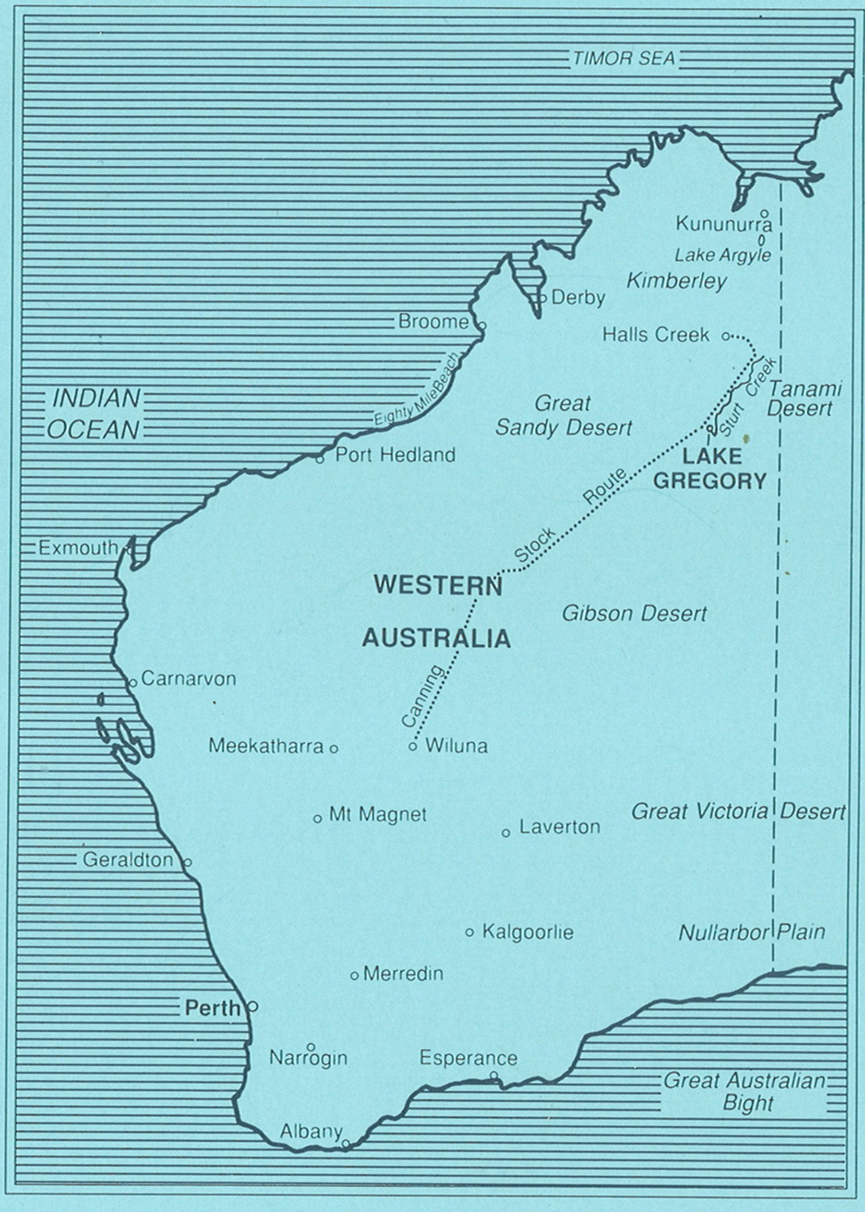
The Natural Features of Lake Gregory: A Preliminary Review

Proceedings of a Workshop on Lake Gregory held at Woodvale April 1989

Edited by S.A.Halse



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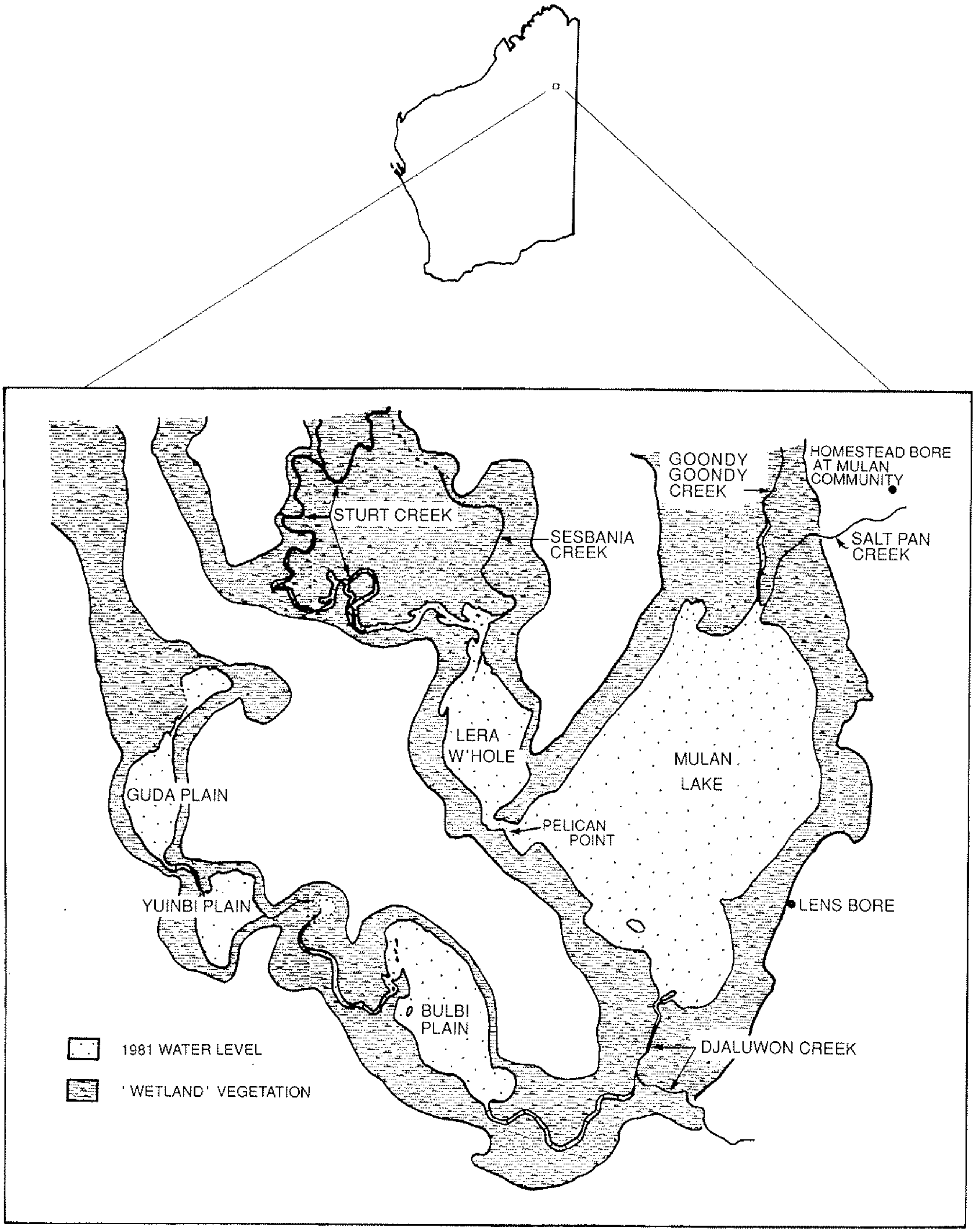

Frontispiece

The waterbodies comprising Lake Gregory, the creeks leading into them and associated wetland vegetation mapped from 1981 Landsat imagery.

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Preface

Lake Gregory is a large fresh to brackish lake in the Tanami Desert on the north-eastern boundary of the Great Sandy Desert. It consists of several interconnected waterbodies. Mulan Lake, which is usually referred to as Lake Gregory, is the largest of these (Frontispiece). The major catchment area of the lake lies in the south-east Kimberley with Sturt Creek emptying into the lake through a series of anastomosing channels leading into Lera Water-hole, Mulan Lake and Guda Plain. There is also a local catchment area to the east, which is drained by Salt Pan and Djaluwon Creeks.

The area has considerable biological importance, which led to a request by the Department of Fisheries and Fauna (wildlife branch now part of the Department of Conservation and Land Management) in 1961 that the area be reserved for conservation of Fauna and Flora. However, the area was part of Billiluna Pastoral Lease at the time and the Department of Lands and Surveys (now Department of Land Administration) refused the request. Further efforts to have the area made a reserve in 1974 were abandoned because the Billiluna Pastoral Lease was still current but the Conservation Through Reserves Committee (1974, Conservation reserves in Western Australia. Department of Conservation and Environment, Perth. Recommendation 12.4) recommended that the area be surveyed to determine whether a reserve should be created.

The Billiluna Pastoral Lease was sub-divided in 1977 and Lake Gregory Pastoral Lease was established on the area around the lake. That lease is held by the Aboriginal Lands Trust for the Mulan Aboriginal Community.

The Department of Conservation and Land Management regards the lake as a very important natural area and, together with the Museum of Victoria, University of Adelaide and University of Western Australia, is about to embark on a multi-disciplinary study of the lake that will include waterbirds, palaeohistory and limnology. On the suggestion of Dr J.M. Bowler of the Museum of Victoria, it was decided to hold a workshop on Lake Gregory prior to putting together a research program. Individuals with expertise relating to Lake Gregory and its management were invited to present papers to summarize current knowledge of the hydrogeology, palaeohydrology, geomorphology, limnology, flora, waterbirds and management issues of the lake. As a result of discussion among the speakers and other participants at the workshop (all of whom had an interest in Lake Gregory or wildlife management), some special features of Lake Gregory and issues that should be addressed in the proposed study were identified.

This Occasional Paper contains the papers presented at the workshop and a summary of resulting discussions and conclusions.

S.A. Halse

Workshop Participants

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*A representative of the Aboriginal Lands Trust was invited but was unable to attend.

Contents

Paper 1

The Inferred Hydrogeology of Lake Gregory

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INTRODUCTION

The purpose of this paper is to review the available hydrogeological information relating to Lake Gregory. Examination of Geological Survey information reveals that there are very limited data and consequently comments on the hydrogeology are mainly inferred.

Climate

Lake Gregory has an arid climate with an average annual rainfall of about 250 mm. However, annual rainfall varies widely and is usually received in short intense events associated with thunderstorms or cyclonic activity.

The average annual evaporation is about 4000 mm, which results in surface water persisting for only short periods.

Physiography

Lake Gregory is situated at the terminal end of Sturt Creek and Djaluwon Creek (Fig. 1.1) and has a catchment area of about 65 000 km^2. Large streamflows have been observed in Sturt Creek but no stream gauging has been undertaken. A number of semi-permanent pools (water-holes) occur at some places along Sturt Creek and the drainages which link associated clay pans in the lower reaches of Sturt Creek before it enters Lake Gregory.

Lake Gregory is about 200 m above sea level and has an area of about 120 km^2. The bed of the lake is composed of clay with local development of salt and gypsum pans. The lake may remain filled with water for several years after stream flow.

GEOLOGY

Stratigraphy and structure

Lake Gregory is situated in the north-east Canning Basin, within the Gregory Sub-Basin (Fig. 1.2). It is underlain by up to 16 000 m of sedimentary rocks, ranging in age from Ordovician to Mid-Triassic, which are covered by a veneer of alluvium and lacustrine sediments believed to attain a maximum thickness of about 30 m.

The Ordovician to Mid-Triassic sediments are gently folded and may be incised by a palaeovalley to a depth of about 30 m and infilled by flat-lying alluvial and lacustrine sediments.

Sturt Creek is believed to form the headwaters of a large palaeoriver which once flowed westward across the Canning Basin to the Indian Ocean (Fig. 1.3). The river may have existed since the Eocene but in the Late Tertiary (Mid-Miocene), when the climate changed from humid to arid, alluvial sediments choked the drainage and were subsequently partially covered by seif dunes. Only the headwaters of the drainage system remained active.

