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THE INFLUENCE OF TURBID WATERS ON WATERBIRD NUMBERS AND DIVERSITY: A COMPARISON OF LAKES YUMBERARRA AND KARATTA, CURRAWINYA NATIONAL PARK, SOUTH-WEST QUEENSLAND

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Lakes Yumberarra and Karatta are two nearby intermittent lakes associated with the Paroo River, that differ in many respects. Yumberarra supports 53 species of waterbirds with numbers up to 11 500 at any one time, but Karatta has only 23 species with a maximum of 100 individuals seen at one time. While Karatta is one-third the size of Yumberarra, and has different dominant invertebrates, the main difference is its very high turbidity and lack of macrophytes. This severely restricts waterbird diversity and numbers. The high turbidity is recent and is associated with a severely eroded catchment and partial infilling of the lake.

INTRODUCTION

The Paroo River is the last free-flowing major river in the Murray Darling Basin. One of the most important associated wetland areas is within the Currawinya National Park in Queensland, which is also listed as a wetland of international importance under the Ramsar Convention (ANCA 1996). Two large wetlands in the area, Lakes Wyara and Numalla are known for their importance to waterbirds (Kingsford and Porter 1994, 1999). The two lakes however, provide different habitats, mediated by their different salinities and water turbidities so that species composition, species richness and numbers of birds differ between them. Other wetlands in the park also exhibit large differences in their waterbirds (McDougall, unpubl. data) and given the observation that the very turbid claypans have few waterbirds (Timms 1997a), it is possible that water turbidity alone is important in influencing waterbird use of wetlands. Certainly Briggs (1994) opines that lake siltation (which generally also increases water turbidity) makes wetlands less attractive to waterbirds.

Given that many wetlands in Australia naturally have turbid waters (Bayly and Williams 1973), and turbidity is increasing in many (Department Environment, Sport and Territories 1996), turbidity as a factor in waterbird ecology needs more study. A problem in assessing its importance is having comparative sites that differ only in turbidity. The Wyara-Numalla comparsion by Kingsford and Porter (1994) is confounded by salinity which affects food supply directly (e.g. invertebrates, fish) as well as indirectly via turbidity differences. Comparative study of other wetlands at Currawinya can be invalidated by their belonging to different types, so their structure and functioning is different (Timms and Boulton, in review). For instance the claypans mentioned above have many differences to freshwater lakes besides turbidity (Timms 1999), so their comparative lack of waterbirds could have other causes.

This study overcomes these problems by considering two nearby lakes in Currawinya National Park that have similar typology (Timms and Boulton, in review), are both moderately sized and fresh, but differ greatly in turbidity (Timms 1997a). Lake Karatta is partially infilled with sediments delivered from a badly eroded subcatchment during the last 50 years making its waters permanently turbid. Nearby Lake Yumberarra contains no obvious recent sediments and generally has clear waters. The aim of this study is to relate environmental conditions, including water quality, aquatic plants, invertebrates with numbers and species of waterbirds in the two lakes after a major filling in July 1998. Special attention is given to answering the question as to why there are so few waterbirds in Lake Karatta.

STUDY SITES

Lakes Yumberarra (144°19'E, 28°53'S) and Karatta (144°17'E, 28°54'S) lie at the edge of the Paroo floodplain in south-west Queensland and are about three kilometres apart (Fig. 1). When full, L. Yumberarra (171 ha) is three times larger than L. Karatta (57 ha) and about twice as deep. Both fill irregularly, then dry many months to a few years later. Generally L. Yumberarra receives its waters from Paroo floods via Carwarra Creek and a connection via South Kaponyee Lake. L. Karatta fills sometimes the same way, but more often from Stinking Well Creek from the west (Timms 1997a).

Lake Karatta's substrate is of red clayey loam and since at least 1993 lake waters have generally been very turbid (<10 cm Secchi disc depth (Timms 1997a)). By contrast L. Yumberarra is floored with grey mud. Its waters are generally clear (Secchi disc values >50 cm). Waters in both lakes concentrate as they recede with L. Karatta remaining fresh, and Lake Yumberarra generally becoming saline (reaching about sea water salinity) before drying (Timms 1997a).

