Journal of the Royal Society of Western Australia, 83:17-28, 2000

Monitoring aquatic invertebrates and waterbirds at Toolibin and Walbyring Lakes in the Western Australian wheatbelt

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Manuscript received May 1999; accepted December 1999

Abstract

Toolibin and Walbyring Lakes are adjacent wetlands in the Western Australian wheatbelt, a region with widespread secondary salinization. Salinity of water in Toolibin has increased in recent years and a Recovery Plan is being implemented to reduce salt loads; Walbyring is also threatened by salinization. As part of a monitoring program to evaluate success of recovery actions, waterbirds and aquatic invertebrates were sampled at both wetlands in December 1996. Toolibin Lake had the richer waterbird community, while Walbyring Lake contained more invertebrate species. Results suggested that gross changes in wetland communities can be detected by monitoring based on an annual waterbird survey and a pair of invertebrate samples collected with 110 µm and 250 µm-mesh pondnets. Comparison of waterbird data from Toolibin in 1996 with earlier surveys showed increases in salinity to 1996 affected occurrence of only a few species. Comparison of invertebrate data from both wetlands in 1996 with surveys in 1992 provided little evidence that increased salinities affected invertebrates, other than water mites. It is suggested that the freshwater fauna of the wheatbelt is comparatively salt-tolerant and substantial changes in community composition will be seen only when salinities exceed 10 000 mg L^{-1}.

Keywords: aquatic invertebrates, waterbirds, monitoring, salinity, wetland, monitoring

Introduction

Toolibin and Walbyring Lakes, approximately 40 km east of Narrogin in the wheatbelt region of south-west Western Australia, are part of a series of seasonally or intermittently flooded wetlands forming the headwaters of the Arthur River, which then flows into the Blackwood River. For many years, the two wetlands were popular duck-hunting sites but Toolibin was closed to hunting in 1974 and Walbyring in 1992. Since then, management has been focused on conservation values of the wetlands (Northern Arthur River Wetlands Committee 1987; Froend *et al.* 1997). Toolibin (296 ha) is larger than Walbyring (53 ha) but they are superficially similar. Both support extensive stands of *Casuarina obesa* and *Melaleuca* trees across the lake-bed as well around the shoreline (Froend *et al.* 1987; Halse *et al.* 1993a), although stands are better developed at Toolibin and were one of the justifications for it being listed in 1990 as a Wetland of International Importance under the Ramsar Convention (Froend *et al.* 1997). Another justification was the waterbird community at Toolibin. Up to 1995, 49 waterbird species had been recorded, with evidence of breeding by 25 species (Froend *et al.* 1997). Doupé & Horwitz (1995) also found what appeared to be, in the absence of comparative data from other wheatbelt wetlands, a rich invertebrate fauna at Toolibin, as well as Walbyring, and suggested that regular sampling of aquatic invertebrate assemblages could be an effective way of monitoring ecological condition of these wetlands.

Secondary salinization is probably the most serious threat to conservation of wetland biota in the Western Australian wheatbelt (see Williams 1987). Over the past 60 years, almost all wetlands in the region have become saline, with resultant death of trees that initially grew on the lake-bed or low on the shoreline (Halse *et al.* 1993a). Toolibin and Walbyring are exceptional in that they have remained comparatively fresh, perhaps because of unusual hydrogeology. Nevertheless, salinity is increasing at Toolibin and, to a lesser extent, at Walbyring and the biological communities at both are now threatened (Froend *et al.* 1997). To reduce the threat at Toolibin, land on the western side of the lake was bought for conservation purposes and planted with trees in 1988. In addition, drainage in the catchment was altered to reduce the salinity of surface water flowing into the lake, and groundwater pumps were installed to lower the water-table beneath it (Halse 1988; Hooper & Wallace 1994). A Recovery Plan recommended that, in association with these recovery actions, biological attributes of Toolibin should be monitored because they are the reason the lake is being conserved and provide the ultimate measure of success of recovery actions (unpublished report, R Froend & A Storey, Department of Conservation and Land Management, 1996).

Two biological attributes recommended for monitoring are waterbirds and aquatic invertebrates. It was proposed that Walbyring be sampled as well as Toolibin because, in recent years, it has been the fresher of the two wetlands (unpublished data, J A K Lane, Department of Conservation and Land Management) and Doupé & Horwitz (1995) found it contained more species of aquatic invertebrates. This paper presents results of waterbird and invertebrate monitoring in December 1996 with three objectives. First, to provide data on condition of the two wetlands in 1996. Toolibin has long been recognised as having high conservation values and being worthy of management intervention to maintain these values (Halse 1988; Hooper & Wallace 1994). It may serve as a useful benchmark when assessing conservation values of other wheatbelt wetlands. Second, to evaluate whether the monitoring methodologies reliably characterised faunal communities of the wetlands and enabled changes in ecological character to be recognised. Third, to examine whether increased salinity has altered waterbird and aquatic invertebrate communities at Toolibin and Walbyring.

Methods

After drying during the previous summer, Toolibin and Walbyring flooded in July 1996 and retained water in early December 1996. Waterbirds were surveyed by GBP on foot and by canoe on 4 December 1996. Binoculars and a spotting scope were used and comprehensive waterbird counts were obtained for both wetlands. Incomplete waterbird surveys were made by SAH on 18 December 1996 by scanning with a spotting scope from various sectors of the wetlands while sampling invertebrates.

Aquatic invertebrates were sampled on 18 December. Three pairs of samples (each pair constituting one replicate) were collected from different sectors of Toolibin (Fig 1) to maximise the range of habitats sampled, using pond-nets with mesh sizes of 110 µm and 250 µm. Each replicate consisted of 50 m of sweeping through the water column, submerged vegetation, bottom sediments and scraping past logs and tree trunks with the 250 µm-mesh pond-net and 20 m of sweeping for zooplankton with the 110 µm-mesh pond-net. The 250 µm-mesh sweeps were not continuous; they were collected over a distance of about 200 m. In Walbyring, 250 µm-mesh sweeps were collected from three sectors but a matching 110 µm-mesh zooplankton sample was taken only in sector 2 (Fig 1).

