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Waterfowl Usage of Wetlands in the South-East Arid Interior of Western Australia 1992–93

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Summary: This paper reports the use by 35 waterfowl species of 23 wetlands in the arid south-east interior of Western Australia following the wettest year on record for much of the region. The majority of the wetlands are saline with individual wetlands varying from brackish to hypersaline over relatively short periods that markedly affected use by waterfowl. Some freshwater wetlands supported more species (but not individuals) than saline ones, although the salt lakes were significant functioning wetlands supporting greater numbers of certain species. Onset of breeding for early breeding species is two months after the rainfall event. Probably a short period of maximum biological productivity follows initial filling which also triggers breeding enhanced by the fact that these wetlands were all dry previous to this rainfall event. Breeding did not appear to extend into a second season despite adequate water levels and was not inhibited by low winter temperatures.

As a dry continent, Australia's wetlands have always been subject to considerable interest; both for their intrinsic biological, recreational and aesthetic value and, more recently, for their conservation and management. Most wetland studies have focused on wetlands in relatively mesic parts of Australia; it is only very recently that arid zone wetlands have been studied, and most work has concentrated on nomadism, factors affecting breeding and the influence of salinity. In Western Australia Halse et al. (1993) examined 95 wetlands in the south-west and concluded that waterfowl presence was related to six wetland characteristics. Geographically the study reported here sits immediately to the east of that study and there is no overlap. Its purpose is to describe the waterfowl response to the 1992 rainfall event and evaluate the contribution to regional biodiversity that these wetlands provide.

Study area

The south-east interior of Western Australia coincides with the area loosely referred to as the Goldfields (Fig. 1); it is located between the Wheatbelt/Murchison and the Nullarbor Plain/Great Victoria Desert. The area covered by this paper is similar to the 'south-eastern interior' of Storr (1986) except that here it excludes the Great Victoria Desert. Climate, landforms, vegetation and flora of this area are described by Beard (1974, 1975, 1976). In general, eucalypt and mulga dominate woodlands that occupy the south and north of the re-

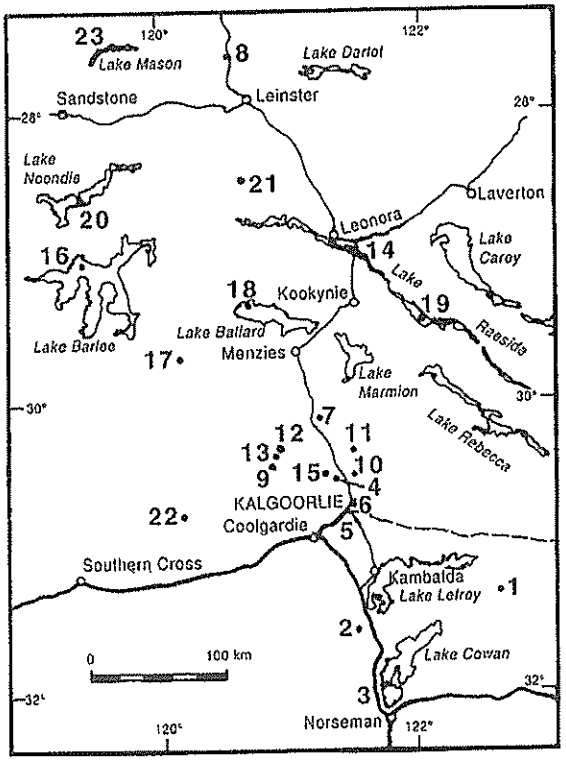

Figure 1 The south-east interior. Numerals refer to wetlands in Table 2.

Table 1 Monthly actual and average rainfall (mm) 1992.

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
KALGOORLIE													
Actual	1	21	105	75	78	88	6	74	33	15	21	13	530
Average	22	28	19	19	28	31	26	20	14	16	18	15	256
LEONORA													
Actual	3	43	153	43	8	26	1	58	19	30	7	2	393
Average	23	26	28	20	25	26	18	16	9	8	19	16	234
LAVERTON													
Actual	13	32	38	87	34	23	2	46	14	34	6	2	331
Average	22	25	30	22	25	25	16	14	8	7	14	16	224
SANDSTONE													
Actual	14	16	138	97	24	53	4	85	17	27	1	0	476
Average	29	26	26	18	27	28	23	18	6	8	10	15	234

gion respectively, interspersed with sandplains, granite outcrops, greenstone hills and drainage lines that all host different vegetation.

