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Australia’s migratory shorebirds

Trends and prospects

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Executive summary

Coastal Australia is home to 37 regularly occurring migratory shorebird species, with many protected areas including Ramsar sites designated on the basis of shorebird populations. However, Australia's coastal migratory shorebirds have been declining rapidly for decades, making them the focus of intense conservation efforts by multiple levels of government domestically and overseas. With the most recent national analyses based on data about 10 years old, it remains unclear whether these conservation efforts are starting to result in improvements in migratory shorebird population trends. In this project we update national trend analyses to determine whether the declines have decelerated.

We focused on the 15 migratory shorebird taxa whose conservation status is currently being reassessed by the Australian Government Department of Climate Change, Energy, the Environment and Water. We analysed 28 years of monitoring data collected by citizen science and curated by BirdLife Australia's National Shorebird Monitoring Programme. We used N-mixture models, which estimate the abundance of each species at each surveyed site each year, while accounting for imperfect detection of individuals as well as among-area differences, temporal trends, and over-dispersion in abundance. These models allowed us to estimate the total abundance of each species across all shorebird areas each year.

We were able to estimate the population trend for 14 of the 15 species. Based on our results, four species (Black-tailed Godwit, Common Greenshank, Curlew Sandpiper, and Eastern Curlew) have declined more than 50% over the longer of three generations or 10 years, consistent with listing them as nationally Endangered. Three species (Great Knot, Grey Plover, and Nunivak Bar-tailed Godwit) have declined more than 30%, consistent with listing them as Vulnerable. Declines in Great Knot and Grey Plover were however not statistically significant. Five other species (Greater Sand Plover, Latham's Snipe, Northern Siberian Bar-tailed Godwit, Ruddy Turnstone, and Terek Sandpiper) have declined less than 30% while Red Knot and Sharp-tailed Sandpiper have increased. Therefore, these seven species do not qualify for listing as threatened at least on the basis of population trend.

Five of the seven species with declines greater than 30% (Black-tailed Godwit, Curlew Sandpiper, Eastern Curlew, Grey Plover, and Nunivak Bar-tailed Godwit) showed a higher mean annual growth rate from 2012-2021 compared with 1993-2012, suggesting some deceleration in their rate of decline. However, the increase in annual growth rates between the two periods was statistically significant only for Eastern Curlew, as there was high uncertainty in the annual growth rate from 2013-2022 for most species. None of the species is yet exhibiting population recovery.

We stress that the deceleration in the decline of some migratory shorebirds reported here does not equate to population recovery, and it remains unclear exactly why the trends for some species have decelerated. However, trends must stop before they can reverse, and so this study presents the first evidence of multi-species improvements in population trajectory for migratory shorebirds in the East Asian - Australasian Flyway. We urge a redoubling of conservation efforts in Australia and around the flyway, to capitalize on this progress, and achieve recovery of these species.

Introduction

Australia forms the southern terminus of the East Asian – Australasian Flyway. Millions of migratory shorebirds journey each year from their breeding grounds in the Arctic and subarctic to Australasia, stopping at critical refuelling points in East Asia along the way. Shorebirds depend exclusively on wetlands during migration and non-breeding season, with the majority of species being mostly restricted to coastal intertidal habitats, where they look for invertebrate prey in sediment or among the rocks.

Many migratory shorebird populations are in rapid decline at individual sites and across large geographies such as continental Australia (Clemens et al. 2016; Studds et al. 2017). Eight migratory shorebird taxa are currently listed as nationally threatened based on declines measured in Australia, and it is clear that the entire assemblage is imperilled.

Threats to migratory shorebirds include climate change and habitat on the breeding grounds (Wauchope et al. 2017; Morrick et al. 2022), sea-level rise (Iwamura et al. 2013, 2014), hunting of birds for sport and subsistence (Gallo-Cajiao et al. 2021), vegetation encroachment on tidal flats (Jackson et al. 2021; Choi et al. 2022) and human disturbance (Dhanjal-Adams et al. 2016; Stigner et al. 2016). Threats to migratory species are often a combination of factors operating at multiple stages of the annual cycle (Runge et al. 2014), and indeed Bar-tailed Godwit declines in Australia have been linked to threats both within Australia and beyond (Murray et al. 2018).

Despite this broad range of threats, the single biggest threat to migratory shorebird populations in the East Asian – Australasian Flyway appears to be loss of intertidal habitat in the Yellow Sea, a key region where birds rest and refuel during their migratory journey (Amano et al. 2010; Studds et al. 2017). About two-thirds of intertidal habitat in the Yellow Sea has disappeared in the last 50 years, mostly as a result of coastal reclamation projects and changes in sedimentation inputs from the major rivers (Murray et al. 2014). Migratory shorebird species with a greater reliance on the Yellow Sea during migration have declined the fastest in Australia (Studds et al. 2017), and combined with evidence that mortality is high on migration journeys from the Yellow Sea (Piersma et al. 2016), it is now widely acknowledged that habitat loss in the Yellow Sea is the principal driver of shorebird declines.

Various conservation mechanisms have been developed in the East Asian – Australasian Flyway to try to arrest these rapid declines in migratory shorebirds. Eleven bilateral migratory bird agreements have been signed by various countries, including arrangements between Australia and China, Korea and Japan (Gallo-Cajiao et al. 2019). The East Asian – Australasian Flyway Partnership is a voluntary non-binding initiative focused mostly on identifying and protecting important habitats for migratory waterbirds around the flyway. From an initial low baseline of protection of important shorebird habitat (Murray & Fuller 2015), the last decade has seen major conservation initiatives in the Yellow Sea, culminating in a moratorium on most forms of coastal reclamation in China, and the inscription of a series of World Heritage Properties along the Chinese and Korean coasts of the Yellow Sea. Many of the most important remaining shorebird stopover habitats are now protected in the Yellow Sea, albeit with some notable exceptions such as Liangyunggang (Yang et al. 2021).

A key question is whether this conservation activity is starting to reduce the rates of decline of migratory shorebirds in the East Asian – Australasian Flyway. However, available migratory shorebird trend analyses are now nearly 10 years old, meaning the information available to assess where conservation actions are needed most urgently and whether conservation efforts are helping species recover are outdated. To ensure populations have the best chance of recovery and that resources are allocated where they are most likely to have the greatest positive impacts, it is critical to maintain up-to-date information on species trends.

