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Continental-scale decreases in shorebird populations in Australia

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Abstract

Shorebird population decreases are increasingly evident worldwide, especially in the East Asian-Australasian Flyway (EAAF). To arrest these declines, it is important to understand the scale of both the problem and the solution. We analysed an expansive Australian citizen science data set spanning the years from 1973 to 2014 to explore factors related to differences in trends among shorebird populations in wetlands throughout Australia. Of seven resident Australian shorebird species, the four inland species exhibited continental decreases, while the three coastal species did not. Decreases in inland resident shorebirds were related to changes in water availability at non-tidal wetlands, suggesting that degradation of wetlands in Australia's interior is playing a role in these declines. The analyses also revealed continental decreases in abundance in 12 of 19 migratory shorebird species, and decreases in 17 of 19 migratory species in the southern half of Australia over the past 15 years. Many trends were most strongly associated with continental gradients in latitude

or longitude, suggesting some large-scale patterns in the decreases with steeper declines often evident in the south of Australia. After accounting for this effect, local variables did not explain variation in migratory shorebird trends between sites. Our results are consistent with other studies indicating that migratory shorebird population decreases in the EAAF are most likely being driven primarily by factors outside Australia. This reinforces the need for urgent overseas conservation actions. However, substantially heterogeneous trends within Australia, combined with inland resident shorebird declines indicate effective management of Australian shorebird habitat remains important.

Introduction

Targeting conservation action requires an understanding of when and where populations are limited (Newton 1998; Faaborg *et al.* 2010), as well as an understanding of which species are decreasing most rapidly and therefore in greatest need of conservation action (Atkinson *et al.* 2006; Mace *et al.* 2008). However, identifying factors limiting populations can be difficult for highly mobile species that seek out irregular pulses in resource availability (Bull *et al.* 2013), or for migratory species that traverse many habitats (Carlisle *et al.* 2009; Faaborg *et al.* 2010). Despite these difficulties, it is crucial that conservation actions are spatially targeted, particularly in the case of migratory species, which are decreasing more rapidly than non-migratory species (Sanderson *et al.* 2006; Wilcove *et al.* 2008). Migratory shorebird populations using the East Asian-Australasian Flyway (EAAF) exemplify a group of birds that are decreasing based on a growing number of reports from non-breeding sites where they spend the austral summer (Barter 1992; Reid *et al.* 2003; Close 2008; Nebel *et al.* 2008; Creed *et al.* 2009; Rogers *et al.* 2009; Amano *et al.* 2010; Wilson *et al.* 2011a; Minton *et al.* 2012; Hansen *et al.* 2015).

Despite this growing evidence of local declines in migratory shorebirds, analyses have yielded heterogeneous rates of change for some species (Table S1 in Supplementary Material, available online only). For example, Red-necked Stint (*Calidris ruficollis*) populations are increasing in Moreton Bay, Queensland (Wilson *et al.* 2011a), stable in many places in southeast Victoria (Herrod 2010; Minton *et al.* 2012; Rogers *et al.* 2013), decreasing significantly at the Swan Estuary, Western Australia (Creed *et al.* 2009), and showing some evidence of decrease in South Australia, Tasmania, New South Wales, Western Australia, Korea and Japan (Table S1). Continental-scale trends have not been reported for most of Australia's shorebirds. In addition, Australian resident shorebirds have been counted in many of these areas, but often have not had their trends assessed (Table S1). Shorebird monitoring programs in Australia typically target migratory species, yet they also represent the best available data on three coastal resident species, and four that breed primarily at inland wetlands but often seek refuge on the coast in time of drought. The largest study to date on resident shorebird trends identified declines in species such as Red-necked Avocet (*Recurvirostra novaehollandiae*) and Black-winged Stilt (*Himantopus himantopus*) across one-third of the interior of the continent (Nebel *et al.* 2008), but the possibility that birds may have simply redistributed themselves to coastal habitats has not been assessed.

Research to date has highlighted two factors likely related to Australian shorebird declines. First, for shorebird species that stay in Australia year-round (hereafter 'resident' species), the loss or degradation of inland wetlands in Australia (Finlayson *et al.* 2013; Nielsen *et al.* 2013) has coincided with large population decreases in both resident and migratory shorebirds that use inland wetlands (Nebel *et al.* 2008). The collapse of estuarine wetland ecosystems such as the Coorong in South Australia, as a result of flow regulation in the Murray-Darling Basin, has also resulted in the loss of thousands of shorebirds (Wainwright *et al.* 2008; Paton *et al.* 2009; Paton *et al.* 2012). Second, for migratory shorebirds that visit Australia, large-scale loss and degradation of important refuelling habitat in East Asia's Yellow Sea has been documented (Moores *et al.* 2008; MacKinnon *et al.* 2012; Ma *et al.* 2014; Murray *et al.* 2014) and is widely thought to be driving decreases in Australia's migratory shorebird populations. This conclusion is supported by modelling demonstrating how loss of Yellow Sea habitats could have a disproportionately large impact on shorebird populations because many birds pass through these migration bottlenecks (Iwamura *et al.* 2013). A recent study has also indicated that changes in arctic conditions were not related to breeding success, suggesting that population decreases were more likely related to loss of stop-over or non-breeding habitat (Aharon-Rotman *et al.* 2015). Taken together, these studies suggest the loss of Yellow Sea intertidal habitat could be a primary driver of migratory shorebird population decreases throughout the EAAF.

While the evidence to date points toward the loss of habitat in Asia as a likely cause of decreases in migratory shorebirds, wetland habitat degradation in Australia is also a plausible explanation. Indeed, recent studies have highlighted the potential loss of non-breeding habitat to impact migratory populations (Norris *et al.* 2004; Norris 2005; Alves *et al.* 2013). Some of the local impacts that could be contributing to shorebird population declines in Australia include diminishing food supply (Baker *et al.* 2004), a loss of adequate roosting sites (Rogers *et al.* 2006b), additional local habitat loss (Burton *et al.* 2006), and disturbance (Colwell 2010). Australia's shorebird areas vary widely in their exposure to human activity, the degree to which they are protected and the condition of available habitat. This variation and an expansive continental monitoring data set on shorebird abundance provides an opportunity to explore the geographic patterns of population change as well as whether shorebirds are decreasing at greater rates in those non-breeding habitats facing greater threats.

Australia has invested considerable resources in working to ensure that shorebirds are protected, listing all migratory shorebirds under the Environment Protection and Biodiversity Conservation Act 1999 as matters of national environmental significance, which must be considered when any human actions could potentially impact these species (DEWHA 2009). Australia has also designated 65 Ramsar sites as wetlands of international importance, and promotes sympathetic management by stakeholders to protect these areas to ensure they maintain their ecological character (Zeileis *et al.* 2005). While Ramsar designation has been found to be positively related to waterbird abundance in some areas (Kleijn *et al.* 2014), there has not yet been an assessment of whether shorebird populations are faring better in Australian Ramsar sites than in other areas.

If any local threats are extensively impacting shorebird populations in Australia, we might expect to find variables at the scale of individual wetlands in Australia to correlate with variation in local population trends for both residents and migrants. If, on the other hand, remote drivers were the dominant reason for changes in migratory shorebird populations, we might expect population changes to be widespread across Australia because birds from throughout the continent pass through the impacted Yellow Sea habitats (Minton *et al.* 2006; Minton *et al.* 2011b). We also would expect local-scale variables to explain little or no variation in trends among sites, and for trends in co-occurring resident shorebird species to be unrelated. Further, due to the substantial variation in the importance of particular East Asian staging sites to different species (Rogers *et al.* 2010; Moores 2012), we might expect rates of decline to vary between species, but also to show broad geographic patterns reflecting different migration strategies, with some species from eastern or western Australia, for example, more reliant on eastern or western parts of East Asia (Minton *et al.* 2006; Wilson *et al.* 2007; Minton *et al.* 2011b). We also expected decreases to be greater in the south of Australia if remote drivers were dominant because if fewer migratory shorebirds were flying to Australia each year, young shorebirds reaching Australia for the first time may select less densely populated non-breeding habitats in the north to shorten migration distances. This greater rate of decline at the edge of species range was one explanation offered when relatively large, continuing declines were reported in Eastern Curlew (*Numenius madagascariensis*) in Tasmania (Reid *et al.* 2003).

Here we use an expansive citizen science data set spanning the years from 1973 to 2014 to provide a synthesis of population trends for twenty-six shorebird species (Table 1) in 153 shorebird areas across the Australian continent. We analyse geographic variation in trends, associating them with threats and protective measures operating at shorebird sites to identify elements related to population declines.

Methods

Count Data

For over three decades shorebird abundance data have been collected as part of a continental-wide citizen science monitoring program. While funded, this program produced nearly twice as much data in the early 1980s (Lane 1987; Barter 1993; Wilson 2001) and again in the last decade as it did in the 1990s (Gosbell *et al.* 2006; Oldland *et al.* 2008). The resulting available data are both spatially and temporally heterogeneous (Clemens *et al.* 2012), and historic reporting varied in accuracy and extent. The observers who carried out these surveys have made efforts to avoid double-counting, to count all shorebirds in their survey areas consistently (in some cases for over a 35-year period), and to explain their sites and methods to their successors.

The spatial extents of each survey have recently been vetted and digitised into mapped polygons which are now standardised (Clemens *et al.* 2014). Mapped count data were organised into hierarchical spatial units. 'Count areas' represent the finest spatial resolutions at which a count was recorded, that were then grouped into 'shorebird areas'. These shorebird areas represent the entire area known to be used by a local population of migratory shorebirds during the peak of the non-breeding season (Clemens *et al.* 2014). Resident species' movements, behaviour, or home range were not considered when setting boundaries for these areas. In a few time series where shorebird area totals were reported instead of count area totals in some years, shorebird area totals were used for the entire time series. Count area data were consistently reported in most time series, but shorebird area data varied temporally in coverage with the percent of available count areas within each shorebird area varying overall from 2% to 100% coverage in any summer (mean 60%; 25% quantile = 33%; 75% quantile = 100%). Data with undefinable spatial coverage were excluded from these analyses. Further, only shorebird areas with at least five years of data (range = 5 to 42, mean = 14.8, 75% quantile = 20 years) were used in these analyses. This maximised inclusion of local wetlands that have changed greatly over time, while maintaining enough data to capture some of the likely variation in those short time series. All remaining data also varied in frequency of counts each summer with each count area recording a mean of 1.79 counts per year (range 1-8, median = 1).

Shorebird surveys were conducted between 1973 and 2014. In coastal (tidal) count areas, these surveys were conducted at roost sites within two hours of high tide, while at inland (non-tidal) count areas, no time-constraint was applied. We only used data from the peak of the summer non-breeding period, from November to February, since movements between shorebird areas are less likely to occur during this period. At this time, migratory shorebirds have completed southward migration, have yet to begin their northward migration and adults are carrying out their annual primary moult (Marchant *et al.* 1993; Higgins *et al.* 1996). Resident species on the other hand breed during this period, but these surveys were not timed or distributed ideally for resident shorebirds. Nonetheless these data often captured large groups of residents in post-breeding flocks, especially in late January and February, when most of the counts were conducted. These standardised repeated counts represent the best available continental-scale count time series for several resident species.

Factors affecting local trends

Variables that were thought likely to be related to local shorebird trends were human population density near the shorebird area, the estimated size of the shorebird area, its protected area status, Ramsar designation, type of wetland, distance of the shorebird area to the coast, the latitude and longitude of each site, expert assessed threats to shorebirds and finally variables related to data quality. Resampling and extraction of all variables was done in R 3.1.2 (R Development Core Team 2014), using the raster package (Hijmans 2014) while work on shapefiles was done primarily in ArcMap 10.2 (ESRI 2011) with the spatial analyst extension.

Human population density was estimated by generalising the Australian Bureau of Statistics 1 km grid representing human population density based on the 2011 census (Australian Population Grid 2011, ABS catalogue number 1270.0.55.007), and resampling by average to a grid of 10km^2 (the average size of a shorebird area) and taking the average population density from where it intersected the centroid of each shorebird area.

We acquired data about area in hectares of each shorebird area from Shorebirds 2020 (see http://birdlife.org.au/projects/shorebirds-2020).

Protected area status was derived from the Australian Government's *Collaborative Australian Protected Area Database*, CAPAD 2014. Protected area status was based on IUCN classifications where: Ia = Strict Nature Reserve; Ib = Wilderness Area; II = National Park; III = Natural Monument or Feature; IV = Habitat / Species Management Area; V = Protected Landscape / Seascape; VI = Protected area with sustainable use of natural resources. Trends in shorebird abundance in relation to protected areas were compared in several ways. First, all IUCN classified areas were grouped and compared to unprotected areas. Then areas with each IUCN classification were compared against all other categories resulting in seven comparisons, and finally areas classified as either I, II or III were compared against all other areas.

Ramsar designations for each site were derived by intersecting the Australian Government Department of the Environment's 2011 Australia's Ramsar Wetlands shapefile with shorebird areas.

Wetland types were compared by contrasting trends at non-tidal wetlands with trends at coastal (tidal) wetlands, and by comparing both salt works and sewerage works to all other wetlands.

We estimated distance to the coast as the shortest Euclidean distance of each shorebird area centroid to the closest coastline.

The latitude and longitude of the centroid of each shorebird area were used to test for geographic variation in local population trends. Comparisons of Australian trends north or south of -27.8 degrees latitude were also made: this latitudinal threshold was selected because it approximately bisects the continent and was close to the state borders of Queensland and New South Wales, a region where the abundance sand plovers, Terek Sandpiper (*Xenus cinereus*) and Grey-tailed Tattler (*Tringa brevipes*) becomes greater to the north (Bamford *et al.* 2008). Comparisons of trends east or west of 129 degrees longitude were also made, which is roughly where the eastern boundary to Western Australia is found. In the south there is a long stretch of coast extending west from this boundary where few shorebirds are found, and in the north this boundary falls between areas that are sampled regularly.

Variables related to threats were derived from experts. On 2-3 February 2015, 14 shorebird experts attended a national shorebird count data workshop in Melbourne. Each expert had 10-40 years of experience in shorebird ecology and monitoring, including field monitoring at most shorebird areas in Australia. Expert opinion was used to rank available population data from each of 295 shorebird areas into seven qualitative classes of data quality. Scores ranged from one for shorebird areas with the longest, most consistent temporal and spatial coverage, to seven for those shorebird areas with the shortest and least consistent data. Areas scored as a seven had time series that were too sparse or short and were therefore removed from further analyses. This left 153 shorebird areas with sufficient data: 26 areas scored a one, 23 areas scored a two, 20 areas scored a three, 43 areas scored a four, six areas scored a five, and 35 areas scored a six. As data on potential shorebird threats were not available for all shorebird areas, a list of threats most likely to be operating at individual shorebird areas was identified at the expert workshop. The threats identified were (a) reduction of available roost sites, (b) anthropogenic disturbance or agitation to the birds, (c) diminishing water quality, (d) loss of foraging habitat, (e) anthropogenic impacts from aquaculture, management, or industrial activity on the environment, and (f) inappropriate water levels for non-tidal wetlands where water levels may be too low, possibly empty, or too high leaving the invertebrate prey in the mud inaccessible (termed water availability). Workshop participants were then asked to determine if they believed each of these threats could be having local impacts on shorebirds in each shorebird area, and 83 of the 153 shorebird areas had prevailing threats scored, leaving 70 areas that were not assessed due to uncertainty.

We tested four other explanatory variables related to data quality comprising: the number of years of data for that shorebird area, the year the time series began for a shorebird area, the length of the time series in years, and the expert-derived data quality score (see above).

Statistical Analyses

Statistical analyses were conducted in R 3.1.2 (R Development Core Team 2014) and followed existing linear multilevel or hierarchical mixed effects modelling procedures (Gelman *et al.* 2007; Venables 2014). We also largely followed established R code for the statistics (Gelman *et al.* 2012; Kuznetsova *et al.* 2014; Bates *et al.* 2015), and data collation and manipulation (Zeileis *et al.* 2005; Venables 2013; Wickham *et al.* 2014). Data quality as scored by experts, length of time series, years of data, and year of first count were highly correlated ($r > 0.7$), so only data quality and years of data were explored further. All count data were $\ln(x + 0.9)$ transformed prior to analyses, where x represents a given count.

Multilevel or hierarchical linear regression as specified here present a number of advantages for analysing sparse datasets: (1) it allows direct modelling of the variation among shorebird areas; (2) it allows the inclusion of shorebird area level predictors; (3) it accounts for the spatial hierarchy in the data which are collected at the count area resolution grouped by shorebird area, and then grouped for all of Australia; (4) it accounts for data that varies in length of time series and amount of missing data; and (5) it inherently gives more weight to those time series with larger abundances and less variation. Data available for each count area were pooled if more than one count was conducted in selected summer months. In other words, if eight counts were conducted one summer at a count area, all eight data points were used in that year to calculate the regression, along with the five counts in the following year, and the single count in the year after that etc. Year (of the January in any given summer survey period) which ranged from 1973 to 2014 was treated as a fixed effect and was transformed by subtracting 1980 (the year when many time series started) and then subtracting the mean from each new value, resulting in intercepts roughly centred within each shorebird area time series.