Australian Nature Conservation Agency (ANCA undated) indicate 19 types of inland wetland in Australia; of these the following 7 types are present in the south-east interior and are represented by the 23 wetlands studied (see Fig. 1 and Table 2): B8 Intermittent saline lake, etc.; B12 Seasonal saline marsh; B6 Seasonal freshwater lake; B10 Intermittent freshwater marsh; B13 Shrub dominated freshwater marsh; B14 Seasonally flooded freshwater wooded swamp; and C2 Man made small dams < 8 ha in area.

Saline wetland types predominate both numerically and in area. Seldom do any of the six natural types occur on their own; nearly always they occur as systems. For example saline marshes always occur peripherally to saline lakes and the four freshwater types usually exist together, particularly after extreme rainfall events such as occurred in 1992. Station dams also function as significant arid wetlands but they are not dealt with in this paper.

Saline wetlands are always associated with ancient dry river valleys that were functional rivers in the late Cretaceous to early Tertiary periods between 100 and 35 million years ago when the rainfall was much higher than at present (van der Graaff et al. 1977). These rivers drained south-eastward into the Eucla and Officer basins from a divide running north–south just west of Lake Barlee (#16) Presently these palaeodrainage systems consist of vast salt lakes joined by narrow channels in wide, open valleys with a characteristic chenopod shrubland vegetation. Although these paleorivers are coordinated into systems (e.g. van der Graaff et al. [1977] recognise four in the area covered by this paper) only very infrequently is there any downstream drainage. Lake Raeside (#19) flowed under the road crossing 15 km south of Leonora between March 1992 and mid-1993 for the first time since 1975 when it joined Ponton Creek and flowed into Lake Boonderoo; however, in 1992 this did not happen. These infrequent events are probably significant for nutrient transfer and cycling of these intermittent saline wetlands. Substantial changes of salinity coinciding with their drying cycle are characteristic of these saline wetlands. Black Flag Lake (#15) for example had 5150 mg/l TDS (Total Dissolved Solutes) on 18 December 1992 and 135 000 mg/l TDS on 17 December 1993 two weeks before completely drying.

Freshwater wetlands on the other hand are minor sunklands or claypans which fill from local centripetal drainage from relatively small areas. Rowles Lagoon (#9) the largest and most permanent of these has a catchment area of 25-30 000 ha; most freshwater wetlands drain considerably smaller areas. Salinity of freshwater wetlands remains much more constant and there is only a marginal increase coinciding with their drying cycle, for example Rowles Lagoon salinity increased only from 85 mg/l to 230 mg/l TDS between 27 December 1992 and 25 November 1994.

Climate varies over the south-east interior from semi-desert (mediterranean) in the south to desert (summer and winter rainfall) in the north. Temperatures vary seasonally. Winters are cool-cold with occasional subzero temperatures, whereas summer maxima frequently exceed 40°C.

Long, hot summers account for very high evaporation rates varying between 2500 mm and 3500 mm per annum; this exceeds the rate of precipitation by between 10 and 15 times, which influences duration of inundation of wetlands

Rainfall data for 1992 (Table 1) from monthly weather reviews (Bureau of Metereology 1992, 1993) show that for all centres very much above average rainfall began in March and continued for the rest of the year although there was a temporary respite in July. The accumulated average for the south east rainfall district was 527 mm, compared to the long term average of 258 mm (Fig. 2). Many centres including Kalgoorlie and Norseman recorded their highest annual rainfall on record. These rainfall events coincided with a warm Pacific or El Ñino Southern Oscillation (ENSO) which started in 1991 and had begun to decline by May 1992 (Wright 1993).

Widespread storms in March and April were primarily due to mid-level instability in an easterly flow and some of these storms produced hail and flash flooding during 14–20 March and 23 March.

Further rains in the winter months were due mainly to tropical cloud from the north-west interacting with cold fronts to the south (Joe Courtney pers. comm.). In 1993 above average rainfall continued in all centres; the accumulated district average was 300 mm.