HYDROGEOLOGY

Water table

A regional water table (unconfined groundwater) is believed to extend throughout the region within the alluvium (where sufficiently thick) and in the weathered uppermost part of outcropping Permian and Triassic sediments. Depending on elevation the water table ranges in depth from about 20 m in upland areas to about 3 m or less at Lake Gregory. The configuration of the water table probably approximates the regional topography and flow probably converges on the area in the vicinity of Lake Gregory where the groundwater is discharged

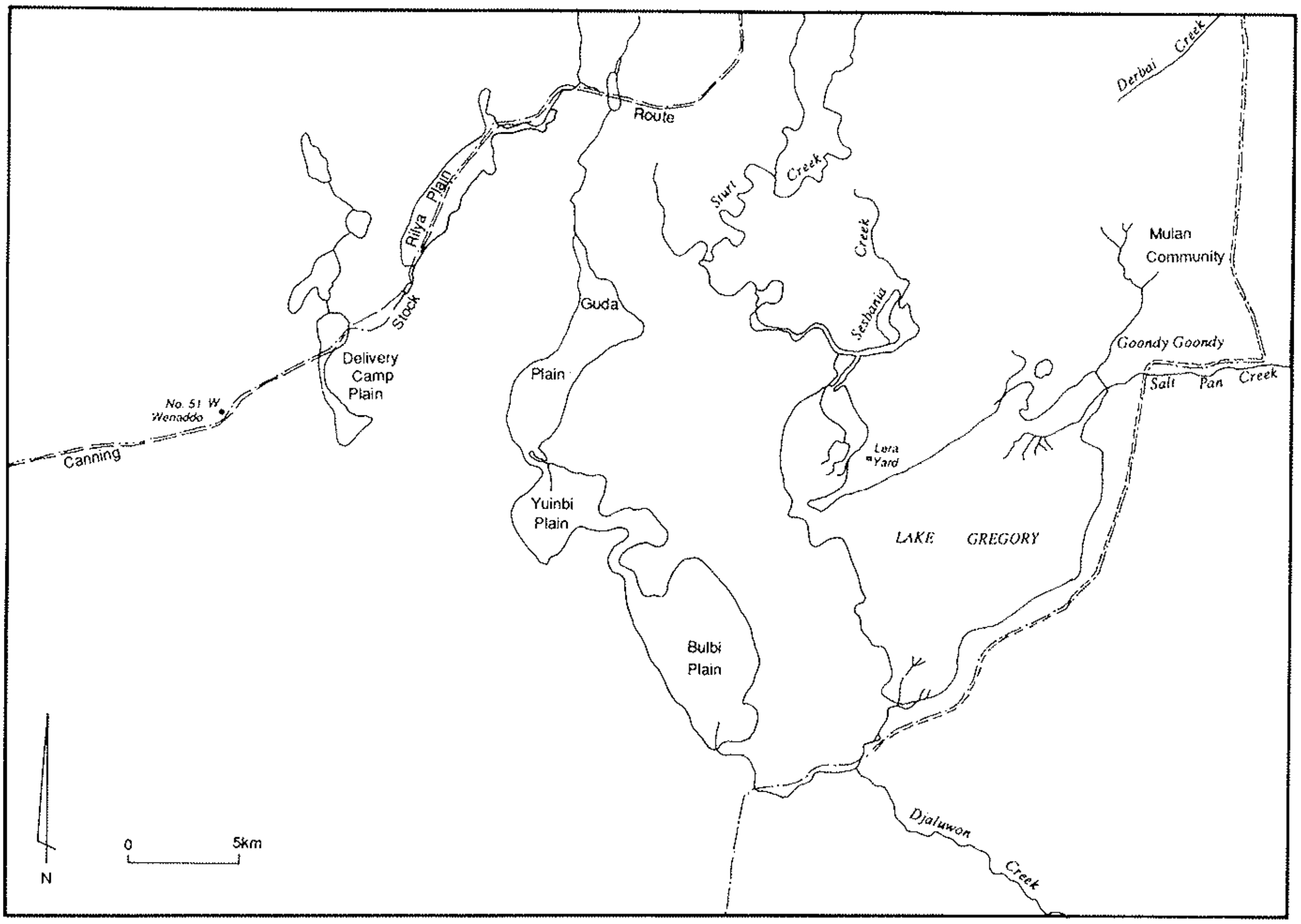

Figure 1.1
Location of the main features of the Lake Gregory system.

by evaporation from water-holes, evapotranspiration from vegetation, and possibly by sub-surface discharge. Groundwater is likely to increase in salinity toward Lake Gregory and is believed to be generally brackish to saline.

Confined aquifers

Sandstones in the Ordovician - Mid-Triassic sediments underlying the alluvial sediments contain confined groundwater flow systems, in which the directions of groundwater flow are unknown. The groundwater is believed to vary from brackish to saline.

Lake Gregory

Sturt Creek forms a delta-like system of distributory channels and clay pans before entering Lake Gregory. It is inferred that many of the clay pans may temporarily hold fresh to brackish water after stream flow. However, for most of the year surface water occurs only in overdeepened areas along distributory channels as semi-permanent water-holes which are presumed to be also maintained by some groundwater inflow when the water table is high.

The nature of the underlying Triassic sediments make it unlikely that there is subsurface input to, or leakage from, Lake Gregory that involves the confined aquifer. However, there is undoubtedly an input from the unconfined groundwater in alluvial sediments. It is also inferred that some sub-surface discharge of saline groundwater (and lake water) may occur via the palaeoriver channel as the development of salt is small when compared with some other salt lakes which occur in Western Australia.

The development of salt pans probably mainly represents a build-up of cyclic salt which is only partly flushed or removed by ablation from the lake surface.

CONCLUSIONS

(1) There is very limited hydrogeological information about Lake Gregory.

(2) The lake is situated in a 'delta-like' area at the end of an active drainage which formed the headwaters of an extensive palaeoriver system which formerly extended to the Indian Ocean.

(3) The lake is inferred to be maintained by surface inflow principally from Sturt Creek and by a minor contribution of groundwater from unconfined groundwater in alluvial sediments and weathered Permian-Triassic sedimentary rocks.

(4) Some subsurface discharge may occur from Lake Gregory.

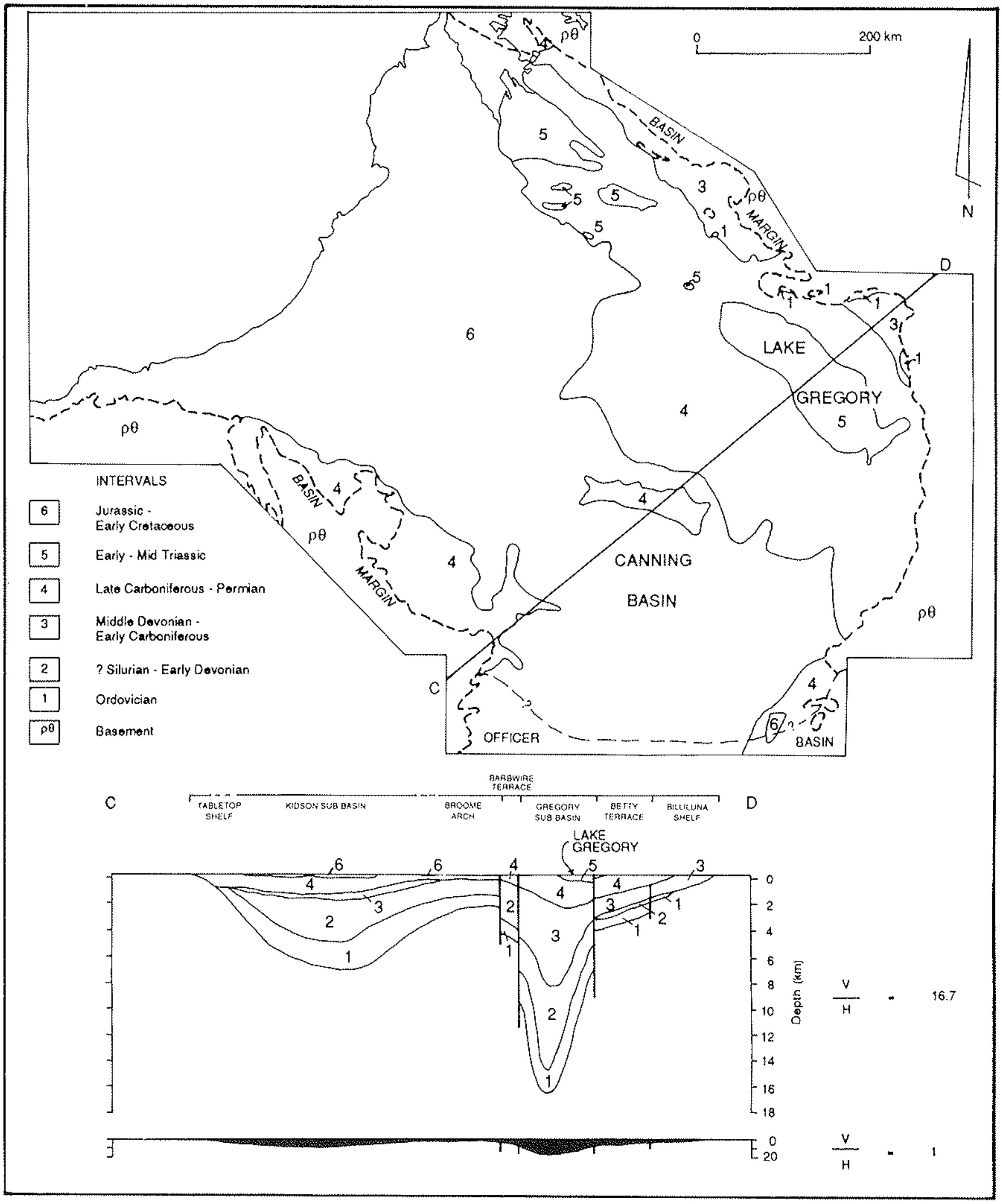

Figure 1.2

Transect (C-D) through the Canning Basin, including the Gregory Sub-Basin, showing the generalised geology of the region.

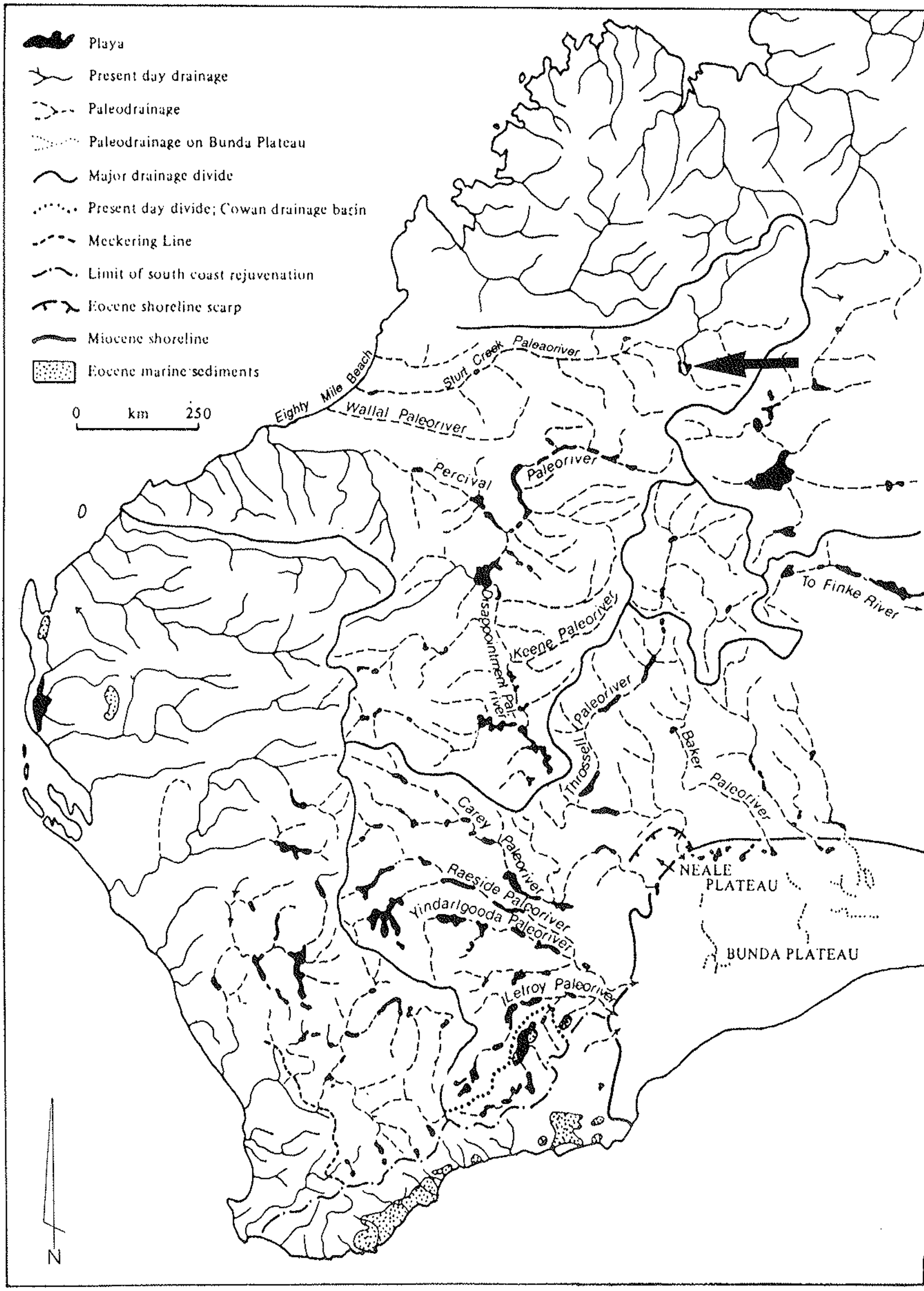

Figure 1.3

Present-day and palaeodrainage systems in Western Australia, including the Sturt Creek palaeoriver system. Lake Gregory is arrowed.

Paper 2

Lake Gregory - Geomorphology and Palaeohydrology

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INTRODUCTION

The Lake Gregory system, lying on the northern side of the Australian arid region in the monsoonal summer rainfall zone, provides key sites for elaboration of environmental change. The Australian National University, in its program of semi-arid region studies and the elucidation of Australia's climatic history, sponsored its first expedition to the Gregory lakes in 1978. This was designed to study the geomorphology, to sample the lake sediments and to ascertain whether the lakes could be used to provide a detailed hydrologic history. In 1978 the lakes contained substantial amounts of water. Water samples and some sediments were returned for laboratory analyses; regional observations on the geomorphology and sand dune relationships were obtained.

