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Long-term trends of shorebird populations in eastern Australia and impacts of freshwater extraction

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ABSTRACT

Shorebirds (*Charadriiformes*) and their wetland habitats are under threat worldwide. While data exist for shorebird population trends for many parts of the world, two thirds of Australia's populations have not been assessed. We report the results of a large-scale aerial shorebird survey, sampling about a third of the Australian continent over a period of 24 years (1983–2006). Migratory shorebirds have declined by 73%, Australian resident shorebirds by 81%. Of the 10 wetlands supporting the highest number of shorebirds within the survey bands, eight were inland wetlands and only two coastal, emphasising the importance of inland wetlands for shorebirds. Wetland area decreased significantly at four of the 10 main sites. Annual rainfall showed no trends (1983–2005) but water extraction was substantial for four of the 10 wetlands, contributing to reduced flooding extent and frequency. Loss of wetlands due to river regulation is a significant contributor to the drastic decline in shorebird numbers in Australia, largely unrecognized in international conservation agreements in Australia.

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1. Introduction

The world is currently undergoing its sixth mass extinction (May et al., 1995), with extinction rates at least several hundred times higher than previously in human history (Pimm and Brooks, 2000). For birds, 20% of the species alive when records began are now extinct (Wilson, 1992). A critical challenge for conservation biology is estimation of population trends (Lawton and May, 1995), especially for species of conservation concern, where further decline might lead to extinction and management is necessary for their survival (Caughley and Gunn, 1996). Even though birds are well studied, few long-term population data exist that separate stochastic variation from population declines. Difficulties in identifying trends are exacerbated for highly mobile species.

Many shorebirds or waders (*Charadriiformes*) are long-distance migrants. They breed in the arctic tundra and spend

the non-breeding season at temperate or tropical latitudes. About eight million migratory shorebirds use the East Asian–Australasian Flyway (Bamford et al., 2006), linking the breeding areas in eastern Siberia and western Alaska with the non-breeding areas in Australia and New Zealand (Battley and Rogers, 2007). In Australia, shorebirds were thought to use primarily coastal habitats but the importance of inland wetlands is increasingly realised (Kingsford and Porter, 1993). These inland wetlands vary considerably in availability reflecting stochastic rainfall and river flows (Roshier et al., 2001). The availability of many of these inland wetlands in Australia has been reduced by dams, water extractions and levee banks, particularly in the southeast of the continent (Kingsford, 2000).

Worldwide, shorebird populations have undergone considerable declines. Of the 237 populations with trend data, 52% are in decline, while only 8% are increasing. For two thirds of the 57 Australian shorebird populations, no trend data exist

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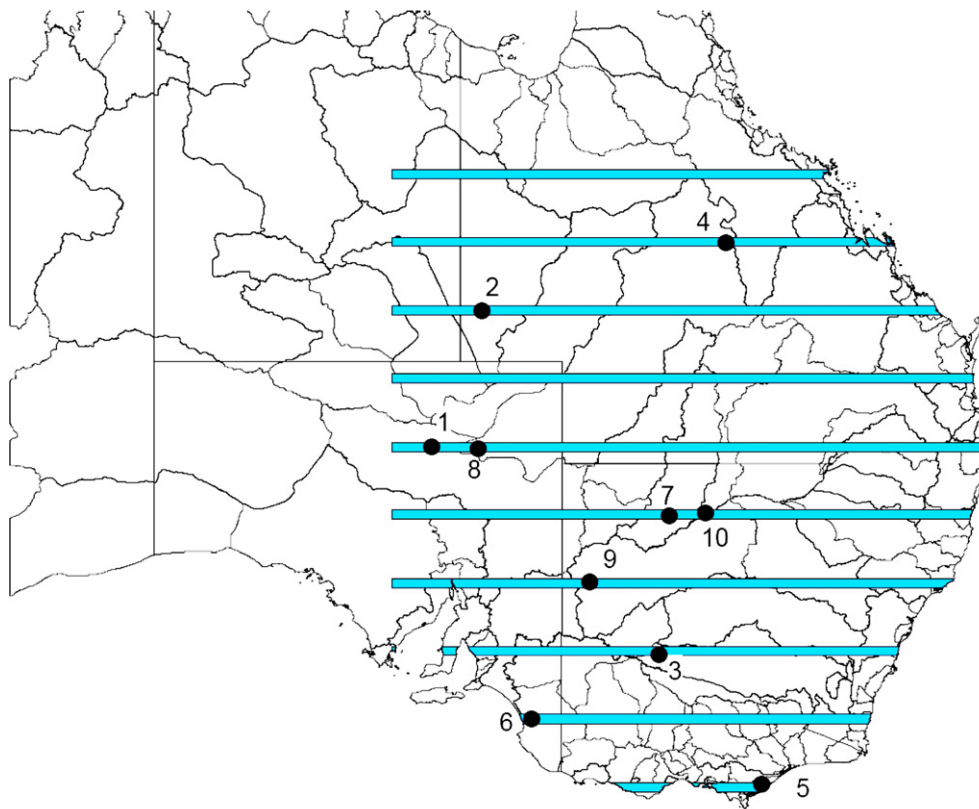