In this report, we update national trend analysis to determine whether the declines in migratory shorebird populations have decelerated. We analyse 28 years of shorebird monitoring data collected by citizen science groups across Australia and curated by BirdLife Australia's National Shorebird Monitoring Programme.

Methods

Database

We used data on shorebird counts from around Australia. The majority of the records are from Birdlife's Birdata database. We supplemented this data with bird surveys within the Coorong, from David Paton, and from data available from the South Australian Government (Paton et al. 2016). Data for some shorebird areas, namely Eighty Mile Beach, Roebuck Bay, Werribee / Avalon, did not have count area level data for a number of recent years (2019-2022), but had aggregated summary data available.

Within the database, observations of the number of individuals per species are collected in "count areas", which are generally one high tide roost, or segments of beach. Count areas are situated within "shorebird areas", which are the maximum areas in which individual birds are likely to move within a non-breeding season, for example an estuary (Clemens et al. 2014). The database contains >380,000 records from 448 shorebird areas around the country (Figure 1).

Data on individual species generation times was sourced from Bird et al. (2020).

Data cleaning

For our analysis, we aggregated the data into independent count occasions for each shorebird area within each Austral summer (November, December, January, and February), here termed "season". The database was first subset to records that had complete fields for "shorebird area", "point count ID", "count", and "date". Data were then aggregated to find the maximum count per species per count area per month. The maximum counts per count area per month were then summed across shorebird area to yield a "best count" for each shorebird area within any given month. For shorebird areas with counts across multiple months, we used the top two counts per season as input for our data analysis. Finally, we only included shorebird areas that had at least 500 birds observed over the entire time series and had at least one count for at least half of the years in the entire time series (14 years of the 28 years in the time series). Structured, regular monitoring across a large portion of the continent began in 1993, so we used data from 1993-2021.

Modelling abundance and population trends

The objective of our modelling was to estimate abundance and population trends of the targeted species at the national level, using the time-series data described above. Following the successful example of modelling population trends of shorebirds in Australia and New Zealand by Studds et al (2017), we also used hierarchical Bayesian N-mixture models, which estimate the abundance of each species at each shorebird area each year, while accounting for imperfect detection of individuals as well as among-area difference, temporal trends, and over-dispersion in abundance. The model allowed us to estimate the abundance of each species at each shorebird area each year.

We fitted the model to all targeted species using the program JAGS (Hornik et al. 2003) through the R2jags package (Su, Yajima, and Edu 2022) in R version 4.3.1 (R Core Team 2023). We first ran three chains with different initial values for 3,000,000 iterations with the first 500,000 discarded as burn-in and the reminder thinned to one in every 500 iterations to save storage space. Model convergence was checked with R-hat values (<1.1) and trace plots. If the model did not converge, we increased the number of iterations up to 30,000,000 with the first 1,000,000 discarded as burn-in and the reminder thinned to one in every 5,800 iterations.

Using model outputs, we then estimated the rate of change in total abundance across all shorebird areas. For a given time frame (28 years, the longer of three generations or 10 years, 1993-2012, 2012-2021) we calculated annual population growth rates using negative binomial generalised linear models (GLMs) to account for overdispersion. We first fitted the GLM with total abundance as the response variable and year as the explanatory variable, to each of the 15,000 posterior samples from the hierarchical Bayesian N-mixture model. We then sampled 1,000 growth rates from a normal distribution with the mean of the slope and standard deviation of the associated standard error estimated by each regression. Using a total of 15,000,000 slope estimates, we calculated the mean and 2.5 and 97.5 percentiles. To assess whether the annual growth rates changed between 1993-2012 and 2012-2021, we also took the difference in the growth rates between 1993-2012 and 2012-2021 using the 15,000,000 slope estimates, and calculated the mean and 2.5 and 97.5 percentiles.

We then calculated percent change in total abundance over the 28 years and the longer of three generations or 10 years, as well as percent annual change in total abundance over the 28 years, 1993-2012, and 2012-2021, as follows:

% change in total abundance over T years

$$= 100 \times \exp(\text{annual growth rate over the relevant time period} \times (T - 1) - 1),$$

% annual change in total abundance

$$= 100 \times \exp(\text{annual growth rate over the relevant time period} - 1).$$

We used IUCN criterion A2 (IUCN 2012), to assess whether species qualify for listing as threatened based on estimated declines over the longer of three generations or 10 years. These thresholds are that population reduction (measured over the longer of 10 years or 3 generations) is ≥:

- 80% - Critically Endangered,
- 50% - Endangered, and
- 30% - Vulnerable.

To use IUCN criterion A1, which is based on different thresholds, the following three conditions must be met: “the causes of the reduction are clearly reversible AND understood AND have ceased” (IUCN 2012). In our case, none of the three conditions were met and therefore we used IUCN criterion A2.