A second expedition in 1979 visited the lakes under dry-lake conditions. Further field sampling was undertaken but it proved impossible to venture onto the floor of the main lake which had only recently dried, because of soft ground surface conditions unsuitable for vehicle transport. Coring and sediment sampling was therefore restricted to the margins of the basins.

Following the discovery of trace elements of economic interest a third brief visit was made in 1981 to report some findings of the earlier study to the Aboriginal community.

The Gregory lakes provide what is perhaps a unique example of human-land relationships in the anthropological history of Australia. They lie in an area in which the original occupants now have land rights and undertake commercial pastoral activities in the very heartland of their traditional country. Additionally, the water bodies obviously act as a central or focal point, not only in the whole ecology of the region, but also in the cultural and social organisation of the indigenous people. This was brought home to us rather startlingly during the first 1978 visit.

Having provided the Mulan community with a copy of a geomorphic map indicating some areas of interest to us, we requested permission to traverse specific areas. After satisfying the initial inquiries of the elders of the community, we then asked the community elders to identify those areas of special or sacred interest to which we should not travel or in which work was inhibited. At this point, one old man who had been sitting quietly through the early discussions, drew from behind his back a copy of the map we had provided and on it were already marked several areas where excavation activities were specifically forbidden. It was in one sense no surprise to find that the major area of exclusion was exactly the one in which, from the palaeohydrologic evidence, we would have predicted the presence of earlier human occupation, centred on a most favourable lake shore habitat.

As in southern Australia where the lunette dunes preserve the most detailed and exciting components of Aboriginal history, so too here in the modern community the area identified was precisely equivalent to the lunette accumulation zone, in this case on the north-western side of the lake. Named Yadjulano, this encompasses the transverse dune ridge at the point of entry of Sturt Creek into Leira (= Lera) Water-hole and extends to the shoreline on the western side of Malan Lake opposite Pelican Point (Fig. 2.1). We have here an example of continuity of cultural relationships between lakes and lake-shore features. In southern Australia lake-shore occupational evidence extends back some 40 000 years; here in the Gregory lakes apparently similar occupational memory continues to be major social concern of the community to the present day.

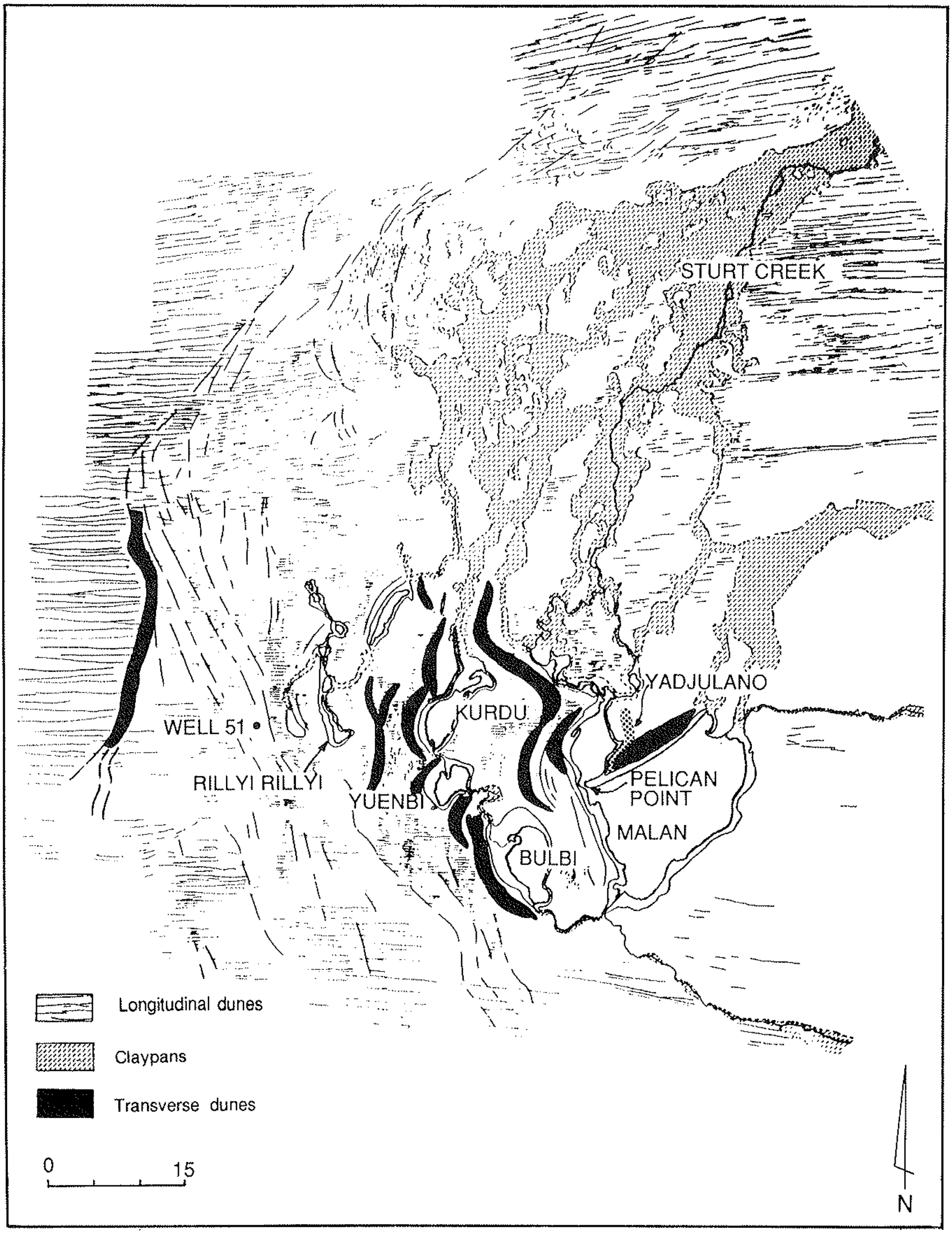

Figure 2.1

Geomorphic map of the Gregory lakes system showing the anastomosing streams of Sturt Creek feeding the interconnected chain of lakes. The lakes set within the east to west regional dune fields of the Great Sandy Desert possess north-south transverse ridges on their western (downwind) side. On the far west of Rillyi Rillyi a north-south ridge represents the western shoreline of a mega-lake, an ancestral phase of the modern Gregory system.

Given the tropical setting and key location the Gregory lakes, in terms of our understanding of Australia's palaeoclimatic history and ethnographic human landscape relationships, represent a unique environment worthy of detailed examination.

GEOMORPHIC SETTING

Sturt Creek, which arises on the eastern margin of the Kimberley, represents one of the few major streams in Australia which terminate within the desert in a relatively freshwater drainage system. This provides a context in which freshwater sits in juxtaposition with arid-land communities of animals and plants. It is a special setting in which waterbirds particularly, and other components of desert ecology, have almost continuous access to fresh water.

The Sturt drainage clearly represents a remnant of a more ancient palaeo-drainage system that once drained through the west of what is today the Great Sandy Desert. Termination or truncation of that drainage was almost certainly due to the development of aridity and blocking by sand dune development. Although the age of such trunk disruption is not identified in northern Australia, by comparison with evidence from southern Australia, such events probably occurred within the last 500 000 years.

LAND UNITS

The Gregory area may be divided into a number of land units characterised by the controlling processes and developed landforms -

(1) *Sturt Creek*

Sturt Creek flows as a single or relatively confined channel in a north-south direction past Halls Creek until, south of Halls Creek, it breaks up into an anastomosing distributory system with a myriad of small channels branching out in a finger-like distributory pattern to feed into the lakes.

(2) *The Lake Gregory Chain*

The Gregory lakes consist of a series of shallow, interconnected basins fed by two main distributories of Sturt Creek. On the western side, the chain of lakes includes Rillyi Rillyi on the far west and three interconnected basins (Kurdu[1], Yuenbi and Bulbi) in the centre (Fig. 2.1).

1 See Table 2.1 for reconciliation with names used in other papers.

The eastern arm of Sturt Creek discharges through Leira Water-hole past the Pelican Point peninsula into the main basin (Malan or Barrago). The basin floors are at a slightly different level allowing the lake waters to decant during the evaporative stage with the consequence that salts are transported towards the south into the deepest part of the system which is found in the eastern Malan Lake. Thus, the chemical, sedimentary and landform characteristics affected by salt concentration are, in turn, very different from one basin to the next. This is borne out in the chemical analyses described later.

Lac-Aeolian Units

As in southern Australia, the lake basins have distinctive aeolian transverse ridges developed on the downwind (the western or north-western) margin. In Malan Lake the large ridge near Yadjulano forms a most characteristic feature. On the western side of Bulbi, Yuenbi and Kurdu, equivalent transverse ridges occur (Fig. 2.1). However, unlike the transverse ridges or lunettes in southern Australia which are often clay-rich or gypseous, those in the Gregory area are dominantly composed of quartz sand suggesting an association with full lake rather than dry phases.

In addition to the shoreline ridges which at times define considerably expanded basins, an outer ridge some 25 km west of Rillyi Rillyi defines what is almost certainly the western margin of a greatly expanded, mega-lake phase in the early history of the Gregory basins. The Canning Stock Route running south-west from Well 51 crosses this ridge which in turn provides an important separation in the dune system. Between the outer transverse ridge and Rillyi Rillyi a number of north-south subdued transverse ridges almost certainly represent contractional phases of the mega-lake towards the present smaller basins.

Aeolian-longitudinal dunes

The basins are set within the general framework of the longitudinal dune systems of the Great Sandy Desert. However, in proximity to the lake two distinct longitudinal dune systems are evident.

Beyond the western transverse ridge the high and wide strong red-brown east-west dunes, typical of the Great Sandy Desert, extend westwards towards the Indian Ocean.

On the inner margin of the transverse ridge, in proximity to the basins, a quite different longitudinal dune system has developed. While the east to east-west orientation is identical to that of the larger regional dunes the system is composed of dunes which are much smaller in length, lower in amplitude and much more closely spaced. In addition they often possess small, transverse connecting links providing a type of chain armour pattern on aerial photographs.

These clearly relate to a younger development showing a much lower degree of organisation and soil development in terms of their rubefaction. The dunes are much paler in colour than the regional strong red dunes.

AREA RELATIONSHIPS

The areas of the individual basins as defined from their most prominent shorelines are listed in Table 2.1. This amounts to a total of 387 km^2 for the area subject to more frequent flooding.

By comparison the area of the mega-lake defined from the location and orientation of the outer strand line covered in excess of 5000 km^2, more than 15 times the total water surface of the inner basins

Table 2.1

Areas of the Gregory basins measured from the most prominent and therefore the most frequently occupied shoreline levels. Note the total area, approximately 400 km^2, is small by comparison with the ancestral or mega-lake which, measured on the basis of the outer strandline morphology, was more than 12 times the size of the present water bodies. The age of the mega-lake can be estimated only approximately from current data as being more than about 40 000 years BP.

LAKE GREGORY

Main water bodies	*Area (km^2)*
Malan (= Mulan)	267
Bulbi	44
Yeunbi (= Yuinby)	15
Kurdu (= Guda)	30
Rillyi Rillyi (= Rilya)	11
Gillung (= Delivery Camp)	13
Other	7
	387
Outer strand lines	5492

LAKE-AEOLIAN RELATIONSHIPS

In addition to the transverse dunes on the western side of the basins evidence occurs of longitudinal dune encroachment over the lake floors especially in the south-eastern side of Malan Lake. Figure 2.2a shows in diagrammatic form the relationships between east to west longitudinal dunes of the inner system encroaching onto the south-eastern margin of the lake. Evidence of high water levels or strand line deposits can be found along the dune corridor indicating that after the westward advance of those dunes significant periods of high lake levels have in turn encroached upon the dunes themselves.

A cross-section through the dunes south of the lake shown diagrammatically in Figure 2.2b reveals the presence of lacustrine shells extending well beyond the margin of the present basin and underlying the longitudinal dune system. A strongly developed red calcareous soil formed on those lake sediments passes in horizontal fashion below the longitudinal dunes indicating a significant period of pedogenesis between the contraction of the outer lake and the much later development of the inner longitudinal dune system.

Radiocarbon dates from the shells and associated soil carbonate indicate deposition beyond 30 000 before present (BP). Although direct dating is not available for the longitudinal dunes, by comparison with events elsewhere in Australia, we assume an age close to 18 000 BP, which was the period of the last glacial maximum aridity. This needs to be tested by further detailed study.

LACUSTRINE FAUNA

A list of the lacustrine fauna identified during the 1978 visit is provided in Table 2.2. During August 1978 very extensive algal deposits, including possible samples of *Chara* sp. and *Cladophora* sp., formed thick green aquatic growths in the shallow waters (up to 1 m deep) along the shores of Malan Lake. Hosts of ostracods and other aquatic animals were visible in the waters at that time.