Invertebrate samples were immediately preserved in 70 % alcohol and returned to the laboratory for sorting. In the laboratory, each 250 µm-mesh sample was washed and larger pieces of organic debris were removed before the sample was poured through three sieves with 2 mm, 500 µm and 250 µm mesh size. The portion of the sample retained in each sieve was sorted under a dissecting microscope and all taxa were identified to the lowest level possible (usually species). The 110 µm-mesh samples were sorted without sieving.

In each sector of Toolibin where invertebrates were sampled, conductivity, pH, dissolved oxygen and temperature were measured *in situ* with a WTW Multiline P4 meter and water samples were collected for laboratory measurement of total dissolved phosphorus, total dissolved nitrogen, chlorophyll *a,b,c* and phaeophytin. Extra samples were collected in the eastern sector to determine total dissolved solids (TDS) by gravimetry, ionic composition, colour and turbidity. Analytical methods described by Eaton *et al.* (1995) were used. At Walbyring, water quality parameters were measured only in sector 2.

Analysis

Long-term trends in salinity at Toolibin were examined using depth and salinity data collected two-monthly

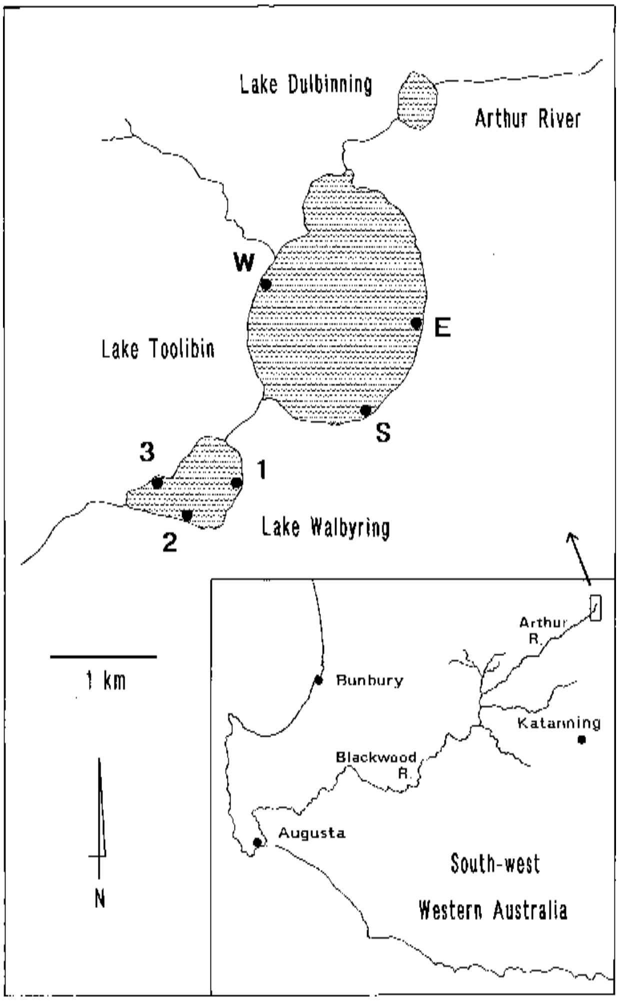

Figure 1. Sectors sampled for invertebrates at Toolibin and Walbyring Lakes on the Northern Arthur River, south-western Australia, and connection of the lakes with the Blackwood River.

between 1981-85, and each September and November subsequently, by J A K Lane at the Department of Conservation and Land Management depth gauge (Lane & Munro 1983; unpublished data, J A K Lane, CALM).

Long-term changes in the waterbird community at Toolibin were examined using the December 1996 surveys and six previous spring (August-October) surveys identified by Froend *et al.* (1997) as representing pre-salinization (combined data from surveys between 1965-74) and current baseline (1975, 1981-84) communities. The 1990 survey that Froend *et al.* (1997) designated as current baseline was an outlier (see Fig 4 in Froend *et al.* 1997) and was omitted from analyses. Relationships between number of species recorded and calendar year or salinity at time of survey were examined by correlation analysis. The relationship between surveys, in terms of species composition, was examined firstly by classifying surveys, using unweighted pair group arithmetic averaging in the PATN analysis package with presence/absence waterbird data, the Czekanowski association measure and a β-value of -0.1 (Belbin 1993). Presence/absence data were used because the composite pre-salinization survey represented a species list rather than reliable counts. Secondly, surveys were plotted on an ordination using semi-strong-hybrid multi-dimensional scaling with orthogonal axis rotation.

The ability of single surveys to distinguish waterbird communities of different wetlands, in an ordination, was examined by including data from Walbyring and earlier surveys of Lakes Chandala, Cooloongup and Eganu and a small wetland on the eastern side of Watheroo National Park in the ordination of Toolibin surveys. Chandala, a freshwater wetland with *Melaleuca rhaphiophylla* trees growing across the lake-bed, and Cooloongup, a shallow saline wetland with freshwater seeps and extensive sedge beds, are on the Swan Coastal Plain and were surveyed in October 1990 and 1991 (Storey *et al.* 1993a). Eganu, formerly a *Casuarina obesa/Melaleuca* wetland and now severely salinized, and the Watheroo wetland, a brackish *Casuarina obesa* wetland in which water levels have risen markedly over the last 20 years (see Halse 1981), were surveyed during November 1989 and 1991 (unpublished data, S A Halse).

For invertebrate sampling, the amount of fidelity shown by replicates to composite samples in a classification of Toolibin and Walbyring invertebrate data was used to evaluate whether one replicate (a single pair of 250 µm and 110 µm sweeps) adequately characterised the invertebrate communities of the two wetlands. Composite samples comprised all taxa collected in the three replicates for each wetland. The classification was done using unweighted pair group arithmetic averaging, presence/absence data, the Czekanowski association measure and a β-value of -0.1. Sampling effort was slightly lower in the two Walbyring replicates without 110 µm-mesh samples (sectors 1 and 3) than other replicates.

Whether single replicates were likely to detect gross changes in the invertebrate communities of Toolibin and Walbyring was examined by ordinating data from the two lakes with data from Chandala, Cooloongup and a small wetland near Gingin. These three wetlands were sampled in October-November 1989 and 1990 by randomly taking six 10 m sweeps with a 250 µm-mesh pondnet from around the wetland margin (Davis *et al.* 1993). Semi-strong-hybrid multi-dimensional scaling with orthogonal axis rotation was used. Replicates were not compared with earlier data from Toolibin and Walbyring (Doupé & Horwitz 1995), to examine whether communities had changed over time, because of very substantial differences in sampling methodology.