Multilevel linear regressions included: fixed effects for overall Australia-wide intercept and slope; shorebird area-level predictors of latitude and longitude and interaction terms with time; random effects for intercepts that varied by count area within a shorebird area; and correlated varying shorebird area intercepts and slopes (Eq. 1). We tested the predictors like latitude, longitude, human density and other variables (see above) at the level of shorebird area by first adding those variables and their interaction terms to the model, and then looking both for significant parameter estimates (*t*-tests), and graphical interpretations. Expert-assessed threats were tested separately (see below). Latitude and longitude were hypothesised to be related to large-scale variation in trend across Australia. Therefore we included both latitude and longitude in any model that compared local area trends to ensure large geographic trends did not confound local area trend comparisons. In some cases latitude and longitude were correlated, so when making determinations on whether latitude or longitude was related to local trends, they were tested independently using both the entire available time series and again from 1996 to 2014. This later period was selected for comparison as surveys were available across more of the continent during this time, especially in northern Australia. Models were run separately for each of the 26 species tested. This model (Eq. 1) was used to generate the deviation of estimates of population change at individual shorebird areas (the random effects for slope) from the national average trend when large-scale variables such as latitude and longitude were included in the model (the fixed effects). It was also used to test for the significance of other continuous variables such as human population density, area, data quality, or the distance to the coast. These variables are not specified below, but were treated and added in the same way as either latitude or longitude.

Equation 1:

$$Y_{ica} = \beta_0 + \beta_1 S_{1a} + \beta_2 S_{2a} + \beta_3 T_{ca} + \beta_{13} S_{1a} T_{ca} + \beta_{23} S_{2a} T_{ca} + (B_{0a} + B_{3a} T_{ca}) + B_{0ca} + \varepsilon_{ica}$$

Y_{ica}	Count *i* in count area *c* of shorebird area *a*, (or ‘sector *ca*’ for short)
S_{1a}, S_{2a}	Spatial predictors: Latitude and Longitude, respectively for shorebird area *a*
T_{ca}	Temporal predictors: the time of the count, measured in years from the mid-point of the recording years for sector *ca*
$\beta_0, \beta_1, \beta_2, \beta_3, \beta_{13}, \beta_{23}$	Fixed effect coefficients for spatial and temporal terms, and spatio-temporal interactions
$(B_{0a} + B_{3a} T_{ca})$	Random effect term. B_{0a} and B_{3a} are correlated random perturbations to the fixed coefficients β_0 and β_3 respectively
B_{0ca}	Random effect term. A further independent random perturbation to β_0 applying at the ca-sector level
ε_{ica}	Random error term at the individual observation level

To estimate rates of overall population change across Australia, we removed the effects of latitude and longitude (Eq. 2a) and took the mean of estimated shorebird area slopes weighted by mean abundance (M) at each shorebird area (random effect estimates from Eq. 1). This allowed trends from shorebird areas with more individuals to be weighted more highly. Equation 2b which added a random weight to Eq. 1 and Eq. 2a were then run 200 times for each species (increasing iterations above 200 did not alter parameter estimates notably) to allow for the calculation of confidence intervals and standard errors of the estimated overall Australia wide slope which were calculated from quantiles of the 200 estimates (Eq. 3).

Equation 2a (estimate of slope for each shorebird area with the effects of latitude and longitude removed):

$$B_{at} = \hat{B}_{3at} + \hat{\beta}_{13t}(S_{1a}) + \hat{\beta}_{23t}(S_{2a})$$

B_{at} For each species, the estimated slope for each shorebird area (*a*) for each of 200 iterations (*t*) of either Eq. 1 or Eq. 2b with effects of latitude and longitude removed

$\hat{B}_{3at}$ For each species, the estimated slope for each shorebird area (*a*) for each of 200 iterations (*t*) of either Eq. 1 or Eq. 2b

S_{1a}, S_{2a} Spatial predictors: Latitude and Longitude, respectively for shorebird area *a*

Equation 2b (equation 1 repeated with a random weight added):

$$Y_{ica} = \beta_0 + \beta_1 S_{1a} + \beta_2 S_{2a} + \beta_3 T_{ca} + \beta_{13} S_{1a} T_{ca} + \beta_{23} S_{2a} T_{ca} + (B_{0a} + B_{3a} T_{ca}) + B_{0ca} + \varepsilon_{ica}, W_{icat}$$

t Model iteration (out of 200)

W_{icat} A weight for each observation *ica* generated from a random draw from the exponential distribution

Equation 3:

$$\overline{X}_t = \frac{\sum_{i=1}^{n} MiXit}{\sum_{i=1}^{n} Mi}$$

lower 95% CI bound of $\overline{X}$ = 0.025 quantile($\overline{X}_t$)
upper 95% CI bound of $\overline{X}$ = 0.975 quantile($\overline{X}_t$)
se of $\overline{X}$ = se(quantile($\overline{X}_t$))

$\overline{X}_t$ Weighted mean of each iteration *t*, Australia wide trend estimate

n Number of shorebird areas *a* which were included for each species

t model iteration (out of 200) of Eq. 2a

Xit B_{at} from Eq. 2b

M_i Weight equal to the mean shorebird area abundance for each area *a*

Models were assessed by inspecting residual versus fitted value plots, and random effects plots (Zuur *et al.* 2009). Residual plots showed acceptable homogeneity of variance, while probability plots were acceptably linear, and histograms of the random effects were broadly normally distributed if a little skewed for some species. These methods allowed confidence intervals to be asymmetrical, and 95% confidence intervals excluding zero represented significant results.

Subsets of the above model were also run where only the high quality data were used; i.e. data quality of 1, or data quality scores 1 - 3. Fixed effects for these different subsets were broadly similar to those when data with quality scores of 1 – 6 were used. This suggested that when estimating overall trends, our models were able to account for much of the variation associated with the poorer data quality scores. All analyses presented below are therefore inclusive of data quality 1 – 6.

Correlations between deviations of shorebird area estimated slopes (random effects) from overall average slope (fixed effect) and average shorebird abundance were also calculated using Pearson's correlation coefficient to help understand whether trend was correlated with abundance. Variables related to the ability to detect trends; quality of data and years of data were added as terms in the above model (Eq. 1), but without latitude and longitude, using t-tests again to assess significance.

Expert assessments of threats were analysed using simple bar plots of slopes from shorebird areas where experts thought the threat was operating compared to shorebird areas where the threat was not thought to be operating (the random effects of shorebird area slope from Eq. 1), and Wilcoxon-Mann-Whitney-U tests.

Shorebird area trends (random effects of slope Eq. 1) for each species for each shorebird area (with sufficient data) were then ranked independently based on the shorebird area trend's distance from the mean of all shorebird area trends, with values scored as positive when above the mean and negative when below the mean. Values < 1 SD (standard deviation of the mean) were scored +/- 0.1, 1-2 SD were +/- 1, and >2 SD were +/- 2. These ranks were then summed across species groups to assess which areas had the most species increasing or decreasing relatively more than average. Overall summed ranks reflected areas with high species diversity that were on average retaining or losing more shorebirds.

Results

Continental-scale shorebird population trends

Analyses identified significant decreasing population trends in 12 of 19 migratory shorebird species throughout Australia (Table 1). Five of the remaining species showed significant decreases in southern Australia after 1996 (Table 2). Despite a predominantly coastal sampling effort (Fig. 1), four resident shorebirds most common on non-tidal wetlands were also observed to be decreasing significantly (Table 1): Red-necked Avocet, Black-winged Stilt, Red-kneed Dotterel (*Erythrogonys cinctus*) and Black-fronted Dotterel (*Elseyornis melanops*). These results contrast with the three other resident species, which are either partially or entirely dependent on coastal ecosystems. Australian Pied Oystercatcher (*Haematopus longirostris*) and Sooty Oystercatcher (*Haematopus fuliginosus*) were both increasing significantly while Red-capped Plover (*Charadrius ruficapillus*) did not show overall significant trends at the continental-scale (Table 1).

Geographic patterns of population change among shorebird species

The estimated rate of change in mean count at each shorebird area varied widely throughout Australia (Fig. 1; Figs S1 – S6 in Supplementary Material). However, that variation was explained primarily by latitude or longitude, with the magnitude and even the direction of the effect varying between species in the truncated time series from 1996 to 2014 (Figs 3, 4; Tables 1, 2).

Overall results suggest more species decreased more rapidly in southern and eastern Australia than elsewhere (Tables 1, 2; Fig. 4). However, these decreases in the south and east were not offset by increases in northern or western Australia, where most shorebird species were also decreasing, albeit at a slower or more variable rate (Fig. 4). These generalisations did not apply universally. For example, Bar-tailed Godwit (*Limosa lapponica*) decreased more in the north of Australia, while Greater Sand Plover (*Charadrius leschenaultii*) decreased more in the west while increasing a little in the east (Table 1). Of all the species tested, 17 of 19 migratory species, and two of seven resident species, had trends that were significantly related to latitude or longitude. These results highlight how trends are not occurring evenly across Australia (Table 1; Fig. 4).

In southern Australia since 1996, 14 of 19 migratory shorebird species were decreasing significantly, while in northern Australia only five of 19 migratory shorebird species were decreasing with three increasing significantly (Table 2). Similarly, four of seven resident species were decreasing in the south, while no resident species were decreasing significantly in the north (Table 2; Fig. 4). These results highlight some important differences in trends. For example, 85% of Red Knot (*Calidris canutus*) are found in the north of the country and populations exhibited a stable trend there, while the species is clearly decreasing across many areas in the south of the country (Table 2, Figure 4). Also, the stable Australia-wide Grey-tailed Tattler population (Table 1) masks the virtual disappearance of relatively small southern Australian populations in places such as Tasmania and Victoria. Similar patterns of decreases of small populations in the south are evident in otherwise apparently stable populations of Greater Sand Plover, and Marsh Sandpiper (*Tringa stagnatilis*) (Table 2). Finally, some shorebird species with a less northerly distribution, such as Red-necked Stint and Sharp-tailed Sandpiper (*Calidris acuminata*), were also decreasing significantly in the south, but were stable or increasing significantly in the north (Table 2). Similar, albeit less pronounced regional differences in the rate of change were evident when comparing the east and west of the continent (Figure 4).

Areas with better quality data or more years of data revealed significantly larger decreases ($P < 0.05$) in seven of the 26 species modelled (Figure 5; Table 1). As time series tended to be longer in southern and eastern Australia, we evaluated the differences in results when using the entire time series from 1973 to 2014 compared to results from a truncated data set from 1996 to 2014, a period more closely matching average time series length in the north. The truncated dataset at a continental-scale revealed similar results to those from the entire time series (Table 1), but significant decreases were not detected in the shorter time series for either Pacific Golden Plover (*Pluvialis fulva*) or Sharp-tailed Sandpiper, while significant decreases were evident in Marsh Sandpiper and Red-capped Plover, and there were notable differences in the size of estimated decreases for some species (Table S4). Using the entire time series also revealed 26 similar geographic patterns of decline related to gradients of latitude or longitude to those reported for the truncated data in Table 1 (Table S4). Across this truncated time series five species were declining more in the south, three in the north, nine in the east, and four in the west.

Comparing trends among local areas

After accounting for latitude and longitude, it was clear that different species were declining at different rates in different areas, with trends for individual shorebird areas occasionally differing by over two standard deviations from the overall Australian trend (Table S2). For example, despite national declines Eastern Curlew were increasing at Botany Bay, while they were decreasing more rapidly in the Tweed River Estuary than anywhere else in the country (Table S2). The areas that appear to be losing large numbers of multiple shorebird species most rapidly were Mackay, Richmond River Estuary, Gulf of St Vincent, Moolap Saltworks, the Hunter Estuary, the Tweed Estuary, the Coorong, Kangaroo Island, Shoalhaven Estuary, Port Stevens and Corner Inlet, while the areas where shorebird retention was highest were Bushland Beach, Lucinda, Manning River Estuary, North Darwin, Cape Bowling Green, the Lake Connewarre area, the Tamar Estuary, Warden Lakes, the coastal stretch from Discovery Bay to the Glenelg River and Streaky Bay (Table S3). The patterns were similar between resident and migratory species, but some differences stood out within individual shorebird areas. The migratory shorebird rank at the Hunter Estuary was the worst in the country while residents were doing slightly better than average (Table S3). At Shallow Inlet, resident shorebirds were doing slightly worse than average, while migratory shorebirds were on average doing better than all but one other area (Table S3). The expert assessments of areas thought to be potentially impacted by any given threat are reported in Table S3.

Relationship between shorebird population trends and local factors

Local non-tidal wetland water availability was the only expert-assessed threat tested that was related to greater rates of decrease between shorebird areas, and this relationship was only significant for inland resident shorebird species ($P < 0.05$, Figure 2). There was a weaker relationship for migratory species that frequent inland wetlands ($P = 0.087$, Fig. S7). Rates of population change did not differ in areas where local populations were thought to be threatened by: (i) unfavourable water quality, (ii) a loss of foraging habitat (Fig. S7), (iii) lack of available roosts, (iv) threatening human activities or management, or (v) disturbance, despite being seen as a threat at ≥50% of shorebird areas (Fig. S7). Similarly, trends did not differ with the number of threats operating in a shorebird area (Fig. S7).

None of the other local variables tested was significant, once latitude and longitude were included in the model. These included human population density near the local shorebird area; the estimated size of the local shorebird area; the shorebird area's protected area status; whether the shorebird area was a Ramsar site; type of wetland; and the distance of the shorebird area to the coast. A correlation matrix revealed that none of these local variables, or the expert-derived threat assessments were correlated (>0.35) to latitude or longitude.

Discussion

Long-term decreases in 12 of 19 migratory shorebirds were revealed in this study (Table 1). Five of the seven species not showing overall declines were decreasing significantly south of -27.8 degrees latitude since 1996 (Table 2). Of migratory species, only Grey-tailed Tattler showed no decreases in all geographic and temporal subsets of data (Table S4). This contrasts with the decreases previously reported for Grey-tailed Tattler in Victoria, South Australia and Tasmania (Table S1), but those areas reporting declines only supported relatively small populations of Grey-tailed Tattler. For most migratory species, however, this study revealed continental trends that suggested greater decreases than previously reported. For example, Red-necked Stint, and Sharp-tailed Sandpiper are two of the most widespread migratory shorebirds in Australia, and were found to be decreasing overall despite previously reported contrasting trends (Tables S1, S4).

These population declines in migratory shorebirds were widespread across Australia which likely reflects the reliance of migrants on disappearing East Asian habitats (Minton *et al.* 2006; Minton *et al.* 2011b). The interspecific differences in trends were consistent with the variable degree to which species are reliant on the most threatened East Asian habitats (Rogers *et al.* 2006a; Rogers *et al.* 2010). Furthermore, co-occurring coastal resident species were not decreasing in habitats where migratory species were decreasing, and neither this study nor previous studies at local Australian shorebird areas identified local factors related to declines in migratory species (Wilson *et al.* 2011a; Minton *et al.* 2012; Hansen *et al.* 2015). After this study, the largest known impact to migratory shorebirds remains the loss of critical intertidal habitats in the Yellow Sea (Moores *et al.* 2008; Amano *et al.* 2010; Rogers *et al.* 2010; Yang *et al.* 2011; Murray *et al.* 2014; Murray *et al.* 2015) and that is likely impacting shorebird populations strongly because of the role of the Yellow Sea as a staging area for so many shorebirds in this flyway (Iwamura *et al.* 2013).

The degree to which these results suggest flyway-scale declines vary by species depending on a combination of the percentage of each species flyway population in Australia (Table 1), the degree to which their Australian distribution is well sampled (Clemens *et al.* 2010), and the strength of decline reported here and in other analyses (Tables S1, S4).

Contrastingly, Australian Pied Oystercatcher and Sooty Oystercatcher, two resident species that breed and spend their lives in coastal habitats were increasing overall in Australia (Table 1). Similarly, Red-capped Plover, a resident species that is common on the coast is showing a stable population overall, in spite of apparent decreases in different subsets of the data (Table S4). However, all four resident shorebird species which are more reliant on non-tidal wetlands, i.e. Red-necked Avocet, Black-winged Stilt, Black-fronted Dotterel, and Red-kneed Dotterel, were decreasing significantly. These species are relatively uncommon on the coast where most sampling in this study took place, but they do appear at the coast in large numbers when inland conditions become dry. Our results suggest that previously reported decreases in both Red-necked Avocet and Black-winged Stilt counts across inland eastern Australia (Nebel *et al.* 2008) were not offset by individuals moving to coastal habitats. Widespread decreases in Black-fronted Dotterel have not been reported previously, while decreases in Red-kneed Dotterel had only been reported previously in the Gulf of St Vincent (Close 2008), and in comparisons of Atlas data before and after 1998 (Barrett *et al.* 2002). Together our results paint a bleak picture for the status of Australia's migratory shorebirds and those resident species that move around widely across the continents' interior.