Fig. 1 – Catchment boundaries and locations of the 10 wetlands supporting the highest number of shorebirds (at least 6000 individuals as maximum yearly count) within the 10 survey bands across eastern Australia. The western limit of each band was 136°00'E, except for the two most southern bands (Bands 1 and 2), which ended on the west coast. The eastern limit of all bands was the east coast of Australia. 1 – Lake Eyre North, 2 – Lake Torquinie/Mumbleberry Lake, 3 – Lowbidgee, 4 – Lake Galilee, 5 – Lake Denison/Jack Smith Lake, 6 – Coorong, 7 – Paroo River overflow, 8 – Cooper Creek wetlands, 9 – Lake Cawndilla/Nettlegoe Lake, 10 – Mid-Darling River (see Table 3 for habitat descriptions).

(Wetlands International, 2006). We investigated changes in shorebirds numbers in eastern Australia over a 24-year period, using systematic waterbird surveys that sampled more than a third of the continent. Waterbirds were counted on about 2000 wetlands along 10 survey bands across the eastern half of the continent (Fig. 1). Trends in shorebirds numbers and wetland area at the 10 most important wetlands were linked to anthropogenic changes to river flows over the past two decades that could have detrimentally affected wetland habitat (Kingsford, 2000).

2. Methods

Shorebirds were counted as part of annual (October) aerial waterbird surveys across eastern Australia (38°30'S–20°30'S) between 1983 and 2006; methodology remained unaltered throughout this period (Kingsford et al., 1999). Surveys were flown along ten 30 km-wide survey bands (Fig. 1). The survey bands cover 12% (332,360 km²) of eastern Australia (2,697,000 km²). All wetlands larger than 1 ha were surveyed within each band and given a unique number. Smaller wetlands were counted on an ad hoc basis and identified by their latitude and longitude (Kingsford et al., 2003).

Wetlands were surveyed from a high-winged aircraft (Cessna 206) with one observer on each side of the plane estimat-

ing the number of shorebirds onto mini-cassette recorders. The aircraft was flown at 167 km h⁻¹ at a height of 30–45 m within 150 m of the shoreline, where waterbirds usually congregate (Kingsford and Porter, 1994). Either the whole wetland was circumnavigated or a proportion of the wetland (>50%) counted. Counts were totalled for each observer to give either a total count or a proportional count for the wetland. We extrapolated counts on proportions of wetlands to give an index of total shorebird numbers for the whole wetland unless only part of the wetland was within the band (Kingsford et al., 2003). The proportion of the wetland filled with water was also estimated each year, which was used to calculate changes in wetland area over time.

Six resident shorebirds were identified to species: black-winged stilt *Himantopus leucocephalus*, banded stilt *Cladorhynchus leucocephalus*, red-necked avocet *Recurvirostra novaehollandiae*, pied oystercatcher *Haematopus longirostris*, banded lapwing *Vanellus tricolor* and masked lapwing *Vanellus miles*. All others were counted as either 'large' or 'small' shorebirds. All species in the 'large' category and all but four in the 'small' category were migratory (Higgins and Davies, 1996; Marchant and Higgins, 1993). Those data were used to calculate trends in migratory shorebirds, as numbers of small resident species on inland wetlands appear to be relatively low (Halse et al., 2005; Howarth and Grant, 1982).

We identified the 10 most important wetlands for shorebirds by the highest annual count (summed across all species) during the study period. Analyses of temporal trends at the 10 main sites were restricted to years when the wetland held water; sample sizes may vary accordingly. We analysed the frequency of wetland use by shorebirds as an additional measure of importance. Changes in any of the tributaries of the main river system can affect a wetland, so large-scale variables and processes were therefore investigated at the catchment scale. These were annual river runoff and developed yield (Australian Water Resources Council, 1987a), human population (Australian Water Resources Council, 1987b), irrigated land area (National Land & Water Resources Audit; <http://audit.ea.gov.au/anra/>; accessed 21 August 2007, Paroo catchment only: National Water Commission (2007)), dam capacity (GeoScience Australia; <http://www.ga.gov.au/>; accessed 21 August 2007) and rainfall (Australian Bureau of Meteorology, 2006). In catchments with local rainfall, we used the annual mean daily rainfall of two or three rainfall stations to calculate annual mean and temporal change (1983–2005; no 2006 data available); for catchment-wide rainfall we used four stations at high elevations and one station at low elevation, as 80% of the runoff in the Great Dividing Range, where most river regulation has occurred, is from a catchment's slopes (Eastburn, 1990; Thoms et al., 2004).