Adequacy of the invertebrate sampling methods employed at Toolibin and Walbyring, in terms of providing a complete species list for the taxa identified, was assessed using the equation of Kay *et al.* (1999) to estimate total numbers of invertebrate species present in each wetland, and number of replicates required before another collected fewer than one extra species;

$$a_i = a_{i-1} \times (a_3/a_2)$$

where a_i was the average number of additional species collected in the i^{th} replicate and a_2 and a_3 were the average number of additional species collected in the second and third replicates, respectively.

Results

Water chemistry

Maximum water depths on 4 December 1996 were about 0.8 m at Toolibin and Walbyring. Depths were reduced by about 0.1 m on 18 December 1996 (Table 1), when salinity at Toolibin varied from 9400 mg L^{-1} TDS on the eastern side to about 12 500 mg L^{-1} (estimated from conductivity, see Table 1) on the more saline western side. Walbyring had a salinity of 2800 mg L^{-1} TDS. Ionic composition of both wetlands was dominated by sodium chloride. Levels of nutrients and chlorophyll in Toolibin were low and differences between sites were small. There was a mild algal bloom in Walbyring (Table 1). Salinities measured at Toolibin during previous waterbird surveys between 1975 and 1990 varied from 960-3800 mg L^{-1} TDS; maximum depth was 0.8 m in 1975 and 1988 and ranged

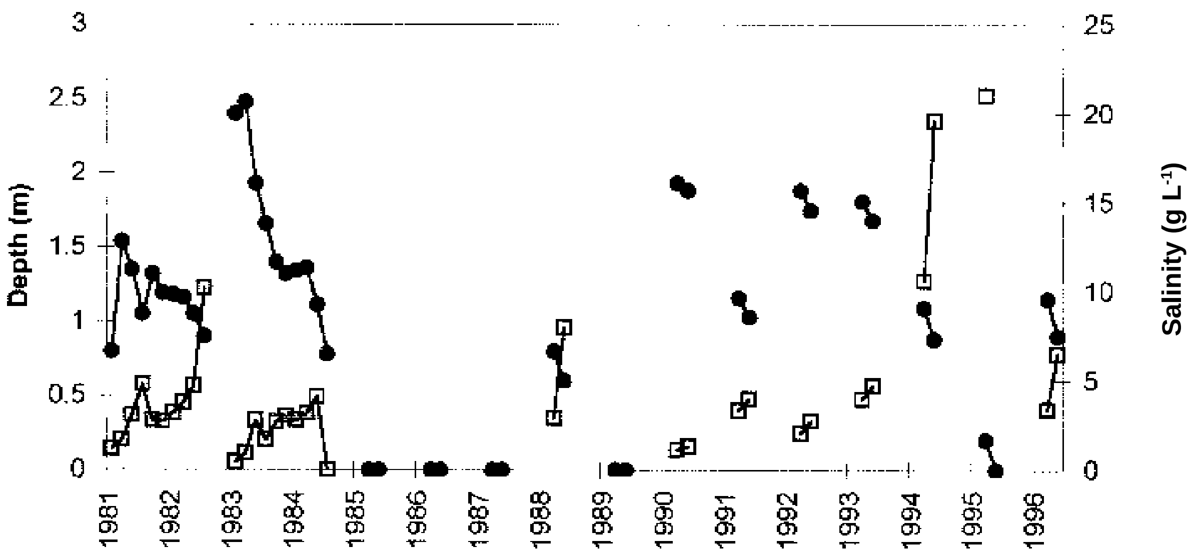

Figure 2. Depth (●) and salinity (□) at Toolibin Lake at 2-monthly intervals from July 1981 to May 1995 and each September and November thereafter (unpublished data, J A K Lane, Department of Conservation and Land Management), except in 1996 when December data are used instead of November (modified from Froend *et al.* 1997)

Table 1

Chemical and physical measurements of water in sectors of Toolibin and Walbyring Lakes on 18 December 1996 (see Fig 1 for location of sectors).

	Toolibin East	Toolibin South	Toolibin West	Walbyring 2
Lake Depth (m)	0.66			0.74
pH	7.0	7.1	7.0	6.9
Dissolved Oxygen (%)	217	217	215	154
Temperature (°C)	32	31	26.5	27
Colour (TCU)	54			89
Turbidity (NTU)	1.2			66
Total Dissolved Solids (mg L^{-1})	9400			2800
Conductivity (mS m^{-1})	1520	1690	2020	470
Alkalinity (mg L^{-1})	95			220
Ca^{2+} (mg L^{-1})	280			78
Mg^{2+} (mg L^{-1})	380			81
Na^{+} (mg L^{-1})	2800			800
K^{+} (mg L^{-1})	47			23
CO_3^{2-} (mg L^{-1})	<2			<2
HCO_3^{-} (mg L^{-1})	120			280
$C1^{-}$ (mg L^{-1})	5300			1300
SO_4^{2-} (mg L^{-1})	570			74
SiO_2 (mg L^{-1})	4.0			14
Total Dissolved Nitrogen (mg L^{-1})	4.2	3.6	4.0	3.0
Total Dissolved Phosphorus (mg L^{-1})	0.01	0.01	0.01	0.03
Chlorophyll *a,b,c* (mg L^{-1})	0.003	0.001	0.006	0.036
Phaeophytin (mg L^{-1})	<0.001	<0.001	<0.001	0.007

Table 2

Counts of waterbird species recorded at Toolibin and Walbyring Lakes in December 1996.