Table 2.2

List of fauna from Lake Gregory collected mainly from near Leira Water-hole and the northern margin of Malan Lake in August 1978.

MOLLUSCA

Sermyla sp.	*Corbiculina* sp.
Ameranna sp.	*Velesunio wilsonii*
Plotiopsis sp.	*Helicorbis* sp.
Lymnae sp.	?*Pettancylus* sp.

Identified originally by Leon Barmutta

OSTRACODA - abundant

ALGAE

Chara sp. - abundant
Cladophora sp. - possibly present

CHEMICAL ANALYSES

The chemical analyses listed in Table 2.3 reflect the great variety in evolution of the various waters in the basins. This is largely a reflection of the differing decanting histories as the waters at various stages of evaporation are decanted from one basin to the next. Note the extremely high pH of Malan Lake - up to 11 in 1978. This was associated with the very high algal productivity in the lake.

In the sediments of Malan Lake, traces of trona - a hydrous sodium carbonate - which is a mineral rarely found in Australia, are consistent with a high pH. The mineral, of considerable economic significance as a flux in aluminium smelting, occurred only in minute quantities of no economic value. Its presence is significant as an indicator of the geochemical evolution of the waters. Of additional interest are the very high silica values in the 1978 records. Note also the high carbonate in the Malan 1978 algal depositional phase.

Silica values remain consistently high by comparison with lakes elsewhere in Australia. The occurrence at Yuenbi of silica to 33 ppm almost certainly is associated with the development of authogenic silica (clay) minerals. The turbidity of that water was extremely high (it looked rather like milk) strongly suggesting the presence of colloidal amorphous silicate minerals.

HYDROLOGIC CONTROLS

The Gregory lakes differ from most salt lakes in central and southern Australia in that they do not preserve a salt crust at the surface on drying. This is almost certainly a reflection of the regional and local groundwater relationships. The evidence suggests that the regional groundwater levels lie below the lake floor in such a way as to permit the lakes on drying to lose salts to the groundwater whereas in most other parts of Australia these basins become groundwater discharge systems. In this context, the Gregory basins are almost certainly groundwater recharge systems. The relationships between the lake water and the local and regional groundwater require further elaboration.

Table 2.3

Chemical analyses from the Gregory lake system determined from water samples collected in August 1978 and September 1981. Note that the main basin, alternatively named Gregory, Malan or Barago, contains the largest water volume and at times of drying as in 1978 evolves to a chemical composition substantially different from that of other Australian salt lakes. Results are in ppm.

	pH	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^-	SO_4^{2-}	CL^-	SiO_2
AUGUST 1978											
Sturt Creek (Gilwah)	7.33	1710	54.0	37.3	484	29.2	nil	122	260	718	3.9
Malan	11.04	10790	52.0	153	3620	286	31	156	650	5800	2.0
Yeunbi	7.98	n/d	(49.1)	(6.1)	159	31.7	nil	180	(55)	138	(33)
Bulbi	7.30	24170	920	222	7610	288	nil	165	2530	12320	6.9
SEPTEMBER 1981											
Sturt Creek (Gilwah)	9.06	1300	67.0	9.5	344	26.6	5	44	160	560	5.0
Leira	9.38	1400	62.5	9.7	396	31.1	7	35	157	634	4.5
Pelican Point	8.35	2100	74.6	34.8	612	51.6	tr	120	220	1000	5.0
Malan	8.41	2200	87.7	24.2	658	55.6	tr	118	247	1038	5.0

In terms of maximum depths in the absence of detailed topographic levels we estimate from the shoreline position of Malan Lake that the most frequently occupied level would provide a lake of approximately 3-4 m deep in the centre.

In a survey from Rillyi Rillyi west to the transverse dune ridge, beach gravels were identified lying some 10 m above lacustrine shelly carbonates close to Well 51 (Fig. 2.1). Thus the depth of the mega-lake must have been in excess of 10 m. Additional data now available from seismic surveys should permit refinement and more accurate estimates of lake beach and lake depth levels. A summary diagram may be prepared on the basis of the evidence currently available to indicate the pattern of hydrologic change which has led to the evolution of the present lake system. Additional dating is required to refine this pattern and thereby permit accurate correlations with other sequences in Australia and elsewhere in the world. In this context the Gregory lakes provide a unique environment for palaeohydrologic studies.

ACKNOWLEDGEMENTS

This work could not have been undertaken without the closest cooperation with the Mulan Aboriginal Community under the leadership of Mr Rex Johns. Many Aboriginal elders and colleagues assisted in the fieldwork and provided essential and basic information at every level of that operation. The fieldwork was facilitated by the generosity and hospitality of the Community at Balgo Mission to whom our great debt is acknowledged.

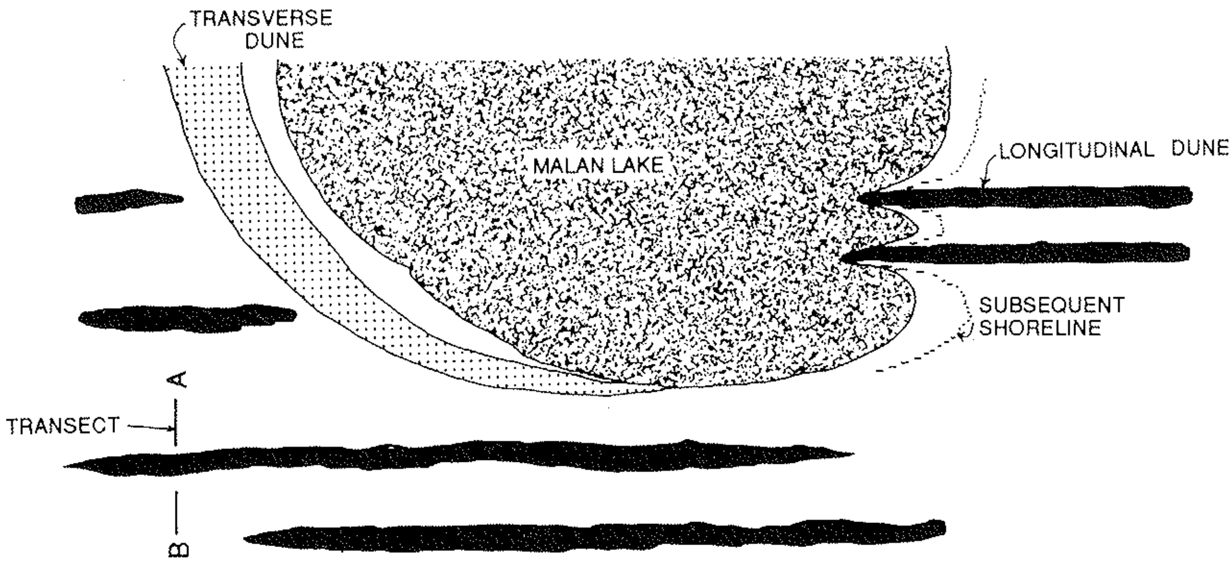

Figure 2.2a

Diagramatic relationships between the lake features such as those in the Malan basin, the transverse (western) lake-shore dune, and the west to east longitudinal dunes which on the south-eastern corner of the Malan Lake have transgressed across the lake floor. A later shoreline (dotted curve) has developed with inundation down the swales of the longitudinal dunes. This type of relationship allows us to establish a relative evolutionary sequence in which lake activity was followed by a drying phase when the east to west dunes transgressed across the dry lake floor; this was in turn followed by a return of water to the lakes with flooding of the earlier dune system.

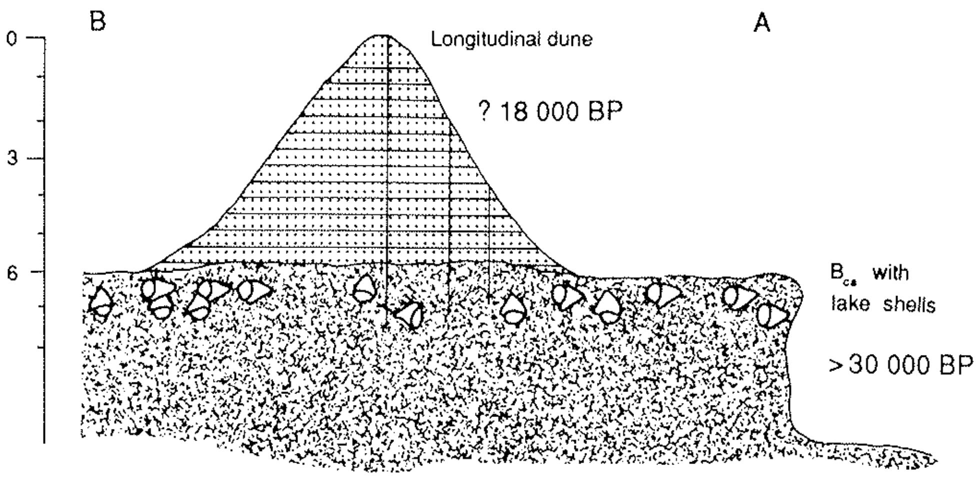

Figure 2.2b

A diagramatic north-south cross-section through a longitudinal dune (see Fig. 2.2a). The dunes have developed on a series of older lake deposits in which limnaeid shells are now cemented into a red calcareous soil. The soil horizon passes horizontally beneath the longitudinal dune emphasising that a substantial time period separates deposition of the lake sediments followed by soil formation and later dune building. By analogy with other areas, the longitudinal dunes are tentatively correlated with the last glacial maximum about 18 000 BP. Radiocarbon dates from the underlying carbonate and shell deposits establish the age of soil and lake sediments as being 30 000 BP.

Paper 3

The Flora of Lake Gregory

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INTRODUCTION

Lake Gregory is a well-known name among natural scientists and is the type locality for several plant species described by Ferdinand von Mueller. However, except for the early collections made for von Mueller and a survey in 1979 by the former Department of Fisheries and Wildlife (now Conservation and Land Management) (George and Mitchell 1983; McKenzie *et al.* 1983), no botanical work has been done at the lake.

This paper summarizes the very limited floristic information that exists and documents in a preliminary way the reduction in area of live trees over the past 40 years.

RIPARIAN VEGETATION

In 1979 Lake Gregory was almost dry and there was a wide (1 km at south-eastern part of Mulan Lake) band of samphire inside the lake margin, in which *Halosarcia halocnemoides tenuis* was dominant and *H. indica leiostachya, Cressa cretica, Eragrostis dielsii, Morgania floribunda, Sida rohlenae* and *Swainsonia* sp. also occurred (McKenzie *et al.* 1983). The same species were recorded in 1988.[1]

At the edge of the lake the samphire belt intergraded with a belt of 4-6 m high *Acacia* aff. *tephrina* trees. Beneath the trees the ground flora included *Eragrostis dielsii, H. halocnemoides tenuis, Salsola kali* and *Trianthema triquetra*. The *A.* aff. *tephrina* around Mulan Lake in 1979 appeared to be a regenerating stand; mature stands occurred around Bulbi Plain. Some tall dead *A.* aff. *tephrina* occurred in the samphire belt around Mulan Lake (McKenzie *et al.* 1983).

McKenzie *et al.* (1983) reported a transition to spinifex (mostly *Triodia pungens*) beyond the *A.* aff. *tephrina* belt. *Eucalyptus microtheca, A.* aff. *tephrina* and *Hakea ?suberea* trees occurred among the spinifex. Farther from the wetland there were low dunes that supported the spinifexes *Plectrachne schinzii* and *Triodia pungens* and a variety of grasses, herbs and shrubs.

The vegetation around Djaluwon Creek differed from that around the lake areas. It was much denser, especially away from Mulan Lake, and consisted of *E. camaldulensis, E. microtheca, A. holosericea* and *Grevillea striata* trees, *Melaleuca glomerulata* and *M. lasiandra* shrubs and the grasses *Eulalia fulva* and *Cenchrus ciliarus*. The sedge *Cyperus dactylotes* also grew on parts of the creek bank (McKenzie *et al.* 1983).

AQUATIC VEGETATION

There is no published information about the aquatic flora of Lake Gregory but visitors to the lake when water levels have been low have noticed a mat of dried aquatic vegetation on the ground and some *Myriophyllum* sp. was collected in March 1988.[2] Photographs of the lake suggest macrophytes would grow extensively at times and that species of *Ruppia* probably occur there. Photographs of the lake also show extensive algal blooms (probably *Cladophora* sp.) and it is likely that Characeae occur there.

VEGETATION CHANGE

Using aerial photography from 1953, 1971 and 1988 we attempted to map changes in the riparian vegetation around Mulan Lake and Lera Water-hole over the last 35 years (Figs 3.1-3). Comparison of the

1 S.A. Halse and G.B. Pearson, Department of Conservation and Land Management (unpublished data).

2 S.A. Halse and G.B. Pearson, Department of Conservation and Land Management (unpublished data).

extent of the tree belts around the lake is complicated by the different scales of the three sets of photography and the difficulty experienced delineating the boundary of the 'wetland' area. Nevertheless, there was an obvious reduction in extent of trees between 1953 and 1971 (cf. Figs 3.1 and 3.2). Because we included tree belts outside the wetland boundary in the 1988 assessment (Fig. 3.3), at first glance the extent of trees appears to have increased between 1971 and 1988. In fact, all the tree belts present *within the wetland boundary* on the eastern and north-western sides of the lake in 1971 had disappeared by 1988. There was also a reduction in the extent of trees on the western side of the lake, especially around Lera Water-hole.