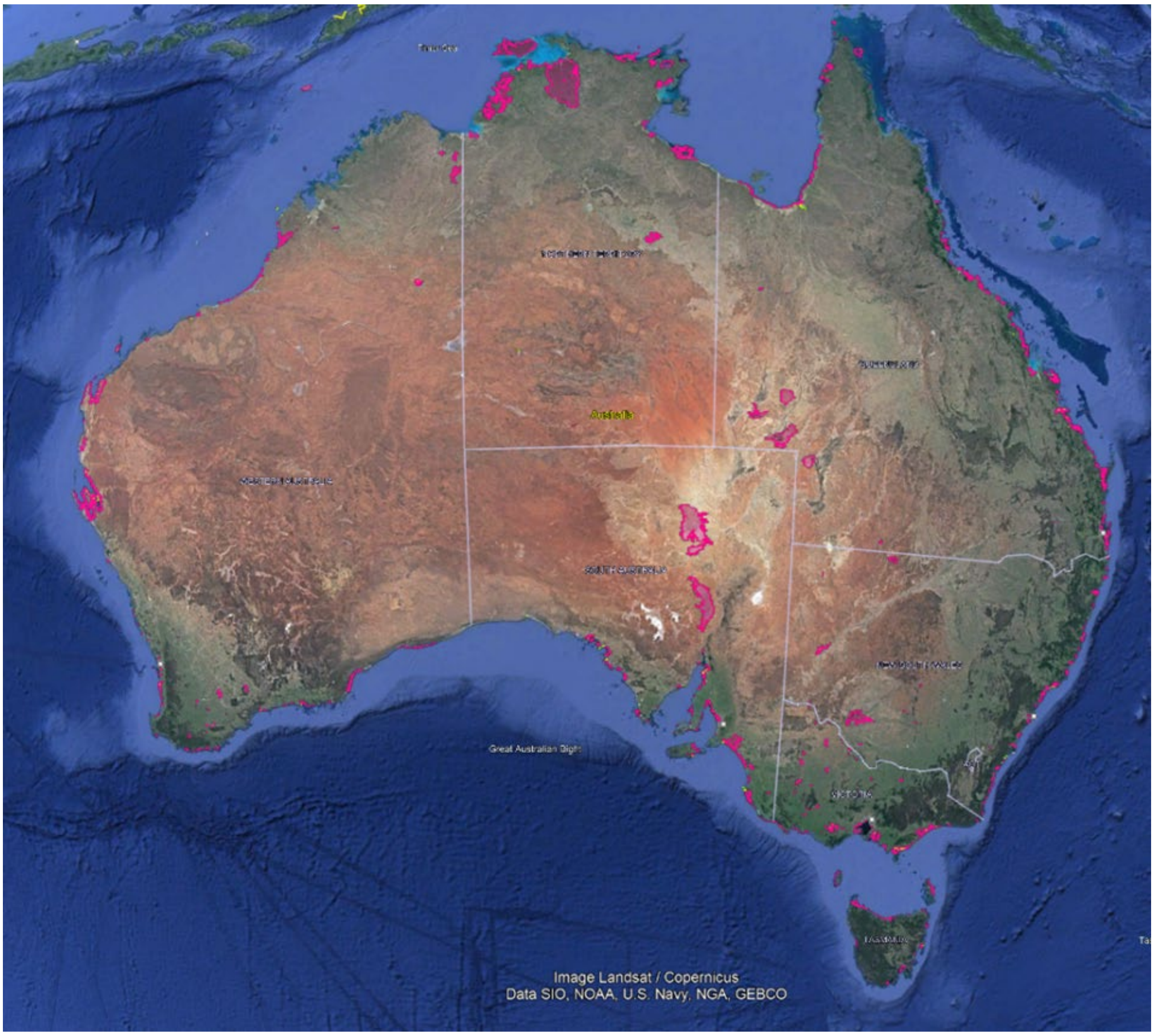

Figure 1. 448 shorebird areas that get regular structured counts from Birdlife’s Shorebird Monitoring Program. Base image: Google Earth 2021.

Results

Summary of population change for species under assessment

We were able to estimate the population trend and the total estimated change in population over the longer of three generations or 10 years for 14 of the 15 species (Table 1, Figure 2). Asian Dowitcher had only one shorebird area that met our selection criteria for the analysis and therefore we were not able to estimate its population trend.

Four species (Black-tailed Godwit, Common Greenshank, Curlew Sandpiper, and Eastern Curlew) have declined more than 50% (and less than 80%), consistent with a listing as Endangered.

Three species (Great Knot, Grey Plover, and Nunivak Bar-tailed Godwit) have declined more than 30% (and less than 50%), consistent with listing them as Vulnerable. However, the 95% confidence interval of the estimated change for Great Knot and Grey Plover overlapped with zero, indicating that their declines are not statistically significant.

Five other species (Greater Sand Plover, Latham’s Snipe, Northern Siberian Bar-tailed Godwit, Ruddy Turnstone, and Terek Sandpiper) have declined less than 30% while Red Knot and Sharp-tailed Sandpiper have increased. The 95% confidence interval of the estimated change for the seven species also overlapped with zero. Therefore, these seven species do not appear to qualify for listing as threatened at least on the basis of population trend.

Five of the seven species with more than 30% declines (Black-tailed Godwit, Curlew Sandpiper, Eastern Curlew, Grey Plover, and Nunivak Bar-tailed Godwit) showed a higher mean annual growth rate from 2012-2021 compared with 1993-2012, suggesting some deceleration in their rate of decline. However, the 95% confidence interval of the difference in annual growth rates between the two periods did not overlap with zero only for Eastern Curlew, indicating that the difference was statistically significant only for that species.

Table 1. Percentage change in the total abundance over the longer of three generation times or 10 years (time period used for assessment). N/A indicates species that could not be adequately modelled due to the lack of count data. Statistically significant percent changes over the time period are highlighted in bold. Declines consistent with listing as Endangered (≥ 50%) are highlighted in orange and Vulnerable (≥ 30%) in yellow. APAB 2020: The Action Plan for Australian Birds 2020 (Garnett & Baker 2021).

Species	APAB 2020 Status	Time period used for assessment (years)	% change over the time period (95% CI)
Asian Dowitcher (*Limnodromus semipalmatus*)	Vulnerable	17	N/A
Black-tailed Godwit (*Limosa limosa*)	Endangered	23	**-77.50 (-89.93, -50.41)**
Common Greenshank (*Tringa nebularia*)	Vulnerable	19	**-60.49 (-77.94, -31.13)**
Curlew Sandpiper (*Calidris ferruginea*)	Endangered	16	**-52.99 (-72.34, -18.76)**
Eastern Curlew (*Numenius madagascariensis*)	Endangered	20	**-63.64 (-72.84, -51.61)**
Great Knot (*Calidris tenuirostris*)	Near Threatened	19	-32.41 (-69.20, 48.48)
Greater Sand Plover (*Charadrius leschenaultii*)	Near Threatened	17	-14.09 (-75.15, 226.00)
Grey Plover (*Pluvialis squatarola*)	Vulnerable	23	-37.04 (-63.56, 8.96)
Latham's Snipe (*Gallinago hardwickii*)	Vulnerable	10	-16.80 (-85.29, 404.30)
Northern Siberian Bar-tailed Godwit (*Limosa lapponica menzbieri*)	Endangered	25	-6.30 (-66.96, 152.60)
Nunivak Bar-tailed Godwit (*Limosa lapponica baueri*)	Endangered	25	**-47.19 (-64.56, -23.20)**
Red Knot (*Calidris canutus*)	Vulnerable	21	6.11 (-63.93, 207.40)
Ruddy Turnstone (*Arenaria interpres*)	Endangered	19	-26.11 (-53.57, 21.81)
Sharp-tailed Sandpiper (*Calidris acuminata*)	Vulnerable	15	19.77 (-51.86, 235.20)
Terek Sandpiper (*Xenus cinereus*)	Vulnerable	14	-19.59 (-77.44, 222.20)