		Toolibin 4.xii.96	Toolibin 18.xii.96	Walbyring 4.xii.96	Walbyring 18.xii.96
Blue-billed duck	*Oxyura australis*			2	
Musk duck	*Biziura lobata*			6	4
Freckled duck	*Stictonetta naevosa*	1	25	33	
Black swan	*Cygnus atratus*	1	2	1	
Australian shelduck	*Tadorna tadornoides*	74	97	5	57
Australian wood duck	*Chenonetta jubata*	8		20	20
Pacific black duck	*Anas superciliosa*	17	3	44	1
Australiasian shoveler	*Anas rhynchotis*	4	56	8	
Grey teal	*Anas gracilis*	194	1162	430	367
Pink-eared duck	*Malacorhynchus membranaceus*	154	134	300	8
Hardhead	*Aythya australis*	25	60	36	58
Hoary-headed grebe	*Poliocephalus poliocephalus*	14	1	28	22
Little pied cormorant	*Phalocrocorax melanoleucos*	10	1		
Great cormorant	*Phalocrocorax carbo*	1			
White-faced heron	*Ardea novaehollandiae*	5	2	6	
White-necked heron	*Ardea pacifica*	2	1		
Great egret	*Egretta alba*		1		
Nankeen night heron	*Nycticorax caledonicus*	5			
Yellow-billed spoonbill	*Platalea flavipes*	26	2	1	4
Dusky moorhen	*Gallinula tenebrosa*			1	2
Eurasian coot	*Fulica atra*	201	281	6	12
Marsh sandpiper	*Tringa stagnatilis*	1			
Black-winged stilt	*Himantopus himantopus*	51	19		
Red-kneed dotterel	*Erythrogrys cinctus*	60	11		
Unidentified shorebird[1]			1		
Number of birds		**854**	**1859**	**927**	**555**
Number of species		**20**	**18**	**16**	**11**

[1]Probably a Marsh Sandpiper but excluded from the ordination.

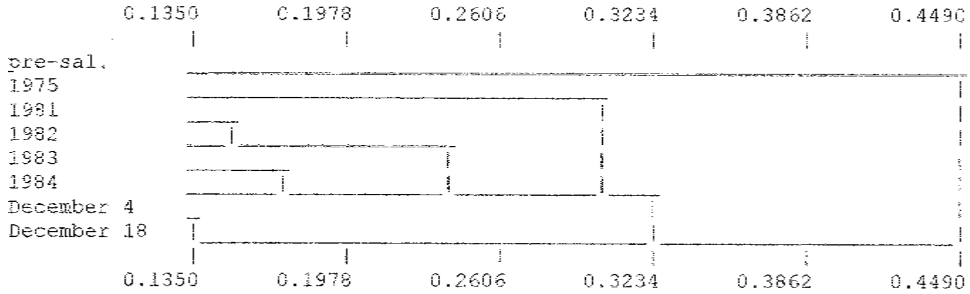

Figure 3. Classification of 8 waterbird surveys at Toolibin Lake, based on species composition. The pre-salinization survey contains composite data from 1965-74 and the December surveys were conducted in 1996.

from 1.2-2.0 m during other surveys (unpublished data, J A K Lane, CALM).

Between 1993 and 1995, salinity levels in Toolibin increased compared with the previous 12 years (Fig 2). This trend lessened in 1996 after the installation of a separator on the inflow channel so that only fresh water flowed into the lake. Toolibin did not overflow into the Arthur River and, therefore, export salt, between 1993 and December 1996 (unpublished report, R Froend & A Storey, Department of Conservation and Land Management, 1996).

Waterbirds

A total of 854 waterbirds of 20 species were recorded at Toolibin on 4 December 1996, and 1858 waterbirds of 17 species were recorded on 18 December 1996. Equivalent counts at Walbyring were 927 waterbirds of 16 species on 4 December, and 555 waterbirds of 11 species on 18 December (Table 2). Assuming the unidentified pale sandpiper-like shorebird seen at Toolibin on 18 December was a marsh sandpiper, all but three species recorded on 4 December were seen during the second survey. One additional species, the great egret, was seen.

The most interesting waterbird sightings were freckled ducks at Walbyring on 4 December and Toolibin on 18 December, the marsh sandpiper at Toolibin on 4 December and dusky moorhens at Walbyring during both surveys (Table 2). Marsh sandpipers have not been recorded previously at Toolibin, although they are quite common around fresh and brackish wetlands in south-western Australia (Jaensch *et al.* 1988), and the sighting increased the species list for Toolibin to 50. Similarly, dusky moorhens have not been recorded previously at Walbrying or Toolibin. Freckled ducks occur regularly at Toolibin, with 600 being recorded in 1981 (Jaensch *et al.* 1988) and several hundred in 1960 (see Froend *et al.* 1997), but the count of 25 on 18 December represented a significant concentration in south-western Australia (Halse *et al.* 1995). The 33 freckled ducks seen at Walbyring on 4 December were probably the same flock as seen at Toolibin two weeks later.

Numbers of waterbird species recorded at Toolibin each survey were not significantly correlated with calendar year ($r = -0.58$, $n = 8$, $P = 0.13$) or salinity at the time of survey ($r = -0.37$, $n = 8$, $P = 0.48$), assuming the pre-salinization salinity was 1000 mg L^{-1}. The largest differences in community composition were between the

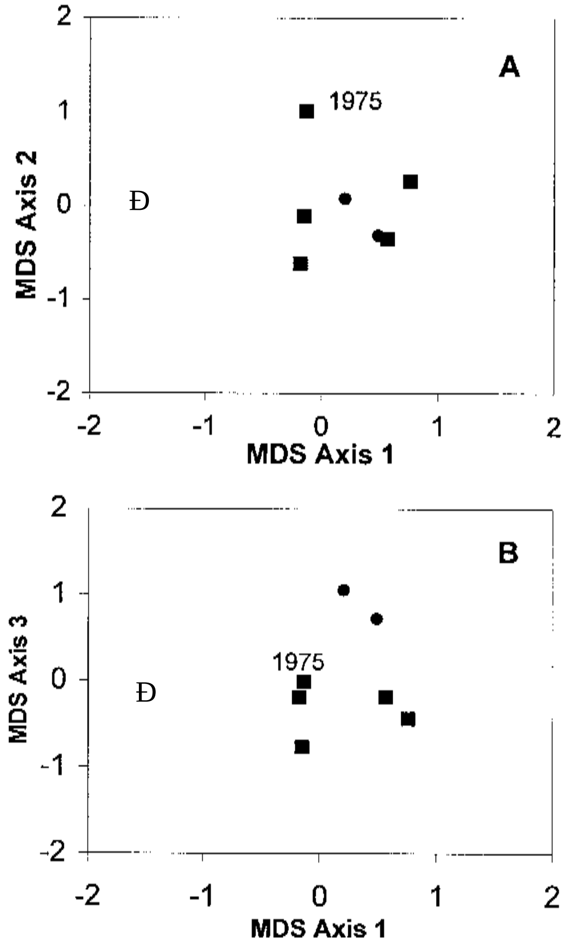

Figure 4. Three-dimensional ordination of 8 waterbird surveys from Toolibin Lake, based on species composition, showing relative positions of pre-salinization (Ð), baseline (1975, 1981-84,) and 1996 surveys ( ); stress = 0.10.