Visitors to the lake in the last few years have confirmed the results of the analysis from aerial photographs: they have reported that the extensive thickets of trees around the south-eastern and north-western parts of Mulan Lake, the eastern side of Lera Water-hole and around Salt Pan Creek died as a result of 1982 floods and have not regenerated.

Although there is no unequivocal evidence it appears that cattle, and perhaps horse, grazing is the reason there has not been regeneration of trees from seedlings. The 1988 aerial photography shows extensive cattle tracks on the shore of the lake, which suggests that grazing pressure is intense.

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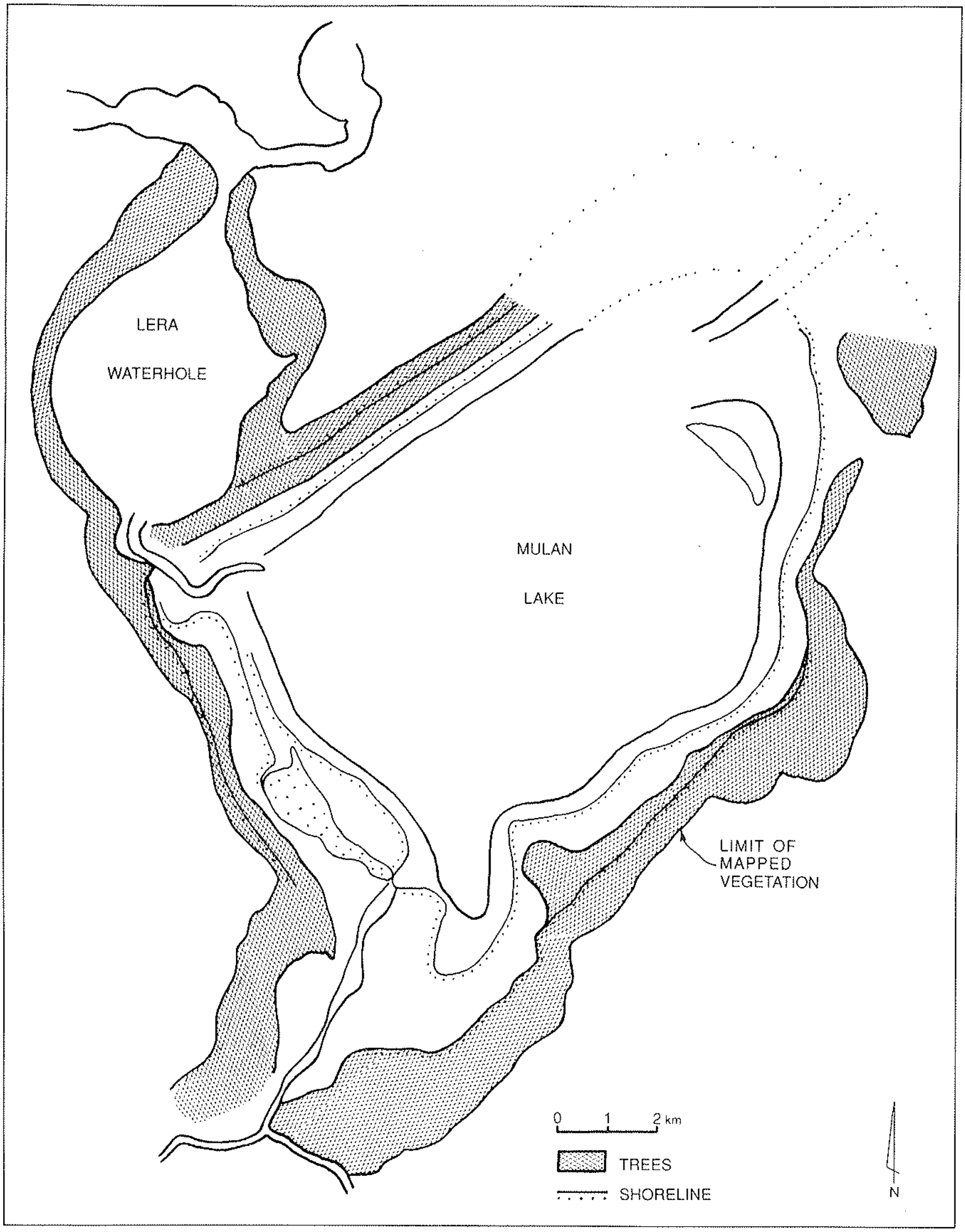

Figure 3.1

The extent of trees around Lake Gregory in 1953 (based on 1:50 000 aerial photographs). The lake was dry in 1953 but some obvious vegetated 'shore-lines' around the edge of the lake are marked.

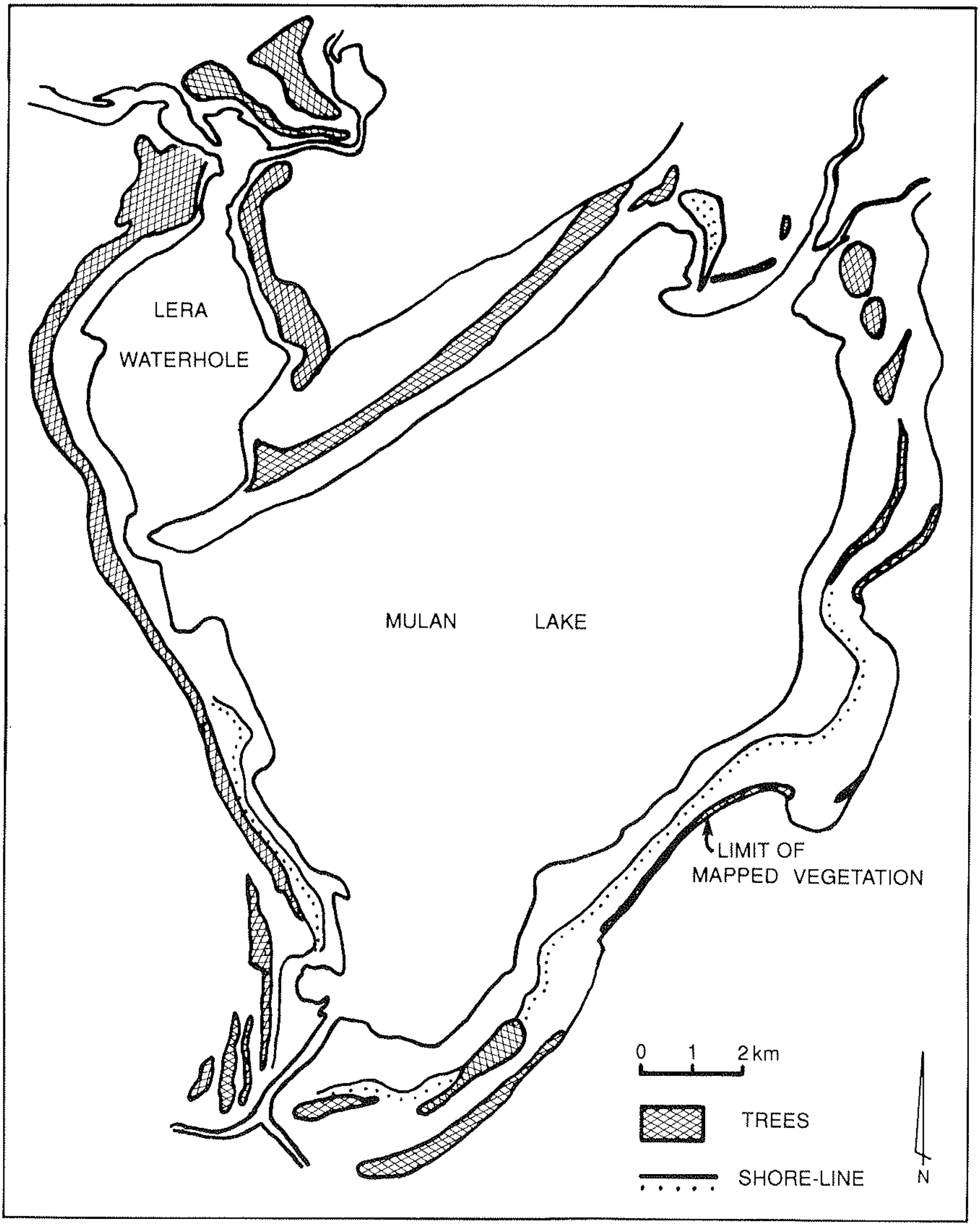

Figure 3.2

The extent of trees around Lake Gregory in 1971 (based on 1:86 100 aerial photographs). The inner line indicates the 1971 water level, some obvious 'shore-lines' outside this are also marked.

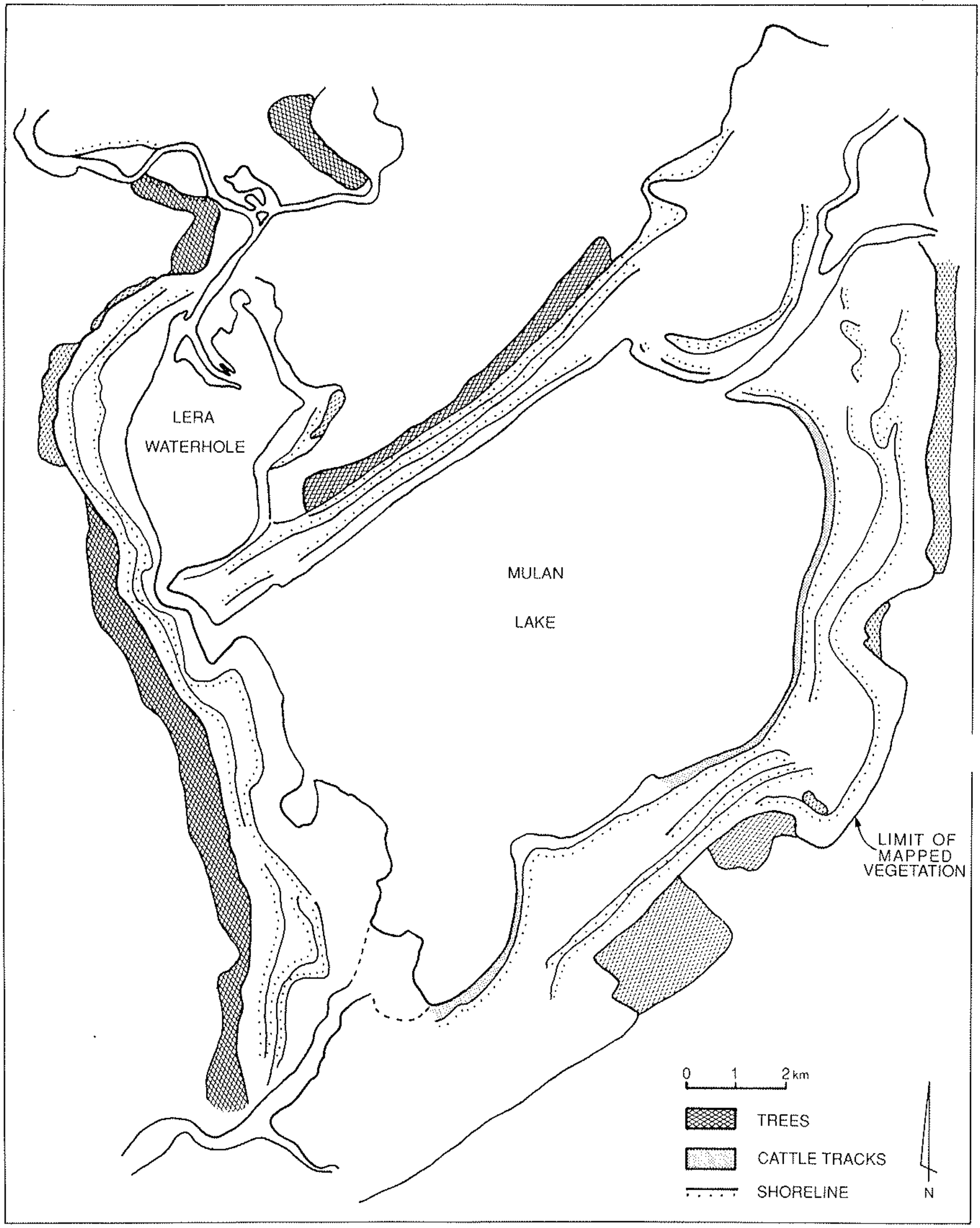

Figure 3.3

The extent of trees (including those beyond the wetland boundary) around Lake Gregory in 1988 (based on 1:25 000 aerial photographs). The inner line indicates the 1988 water level, some obvious 'shore-lines' and areas with extensive cattle tracks are also marked.