Lake Karatta's catchment is severely eroded by overgrazing, so that there are extensive bare areas and much gullying. This occurred largely in the 1950s to 80s (P. Purtle, pers. comm.). During rain events, runoff carries large amounts of sediment via Stinking Well Creek into the lake, and has built a large deltaic fan and filled the remainder with up to 42 centimetres of a clayey loam (Timms 1997a). On occasion some water from L. Karatta reaches L. Yumberarra, and although it is turbid, there is no evidence that sediments are being moved beyond Lake Karatta, which is acting as a sediment trap.

For a few months prior to July 1998 Lake Yumberarra was dry and Lake Karatta was less than 20 centimetres deep and occupied less than a third of its basin. Following unusual local heavy rainfall in July 1998 (162.7 mm at Currawinya Homestead; mean annual rainfall 280 mm but 648 mm in 1998) L. Yumberarra filled to a high water mark indicated by a beach and row of trees while Lake Karatta's water level exceeded a similar beach and treeline. Both lakes were connected and overflowed to the Paroo River to the north (Fig. 1).

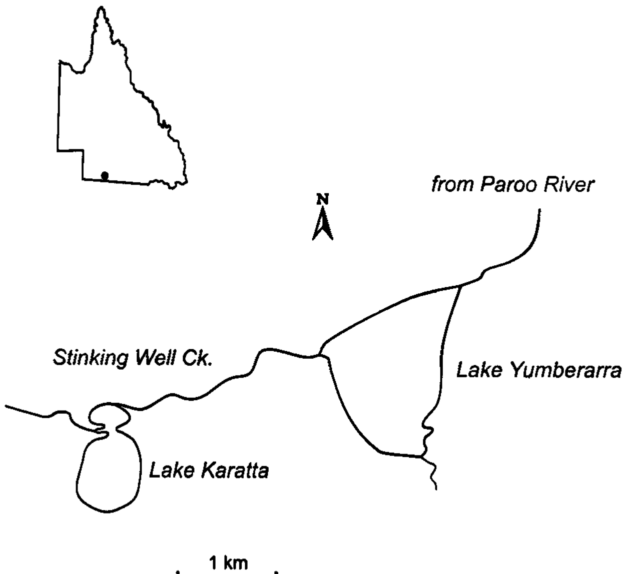

Figure 1. *Map of Lakes Yumberarra and Karatta. Showing their location in south-western Queensland.*

METHODS

Of a complex of environmental factors that could be affecting the attractiveness of each lake to waterbirds, only those known to be important (Kingsford and Porter 1994) were studied. These were: turbidity; salinity; and three food categories (aquatic plants, littoral invertebrates and zooplankton). Water level was also monitored, but importantly at all times there were large areas in each lake less than 1 metre deep and all parts were less than 3.5 metres deep, so that most or all of each lake was available for bottom feeders. Fish (mainly *Gambusia holbrooki*) were known to be present in both, but no adequate sampling gear was available.

Once access could be gained, the lakes were visited eight times at about two monthly intervals from September 1998 to December 1999. Physical and chemical measurements were taken each visit at sites as close as possible to the previous site, in both lakes. As each lake receded in water level, the site had to be shifted a few metres further from the high shore line so as to be in the same relative position offshore. Lake level was recorded using a staff, conductivity was determined with a Hanna HI 8924 Conductivity Meter, and pH with a Hanna HI 8633 pH Meter. Turbidity was measured in the laboratory on a freshly agitated field sample in a spectrophotometer at 450 nanometres.

Plant abundance in mean percentage cover was estimated by eye at five sites each about 10–20 metres offshore on the eastern shore of L. Yumberarra and western shore of L. Karatta with a 50 centimetre × 50 centimetre quadrant placed randomally. Two samples of zooplankton were collected with a net of mesh size of 159 micrometres and net aperture of 30 × 15 centimetres which was trawled for one minute on open water. A crude measure of biomass (the settling volume in ml) was obtained by letting the contents of the preserved collections settle for 10 minutes in a measuring cylinder. Littoral invertebrates were caught with a net of 30 × 15 centimetres, and of mesh size of 1 millimetre. Triple collections of one minute each were made, and their dry weight biomass determined after drying at 60°C for 24 hours or more till dry. Species richness and species dominance were assessed from separate collections made for 15 minutes in which the numbers of each species were counted. Total bird counts were made with the aid of spotting scope or binoculars, by walking along the eastern shore of L. Yumberarra and western shore of L. Karatta, so that the whole area of each lake was scanned. Due to time constraints the counts were not replicated. Birds were placed in ecological groupings following Kingsford and Porter (1994).