pre-salinization and subsequent surveys (Figs 3 & 4). This may be partly artefactual because the pre-salinization survey was created by combining records from many small surveys between 1965-74 and comprised a number of species (37) that was higher than likely to be seen in any single survey either pre- or post-salinization. A "post-salinization survey" created by combining the 7 surveys between 1975-96 would have recorded a similar number of species (35). Nevertheless, 11 species recorded pre-salinization were not recorded in subsequent surveys and 9 species recorded post-salinization were not

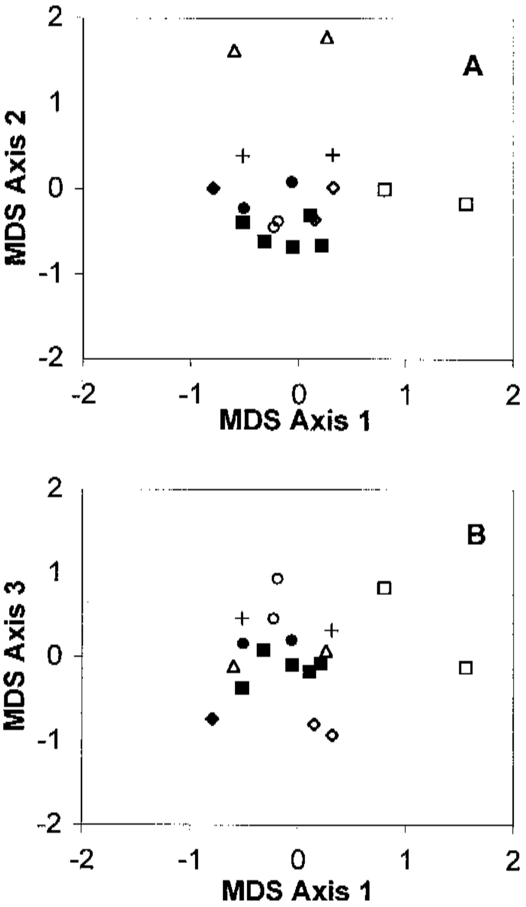

Figure 5. Three-dimensional ordination of waterbird surveys from Toolibin Lake (presalinity, ▯ ; baseline, ▯ ; 1996, ⇑), Walbyring Lake (O), Lake Chandala ( ), Lake Cooloongup (Δ), Lake Eganu (▯) and a small wetland (+) on the eastern edge of Watheroo National Park (see text for details), showing separation of Eganu, Cooloongup and Chandala from the other, *Casuarina obesa*-dominated wetlands; stress = 0.14.

recorded earlier. Some of these differences may have resulted from sampling error but the post-salinization disappearance from Toolibin of species with strong preference for fresh water, such as Australasian bitterns and purple swamphens, appears to have been a real response to salt-induced habitat change at the lake (Froend *et al.* 1997).

Although grouped together by Froend *et al.* (1997), the 1975 and early 1980s baseline surveys had slightly different waterbird communities (Figs 3 & 4). Further change was observed in 1996, suggesting that a series of changes have occurred in the waterbird community at Toolibin over the last 30 years. Species that were common in pre-salinization and baseline surveys but absent from 1996 were musk ducks (all earlier surveys), great crested grebes (five-sixths of surveys), Australasian grebes (two-thirds), blue-billed ducks and little black cormorants (half). None of these species commonly occur in very saline water and, other than little black cormorants, rarely occur at salinities >10 000 mg L^{-1} (see Jaensch *et al.* 1988; Halse *et al.* 1993b).

Compared with the large differences between wetland types, changes in the waterbird community at Toolibin have been relatively small (Fig 5). The waterbird community of Toolibin was readily distinguished from that of the *Melaleuca*-dominated Chandala, heavily salinized Eganu and sedge-lined Cooloongup. The communities of Walbyring and Watheroo, both *Casuarina obesa* wetlands in the early stages of salinization, were fairly similar to Toolibin. Prior to salinization, Eganu contained extensive stands of *Casuarina obesa* and *Melaleuca* sp and its waterbird community probably gives an indication of what will occur at Toolibin (and Walbyring and Watheroo) if salinization continues.

Aquatic invertebrates

A total of 83 species of aquatic invertebrate were collected on 18 December, with 52 and 63 species recorded in Toolibin and Walbyring, respectively (Appendix). Rotifers were present but were poorly collected because mesh sizes were too large. Fauna in the sweeps was dominated by insects (65 % of species), with crustaceans accounting for another 28 %, annelids 5 % and molluscs 2 %. Beetles (28 % of insect species) and chironomids (19 %) were the major groups of insects, while ostracods (43 %) were the main group of crustaceans. Nearly all species collected were widespread fresh or brackish water taxa, although some halophilous species occurred in the sweep on the western side of Toolibin, including the beetle *Necterosoma penicillatus* (see Halse 1981) and ostracod *Mytilocypris tasmanica chapmani* (see De Deckker 1983).

Three replicate invertebrate samples provided fairly complete species lists at Toolibin and Walbyring for the taxa that were identified (Fig 6). Between 4 and 5 replicates (95 % confidence limits) were required at Toolibin before another would collect, on average, < 1 extra species (*i.e.* the species list would be almost complete); between 4 and 6 were required at Walbyring. Proportion of the invertebrate fauna in each wetland collected by individual replicates varied from 69-80 %, with three replicates collecting, on average, 92-93 % of the fauna. All replicates appeared sufficiently comprehensive to characterize the wetland from which they were collected (Fig 7), although small dissimilarities occurred between the replicate from the more saline

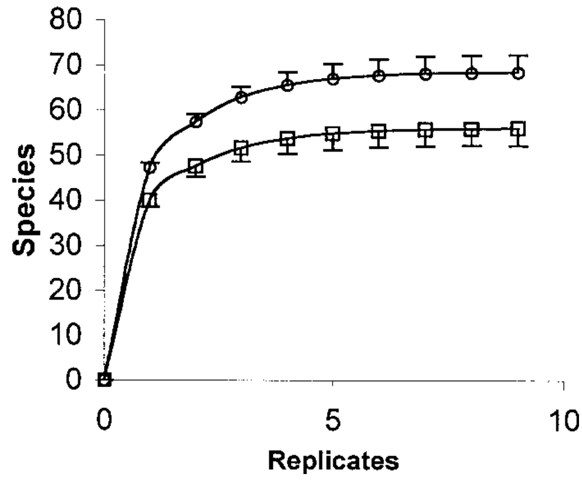

Figure 6. Accumulation of invertebrate species at Toolibin (▯) and Walbyring (O) Lakes with increasing numbers of replicates (see text for details); error bars are ± 1 SE.

