.

Figure 11 – Horses graze on the floor of Mulan Lake.

References

Allen, A. D. (ed.) (1990) *The Inferred Hydrogeology of Lake Gregory*. The natural features of Lake Gregory: a preliminary review. Occasional Paper 2/90. Department of Conservation and Land Management, Perth, Australia.

Balgo-Kutjungka Catholic Parish. (2007). <http://www.users.bigpond.com/kutjungka/> Accessed on 21 November 2008.

Bureau of Meteorology. (2009) Climate Statistics for Australian Locations. Bureau of Meteorology. <http://www.bom.gov.au/climate/averages/> Accessed on 5 January 2009.

CSIRO. (Undated) Climate Change in the Kimberley Region. CSIRO Marine and Atmospheric Research. <www.sharingknowledge.net.au/files/kimberleyv1_2006.pdf> Accessed on 04/09/2008.

DEWHA. (2008) Paruku Indigenous Protected Area. Department of the Environment, Water, Heritage and the Arts. <http://www.environment.gov.au/indigenous/ipa/declared/paruku.html> Accessed on 21 November 2008.

Environment Australia. (2001) *A Directory of Important Wetlands in Australia, Third Edition*. Environment Australia, Canberra.

Graham, G. (2001) Tanami Desert 1 (Tan1 - Tanami subregion). In *A Biodiversity Audit of Western Australia's 53 Biogeographic Subregions in 2002*. (McKenzie, N. L., May, J. E., and McKenna, S., eds). Pages 326-331. Department of Environment and Conservation, Perth, Australia.

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

Halse, S. A. (1990) Waterbirds at Lake Gregory: Available Data and Information Required. In *The natural features of Lake Gregory: a preliminary review. Occasional Paper 2/90*. (Halse, S. A., ed.). Pages 20-29. Department of Conservation and Land Management, Perth, Australia.

Halse, S. A., Jaensch, R. P., Munro, D. R., and Pearson, G. B. (1990) *Annual waterfowl counts in south-western Australia - 1988/89*. Technical Report No. 25. Department of Conservation and Land Management, Perth, Australia. September 1990.

Halse, S. A., Pearson, G. B., and Kay, W. R. (1998a) Arid Zone Networks in Time and Space: Waterbird Use of Lake Gregory in North-Western Australia. *International Journal of Ecology and Environmental Sciences* **24**: 207-222.

Halse, S. A., Shiel, R. J., and Williams, W. D. (1998b) Aquatic invertebrates of Lake Gregory, northwestern Australia, in relation to salinity and ionic composition. *Hydrobiologia* **381**: 15-29.

Handasyde, T. (2006) *An overview of the vegetation of the Paruku (Lake Gregory) wetlands*.

Jaensch, R. P., and Vervest, R. M. (1990) *Waterbirds at Remote Wetlands in Western Australia 1986-8, Part One: Lake Argyle and Lake Gregory*. RAOU Report No. 32. Royal Australasian Ornithologists Union, Perth, Australia.

Jaensch, R. P. (1993) Lake Gregory System - WA096. In *Australian Wetlands Database*. Department of Environment, Heritage and the Arts. Accessed on 23 April2009.

Kimberley Land Council. (1999) *The Plan for Tjurabalan Traditional Owners to look after the Paraku Indigenous Protected Area*. Kimberley Land Council.

Marchant, N. G., and Halse, S. A. (eds). (1990) *The flora of Lake Gregory*. The natural features of Lake Gregory: a preliminary review. Occasional Paper 2/90. Department of Conservation and Land Management, Perth, Australia.

Paraku IPA. (2004) *Management Plan for Community.* .

Paton, J. B. (unpublished data). In: Halse et al. 1990.

Russell-Smith, J. (2005) *Fire in the Kimberley and Inland Regions of WA – Issues Paper*. Environmental Protection Authority, Perth, Australia.

Smith, L. A., and Johnstone, R. E. (1978) Bird notes from Gregory Salt Lake, Great Sandy Desert, Western Australia. *Western Australian Naturalist* **14**: 65-67.