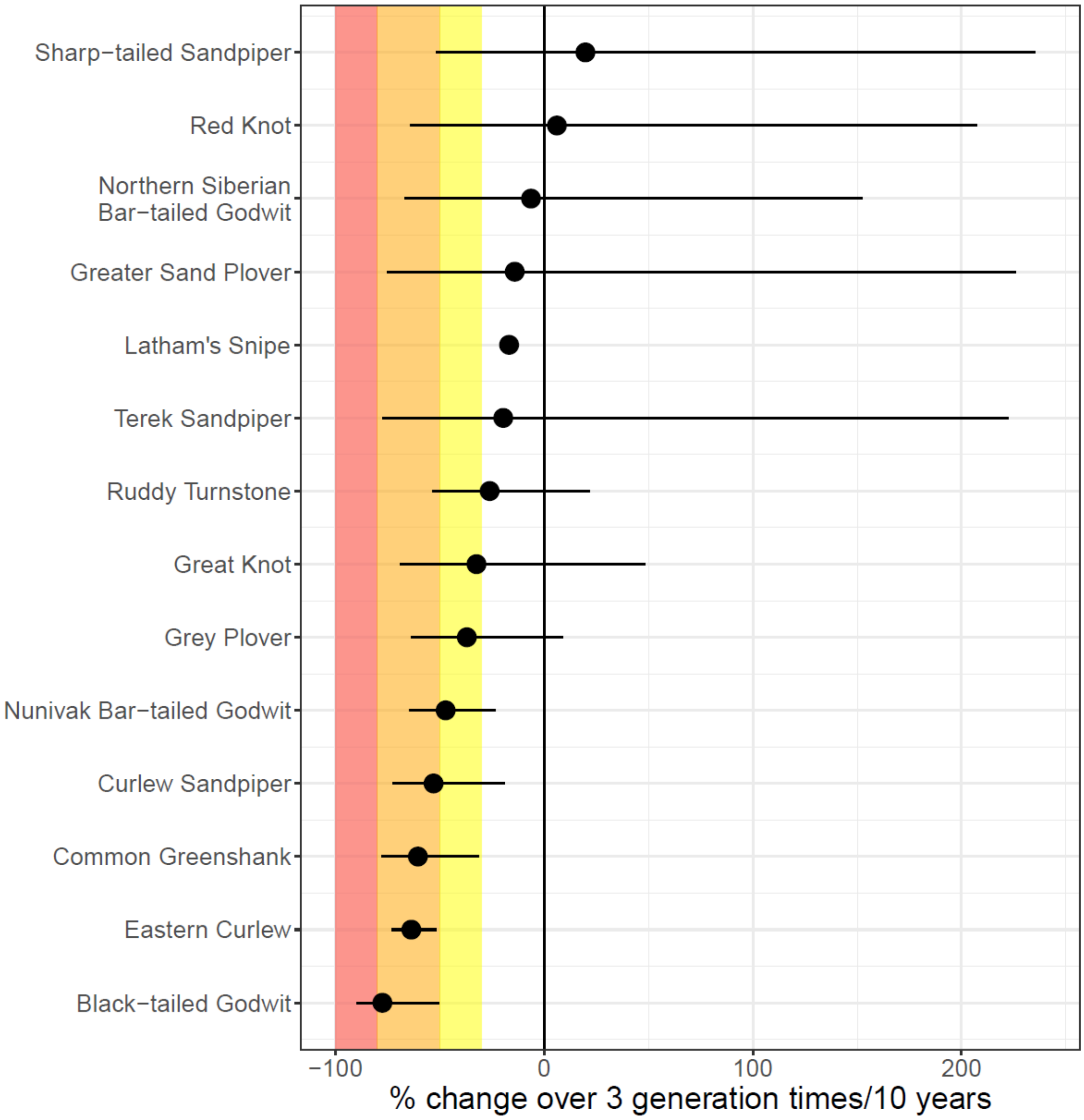

Figure 2. Percentage change (and associated 95% confidence intervals shown with the bars) in the estimated total abundance over the longer of three generations or 10 years. The shaded areas indicate % population size reduction consistent with listing as Critically Endangered (red, ≥ 80%), Endangered (orange, ≥ 50%), and Vulnerable (yellow, ≥ 30%) based on the IUCN Red List Criteria A2 (IUCN 2012). The 95% confidence interval for Latham’s Snipe is not shown, as it exceeds the x-axis range (see the actual value in Table 1).

Individual species trends and metrics of change

Black-tailed Godwit

The Action Plan for Australian Birds 2020 status: Endangered

Global Status (IUCN Red List 2022.2): Near Threatened

EPBC Act status: Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	10
Generation time:	7.7 years (Bird et al. 2020)
Percent change in abundance over three generations:	-77.50 (95%CI: -89.93, -50.41)
Percent change in abundance between 1993 and 2021:	-79.54 (95%CI: -91.35, -53.62)
Percent annual change in abundance between 1993 and 2021:	-5.51 (95%CI: -8.37, -2.71)
Percent annual change in abundance between 1993 and 2012:	-5.70 (95%CI: -10.58, -0.74)
Percent annual change in abundance between 2012 and 2021:	-0.013 (95%CI: -9.53, 10.74)
Change in annual growth rate between 1993-2012 and 2012-2021:	0.059 (95%CI: -0.057, 0.17)