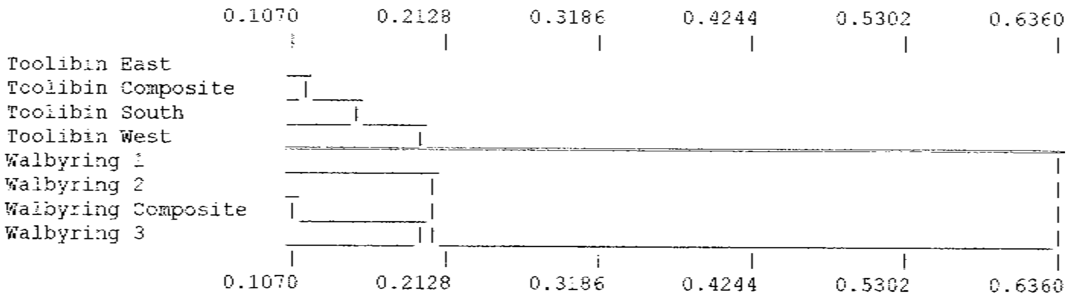

Figure 7. Classification of replicates and composite samples from Toolibin and Walbyring Lakes, showing the similarity of replicates from the same wetland.

western sector of Toolibin and other Toolibin replicates and between the Walbyring replicate from sector 2, at which 3 extra species were collected in the 110 µm-mesh sweep (Appendix), and other Walbyring replicates. When samples from three wetlands on the Swan Coastal Plain (Chandala, Cooloongup and Gingin) were included with Tolibin and Walbyring in a classification, all wetlands were separated clearly, with replicates from Toolibin and Walbyring clustering close to the composite sample of the respective lake (Fig 8).

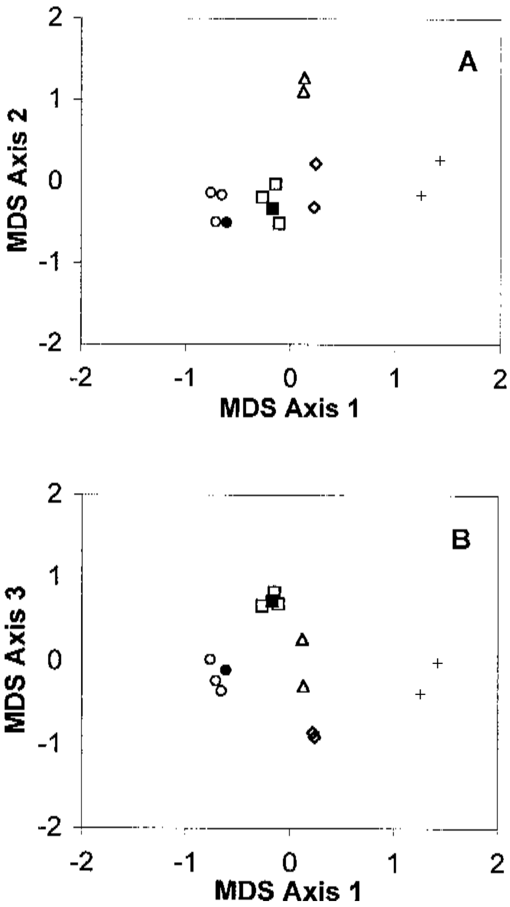

Figure 8. Three-dimensional ordination of invertebrate replicates and composite samples from Toolibin (□) and Walbyring (O) Lakes, Lake Chandala (   ), Lake Cooloongup (Ð), and 2 samples from a small wetland near Gingin (+) for different years (see text for details), showing discrimination between wetlands and proximity of replicates to the composite samples (filled symbols); stress = 0.09.

Discussion

Surveys of south-western Australian wetlands in the early 1980s showed Toolibin to be among the 10% of wetlands supporting most waterbird species (Jaensch *et al.* 1988; Halse *et al.* 1993b). The 20 species recorded at Toolibin on 4 December 1996 reflected this high waterbird conservation value. Toolibin provides an excellent benchmark against which to assess waterbird conservation value of other wetlands because its use by, and value to, waterbirds is widely accepted and management responses are well documented (Halse 1988; Hooper & Wallace 1994; Froend *et al.* 1997).

This study collected more invertebrate species at Toolibin than Doupé & Horwitz (1995) collected in October 1992 (52 *vs* 36) because sampling and sorting effort was greater and probably provides a better estimate of the conservation value of the lake. With 52 species in 1996, Toolibin appeared to have moderate invertebrate conservation value, based on species richness, although comparisons with other wetlands may be confounded by differences in sampling effort (see Fig 6). Five wheatbelt wetlands sampled in October 1997, with similar methodology but about 50% more effort than Toolibin, had 20-87 invertebrate species (mean 51 ± se 11) (unpublished data, S A Halse). With six 10 m sweeps using a 250 µm mesh pond-net, Davis *et al.* (1993) recorded 12-66 species (mean 35 ± se 2) in a single spring sampling of 40 wetlands on the Swan Coastal Plain. Storey *et al.* (1993b) recorded 36-70 species (mean 57 ± se 10) in February in three wetlands at Two Peoples Bay in the wet south-west corner of Western Australia with similar methodology, but about half the sampling effort, of this study.

Judged by species richness, Walbyring appeared to have greater invertebrate conservation value than Toolibin during this study (Appendix). Doupé & Horwitz (1995) also found higher invertebrate species richness per unit sampling effort at Walbyring. Neither lake is particularly satisfactory as a benchmark against which to compare the conservation value of other wetlands for invertebrates, because their species richness is intermediate and the management implications of their invertebrate lists are unclear.