Start, A. N., and Fuller, P. J. (1983) Birds. In *Wildlife of the Great Sandy Desert, Western Australia*. (Burdbidge, A. A. and McKenzie, N. L., eds). Pages 94-108. Western Australian Wildlife Research Bulletin No. 12.

Wallace, K. J., B.C. Beecham., B.H. Bone. (2003) *Managing Natural Biodiversity in the Western Australian Wheatbelt: a conceptual framework*. Department of Conservation and Land Management, Perth, W.A.

Watkins, D., Brennan, K., Lange, C., Jaensch, R. P., and Finlayson, M. (1997) *Management Planning for Ramsar Sites in the Kimberley Region of Western Australia*. Prepared for the Department of Conservation and Land Management by Wetlands International Oceania, Canberra, Australia.

Appendix 1 – Aquatic Invertebrate Data

Table 9 – Aquatic invertebrates collected from the eastern shore of Mulan Lake (site 5 of Halse et al. 1998b).

Class	Order	Family	Lowest ID	Halse site 5 Oct 1989	Halse site 5 May 1991	Halse site 5 Aug 1993	RCM013 May 2008
Rotifera	Flosculariacea	Testudinellidae	*Testudinella patina*		✓		
	Ploimida	Euchlanidae	*Euchlanis dilatata*			✓	
			Euchlanis sp.		✓		
		Lecanidae	*Lecane bulla*			✓	
			Lecane luna			✓	
			Lecane lunaris			✓	
			Lecane quadridentata		✓	✓	
			Lecane sp. s.str.		✓		
		Notommatidae	*Eosphora najas*			✓	
		Trichocercidae	*Trichocerca bicristata*			✓	
Gastropoda	Basommatophora	Planorbidae	*Gyraulus* sp.				2
			Ameriana spp.				1,2,3
Bivalvia	Unionida	Hyriidae	*Velesunio wilsoni*	✓			
Arachnida	Acariformes	Eylaidae	*Eylais* sp.			✓	
		Limnesiidae	*Limnesia solida*				1,2
			Limnesia sp.			✓	
		Pionidae	*Piona* sp.			✓	
		Arrenuridae	*Arrenurus tripartitus*				2
			Arrenurus sp.			✓	
	Acariformes	-	Acariformes		✓		
	Acariformes	-	Oribatida				1,3

Class	Order	Family	Lowest ID	Halse site 5 Oct 1989	Halse site 5 May 1991	Halse site 5 Aug 1993	RCM013 May 2008
Crustacea	Cladocera	Chydoridae	*Alona* sp.			✓	
			Leberis cf. *diaphanus*			✓	
		Daphniidae	*Ceriodaphnia* aff *cornuta*			✓	
			Daphnia carinata			✓	
			Scapholeberis sp.			✓	
			Simocephalus sp.			✓	
		Moinidae	*Moina* sp.	✓		✓	
	Ostracoda	Limnocytheridae	*Limnocythere dorsosicula*			✓	
		Cyprididae	*Bennelongia barangaroo*		✓	✓	
			Cyprinotus kimberleyensis		✓	✓	
			Heterocypris gregarius	✓	✓		
			Heterocypris sp. 376 (GRE)			✓	
			Cypricercus salinus			✓	
			Cypricercus aff *salinus*		✓		
	Copepoda	Centropagidae	*Boeckella triarticulata*		✓	✓	
			Calamoecia canberra		✓	✓	
		Cyclopidae	*Microcyclops varicans*			✓	
			Mesocyclops notius		✓	✓	
			Apocyclops dengizicus	✓			
		Canthocamptidae	*Cletocamptus dietersi*	✓			
Insecta	Coleoptera	Dytiscidae	*Hyphydrus lyratus*		✓	✓	
			Hydroglyphus leai				3
			Hydroglyphus grammopterus (=*trilineatus*)		✓		
		Hydrophilidae	*Berosus* sp.				2,3
			Enochrus sp.		✓		
	Diptera	Culicidae	*Anopheles amictus*			✓	