Population estimates for shorebirds in eastern Australia were derived using Jolly's ratio estimate for sampling units of unequal size (Jolly, 1969), which is based on the ratio between animals counted and survey band area. It uses density as opposed to number of animals per survey band, thereby eliminating the effect of size differences among sampling units. Temporal variation in shorebird abundance were analysed using General Linear Models (SYSTAT, 2005). Count data were log transformed ($\log_{10}(n + 1)$) prior to analyses to stabilise variances. Non-independence of observations due to temporal autocorrelation was examined with Mantel tests (Legendre and Legendre, 1998). We used euclidean distance matrices of time between counts, 999 iterations and a normalized Mantel statistic (r_m) in the Mantel Package, Version 0.33, Last Resort Software (Bedward, 2001). Temporal autocorrelation was not significant ($p = 0.087$). We conducted power analyses of non-significant temporal trends using an a-priori sample size calculator (Soper, 2007). Temporal population trends were also expressed in changes by decade. Mean numbers during the 1990s and between 2000 and 2006 were calculated as the proportion of the mean during the 1980s (1983–1989).

3. Results

Between 1983 and 2006, shorebirds were counted on 1447 unique wetlands across eastern Australia (Fig. 1) at least once; not all surveyed wetlands had shorebirds. Of the wetlands with shorebirds, about half ($n = 792$) the wetlands were small (<1 ha) and counted in one year only, supporting relatively few shorebirds (mean: 9 ± 1.52 , range: 1–201). Wetlands that were 1 ha or larger supported on average 338 (± 56.87 , range: 1–92,842) individuals. The highest population estimate for eastern Australia for a particular year was in 1984 ($n = 1,442,143$) and the lowest was in 1998 ($n = 34,847$). Over the 24-year study

period, annual population estimates of shorebirds in eastern Australia declined significantly ($F_{1,22} = 20.42$, $p < 0.001$; Fig. 2). This relationship remained significant when 1984, a year with exceptional high numbers of shorebirds, was removed from the regression. In the 1980s, the annual mean was 404,703 ($\pm 176,721$) shorebirds, in the 1990s, it had declined by 50% to 201,750 ($\pm 45,767$), and between 2000 and 2006, the mean was only 92,090 ($\pm 12,666$). Populations in the 2000s had thus decreased by 77% compared to the 1980s.

The mean count (sum per year) was highest for small shorebirds ($n = 15,167$) and lowest for pied oystercatcher ($n = 4$). Among-year variation was high in all species (Table 1). A significant decline in estimated numbers between 1983 and 2006 occurred for banded lapwings ($F_{1,22} = 8.19$, $p = 0.009$), masked lapwings ($F_{1,22} = 9.81$, $p = 0.005$), red-necked avocets ($F_{1,22} = 18.81$, $p < 0.001$), black-winged stilts ($F_{1,22} = 17.27$, $p < 0.001$) and small shorebirds ($F_{1,22} = 7.11$, $p = 0.014$; Fig. 3). No temporal trend was detected for banded stilts, pied oystercatcher or large shorebirds ($p > 0.9$; Fig. 3). Power analyses ($\alpha = 0.05$, power = 0.08) showed that 59 years of data would be needed

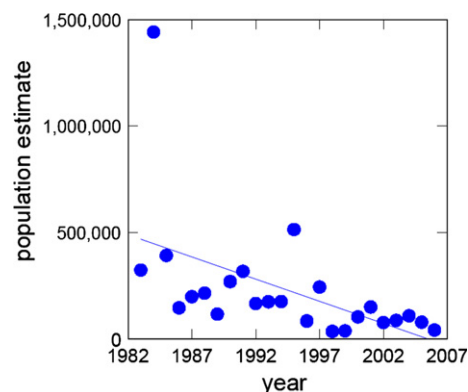


Fig. 2 – Annual population estimates with linear regression line of shorebird numbers (migratory and resident) based on data collected during annual aerial surveys during October, 1983–2006. Estimates were derived from systematic sampling of 10 surveys bands, which cover 12% (332,360 km²) of eastern Australia (2,697,000 km²), a third of the continent.

Table 1 – Numbers (maximum, median, mean, S.E.) of migratory (m) and resident (r) shorebirds counted along 10 survey bands during annual aerial surveys of eastern Australia (1983–2006)

Species	Maximum (year)	Median	Mean	S.E.
Large shorebirds (m)	4528 (1995)	176	448	185
Small shorebirds (m) ^a	93,030 (1984)	8331	15,167	4059
Black-winged stilt (r)	57,855 (1984)	6509	9475	2386
Banded stilt (r)	9000 (1984)	877	1527	408
Red-necked avocet (r)	46,755 (1984)	3807	6488	1957
Banded lapwing (r)	1180 (1984)	8	79	49
Masked lapwing (r)	3761 (1990)	472	877	179
Pied oystercatcher (r)	15 (1995)	0	4	1
Total	209,846 (1984)	23,801	34,065	8481

^a Predominantly migratory shorebirds.

to detect a significant decline in banded stilts, 148 years in large shorebirds, and 760 years in pied oystercatchers, given the variation in estimates and comparatively low numbers. Between the 1980s and 2000s, migrants had declined by 73% (small shorebirds: -73%, large shorebirds: -29%), and residents by 81% (banded lapwings: -98%, masked lapwings: 69%, red-necked avocets: -85%, black-winged stilts: -80%; Table 2). Four of the six resident species were declining. On average, there were slightly more resident than migratory shorebirds (mean% of residents: $57 \pm 3\%$, range: 33–86%).