It is of relevance to wetland ecology, particularly nutrient cycling and productivity, that except for 1990 the three years prior to this wet event had less than average rainfall and all wetlands were completely dry.

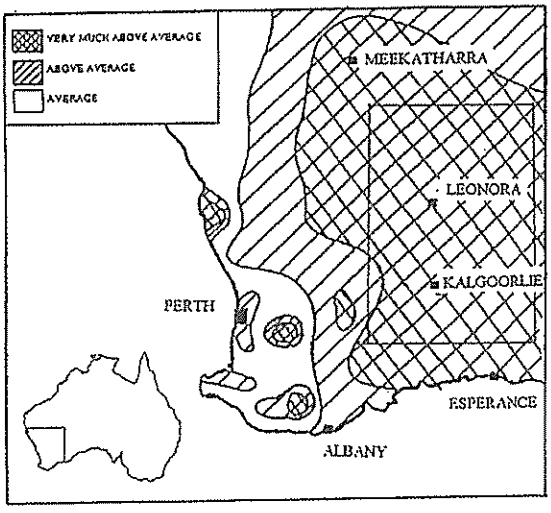

Figure 2 Decile range distribution of rainfall for 1992.

Methods

Most of the wetlands were surveyed for waterfowl opportunistically from either the shore or from a dinghy. Waterfowl were identified, relative abundance assessed and breeding recorded. Due to the size of most lakes and their inaccessibility most surveys were only partial. The number of visits to each wetland are shown in Table 2. Rowles Lagoon (#9) and Lake Arrow (#4) were visited monthly and weekly respectively while they were inundated. Two aerial surveys were completed in June 1992: a reconnaisance (3 and 4 June) at 500 feet of the area based on NOAA satellite imagery and a low level survey of Banded Stilts breeding on Lake Barlee (#16) on 29 June. Salinity was determined at Kalgoorlie College with a HANNA HI 8820 conductivity meter. Salinity sampling was opportunistic; not all lakes were sampled nor was sampling done regularly.

Results

Most lakes filled in March 1992. An exception was Rowles Lagoon (#9), which filled on 30 December 1991 following 110 mm in four hours recorded at nearby Credo Station (Tim Funston pers. comm.) and reached a maximum depth of 6.5 m in October 1992. This was the most significant inundation event at Rowles Lagoon since 1948. The Lagoon and its associated three lakes (Carnage, Clear and Muddy #13) contained high water levels throughout 1993 and 1994 and still contained 4.9 m in August 1995. Lake Arrow (#4) was dry by December 1992 (maximum level 50 cm).. Black Flag Lake (#15) was dry by January 1994 (maximum level 1.7 m). Lake Noondie (#20) had a maximum depth of approximately 1.0 m; it was mostly dry by January 1993 except for some arms of the lake that retained water until April 1993 (David Lefroy pers. comm.). Lake Mason (#23) held water until April 1993 and reached a maximum depth of 3.5 m (Allan Humphries pers. comm.). There are no data on depth or duration of inundation of other lakes in this study.

The waterfowl recorded on each of the 23 wetlands surveyed are shown in Table 2 and also indicated are the number of visits, breeding records and wetland types. Some lakes that were only assessed from the air and for which there are few species records are omitted from this table. This study recorded 35 of the 52 water-

Table 2 Waterfowl occurrence on south-eastern wetlands 1992–93. B = breeding record. X = species recorded