Class	Order	Family	Lowest ID	Halse site 5 Oct 1989	Halse site 5 May 1991	Halse site 5 Aug 1993	RCM013 May 2008
Insecta	Diptera	Ceratopogonidae	*Bezzia* sp.				1,2,3
		Stratiomyidae	Stratiomyidae			✓	
		Chironomidae	*Clinotanypus crux*				1,2,3
			Procladius paludicola			✓	1,2,3
			Ablabesmyia aff *notabilis*		✓	✓	
			Larsia albiceps			✓	2
			Nanocladius sp.			✓	
			Cladotanytarsus aff K4			✓	
			Tanytarsus barbitarsis	✓			
			Tanytarsus fuscithorax/semibarbitarsus				2
			Tanytarsus aff *bispinosus*			✓	
			Tanytarsus aff *manleyensis*		✓		
			Chironomus sp.		✓		
			Dicrotendipes sp. K8 (of Halse et al. 1998b)		✓	✓	
			Dicrotendipes sp. K4				2
			Polypedilum leei			✓	1,2
			Polypedilum nubifer				1,2
			Cryptochironomus griseidorsum			✓	1,2,3
			Microchironomus sp P1(= sp B1 cranston)				1,3
			Paracladopelma aff M3			✓	
			Parachironomus sp.		✓		
	Ephemeroptera	Baetidae	*Cloeon* sp.				2
		Caenidae	*Tasmanocoenis* sp. LGA			✓	
	Hemiptera	Gerridae	Gerridae			✓	
		Corixidae	*Micronecta robusta*		✓		
			Micronecta gracilis		✓	✓	

Class	Order	Family	Lowest ID	Halse site 5 Oct 1989	Halse site 5 May 1991	Halse site 5 Aug 1993	RCM013 May 2008
Insecta	Hemiptera	Corixidae	*Micronecta micra*				2
			Micronecta sp. K2				2,3
		Notonectidae	*Anisops paraexigerus*		✓		
			Anisops semitus		✓		
		Pleidae	*Paraplea* sp.			✓	
	Odonata	Coenagrionidae	*Austroagrion watsoni*				2
			Austroagrion sp.		✓		3
			Ischnura heterosticta heterosticta			✓	
			Xanthagrion erythroneurum			✓	2
		Aeshnidae	*Hemianax papuensis*		✓	✓	
		Libellulidae	*Diplacodes bipunctata*		✓		
			Neurothemis stigmatizans stigmatizans				2
		Hemicorduliidae	*Hemicordulia tau*		✓		
			Hemicordulia intermedia				2
		Urothemistidae	*Macrodiplax cora*			✓	
	Trichoptera	Ecnomidae	*Ecnomus* sp.K1				2
		Leptoceridae	*Oecetis* sp.				2,3
			Triplectides australis		✓		2

* Samples 1, 2 and 3 denote the three RCM sub-samples:

- Deeper water with sparse macrophyte amongst dead trees
- Shallower water with moderately dense macrophytes
- Shallower water with very sparse macrophytes

Appendix 2 – Waterbird Data

Table 10 – Waterbirds observed at Lake Gregory.