Both the waterbird and invertebrate survey methodologies used in this study produced results that could be used to characterise wetlands. Despite the waterbird survey of Toolibin on 18 December being rather cursory and undertaken two weeks after the more thorough survey of 4 December, species composition was similar and surveys occupied similar positions in ordination space (Figs 4 & 5). Walbyring was also characterised adequately, despite either substantial changes in species composition between surveys or some species being overlooked on 18 December. Both sets of surveys confirmed the long-term pattern of greater waterbird richness at Toolibin than Walbyring (Jaensch *et al.* 1988) and clearly separated Toolibin and Walbyring from wetlands without extensive living *Casuarina obesa*.

Froend *et al*. (1997) proposed that ordination could be used to track changes in wetland communities through time and results from Toolibin suggest this can be done for waterbirds using a single survey each year (Figs 4 & 5). There are some important considerations, however, that apply to monitoring both waterbirds and invertebrates. Firstly, numbers and species of waterbirds and invertebrates using a wetland fluctuate seasonally and annually accordingly to wetland conditions (Gosper *et al.* 1983; Halse *et al*. 1992; Davis *et al*. 1993), so inter-annual comparisons should be restricted to the same season in years with roughly similar wetland depths. Secondly, sampling errors may be large owing to changes in species composition during the day of survey (mostly a problem with waterbirds), species being overlooked by the survey, collecting and sorting techniques used, and mis-identification. The closeness of the two 1996 waterbird surveys in ordination space in relation to surveys of other wetlands (Fig 5) shows the waterbird survey methodology is robust when examining large changes in community composition, although sampling error may become important when looking at small changes. Similarly, mesh size and sector of the wetland sampled may affect results when small changes in invertebrate communities are being examined. Use of two or more pairs of invertebrate sweeps from different sectors and several waterbird surveys over a short time period each year (Lougheed *et al*. 1999) will reduce sampling error.

Salinity levels have not yet risen dramatically at Toolibin (Fig 2) and, therefore, the effects of increasing salinity on the fauna have been slight. Few waterbird species have stopped using the lake, which is not surprising given that most species found in fresh water in south-western Australia also occur in brackish and slightly saline water. The average long-term waterbird list for regularly filled fresh (< 3 000 mg L^{-1}) wetlands surveyed in the south-west between 1981 and 1985 was 18 species, for brackish wetlands (3 000-10 000 mg L^{-1}) it was 40 and for wetlands with spring salinities between 10 000 and 25 000 mg L^{-1} TDS it was 20 (Halse *et al.* 1993b).

Williams *et al*. (1991) proposed that freshwater invertebrates in low-land Australian rivers are salt-tolerant, based on sampling along the Blackwood River (downstream from Toolibin and Walbyring) in Western Australia and the Glenelg River in Victoria, neither of which showed a correlation between macroinvertebrate community composition and salinity. In contrast, Bunn & Davies (1992) argued that a suite of salt-sensitive species been lost from Western Australian rivers. Data from Toolibin and Walbyring appear to support Williams *et al.* (1991) and we suggest that most freshwater invertebrates of lentic wetlands in much of south-western Australia are comparatively salt-tolerant. Despite an approximate threefold increase in salinity, more invertebrate species were collected at both Toolibin and Walbyring in December 1996 than by Doupé & Horwitz (1995) in September 1992. Water mites (Acarina) were the only group collected by Doupé & Horwitz (1995) that were absent from the more saline 1996 samples.

Davis *et al.* (1993) recognized a group of freshwater invertebrates in wetlands around Perth with salinity tolerances up to 20 000 mg L^{-1}. Frey (1991, 1998) noted that seasonal flooding and drying of many wetlands in south-western Australia produced brackish conditions as the wetlands dried and, as a result, some chydorid cladocerans are adapted to moderate levels of salinity. *Pleuroxus* and related genera, in particular, appear to thrive in brackish water and are found in south-western Australia at salinities exceeding their observed ranges elsewhere. Halse (1981) collected the amphipod *Austrochiltonia subtenuis* and ostracod *Mytilocypris mytiloides* in the northern part of the Western Australia wheatbelt at higher salinities than they have been recorded in eastern Australia. It is only in the extreme south-west of Western Australia that a high proportion of the aquatic invertebrate fauna appears to be salt-sensitive (see Storey *et al*. 1993b; Edward *et al*. 1994; Horwitz 1997), although many of the species in granite rock pools of the wheatbelt may be restricted to fresh water (see species list in Bayly 1997) and salt-sensitive freshwater species do occur in other wheatbelt wetlands.

While our surveys suggest that salinization has caused only small changes in the Toolibin fauna to date, the occurrence of halophilous invertebrate species on the western side of the lake indicates that the lake may be approaching a salinity threshold, above which dramatic changes will occur. Other studies in Western Australia suggest the threshold is between 10 000 and 20 000 mg L^{-1} TDS (Halse *et al.* 1993b, Davis *et al.* 1993). Until biological responses to salinity are better documented, priority should be given to maintaining salinity of Toolibin below 10 000 mg L^{-1} TDS. The long-term management objective for the lake is that salinity should be less than 1000 mg L^{-1} TDS when it is full (Froend *et al.* 1997). This may allow salt-sensitive species that have disappeared from Toolibin, such as Australasian bitterns and purple swamphens, to use the lake again.

Acknowledgements: J A K Lane provided most of the salinity and depth data for the two lakes and C Hassell, W R Kay, A M Pinder, M J Smith and J Sparrow assisted with fieldwork. We thank S A Harrington (mosquitoes), I Landsbury (hemipterans), A M Pinder (oligochaetes), S Slack-Smith (molluscs), R M St Clair (caddisflies) and C H S Watts (beetles) for help with identifications. R S Schulz (Chemistry Centre, WA) supervised the chemical analyses and P H J Horwitz commented on a draft of the manuscript.