The 10 wetlands (see Table 3 for site descriptions) with the highest number of shorebirds, in order of highest annual count (*n*) (year of count in parentheses), were: (1) Lake Eyre North, *n* = 92,842 (1984), (2) Lake Torquinie/Mumbleberry Lake, *n* = 48,052 (1995), (3) Lowbidgee, *n* = 44,532 (1984), (4) Lake Galilee, *n* = 23,385 (1984), (5) Lake Denison/Jack Smith Lake, *n* = 21,097 (1985), (6) Coorong, *n* = 20,504 (1987), (7) Paroo River overflow, *n* = 14,785 (1985), (8) Cooper Creek wetlands, *n* = 10,655 (1990), (9) Lake Cawndilla/Nettlegoe Lake, *n* = 9023 (1995), and (10) Mid-Darling River, *n* = 6901 (1984). Seven of the 10 highest

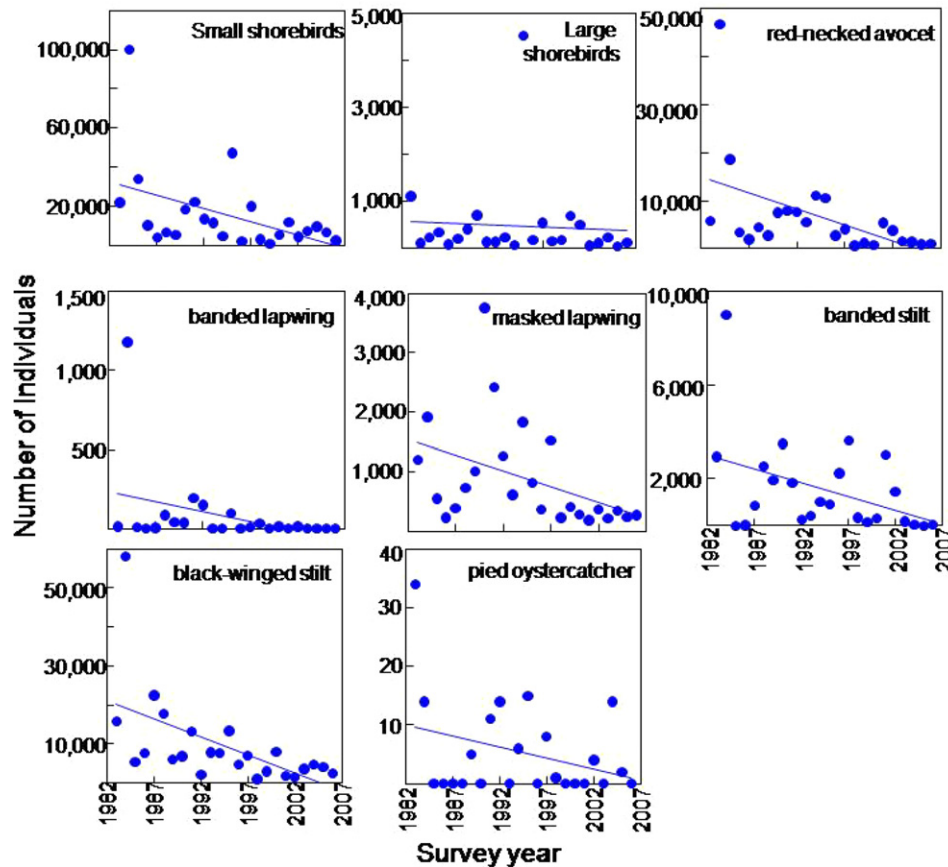


Fig. 3 – Annual sums with linear regression lines of shorebirds (migratory and resident) over the 24-year study period counted across the 10 survey bands.

Table 2 – Numbers (mean, S.E.) of migratory (m) and resident (r) shorebirds counted along 10 survey bands during aerial surveys of eastern Australia by decade (number of years in parentheses) and proportional change to 1980s level

Species	1980s (8)	1990s (10)		2000s (6)	
	Mean ± S.E.	Mean ± S.E.	Change (%) ^a	Mean ± S.E.	Change (%) ^a
Large shorebirds (m)	337 ± 134	671 ± 433	+99	240 ± 95	-29
Small shorebirds (m) ^b	24,954 ± 12,062	14,255 ± 4400	-43	6683 ± 1190	-65
Black-winged stilt (r)	19,069 ± 6914	6731 ± 1330	-65	3802 ± 854	-80
Banded stilt (r)	2473 ± 1173	1427 ± 415	-42	724 ± 426	-71
Red-necked avocet (r)	11,996 ± 6186	5918 ± 1160	-51	1796 ± 614	-85
Banded lapwing (r)	191 ± 165	53 ± 23	-72	4 ± 2	-98
Masked lapwing (r)	856 ± 218	1318 ± 353	+54	267 ± 25	-69
Pied oystercatcher (r)	4 ± 2	6 ± 2	+48	3 ± 2	-23

a Change relative to 1980s population.

b Predominantly migratory shorebirds.