We found that inland resident shorebirds were decreasing most at sites where water availability was scored by experts as a threat, suggesting that wetland degradation is impacting some resident shorebird species. A similar finding emerged from a study based on an independent, broad-scale aerial survey (Nebel *et al.* 2008). Intriguingly, none of the other local expert assessed threats that we tested, nor the proxies of threat such as human density, or protected area status were associated with trends in shorebird abundance at shorebird areas. Despite this, there were several clear examples where trends showed great heterogeneity across different shorebird areas (Tables S2, S3), yet the kinds of conditions found in areas with the largest decreases were not found to be widespread across Australia. While there was no clear evidence that birds had relocated from those areas with the largest decreases such as the Coorong, given the scale of declines nationally such movements could be easily masked. Further study will be needed to determine whether the internationally important numbers of shorebirds that disappeared from some shorebird areas suffered mortality, reduced fecundity, or simply moved.

Geographic variation in trends

For migratory species, latitude and / or longitude were the only two variables we found that were related to the rates of population change among shorebird areas. Seventeen of 19 migratory species had rates of change that varied with latitude and / or longitude, but only two of seven resident species showed these relationships. These geographic relationships varied by species, with Bar-tailed Godwit declining more rapidly in the north, Eastern Curlew in the south and east, Red-necked Stint in the east, and Sharp-tailed Sandpiper in the west and south (Table 1).

The strength of the geographic patterns in population trends was surprising given the absence of strong site-level effects. While we cannot rule out the possibility that local variables shared across regional levels could explain the geographic patterns, it is difficult to conceive of examples of local variables that might act in opposite geographic directions on similar species which use the same habitats. The varied patterns of association between population change and geographic location in species using the same habitats are consistent with the notion that population impacts are occurring outside Australia. There are several possible explanations for these patterns.

First, populations that occupy different parts of Australia could be connected via migration to specific areas of staging habitat and/or breeding habitat overseas, which if impacted would be reflected in the Australian population connected to that area. Indeed, shorebirds migrate through the flyway using species-specific routes, with some populations much more reliant on certain East Asian intertidal habitats which have been impacted to varying degrees such as Saemangeum (Moores 2012), Chongmin Dongtan (Ma *et al.* 2009), Bohai Bay (Rogers *et al.* 2010) and Yalu Jiang (Barter *et al.* 2004; Riegen *et al.* 2006; Choi *et al.* 2015).

Second, population decreases could be associated with the density of birds present in different regions of Australia. While this idea is not consistent with the high site fidelity reported in several migratory shorebird species in our region (Conklin *et al.* 2010; Clemens *et al.* 2014), Eastern Curlew and Grey Plover (*Pluvialis squatarola*) were declining more rapidly in regions where they are more abundant (Table 1). These species are highly sensitive to interference competition (Folmer *et al.* 2010), and one might expect more rapid declines in more densely populated sites. However, as correlations between a species trend and the number of individuals present at a shorebird area were not high (Table 2), it is unlikely that strong density-dependence effects trends in most of these species. Weak support for this possibility is none-the-less present (Table 2).

Finally, the observed geographic patterns could relate to variation in migratory pathways over time or between different species or sub-species. We expected to find the greatest declines in the south because if external drivers are affecting population decreases, migrants would not to need to migrate as far south to find unoccupied habitat (Cresswell 2014). However, while many species were indeed decreasing more quickly in the south, others were decreasing more in the north. As we learn more about the varied migration strategies between subspecies (Battley *et al.* 2012) and species (Minton *et al.* 2011a; Minton et al. 2011b; Minton et al. 2006; Wilson et al. 2007) we may discover that juveniles are still tending to occupy the first suitable habitat with vacancies that they encounter but that different species or sub-species discover Australia in different ways, for example with *baueri* Bar-tailed Godwits arriving into Australia from the southeast first, and hence decreasing least in this area.

Local trends and threats

Despite the predominance of geographic-scale patterns detected here, there have been examples of severe changes at individual shorebird areas and management will be needed to address these. Historic local reductions in shorebird populations were underway well before the time series analysed here began, for example, through wetland drainage in south-eastern South Australia (Taffs 2001), and intertidal habitat loss in Botany Bay (Pegler 1997). More recent loss or degradation of Australia's inland wetlands (Finlayson 2013; Nielsen *et al.* 2013; van Dijk *et al.* 2013), and the collapse of the Coorong estuarine ecosystem, show clearly that such cases are still occurring (Nebel *et al.* 2008; Paton *et al.* 2009; Paton *et al.* 2012). Indeed, careful management of wetlands is crucial to maintain their suitability for shorebirds. We found larger decreases in shorebirds using wetlands that were scored by experts as too full (from water storage) or too dry. Further, the coastal decreases of Black-winged Stilt, Black-fronted Dotterel, Red-kneed Dotterel, Sharp-tailed Sandpiper, Curlew Sandpiper (*Calidris ferruginea*), Common Greenshank (*Tringa nebularia*) and Red-necked Stint, suggest that decreases at inland sites (Nebel *et al.* 2008) were not simply offset by redistribution of birds to the coast.

Areas that are suffering more rapid shorebird declines than many other locations contrast sharply with those retaining populations more effectively (Table S3). These differences in trends between shorebird areas suggest to us that comparisons reported in this study (Tables S2, S3) provide better indications of which areas have exceeded a 'limit of acceptable change' in shorebird abundance than can be provided from monitoring of individual areas. Without these kinds of comparisons it is far more difficult to decipher whether local population decreases simply reflect large-scale population changes unrelated to the local environment, or if local ecological changes may be responsible for local declines. Studies which then compare the interactions of precisely measured ecological variables coupled with measures of shorebird body mass, changing juvenile proportions, energy budgets, intake rates, or demographic rates would provide direction on how precisely to improve shorebird conditions at local areas (van de Kam *et al.* 2004; Colwell 2010; Faaborg *et al.* 2010; Weston *et al.* 2012).

Methodological caveats

Shorebirds can be difficult to count accurately, and they are highly mobile (Wilson *et al.* 2011b). Resulting noise in the data can make it difficult to detect all trends that are present, and lead to trend estimates that cannot strictly be compared among species (Bart *et al.* 2012), but is unlikely to lead to erroneous declines being detected. For example, log-transformed count data coupled with linear regressions may suggest trends are present or more severe than would be revealed by other more conservative techniques that may miss genuine trends (Wilson *et al.* 2011b). Also, taking a maximum likelihood estimate of many potentially exaggerated trends may result in larger rates of decline than would have been detected with other methods. These potential issues could be exacerbated when comparing trends between areas due to our finding that the magnitude of population decrease was correlated to the length of time series, and quality of available data in seven species (Figure 4). Therefore, the results reported here may include some ordering that is still influenced by data quality (Tables S2, S3), something more likely in areas with fewer than 10 years of data. For example, the Lake Albacutya Ramsar site did not rank as an area losing more birds than other areas nationally due to only having 5 years of data available. More data would have resulted in this ephemeral wetland being ranked among the places that have lost the most shorebirds as significant numbers of shorebirds have not been recorded there since 1983, and the only time it has had water since was in 1993.

It is possible that some of the trends reported here might be exaggerated, but it is also possible that some trends were missed, and we have attempted to strike a balance between these two errors. Taking one example in detail, 85% (over 100,000) of all the Great Knot (*Calidris tenuirostris*) counted in Australia are found at three shorebird areas in north-west Australia. A simple linear regression of pooled data from north-western Australia indicates an average rate of decline of approximately 1.8% per year, but due to variation in the data that result is not significant. If we compare some of the only complete ground counts of the entire length of 80-mile beach a similar 20% reduction in abundance in c. 10 years is suggested (Rogers *et al.* 2007). However, there have been several areas in central and northern Queensland that have recorded an increase in the number of Great Knot, in two cases going from small populations to a couple thousand birds. Despite weighting trends by average abundance of shorebirds found in a shorebird area when estimating overall trends, these smaller but less variable increases contribute more to estimates of northern Australian trends than the decline in north-western Western Australia which is down-weighted due to the high variation in those counts. It is likely that if there were 35 years of data available from north-western Western Australia decreases in counts of Great Knot may be more evident. It is also possible that directly addressing the large amount of variation present, particularly large in these data in species like Great Knot, would uncover significant population trends that were missed in these analyses.

These analyses also did not account for non-linear trends in the data. While diagnostic plots did not reveal this to be a large problem, non-linearity of declines has been observed in time-series analyses for several migratory species in Australia (Minton *et al.* 2012; Hansen *et al.* 2015), and is indicated in some species by different rates of decline over different time periods (Table S4). However, trends reported here are remarkably consistent with the overview of trends previously reported from individual shorebird areas which were based on a wide variety of methods (Table S1), and this suggests these methodological issues were not overly influential on results.

Conclusions

Our synthesis of Australian shorebird monitoring data collected by volunteers for over three decades has revealed continental decreases in most migratory shorebird species. Four resident shorebirds most common at Australian inland wetlands were also declining, while coastal resident species were stable or increasing. Site-level variables did not identify any widespread correlates of local population declines that suggest current limitation of migratory shorebirds in Australia. Instead, the broad similarity of declines across diverse Australian habitats, and geographic patterns of decrease for similar species that use the same habitats but go in opposite directions across the continent are consistent with the idea that Australia's migratory shorebirds are being impacted most by threats operating overseas. The key exception to this is the strong association between declines in four species of resident shorebirds that use inland wetlands, and inappropriate water levels, a threat that is likely to grow as the climate changes (Finlayson *et al.* 2013).

While for migratory shorebirds there is a clear need for increased advocacy for conservation actions overseas, the substantial variability in trends at individual sites across the continent combined with the evidence of inland resident shorebird declines indicates there remains an important role for effective management of shorebird habitat in Australia.

Acknowledgments

The trends found in these data relate to the high quality of available data which is due to the citizens who are taking part. Many of the counters are often professional biologists or ecologists who have routinely given up their weekends month after month, year after year, to monitor shorebirds. Determining the best method for monitoring shorebirds in Australia takes considerable time, as each site is unique regarding how to best get a repeatable count. That understanding requires knowledge on how birds use the available habitat within each area given the tides and other variables. Building those understandings and committing to surveying for decades are unique qualities of the volunteers contributing to these data. Further, these volunteers are often effective conservation champions whose active work on behalf of shorebirds likely helped protect many coastal shorebird habitats.

We thank the Australasian Wader Studies Group, the Albany branch of BAWA, Atlas of Australian Birds, Bird Observation and Conservation Australia, BirdLife Australia, BirdLife Australia Western Australia, Birds Tasmania, Esperance Branch of BAWA, Eyre Bird Observatory, Friends of Shorebirds SE, Global Flyway Network, Broome Bird Observatory, Friends of Streaky Bay District Parks, Hunter Bird Observers Club, New South Wales Wader Study Group, Queensland Wader Study Group, (QWSG), The South Australian Ornithological Association Inc., the Victorian Wader Study Group, Western Australia Wader Study Group, and the Shorebirds 2020 program. We would also like to acknowledge the support given through the Stuart Leslie Bird Research Award and BirdLife Australia. Additional acknowledgments of some of the many individuals who made this work possible are listed in Supplementary Material.

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Table 1. Estimated population changes in Australian shorebird species from all available data from 1973-2014, with estimates of how well each species was sampled within Australia, whether decreases or increases are greater in the north, south, east or west of the continent, and if data quality was significantly related to trend.

Variable explanations: [1] slope estimates of log-transformed counts over time (per year) approximate % change per year; [2] standard error of quantiles of 200 model runs, bold = 95% confidence intervals that do not span zero; [3] 0.025 and 0.975 quantiles of 200 model runs; [4] % of flyway population estimated in Australia (Bamford *et al*. 2008); [5] how well species' distribution in Australia is sampled, both geographically and temporally; [6] I = increase; D = decrease; as one goes N = north; S = south (data for these reported comparisons only from the years 1996 – 2014), n = not significant; [7] I = increase; D = decrease; as one goes E = east; W = west(data for these reported comparisons only from the years 1996 – 2014); [8] Quality scored (1=excellent – 6 = poor) by experts on length of time series and spatial and temporal consistency of coverage (y = significant); * ANOVA of lmer fixed effects term significant: $P < 0.05$; ** ANOVA of lmer fixed effects term interaction term with time significant: $P < 0.05$; *** ANOVA of lmer of both fixed effects terms and interaction term significant: $P < 0.05$.

Species	Slope[1]	se [2]	95% CI [3]	Flyway[4] (%)	Sampling [5]	Latitude [6]	Longitude [7]	Quality[8]
Migratory Species								
Curlew Sandpiper *Calidris ferruginea*	-9.53	**1.32**	-11.01 to -8.37	65	high	(D –S)**	(D – W)***	y***
Lesser Sand Plover *Charadrius mongolus*	-7.16	**1.56**	-8.91 to -5.8	17	low	(D –N)*	(D –E)**	y*
Sharp-tailed Sandpiper *Calidris acuminata*	-5.73	**2.88**	-7.93 to -2.16	90	modest	(D –S)***	(D –W)*	y*
Terek Sandpiper *Xenus cinereus*	-5.40	**2.10**	-7.42 to -3.22	40	modest	(D –N)*	(D –E)*	n
Black-tailed Godwit *Limosa limosa*	-5.38	**5.15**	-11.65 to -1.36	45	low	(D –S)*	n	n
Red-necked Stint *Calidris ruficollis*	-3.35	**1.02**	-4.31 to -2.26	85	high	n	(D –E)*	y*
Bar-tailed Godwit *Limosa lapponica*	-3.22	**0.91**	-4.09 to -2.26	55	high	(D –N)*	n	n
Ruddy Turnstone *Arenaria interpres*	-3.17	**0.92**	-4.15 to -2.3	55	modest	(D –S)**	(D –E)*	n
Eastern Curlew *Numenius madagascariensis*	-2.97	**0.71**	-3.69 to -2.26	75	high	(D –S)**	(D –E)**	n
Pacific Golden Plover *Pluvialis fulva*	-2.02	**0.57**	-2.45 to -1.31	1 to 7	modest	n	n	y***
Grey Plover *Pluvialis squatarola*	-2.02	**0.68**	-2.71 to -1.35	10	modest	(D –S)**	(D –W)*	n
Common Greenshank *Tringa nebularia*	-1.98	**0.62**	-2.6 to -1.35	30	modest	(D –S)**	(D –E)*	y*
Red Knot *Calidris canutus*	-1.65	3.15	-4.38 to 1.91	60	modest	(D –S)**	(D –W)*	n
Marsh Sandpiper *Tringa stagnatilis*	-0.90	1.95	-2.7 to 1.2	1 to 13	low	n	n	n
Sanderling *Calidris alba*	0.08	1.85	-1.91 to 1.79	45	low	n	(I –W)*	n
Greater Sand Plover *Charadrius leschenaultii*	0.54	1.72	-1.22 to 2.21	70	modest	(D –S)***	(D –W)*	n

Whimbrel *Numenius phaeopus*	0.65	1.61	-1.27 to 1.95	30	low	(I –N)*	n	n
Great Knot *Calidris tenuirostris*	1.43	1.81	-0.45 to 3.17	95	modest	(I –N)*	(I –E)*	y*
Grey-tailed Tattler *Tringa brevipes*	1.93	2.14	-0.34 to 3.93	90	modest	(I –N)*	(I –E)*	n
Resident Species								
Red-necked Avocet *Recurvirostra novaehollandiae*	-2.87	**1.62**	-4.17 to -0.94	-	low	n	n	n
Black-winged Stilt *Himantopus himantopus*	-1.81	**1.19**	-2.93 to -0.54	-	low	n	n	n
Black-fronted Dotterel *Elseyornis melanops*	-2.48	**0.67**	-4.06 to -0.96	-	low	n	n	n
Red-kneed Dotterel *Erythrogonys cinctus*	-2.1	**0.57**	-3.45 to -0.89	-	low	n	n	n
Red-capped Plover *Charadrius ruficapillus*	-0.67	1.29	-1.89 to 0.7	-	low	n	(D –E)*	n
Sooty Oystercatcher *Haematopus fuliginosus*	0.89	**0.85**	0.16 to 1.86	-	low	n	n	n
Australian Pied Oystercatcher *Haematopus longirostris*	1.43	**0.73**	0.63 to 2.09	-	low	(I –S)**	n	n

Table 2. Species, number in north versus in south in time series from 1996 -2014, slope (change in abundance per year), upper and lower 95% CI's; correlation between rate of change and abundance within shorebird areas when latitude and longitude are in the model is also reported.