Wetlands	1 Fitzgerald Lagoon	2 Lake Wannaway	3 Lake Cowan	4 Lake Arrow	5 Lake Douglas	6 Lake Hannans	7 Canegrass Swamp	8 Lake Miranda	9 Rowles Lagoon	10 King of the West	11 Lignum Swamp	12 Brown Lagoon	13 Lake Carnage*	14 Malcolm Dam	15 Black Flag Lake	16 Lake Barlee	17 Galah Rock Lake	18 Lake Ballard	19 Lake Raeside	20 Lake Noondie	21 Pinnacles St'n Lake	22 Lake Walton	23 Lake Mason
Type (S)	B,10	B,8	B,12	B,8	C,2	B,8	B,10	B,8	B,6, 13,14	B,8	B,13	B,6	B,6, 14	C,2	B,8	B,8	B,8	B,8	B,8	B,8	B,8	B,8	B,8
No. Visits	1	6	9	17	5	4	5	3	13	4	1	2	2	2	6	2	1	1	1	1	1	1	1
Blue-billed Duck									X			X	X										
Musk Duck									B			B	X										
Freckled Duck									B		X	B	X										
Black Swan		B		B		B		B	B	B		B	B	X	X	B		X	B	X	B	X	B
Aust. Shelduck	B	B	B	X		B		X	X	B		B	X		X	B	X	X	X	X	X	X	X
Aust. Wood Duck		X	X				X		X				X		X	X					X		
Pacific Black Duck	X	X	X	X	X	X	X		X			X	X		X	X		X					
Australasian Shoveler		X	X	X			X	X			X												
Grey Teal	X	X	B	X	B	X	X	B	B	X		B	B		X	X	B	B	X	X	X	X	X
Chestnut Teal	X		X			B																	
Pink-eared Duck		X	B						X		X	B	B		X	X							
Hardhead		X					X	X	X			X	X										
Australasian Grebe									B														
Hoary-headed Grebe	X	X	X	B	X		B	B	X	X	B	X	X	X	X	B	X						X
Little Pied Cormorant									X														
Little Black Cormorant									X														
White-faced Heron		X	X	X	X	X			B			X	X		X	X	X	X	X	X		X	
White-necked Heron			X	X	X	X	X							X	X				X				
Great Egret				X																			
Straw-necked Ibis				X		X												X	X				
Yellow Billed Spoonbill					X				X														
Aust. Spotted Crake							B				X												
Black-tailed Native Hen		X	X		X		X		X		X		X	X	X	X							X
Eurasian Coot	X	X	X		X	X	X	X	B			X	B		X						X		
Black-tailed Godwit			X						X														
Common Greenshank		X	X			X							X										
Black-winged Stilt				B		X		B		X		X	B	X	X								X
Banded Stilt				X						X					X	B		X	X				
Red-necked Avocet				B		X		B		X				X	X	X				X			X
Red-capped Plover				X		X		X		B			X	X	X	X							X
Black-fronted Dotterel		X							X			X	X										
Hooded Plover				X												X		X					
Red-kneed Dotterel				B		X			B														
Gull-billed Tern								X															X
Whiskered Tern								X	X			B	X	X	X								

*Includes data from Clear & Muddy Lakes

fowl species reported from the south-east interior by Storr (1986).

Grey Teal, Black Swans and Australian Shelducks all had dependent young as early as May–June 1992, i.e. two months after the rainfall; they continued to breed throughout winter in spite of cold temperatures, although for June the minima were more than 1°C above normal (Bureau of Meterology 1992). Pink-eared Ducks apparently did not breed until the following summmer; possibly low inland winter temperatures, unlike in the south-west, were an impediment to rapid response breeding. Hoary-headed Grebes appeared to breed earlier (i.e. in winter) than in the south-west and Red-kneed Dotterels also began breeding in July. Red-necked Avocets and Banded Stilts began breeding in June though the latter may have started earlier. All the above species continued to have dependent young throughout spring, with Coots and Red-capped Plovers first having clutches in August. More species bred in November than in other months. Chestnut Teal, Freckled Ducks, Pink-eared Ducks and Musk Ducks appeared not to breed until summer.

Annotated list of species

Nomenclature follows Christidis & Boles (1994) and description of clutch or brood size follows Storr (1986). Thus, C/4 (1), for example, indicates one clutch of 4 eggs, B/5 (3) indicates three broods each with five dependent young.

Oxyura australis Blue-billed Duck

Very restricted (recorded on three wetlands #9, 12, 13) and rare; only recorded as solitary birds; the least frequently observed anatid during this project. Only on freshwater wetlands.

Biziura lobata Musk Duck

Very restricted (recorded on three wetlands #9, 12, 13) and rare; additionally on Wangine Lake in September 1992, Michael Blythe (pers. comm.). Fresh-brackish water only. Breeding records: C/7(1), C/8(1). Deep, cup-like nests were in lower branches of Teatree *Melaleuca xerophila* and Lignum *Muehlenbeckia cunninghamii* shrubs approximately 40 cm above water.