Paper 4

Lake Gregory: A Limnological Perspective on Proposed Research

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INTRODUCTION

Commonly held views concerning the biota, especially the fauna, of temporary bodies of fresh water are that their biological diversity is greatly reduced *vis-à-vis* that of permanent fresh waters, that the fauna is characterised above all by taxa of the Branchiopoda (Notostraca, Anostraca and Conchostraca), and that all species, because they need to be resistant to desiccation, are widely dispersed (since the resistant stage is usually the egg stage, it is small and therefore easily dispersed) and, consequently, have large gene pools.

Increasingly, it is becoming clear that these views do not coincide closely with reality. It appears that they represent more a set of preconceptions based on some few studies in the northern temperate region than observations based on actual studies of temporary fresh waters outside the northern temperate region.

Studies of temporary fresh waters in Australia are now showing that in many such waters biological diversity (richness) is extremely high; it is certainly higher than expected and often much higher than in nearby permanent bodies of water. Further, rigorous taxonomic investigations are beginning to reveal considerable regional endemicity: the taxa of temporary waters are not widespread with large gene pools - selection has been for local adaptation. Indeed, many features formerly thought to be devices to ensure good dispersal may be devices to prevent dispersal. The hooks on the ephippia of certain Cladocera are a case in point; rather than being a means of promoting dispersal (by catching on to the feet of birds) they are a means of preventing it (they catch on to the substratum). Finally, the fauna of many temporary fresh waters is not characterised by species of Notostraca, Anostraca and Conchostraca: these groups occur, if they do, only in the early part of the season before the appearance of predators (beetles, tadpoles, dragonfly nymphs). The characteristic fauna of temporary waters is similar to that of permanent waters: it comprises Cladocera, Copepoda and Rotifera among the zooplankton, and, *inter alia*, Hemiptera, Diptera, Coleoptera and Trichoptera among the zoobenthos.

The generally accepted view of evolutionary relationships between the fauna of temporary fresh waters and permanent fresh waters is that the former is a subset of the latter. That is, those elements of the fauna of permanent fresh waters able to withstand desiccation and with good dispersal mechanisms colonized temporary fresh waters. My view is that evolution largely proceeded in the reverse direction: the fauna of permanent fresh waters is a subset of that present in temporary fresh waters. A more complete exposition of this view is given in Williams (1988).

SIGNIFICANCE OF LAKE GREGORY

This rather lengthy introduction to a consideration of the limnological significance of Lake Gregory needs little explanation given that Lake Gregory is a large temporary body of water in a part of Australia where such bodies of water have been little studied. However, its significance goes beyond a simple regional extension of our knowledge. It has added significance because Lake Gregory is situated in an area of Australia where rainfall variability is not excessively high (that is, the lake is predictably filled), and where rain falls in summer (i.e. the warm season). In southern Australia temporary bodies of water mostly contain water in the winter (cool) season.

These two facts are considered important because of recently proposed ideas concerning the evolution of the fauna of Australian salt lakes, ideas which are probably equally applicable to the fauna of temporary fresh waters in Australia (Williams 1984).

In brief, it is suggested that past climatic changes have been a major evolutionary force during speciation in the fauna of temporary fresh (and salt) waters. The suggestion involves several hypotheses:

(1) That the fauna of temporary inland waters evolved only in predictably-filled localities. Localities which fill episodically contain only easily dispersed species.

(2) That single environmental factors (such as salinity in the case of salt lakes) are not important *per se*; it is the temporal combination of environmental factors which is important (such as salinity, temperature and rainfall pattern).

(3) As climate changed in Australia, so areas of predictably-filled temporary waters moved as a consequence, with their assemblages of biota being subjected to different patterns of climate: in the north they were subjected to warm, wet summers and in the south to cold, wet winters. Such fundamentally different climatic patterns would have caused adaptive changes, and these could easily come to have a genetic basis given the discrete nature of many temporary water-bodies and the poor dispersal powers of the fauna. In other words, exposure to selectively different environmental factors under conditions of geographical isolation led to speciation.

Under this scenario, the present major distributional areas of temporary water in Western Australia can be envisaged as:

(1) A northern area including part of the Kimberley and the regions immediately to the south (this area includes the Lake Gregory system). These water-bodies are predictably filled and contain water mostly in summer.

(2) A central area where water-bodies are episodically filled.

(3) A south-western area where water-bodies are again predictably filled but contain water mostly in winter.

Of these areas, only (3) has been studied to any degree, and most of the localities that have been investigated are saline.

Water-bodies of the central area (2) are amenable to study only with difficulty. Apart from their isolation, and therefore inaccessibility, study of them must follow unpredictable events - and for this reason alone is difficult, given the present nature of grant support. It is not surprising that very little is known about their biology. Presumably, waters in this area will prove to have a fauna in general character not dissimilar to that in Lake Eyre, as recently studied by Williams and Kokkinn (1988), i.e. it will comprise widely distributed forms having good dispersal mechanisms.

Within the present context, of course, it is area (1) that is of greatest interest, for it is here that Lake Gregory lies. Its fauna seems most likely to be one of two possible sorts. It could consist of an entirely new set of northern endemics, which evolved under conditions of predictably wet summers, and which have been able to withstand the vagaries of past climatic change (and thus extinction during periods of aridity when perhaps, unlike the south, few refugia existed). Or it could consist of a subset, or the whole of the fauna, presently also found in the second area which in the absence of a persistent local endemic assemblage has colonized the otherwise 'evolutionarily' empty niches.

Thus an investigation of the fauna of lakes in the northern areas of Western Australia, wherein Lake Gregory lies, will be of much interest to a variety of biologists. It will be of interest to taxonomists for whom there will be species either locally endemic or representative of the easily dispersed, widespread but little investigated fauna of episodically filled waters of central Australia. It will be of interest to ecologists concerned with temporary waters; for these biologists, interest will focus on the 'reversed' seasonal patterns of inundation and growth. And it will be of interest to biogeographers, for it has the potential to provide significant evidence concerning the evolution of the fauna of Australia's temporary bodies of water.

Even a single collecting trip when the lake is full should provide a great deal of data to illuminate much of the speculation outlined above.

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Paper 5

Waterbirds at Lake Gregory: Available Data and Information Required

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ANECEDOTAL ACCOUNTS

There is little information available about waterbirds at Lake Gregory prior to 1977. Nevertheless, some of the early European explorers were most impressed by the abundance of waterbirds and Carnegie (1898, p. 371) who camped there in April 1886 wrote 'The lakes and creek abound in wildfowl of all kinds...so dense was the crowd of shags, pelicans, snipe, small gulls, whistling duck, teal and other birds, that to say there was acre upon acre of wildfowl would not be wide of the mark...'. The lake was slightly brackish at the time.

Among more recent visitors Dr P.E. Playford commented that in July 1973 'The bird life is spectacular, with flocks of hundreds of pelicans and numerous Black Swans, ducks and other waterbirds'.[1] Wildlife Officer L. Campbell visited the lake in August 1975 and reported that there were 'huge' numbers of Brolgas and Pacific Black Ducks, 'plentiful' Australian Pelicans and Black Swans, and that Pink-eared Ducks were present among 'many different' species of waterbird.[1]

WATERBIRD SURVEYS

The first detailed survey of waterbirds at Lake Gregory was undertaken by Smith and Johnstone (1978), who spent 6-7 November 1977 there and traversed 13 km of the eastern shoreline of Mulan Lake between Salt Pan Creek and Lens Bore. The lake was approximately half-full and Smith and Johnstone recorded about 10 900 birds comprising 26 species (Table 5.1). The approximate length of the shoreline of Mulan Lake and Lera Water-hole is 70 km and, if birds were evenly distributed around the shore of the lake, Smith and Johnstone's count suggests the total number of waterbirds was around 50 000 (Table 5.1). Bulbi Plain, which has a shoreline of approximately 16 km, may also have contained water and, therefore, additional birds. One species was recorded breeding during Smith and Johnstone's survey (Table 5.2).

The lake system was surveyed again from 23-28 April 1979 when the water level was very low (Start and Fuller 1983). Survey effort was concentrated around Sturt and Djaluwon Creeks and only 69 birds were recorded on the Mulan Lake and a total of 19 species in the lake and creeks (Table 5.1).

There was a substantial inflow in summer of 1979/80 and the lake system was approximately two-thirds full when 20 km along the western shore of Bulbi Plain and eastern shore of Mulan Lake was surveyed between 30 May - 4 June 1980. Approximately 34 000 birds of 26 species were counted (Start and Fuller 1983) and, on the basis of the proportion of shoreline traversed, probably 100 000 birds were present (Table 5.1).

In 1982 the Lake Gregory system flooded into the surrounding desert after heavy rains in the catchment (McKenzie *et al.* 1983). The lake was visited between 10-15 May 1983 by J.B. Paton and others when still extensively flooded, although tide-marks on trees within Mulan Lake suggested it was about 1.2 m below the maximum flood level. The low dunes around the lake were still inundated. In contrast, during surveys by Smith and Johnstone (1978) and Start and Fuller (1983), the shoreline comprised only mudflats without any inundated trees. Only small parts of Mulan Lake and Lera Water-hole were surveyed by Paton and about 2000 birds of 28 species were recorded (Table 5.1). Five species were recorded breeding (Table 5.2).

1 Department of Conservation and Land Management file on Lake Gregory.

Between 26-29 August 1986 Lake Gregory was surveyed by a group from the Royal Australasian Ornithologists Union (RAOU). The system was full, being flooded beyond its mapped boundary, and many of the dead trees fringing the lake (killed by earlier flooding) were still inundated. The main survey was preceded by an aerial survey in May; in August virtually all the lake complex was covered (Jaensch and Vervest 1990). Almost 240 000 waterbirds of 57 species were counted (Table 5.1). Five species were recorded breeding (Table 5.2).

There was no inflow of water into Lake Gregory in the summers of 1986/87 and 1987/88 so that it was only one-third full when surveyed between 30-31 March 1988 by S.A. Halse and G.B. Pearson. The northern and eastern shorelines of Mulan Lake and Lera Water-hole were traversed from Sesbania Creek to Lens Bore, a distance of almost 40 km. Thirty-two species were recorded in the lake itself and adjacent parts of Sturt Creek and, by extrapolating the numbers seen of the more common species, it was calculated that the Lake Gregory system contained approximately 600 000 waterbirds (Table 5.1). The birds were most dense in Lera Water-hole.

Halse and Pearson's estimate of the number of birds on the Lake Gregory complex represents one of the highest waterbird 'counts' in Australia. Although they are confident of the order of magnitude of their estimate, there is a need for more detailed surveys to provide exact numbers. In an attempt to do this the RAOU visited the lake between 11-12 May 1988, six weeks after Halse and Pearson, made an aerial survey and also covered most of the lake on the ground (Jaensch and Vervest 1989). In contrast to six weeks previously, only 75 000 birds were counted. Thirty-six species were recorded (Table 5.1).

Altogether 59 species of waterbird have been recorded at Lake Gregory in the seven surveys since 1977 that are reported here (Table 5.1). Eight species have been observed breeding (Table 5.2).

MAJOR SPECIES

Very high numbers of some species have been recorded at Lake Gregory (Table 5.1). Of special interest are Pink-eared Ducks. By extrapolating their count to the whole lake (allowing for the fact that densities were higher in Lera Water-hole than elsewhere) Halse and Pearson estimated 150 000 - 200 000 Pink-eared Ducks were present in March 1988. This is a much higher number than recorded anywhere else in Australia. To put it in context, surveys of 20-30 estuaries and 200-350 lakes and swamps in south-western Australia each March between 1986-88 recorded only about 2200, 7900 and 6100 Pink-eared Ducks, respectively (Jaensch and Vervest 1988 a, b). Surveys of approximately 12 per cent of the land area of eastern Australia each October between 1983-87 recorded a maximum of 121 000 and a minimum of 17 000 Pink-eared Ducks (Braithwaite *et al.* 1985 a, b, 1986, 1987; Kingsford *et al.* 1988).

Similarly, very large numbers of Grey Teal (~150 000) Eurasian Coots (~100 000) and Hardheads (~60 000) were estimated to be present in March 1988 (similar numbers of Eurasian Coots were recorded in 1986) that far exceeded numbers counted in the annual waterfowl counts in south-western Australia (Jaensh and Vervest 1988 a, b). The count of Hardheads was of special Western Australian relevance; annual counts of this species in the south-west between 1986-88 were 433, 747 and 1351, respectively. About 51 000 Hardheads were recorded in Lake Argyle in August 1986 (Jaensch and Vervest 1989).

The estimate of 50 000 Pacific Black Ducks in March 1988 is as high as has been recorded anywhere in northern Australia; the highest count from Lake Argyle is 16 000 in November 1979 (Gowland 1983) and only about 50 000 Pacific Black Duck were counted in Lake Gallilee in Queensland in October 1984 when it contained over 1 000 000 waterbirds (Braithwaite *et al.* 1985b).

Although the 5000 - 10 000 Maned Duck estimated to be present in March 1988 is not high in terms of the numbers that occur in a region, such a large aggregation does not occur elsewhere in Western Australia.

Numbers of Little Black Cormorants at Lake Gregory were very high (~60 000) in both 1986 and 1988; these are possibly the highest counts for the species at one locality in Australia (see Jaensch and Vervest 1989). Numbers counted in the annual surveys in south-eastern Australia varied between 4000 and 24 000 (Braithwaite *et al.* 1985 a, b, 1986, 1987; Kingsford *et al.* 1988).