Paired t-tests were used to test the significance of differences in zooplankton and littoral invertebrate biomass and bird numbers between the lakes (Sokal and Rolf 1983).

RESULTS

(a) Lake environments

In July 1998, L. Karatta was about 2.2 metres deep and L. Yumberarra about 4 metres deep. Both lakes receded thereafter with some further minor inflows in September 1998, May, October, and November 1999, mainly from Stinking Well Creek into L. Karatta (Fig. 2). During recession Lake Yumberarra changed from being about three times larger than Lake Karatta to about 2.5 times larger.

Following inundation water in both lakes was initially fresh (estimated to be less than 80 µS/cm[1]) but ionic content gradually increased throughout the study, especially in L. Yumberarra (Fig. 2). Although initially similar, pH was higher in L. Yumberarra (mean = 9.6 ± 0.9) than L. Karatta (mean 8.0 ± 0.6). Turbidity was markedly different, L. Yumberarra quickly declined from 90 to about 10 FTU[2], while L. Karatta steadily increased to values greater than 1 000 FTU (Fig. 2).

(b) Plants and invertebrates

During the study period macrophytes grew in L. Yumberarra (*Myriophyllum verrucosum, Chara* spp., and *Lepilaena bilocularis*), particularly in the second spring and summer, while none were found in L. Karatta (Fig. 2).

Zooplankton in L. Yumberarra was dominated (the dominant species varying with the seasons) by *Boeckella triarticulata, Daphnia angulata* and *Ceriodaphnia 'dubia'* and as well *Calamoecia canberra, Microcyclops* sp. and *Cyprinotus* sp. were numerous at times. In L. Karatta almost invariably *Calamoecia canberra* was most numerous followed by *Boeckella triarticulata. Diaphanosoma unguiculatum, Calamoecia lucasi,* and *Moina australiensis* were numerous at times. With two exceptions the biomass of zooplankton was greater in L. Yumberarra than in L. Karatta (Fig. 2), averaging 19 ± 22.7 millilitres and 8 ± 5.9 millilitres per minute of collection, respectively. However, the difference between the two lakes over the study period was not significant ($t = 1.22$, $p = 0.268$, $df = 6$).

Littoral invertebrates in L. Yumberarra were dominated numerically by *Micronecta* sp., but significant numbers of *Cloeon* sp., *Tasmanocoenis tillyardi, Anisops gratus, Triplectides australis, Antiporus gilberti,* and various odonatans and chironomids were recorded at times. By contrast in L. Karatta, the numerical dominants were *Anisops* spp., particularly *A. gratus* and *A. stahi*, with *Tasmanocoenis tillyardi, Micronecta* sp., *Agraptocorixa* spp., *Eretes australis, Antiporus gilberti,* and various chironomids, particularly *Chironomus* sp., important at times. Momentary species richness[3] averaged a little higher in Lake Yumberarra (13.6 species) than Lake Karatta (11.7

[1] µS/cm = microSiemens per centimetre

[2] FTU = Fittou Turbidity Units

[3] Momentary species richness is determined from the numbers of species in a collection taken at a specific time. Cumulative species richness is determined when you add all species in all collections.