Variable explanations: [1] Population estimates for the north and the south of Australia (Bamford *et al*. 2008); [2] slope estimates of log-transformed counts over time (per year) approximate % change per year; [3] standard error of 200 model runs, bold = 95% confidence intervals that do not span zero; [4] Pearson correlation between random effects for all areas and shorebird area abundance;

Species	North [1] population estimate	South [1] population estimate	North slope [2]	North se [3]	North 95% CI	South slope [2]	South se [3]	South 95% CI	Corr [4]
Migratory Species									
Black-tailed Godwit	65000	4850	-12.71	**10.68**	-21.76 to -0.39	-3.22	**3.32**	-7.12 to -0.49	-0.37
Lesser Sand Plover	24000	1360	-10.63	**3.34**	-14.01 to -7.33	-5.42	**3.27**	-8.27 to -1.73	-0.26
Terek Sandpiper	22000	760	-4.90	**2.48**	-7.65 to -2.7	-4.81	**2.25**	-6.99 to -2.49	-0.37
Bar-tailed Godwit	168000	17760	-3.83	**1.69**	-5.72 to -2.33	1.33	2.56	-1 to 4.11	-0.11
Red-necked Stint	95000	175800	-3.06	3.27	-5.81 to 0.73	-3.86	**2.36**	-5.84 to -1.13	-0.09
Eastern Curlew	22400	5600	-2.91	**1.11**	-4.25 to -2.03	-6.95	**2.18**	-9.17 to -4.82	-0.16
Whimbrel	29350	820	-1.12	2.58	-4.08 to 1.08	-0.49	1.87	-1.33 to 2.41	0.13
Ruddy Turnstone	8700	10800	-1.09	3.14	-4.22 to 2.06	-7.26	**2.09**	-9.02 to -4.83	-0.26
Curlew Sandpiper	60000	58500	-0.98	2.48	-3.49 to 1.46	-11.15	**2.74**	-13.98 to -8.51	-0.31
Pacific Golden Plover	4600	2750	-0.17	1.09	-1.53 to 0.65	-0.98	1.43	-2.19 to 0.68	-0.2
Marsh Sandpiper	9700	3050	-0.03	2.33	-2.12 to 2.55	-13.04	**3.66**	-16.25 to -8.93	0.06
Great Knot	358000	6100	0.01	2.41	-2.51 to 2.31	-3.31	**2.71**	-6.09 to -0.66	-0.17
Grey Plover	6700	4950	0.22	2.10	-2.22 to 1.97	-2.78	**2.24**	-4.67 to -0.19	-0.37
Greater Sand Plover	74000	330	0.34	2.15	-2.19 to 2.11	-3.40	**2.62**	-5.75 to -0.5	-0.17
Common Greenshank	13000	5900	0.36	1.60	-1.19 to 2.02	-3.80	**1.45**	-5.29 to -2.4	-0.1
Red Knot	118000	16850	1.08	5.65	-4.34 to 6.96	-5.64	**2.98**	-9.19 to -3.22	0.01
Grey-tailed Tattler	44000	810	2.65	**2.61**	0.13 to 5.34	-0.73	2.83	-3.39 to 2.28	0.26
Sanderling	3700	6310	7.48	**3.97**	2.92 to 10.87	-6.52	**4.84**	-10.88 to -1.19	0.07
Sharp-tailed Sandpiper	42000	98550	8.34	**5.45**	3.73 to 14.63	-4.75	6.27	-10.22 to 2.33	-0.15
Resident Species									
Sooty Oystercatcher	-	-	-1.30	1.25	-2.48 to 0.02	3.61	**2.07**	1.49 to 5.62	-0.01
Red-kneed Dotterel	-	-	-2.09	2.92	-4.17 to 6.67	-2.16	**0.71**	-3.55 to -0.66	-0.36
Black-fronted Dotterel	-	-	-0.07	1.75	-3.61 to 3.14	-2.44	**0.52**	-3.78 to -1.71	-0.05
Red-capped Plover	-	-	0.27	2.53	-2.39 to 2.66	-2.78	2.77	-5.29 to 0.26	0.09
Australian Pied Oystercatcher	-	-	0.31	4.18	-4.59 to 3.78	3.02	**1.30**	1.64 to 4.24	-0.01
Black-winged Stilt	-	-	7.64	**5.45**	2.09 to 12.99	-7.25	**4.06**	-12.67 to -4.55	-0.19
Red-necked Avocet	-	-	29.63	**22.46**	12.18 to 57.11	-5.28	**3.83**	-8.94 to -1.27	-0.23

Fig. 1. Decreases (dark circles) and increases (light circles) in shorebird abundance over time estimated from models not including latitude or longitude for (a) Eastern Curlew: 3.2% national decline, with decreases greater in the south and east of Australia; (b) Ruddy Turnstone: 3.3% national decline, with decreases slightly greater in the south; (c) Red-necked Stint: 3.3% national decline, with decreases slightly greater in the south; and (d) Sooty Oystercatcher: 0.7% national increase, with increases greater in the south. Circle size is proportional to 0.5 x standard deviation of the trend.

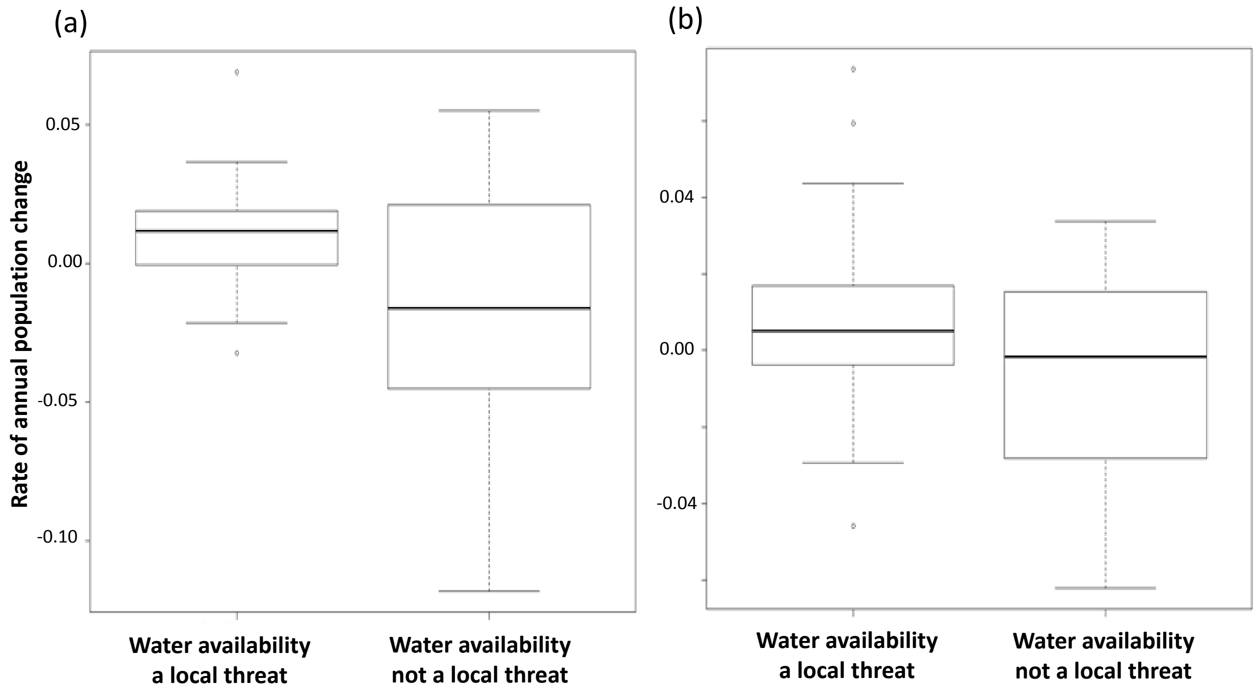

Figure 2. Differences in population change for (a) Red-necked Avocet and (b) all four inland resident shorebirds according to whether water availability was scored as local threat. Differences are significant in both cases (Red-necked Avocet, Wilcoxon-Mann Whitney-U: W = 751, $P < 0.05$, n (not a threat) = 29, n (threat) = 18; inland resident shorebirds, Wilcoxon-Mann Whitney-U: W = 355, $P < 0.05$, n (not a threat) = 57, n (threat) = 20). Median = dark horizontal line, upper edge of box = 75th percentile, lower edge of box = 25th percentile; whisker line ± 1.5 x interquartile range (75^{th} percentile – 25^{th} percentile), open circles = outliers.

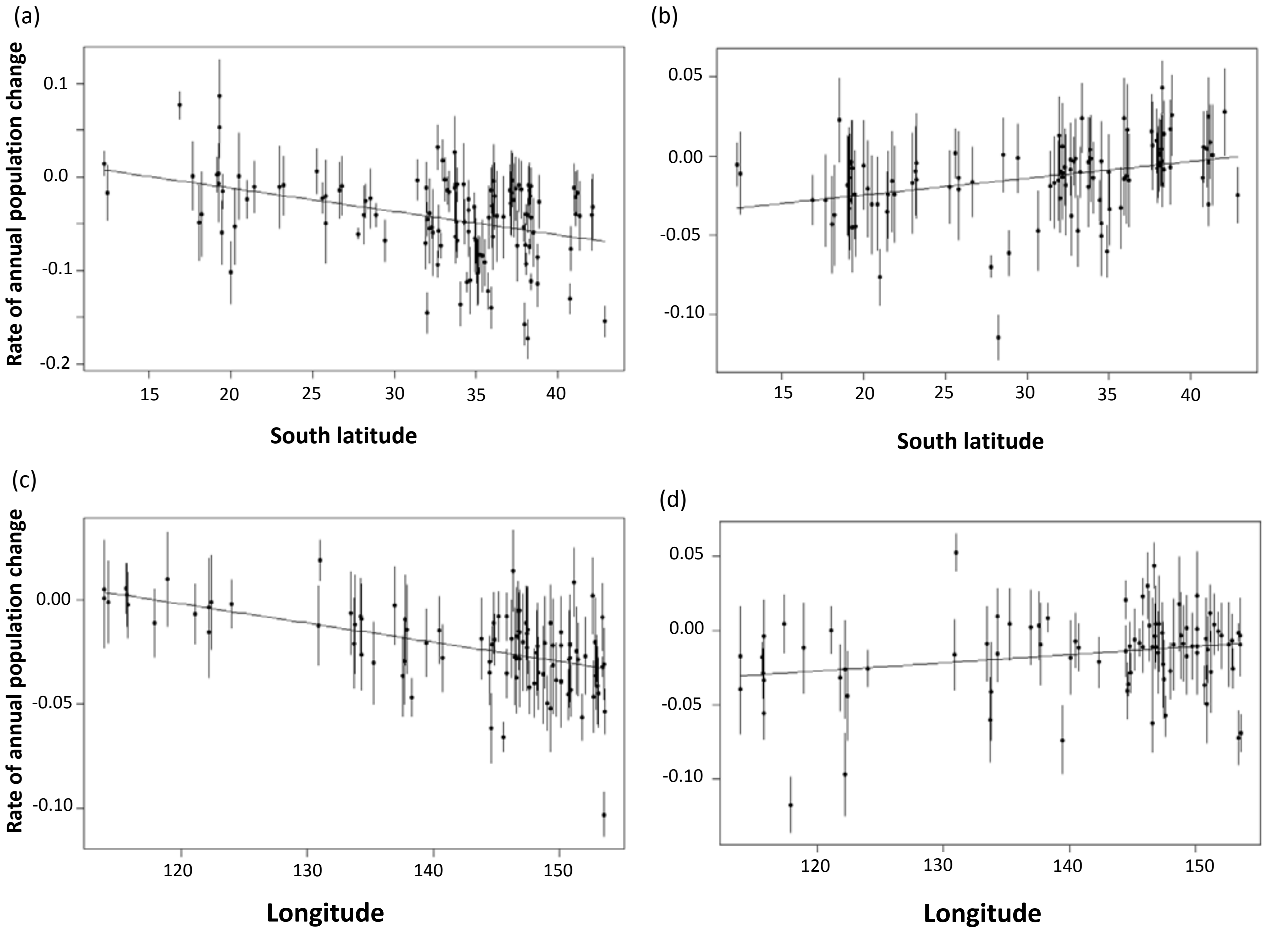

Fig. 3. Annual change in abundance for (a) Curlew Sandpiper, (b) Bar-tailed Godwit, (c) Eastern Curlew, and (d) Red Knot compared to latitude or longitude. Data points are the slope of the estimated trend at each shorebird area monitored, and vertical lines are ± 1 SE. See Table 1 for full statistical results.

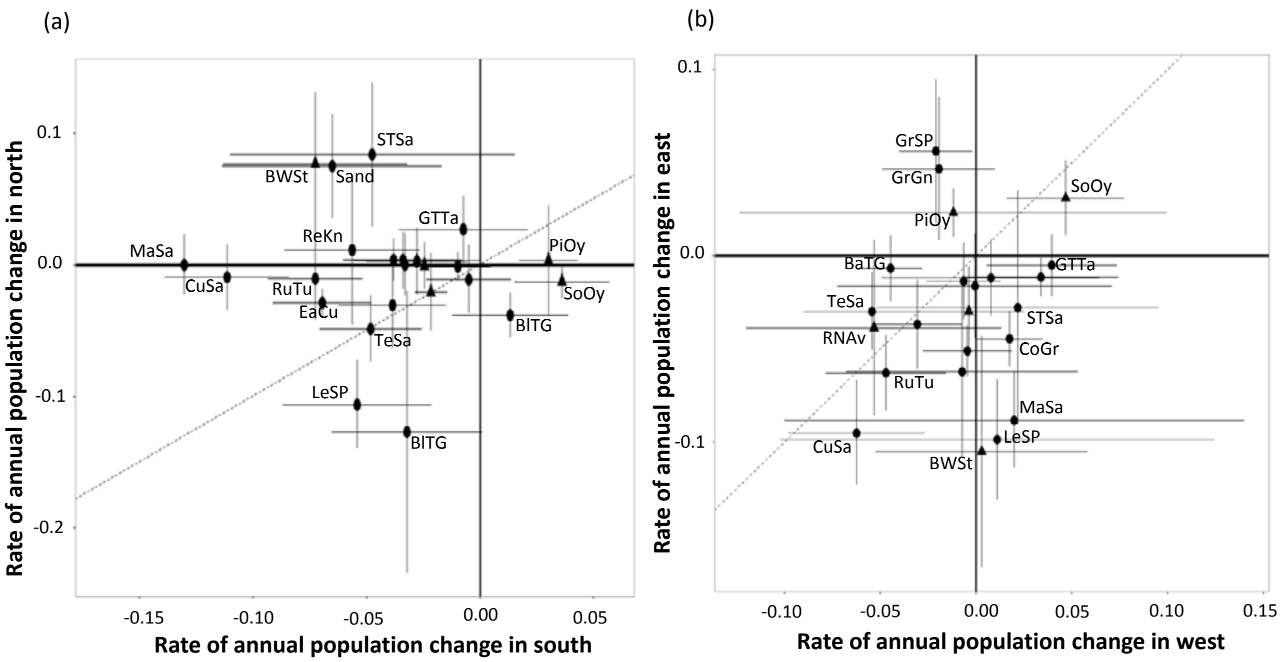

Fig. 4. Geographical differences in estimated trend for shorebird species across the Australian continent for (a) areas north or south of 28.7 degrees latitude, and (b) east or west of 129 degrees longitude. Red-necked Avocet was an outlier and is excluded from the north-south plot; see Table 2), while Black-tailed Godwit, Black-fronted Dotterel and Red-kneed Dotterel were outliers and excluded from the east-west plot. Dashed line indicates the case where trends are equal in both geographic regions. Filled circles represent migratory species and triangles represent resident species; lines are ± 1 SE. See Table S1 for species abbreviations.