Common name	Latin name	Nov 1977[a]	Apr 1979[b]	May/June 1980[b]	May 1983[c]	Aug 1986[d]	Mar 1988[e]	May 1988[d]	Oct 1989[e]	Jun 1991[e]	Sep 1991[e]	Mar 1993[e]	Aug 1993[e]	May 1994[e]	Oct 1995[e]	May 2008[f]
Australasian Grebe	*Tachybaptus novaehollandiae*	14		1		108					5		2	9	59	
^ Australian Pelican	*Pelecanus conspicillatus*	420		>6,000	~40	3,097	5,000-6,000	824	299	28	664	144	1,089	204	1,460	
Australian Pratincole	*Stiltia isabella*	35				295	✓	16	362	23		4	25	1	30	
Australian Shelduck	*Tadorna tadornoides*		✓ *			4				2			2		6	
Australian White Ibis	*Threskiornis molucca*					26	✓	2	6		10	5	83	5	23	
^ Australian Wood Duck	*Chenonetta jubata*			4	>12	353	5,000-10,000	105	157	17	132		196	3	768	
Banded Lapwing	*Vanellus tricolor*								1				13	216		
Banded Stilt	*Cladorhynchus leucocephalus*	34						9								
Black-fronted Dotterel	*Elseyornis melanops*	6		>10	few	20			9	22	9		7	9	13	
Black-necked Stork	*Ephippiorhynchus asiaticus*	1				3										2
# Bar-tailed Godwit	*Limosa lapponica*					1										
# Black-tailed Godwit	*Limosa limosa*								16						1	
Black-tailed Native Hen	*Gallinula ventralis*					39	✓			12	42		108	59	20	
^ Black-winged Stilt	*Himantopus himantopus*		1	1		611	✓	18	638	81	254	87	1,537	63	1,304	
^ Black Swan	*Cygnus atratus*	400	✓ *	18	~30	5,775	~5,000	4,027	756	137	263	941	2,012	499	4,183	100
Brolga	*Grus rubicunda*	570	~50	~100	2	3,530	✓	499	1,929	31	1,662	5	311	47	2,977	3
Buff-banded Rail	*Gallirallus philippensis*								1							
# ^ Caspian Tern	*Hydroprogne caspia*	20	✓ *	62	>15	1,560	✓	760	802	889	735	119	399	40	216	✓
# Cattle Egret	*Bubulcus ibis*													11		
Clamorous Reed Warbler	*Acrocephalus stentoreus*												1			
# Common Greenshank	*Tringa nebularia*	4	1			4			13		5			6	11	
Common Sandpiper	*Tringa hypoleucos*		3			3			4		2				2	
# Curlew Sandpiper	*Calidris ferruginea*					359	✓	10	433							
^ Darter	*Anhinga melanogaster*	30		10	~30	854	~5,000	684	83	21	111	26	564	129	723	3
^ Eurasian Coot	*Fulica atra*	5,000	2		mod. common	74,258	~100,000	3,407	20,040	2,995	13,777	8	3,473	1,331	23,982	100
Freckled Duck	*Stictonetta naevosa*					898		52		6	11		21		333	10
# Glossy Ibis	*Plegadis falcinellus*				~4	64			1	34	238		553	77	1,142	
Great Cormorant	*Phalacrocorax carbo*					4								1		
^ Great Crested Grebe	*Podiceps cristatus*					842	✓	77			52	3	25		33	
# ^ Great Egret	*Ardea alba*	25		16	>20	355	✓	35	44	47	373	6	310	60	1,169	
Green Pygmy-Goose	*Nettapus pulchellus*												2		10	
# Grey Plover	*Pluvialis squatarola*								1							
^ Grey Teal	*Anas gracilis*	3,500	✓ *	>25,000	~12	11,133	~150,000	21,015	4,770	32,922	46,303	1,176	19,943	2,189	44,200	100
# Grey-tailed Tattler	*Tringa brevipes*								1						1	
Gull-billed Tern	*Gelochelidon nilotica*	56	✓ *	9	2	82	✓		6	2	28	174	148	4	768	
^ Hardhead	*Aytha australis*	6		6	~12	16,037	~60,000	9,936	1,796	4,098	48,971	164	20,618	23,121	21,778	100
Hoary-headed Grebe	*Poliocephalus poliocephalus*		2			5	✓	47	4	11	19		3	5	28	2
Intermediate Egret	*Ardea intermedia*				1	8			2	9	5		4	5	2	1
^ Little Black Cormorant	*Phalacrocorax sulcirostris*	330			common	59,982	50,000-60,000	15,480	20	285	3,561	6	3,912	11,591	4,658	100
Little Egret	*Egretta garzetta*					5			1		5		1	13	1	