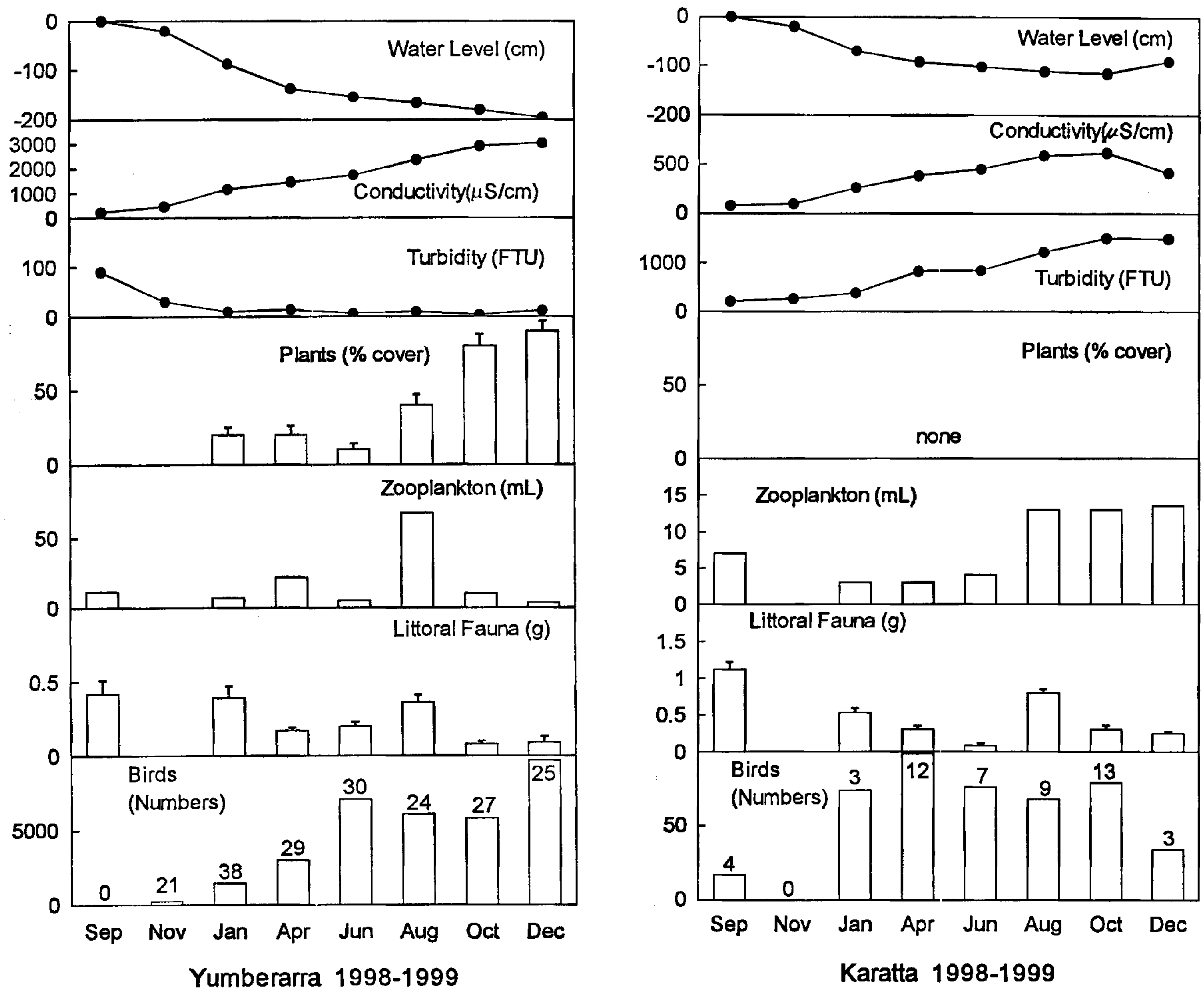

Figure 2. *Changes in water level, conductivity, turbidity, and the abundance of plants, zooplankton, littoral invertebrates and waterbirds in (a) Lake Yumberarra and (b) Lake Karatta. See text for information on measurements. The figures given on top of the histogram for bird numbers refer to the number of species present. The figure for September at Yumberarra has been lost, but was of the order of a few hundred individuals belonging to less than 20 species. FTU* = Fittou Turbidity Units, *µS/cm* = microSiemens per centimetre.

species), but the cumulative numbers of species were similar (35 *vs* 34). Of these only 15 species (mostly the dominant species) were common to both lakes, but also common was the yabbie *Cherax destructor*, an important food item for some birds. Littoral faunal biomass was almost always higher in Lake Karatta (mean 0.406 ± 0.360 gram/minute collection) than in Lake Yumberarra (mean 0.242 ± 0.144 gram/minute collection) (Fig. 2). This difference was statistically significant (t = 2.47, p = 0.048, df = 6).