Table 3 – Descriptions of the 10 most important shorebird sites (Fig. 1), from the 10 aerial survey bands covering eastern Australia (see Fig. 1), based on maximum yearly count, frequencies of flooding (years with water/years in study period) and of usage by shorebirds (years with shorebirds/years with water)

Wetland	Latitude/longitude	Description	Area (ha) ^a	Frequency of flooding	Frequency of use
Lake Eyre North	–28.5011/137.3497	Saline temporary lake (3–10 m depth), receives water every 1–3 yrs but seldom fills (1949, 1974, 1984, 1989). World's largest internally draining system with a catchment of 1.2 million km ² that covers one sixth of the Australian land surface	203 021 [*]	0.13	1.00
Lake Torquinie/ Mumbleberry Lake ^b	–24.5213/138.6471	Shallow saline temporary lakes, frequently dry with a closed (endorheic) drainage basin	2438	0.26	1.00
Lowbidgee	–34.4350/143.8008	Freshwater riverine wetland complex, with deep permanent river channels and waterholes as well as extensive temporary floodplain wetlands	92,055	1.00	1.00
Lake Galilee	–22.4743/145.7727	Saline temporary lake, shallow (<3 m) with a closed drainage basin	14,845 [*]	0.67	0.88
Lake Denison/ Jack Smith Lake	–38.4757/147.0471	Saline permanent estuarine wetland with extensive mudflats	2372	1.00	1.00
Coorong	–36.0589/139.9014	Saline estuarine wetland complex with strong salinity gradient from freshwater inflows. Extensive macrophytes when conditions are suitable	8337	0.96	1.00
Paroo River overflow	–30.3917/144.0114	Freshwater riverine wetland complex, includes large terminal lakes, extensive floodplains, river channels and billabongs	44,189	0.92	0.95
Cooper Creek wetlands	–28.4683/138.8263	Freshwater riverine wetland complex, with permanent and temporary waterholes, channels and terminal lakes	8110	0.92	0.59
Lake Cawndilla/ Nettlegoe Lake	–32.4801/142.1675	Freshwater permanent lake, regulated for used as water storage connected to the Darling River	27,077	0.88	0.82
Mid-Darling River	–30.5641/145.0188	Freshwater riverine wetland complex with permanent river waterholes, billabongs and temporary floodplain wetlands	570	1.00	0.13

Area estimates are for only the part of the wetland within the survey band, not the total wetland area.
a Wetlands with an asterisk are only partly within the survey band.
b Not surveyed in 2002.

counts were in the first five years of the survey (1983–1987). The four highest ranked wetlands were inland, and only two of the 10 wetlands (Lake Denison/Jack Smith Lake, and Coorong) were on the coast (Fig. 1).

Wetlands in arid Australia do not hold water every year. The frequency with which wetlands are available and used by shorebirds is therefore an important aspect when assessing their importance. The frequency with which the 10 main wetlands held water (years with water/years in study period) ranged from 0.13 to 1.00 (i.e. 100%). In the years they held water, the frequency with which they were used (years with shorebirds/years with water) showed the same range (Table 3). The most important wetland for shorebirds, Lake Eyre North, only flooded three times at the time of the survey during the study period, but every time it held water, it was used by shorebirds. The frequency of flooding was also low at the second most important site, Lake Torquinie/Mumbleberry Lake, but was also used every time it held water. The lowest ranked site, Mid-Darling River, was flooded every time, but only used in three years. Numbers of shorebirds in years with water declined significantly over time at Lowbidgee ($F_{1,22} = 23.83$, $p < 0.001$), and the Coorong ($F_{1,21} = 6.56$, $p = 0.018$). We detected no trend at all other sites ($p > 0.08$; Fig. 4).

Wetland area in years when the wetland held water declined significantly at Lowbidgee ($F_{1,22} = 17.37$, $p < 0.001$), Lake Denison/Jack Smith Lake ($F_{1,22} = 20.685$, $p < 0.001$), the Coorong ($F_{1,21} = 8.70$, $p = 0.008$) and Mid-Darling River ($F_{1,22} = 21.13$, $p < 0.001$). No change was detected at the other six wetlands ($p > 0.07$). Note that some caution is required in interpreting wetland area and count data where only a portion of the wetland has been sampled (see Table 3).

Human population, irrigated area, water storages and river flows of the 10 main wetlands varied substantially among catchments (Table 4). Population size was large (200,000 or more people) in the catchments of Lowbidgee, Lake Cawndilla/Nettlegoe Lake, Mid-Darling River, Coorong, and Lake Torquinie/Mumbleberry Lake and small (<200,000 people) at the other five catchments. The area of land used for irrigation (1996/97) was large (>165,000 ha) in the catchments of the Coorong, Lowbidgee, Mid-Darling River and Lake Cawndilla/Nettlegoe Lake, considerable at the Lake Denison/Jack Smith Lake catchments (9744 ha) and small (<500 ha) in the catchments of the Paroo River overflow, Lake Torquinie/Mumbleberry Lake, Lake Galilee, Cooper Creek wetlands and Lake Eyre North. The proportion of irrigated area in the catchments increased substantially (+81% to +98%) between 1983/84 and 1996/97 for Mid-Darling River and Lake Cawndilla/Nettlegoe