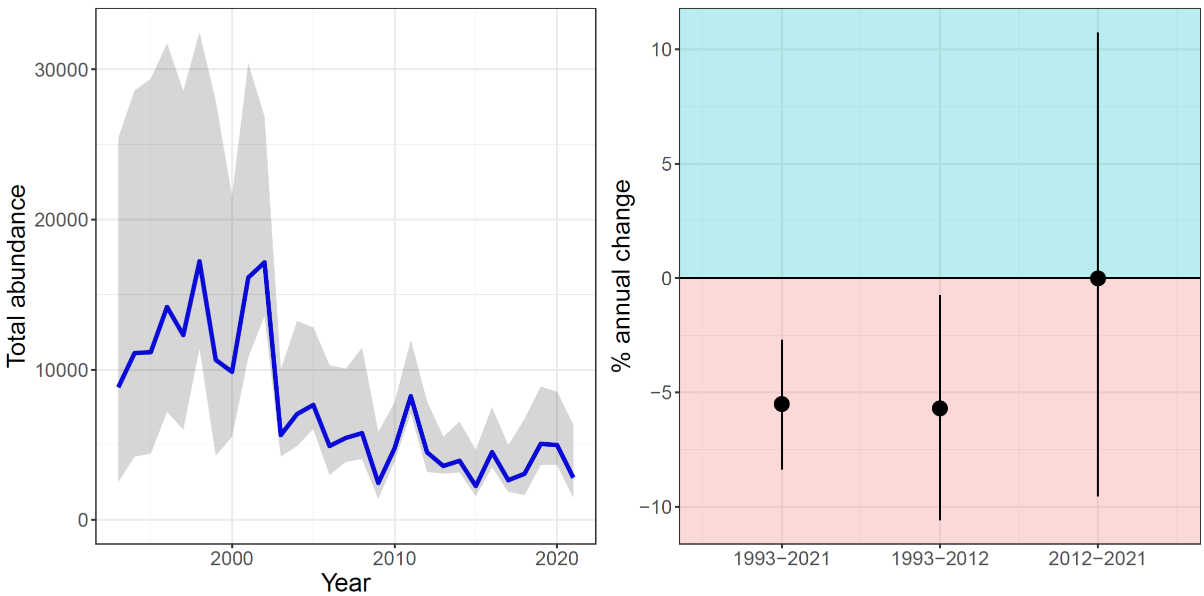

Figure 3. Left: Population trend for Black-tailed Godwit from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Common Greenshank

The Action Plan for Australian Birds 2020 status: Vulnerable

Global Status (IUCN Red List 2022.2): Least Concern

EPBC Act status: Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	33
Generation time:	6.3 years (Bird et al. 2020)
Percent change in abundance over three generations:	-60.49 (95%CI: -77.94, -31.13)
Percent change in abundance between 1993 and 2021:	-72.30 (95%CI: -84.31, -52.62)
Percent annual change in abundance between 1993 and 2021:	-4.48 (95%CI: -6.40, -2.63)
Percent annual change in abundance between 1993 and 2012:	-4.36 (95%CI: -7.46, -1.34)
Percent annual change in abundance between 2012 and 2021:	-8.59 (95%CI: -14.85, -0.73)
Change in annual growth rate between 1993-2012 and 2012-2021:	-0.045 (95%CI: -0.13, 0.046)

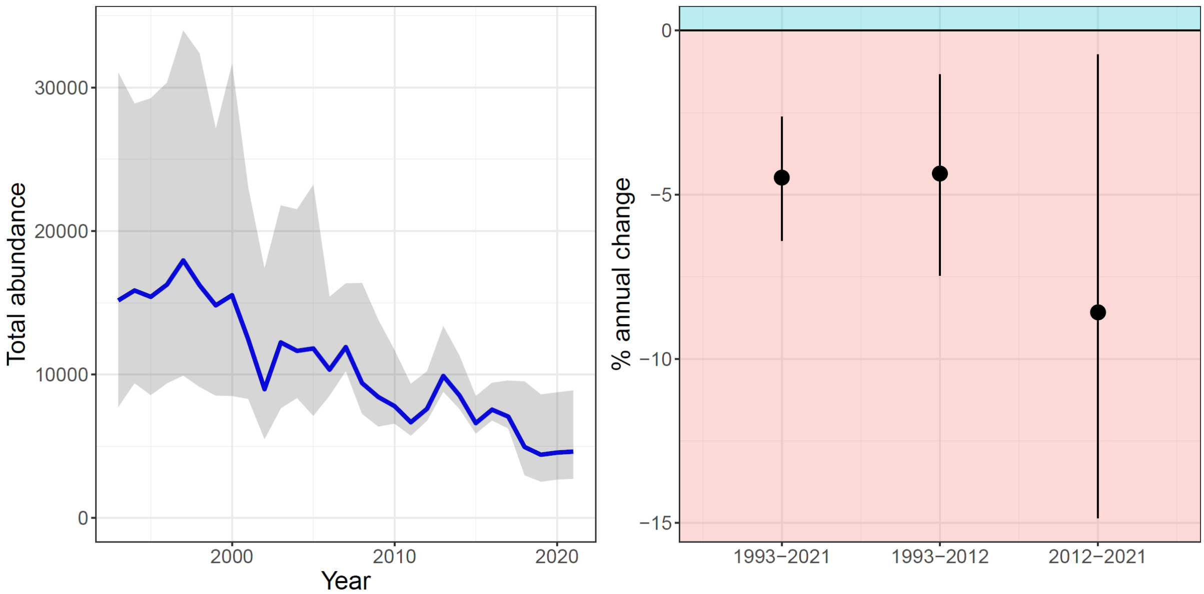

Figure 4. Left: Population trend for Common Greenshank from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Curlew Sandpiper

The Action Plan for Australian Birds 2020 status: Endangered

Global Status (IUCN Red List 2022.2): Near Threatened

EPBC Act status: Critically Endangered (2015), Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	32
Generation time:	5.5 years (Bird et al. 2020)
Percent change in abundance over three generations:	-52.99 (95%CI: -72.34, -18.76)
Percent change in abundance between 1993 and 2021:	-84.51 (95%CI: -90.95, -74.38)
Percent annual change in abundance between 1993 and 2021:	-6.44 (95%CI: -8.22, -4.75)
Percent annual change in abundance between 1993 and 2012:	-8.51 (95%CI: -11.34, -5.78)
Percent annual change in abundance between 2012 and 2021:	-3.84 (95%CI: -10.25, 3.47)
Change in annual growth rate between 1993-2012 and 2012-2021:	0.050 (95%CI: -0.028, 0.13)