(c) Waterbirds

Fifty-three species of waterbirds were recorded over the duration of the study from L. Yumberarra and twenty-three from L. Karatta (Table 1). The Eurasian Coot *Fulica atra* was by far the most numerous bird on L. Yumberarrra, followed by Pink-eared Duck *Malacorhynchus membranaceus*, Hardhead *Aythya australis*, Hoary-headed Grebe *Poliocephalus poliocephalus*, Grey Teal *Anas gracilis* and Black Swan *Cygnus atratus*. Fifteen species, mainly large (6 species) or small (4 species) waders, were uncommon (mean number of individuals less than 1) (Table 1). The most numerous birds on L. Karatta were the Hoary-headed Grebe, followed by Yellow-billed Spoonbills *Platalea flavipes*, Pink-eared Duck, and Red-necked Avocet *Recurvirostra novaehollandiae* (Table 1). Twelve species were uncommon, with no particular ecological grouping of birds over-represented. There was a clear difference between the lakes in numbers of birds — L. Yumberarra had a mean number of 5 033 birds and L. Karatta 61.7 birds. Not surprisingly paired t-tests were strongly significant (t = 3.43, p = 0.014, df = 6). Maximum daily counts were 11 473 on L. Yumberarra (Dec. 1999) and 101

TABLE 1

Mean number, standard error and range of abundances of waterbird species in Lakes Yumberarra and Karatta from September 1998 to December 1999.

Species	Foraging groups[1]	L. Yumberarra mean	L. Yumberarra SE	L. Yumberarra range	L. Karatta mean	L. Karatta SE	L. Karatta range
Blue-billed Duck *Oxyura australis*	d	4.8	6.9	0–20	0		
Musk Duck *Biziura lobata*	pw	4.4	9.6	0–15	0.3	0.7	0–2
Freckled Duck *Stictonetta naevosa*	d	9.7	15	0–35	0		
Black Swan *Cygnus atratus*	h	221.1*	212.9	47–667	0.3	0.7	0–2
Australian Wood Duck *Chenonetta jubata*	h	17.8	30.2	0–82	3.4	6.4	0–16
Pacific Black Duck *Anas superciliosa*	d	7*	8	1–21	2	3.7	0–8
Australasian Shoveler *Anas rhynchotis*	d	12.4	13	1–33	0		
Grey Teal *Anas gracilis*	d	224.6*	409.2	33–1 150	8.3	11.8	0–32
Chestnut Teal *Anas castanea*	d	a			0		
Pink-eared Duck *Malacorhynchus membranaceus*	d	571.8	773.3	33–2 199	5.6	7.8	0–22
Hardhead *Aythya australis*	d	270.7	405.5	7–1 121	0.9	2.1	0–6
Australasian Grebe *Tachybaptus novaehollandiae*	d	46.2*	11.6	0–272	0.9	2.5	0–7
Hoary-headed Grebe *Poliocephalus poliocephalus*	d	257.4*	220.4	65–578	12.9	22.9	0–60
Great Crested Grebe *Podiceps cristatus*	pw	1.4	2	0–5	0		
Darter *Anhinga melanogaster*	pw	3	5.9	0–16	0		
Little Pied Cormorant *Phalacrocorax melanoleucos*	pw	8	7.3	0–17	0.3	0.7	0–2
Pied Cormorant *Phalacrocorax varius*	pw	4.3*	4.8	0–11	0		
Little Black Cormorant *Phalacrocorax sulcirostris*	pw	26.2	60.9	0–165	0		
Great Cormorant *Phalacrocorax carbo*	pw	2.1	4.4	0–12	0		
Australian Pelican *Pelecanus conspicillatus*	pw	85.3	119.6	0–302	b		
White-faced Heron *Egretta novaehollandiae*	pw	0.7	1.5	0–4	0		
White-necked Heron *Ardea pacifica*	pw	a			1.1*	3.2	0–9
Great Egret *Ardea alba*	pw	0.6	0.4	0.4	0.1	0.4	0–1
Intermediate Egret *Ardea intermedia*	pw	a			0		
Nankeen Night Heron *Nycticorax caledonicus*	pw	a			0		
Glossy Ibis *Plegadis falcinellus*	pw	19.4	18	0–101	0		
Australian White Ibis *Threskiornis molucca*	pw	3.7	2.6	0–13	0.4	0.5	0–1
Straw-necked Ibis *Threskiornis spinicollis*	pw	2.3	5.5	0–11	0.4	1	0–3
Royal Spoonbill *Platalea regia*	pw	4.6	8.7	0–32	0.1	0.4	0–1
Yellow-billed Spoonbill *Platalea flavipes*	pw	3	2.9	0–6	9.9*	9.4	0–25
Brolga *Grus rubicunda*	h	0.8	1.6	0–4	0		
Australian Spotted Crake *Porzana fluminea*	h	a			0		
Purple Swamphen *Porphyrio porphyrio*	h	1	6	0–7	0		
Black-tailed Native Hen *Gallinula ventralis*	h	47.3	77.9	0–178	0		
Eurasian Coot *Fulica atra*	h	3 002.4*	3 312.6	36–8 393	1	1.9	0–4
Latham's Snipe *Gallinago hardwickii*	w	0.4	0.8	0–2	0		
Black-tailed Godwit *Limosa limosa*	w	0.2	0.4	0–1	0		
Marsh Sandpiper *Tringa stagnatilis*	w	a			0		
Common Greenshank *Tringa nebularia*	w	2.1	4	0–11	0.1	0.4	0–1
Sharp-tailed Sandpiper *Calidris acuminata*	w	5.1	9.1	0–22	0		
Black-winged Stilt *Himantopus himantopus*	w	54.8*	30.6	1–89	0		
Banded Stilt *Cladorhynchus leucocephalus*	w	a			0		
Red-necked Avocet *Recurvirostra novaehollandiae*	w	36.1	50.7	0–109	4.8	9.7	0–28
Red-capped Plover *Charadrius ruficapillus*	w	25.7	23.6	0–70	0.1	0.4	0–1
Black-fronted Dotteral *Elseyornis melanops*	w	9	10.9	0–25	2.3	4	0–12
Red-kneed Dotteral *Erythrogonys cinctus*	w	4.3	1.5	0–26	0		
Masked Lapwing *Vanellus miles*	w	20.8	13.8	1–47	0.8	1.4	0–3
Silver Gull *Larus novaehollandiae*	w	14	15	1–33	0		
Gull-billed Tern *Sterna nilotica*	pw	6.8	6	0–32	0		
Caspian Tern *Sterna caspia*	pw	1.4	2	0–4	0		
Whiskered Tern *Chlidonias hybridus*	pw	31*	42.6	0–112	0.3	0.7	0–2
Clamorous Reed-warbler *Acrocephalus stentoreus*		0.3	0.5	0–2	0		
Little Grassbird *Megalurus gramineus*		0.4	0.6	0–3	0		