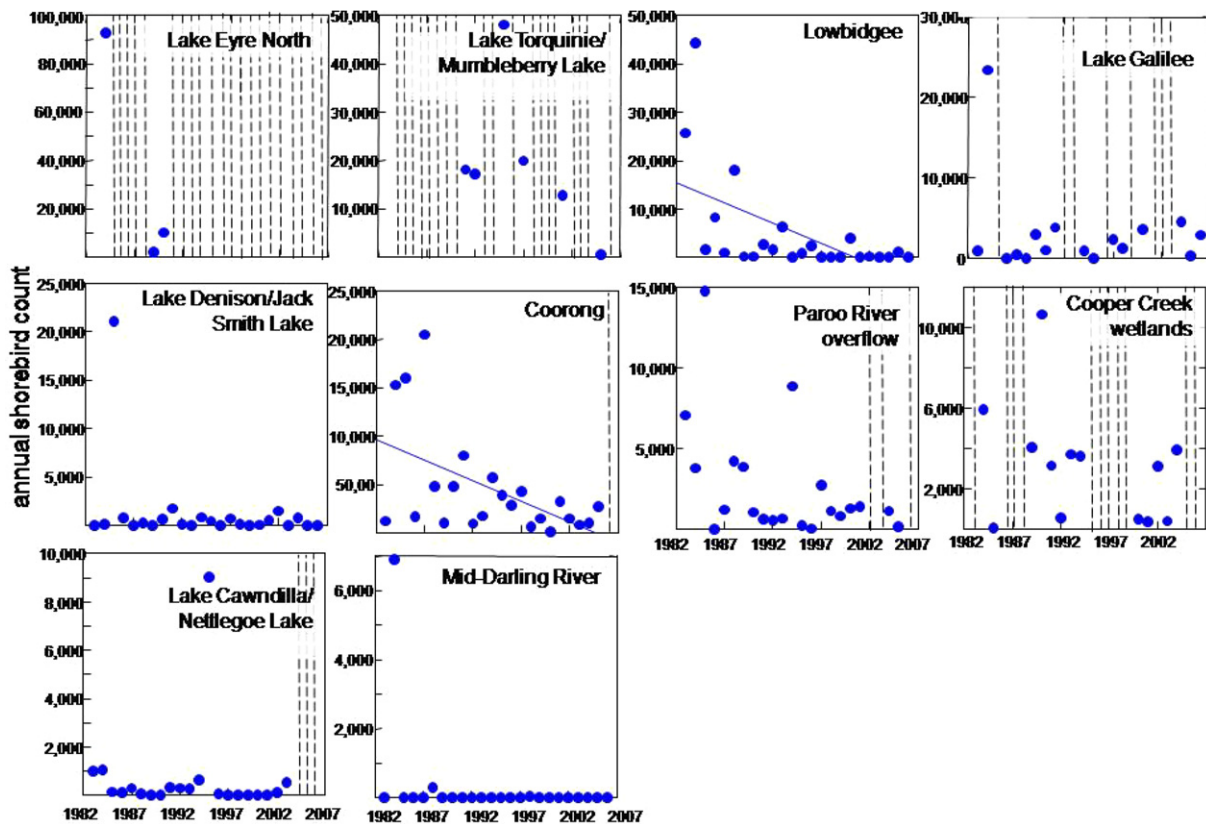


Fig. 4 – Shorebird numbers over the 24-year study period at the 10 main wetlands. Significant declines are shown by regression lines. The stippled lines indicate years when the wetland did not hold water, which were excluded from the analyses.

Lake and to a lesser extent (+10% to +32%) for Lake Denison/Jack Smith Lake, Coorong and Lowbidgee. While the proportion of the irrigated area increased by 625% at the Lake Torquinie/Mumbleberry Lake catchment, the total irrigated area was only 29 ha. Irrigated area decreased at the catchments of Lake Eyre North, Lake Galilee and Cooper Creek wetlands and did not change at the Paroo River Overflow.

Number of dams and their combined storage capacity was large (>30 and >5,000,000 ML, respectively) for the river systems upstream of Lowbidgee, Coorong, Lake Cawndilla/Nettlegoe Lake and Mid-Darling River and relatively low (<10 and <60,000 ML, respectively) in the catchments of Lake Eyre North, Lake Torquinie/Mumbleberry Lake, Lake Galilee, Lake Denison/Jack Smith Lake, Paroo River Overflow and Cooper Creek wetlands. Storage capacity was associated with the relative amount of water extracted (developed yield/mean annual runoff), ranging from 21% to 60%, compared with catchments where relatively little water was extracted (0–3%). At the Denison/Jack Smith Lake, Coorong, and Lowbidgee catchments, developed yield increased between 1983/84 and 2000, at the other seven catchments it decreased or no data were available. The relative amount of water extracted (developed yield in 2000/mean annual runoff) was high (20–60%) at Lowbidgee, Coorong, Mid-Darling River, and Lake Cawndilla/Nettlegoe Lake and small (<5%) at the others six catchments. Mean daily rainfall (1983–2005) was lowest in the Lake Torquinie/Mumbleberry Lake catchment (0.76 mm/day) and highest

in the Lake Denison/Jack Smith Lake catchment (2.73 mm/day). No change in rainfall between 1983 and 2005 was detected in any of the catchments ($p > 0.1$).

