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Waterbirds of the Saline Lakes of the Paroo, Arid-Zone Australia: A Review with Special Reference to Diversity and Conservation

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ABSTRACT

About sixty species of waterbird live in the Paroo area of Australia and most of these have been recorded on its 150+ saline lakes of various salinities and sizes. Unlike water plants, invertebrates and fish, avian species richness is hardly influenced by salinity in the Paroo, although the data suggest that richness might be lower in hypersaline lakes. Common species at salinities < 30 g/l include Eurasian coot, Black swan, Pink-eared duck, Grey teal, and Australian pelican while at salinities > 100 g/l Red-necked avocets and stilts are common. Because saline lakes generally have more abundant food than freshwater lakes, waterbirds tend to be more abundant on them. However, most species do not utilize them for breeding, unless islands are present as in Lake Wyara. Bird numbers fluctuate widely in response to many factors, including food availability and state of wetlands elsewhere in the inland. Birds move freely between fresh and saline waters and are nomadic between wetlands across the vast Australian inland. Some Paroo salinas and their birds are threatened by localized siltation and local freshwater lakes could be destroyed by water harvesting for desert irrigation. The effect of water harvesting on other inland wetlands could also affect the Paroo and its salinas.

INTRODUCTION

The interconnected Paroo-Warrego catchment, the westernmost of the Murray-Darling Basin, contains the largest concentration of wetlands in Australia, and indeed is significant on a world scale (Kingsford & Porter 1999; Kingsford et al. 2004). In wet years 12% of the landscape is inundated, meaning there are 1.8 million ha of wetlands of various types (Kingsford & Porter 1999; Kingsford et al. 2004). Of these, saline lakes comprise 1.5×10^4 ha (0.8%) organized into 170 discrete salinas, the great majority of which lie in the Paroo catchment (155) and in NSW (118). These wetlands are saline because they are located in endorheic basins away from the main flood channels and are rarely, if ever, flushed of any accumulated salt. This region of Australia experiences short 'boom' periods in wet (La Nina) years, interspersed with long, irregular and unpredictable periods of 'bust' levels of productivity during dry (El Nino) years (Kingsford et al. 1999).



Figure 1–Map of the Paroo showing many of the study sites mentioned in the text.

The arid inland of Australia was once thought to be of little value to waterbirds (Frith 1982), but perspectives and focus changed in the 1980s due to the work of Braithwaite, Briggs, Halse, Kingsford and Maher, among others (see Kingsford & Porter 1999). In particular, Kingsford and colleagues have shown that the Paroo wetlands episodically support a relatively diverse and an abundant waterbird fauna. It is the aim of this review to record the importance of Paroo saline lakes for waterbirds. This needs to be done in the context of the unique environment in inland Australia (Stafford Smith & Morton 1990) and of the interconnectivity of the waterbirds of all inland saline and freshwater lakes (Kingsford & Porter 1994, 1999; Kingsford 2000).

Table 1—Some saline lakes of Paroo. The other 135 lakes are omitted as no data available for them, or they were too small (< 20 ha).