[1] after Kingsford and Porter (1994) pw = piscivores or large wading birds that feed on large invertebrates greater than 5 millimetres.
d = most duck species and little grebes, h = herbivores and w = small wading birds.

a = seen on lake at time other than when count made.

b = 875 birds landed on the lake and left 10 minutes afterward.

* = breeding on lake, but those recorded on Karatta seen after December 1999.

on L. Karatta (April 1999). All species fluctuated widely in numbers during the study as the lakes changed. For instance, Black-tailed Native Hens *Gallinula ventralis* were only present in the early stages of filling when the lake shore reached the cover of littoral trees. Also piscivorous birds were uncommon after August 1999 when mosquito fish apparently became too uncommon (as judged by their lack of appearance in littoral invertebrate nets after August 1999). At least nine species bred in Yumberarra soon after if filled, but none bred in Lake Karatta during this filling (Table 1).

Almost all species of waterbirds were far more common on L. Yumberarra than on L. Karatta. However, Yellow-billed Spoonbill was more common on L. Karatta. The Pacific Black Duck *Anas superciliosa* and Black-fronted Dotteral *Elseyornis melanops* were about as common on each lake if the much greater area (3×) of L. Yumberarra is considered. Most of L. Karatta's birds were seen in the shallow northern bowl of the lake. Overall, if waterbirds are considered in their foraging groupings (following Kingsford and Porter 1994), then the greatest difference between the two lakes is in their herbivore component, followed by ducks and small grebes, small waders and finally the piscivore or large invertebrate feeders (Fig. 3).

DISCUSSION

With 53 species of waterbirds, L. Yumberarra is of similar species richness to many of the larger Paroo lakes. For example, (L. Altiboulka has 53 species by ground counts and 38 by aerial counts (Kingsford *et al.* 1994). It has more species of birds than nearby Lakes Wyara and Numalla (41 species), but these figures relate to aerial surveys and waders were not all identified to species level. Also observations were more frequent on L. Yumberarra and some ecotonal species (e.g. Clamorous Reed Warbler *Acrocephalus stentoreus*) were included. Although absolute numbers of birds on L. Yumberarra were high they were not as great as on many other Paroo lakes (11 500 compare with greater than 35 000 in six lakes — Kingsford *et al.* 1994). However, density is as high as any Paroo lake (maximum density of 76.6 birds ha^{-1} on L. Yumberarra compared with 79.7 birds ha^{-1} on Lower Bell Lake — Kingsford *et al.* 1994). In summary L. Yumberarra, given its size, is equally or more attractive to waterbirds than other important lakes in the Paroo, even L. Wyara (Kingsford and Porter 1994).