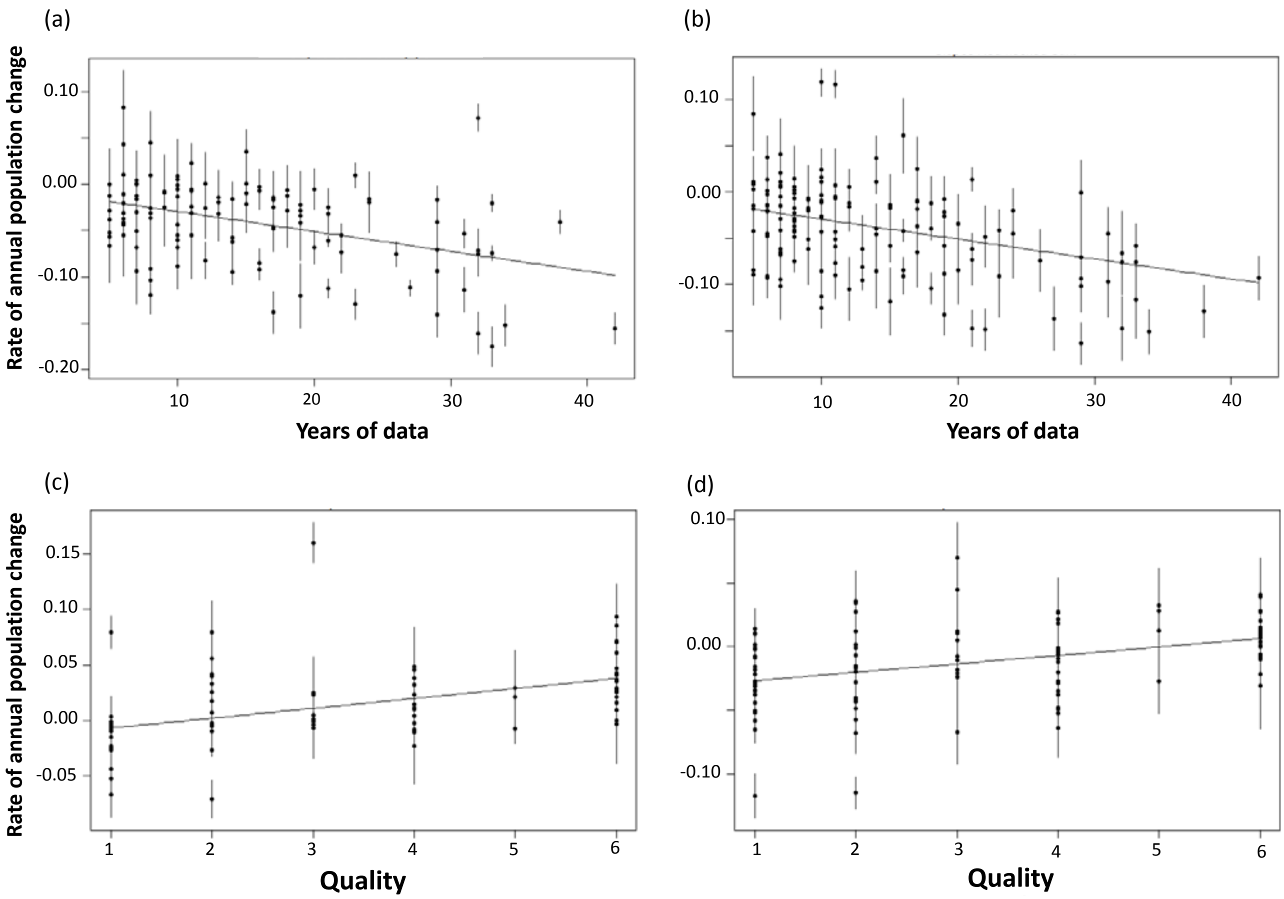

Fig. 5. Annual change in abundance of (a) Curlew Sandpiper and (b) Red-necked Stint compared with the number of years of monitoring data from any shorebird area. Data points are annual change as measured at individual shorebird areas, vertical lines ± 1 SE. Also shown is the annual change in abundance of (c) Great Knot and (d) Pacific Golden Plover compared with an expert-assessed index of quality of monitoring. Areas with a data quality score of 1 have many years of count data, and consistent spatial and temporal coverage, while those with many data gaps score 6. See Table 1 for data on all species.

Supplementary Material

Continental-scale decreases in shorebird populations in Australia

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Table S1. Summary of reported trends from Australia and Japan.

Common Name	abbreviation	Australia (this study)	Western Port, Vic. (Hansen et al. 2015)	Korea (Moores et al. 2014)	Western Treatment Plant, other Victoria sites (Rogers et al 2013; Lyon et al 2014)	Corner Inlet, Vic. (Minton et al. 2012)	Cape Portland, George TownTas. (Cooper et al 2012)	The Coorong, South Australia (Paton et al 2012)	Moreton Bay, Qld (Wilson et al 2011)	Japan (Amano et al. 2010)	Hunter Estuary, NSW (Spencer 2010)	Bellarine Peninsula, Vic. (Herrod 2010)	NNW Western Australia (Rogers et al. 2009; Rogers et al. 2011)	Swan River Estuary, WA. (Creed & Bailey 1998; Creed & Bailey 2009)	Gulf of St Vincent, SA. (Close 2008)	Australia (Olsen & Silcocks 2008; & Bartlet et al. 2003)	Inland 1/3 of eastern Australia (Nebel et al 2008)	south-east Australia (Gosbell & Clemens 2006)
Bar-tailed Godwit	BaTG	D	d	-	-	-	D	-	D	D	d	-	D	D	D	i		d
Black-tailed Godwit	BlTG	D		D				d	-	-	D	D	-		D	D		d
Common Greenshank	CoGr	D	D	-	D	D	d	D	D	i	-	d	-	-	d	d		
Curlew Sandpiper	CuSa	D	D	-	D	D	D	D	d	i	D	D	D	D	D	D		D
Eastern Curlew	EaCu	D	D	D	D	D	D	D	d	-	-	D	d		d	d		D
Great Knot	GrKn	-		d		D		d	D	i	-	D	D	d	d			
Greater Sand Plover	GrSP	-		D	-	d	d		d	i	d		d					
Grey Plover	GrPl	D		d		D	d		d	D		D	D	D	D			d
Grey-tailed Tattler	GTTa	-	D				d		-	i	-	D	-		D	d		d
Latham's Snipe	LaSn									-						d		
Lesser Sand Plover	LeSP	D	-	d		d	d		-	-	D	D	-					d
Marsh Sandpiper	MaSa	-			-				-	i	-	I	-		i			
Pacific Golden Plover	PGPl	D	d	-	D		d		i	-	D	D	-			d		d
Red Knot	ReKn	-	d	D	D	D	d		D	i	-	D	d	d	d			d
Red-necked Stint	RNSt	D	-	d	-	-	d	d	I	d	d	-	d	D	d	-		
Ruddy Turnstone	RuTu	D	D	D		D	D		D	D	-	D	d		I			
Sanderling	Sand	-		-		-		d		i			-			i		
Sharp-tailed Sandpiper	STSa	D	-	d	D	d	-	D	i	d	d	d		D	D	d		d
Terek Sandpiper	TeSa	D		-			d		-	i	-		D			d		d
Whimbrel	Whim	-	d	-		I			D	d	-		I					
Australian Pied Oystercatc	PiOy	I	I		I	-		D				-	-		I	i		
Banded Lapwing	BaLa		-												D	d	d	
Black-fronted Dotterel	BFDo	D			-													
Black-winged Stilt	BWSt	D			-			d	-					-	d	d	d	
Masked Lapwing	MaLa		D		D				-			-			d	d	d	
Red-capped Plover	RCPl	-	-		-			-	-				-	-	D	d		
Red-kneed Dotterel	RKDo	D			-			-							D	i / d		
Red-necked Avocet	RNAv	D			-			-	-					d	D	d	d	
Sooty Oystercatcher	SoOy	I				I		-							i			

D = strong evidence of decline, d = some evidence of decline, i = some evidence of increase, I = strong evidence of increase, - = no long-term change detected

Severe declines of Eastern Curlew in SE Tas (Ried and Park 2003)

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Table S2. Suggested top ten and bottom ten areas in terms of relative shorebird trends in areas being monitored for selected species; each shorebird area trend compared to average of all shorebird trends for each species with values scored as positive when above the mean and negative when below the mean; values greater than two standard deviations from the mean were scored SD +/- 2, values between one and two scored SD +/- 1, and within one standard deviation were scored +/- 0.1. Columns are sorted in order from biggest decrease to biggest increase. See Table S1 for species abbreviations

BaTG Area	BaTG Rank	RNSt Area	RNSt Rank	EaCu Area	EaCu Rank	CuSa Area	CuSa Rank
Tweed	-2	Shoalhaven Estuary	-2	Tweed	-2	Moolap Saltworks	-2
Moreton Bay	-2	Lake Robe	-2	Western Port Bay	-2	Carpenter Rocks	-2
Mackay	-2	Hastings River	-1	Werribee Avalon	-2	Bowen	-2
Shoalhaven Estuary	-2	Moolap Saltworks	-1	Mackay	-1	Botany Bay	-2
Richmond River estuary	-2	Gulf of St Vincent	-1	Armstrong	-1	SE Tasmania	-2
Coffin Bay	-1	Swan estuary WA	-1	Gulf of St Vincent	-1	Coorong	-2
Baird Bay	-1	Herdsman Lake	-1	Hunter Estuary	-1	Swan estuary WA	-2
Nambucca River	-1	Armstrong Beach	-1	Richmond River estuary	-1	Robbins Passage Boullanger Bay	-1
Lake Illawarra	-1	Lake Reeve Gippsland Lakes	-1	Toogoom to Point Vernon	-1	Kangaroo Island	-1
George Town Reserve	-1	Parramatta River	-1	Kangaroo Island	-1	Gulf of St Vincent	-1
Brou Lake	1	Lake Eliza	1	Franklin Harbour	1	Discovery Bay to Glenelg River	1
Manning River Estuary	1	Lake Illawarra	1	North Darwin	1	Lades Beach	1
North Darwin	1	Longreef	1	Laverton Altona	1	Lake Robe	1
Kelso, Tamar Estuary	1	Tuross	2	Lades Beach	1	Warden Lakes Esperance	1
Moulting Lagoon	1	Canunda National Park	2	Clarence River	1	Bowling Green Bay	1
Shallow Inlet	1	Kelso, Tamar Estuary	2	East Port Phillip	1	Sceale Bay	1
Coorong	1	Manning River Estuary	2	George Town Reserve	1	Cairns area	1
Tuggerah Lakes	1	Lake George	2	Manning River Estuary	2	Munderoo Bay to Tickera Bay	1
Lake Connewarre area	2	Bushland Beach	2	Lucinda	2	Streaky Bay	1
Lucinda	2	Yokinup	2	Botany Bay	2	Cape Bowling Green	2

ReKn Area	ReKn Rank	STSa Area	STSa Rank	GrKn Area	GrKn Rank	CoGr Area	CoGr Rank
Albany	-2	Port Stephens	-2	Mackay	-2	Moolap Saltworks	-2
Dampier Saltworks	-2	Moolap Saltworks	-2	Swan estuary WA	-2	Gulf of St Vincent	-2
Clarence River	-2	Coobowie Inlet Yorke Peninsula	-1	Moreton Bay	-1	Bool lagoon	-2
Richmond River estuary	-2	Bowen	-1	Richmond River estuary	-1	Corner Inlet	-2
Coorong	-2	Kangaroo Island	-1	Swan Bay Mud Islands	-1	Tullakool Saltworks	-1
Corner Inlet	-1	Carpenter Rocks	-1	Eighty Mile Beach	-1	Broadwater Busselton	-1
Murat Bay	-1	Coorong	-1	Camila Beach	-1	Coorong	-1
Lake Illawarra	-1	Coffin Bay	-1	Corner Inlet	-1	Mackay	-1
SE Tasmania	-1	Tourville Bay	-1	Great Sandy Straight	-1	Cairns area	-1
Alva Beach	-1	Armstrong	-1	Murat Bay	-1	Anderson Inlet	-1
Repulse Bay	1	Streaky Bay	1	Tourville Bay	0.1	East Port Phillip	1
Swan River Rottnest Island	1	Discovery Bay to Glenelg River	1	Robbins Passage Boullanger Bay	0.1	Munderoo Bay to Tickera Bay	1
Baird Bay	1	Shallow Inlet	1	Lucinda	1	Lake Illawarra	1
Gulf of St Vincent	1	King Island	1	Cairns area	1	Bushland Beach	1
Tuross	1	Munderoo Bay to Tickera Bay	1	Shallow Inlet	1	Parramatta River	1
Wilson Inlet	1	Wilson Inlet	1	Cape Bowling Green	1	Baird Bay	1
Lake Connewarre area	1	Robbins Passage Boullanger Bay	1	Clarence River	1	Botany Bay	1
Bushland Beach	1	Bowling Green Bay	1	Armstrong	1	Streaky Bay	1
Shallow Inlet	1	Moreton Bay	2	Townsville	1	Warden Lakes Esperance	1
North Darwin	2	Lades Beach	2	Bushland Beach	2	Discovery Bay to Glenelg River	2

Table S2. (continued)

GTTa Area	GTTa Rank	PGPI Area	PGPI Rank	RCPI Area	RCPI Rank	RuTu Area	RuTu Rank
Tweed	-2	Moolap Saltworks	-2	Hastings River	-2	Port Fairy	-2
Port Stephens	-2	Shoalhaven Estuary	-2	Shoalhaven Estuary	-2	Corner Inlet	-2
Hunter Estuary	-2	Mackay	-1	Gulf of St Vincent	-2	Bellambi Point	-2
Bowen	-2	Kangaroo Island	-1	Port Stephens	-1	Darwin Harbour	-2
Darwin Harbour	-2	Port Fairy	-1	Franklin Harbour	-1	Port MacDonnell	-1
Mackay	-2	George Town Reserve	-1	Brunswick River Estuary	-1	Murat Bay	-1
North Darwin	-1	Port MacDonnell	-1	Roebuck Bay	-1	Swan Bay Mud Islands	-1
Shark Bay Carnarvon	-1	Port Stephens	-1	Alva Beach	-1	George Town Reserve	-1
Port MacDonnell	-1	Dampier Saltworks	-1	Tourville Bay	-1	Hunter Estuary	-1
Moreton Bay	-1	King Island	-1	Richmond River estuary	-1	King Island	-1
Shallow Inlet	0.1	Roebuck Bay	1	Eighty Mile Beach	1	Brunswick River Estuary	0.1
Great Sandy Straight	1	Cape Bowling Green	1	Tuross	1	Stansbury Oyster Point Yorke	1
Clarence River	1	Moulting Lagoon	1	Kinka Beach	1	Manning River Estuary	1
Richmond River estuary	1	Canunda National Park	1	George Town Reserve	1	Franklin Harbour	1
Armstrong Beach	1	Jack Smith Lake Gippsland Lakes	1	Port Hedland	1	Narawntapu National Park	1
St Helens Beach	1	Manning River Estuary	1	Kinka Wetlands	1	Clarence River	1
Botany Bay	1	Streaky Bay	1	Jack Smith Lake Gippsland Lakes	1	Streaky Bay	2
Bushland Beach	2	Longreef	1	Cape Portland	2	Bushland Beach	2
Eighty Mile Beach	2	Lades Beach	2	Kelso, Tamar Estuary	2	Baird Bay	2
Cairns area	2	Lake Eliza	2	Dampier Saltworks	2	Kelso, Tamar Estuary	2

PiOy Area	PiOy Rank	RNAv Area	RNAv Rank	BITG Area	BITG Rank	Whim Area	Whim Rank
Woodman Point	-2	Moolap Saltworks	-2	Roebuck Bay	-2	Hunter Estuary	-2
Ocean Beach	-1	Tullakool Saltworks	-2	Coorong	-2	Brunswick River Estuary	-1
Shallow Inlet	-1	Lake Hindmarsh Wimmera	-1	Armstrong	-2	Port Stephens	-1
Hutt Lagoon	-1	Swan Coastal Plain Lakes	-1	Armstrong Beach	-2	Dampier Saltworks	-1
Robbins Passage Boullanger Bay	-1	Coorong	-1	Gulf of St Vincent	-1	Toogoom to Point Vernon	-1
Port Fairy	-1	Kerang Lakes	-1	Dampier Saltworks	-1	Bushland Beach	-1
Shoalhaven Estuary	-1	Gulf of St Vincent	-1	Repulse Bay	-1	Camden Haven	-1
Tweed	-1	Peel Yalgorup Lakes	-1	Werribee Avalon	-0	Gulf of St Vincent	-0
Murat Bay	-1	Lake Eliza	-0	Bowen	-0	Carpenter Rocks	-0
Swan Bay Mud Islands	-1	Lake Albacutya Wimmera	-0	Hunter Estuary	-0	Nambucca River	-0
Carpenter Rocks	1	Clarence River	0.1	Sandy Point Capr. Res	0.1	Lucinda	0.1
Yokinup	1	Lake Wyn Wyn area Wimmera	0.1	Botany Bay	0.1	SE Tasmania	1
Bushland Beach	1	East Port Phillip	0.1	Clarence River	0.1	Parramatta River	1
Cape Portland	1	Lake Gore	1	Eighty Mile Beach	0.1	Corner Inlet	1
Botany Bay	1	Warden Lakes Esperance	1	Bushland Beach	1	George Town Reserve	1
Lucinda	2	Nericon Swamp	1	Cairns area	1	Alva Beach	1
Discovery Bay to Glenelg River	2	Western Port Bay	1	Coffin Bay	1	Armstrong Beach	1
Manning River Estuary	2	Lake Corangamite area	1	Bush Point	1	Mackay	1
George Town Reserve	2	Wilson Inlet	1	North Darwin	1	Eighty Mile Beach	2
Swan estuary WA	2	Parramatta River	2	Cape Bowling Green	2	Botany Bay	2

Table S3. Shorebird area trend ranks, expert threat assessments (Y = threat believed to be having local impacts on shorebirds) and data quality of 83 shorebird areas in Australia. Variable explanations: [1,2,3] Shorebird area trend compared to average of all shorebird area trends for each species then summed across all species (n=26), residents (n=7) or migrants (n= 19): with values scored as positive when above the mean and negative when below the mean. Values within one standard deviation of the mean were scored +/- 0.1, between one and two SD +/- 1, and greater than two SD +/- 2; [4] Data quality score: 1 = best quality data, long time series with complete spatial and temporal coverage, to 6 = worst quality data used.