4. Discussion

Shorebird populations across a third of Australia are in serious decline, based on data from systematic surveys over 24 years. Between the 1980s until 2006, the mean number of shorebirds declined by 77%. The magnitude and scale of this change has not been reported for the Australian continent and reflects a general trend around the globe, where more than half of all shorebird populations with known trends are declining (Wetlands International, 2006). Generally, estimates of the magnitude of population declines are only available for single species (Baker et al., 2004) and are rare for large geographical scales (but see Bart et al., 2007) as in this study.

Migratory shorebirds constituted on average just less than half of the shorebirds. Between the 1980s and this century, migratory shorebirds declined by 73% and Australian residents by 81%. Our data showed no trend for the large migratory shorebirds. The Waterbird Population Estimates 2006 (Wetlands International, 2006) showed that for 67% of the migratory shorebird populations in Australia and for nearly half of the residents, no trend data exist. Our results suggest that many of these populations may also be declining.

Table 4 – Catchment areas of 10 main wetlands and potential factors that affect wetland availability (frequency of flooding and extent): population, land and water use, at the catchment level

Wetland	Drainage basin	Catchment area	Population ('000) in '83 ^a	Irrigated area (ha) (1996/97); % change '83/84–'96/97 ^b	Number of dams (capacity in ML) ^c	Mean annual runoff GL '83–84 ^d	Developed yield (GL) '83/84 ^d	Developed yield (GL) '00 ^d	Change in developed yield ('83/84–'00) (%)	Developed yield ('00)/runoff (%)
L. Eyre North	L. Eyre	L. Eyre Division ^e	47	414; –9.6%	8 (52,805)	6307	26	0.4	–98	0
L. Torquinie/Mumbleberry L.	L. Eyre	Georgina R.	6 ^f	29, +625.0%	0 (0)	2000	0	0.2	n/a	0.0
Lowbidgee	Murray–Darling	Murrumbidgee R.	200	348,692; +31.8	34 (5,109,442)	3800	2140	2272	+6	60
L. Galilee	L. Eyre	Cooper Cr.	13	250; –15.0%	1 (420)	2330	22	0	–100	0
L. Denison/Jack Smith L.	Southeast coast	South Gippsland	50	9744; +9.7%	8 (11,177)	700	18	22	+22	3
Coorong	Southeast coast/ Murray–Darling	Darling Basin ^g and others ^h	1594	1278 913; +28.4%	278 (34,989 567)	24,634	10,008	10,903	+9	44
Paroo R. Overflow	Murray–Darling	Paroo R.	4	6449; +97.3%	1 (0)	717	0	0	n/a	0
Cooper Creek wetlands	L. Eyre	Cooper Cr.	13	250; –15.0%	1 (420)	2330	22	0	–100	0
L. Cawndilla/Nettlegoe L.	Murray–Darling	Darling Basin ^g	543	350,545; +81.1	104 (12,036,002)	7705	1727	1656	–4	21
Mid-Darling R.	Murray–Darling	Darling Basin ^g	543	350,545; +81.1	104 (12 036 002)	7705	1727	1656	–4	21

a Australian Water Resources Council (1987b).

b <http://audit.ea.gov.au/anra/>; accessed 21 August 2007.

c Geoscience Australia (<http://www.ga.gov.au/>; accessed 21 August 2007).

d Australian Water Resources Council (1987a).

e L. Frome, Finke R., Todd R., Hay R., Georgina R., Diamantia R., Cooper Cr.

f population data for Georgina R., Diamantia R. and Hay R. Catchments combined.

g Darling R., Paroo R., Warrego R., Condamine-Culgoa Rs., Moonie R., Border Rs., Gwydir R., Namoi R., Castlereagh R., and Macquarie-Bogan Rs. Catchments.

h Lower Murray R., Mallee, Millicent Coast, Wimmera-Avon Rs., Avoca R., Loddon R., Campaspe R., Goulbourn R., Broken R., Ovens R., Kiewa R., Upper Murray R., Murray-Riverina, Murrumbidgee R., Lachlan R., Benanee.

Shorebird populations decline with reduced breeding success or survival. For resident species, causes are confined to Australia, but for migrants, impacts can occur at migratory stop-over sites or on the breeding grounds in Asia or Alaska. Four of the six resident shorebird species had declined, implicating detrimental factors within Australia that affect not only residents but also migrants, given the similarities in habitat use (Higgins and Davies, 1996; Marchant and Higgins, 1993). For the two resident species where no significant trend occurred, high variability of estimates contributed to low statistical power. Generally, the more important wetland sites in Australia for shorebirds were thought to be on the coast (Lane, 1987; Watkins, 1993), but we found that eight of the top 10 sites in the survey bands were inland, including the four most important ones. Threats to inland wetlands are thus highly relevant to shorebird conservation.