By contrast, when compared to other smaller freshwater lakes in the region (Timms and Boulton, in review), Lake Karatta is depauperate, both in species numbers and individuals of birds. At 23 species it is less speciose than other smaller lakes (e.g. Green L. 33 species, Waitchie L. 30 species, Yantara L. 28 species — Kingsford *et al.* 1994), and with a mean number of 62 birds, a maximum of 101 birds, and a maximum density of 2 birds ha^{-1}, it supports far fewer waterbirds than other Paroo lakes (which have more than 1 500 birds maximum and densities more than 2 birds ha^{-1} at a minimum) (Kingsford *et al.* 1994).

A more diverse array of birds bred in L. Yumberarra (9 species) than in most Paroo lakes (mean number of 3.4 species in 30 lakes — Kingsford *et al.* 1994) while L. Karatta (0 or 2 species if observations outside the study period are included) was at the other end of the scale. In both lakes few individuals were involved in breeding compared to many, indeed large numbers of breeding birds, in some other wetlands (e.g. Yantabulla Swamp — Kingsford *et al.* 1994).

Waterbirds are thus more numerous and diverse on L. Yumberarra than on L. Karatta. This remains so even when the larger size (2.5–3 times as large during the study) of Lake Yumberarra is considered. Possible explanations for this difference lie in geomorphology, water chemistry, hydrology and food resources, specifically aquatic plants, invertebrates and fish, of the two lakes. Their geomorphologies and water chemistry are similar (Timms 1997a, Fig. 2). Both lakes filled at the same time with

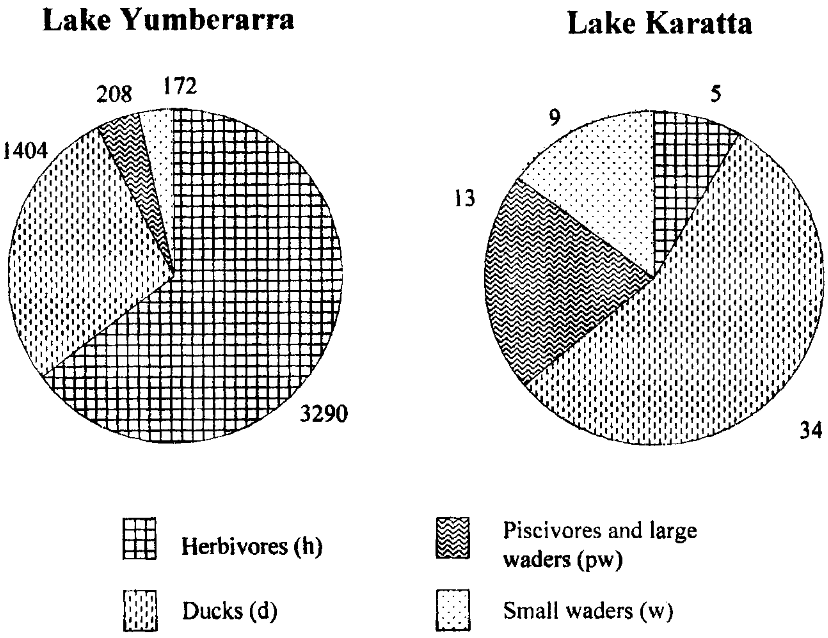

Figure 3. *Comparsion of foraging groups in Lakes Yumberarra and Karatta. The pie charts show the relative mean numbers of individuals in each group; mean numbers are given as well for each group. For composition of the foraging groups see Table 1.*

turbid water but water soon cleared in L. Yumberarra although it remained very turbid in L. Karatta (Fig. 2) due to wind stirring of the large supply of clay particles in the sediments. Turbidity is the major difference in physical and chemical environment between the two lakes.

The two lakes have markedly different abundances of aquatic plants, with large areas of the bed of L. Yumberrara covered in macrophytes and none in L. Karatta (Fig. 2). This factor is known to greatly influence bird numbers in lakes (Kingsford and Porter 1994).