Stictonetta naevosa Freckled Duck

Restricted (recorded on four wetlands #9, 11, 12, 13) but locally common (Rowles Lagoon system only). Only recorded on freshwater wetlands herein described as shrub dominated freshwater marshes with two dominant plant species; Lignum and Teatree. Data for Rowles Lagoon system indicate a post breeding increase from a minimum of nine pairs in November 1992 to a minimum of 85-90 individuals in August 1993. Breeding records: B/4 (1) downy young, Brown Lagoon, January 1993. B/1 (1) near-fledged young, Rowles Lagoon, February 1993.

Cygnus atratus Black Swan

Widespread (recorded on 17 wetlands) and fairly common. During the aerial survey Black Swans were most abundant in narrow constrictions in Lake Raeside where up to 50 could be seen at once. Here water depth was approximately 1m and green aquatic plant growth was prolific. Towards the end of 1992 there was a build-up to thousands of swans on Hannans and Black Flag Lakes. Breeding records: Nesting between late May and end of July 1992. Cygnets present between June 1992 and January 1993. B/8 (2), B/6 (2), B/5 (5), B/4 (2), B/3 (2).

Tadorna tadornoides Australian Shelduck

Widespread (recorded on 18 wetlands) and common. Flock size is clearly dependent upon drying and breeding cycle; smaller flocks (20-30 birds) present with abundant waters increasing to 400-500 (e.g. Hannans Lake in November 1992). Apparently also the last species to leave wetlands as they dry out. For example some 200-300 were present on Black Flag Lake in December 1993 when the depth was 20cm and the salinity 135 000 mg/l TDS. Two weeks later the Lake was completely dry. Breeding records: B/3 (1), B/4 (1), B/6 (2), B/7 (1), B/8 (2), B/9 (1) between June and December 1992.

Chenonetta jubata Australian Wood Duck

Fairly widespread (recorded on eight wetlands #2, 3, 7, 9, 13, 15, 16, 21) and abundant. Only recorded on freshwater wetlands or saline wetlands very early in their drying cycle. Usually grazing grasses or algal growth on littoral fringe. Maximum flock size approximately 150.

Anas superciliosa Pacific Black Duck

Widespread (recorded on 13 wetlands) but uncommon. Apparently only recorded on fresh or saline wetlands very early in their drying cycle; only present singly, pairs or in small flocks to five.

Anas rhynchotis Australasian Shoveler

Fairly widespread (recorded on six wetlands #2, 3, 4, 7, 8, 11) but uncommon. Usually recorded in pairs, one flock of 20.

Anas gracilis Grey Teal

Very widespread (recorded on 21 wetlands) and very common species; the most abundant anatid by several orders of magnitude in this area in 1992–93. Commonly seen in flocks of 40-60 on larger lakes. Monthly data for Rowles Lagoon indicate a decline in numbers in mid 1993 followed by a later increase as other wetlands dried out. Flock of approximately 100 present on Lake Wannaway just before it dried out in March 1994 when salinity was 64 000 mg/l TDS. Breeding records: B/2 (1), B/3 (1), B/5 (8), B/6 (5), B/7 (3), B/10 (2); all between May 1992 and January 1993.

Anas castanea Chestnut Teal

Very restricted (recorded on three wetlands #1, 3, 6) and rare. A flock of 20 on saline marsh 30 km north of Norseman. Breeding record: B/12 (1) on Hannans Lake in November 1992.

Malacorynchus membranaceus Pink-eared Duck

Fairly widespread (recorded on eight wetlands #2, 3, 9, 11, 12, 13, 15, 16) and common. Usually recorded in pairs, though flocks to 100 were occasionally recorded on Rowles Lagoon. Breeding records: C/1 (1) nest in hollow tree spout, November 1992. B/3 (1), B/4 (1), B/5 (1) December 1992 and January 1993.

Aythya australis Hardhead

Fairly widespread (recorded on six wetlands #2, 7, 8, 9, 12, 13) but rare. Only recorded singly and in pairs on freshwater wetlands.

Tachybaptus novaehollandiae Australasian Grebe

One record; a single bird in breeding plumage on Rowles Lagoon in October 1993.