Masked Lapwings are confined to the northern part of Western Australia although the species is widespread in eastern Australia. Halse and Pearson estimated that 10 000 were present in March 1988 which represents a significant concentration of this widespread bird. Similarly, 10 000 - 15 000 Sharp-tailed Sandpipers were estimated to be present in March 1988, which represents a significant concentration of the species although larger numbers have been recorded previously at Anna Plains and in eastern Australia (Blakers *et al.* 1984).

The count of 898 Freckled Ducks made in August 1986, although not high in absolute terms, is the largest concentration of this species recorded in Western Australia. Freckled Ducks are gazetted 'rare and endangered' under the Western Australian Wildlife Conservation Act.

SIGNIFICANCE FOR WATERBIRDS

Number of waterbirds

The number of waterbirds estimated to be present at Lake Gregory in March 1988 places it among the most important wetlands in Australia in terms of maximum number of birds counted and makes it easily the most important Western Australian wetland. The only Australian lake from which a higher count has been published is Lake Gallilee, in which more than 1 000 000 birds were counted in 1984; although similar numbers probably occur in nearby Lake Buchanan (Braithwaite *et al.* 1987). The surveys of Lake Gregory are too few and incomplete to gauge how many birds it usually supports but it would appear from Table 5.1 that the lake often contains more than 100 000 birds, which probably makes it the most important inland wetland in Australia in terms of regularly supporting high numbers of birds. Some coastal sites (e.g. the Coorong in South Australia and Eighty-mile Beach in Western Australia) support more birds but these are predominantly waders whereas Lake Gregory supports mostly ducks, coots and cormorants.

The origin of the birds in Lake Gregory in March 1988 (and August 1986) is unclear. However, waterbird counts in eastern Australia in October 1987 were extremely low (Kingsford *et al.* 1988), which suggests the possibility that some birds may have moved westwards from eastern Australia into the Northern Territory and Kimberley. Conditions were dry in the Kimberley during the summer of 1987/88 and Lake Gregory (perhaps together with Lake Argyle) may have supported a large proportion of the birds in the region. After heavy rains in the Kimberley and north-western Australia the birds dispersed and only moderate numbers remained at Lake Gregory by May 1988 (Table 5.1). If this speculative scenario is correct Lake Gregory has a very important, albeit sporadic, role in waterbird conservation at a national level. There is no doubt that waterbirds move long distances in response to rainfall or other factors; Frith (1962) showed that Grey Teal banded in the Northern Territory during a drought in eastern Australia subsequently moved extensively into eastern Australia, the Kimberley and south-western Australia. Recoveries in northern Australia of Grey Teal and Pacific Black Duck banded in the south-west show that the reverse movement also occurs.[2]

The significance of Lake Gregory as a dry season refuge for birds in the Kimberley is unclear without more detailed waterbird counts at Lake Gregory and in the Kimberley and a better understanding of the Australia-wide movements of waterbirds. However, the fairly consistently high numbers of birds recorded during winter suggests that it may have an important, regular role in this respect. Its role as an Australia-wide refuge, if it exists, is probably secondary to the regional role.

The large number of Sharp-tailed Sandpipers at the Lake in March 1988 was probably a pre-migratory concentration and in years when water levels are suitable Lake Gregory may be used extensively by the less marine wader species on their return migration to the northern hemisphere.

Breeding

It is not clear at which time of the year most breeding occurs at Lake Gregory but it probably has a Kimberley pattern because that is where the catchment area of the lake lies. Most breeding in the Kimberley occurs during January - March (Slater 1959; Halse and Jaensch 1989). Lake Gregory has already been shown to be an important breeding site for Little Black Cormorants and Caspian Terns (Table 5.2; see Jaensch and Vervest 1990). It is possible that Lake Gregory is a recruitment area for Little Black Cormorants, Caspian Terns and some other species, with birds born at the lake subsequently dispersing to other parts of Australia. A significant number of Pied Cormorants bred there in 1986 and several other species have been recorded breeding.

However, information about breeding is incomplete and is virtually limited to the results of winter surveys. Additional surveys during the presumptive breeding season during a year when the lake contains plenty of water are required to determine fully the importance of Lake Gregory and the anastomosing channels of Sturt Creek as breeding areas for waterbirds.

HOW DOES THE LAKE FUNCTION?

The speculation above about the significance of Lake Gregory at a regional and national level must be

2 S.A. Halse, D.A. Diepeveen and D.R. Munro (in prep.). Recoveries of Grey Teal and Pacific Black Ducks in south-western Australia 1952-76.

tempered with the recognition that the lake shows considerable year-to-year variation in depth that constrains its waterbird carrying capacity. The surveys since 1977 suggest that carrying capacity drops substantially when the lake is nearly dry or flooded into the surrounding sand dunes. Presumably extensive flooding makes most of the lake shoreline too deep for birds to get access to food. At intermediate depths the carrying capacity of the lake appears to be in the order of 100 000s of birds.

There is not enough information to deduce fully the seasonal pattern of waterbird abundance at intermediate depths although, as mentioned above, it can reasonably be assumed that numbers are maximal in winter. In the wet season many species probably disperse to breed on flood-plains to the north unless it is a dry year (e.g. 1988). However, at least some piscivorous species remain at the lake to breed when conditions are suitable (Table 5.2; Jaensch and Vervest 1990) and it is possible that some species of ducks and other birds also breed there or on Sturt Creek in significant numbers (see above).

The extent of breeding is undoubtedly dependent on water depth. Most of the species that occur at the lake are tree-nesting and are only likely to breed when the fringing trees are flooded. Some species probably require live trees in which to nest, although for cormorants dead trees are usually adequate. Ground-nesting species, such as terns and small waders, probably nest most frequently on the shallow lakes (Bulbi, Yuinby and Guda Plains) in the western part of the system. These contain water only when water levels are fairly high.

The food sources used by birds at Lake Gregory are not known but there are a lot of piscivorous birds (pelicans, cormorants, Darter) and the lake contains a lot of fish (Carnegie 1898, p.371).[3] Presumably other birds at the lake mostly feed on macrophytes, algae and aquatic invertebrates although more terrestrial species, such as Brolgas and ibises, would feed on terrestrial invertebrates and small vertebrates around the lake.

INFORMATION REQUIRED

On the basis of the information summarized above, there appear to be four areas in which more information is required and a series of questions, some of which overlap, can be posed within these areas.

Number of waterbirds

(1) When water levels are intermediate and the carrying capacity of the lake is high, what external factors determine the number of birds at Lake Gregory? There are probably two sets of factors operating: firstly, wetland conditions elsewhere in Australia and the Australia-wide movement of waterbirds; and secondly, seasonal conditions in the Kimberley region. Aerial surveys of waterbirds in the Kimberley in conjunction with the annual surveys in eastern and south-western Australia would show the relative importance of each set of factors in a given year and would provide data on the effect of wetland conditions at Lake Gregory and elsewhere in the Kimberley on waterbird numbers in Lake Gregory.

(2) Where do the waterbirds seen in these large concentrations at Lake Gregory come from and go to? A colour-marking program would answer this question.

Carrying capacity

(3) What do birds feed upon at the lake, when and why does food availability limit numbers? Studies of diet, feeding behaviour, body weight (or condition) and construction of energy budgets, together with measurements of the biomass of different foods and their distribution in the lake, would be required to answer this question.

(4) Are bird numbers at the lake limited by factors other than food (e.g. roosting habitat)? The behavioural studies required to answer question (3) would give some indications of the answer to this question.

Breeding

(5) How many species breed at the lake when conditions are favourable? Regular visits to the lake during the likely breeding season during several years with varying water depths would be required to answer this fully.

(6) What are the breeding requirements of the species that breed in significant numbers in Lake Gregory? This question could be answered by fairly simple studies, both in Lake Gregory and elsewhere, of breeding success and habitat use by the relevant species.

3 J.B. Paton, an amateur ornithologist from South Australia, also recorded that fish were abundant in 1983 (personal communication).

Management

(7) How is the current management of the lake affecting its value as a site of significant waterbird aggregation and breeding? The studies outlined under **Carrying capacity** and **Breeding** would provide most of the answers required here.

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Table 5.1
Waterbirds Recorded at Lake Gregory

	Nov 1977[a]	Apr 1979[b]	May/ June 1980[b]	May 1983[c]	Aug 1986[d]	Mar 1988[e]	May 1988[d]
LAKE CONDITIONS							
Approximate condition	half full	almost dry	two-thirds full	full	full	third full	third full
Depth (m)					6.5		>3
Salinity (ppt TDS)				fresh	1.4	~ 6.0	~ 6.0
pH						~ 8.7	~ 9.1
SPECIES							
Great Crested Grebe *Podiceps cristatus*					842	+	77
Hoary-headed Grebe *Poliocephalus poliocephalus*		2			5	+	47
Australasian Grebe *Tachybaptus novaehollandiae*	14		1		108		
Australian Pelican *Pelecanus conspicillatus*	420		>6000	~ 40	3097	5000-6000†	824
Darter *Anhinga melanogaster*	30		1	~ 30	854	~ 5000	684
Great Cormorant *Phalacrocorax carbo*					4		
Pied Cormorant *Phalacrocorax varius*				~ 50	2230	~ 1000†	1340
Little Black Cormorant *Phalacrocorax sulcirostris*	330			common	59 982	50 000-60 000†	15 480
Little Pied Cormorant *Phalacrocorax melanoleucos*				mod common	589		10
Pacific Heron *Ardea pacifica*	2	4	79		18		
White-faced Heron *Ardea novaehollandiae*		*	12	3	1		
Great Egret *Egretta alba*	25		16	20+	355	+	35
Little Egret *Egretta garzetta*					5		

Table 5.1 *(continued)*

	Nov 1977[a]	Apr 1979[b]	May/ June 1980[b]	May 1983[c]	Aug 1986[d]	Mar 1988[e]	May 1988[d]
Intermediate Egret *Egretta intermedia*				1	8		
Rufous Night Heron *Nycticorax caledonicus*				30+	27		
Black-necked Stork *Xenorhynchus asiaticus*	1				3		
Glossy Ibis *Plegadis falcinellus*				~4	64		
Sacred Ibis *Threskiornis aethiopica*					26	+	2
Straw-necked Ibis *Theskiornis spinicollis*			3	4+	255	+	56
Royal Spoonbill *Platalea regia*	2		1	~40+	62	+	16
Yellow-billed Spoonbill *Platalea flavipes*			7	3	20	*	2
Magpie Goose *Anseranas semipalmata*					135		3
Wandering Whistling-Duck *Dendrocygna arcuata*					1570		
Plumed Whistling-Duck *Dendrocygna eytoni*				150	13 150	+	1750
Black Swan *Cygnus atratus*	400	*	18	~30	5775	~5000	4027
Freckled Duck *Stictonetta naevosa*					898		52
Australian Shelduck *Tadorna tadornoides*		*			4		
Pacific Black Duck *Anas superciliosa*	200	*		~10	277	~50 000	1198
Grey Teal *Anas gibberifrons*	3500	*	>25 000	~12	11 133	~150 000	21 015
Pink-eared Duck *Malacorhynchus membranaceus*		*	50	~60	33 849	150 000-200 000	9423
Hardhead *Aythya australis*	6		6	~12	16 037	~60 000	9936

Table 5.1 *(continued)*

	Nov 1977[a]	Apr 1979[b]	May/ June 1980[b]	May 1983[c]	Aug 1986[d]	Mar 1988[e]	May 1988[d]
Maned Duck *Chenonetta jubata*			4	12+	353	5000 -10 000	105
Marsh Harrier *Circus aeruginosus*			*		2		4
Black-tailed Native-hen *ventralis*					39	+	
Purple Swamphen *Porphyrio porphyrio*					2		
Eurasian Coot *Fulica atra*	5000	2		mod common	74 258	~100 000	3407
Brolga *Grus rubicundus*	570	~50	~100	2	3530	+	499
Masked Lapwing *Vanellus miles*	20			2	215	~10 000	8
Red-kneed Dotterel *Erythrogonys cinctus*			5		73		
Oriental Plover *Charadrius veredus*	90					+	
Red-capped Plover *Charadrius ruficapillus*	+		250		515	+	116
Black-fronted Plover *Charadrius melanops*	6		>10	few	20		
Black-winged Stilt *Himantopus himantopus*		1	1		611	+	18
Banded Stilt *Cladorhynchus leucocephalus*	34						9
Red-necked Avocet *Recurvirostra novaehollandiae*		3	25		204		174
Wood Sandpiper *Tringa glareola*	8				19		
Common Sandpiper *Tringa hypoleucos*		3			3		
Greenshank *Tringa nebularia*	4	1			4		
Marsh Sandpiper *Tringa stagnatilis*					46		

Table 5.1 *(continued)*

	Nov 1977a	Apr 1979b	May/ June 1980b	May 1983c	Aug 1986d	Mar 1988e	May 1988d
Bar-tailed Godwit *Limosa lapponica*					1		
Sharp-tailed Sandpiper *Calidris acuminata*	36				1442	10 000-15 000	10
Red-necked Stint *Calidris ruficollis*		3	1		337		100
Long-toed Stint *Calidris subminuta*					3		
Curlew Sandpiper *Calidris ferruginea*					359	+	10
Australian Pratincole *Stiltia isabella*	35				295	+	16
Silver Gull *Larus novaehollandiae*		*	~70	few	89	+	486
Whiskered Tern *Chlidonias hybrida*	70	*	2000	mod common	1996	+	1795
Gull-billed Tern *Gelochelidon nilotica*	56	*	9	2	82	+	
Caspian Tern *Hydroprogne caspia*	20	*	62	15+	1560	+	760
No. of Species	26	19	26	28	57	32	36
No. of Birds Counted	>10 879	69	>33 731	?2000	239 666	-	75 524
Estimated No. of Birds	50 000	<1000	100 000	?	239 666	600 000	75 524

+ present but numbers not recorded
* present in Sturt Creek just north of lake
[a] Smith and Johnstone (1978)
[b] Start and Fuller (1983)
[c] J.B. Paton (unpublished data)
[d] Jaensch and Vervest (1989)
[e] S.A. Halse and G.B. Pearson (unpublished data) - figures for individual species are extrapolated for the whole system based on approximate numbers per kilometre at various parts of the traverse unless marked with † when they represent numbers of birds seen.