Common name	Latin name	Nov 1977[a]	Apr 1979[b]	May/June 1980[b]	May 1983[c]	Aug 1986[d]	Mar 1988[e]	May 1988[d]	Oct 1989[e]	Jun 1991[e]	Sep 1991[e]	Mar 1993[e]	Aug 1993[e]	May 1994[e]	Oct 1995[e]	May 2008[f]
^ Little Pied Cormorant	*Phalacrocorax melanoleucos*				mod. Common	589		10		17	599	56	351	158	640	3
# Long-toed Stint	*Calidris subminuta*					3			13						1	
^ Magpie Goose	*Anseranas semipalmata*					135		3		9	601,994	9	192	4	268	3
# Marsh Sandpiper	*Tringa stagnatilis*					46			788	1					35	
Masked Lapwing	*Vanellus miles*	20			2	215	~10,000	8	174	7	47	23	151	85	319	
Musk Duck	*Bizuria lobata*									2						
^ Nankeen Night Heron	*Nycticorax caledonicus*				>30	27				54	369	38	197	11	102	
# Oriental Plover	*Charadrius veredus*	90						✓	25,707						901	
Pacific Black Duck	*Anas superciliosa*	200	✓*		~10	277	~50,000	1,198	1,843	43	1,761	74	2,249	42	6,970	3
# Pacific Golden Plover	*Pluvialis fulva*								1							
# Painted Snipe	*Rostratula benghalensis*														1	
^ Pied Cormorant	*Phalacrocorax varius*				~50	2,230	~1,000	1340	6	288	305	4	1,047	160	47	
^ Pink-eared Duck	*Malacorhynchus membranaceus*		✓*	50	~60	33,849	150,000-200,000	9,423	1,304	1,023	5,593	55	1,486	123	8,052	10
Plumed Whistling Duck	*Dendrocygna eytoni*				150	13,150	✓	1,750	8,000	360	6,575	126	2,774	80	3,136	
Purple Swamphen	*Porphyrio porphyrio*					2										
^ Red-capped Plover	*Charadrius ruficapillus*	✓		250		515	✓	116	2,199	210	6		52		24	24
Red-kneed Dotterel	*Erythrogonys cinctus*			5		73			3	38	23	1	53	303	29	
Red-necked Avocet	*Recurvirostra novaehollandiae*		3	25		204		174	93	100	9	6			105	
# Red-necked Stint	*Calidris ruficollis*		3	1		337		100	833						4	
Royal Spoonbill	*Platalea regia*	2		1	>~40	62	✓	16	20		108		9	4	3	
# Ruddy Turnstone	*Arenaria interpres*								2							
# Sharp-tailed Sandpiper	*Calidris acuminata*	36				1,442	10,000-15,000	10	7,674						540	
Shoveler	*Anas* sp.														4	
^ Silver Gull	*Larus novaehollandiae*		✓*	~70	few	89	✓	486	231	50	14		50	29	276	
Straw-necked Ibis	*Threskiornis spinicollis*			3	>4	255	✓	2	21	67	222	149	1,030	131	676	
Swamp Harrier	*Circus approximans*			✓*		2		4			1		3	1		
Unidentified Cormorant															2,322	
Unidentified Duck												6	500		22,116	
Unidentified Egret												94	1,538			
Unidentified Grebe														3		
Unidentified Tern															76	
Unidentified Wader												22	532		5,728	
Unidentified Waterbird															3,671	
^ Wandering Whistling Duck	*Dendrocygna arcuata*					1,570					10	11	2,108	60	1,920	
Whiskered Tern	*Sterna hybrida*	70	✓*	2,000	mod. common	1,996	✓	1,795	463	172	170	663	1,054	147	1,362	
White-faced Heron	*Egretta novaehollandiae*			12	3	1			5	11	31	61	438	31	18	
White-necked Heron	*Ardea pacifica*	2	4	79		18				17	83	63	640	5	5	
# White-winged Black Tern	*Chlidonias leucopterus*											47				
# Wood Sandpiper	*Tringa glareola*	8				19			41		3				45	
^ Yellow-billed Spoonbill	*Platalea flavipes*			7	3	20	✓*	2	2		1		124	3	2	

a (Smith and Johnstone 1978)
b (Start and Fuller 1983)
c (Paton unpublished data)
d (Jaensch and Vervest 1990)
e (Halse et al. 1990) – many of the species counts for March 1988 are estimates and some duck counts of duck species in October 1995 were correced for counting efficiency
f RCM survey

Numbers indicate abundance (when known)
Listed under Migratory Bird Agreements JAMBA, CAMBA and/or ROKAMBA
^ Recorded breeding
* Present in Sturt Creek
✓ Present but not counted