Shorebird Area Name	total rank sum [1]	migratory rank sum [2]	resident rank sum [3]	Roost availability	disturbance	water quality	foraging habitat loss	management use	water availability	Quality of time series [4]	Years of data	ramsar	latitude	longitude	state
Gulf of St Vincent	-12	-9	-4	-	Y	Y	-	-	-	2	21	no	-34.5	138.3	SA
Moolap Saltworks	-12	-12	0	-	-	Y	Y	Y	Y	1	33	no	-38.1	144.4	Vic
Hunter Estuary	-12	-13	1.1	Y	Y	-	-	Y	-	1	26	yes	-32.8	151.8	NSW
Coorong	-11	-10	-1	-	Y	Y	Y	Y	Y	1	16	yes	-35.9	139.5	SA
Corner Inlet	-8.2	-8	0.1	-	-	-	-	-	-	1	30	yes	-38.7	146.6	Vic
Swan Bay Mud Islands	-7.5	-7	-1	Y	-	-	-	-	-	1	33	yes	-38.2	144.7	Vic
Tullakool Saltworks	-7.1	-4	-3	-	-	Y	-	Y	Y	4	5	no	-35.4	144.2	NSW
Murat Bay	-6.8	-5	-2	-	-	-	-	Y	-	4	6	no	-32.2	133.7	SA
Swan Estuary, WA	-6.7	-8	1.7	Y	Y	-	Y	-	-	1	34	no	-32.0	115.8	WA
Woodman Point	-5.2	-3	-2	-	Y	Y	-	Y	-	4	19	no	-32.1	115.8	WA
Lake Albacutya Wimmera	-5.1	-2	-3	-	-	-	Y	-	Y	2	5	yes	-35.8	142.0	Vic
Coffin Bay	-5.1	-5	-0	-	-	-	-	-	-	6	7	no	-34.5	135.2	SA
Roebuck Bay	-4.7	-4	-1	Y	Y	-	-	-	-	2	16	yes	-18.1	122.4	WA
Port Fairy	-3.5	-2	-1	-	Y	-	-	-	-	3	16	no	-38.4	142.4	Vic
Port MacDonnell	-3.5	-3	-0	-	Y	-	-	-	-	1	21	no	-38.1	140.7	SA
Lake Hindmarsh Wimmera	-3.4	-0	-3	-	-	Y	-	-	Y	4	10	no	-36.0	141.9	Vic
Albany	-3.1	-4	1.2	Y	Y	-	Y	Y	-	1	21	no	-35.0	117.9	WA
Kerang Lakes	-3.1	-2	-1	-	-	Y	-	-	Y	3	10	yes	-35.5	143.8	Vic
Great Sandy Straight	-2.8	-3	-0	-	Y	-	-	-	-	2	16	yes	-25.6	152.9	Qld
Tourville Bay	-2.8	-2	-1	-	-	-	-	-	-	4	5	no	-32.1	133.5	SA
Bush Point	-2.3	-2	0	Y	-	-	-	-	-	2	10	yes	-18.2	122.2	WA
Hutt Lagoon	-2.3	-1	-1	Y	Y	-	-	-	-	5	6	no	-28.2	114.2	WA
Bool lagoon	-2.1	-2	-0	-	-	-	-	-	Y	4	7	yes	-37.1	140.7	SA
Swan Coastal Plain Lakes	-1.9	-1	-1	Y	-	-	Y	-	Y	2	22	no	-32.3	115.8	WA
Ocean Beach	-1.8	-1	-1	Y	Y	-	Y	Y	-	6	6	no	-42.1	145.3	TAS
SE Tasmania	-1.8	-3	1.2	-	Y	-	-	-	-	1	39	no	-42.8	147.6	TAS
Robbins Passage & Boullanger Bay	-1.6	0.3	-2	-	Y	-	-	Y	-	2	23	no	-40.7	144.8	TAS
Moreton Bay	-1.4	-2	0.2	-	Y	Y	-	-	-	2	30	yes	-27.8	153.4	Qld
Moorland Point	-1.3	-1	0	Y	Y	-	Y	Y	-	6	8	no	-41.2	146.4	TAS
Peel & Yalgorup Lakes	-1.3	-0	-1	Y	Y	Y	Y	Y	Y	1	13	yes	-32.7	115.7	WA
King Island	-1.3	-1	-0	-	Y	-	-	-	-	4	8	no	-39.9	143.8	TAS
Dampier Saltworks	-1.1	-3	2	-	-	-	-	-	-	7	5	no	-17.7	122.2	WA
Werribee Avalon	-1.1	-1	0	-	-	Y	Y	-	-	1	30	yes	-38.0	144.6	Vic
Anderson Inlet	-1	-1	0.1	Y	Y	-	Y	Y	-	1	16	no	-38.7	145.8	Vic
Lake Wyn Wyn area Wimmera	-0.7	0.3	-1	-	-	Y	-	-	Y	4	11	no	-36.7	141.9	Vic
Carpenter Rocks	-0.6	-3	2.1	-	Y	-	-	-	-	1	22	no	-38.0	140.5	SA
Western Port Bay	-0.3	-1	0.9	-	Y	Y	-	Y	-	1	29	yes	-38.4	145.5	Vic
Maurouard Beach	-0.3	-0	-0	Y	Y	-	Y	Y	-	5	10	no	-41.3	148.3	TAS
Shark Bay	-0.3	0.3	-1	-	-	-	-	-	-	4	8	no	-25.8	113.9	WA
Scamander	0	-0	0.1	Y	Y	-	-	Y	-	6	9	no	-41.5	148.3	TAS
Swan Hill	0	-0	0.3	-	-	Y	-	-	Y	3	10	no	-35.2	143.4	Vic

Table S3. (continued).

Shorebird Area Name	total rank sum[1]	migratory rank sum[2]	resident rank sum[3]	Roost availability	disturbance	water quality	foraging habitat loss	management use	water availability	Quality of time series[4]	Years of data	ramsar	latitude	longitude	state
Vasse-Wonnerup Estuary	0	0.1	-0.1	-	-	Y	-	Y	Y	3	8	yes	-33.6	115.4	WA
Esperance	0.1	0.2	-0.1	-	Y	-	-	-	-	6	6	no	-33.9	122.1	WA
Georges Bay	0.1	0.2	-0.1	-	Y	-	Y	-	-	3	11	no	-41.3	148.3	TAS
Policemans Point	0.1	0	0.1	Y	Y	-	Y	-	-	6	5	no	-41.1	148.3	TAS
Lake Buloke Wimmera	0.2	0.3	-0.1	-	-	-	Y	-	Y	2	5	no	-36.2	143.0	Vic
Kinka Beach	0.3	-0.4	0.7	-	Y	-	-	-	-	4	13	no	-23.2	150.8	Qld
Douglas area Wimmera	0.4	1.2	-0.8	-	-	Y	-	-	Y	4	19	no	-37.1	141.7	Vic
Fox and Pub Lakes	0.5	0.3	0.2	-	Y	-	-	-	-	4	10	no	-37.2	139.8	SA
Eyre Island	0.7	0.6	0.1	-	-	-	-	-	-	6	5	no	-32.4	133.8	SA
Nuytsland Nature Reserve	1.1	1.1	0	-	-	-	-	-	-	1	29	no	-33.3	124.0	WA
East Port Phillip	1.3	2.2	-0.9	-	Y	-	-	-	Y	1	29	yes	-38.1	145.2	Vic
Broadwater Busselton	1.3	1.1	0.2	-	-	Y	-	Y	Y	4	6	no	-33.7	115.3	WA
Lake Dulverton	1.3	0.3	1	-	-	-	-	Y	-	5	12	no	-42.3	147.4	TAS
Rottnest Island	1.3	1.3	0	-	-	-	-	-	-	1	29	no	-32.0	115.8	WA
Cape Portland	1.8	-2.1	3.9	-	-	-	-	Y	Y	1	35	no	-40.8	148.0	TAS
Moulting Lagoon	2.1	2.3	-0.2	Y	-	-	-	-	-	5	18	yes	-42.0	148.2	TAS
Lake Gore	2.2	1.1	1.1	-	-	-	-	-	-	4	10	yes	-33.8	121.5	WA
Jack Smith Lake Gippsland Lakes	2.4	1.3	1.1	-	-	Y	-	-	Y	5	6	no	-38.5	147.0	Vic
Narawntapu National Park	2.4	2.5	-0.1	Y	Y	-	Y	-	-	4	18	no	-41.2	146.6	TAS
Port Hedland	2.7	1.7	1	Y	-	-	Y	-	-	4	5	no	-20.2	118.9	WA
Shark Bay Carnarvon	2.7	2.8	-0.1	-	-	-	-	-	-	4	8	no	-25.8	113.9	WA
Botany Bay	2.9	1.1	1.8	Y	Y	-	Y	Y	-	1	24	yes	-34.0	151.2	NSW
Mallacoota	3	3	0	-	-	-	-	-	-	4	10	no	-37.6	149.7	Vic
Sceale Bay	3.2	3.1	0.1	-	-	-	-	Y	-	3	11	no	-33.0	134.2	SA
Lake George	3.4	3.4	0	-	-	Y	Y	Y	-	2	12	no	-37.4	140.0	SA
George Town Reserve	3.5	-0.5	4	Y	Y	-	Y	-	-	1	38	no	-41.1	146.8	TAS
Laverton Altona	3.9	5	-1.1	-	Y	-	Y	-	-	1	31	yes	-37.9	144.8	Vic
Lades Beach	4.2	6.2	-2	Y	Y	-	Y	-	-	3	18	no	-41.0	147.4	TAS
Parramatta River	4.2	1	3.2	Y	Y	-	Y	Y	-	1	20	no	-33.8	151.2	NSW
Lake Corangamite Area	4.3	1.2	3.1	-	-	Y	-	-	Y	3	8	yes	-38.2	143.5	Vic
Wilson Inlet	4.7	3.5	1.2	-	-	-	Y	Y	Y	1	19	no	-35.0	117.4	WA
Eighty Mile Beach	4.8	3.7	1.1	-	-	-	-	-	-	2	9	yes	-19.5	121.1	WA
Yokinup	5.1	2.1	3	-	Y	-	-	-	-	6	8	no	-33.9	123.1	WA
Shallow Inlet	6.2	8.1	-1.9	-	Y	Y	-	-	-	2	10	no	-38.8	146.2	Vic
Baird Bay	6.4	5.4	1	-	-	Y	-	-	-	2	7	no	-33.1	134.3	SA
Cairns area	6.5	5.3	1.2	Y	Y	-	-	Y	-	1	32	no	-16.9	145.8	Qld
Streaky Bay	6.9	6.1	0.8	-	Y	-	-	Y	-	2	15	no	-32.6	134.3	SA
Discovery Bay to Glenelg River	7.2	5.3	1.9	-	-	-	-	-	-	3	11	no	-38.2	141.3	Vic
Warden Lakes Esperance	7.4	5.2	2.2	-	-	-	-	-	-	6	15	no	-33.8	121.8	WA
Kelso, Tamar Estuary	7.7	5.7	2	Y	Y	-	Y	-	-	4	17	no	-41.1	146.8	TAS
Lake Connewarre area	8.4	5.1	3.3	-	Y	-	-	-	-	1	33	yes	-38.2	144.4	Vic
North Darwin	9.6	9.3	0.3	-	Y	-	-	-	-	2	23	no	-12.3	131.0	NT

Table S3. (continued – for areas where expert threat assessments were not available)

Shorebird Area Name	total rank sum	migratory rank sum	resident rank sum	Roost availability	disturbance	water quality	foraging habitat loss	management use	water availability	Quality of time series	Years of data	human density	ramsar	latitude	longitude	state
Mackay	-15.5	-15.8	0.3	NA	NA	NA	NA	NA	NA	2	21	10.0	no	-21.0	149.0	Qld
Richmond River estuary	-13.5	-12.5	-1	NA	NA	NA	NA	NA	NA	1	19	16.0	no	-28.9	153.5	NSW
Tweed	-11.1	-9.4	-1.7	NA	NA	NA	NA	NA	NA	2	17	16.0	no	-28.2	153.5	NSW
Kangaroo Island	-10	-7	-3	NA	NA	NA	NA	NA	NA	4	8	0.6	no	-35.7	137.6	SA
Shoalhaven Estuary	-10	-7	-3	NA	NA	NA	NA	NA	NA	2	18	5.4	no	-34.9	150.7	NSW
Port Stephens	-8.4	-7.5	-0.9	NA	NA	NA	NA	NA	NA	2	14	8.0	no	-32.7	152.1	NSW
Fivebough Swamp	-7.5	-3.4	-4.1	NA	NA	NA	NA	NA	NA	4	13	2.0	yes	-34.5	146.4	NSW
Armstrong	-7.4	-6.4	-1	NA	NA	NA	NA	NA	NA	6	15	10.0	no	-21.5	149.3	Qld
Darwin Harbour	-5.1	-5.1	0	NA	NA	NA	NA	NA	NA	6	8	12.0	no	-12.5	130.9	NT
Armstrong Beach	-4.9	-4.8	-0.1	NA	NA	NA	NA	NA	NA	2	19	10.0	no	-21.4	149.3	Qld
Hastings River	-4.6	-1.7	-2.9	NA	NA	NA	NA	NA	NA	3	20	7.2	no	-31.4	152.9	NSW
Coobowie Inlet Yorke Pen	-4.2	-4.1	-0.1	NA	NA	NA	NA	NA	NA	6	7	0.6	no	-35.1	137.7	SA
Alva Beach	-3.5	-2.6	-0.9	NA	NA	NA	NA	NA	NA	6	7	5.7	no	-19.5	147.5	Qld
Lake Hawdon	-3	-1.1	-1.9	NA	NA	NA	NA	NA	NA	3	8	0.9	no	-37.2	139.9	SA
Repulse Bay	-2.7	-2.7	0	NA	NA	NA	NA	NA	NA	6	7	2.8	no	-20.5	148.7	Qld
Yarrawonga Point	-2.6	-2.4	-0.2	NA	NA	NA	NA	NA	NA	4	9	0.2	no	-21.7	149.5	Qld
Herdsman Lake	-2.5	-2.7	0.2	NA	NA	NA	NA	NA	NA	6	10	164.5	no	-31.9	115.8	WA
Nambucca River	-2.4	-2.3	-0.1	NA	NA	NA	NA	NA	NA	7	10	10.5	no	-30.7	153.0	NSW
Bowen	-2.3	-3.3	1	NA	NA	NA	NA	NA	NA	3	19	2.8	no	-20.0	148.2	Qld
Blakeys Crossing	-2.2	-2.3	0.1	NA	NA	NA	NA	NA	NA	6	9	13.9	no	-19.3	146.8	Qld
Goldsmith Beach to Wattl	-2.1	-2	-0.1	NA	NA	NA	NA	NA	NA	4	8	0.6	no	-35.1	137.7	SA
Mildura	-2.1	-0.1	-2	NA	NA	NA	NA	NA	NA	4	17	5.5	no	-34.3	142.0	Vic
Black Point Yorke	-2	-0.9	-1.1	NA	NA	NA	NA	NA	NA	4	8	0.9	no	-34.6	137.9	SA
Ewen Maddock Dam Calou	-2	-0.9	-1.1	NA	NA	NA	NA	NA	NA	6	17	39.4	no	-26.8	153.0	Qld
Gunyah Beach	-2	-2.1	0.1	NA	NA	NA	NA	NA	NA	3	7	0.3	no	-34.7	135.4	SA
Sandy Point Capr. Res	-2	-1.9	-0.1	NA	NA	NA	NA	NA	NA	6	11	1.6	yes	-23.0	150.8	Qld
Bellambi Point	-1.9	-2	0.1	NA	NA	NA	NA	NA	NA	6	5	79.2	no	-34.4	150.9	NSW
Rivoli Bay	-1.5	-1.7	0.2	NA	NA	NA	NA	NA	NA	4	8	0.9	no	-37.5	140.1	SA
Toolakea Beach - 30k nth T	-1.4	-1.3	-0.1	NA	NA	NA	NA	NA	NA	6	8	13.9	no	-19.1	146.6	Qld
Lake Robe	-1.2	-1.1	-0.1	NA	NA	NA	NA	NA	NA	4	10	0.9	no	-37.2	139.8	SA
Lake Reeve Gippsland Lak	-1	-1	0	NA	NA	NA	NA	NA	NA	4	NA	10.3	yes	-38.3	147.2	Vic
Camden Haven	-0.8	-0.9	0.1	NA	NA	NA	NA	NA	NA	4	6	7.2	no	-31.6	152.8	NSW
Magnetic Island	-0.7	-0.5	-0.2	NA	NA	NA	NA	NA	NA	6	5	5.7	no	-19.2	146.8	Qld
Brunswick River Estuary	-0.4	0.6	-1	NA	NA	NA	NA	NA	NA	3	12	16.0	no	-28.5	153.5	NSW