Poliocephalus poliocephalus Hoary-headed Grebe

Widespread; (recorded on 17 wetlands) and locally abundant. Usually non-flocking, usually in small numbers but consistently throughout wetlands, occasionally flocks to 50, leaves saline wetlands before they become hypersaline. Breeding records: C/4 (1) October 1992; B/2 (3) June, October 1992, January 1993; B/1 (1) June 1992; B/4 (1) October 1992.

Phalacrocorax melanoleucos Little Pied Cormorant

Restricted and uncommon (only recorded on Rowles Lagoon) where two pairs were consistently present.

Phalacrocorax sulcirostris Little Black Cormorant

One record; a single bird on Rowles Lagoon in November 1992

Egretta novaehollandiae White-faced Heron

Widespread (recorded on 15 wetlands) and occasionally common; usually recorded singly or in pairs but present in flocks to 30 at western end of Lake Barlee and 20 on Lake Raeside. Breeding record: One nest in wooded swamp at Rowles Lagoon in October 1992.

Ardea pacifica White-necked Heron

Fairly widespread (recorded on eight wetlands (#3, 4, 5, 6, 7, 14, 15, 19) but uncommon. Only recorded as single birds.

Ardea alba Great Egret

One record; a single bird in peripheral saline marsh at Lake Arrow in August 1992.

Threskiornis spinicollis Straw-necked Ibis

Restricted (recorded on four wetlands #4, 6, 18, 19) and uncommon, on peripheral saline marshes, maximum flock size of six.

Platalea flavipes Yellow-billed Spoonbill

Very restricted (recorded on two wetlands #5, 9) and rare, recorded singly and as a pair.

Porzana fluminea Australian Spotted Crake

Very restricted (recorded on two wetlands #7, 11); and very rare species. The disused nest located by R. Jaensch and R. Vervest in Canegrass *Eragrostis australasicus* at Canegrass Swamp as part of this study is the first breeding record for this species in the south-east interior. Additionally recorded from Rowles Lagoon (Storr 1986).

Gallinula ventralis Black-tailed Native-hen

Widespread (recorded on 11 wetlands) and abundant. Always recorded in littoral vegetation of freshwater wetlands or saline wetlands early in their drying cycle.

Fulica atra Eurasian Coot

Widespread (recorded on 12 wetlands) and very abundant; arguably the most abundant waterfowl encountered during this project. Many thousands could be regularly counted on wetlands surveyed. In April 1993 as many wetlands were drying out elsewhere, between 10-20 000 Coots were present on Black Flag Lake. Breeding records: C/2 (1), C/5 (1), C/7 (2) between August 1992 and January 1993. Nests were in *Melaleuca xerophila*. B/1 (1), B/2 (2), B/3 (1) between November 1992 and January 1993.

Limosa limosa Black-tailed Godwit

Very restricted (recorded on two wetlands #3, 9) and rare. Both records were of solitary birds.

Tringa nebularia Common Greenshank

Restricted (recorded on four wetlands #2, 3, 6, 13); a flock of four on saline marsh 30 km north of Norseman in January 1993. Another flock of four birds was recorded on Wannaway Lake in January 1994.

Himantopus himantopus Black-winged Stilt

Fairly widespread (recorded on nine wetlands #4, 6, 8, 10, 12, 13, 14, 15, 23) and abundant. Recorded in relatively small flocks on saline and freshwater wetlands. Largest flock was 400-500 on Lake Arrow in November 1992, 80% of these were juveniles. Breeding record:- C/4 (6) October 1992, at Lake Arrow.

Cladorhynchus leucocephalus Banded Stilt

Restricted (recorded on six wetlands #4, 10, 15, 16, 18, 19) but locally very abundant. Observations from aircraft give some idea of relative abundance; for example approximately 4000-5000 Banded Stilt were present on Lake Ballard on 3 June 1992, there were 10 000-15 000 on Lake Barlee on the same day. One flock of 2000-3000 was present near islands 15 km north-east of Mt Elvire homestead. Between 2500-3000 were present on King of the West on 10 January 1993 following the drying of the breeding lakes. Breeding records:-apart from a small flock with flightless young on Lake Giles breeding was only confirmed for Lake Barlee. Typically many small groups of 3-4 parents were accompanied by 8-10 flightless young standing in shallow water or leading their young from the shore into the lake as the aircraft flew over.