| Lake | State | Coordinates | Area (ha) | Known salinity range (g/l) | Average salinity type | References |
|-----------------|-------|----------------------|-----------|----------------------------|-----------------------|--|
| Wyara | Qld | 28° 42' S 144° 14' E | 3400 | 2.8-350 | mesosaline | Kingsford & Potter 1994; Timms 1998a, 2007 |
| Yumberarra | Qld | 28° 53' S 144° 19' E | 151 | 0.3-114 | subsaline | Timms & McDougall 2004; Timms 2007 |
| North Blue | Qld | 28° 50' S 144° 57' E | 205 | 0.3-31 | hyposaline | Timms 2007, 2008 |
| Mid Blue | Qld | 28° 52' S 144° 57' E | 210 | 0.7-103 | hyposaline | Timms 2007, 2008 |
| Bulla | Qld | 28° 54' S 144° 55' E | 420 | 1.8-262 | mesosaline | Timms 2007, 2008 |
| Lower Bell | NSW | 29° 30' S 144° 48' E | 160 | 7-123 | mesosaline | Kingsford et al. 1994; Timms 1993, 1998b, 2007 |
| "Bells Bore SL" | NSW | 29° 31' S 144° 50' E | 24 | 29-187 | hypersaline | Timms 1993, 1998b, 2007 |
| Horseshoe | NSW | 29° 32' S 144° 46' E | 746 | 13-310 | hypersaline | Kingsford et al. 1994; Timms 1993, 1998b, 2007 |
| Gidgee | NSW | 29° 33' S 144° 50' E | 185 | 5-52 | hyposaline | Timms 1993, 1998b, 2007 |
| Burkanoko | NSW | 29° 46' S 144° 49' E | 280 | 6-37 | hyposaline | Timms 1993, 1998b, 2007 |
| Nichebulka | NSW | 29° 49' S 144° 48' E | 322 | 54-360 | hypersaline | Kingsford et al. 1994; Timms 1993, 1998b, 2007 |
| "Barrakee" | NSW | 30° 05' S 145° 02' E | 90 | 23-218 | hypersaline | Timms 1993, 1998b, 2007 |
| "Kings Bore" | NSW | 30° 06' S 144° 55' E | 151 | 22-330 | mesosaline | Timms 1993, 1998b |
| Taylors | NSW | 30° 07' S 145° 04' E | 62 | 0.7-9.1 | subsaline | Timms 1993, 1998b, 2007 |
| "Avondale Salt" | NSW | 30° 09' S 144° 39' E | 520 | 9-69 | mesosaline | Timms 1993, 1998b |
| Mere | NSW | 30° 11' S 144° 59' E | 68 | 4-82 | hyposaline | Timms 1993, 1998b |
| Utah | NSW | 30° 15' S 144° 38' E | 1900 | 46-264 | hypersaline | Timms 1993, 1998b |
| Mullawoolka | NSW | 30° 31' S 143° 50' E | 2026 | unknown | subsaline | Kingsford et al. 1994. |

The Lakes

Only a few of the saline lakes of the Paroo are known scientifically. Limnological data are available on 25 salinas in the middle Paroo (Timms 1993, 1997, 1998a), two saline lakes in the southern Paroo (Kingsford et al. 1994; Timms & Boulton 2001) and on seven saline lakes in the Queensland Paroo (Kingsford & Porter 1994, Timms 1998b, 2008; Timms & McDougall 2004). Censuses of waterbirds are available for 14 of these sites (Kingsford & Porter 1994; Kingsford et al. 1994; Timms 1997, 2008; Timms & McDougall 2004). Fortunately these censused lakes include the largest and many of the intermediate-sized ones and most of the 14 are listed in Table 1.

All of the well-studied lakes (i.e. those in Table 1) of the Paroo system are episodic, rather than seasonal or permanent. As a rule, they fill in La Nina years when rainfall is above average and dry in El Nino years when rainfall is scarce. Some contain water for only a few months every few years, while others may have water for many years and then sometimes dry for years also (Timms 2007). All are shallow, rarely exceeding 2 m in depth and often much less. While exhibiting wide ranges in salinity, each has a characteristic 'average' salinity which ranges through the salinity spectrum from subsaline to hypersaline. During droughts when saline lakes have dried or have become hypersaline, most adjacent freshwater lakes salinize naturally before they too dry (e.g. Lake Numalla, Timms 2007). In most cases ionic dominance is markedly by Na

and Cl ions, but some hyposaline lakes have significant amounts of Ca and SO₄ (Timms 1993).