To elucidate the reasons behind the population declines observed in eastern Australia, we examined anthropogenic factors that could contribute to wetland loss at the 10 most significant wetlands within the survey bands. Our data showed that declines in shorebird numbers and wetland habitat are primarily confined to parts of eastern Australia where there is significant development of water resources while no change in annual precipitation has taken place. The wetlands within the Murray–Darling Basin that are heavily regulated are those where we detected the most significant declines in shorebird populations. Numbers of shorebirds declined significantly over time only at Lowbidgee and the Coorong. Lowbidgee is a freshwater riverine wetland complex that always held water during the study period but has experienced significant river development resulting in a decline in all functional groups of waterbirds and degradation or loss of about three quarters of the wetland, much of it during the period of our surveys (Kingsford, 2003; Kingsford and Thomas, 2004). Declines of shorebird population at the Coorong of more than 50% between the 1980s and this century were also reported elsewhere (Gosbell and Christie, 2005; Phillips and Muller, 2006). At both sites, wetland area declined significantly during the study period, as well as at Lake Denison/Jack Smith Lake and Mid-Darling River. Outside the Murray–Darling Basin (Table 4), we found relatively little evidence of declines in shorebird populations at the wetland scale. Given the significance of the declines found across eastern Australia it is possible that declines will become more apparent at local scales even if these habitats are not affected by water resource development.

Catchments of our 10 most important wetlands in the Murray–Darling Basin (Lowbidgee, Coorong, Lake Cawndilla/Nettlegoe Lake and Mid-Darling River) had higher numbers of dams and storage capacity than those in other catchments. Storage capacity was associated with the relative amount of water extracted, predominantly upstream of the major wetlands (Kingsford, 2000). Further, the area of land for irrigated agriculture was large (>300,000 ha) where water extraction was intense, and small (<10,000 ha) where little water was extracted. Only Lake Denison/Jack Smith Lake wetland complex did not seem to be affected by river regulation and yet numbers of shorebirds as well as wetland area declined. It is possible that this was due to changing climate, as Lake Denison/Jack Smith Lake are at the south-east tip of the continent,

which has been severely affected by drought (<http://www.bom.gov.au/>; accessed 10/09/2007), even though daily rainfall within the catchment did not change during the study period. While there was no significant trend in shorebird numbers at Mid-Darling River and Lake Cawndilla/Nettlegoe Lake, case studies have shown that river regulation at these sites has also resulted in decreased waterbird diversity and abundance, as in some wetlands used as regulating storages, water levels are kept artificially high (Kingsford et al., 2004). At all other wetlands, water extraction was minimal, and wetland area and shorebird populations did not decline. Most (75%) of the water diverted from rivers throughout Australia is used to sustain irrigated agriculture (Kingsford, 2003; National Land and Water Resources Audit, 2001).

The decline in migratory population can at least partially be attributed to developments destroying their staging sites. The key staging site for migratory shorebirds in the East Asian–Australasian Flyway is the Yellow Sea, where two million shorebirds of 36 species concentrate (Barter, 2002). However, the river catchments draining into the Yellow Sea also host a growing population of about 600 million people in China and South Korea (about 10% of the world's population) (Anonymous, 2000). Agriculture and industry are progressively reclaiming the tidal feeding grounds of migratory shorebirds in the Yellow Sea (Barter, 2002; Moores, 2006).

Reductions in breeding and recruitment can also contribute to population declines. Migratory shorebirds that visit Australia breed in the arctic and sub-arctic tundra, the boreal forest belt, and the steppes and deserts of eastern Asia (Tomkovich and Weston, 2007). Much of this habitat is remote and unaffected by major wetland loss. However, in the past 40 years, average temperature in the Arctic has risen at almost twice the rate of the rest of the world (Symon et al., 2005). Permafrost may thaw and detrimentally affect shorebird breeding habitat (Harding et al., 2007).

Australia has entered into bilateral Migratory Birds Agreements with Japan (JAMBA), China (CAMBA) and the Republic of Korea (ROKAMBA). These treaties commit each participating country to take special measures to protect birds migrating between them. However, Saemangeum, the most important shorebird site in the Yellow Sea, is being reclaimed (Rogers et al., 2006), with no apparent effort on behalf of the South Korean or Australian Government to stop it. Shorebirds are also protected under international agreements such as the *Convention on Biological Diversity*, and the *Convention on Migratory Species*. The *Ramsar Convention on Wetlands* provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. In Australia, Ramsar sites and migratory shorebirds are also recognised by the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

It is not clear where such agreements have been used effectively in Australia or other participating countries in the protection of migratory shorebird habitats. Decision making in the development of rivers in Australia and their effects on wetlands have seldom adequately considered the country's responsibilities for migratory shorebirds, and developments on staging areas also indicate that these agreements are not effective. Further decline in shorebird populations could be slowed with cessation of habitat loss within Australia.

lia and at migratory stop-over sites. National action should target wetlands of high conservation value for migratory shorebirds and protect the flow regimes that create the shorebird habitat while international engagement should draw attention to the significant impacts of developments on staging areas and give real effect to migratory bird agreements. Land reclamation and water resource development, driven by expanding human population and economic growth, continue to affect shorebird habitats and their populations within Australian and the East-Australasian flyway detrimentally.

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