Table S3. (continued – for areas where expert threat assessments were not available)

Shorebird Area Name	total rank sum	migratory rank sum	resident rank sum	Roost availability	disturbance	water quality	foraging habitat loss	management use	water availability	Quality of time series	Years of data	human density	ramsar	latitude	longitude	state
Stansbury Oyster Point Yo	-0.2	-1.1	0.9	NA	NA	NA	NA	NA	NA	4	5	0.9	no	-34.9	137.8	SA
Toomulla Beach - 45k nth	-0.1	-0.1	0	NA	NA	NA	NA	NA	NA	6	7	1.5	no	-19.1	146.5	Qld
Narooma Estuary	-0.1	0.2	-0.3	NA	NA	NA	NA	NA	NA	6	10	3.2	no	-36.2	150.1	NSW
Sleaford Bay	0	0	0	NA	NA	NA	NA	NA	NA	4	7	1.8	no	-34.9	135.8	SA
Congo Point	0.2	0.2	0	NA	NA	NA	NA	NA	NA	6	7	3.2	no	-36.0	150.2	NSW
Maroochy River	0.3	0.5	-0.2	NA	NA	NA	NA	NA	NA	4	15	39.4	no	-26.6	153.1	Qld
Bowling Green Bay	0.5	0.8	-0.3	NA	NA	NA	NA	NA	NA	6	8	5.7	no	-19.3	147.4	Qld
Lake St Clair	0.5	0.3	0.2	NA	NA	NA	NA	NA	NA	4	9	0.9	no	-37.3	139.9	SA
Kinka Beach and Creek	0.7	0.6	0.1	NA	NA	NA	NA	NA	NA	6	7	13.8	no	-23.3	150.8	Qld
Cungalla	1.1	0.9	0.2	NA	NA	NA	NA	NA	NA	6	5	0.0	no	-19.0	147.1	Qld
Dubbo Sewage Ponds	1.1	-0.1	1.2	NA	NA	NA	NA	NA	NA	4	10	2.0	no	-32.2	148.6	NSW
Camila Beach	1.2	1.3	-0.1	NA	NA	NA	NA	NA	NA	6	10	0.2	no	-21.9	149.5	Qld
Lake Illawarra	1.4	1.2	0.2	NA	NA	NA	NA	NA	NA	2	21	79.2	no	-34.5	150.9	NSW
Bluewater Creek	1.4	1.5	-0.1	NA	NA	NA	NA	NA	NA	6	6	13.9	no	-19.1	146.6	Qld
Franklin Harbour	1.4	2.4	-1	NA	NA	NA	NA	NA	NA	3	10	1.5	no	-33.7	136.9	SA
Kinka Wetlands	1.5	0.7	0.8	NA	NA	NA	NA	NA	NA	6	8	13.8	no	-23.2	150.8	Qld
Moruya Estuary	1.5	1.3	0.2	NA	NA	NA	NA	NA	NA	3	24	3.2	no	-35.9	150.1	NSW
Mullins Swamp	1.6	0.8	0.8	NA	NA	NA	NA	NA	NA	4	6	0.9	no	-37.5	140.1	SA
Toogoom to Point Vernon	1.7	1.8	-0.1	NA	NA	NA	NA	NA	NA	4	15	6.6	no	-25.2	152.7	Qld
Clarence River	1.7	0.8	0.9	NA	NA	NA	NA	NA	NA	2	22	5.1	no	-29.4	153.4	NSW
Brou Lake	2	1.8	0.2	NA	NA	NA	NA	NA	NA	6	9	3.2	no	-36.1	150.1	NSW
Fitzroy River Mouth	2	2	0	NA	NA	NA	NA	NA	NA	4	10	5.7	no	-38.3	141.9	Vic
Nericon Swamp	2	2.1	-0.1	NA	NA	NA	NA	NA	NA	4	6	2.7	no	-34.2	146.0	NSW
St Helens Beach	2.2	1.3	0.9	NA	NA	NA	NA	NA	NA	6	4	1.3	no	-20.8	148.8	Qld
Lake Eliza	2.8	2.9	-0.1	NA	NA	NA	NA	NA	NA	3	8	0.9	no	-37.2	139.9	SA
Hamilton	3	2.2	0.8	NA	NA	NA	NA	NA	NA	5	11	5.7	no	-37.8	142.2	Vic
Townsville	3.8	3.5	0.3	NA	NA	NA	NA	NA	NA	2	24	5.7	no	-19.3	146.9	Qld
Longreef	3.8	2.8	1	NA	NA	NA	NA	NA	NA	4	7	210.2	no	-33.7	151.3	NSW
Munderoo Bay to Tickera I	4.1	4.3	-0.2	NA	NA	NA	NA	NA	NA	4	6	1.5	no	-33.7	137.8	SA
Canunda National Park	4.3	3.3	1	NA	NA	NA	NA	NA	NA	4	7	0.2	no	-37.6	140.2	SA
Tuggerah Lakes	5	3.6	1.4	NA	NA	NA	NA	NA	NA	3	18	210.2	no	-33.3	151.5	NSW
Tuross	6.6	5.5	1.1	NA	NA	NA	NA	NA	NA	6	10	3.2	no	-36.0	150.1	NSW
Cape Bowling Green	8.5	8.6	-0.1	NA	NA	NA	NA	NA	NA	6	6	5.7	no	-19.3	147.4	Qld
Manning River Estuary	11.1	9.1	2	NA	NA	NA	NA	NA	NA	4	9	8.0	no	-31.9	152.6	NSW
Lucinda	13.3	10.3	3	NA	NA	NA	NA	NA	NA	6	8	1.5	no	-18.5	146.3	Qld
Bushland Beach	16.1	14.8	1.3	NA	NA	NA	NA	NA	NA	3	16	13.9	no	-19.2	146.7	Qld

Table S4. Estimated population changes in Australian shorebird species in different subsets of Australian shorebird count data and whether decreases or increases are greater in the north, south, east or west of the continent. Numbers = slope estimates of log-transformed counts over time (per year) approximate % change per year, bold = 95% confidence intervals that do not span zero, (1 = insufficient data, models did not converge); 2 = rates of population change vary by latitude or longitude, I = increase; D = decrease; as one goes N = north; S = south, as one goes E = east; W = west, n = not significant; * ANOVA of lmer fixed effects term significant: P < 0.05; ** ANOVA of lmer fixed effects term interaction term with time significant: P < 0.05; *** ANOVA of lmer of both fixed effects terms and interaction term significant: P < 0.05.

Species	1973-2014 overall	1996-2014 overall	1973-1996 overall [1]	2002-2014 overall [1]	1996 – 2014 west	1996 – 2014 east	Quality score 1 to 3 [1]	Quality score 1 to 5	1973-2014 latitude [2]	1973-2014 longitude [2]
Migratory Species										
Curlew Sandpiper	**-9.53**	**-9.96**	**-9.79**	**-10.2**	**-6.25**	**-9.51**	**-9.2**	**-8.65**	(D –S)**	(D – W)*
Lesser Sand Plover	**-7.16**	**-13.66**	0.12	**-15.74**	1.1	**-9.87**	**-8.08**	**-5.51**	(D –N)*	(D –E)***
Sharp-tailed Sandpiper	**-5.73**	-3.88	**-17.25**	-4.25	2.17	-2.79	**-5.63**	**-5.72**	n	(D –E)*
Terek Sandpiper	**-5.4**	**-5.41**	1.06	**-6.29**	**-5.43**	**-2.99**	**-5.69**	**-5.8**	(D –N)*	(D –E)*
Black-tailed Godwit	**-5.38**	**-11.65**	**-7.12**	**-12.98**	**-23.25**	-0.97	**-9.23**	**-8.27**	(D –S)*	n
Red-necked Stint	**-3.35**	**-4.02**	**-8.37**	**-5.28**	**-3.06**	**-3.69**	**-2.42**	**-1.93**	n	(D –E)*
Bar-tailed Godwit	**-3.22**	**-2.8**	**2.46**	-1.55	**-4.46**	-0.69	**-3.45**	**-3.25**	(D –N)*	n
Ruddy Turnstone	**-3.17**	**-5.8**	1.36	**-4.97**	**-4.72**	**-6.31**	**-2.71**	**-2.83**	n	(D –E)*
Eastern Curlew	**-2.97**	**-4.68**	**+2.5**	**-4.97**	-0.46	**-5.12**	**-2.57**	**-2.63**	(D –S)***	(D –E)***
Pacific Golden Plover	**-2.02**	0.71	**-4.05**	+2.15	3.37	**-1.16**	**-2.55**	**-2.04**	n	n
Grey Plover	**-2.02**	**-1.8**	1.12	-1.46	-0.64	-1.36	**-2.02**	**-2.26**	(D –S)***	(D –W)*
Common Greenshank	**-1.98**	**-2.89**	-0.46	**-2.08**	1.73	**-4.46**	**-1.97**	**-2.37**	n	(D –E)*
Red Knot	-1.65	-2.6	4.32	-2.3	-0.07	-1.65	**-3.04**	**-3.53**	n	(D –W)*
Marsh Sandpiper	-0.9	**-10.89**	**+8.09**	**-9.92**	1.99	**-8.83**	**-2.21**	1.21	n	n
Sanderling	0.08	-1.18	-2.19	-0.3	-0.73	**-6.22**	**+4.06**	**+3.03**	n	(I –W)*
Greater Sand Plover	0.54	0.23	**+3.28**	**-2.61**	**-2.1**	**5.6**	0.78	0.25	(D –S)***	(D –W)*
Whimbrel	0.65	-0.99	2.18	**-3.53**	0.78	-1.18	1.09	0.24	(I –N)*	n
Great Knot	1.43	0.39	2.78	-0.38	-1.95	**+4.66**	1.9	**+2.22**	(I –N)***	(I –E)*
Grey-tailed Tattler	1.93	1.64	0.01	-0.36	**+3.95**	-0.52	**+2.9**	+2.47	(I –N)*	(I –W)*
Resident Species										
Red-necked Avocet	**-2.87**	**-7.01**	**-5.58**	**-15.89**	-5.32	-3.88	**-3.71**	**-3.3**	n	n
Black-winged Stilt	**-1.81**	**-5.07**	1.74	**-4.47**	0.29	**-10.52**	**-2.45**	**-2.97**	n	(D –E)***
Black-fronted Dotterel	**-2.48**				-	-			n	n
Red-kneed Dotterel	**-2.1**				-	-			n	n
Red-capped Plover	-0.67	**-3.19**	**-11.26**	**-4.57**	-0.39	**-3**	**-3.05**	-0.25	n	(D –E)*
Sooty Oystercatcher	**+0.89**	**+2.32**	-0.65	**+7.72**	**4.67**	**+3.08**	**+1.35**	0.84	(I –S)*	n
Australian Pied Oystercatcher	**+1.43**	**+2.32**	**+2,23**	**+3.02**	-1.2	**+2.29**	**+1.76**	**+1.54**	(I –S)*	n

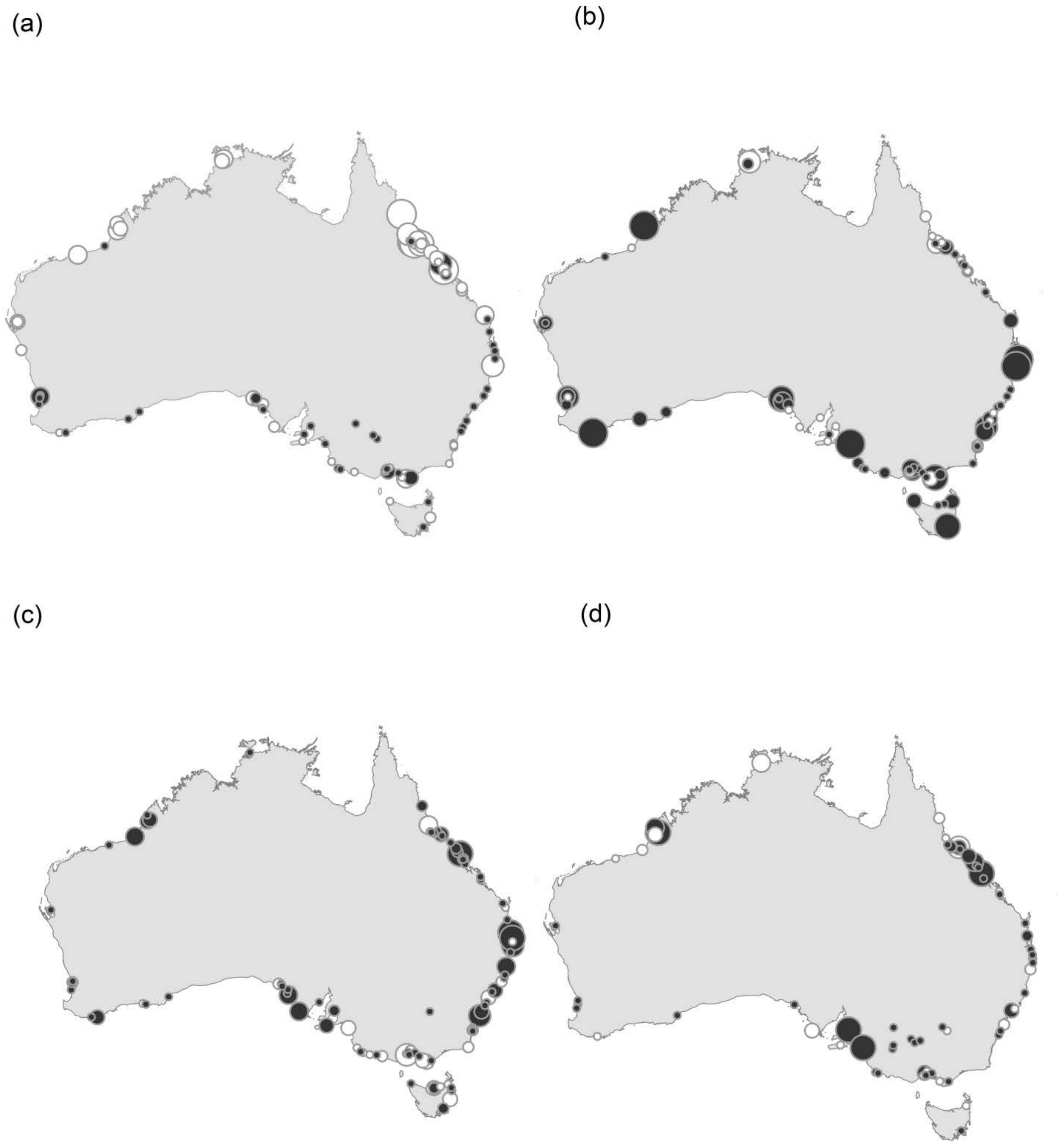

Fig. S1. Decreases (dark circles) and increases (light circles) in shorebird abundance over time estimated from models not including latitude or longitude for (a) Great Knot: no significant trend, increases are greater in the north and east of Australia; (b) Red Knot: no significant trend, decreases slightly greater in the west; (c) Bar-tailed Godwit: 3.2% national declines which are greater in the north; (d) Black-tailed Godwit: 6.1% decreases throughout Australia. Circle size is proportional to 0.5 x standard deviation of the trend.

Fig. S2. Decreases (dark circles) and increases (light circles) in shorebird abundance over time estimated from models not including latitude or longitude for (a) Curlew Sandpiper: 6.1% decreases greater in the south and west of Australia; (b) Sharp-tailed Sandpiper: 4.6% decreases, decreases greater in the east; (c) Common Greenshank: 1.8% national declines which are greater in the east; (d) Marsh Sandpiper: no significant declines throughout Australia. Circle size is proportional to 0.5 x standard deviation of the trend.