Bird Censuses

Recording the diversity and numbers of waterbirds on these saline lakes is challenging. Two basic methods were used in the studies reviewed here: estimates from aerial surveys and direct counts from the ground. In aerial surveys counts were made from a low flying aircraft either using transects across the wetland or proportional counts 150 m away from the shore, where most birds were concentrated (Kingsford & Porter 1994; Kingsford et al. 1994; Kingsford 1999). Each lake was surveyed up to four times on each visit so as to gain a mean and standard deviation for each species on each lake. For species with fewer than 50 individuals sighted, the highest number seen on the four counts was taken as the number present on that visit. Such methods are known to underestimate bird numbers by > 50% for large concentrations and to miss species present in small numbers (Kingsford 1999). However, direct counts from the lake edge ideally record all individuals and species present at the time, but were not repeated due to time constraints (Timms & McDougall 2004; Timms 1997, 2008). Also on larger lakes, only a proportion (often half) of the lake was scanned, introducing another error. Given the mobility of waterbirds, all counts are subject to large random errors, so that single counts are not as reliable as replicated counts.

Table 2–Waterbirds on saline lakes of the Paroo.

| Species | | Feeding group# | Relative numbers in: | | | | | |
|----------------------------|-------------------------------------|----------------|------------------------------|------------------------------------|----------------------------------|-------------------------------|-------------------------------|------------------------------------|
| Common name | Latin name | | fresh L.Numalla ¹ | hyposaline Yumberarra ² | hyposaline Nth Blue ³ | mesosaline WYara ¹ | mesosaline Bulla ³ | hypersaline Horseshoe ⁴ |
| Duck, Blue-billed | <i>Oxyura australis</i> | d | | xx | xx | x | x | |
| Duck, Musk | <i>Biziura lobata</i> | pw | x | x | | x | x | |
| Duck, Freckled | <i>Stictonetta naevosa</i> | d | xxx | xx | x | xx | x | |
| Swan, Black | <i>Cygnus atratus</i> | h | xx | xxx | xxx | xxx | xxx | x |
| Duck, Australian Wood | <i>Chenonetta jubata</i> | h | x | xx | xx | x | x | |
| Duck, Pacific Black | <i>Anas superciliosa</i> | d | xx | xx | xx | x | x | xx |
| Duck, Australian Shoveller | <i>Anas rhynchotis</i> | d | x | xx | xx | xx | xx | x |
| Duck, Grey Teal | <i>Anas gibberifrons</i> | d | xx | xxx | xxxx | xxxx | xxx | xxx |
| Duck, Chestnut Teal | <i>Anas castanea</i> | d | | x | x | | x | |
| Duck, Pink-eared | <i>Malacorhynchus membranaceus</i> | d | xx | xxx | xxx | xxxx | xxx | xxx |
| Duck, Hardhead | <i>Aythya australis</i> | d | xxx | xxx | xx | xxx | xx | x |
| Grebe, Australasian | <i>Tachybaptis novaehollandiae</i> | d | x | xx | xx | x* | xx | x |
| Grebe, Hoary-headed | <i>Poliiocephalus poliocephalis</i> | d | | xxx | xx | | xx | |
| Grebe, Great crested | <i>Podiceps cristatus</i> | pw | x | xx | xx | x | xx | |
| Darter | <i>Anhinga melanogaster</i> | pw | x | xx | x | x | x | |
| Cormorant, Little Pied | <i>Phalacrocarax melanoleucos</i> | pw | x | xx | xx | | x | |
| Cormorant, Pied | <i>Phalacrocarax varius</i> | pw | xx | x | x | x | x | |
| Cormorant, Little Black | <i>Phalacrocarax sulcirostris</i> | pw | x | xx | xx | x | xx | |
| Cormorant, Great | <i>Phalacrocarax carbo</i> | pw | xx | x | | x | | |
| Pelican, Australian | <i>Pelecanus conspicillatus</i> | pw | xx | xx | xx | xxx | xx | |
| Heron, White-faced | <i>Ardea novaehollandiae</i> | pw | x | x | x | x | x | |
| Heron, White-necked | <i>Ardea pacifica</i> | pw | x | x | | | x | |
| Egret, Great | <i>Egretta alba</i> | pw | x | x | x | | x | |
| Egret, Intermediate | <i>Egretta intermedia</i> | pw | | x | | | | |
| Egret, Little | <i>Egretta garzetta</i> | pw | x* | x | | | x | |
| Night Heron, Rufous | <i>Nycticorax caledonicus</i> | pw | | x | | | | |
| Ibis, Glossy | <i>Plegadis falcinellus</i> | pw | x | xx | x | | x | |
| Ibis, Australian White | <i>Threskiornis molucca</i> | pw | x | x | x | | x | |
| Ibis, Straw-necked | <i>Threskiornis spinicollis</i> | pw | x | x | x | | x | |
| Spoonbill, Royal | <i>Platalea regia</i> | pw | x | x | x | | x | |
| Spoonbill, Yellow-billed | <i>Platalea flavipes</i> | pw | xx | xx | x | x | x | |
| Sea Eagle, White-bellied | <i>Haliaeetus leucogaster</i> | pw | | x | | | | |
| Brolga | <i>Grus rubicundus</i> | h | x | x | x | x | x | |
| Crake, Australian Spotted | <i>Porzana fluminea</i> | h | | x | | | | |
| Swamphen, Purple | <i>Porphyrio porphyrio</i> | h | | x | | | | |
| Native Hen, Black-tailed | <i>Gallinula ventralis</i> | h | x | xx | x | | | |
| Moorhen, Dusky | <i>Gallinula tenebrosa</i> | h | | x | | | | |
| Coot, Eurasian | <i>Fulica atra</i> | h | x | xxxx | xxxx | xx | xxxx | x |
| Snipe, Latham's | <i>Gallinago hardwickii</i> | w | | x | | | | |
| Godwit, Black-tailed | <i>Limosa limosa</i> | w | | x | x | | | |
| Sandpiper, Marsh | <i>Tringa stagnalis</i> | w | | x | | | | |
| Sandpiper, Common | <i>Tringa hypoleucos</i> | w | | | x | | x | x |