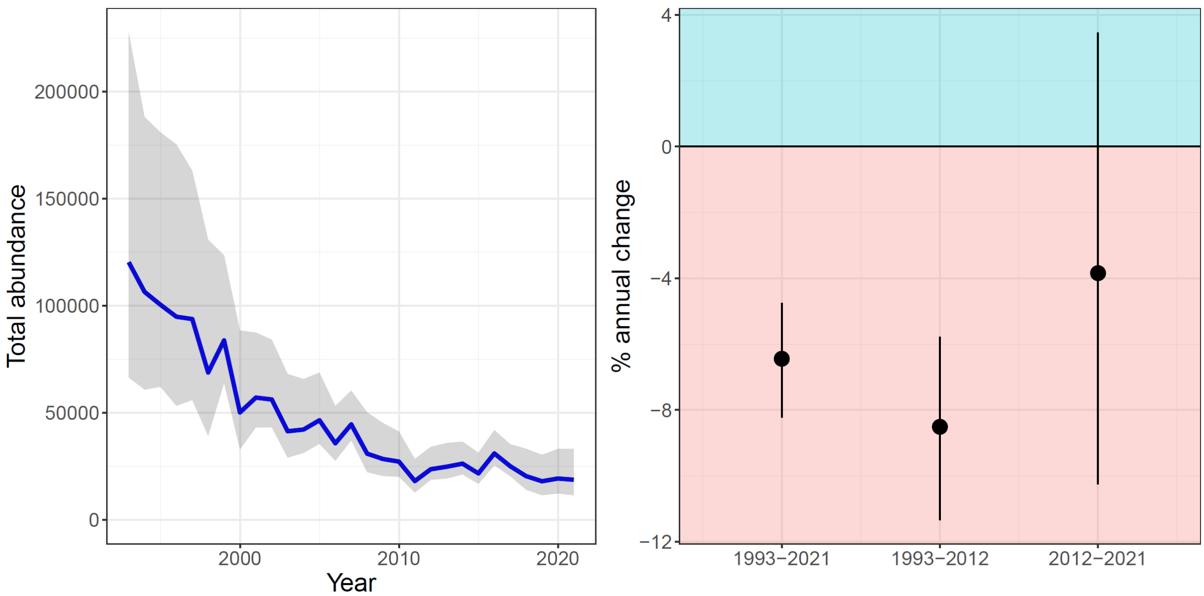

Figure 5. Left: Population trend for Curlew Sandpiper from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Eastern Curlew

The Action Plan for Australian Birds 2020 status: Endangered

Global Status (IUCN Red List 2022.2): Endangered

EPBC Act status: Critically Endangered (2015), Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	36
Generation time:	6.8 years (Bird et al. 2020)
Percent change in abundance over three generations:	-63.64 (95%CI: -72.84, -51.61)
Percent change in abundance between 1993 and 2021:	-77.00 (95%CI: -83.03, -69.21)
Percent annual change in abundance between 1993 and 2021:	-5.11 (95%CI: -6.14, -4.12)
Percent annual change in abundance between 1993 and 2012:	-5.51 (95%CI: -7.31, -3.73)
Percent annual change in abundance between 2012 and 2021:	-1.46 (95%CI: -4.93, 2.11)
Change in annual growth rate between 1993-2012 and 2012-2021:	0.042 (95%CI: 0.00085, 0.083)

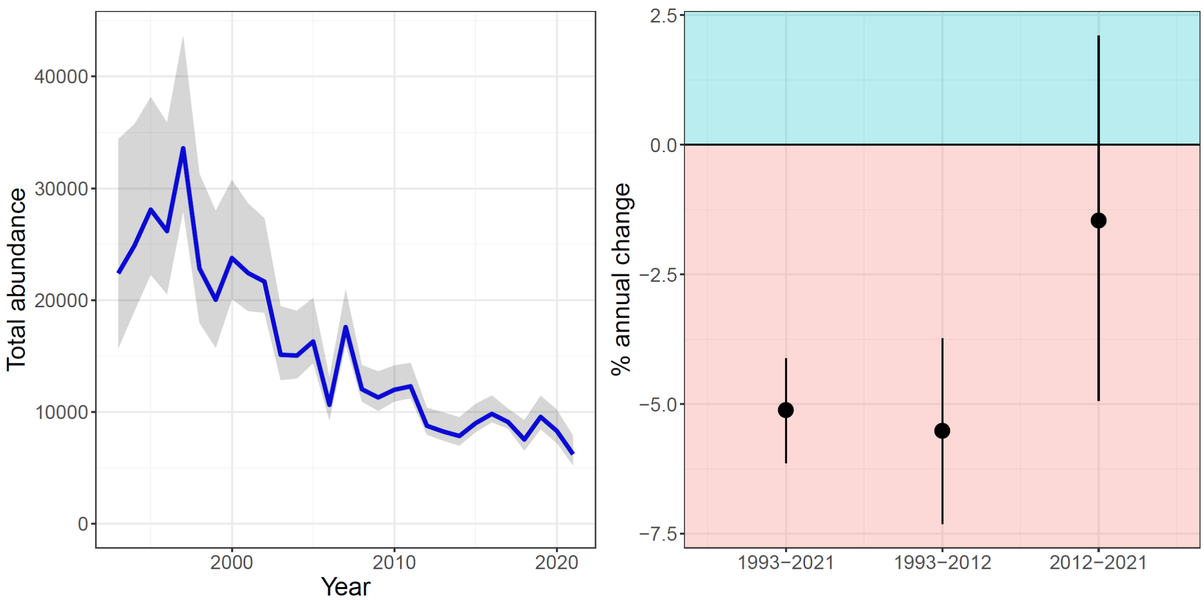

Figure 6. Left: Population trend for Eastern Curlew from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Great Knot

The Action Plan for Australian Birds 2020 status: Near Threatened

Global Status (IUCN Red List 2022.2): Endangered

EPBC Act status: Critically Endangered (2016), Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	21
Generation time:	6.4 years (Bird et al. 2020)
Percent change in abundance over three generations:	-32.41 (95%CI: -69.20, 48.48)
Percent change in abundance between 1993 and 2021:	-23.26 (95%CI: -66.82, 72.18)
Percent annual change in abundance between 1993 and 2021:	-0.94 (95%CI: -3.86, 1.96)
Percent annual change in abundance between 1993 and 2012:	0.24 (95%CI: -4.83, 5.26)
Percent annual change in abundance between 2012 and 2021:	-5.62 (95%CI: -14.64, 5.73)
Change in annual growth rate between 1993-2012 and 2012-2021:	-0.060 (95%CI: -0.18, 0.068)