Recurvirostra novaehollandiae Red-necked Avocet

Fairly widespread (recorded on nine wetlands #4, 6, 8, 10, 14, 15, 16, 20, 22) and moderately abundant. Usually in pairs or small flocks to

20. Breeding records: nesting in June and October 1992, clutch size unknown.

Charadrius ruficapillus Red-capped Plover

Fairly widespread (recorded on nine wetlands #4, 6, 8, 10, 13, 14, 15, 16, 22) and abundant. Only recorded on lakes with wide, littoral mud flat or fringe, sometimes in flocks to 400-500. Breeding record: C/2 (1) in August 1992.

Elseyornis melanops Black-fronted Dotterel

Restricted (recorded on four wetlands #2, 9, 12, 13) and rare. Unlike the Red-kneed Dotterel this species was only recorded in dense fringing shrubland on still moist mud.

Thinornis rubicollis Hooded Plover

Very restricted (recorded on three wetlands #4, 16, 18) and rare, recorded singly and in pairs on exposed littoral mud flats.

Erythrogonys cinctus Red-kneed Dotterel

Very restricted (recorded on three wetlands #4, 6, 9) and uncommon. Present in pairs and flocks to 40 in more open situations (e.g. sand bars and mud flats) than Black-fronted Dotterel. Breeding records: C/4 (5) July 1992, nests in *Halosarcia sp.* shrubs. C/1 (1), C/2 (1), November 1992, nests in *Cratystylis subspinescens* shrubs.

Sterna nilotica Gull-billed Tern

Very restricted, (recorded on two wetlands #8, 23) a solitary bird on Lake Mason in September 1992 and a flock of six on Lake Miranda in November 1992 (Mike Craig pers. comm.).

Chlidonias hybridus Whiskered Tern

Fairly widespread (recorded on six wetlands #8, 9, 12, 13, 14, 15) and uncommon. Only recorded on freshwater wetlands or saline wetlands very early in their drying cycle. Data from Rowles Lagoon indicate they are very nomadic, i.e. either present or absent in flocks to 30 with no apparent pattern. Here they feed on Dragonflies. Breeding record: fledged juveniles with brown blotchy plumage on Brown Lagoon in January 1993.

Discussion

The many species of waterfowl that use the numerous wetlands of the south-east interior following a significant rainfall event have not previously been reported, perhaps due to the infrequency of these events, the remoteness of the wetlands and a lack of observers. Serventy & Marshall (1957) reported inland breeding following cyclonic rains in 1953 and extensive summer rains in 1955; Curry (1979) reported usage, including that by migratory shorebirds, of Lake Violet near Wiluna. Storr (1986) summarised available distributional and breeding data. Burbidge & Fuller (1982) and Pearson (1989) reported Banded Stilt breeding on salt lakes in this region.

Gentilli & Bekle (1983) hypothesised that these occasional inundation events emulate the previous permanent inland habitat for Grey Teal during a wetter Tertiary climate. This is consistent with the results of this study; Grey Teal breed at more sites and reach much higher numbers than any other anatid. Other workers have reviewed movement and breeding patterns of arid zone ducks, e.g. Briggs (1992) indicated protracted breeding and relatively long incubation periods for arid zone ducks also supporting the suggestion that they are adapted to a previously wetter inland climate. Other recent data on waterfowl usage of wetlands in the south-west of Western Australia are Halse et al. (1993) and Goodsell (1990).

Data for the onset of breeding in the south-east interior are in general agreement with those species also known to be early breeders following rainfall in the south-west of Western Australia reported by Halse & Jaensch (1989). Although most wetlands dried out during summer 1992–93, some maintained relatively high water levels that were sufficient to allow access to breeding habitat. These included Rowles Lagoon system, Brown Lagoon and Lake Wannaway. In spite of adequate water levels and water quality, breeding in the second year was uncommon. This suggests that nutrient depletion may act as a factor limiting subsequent breeding in inland wetlands subject to episodic flooding. Briggs (1992) has indicated that wetlands subject to alternate flooding and complete drying, as is the case here, have initial nutrient enhancement due to the more complete breakdown of organic matter associated with the flooding-drying cycle. If this is the case here it is likely that the high nutrient availabilty required for breeding is relatively short-lived and does not extend into a second season. Crome (1986) examined this idea with data from swamps near Hay in arid New South Wales and concluded that the critical factor triggering breeding was the massive production of aquatic invertebrates particularly chironomids following the drying cycle or drawdown of the swamps the preceeding year. He hypothesised that 'nesting activity is positively related to the rate at which food items, i.e. insects or seeds, can be ingested' and that the usual correlates of nesting, i.e. changing water levels and photoperiod, are only minor influences. This is consistent with the conclusions of Serventy & Marshall (1957, p. 124) who, because the rainfall events they described also occurred in the south-west, were able to demonstrate 'a habitational gradient of effect' whereby even with unseasonal rain, high rainfall wetlands do not respond similarly.