| | | | | | | | | |
|-------------------------|---------------------------------------|----|----|----|----|-----|---|----|
| Greenshank, Common | <i>Tringa nebularia</i> | w | x* | x | x | x* | x | x |
| Sandpiper, Sharp-tailed | <i>Calidris acuminata</i> | w | | x | | | | |
| Stint, Red-necked | <i>Calidris ruficollis</i> | w | | x | | | | |
| Stilt, Black-winged | <i>Himantopus himantopus</i> | w | x | xx | xx | xx | x | xx |
| Stilt, Banded | <i>Cladocrhynchus leucocephalus</i> | w | | x | | xx | x | x |
| Avocet, Red-necked | <i>Recurvirostris novaehollandiae</i> | w | x | xx | xx | xx | x | xx |
| Plover, Red-capped | <i>Charadrius ruficapillus</i> | w | x* | xx | x | xx* | x | xx |
| Dotterel, Black-fronted | <i>Euseyornis melanops</i> | w | | xx | | | x | x |
| Dotterel, Red-kneed | <i>Erythronyctes alba</i> | w | | x | | | x | x |
| Lapwing, Masked | <i>Vanellus miles</i> | w | x | xx | x | x | x | |
| Lapwing, Banded | <i>Vanellus tricolor</i> | w | | x | | | | |
| Gull, Silver | <i>Larus novaehollandiae</i> | w | x | xx | xx | xx | x | x |
| Tern, Gull-billed | <i>Sterna nilotica</i> | pw | x | x | | x | x | |
| Tern, Caspian | <i>Sterna caspia</i> | pw | x | x | x | x | x | |
| Tern, Whiskered | <i>Chlidonias hybridus</i> | pw | x | xx | xx | x | x | x |

¹ from Kingsford & Porter 1994, averages of 12 visits; ² from Timms & McDougall 2002, average of 23 visits; ³ from Timms 2008 and unpublished data, averages of 23 visits; ⁴ from Timms 1997 and unpublished data, averages of 6 visits; ^ code x = < 3/km², xx = 3.1 - 30/km², xxx = 31 - 300/km², average, xxxx = > 301/km², all on average, but note that many figures vary widely between visits (see references above); * some species lumped together, see Kingsford & Porter 1994; # from Kingsford & Porter 1994, code d = ducks and small grebes, h = herbivores, pw = piscivores and large invertebrate feeders and w = small wading birds.