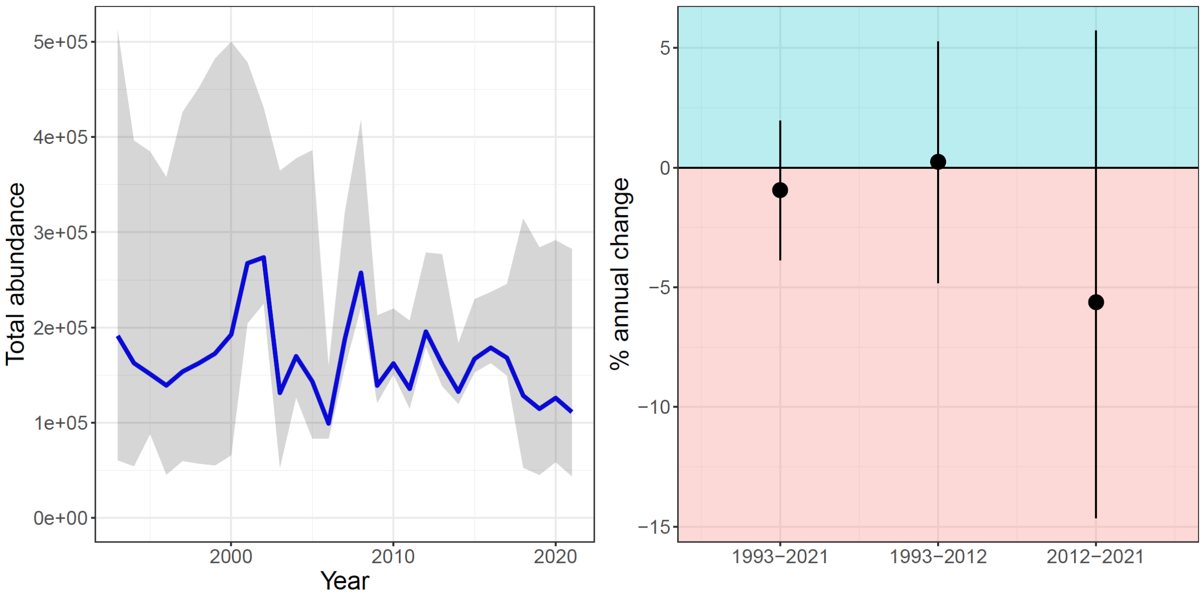

Figure 7. Left: Population trend for Great Knot from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Greater Sand Plover

The Action Plan for Australian Birds 2020 status: Near Threatened

Global Status (IUCN Red List 2022.2): Least Concern

EPBC Act status: Vulnerable (2016), Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	14
Generation time:	5.8 years (Bird et al. 2020)
Percent change in abundance over three generations:	-14.09 (95%CI: -75.15, 226.00)
Percent change in abundance between 1993 and 2021:	-25.46 (95%CI: -81.54, 197.70)
Percent annual change in abundance between 1993 and 2021:	-1.04 (95%CI: -5.86, 3.97)
Percent annual change in abundance between 1993 and 2012:	-0.68 (95%CI: -8.70, 7.45)
Percent annual change in abundance between 2012 and 2021:	-4.63 (95%CI: -20.21, 16.05)
Change in annual growth rate between 1993-2012 and 2012-2021:	-0.041 (95%CI: -0.25, 0.18)

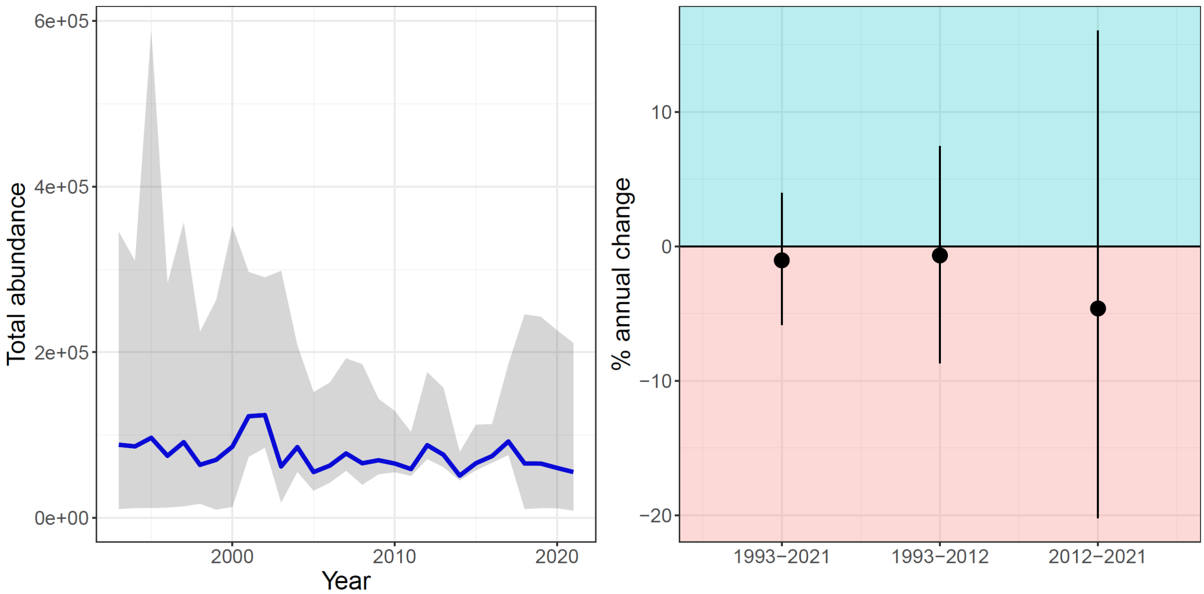

Figure 8. Left: Population trend for Greater Sand Plover from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Grey Plover

The Action Plan for Australian Birds 2020 status: Vulnerable

Global Status (IUCN Red List 2022.2): Least Concern

EPBC Act status: Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	15
Generation time:	7.6 years (Bird et al. 2020)
Percent change in abundance over three generations:	-37.04 (95%CI: -63.56, 8.96)
Percent change in abundance between 1993 and 2021:	-57.03 (95%CI: -76.41, -23.66)
Percent annual change in abundance between 1993 and 2021:	-2.97 (95%CI: -5.03, -0.96)
Percent annual change in abundance between 1993 and 2012:	-4.12 (95%CI: -7.42, -0.99)
Percent annual change in abundance between 2012 and 2021:	0.98 (95%CI: -5.33, 8.44)
Change in annual growth rate between 1993-2012 and 2012-2021:	0.052 (95%CI: -0.023, 0.13)