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Appendix

Aquatic invertebrate species collected in sectors of Toolibin and Walbyring Lakes on 18 December. x = present

	Toolibin East	Toolibin South	Toolibin West	Walbyring 1	Walbyring 2	Walbyring 3
MOLLUSCA						
GASTROPODA						
BASOMMATOPHORA						
Planorbidae						
Isidorella ? bradshawi Iredale				*x*	*x*	*x*
? Bayardella sp				x	x	x
ANNELIDA						
OLIGOCHAETA						
TUBIFICIDA						
Naididae						
Dero nivea Aiyer				x		x
Tubificidae						
Ainudrilus sp				**x**	**x**	**x**
OPISTOPHORA						
Opistophora sp				x	x	x
HIRUDINEA						
RHYNCHOBDELLIFORMES						
Glossiphoniidae						
Glossiphoniidae sp				x		
ARTHROPODA						
CRUSTACEA						
CLADOCERA						
Chydoridae						
Dunhevedia crassa King	x	x	x	x		
Leydigia aff. *australis* Sars				x	x	
Macrothricidae						
Macrothrix aff. *indistincta* Smirnov		x	x			x
Macrothrix aff. *capensis* (Sars)	x	x	x			
Daphnidae						
Daphnia cephalata King						x
Simocephalus vetulus Muller				x	x	x
OSTRACODA						
Cypridopsidae						
Sarscypridopsis aculeata (Costa)					x	
Cyprididae						
Alboa worooa De Deckker	x	x	x	x	x	x
Bennelongia australis (Brady)				x	x	x
Candocypris novaezelandiae (Baird)	x	x		x	x	x
Cypretta baylyi McKenzie				x	x	
Cyprinotus edwardi McKenzie	x	x	x	x	x	x
Diacypris spinosa De Deckker	x	x	x			
Mytilocypris ambiguosa De Deckker	x	x	x	x	x	x
Mytilocypris mytiloides (Brady)	x	x	x			x
Mytilocypris tasmanica chapmani McKenzie			x			
COPEPODA						
Centropagidae						
Boeckella triarticulata (Thompson)	x	x	x	x	x	x
Calamoecia ampulla (Searle)				x	x	x
Cyclopoidae						
Apocyclops dengizicus (Lepeschkin)	x	x	x			
Australocyclops australis (Sars)				x	x	x
Mesocyclops brooksi De Laurentiis *et al.*	x	x	x	x		x
Microcyclops sp				**x**	**x**	
AMPHIPODA						
Ceinidae						
Austrochiltonia subtenuis Hurley	x	x	x	x	x	x
INSECTA						
ZYGOPTERA						
Coenagriidae						
Xanthagrion erythroneurum Selys	x	x	x		x	x
Coenagriidae sp [1]		x		x		
Lestidae						
Austrolestes annulsosus (Selys)	x	x	x	x	x	x
ANISOPTERA						
Aeschnidae						

Appendix (continued)

	Toolibin East	**Toolibin South**	**Toolibin West**	**Walbyring 1**	**Walbyring 2**	**Walbyring 3**
Hemianax papuensis (Burmeister)	x	x	x		x	x
Gomphidae						
Hemicordulia tau Selys	x	x	x	x	x	x
Libellulidae						
Diplacodes bipunctata (Brauer)		x				
Orthetrum caledonicum (Brauer)		x				
HEMIPTERA						
Veliidae						
Microvelia sp				x		
Corixidae						
Agraptocorixa parvipunctata (Hale)	x			x	x	x
Micronecta robusta Hale	x		x	x	x	x
Sigara mullaka Lansbury		x		x		
Notonectidae						
Anisops gratus Hale				x	x	x
Anisops thienemanni Lundblad	x	x	x	x	x	x
DIPTERA						
Tipulidae						
Tipulidae sp	x	x				
Culicidae						
Anopheles annulipes s.l. Walker	x	x				
Chironomidae						
Chironomus occidentalis Skuse	x	x	x			
Chironomus oppositus Walker	x	x	x		x	x
Cladopelma curtivalva (Kieffer)	x	x	x			
Cricotopus albitarsus Walker					x	
Cryptochironomus griseidorsum Keiffer		x		x	x	x
Dicrotendipes conjunctus (Walker)	x	x	x	x	x	x
Kiefferulus intertinctus Skuse	x	x		x	x	
Polpedilum nubifer (Skuse)	x	x	x	x	x	x
Procladius paludicola Skuse	x	x	x	x	x	x
Tanytarsus fuscithorax Skuse	x	x	x	x	x	x
Ceratopogonidae						
Ceratopogoninae sp 1	x		x	x	x	x
Ceratopogoninae sp 2			x			
Ceratopogoninae sp 3						x
Forcipomyiinae sp	x				x	
Stratiomyidae						
Stratiomyidae sp 1	x					
Stratiomyidae sp 2	x	x	x		x	
Stratiomyidae sp 3		x				
Ephydridae						
Ephydridae sp 1			x			
Ephydridae sp 2	x	x	x			
LEPIDOPTERA						
Pyralidae						
Pyralidae sp	x	x	x			
TRICHOPTERA						
Ecnomidae						
Ecnomus sp					x	
Leptoceridae						
Notalina spira St Clair	x	x	x			x
Oecetis sp				x	x	
Triplectides australis Navas	x	x		x	x	x
COLEOPTERA						
Dytiscidae						
Allodessus bistrigatus (Clark)				x	x	x
Antiporus gilberti (Clark)				x	x	x
Lancetes lanceolatus (Clark)	x					
Liodessus inornatus (Sharp)	x					
Macroporus sp [2]					x	x
Megaporus howitti (Clark)					x	x
Necterosoma penicillatus (Clark)			x			
Rhantus suturalis (W S MacLeay)					x	

Table 3 (continued)

	Toolibin East	Toolibin South	Toolibin West	Walbyring 1	Walbyring 2	Walbyring 3
Sternopriscus multimaculatus (Clark)				x	x	x
Hydrophilidae						
Berosus discolor Blackburn [1,3]	x					
Berosus sp 1 [2]	x	x	x	x	x	x
Berosus sp 2 [2]	x	x	x	x	x	x
Enochrus elongatus (MacLeay)					x	
Enochrus eyrensis (Blackburn)				x		
Enochrus maculcieps (MacLeay)						x
Hydrophilidae sp [1,2]					x	x
Number of species	**41**	**41**	**36**	**44**	**51**	**46**

[1] Excluded from analyses; [2] coleopterans for which only larvae collected; [3] excluded from site and wetland total.