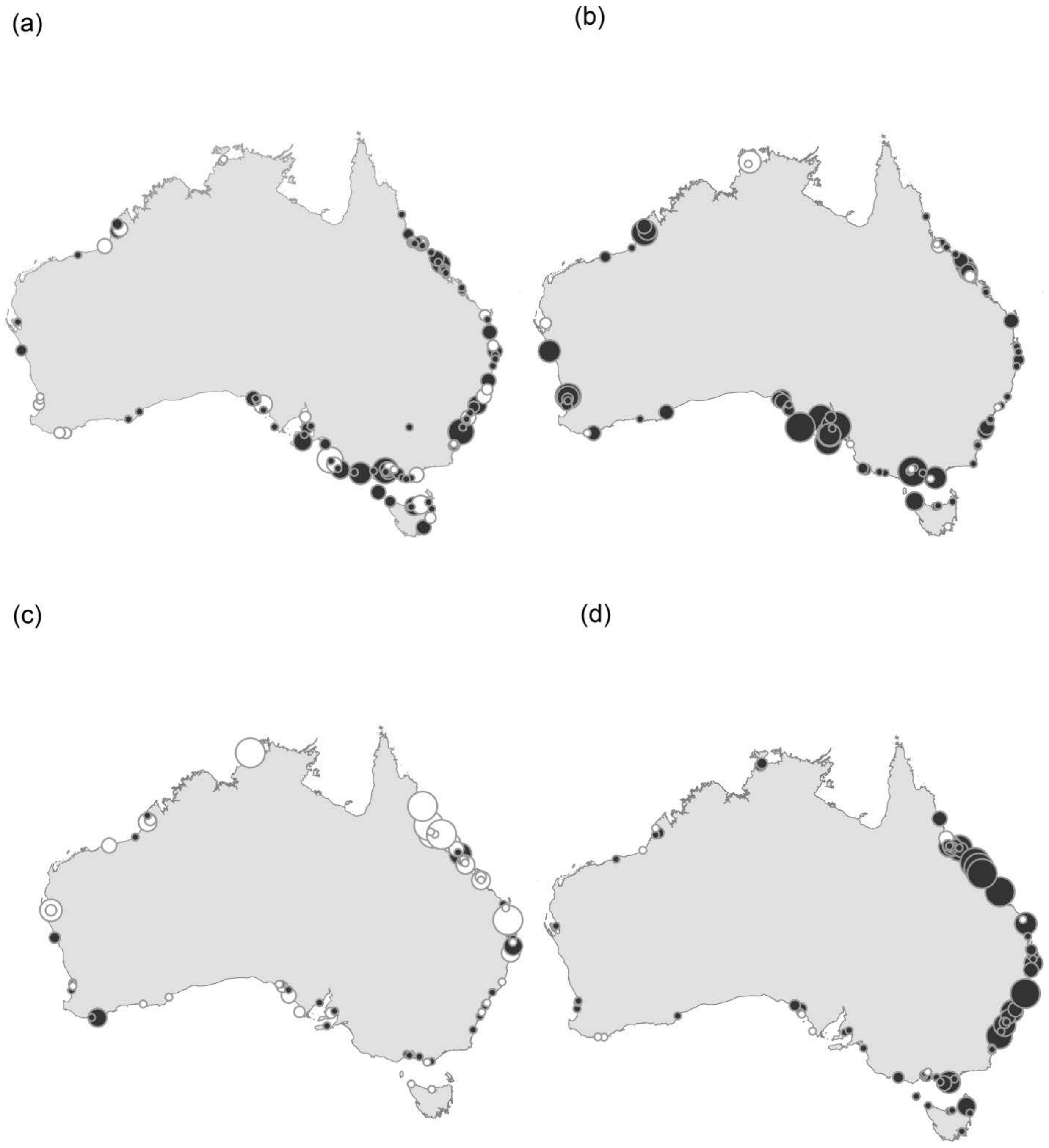

Fig. S3. Decreases (dark circles) and increases (light circles) in shorebird abundance over time estimated from models not including latitude or longitude for (a) Pacific Golden Plover: 2.8% decreases throughout Australia; (b) Grey Plover: 2.0% decreases, decreases greater in the south and west; (c) Greater Sand Plover: no significant trends, decreases which are slightly greater in the south and west; (d) Lesser Sand Plover: 8.5% decreases greater in the north and east of Australia. Circle size is proportional to 0.5 x standard deviation of the trend.

Fig. S4. Decreases (dark circles) and increases (light circles) in shorebird abundance over time estimated from models not including latitude or longitude for (a) Grey-tailed tattler: 2.9% increases greater in north and west of Australia; (b) Terek Sandpiper: 5.8% decreases, decreases greater in the north and east; (c) Whimbrel: no significant trends, increases which are slightly greater in the north; (d) Sanderling: no significant trend, increases slightly greater in the north and west of Australia. Circle size is proportional to 0.5 x standard deviation of the trend.

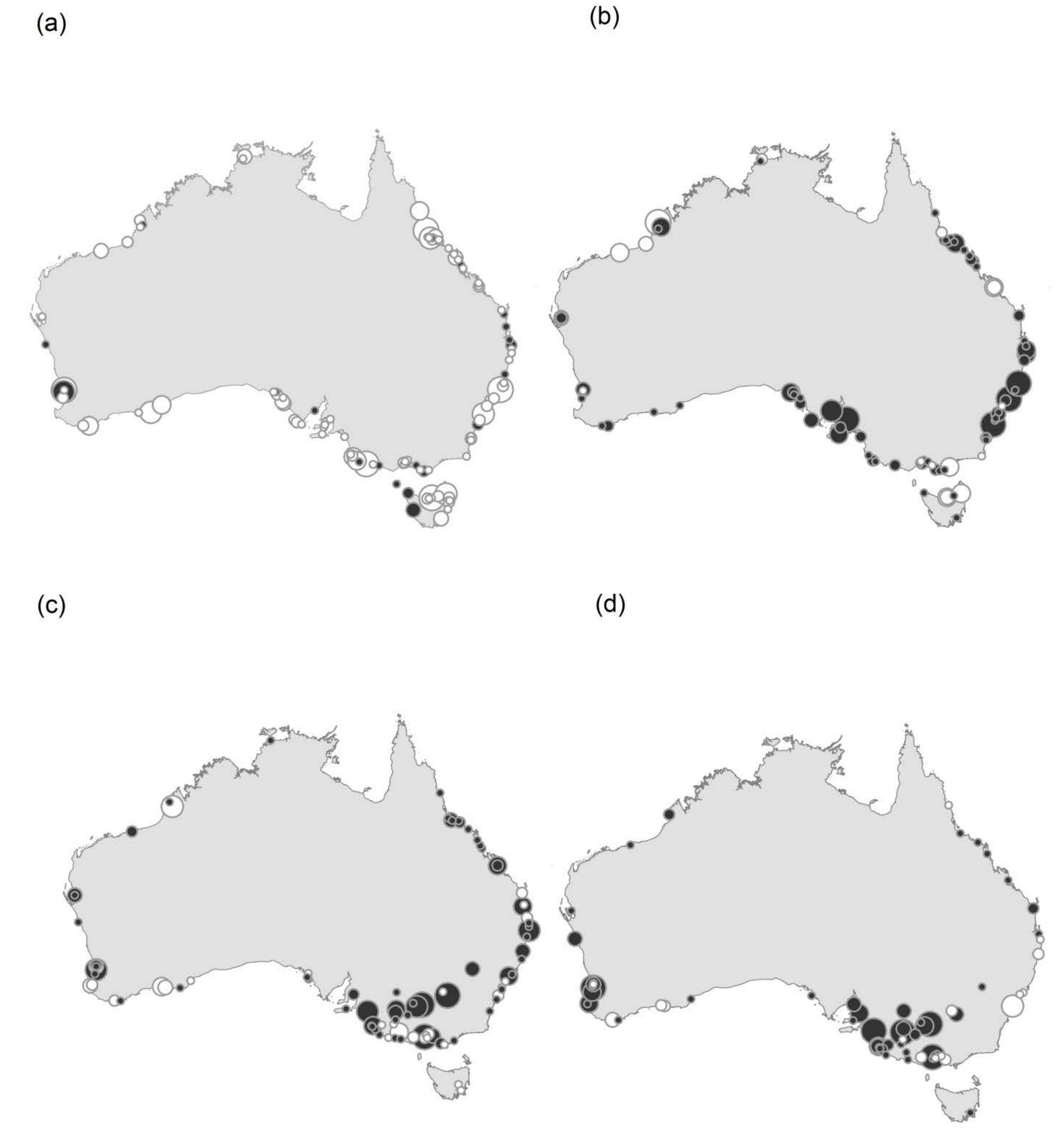

Fig. S5. Decreases (dark circles) and increases (light circles) in shorebird abundance over time estimated from models not including latitude or longitude for (a) Australian Pied Oystercatcher: 1.4% increases greater in south of Australia; (b) Red-capped Plover: no significant trend, decreases slightly greater in the east; (c) Black-winged Stilt: 2.9%, decreases which are slightly greater in the east; (d) Red-necked Avocet: 3.2% decreases throughout Australia. Circle size is proportional to 0.5 x standard deviation of the trend.

Fig. S6. Decreases (dark circles) and increases (light circles) in shorebird abundance over time estimated from models not including latitude or longitude for (a) Red-kneed Dotterel: 2.1% decreases throughout Australia; (b) Black-fronted Dotterel: 2.5%, decreases throughout Australia. Circle size is proportional to 0.5 x standard deviation of the trend.

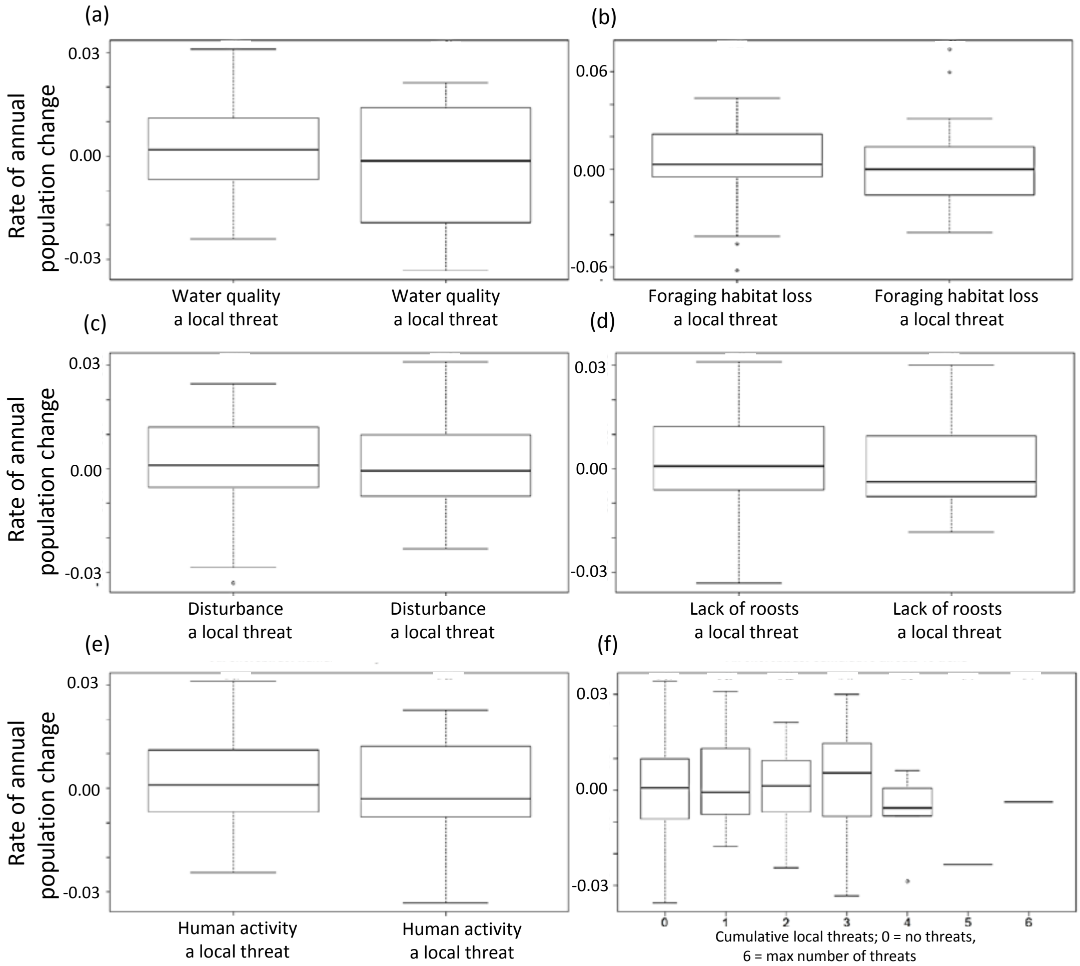

Fig. S7. Non-significant differences in population change for (a) areas for any shorebird species where unfavourable water quality was believed to be a local shorebird threat; (b) for inland resident shorebirds where loss of foraging habitat was thought to be a threat, population changes were generally more negative, but not significantly so; (c) local threats of disturbance; (d) lack of available roosts; (e) human activities were thought to be possibly impacting local populations; or (f) the sum of local threat types in an area. Median = dark horizontal line, upper edge of box = 75th percentile, lower edge of box = 25th percentile; whisker line ± 1.5 x interquartile range (75th percentile – 25th percentile), open circles = outliers.

Supplementary Acknowledgments

As well as the thousands of volunteers who have counted Australia's shorebirds for decades, we specifically thank the many individuals whose work over the years has made this project possible, including: Richard and Margaret Alcorn, Laurel Allsopp, Peter Anton, Mark Antos, George Appleby, Richard Ashby, Rodney Attwood, George and Teresa Baker, Mark Barter, Chris Baxter, Dawn Beck, Rod Bird, Stuart Blackhall, Anne Bondin, Jack and Pat Bourne, Adrian Boyle, Chris Brandis, Linda Brannian, Rob Breeden, Alan Briggs, Hazel Britton, Nigel and Mavis Burgess, Jeff Campbell, Graham Carpenter, Derek Carter, Mike Carter, Denis Charlesworth, Maureen Christie, Jane Cleary, Greg Clancy, Rohan Clarke, Simon Clayton, Jane Cleary, David Close, Chris Coleborn, Lisa Collins, Jane Cooper, Ralph and Barbara Cooper, Ricki Coughlan, Trevor Cowie, Phil Craven, Liz Crawford, Linda Cross, Peter Dann, Chris Davey, Wendy Davies, Kieth Davis, Frank Day, Alma de Rebeira, Gay Deacon, Xenia Dennett, Dave Donato, Peter Driscoll, Peter Duckworth, Phil Du Guesclin, John Eckert, David Edmonds, Glenn Ehmke, Len Ezzy, Rob Farnes, Winston Filewood, Shirley Fish, Tony Flaherty, Alan Fletcher, Duncan Fraser, Barbara Garrett, Andrew Geering, Les George, Heather Gibbs, Alan Gillanders, Doris Graham, Iva Graney, Travis Hague, Margaret Hamon, Ian Hance, Sandra Harding, Judy Harrington, Ken Harris, Angie Haslem, Rick Hawthorne, Jane Hayes, Bruce Haynes, Bryan and Toni Haywood, Colin Heap, Chris Herbert, Tony Hertog, Marilyn Hewish, Janice Hosking, Liz Huxtable, Dean Ingwersen, Roger Jaensh, David James, Chris James, Roz Jessop, Penny Johns, Steve Johnson, Arthur and Sheryl Keates, Wally Klau, Peter Langdon, Jenny Lau, Sharon Lehman, Michael Lenz, Ann Lindsey, John Lowry, Richard Loyn, Hans Lutter, Sue Mather, Golo Maurer, Bernie McCarrick, David McCarthy, Tom McRaet, Peter Menkhorst, Ren Millsom, Euan Moore, Alan Morris, John Mullins, Vicki Natt, John Newman, Mike Newman, David Niland, Gavin O'Brien, James O'Connor, Jo Oldland, Jan Olley, Max O'Sullivan, Priscilla Park, Bob Patterson, Lynn Pedler, Joy Pegler, Doug Phillips, Hugo Phillipps, Robyn Pickering, Chris Purnell, Rick Ressom, David Rohweder, Rosemary Payet, Robyn Pickering, Jenny Powers, Ivor Preston, Bianca Priest, Ken Read, Jim Reside, Mick Roderick, Ken Rogers, Dave Ryan, Toni Ryan, Dick Rule, Bill Russell, Paul Sagar, Mike Schultz, Eric Sedgwick, Bob Semmens, Marion Shaw, Luke Shelly, Paul Shelly, Andrew Silcocks, Donna Smithyman, Roger Standen, Simon Starr, Will Steele, Jonathon Stevenson, Ian Stewart, Phil Straw, Alan Stuart, Rob Tanner, Bryce Taylor, Ian Taylor, Susan Taylor, Margie Tiller, Kent Treloar, Chris Tzaros, Len Underwood, Dave Warne, Paul Wainwright, Brian Walker, Bill Wakefield, Doug Watkins, Toni Webster, Gary Whale, Tom Wheller, Jim and Anthea Whitelaw, Bill and Evelyn Williams, Bill Wright, Boyd Wykes, and Liz Znidersic.