Diversity

As a whole, the Paroo supports about 60 species of waterbirds, with at least 31 of these known to breed in the area (Maher 1991; Maher & Braithwaite 1992; Kingsford et al. 1994). However, species richness on individual salt lakes is lower (Table 2), ranging from 18-43 species on many important lakes (Kingsford & Porter 1994, Timms 2008, Timms 1997 and my unpublished data). On lower salinity (i.e. subsaline, hyposaline) lakes, the dominant species generally are herbivorous Eurasian coot and Black swan, the ducks Pink-eared duck, and Grey teal, and the piscivorous Australian pelican, Little Black and Little Pied cormorants. By contrast, hypersaline lakes are dominated by waders such as Red-necked avocet and stilts (mainly Black-winged), with large waders such as herons, egrets and spoonbills and herbivores such as swans and coots notably absent. Mesosaline lakes like Lake Wyara can have all of these dominants. Other abundant species include Little and Hoary-headed grebes, Freckled duck, Hardhead, Black duck and Australian shoveler mainly in lower salinity lakes, and Silver gulls, terns and small waders such as the Red-capped plover in all saline lakes.

None of these species or others found in saline lakes is restricted to such habitats, though some, such as Pink-eared duck and the Avocet are more common in saline sites (Kingsford et al. 1994). Almost all species in Paroo saline lakes are nomadic throughout the inland (Briggs 1992; Kingsford 1996; Kingsford & Norman 2002) though for

few of the uncommon species, such as the Musk duck and Chestnut teal, the Paroo is at the northern edges of their distribution. Notwithstanding the ubiquity of waterbirds in the inland, Paroo saline lakes, together with associated freshwater lakes, harbor a significant proportion of at least two threatened species — Freckled duck and Blue-billed duck (Kingsford & Porter 1994).

While studies often show an inverse relationship between salinity and bird species richness (Halse et al. 2003), studies in the Paroo have not shown this trend. For example Timms (2008) on the Rockwell Lakes found no correlation between salinity and species richness, possibly because other factors such as habitat heterogeneity overrode the influence of salinity (Timms 2001a). Furthermore, Paroo lists seem to be inflated by rare occurrences of atypical species and by visitors temporarily passing through. Certainly food resources are determined by salinity, with most water plants restricted to < ca. 70 g/l (Porter 2005), fish dying beyond ca 30 g/l in the Paroo (Timms 2008) and invertebrate diversity inversely determined by salinity (Timms 1993). Lower salinity lakes with their resources of aquatic plants, diverse invertebrates and fish, can support wide array of birds (but may not for various reasons—see later), but hypersaline lakes with their limited array of crustaceans, largely brine shrimp and large ostracods, attract mainly avocets, stilts and small waders, with few resources for ducks (and hence occasional records contributing to richness and diversity) and nothing for herbivores and piscivores. Consequently, more intensive field surveys of bird use of lakes in the Paroo might show a decrease in diversity in hypersaline lakes.

Abundance

Salt lakes support greater numbers of waterbirds per unit area than freshwater lakes. In a year-long study at Bloodwood station salt lakes supported more individuals per ha than all other wetland types combined, except for clear freshwaters as they dried (Timms 1997). However, the best example is provided by similar-sized Lakes Wyara and nearby Numalla (Kingsford & Porter 1994). Between 1987 and 1989, Lake Wyara's salinity (actually TDS) varied between 5 and 30 g/l and averaged 19 g/l, while Lake Numalla's waters were always < 2 g/l (Timms 1998b and my unpublished data). In the same period Wyara averaged nearly 4.2×10^4 birds and Numalla 7533 birds (from Table 2, Kingsford & Porter 1994). The difference is explained by greater food resources in Wyara. In Wyara, salt precipitates colloidal clays so that its clear water encourages plant growth. This not only supplies a direct resource to herbivorous birds, but habitat and food for invertebrates (Kingsford & Porter 1994). Zooplankton was six times more abundant in Wyara than in Numalla, and aerial invertebrates caught on sticky traps were seven to eight times more abundant in Wyara (Kingsford & Porter 1994).