Table 5.2
Waterbirds Recorded Breeding at Lake Gregory

Species	Nov 1977[a]	May 1983[b]	Aug 1986[c]
Darter		several, 1 nest with young	
Pied Cormorant		11 nests with young	1000 active nests
Little Black Cormorant		50 nests with eggs/young	8000 active nests
Little Pied Cormorant			10 active nests
Rufous Night Heron		2 nests with young	
Black Swan	2 broods, 1 nest with eggs	5 nests with eggs	
Red-capped Plover			+
Caspian Tern			500 active nests

+ no details given
[a] Smith and Johnstone (1978)
[b] J.B. Paton (unpublished data)
[c] Jaensch and Vervest (1989)

Paper 6

Management of Lake Gregory

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BACKGROUND

Lake Gregory and part of the Sturt Creek system near the lake are included within the Lake Gregory Pastoral Lease, which is held by the Aboriginal Land Trust for the Mulan Aboriginal Community. Management of the lake is ultimately the perogative of the Mulan community but, because the Department of Conservation and Land Management regards Lake Gregory as one of the most important conservation areas in Western Australia, the Department would like the opportunity to influence management practices at the lake.

My original involvement with the Lake Gregory area was as an officer of the former Forests Department. One of our programs involved encouraging Aboriginal communities to plant trees around their settlements. Many seedlings were distributed to both the Lake Gregory (Mulan) and nearby Billiluna communities. Species concentrated on were hardy natives and some exotic fruit trees.

WATER LEVELS

At that time (1981) the level of the lake was not particularly high. The water level rose dramatically in the 1982/83 wet season and appeared to reach its highest level for many years. There is evidence from the vegetation, particularly bands of *Eucalyptus microtheca* beyond the 1982/83 flood level, that previously levels may have been even higher. However, this was probably many years ago. Many *Eucalyptus camaldulensis* along the creeks near the lake, some of which were about 20 years old, were killed during the 1982/83 flood by long inundation (? 18 months). It is unlikely that they had been inundated for long periods previously, suggesting it was at least 20 years since the lake previously flooded to this level. Some *E. microtheca* lower in the lake profile died as a result of earlier, less extensive flooding. These tree deaths show the extreme variability in water levels that occur around the lake. This variability and its timing is the single most important environmental factor to be taken into account when management of the area is considered.

@BODY1IND = I hope that we can get some idea of actual dates, levels and periodicity of previous flood events to give us some idea of the kind of lake system we, the Mulan community and the Department of Conservation and Land Management, will be trying to conserve. It would be even better to get a prediction of future levels.

VEGETATION

Tree species around the lake include *E. microtheca* and *Acacia* aff. *tephrina*, which grows (or grew) in quite extensive stands. Both species were common before the flood of 1982/83 but all *A.* aff. *tephrina* and those *E. microtheca* that were near the lake were killed at this time.

Acacia aff. *tephrina* (live and dead trees) were used extensively for waterbird nesting while inundated after the 1982/83 flood but there has been no regeneration, which brings me to cattle.

CATTLE

My recollection of 1981 is that cattle occurred around the margin of the lake but not in very high numbers. However, they appeared to increase dramatically after the flooding of 1982/83. This was largely a result of concentration as the lake expanded and the area of 'lakeside' habitat was reduced (a mini 'Operation Noah' to rescue cattle stranded on the islands created by rising floodwaters around the lake was put into place during this flooding) and also increased breeding as the result of the favourable conditions.

Few cattle have been mustered for sale and little effective cattle management appears to have been carried out on the pastoral lease in recent years. Estimates of stock on the station for the 1987 year were around 12 000 units. A fairly high proportion of these would have been around the lake. The cattle eat the vegetation around the lake margins and have even been observed feeding on vegetation of some kind in chest-deep water. Regeneration of shrubs and trees after the 1982/83 flood was minimal as a result of cattle grazing. Seeds germinated following rainfall events, only for the small plants to be eaten.

MANAGEMENT

Options for management of the area for conservation purposes appear to revolve around excluding cattle from the lake margins in at least some areas. This is also a desirable aim from the cattle management point of view and is an outcome desired by at least some of the traditional owners of the area. I have spoken to the Lake Gregory Pastoral Lease's pastoral advisor who indicated that he is planning to erect block fences and water points away from the lake to spread the cattle load over more of the property rather than concentrating it around the lake. He was interested in my suggestion that additional block fences should be erected that extend into the lake to exclude cattle from at least some of the major creek entrances. He is seeking the support of the Department of Conservation and Land Management and other relevant authorities for this project.

Preliminary approaches have been made to the Department of Primary Industry and Energy in Canberra who feel that the project could fall into their funding guidelines. I have sought advice from the Department of Agriculture to establish guidelines for fencing that will hopefully accommodate stock management as well as conservation needs.

Paper 7

Summary of Papers Presented and General Discussion

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The overwhelming impression from the previous papers is of the importance of Lake Gregory both as a conservation area for birds, and perhaps aquatic invertebrates, and as a site in which to study climatic history. However, in spite of its importance there has been little biological or geological work at the lake so that much of what has been said in the previous papers is speculative.

SPECIAL FEATURES OF LAKE GREGORY

It has become apparent during the workshop that Lake Gregory possesses a number of unusual features. Some of these are listed below.

(1) Birds - The lake supports some of the largest concentrations of waterbirds of any Australian wetland and, on a regular basis, contains the highest number of waterbirds of any wetland other than some coastal wader sites. It is an important refuge for ducks, coots and fish-eating birds.

The lake is an important breeding area for fish-eating birds and it is possible that the lake and the many anastomosing channels of Sturt Creek constitute an important breeding area for ducks.

(2) Productivity - The lake is a highly productive system, as attested by the very large numbers of birds it supports, the extensive algal mats that develop and anecodotal accounts of the lake teeming with invertebrates.

(3) Inflow of water - One of the reasons for the high productivity of the lake is that water inflow occurs in summer when temperatures are high. Even during winter daytime temperatures are comparatively high. The lake contains water almost permanently; 1979 is the only year during the past 20 the lake is known to have dried and even then the lake mud did not dry out. There is probably some inflow most years and substantial inflow every few years.

(4) Closed system - The lake is on the Mandora Palaeoriver. The westward part of the system became filled in during the Late Tertiary so that Sturt Creek (the headwaters of this ancient system) now empties into Lake Gregory, which has no surface outflow although there is some leakage into the underlying groundwater and loss of groundwater westward along the palaeoriver channel. Lake Gregory is the best example of a closed drainage system in Australia.

(5) Salinity - Although the lake was originally named 'Gregory Salt Sea' and 'Gregory Salt Lake' these were misnomers; the lake varies from fresh to brackish depending on the amount of water it contains. There has not been the long-term build-up of salt expected in such an old closed system because of leakage.

(6) Water chemistry - As in most Australian wetlands, the water at Lake Gregory is dominated by sodium chloride but the water chemistry is unusual in that there is a surplus of sodium, which forms various salts (e.g. Na_2CO_3, Na_2SO_4). The surplus sodium, in conjunction with the high photosynthetic activity, results in the lake having water of high pH. Silica levels in the water are very high, which suggests that the lake supports large populations of diatoms.

(7) Invertebrate fauna - The lake may contain an aquatic invertebrate fauna that is largely restricted to the Kimberley area and which contains specialisations to adapt it to tropical arid-zone lakes.

(8) Wetland model - Lake Gregory is comparable to several of the major arid zone lakes in other parts of the world (e.g. Lake Tchad in Africa).

9) Aboriginal culture - Another asset at Lake Gregory is that Aboriginal culture there is intact and the combination of studies of very recent sedimentary history with anthropological studies may prove fruitful.

POSSIBLE STUDIES

There are a number of topics, some of which have wide application, that could be or need to be researched at Lake Gregory. Topics that have broad implications include:

(1) Palaeohydrology and palaeoclimatology - Being a closed system the lake is particularly amenable to a study of its previous hydrological regimes and, by inference, previous climates. These studies are relevant to the general study of desert formation and the changing productivity of landscapes as a result of changing climates but their applicability to predicting some of the 'Greenhouse' effects increases their importance substantially.

(2) Invertebrate biogeography - Lake Gregory has a long history as a regularly-filled lake in the tropical arid zone. Most of the surface of the earth outside the polar zones is arid but there has been little study of the way in which aquatic systems function in arid areas. It appears likely that north-western Australia was a centre of invertebrate speciation in the same way as south-eastern and south-western Australia were. Lake Gregory is the only large natural lake in the north-west (or any part of the Australian arid zone) that fills regularly and may act as a refugium for a suite of species endemic to the north-west. Knowledge about its role as refuge, the pattern of speciation among animals living there and their adaptations to the hydrologic regime of the lake can be extrapolated to other arid zone situations as well as substantially improving our knowledge of the Australian fauna.

(3) Waterbird refuge - Waterbird counts in Lake Gregory are sufficiently high to suggest it may act as an important refuge in some years. Furthermore, it appears that the lake may be a very significant site for the breeding of piscivorous birds and that, in years of floods, Sturt Creek could be an important area for duck breeding. Waterbird numbers are high enough and the possible breeding activity great enough to mean that waterbird population dynamics at Lake Gregory have Australia-wide implications for waterbird management, which makes Lake Gregory an important area for further waterbird research.

The demonstrated importance of Lake Gregory also justifies research into the best methods of managing it and maintaining it as a functioning ecosystem. The general studies outlined above will contribute to this but additional studies would also be most useful. Some are listed below.

(1) Riparian vegetation - The trees surrounding the lake are very important for the breeding of many bird species. When the lake is very full and floods out to the sand dunes, the trees drown. Under normal circumstances seedlings germinate as the lake recedes and trees re-establish but this does not appear to be happening currently because of heavy grazing by cattle. There is a need to clarify the role of trees in maintaining bird numbers and breeding, assess the impact of loss of the trees and examine ways of ensuring regeneration.

(2) Catchment degradation - Sturt Creek and Lake Gregory probably offer an excellent opportunity to examine the larger scale effects of the introduction of cattle (such as sheet erosion) in the Kimberley on the environment, particularly wetlands.

BASELINE DATA

One of the general comments to emerge from the workshop was the need for baseline data. If some of the early explorers had collected modern scientific data on their visits to Lake Gregory we would be in a much better position to manage the lake than we are in today. Without baseline information there is great difficulty pinpointing the major problems requiring management and assessing their urgency as well as difficulty putting the biological and geological values of an area into context. Therefore, it is important that we begin compiling an inventory for Lake Gregory immediately and establish a monitoring program. Among the first priorities for inventory are:

(1) Collections of aquatic invertebrates, aquatic angiosperms and algae.

(2) Collections of fish.

(3) Water chemistry data.

(4) Collection of shallow cores of the lake bottom to determine recent lake levels, the aquatic fauna within the lake in recent times and surrounding vegetation.

(5) Compilation of a bathymetric map of lake.

A longer-term monitoring program should include data on waterbirds, aquatic flora and fauna and water chemistry as well as:

(1) Water levels in the lake.

(2) Groundwater levels in Lens Bore and Homestead Bore.

(3) Effect of cattle on the riparian vegetation.

(4) Monitoring of the flow in Sturt Creek.

CONCLUSION

Lake Gregory is one of the most important conservation areas in Western Australia. It supports larger numbers of waterbirds than any other lake in Western Australia and has a rich invertebrate fauna. It has extremely interesting and varied water chemistry and constitutes a most unusual hydrological system. There is a need for multi-disciplinary research to be conducted there, with the permission and co-operation of the Mulan Aboriginal Community, to provide a thorough understanding of how the lake functions so that the best possible management can be achieved. In addition to providing management-related information there is scope for research at Lake Gregory, because of its unique characteristics, to examine questions of national and international importance, such as providing insight into the implications of climatic changes likely to occur as a result of the Greenhouse Effect.

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