We have only very limited data on food availability on these wetlands from a surface sample collected at night on Rowles Lagoon that revealed that *Daphnia carinata* was an extremely abundant invertebrate. Our observations are consistent with the hypothesis that breeding activity on arid, intermittent wetlands is primarily governed by nutrient availability rather than photoperiod or water level. The number of breeding species per wetland is influenced by depth and wetland bathymetry. For example at the Rowles Lagoon system (#9, 13) more species were breeding than elsewhere because at peak flood, inundated shrubland and woodland as well as exposed mud banks were present.

Although the opportunistic nature of the fieldwork and the size and remoteness of most of these lakes precluded accurate, comparative data on abundance and species richness, it is clear that at least initially they did support a wide range of species. This was particularly so when water levels were high, salinity low and peripheral saline marshes were inundated. As levels dropped so did species richness; however, very high numbers of some species remained. It is evident that before they become hypersaline many of these lakes provide both breeding habitat for waterfowl and adequate food resources to sustain breeding.

Although our data on salinity of these wetlands are not extensive they do support previous work which indicates that salinity is a primary determinant of wetland utilization. In the south-east interior more species were recorded on freshwater wetlands (see Table 2) but more individuals were present on saline ones, although the saline wetlands were mostly much larger than the freshwater ones. Elsewhere in arid Australia, where a more valid comparison can be made, saline wetlands have been found to support more individuals but fewer species (Kingsford & Porter 1994). In the south-west Goodsell (1990) reported that 90% of all broods were on wetlands with salinities of less than 15 300 mg/l TDS. In the present study only Australian Shelducks and Grey Teal were able to withstand the extremely high salinities encountered on saline wetlands prior to their drying out.

Conservation and management of arid inland lakes

Because nearly all saline wetlands occur either within pastoral leases or as vacant crown land, there are few statutory mechanisms for their protection, although the Western Australian Wildlife Conservation Act protects all fauna irrespective of land tenure. Only Lake Walton, Lake Goongarrie and the southern portion of Lake Marmion occur within lands managed for conservation purposes.

One potential threat is the degradation of peripheral chenopod shrubland by grazing. Other potential impacts are associated with mining by either direct disturbance to lake beds or by leachate discharge from tailings dams or processing works on lake shores or by drawdown of groundwater for mineral processing. Dunlop (1990) has indicated both positive and negative aspects of mining on 'desert' lakes.

Drill pads and causeways constructed for exploration of underlying ore bodies often provide nesting habitat for waterfowl but, as Dunlop (1990) points out, these must be separated from the shoreline to prevent access of feral predators. Cyanide, which is discharged following the extraction of gold from ore, can persist in hypersaline water at higher levels than in water of lesser salinity. Discharge of hypersaline ground water from de-watering open pits or mine shafts into lakes, even if it is not contaminated, should only be undertaken if it does not affect the salinity balance needed by aquatic invertebrates and their successional cycle. It is unlikely that hypersaline re-charge is desirable because the natural re-charge of these lakes is by relatively fresh water and the invertebrate cycle is probably dependent upon a gradual increase in salinity.

Observations in the south-east arid interior suggest that wetlands here are only used to a minor extent by migratory shorebirds. Only Greenshanks and Black-tailed Godwits were recorded in this study; sightings were few and were confined to summer.

The principal conclusion arising from this study is that the waterfowl themselves are probably an expression of ecological processes which go on even when the lakes are dry and appear devoid of life. These lakes are a significant part of the landscape and contribute significantly to the biodiversity of the region and should be managed as such.

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