Among the various salinity types, hyposaline waters often support the most birds followed by mesosaline waters and finally by hypersaline sites. This phenomenon is often seen in the same lake as it changes salinity, e.g. in Lake Horseshoe bird numbers plummeted from 3100 to 465 as salinity increased from 40 g/l to 110 g/l in four months. On the other hand, in the Rockwell lakes there was no correlation between bird species richness or numbers with lake salinity (Timms 2008). This may be due to unquantified fluctuating habitat heterogeneity overriding any salinity effect in these lakes (see earlier), or to loafing birds, which were not distinguished from feeding birds. Freshwater lakes such as Numalla naturally salinize as they dry (Timms 2007) and in doing so attract more waterbirds (Kingsford & Porter 1999). This may not be related to salinity per se, as field observations suggest most of these extra birds are loafing rather than feeding and using such lakes because other sites had dried. This was certainly the case in the Bloodwood study, where numbers in drying and salinizing freshwater lakes increased from ca 6 to 127 ha^{-1} as the other sites dried, with most of the extra birds apparently loafing rather than feeding (Timms 1997).

At times saline lakes support huge numbers of waterbirds. Lakes Wyara (and Numalla) had about 2.8×10^5 (ca 42 ha^{-1}) birds in March 1988 when Wyara was hyposaline (Kingsford & Porter 1994) and even hypersaline Lake Nichebulka has supported more than 1.10×10^4 (ca 33 ha^{-1})

birds (Kingsford et al. 1994). The Lower Bells Creek Lakes (Lower Bell, Mid Bell and Gidgee) have been known to have 1.3×10^4 birds (ca 34 ha^{-1}) (Kingsford 1995). Maximum numbers in the Rockwell Lakes have reached 1.3×10^4 (33.5 ha^{-1}) birds in Lake Bulla and 1.2×10^4 (57.6 ha^{-1}) in Mid Blue Lake (Timms 2008). Lake Altiboulka (area 300 ha) on one occasion had 102.9 birds per ha (Kingsford 1999). However, even larger numbers have been recorded on some larger lakes inland Australia. The Lake Gregory system in northwestern Australia on one occasion had at least 6.5×10^5 birds (Halse et al. 1998), Lake Eyre North (northern SA) 3.25×10^5 , Lake Blanche (northeastern SA) 1.48×10^5 and Lake Galilee (north Qld), 2.54×10^4 (Kingsford 1995). These lakes are all much bigger than the Paroo salinas, but it seems that densities may be greater in the Paroo as none of the above exceed 20 birds ha^{-1} . I suggest the reason for the relatively higher densities in the Paroo, is the small size of its lakes compared to these huge lakes, because small lakes have proportionally more near-shore areas where waterbirds tend to congregate (80% of Wyara's birds occur within 300 m of the shore, Kingsford & Porter 1994).

Fluctuations and Connectivity

Given the episodic nature of the Paroo salinas and their wide changes in salinity when water is present, it is no surprise that bird numbers fluctuate markedly. In Wyara during 1987–89, numbers ranged from < 2600 to > 100000 (Kingsford & Porter 1994). In the Bloodwood study, numbers during 1995 on Gidgee Lake varied between 85 and 3910, and in Horseshoe Lake from 28 to 3050 (Timms 1997 and my unpublished data). Even greater proportional fluctuations have been recorded in the Rockwell lakes, e.g. Lake Bulla (22 to 12850; Timms 2008) and on Lake Altiboulka (517 to 38686; Kingsford 1999). Fluctuations in Lake Gregory have been explained in terms of the amount of water in the lake, the amount of water elsewhere, the taxonomic range of the available food items, and the extent of trees and shrubs inundated (Halse et al. 1998). The latter factor is largely inapplicable to treeless Paroo lakes, but the others are important. The effect of the amount of water and its salinity in Horseshoe Lake has already been noted, and taxonomic range of food available has been noted in Lake Wyara's case (Kingsford & Porter 1994). A specific example is provided by the relationship between the numbers of Pink-eared duck and its food, the cladoceran *Daphnia (Daphniopsis) queenslandensis* in Gidgee Lake (Timms 1997). Finally, low numbers in the Lake Yumberarra and the Rockwell lakes in 2000 are thought to be associated with better conditions in the Lake Eyre Basin at the time (Timms 2008).