The two lakes share many invertebrate species, though the dominant species of the zooplankton and littoral macroinvertebrates were different, associated largely with the different turbidities of the lakes (Timms and Boulton, in review). Zooplankton was generally of greater abundance in L. Yumberarra, but the difference was not significant. By contrast littoral invertebrates were more abundant in L. Karatta and the difference was significant. More zooplankton in L. Yumberarra may have attracted more plankton-feeding birds (e.g. Pink-eared Duck), and the significantly greater biomass of littoral invertebrates may provide more food in L. Karatta. However, these differences are too small to explain the very large difference in waterbirds, and moreover the more important of these differences favours L. Karatta not L. Yumberrara.

The data strongly suggests that turbidity acting through aquatic macrophyte growth is the major factor differentiating the waterbirds in these two lakes. Besides the large difference in food resources based on aquatic plants in the two lakes, the high turbidity must make feeding behaviour relying on vision difficult in L. Karatta. It is not surprising then, that all waterbirds are uncommon in L. Karatta and that the most affected group are the herbivores and mixed feeders like most ducks and small grebes (Fig. 3). The greater abundance of Yellow-billed Spoonbills in L. Karatta is explained by their touch feeding method and the relatively high abundance of Pink-eared Duck by their method of filter feeding on plankton which was sometimes common in L. Karatta. Furthermore, the greater relative number of birds in the northern part of L. Karatta is probably aided by its relative shallowness, the input of terrestrial detritus via Stinking Well Creek, and shelter from wind.

Lake Karatta is not the only wetland with few waterbirds in the Paroo. Highly turbid claypans also support few birds (Timms 1997a, 1997b) and the most common species are the Pink-eared Duck, Grey Teal, and Yellow-billed Spoonbills (Timms, unpubl. data), similar species to those most common in L. Karatta. Interestingly, Lake Karatta shares other features with claypans, including some similar characteristic invertebrates such as *Calamoecia canberra, Diaphanosoma unguiculatum, Moina australiensis, Anisops stahi* and *Eretes australis* (Timms and Boulton, in review). The high turbidity of claypans is believed to be the most significant environmental factor associated with these faunal pecularities (Timms 1999).

Two other Currawinya lakes, clear saline Lake Wyara and moderately turbid freshwater Lake Numalla, also have very different waterbirds. Kingsford and Porter (1994) attributed differences in waterbird numbers and diversity to differences in salinity acting through different food resources. Salt in L.Wyara cleared its waters and allowed abundant macrophyte growth but fish died at higher salinities, whereas in turbid L. Numalla macrophytes were restricted but fish were always abundant. The turbid lake had more species of waterbird than the saline lake and had more piscivores and large waders than the clear saline lake. By contrast the saline lake had many more individuals overall and amongst other foraging groups. In the L. Yumberarra-L. Karatta comparison, both were fresh during the study, so that the clear waters of L. Yumberarra probably resulted from deeper waters and the different nature of the lake bottom than to the influence of salinity on flocculation. Almost all waterbird species were far more common on the clear lake and it had by far the greatest species richness. The difference between these two lakes is not confounded by salinity; it is basically due to turbidity alone. It is concluded that the turbidity levels in L. Numalla (spectrophotometrically derived values of 50–200 FTU — Timms 1997a) are not particularly limiting, whereas the very turbid waters of L. Karatta (FTU of more than 1 000) are limiting to almost all waterbirds.

Lake Karatta has not always been like it is today. Firstly, if water is derived from a Paroo flooding rather than Stinking Well Creek the lake may not be as turbid and in addition more fish species and shrimps would be present (Timms 1997a). This would affect waterbird usage by making it more attractive at least to piscivores and large waders (as in L. Numalla). Secondly, in the 1940s to the 1960s, water in L. Karatta was only moderately turbid (like that in L. Numalla today) (P. Dunk, pers. comm.; P. Purtle, pers. comm.) so waterbird usage may have been similar to that found today in L. Numalla. Clearly the sediments and associated highly turbid water delivered from the severely eroded catchment of Stinking Well Creek is detrimental to birdlife in L. Karatta.

This factor of high turbidity should be added to other adverse human influences on the value of arid-zone wetlands for waterbirds. These include drainage, abstraction of water for irrigation (Kingsford and Porter 1999; Timms 1999), siltation (Briggs 1994; R. Kingsford, pers. comm.; Timms 1992, 1997a), and conversion to a permanent wetland (Briggs *et al.* 1994).

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