These fluctuations in bird numbers are enabled by the birds of the inland being mobile and nomadic (Lawler & Briggs 1991; Briggs 1992; Kingsford & Norman 2002). Exactly what guides them to come and go is unknown, but in effect it means that episodic fillings of remote lakes are generally colonized and their resources harvested by one species or another. When a wetland system dries and enters a 'bust' period, their waterbirds either move to a system in 'boom,' or go to the coast, or occasionally crash catastrophically (Kingsford et al. 1999). Because inland wetlands are episodic, some lakes are utilized only occasionally (Kingsford 1996).

In these movements between lakes, there is full connectivity for waterbirds between fresh and saline waters locally and continentally (Kingsford & Porter 1994; Kingsford et al. 1999). Avian diversity is not much different between the fresh and saline wetlands, though, as seen above, saline sites usually have more individuals because of their greater food resources. No species in the Paroo is restricted to saline waters, but many species, mainly large waders, are rarely seen in salt lakes (see Table 2). This means that bird populations on salt lakes should be considered as an integral part of the population of the entire region, with easy interchange between various water types.

Not only must waterbirds on saline lakes of an area be considered part of the whole population of that area, strong nomadism means that all inland wetland areas of the continent are connected by interchange of populations. Usually there is at least one wetland system in arid Australia with abundant water (Roshier et al. 2002), so waterbirds congregate there. Should saline sites be part of that system, then birds will spread to them. Paroo's waterbirds, including those on the saline wetlands, could be from anywhere in inland Australia, and indeed could move onto any wetland system, fresh or saline.

BREEDING

Most Australian waterbirds do not breed in saline waters (Goodsell 1990; Halse et al. 1993). Of the 31 species known to breed in the Paroo, nine breed in the saline wetlands (Maher 1991), though many utilize the food resources of saline lakes in the process, mainly in the building of body reserves before breeding (Kingsford et al. 1999). It is not known what factors contribute to this avoidance of saline lakes for breeding, but the lack of trees could be adverse for many ducks, cormorants, and large waders. When fringing trees are partially drowned cormorants are known to breed in Lake Gregory (Halse et al. 1998) and also in Lake Wyara (author, unpublished data). Briggs (1992) has noted that breeding is more

common on long lasting wetlands of any type. Given that most saline wetlands are shallow and ephemeral, this may contribute to their avoidance, though it should be noted that in wet La Nina years some salinas such as Lake Gidgee persist for 2 -3 years (Timms 2007) and little breeding occurs. Perhaps the young dehydrate more than the adults (Hannan et al. 2003). Few salt lakes, and most fresh waters for that matter, have persistent islands which provide safe sites for ground-nesting species. In this respect the islands of Lake Wyara are of paramount importance. The most common breeders in Paroo's salinas are Black swans, as well as in some freshwater lakes throughout the Paroo (Kingsford et al. 1994). Considered separately, Paroo lakes are not significant sites on a continental scale, but as a group, Paroo lakes are important breeding sites. Swans have been recorded breeding in Lake Wyara (Kingsford & Porter 1994), Gidgee and Lower Bell Lakes on Bloodwood lakes (Timms 1997) and in Lake Bulla and the Blue Lakes on Rockwell (Timms 2008) as well as in Lake Burkanoko, Mere and Taylors Lakes in the middle Paroo (author, unpublished data). All of these sites were hyposaline or mesosaline at the time and grew abundant aquatic plants, mainly *Chara*, *Lepilaena* and *Ruppia* spp. Other breeding species include Australian pelicans, Little Pied cormorants, Red-necked avocets, Black-winged stilts, Red-capped plovers, Silver gulls, Whiskered terns and Caspian terns. Most of these breed on islands in Lake Wyara (Kingsford & Porter 1994; Timms 1998b). One such island supported ca 1500 nests of Australian pelicans during 1987-1989 and they bred again in 1990-91, 1995 and 1998-2001 (R.T. Kingsford, pers. comm.; A. McDougall, pers. comm.). These pelicans feed mostly in the freshwater Lake Numalla (and hence are an exception to the general movement of resources from saline to fresh waters for breeding), though they and cormorants fish in Wyara till rising salinity kills its fish. Although smaller than the huge colonies of Australian pelicans on Lakes Eyre and Cawndilla, this is an important breeding site as it is more regularly used (Kingsford & Porter 1994). These islands also provide the only breeding site in the Paroo for Silver gulls and Caspian terns. They also are used occasionally by Little Pied cormorants, Red-necked avocets, Red-capped plovers and Whiskered terns.

Breeding is directed by rainfall and river flows (Kingsford & Norman 2002). Black swans are usually the first to breed after a lake fills, because their food (aquatic plants) recolonizes before fish do (Kingsford et al. 1999). As an example, in Lake Wyara the number of nests of swans peaked July to September in 1988 and 1989, and most broods were recorded in September of each of these years, whereas piscivorous pelicans only formed their breeding colony in December of 1988 and their activity peaked in March 1989 (Kingsford & Porter 1994).

CONSERVATION

The saline lakes of the Paroo lie in a remote part of Australia with a low human population and few visitors. Generally the lakes are in pristine condition (Timms 2001b), and common problems elsewhere in Australia such as salinization, permanent flooding and eutrophication are of little concern (Briggs 1994; Kingsford & Norman 2002; Timms 2005). Given the permanent ban on hunting waterfowl in NSW, hardly any birds are shot or are disturbed by hunters. Minor problems in the Paroo include wallowing by feral pigs along shores and hence enhancing sedimentation and perhaps preying on young shorebirds. Furthermore, some of the lower salinity lakes have introduced fish (carp, Mosquito fish) and while they may adversely affect invertebrates, it is possible their presence is advantageous to piscivores. On the other hand, accelerated sedimentation and diversion of water for desert irrigation pose significant threats to these lakes (Kingsford 2000).

Considering sedimentation, Gidgee Lake has lost ca. 50% of its capacity due to recent siltation, meaning it probably holds water for shorter periods after filling (Timms 2007). The islands of Lake Wyara face connection to the coastline because of sedimentation at the mouths of Benangra and Youlainge Creeks, thus potentially giving access to foxes and cats to prey of the island rookeries (Timms 2001b). Despite this lake being a Ramsar site, no permanent solution to this problem is in sight, but temporary protection is provided by a baiting program against foxes. Of greatest concern, however, is the potential of water harvesting for desert irrigation. Though this does not affect Paroo saline waters directly because they are not filled by riverine water, its freshwater lakes could be deprived of water resulting in catastrophic reduction of waterbirds, which by connectivity would pass onto the saline wetlands. Fortunately for the Paroo, there is now an intergovernmental agreement between Queensland and New South Wales not to develop this last free-flowing tributary of the Murray Darling system (NSW National Parks & Wildlife Service 2003). However, with greater connectivity, any water withdrawals affecting other systems (e.g. Lake Eyre basin) could impact on the Paroo and on the birds of all inland wetlands.

CONCLUSIONS

The species composition of waterbirds of Paroo saline lakes is little different from those in nearby freshwater lakes, and indeed from water bodies across the vast inland of Australia. There is a suggestion of an inverse relationship between species richness and salinity, but certainly low salinity waters are more productive than most other fresh waters, so that abundances are often great in hyposaline/mesosaline lakes, including many in the Paroo.

However, populations fluctuate greatly according to ecological state of the lakes, and their nomadic movements between lakes and wetland regions. Some birds breed in Paroo salinas, but not on a significant continental scale, except perhaps Australian pelicans. Paroo salinas (and freshwater wetlands) are almost pristine, but some are adversely affected by accelerated sedimentation and threatened by water diversion for desert irrigation. The latter is particularly pernicious since the wetland habitats in other regions are similarly threatened.

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