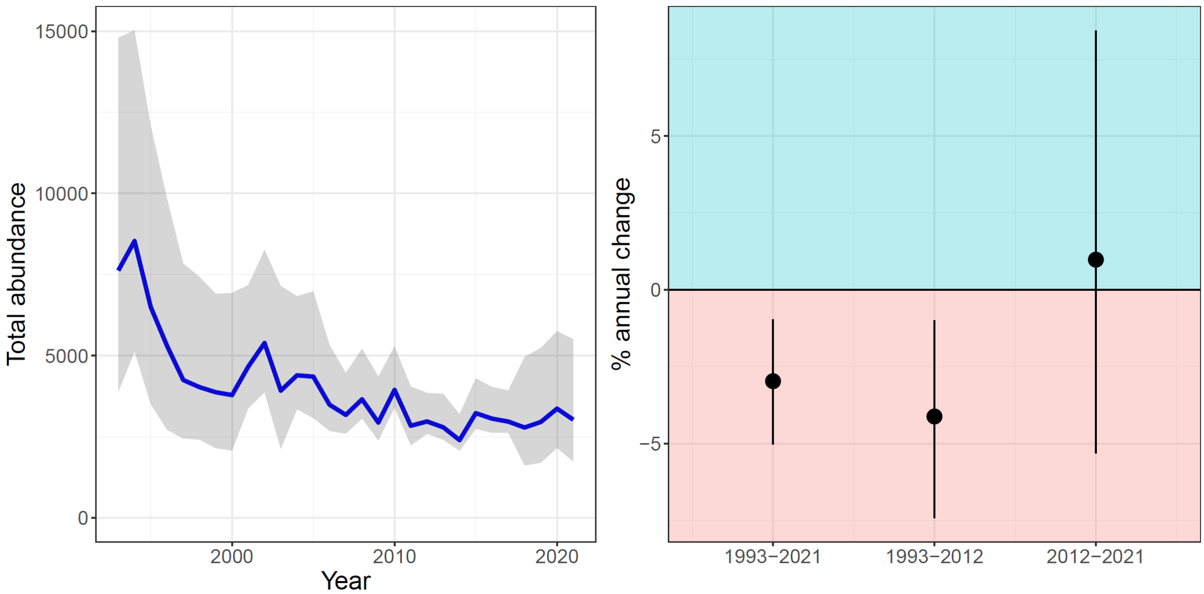

Figure 9. Left: Population trend for Grey Plover from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Latham’s Snipe

The Action Plan for Australian Birds 2020 status: Vulnerable

Global Status (IUCN Red List 2022.2): Near Threatened

EPBC Act status: Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	5
Generation time:	3 years (Bird et al. 2020)
Percent change in abundance over three generations:	-16.80 (95%CI: -85.29, 404.30)
Percent change in abundance between 1993 and 2021:	-66.15 (95%CI: -94.38, 110.60)
Percent annual change in abundance between 1993 and 2021:	-3.79 (95%CI: -9.77, 2.70)
Percent annual change in abundance between 1993 and 2012:	1.94 (95%CI: -6.06, 10.03)
Percent annual change in abundance between 2012 and 2021:	-0.31 (95%CI: -18.33, 22.34)
Change in annual growth rate between 1993-2012 and 2012-2021:	-0.022 (95%CI: -0.24, 0.20)

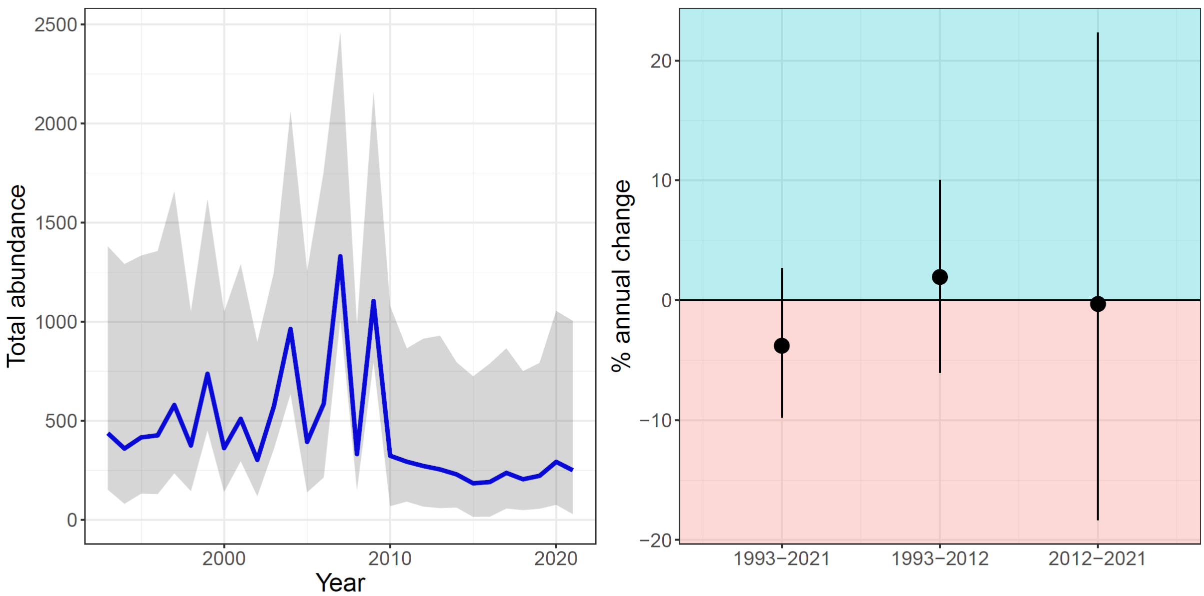

Figure 10. Left: Population trend for Latham’s Snipe from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Northern Siberian Bar-tailed Godwit

The Action Plan for Australian Birds 2020 status: Endangered

Global Status (IUCN Red List 2022.2): Near Threatened (entire species)

EPBC Act status: Critically Endangered (2016), Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	5
Generation time:	8.4 years (Bird et al. 2020)
Percent change in abundance over three generations:	-6.30 (95%CI: -66.96, 152.60)
Percent change in abundance between 1993 and 2021:	-3.60 (95%CI: -67.63, 167.60)
Percent annual change in abundance between 1993 and 2021:	-0.13 (95%CI: -3.95, 3.58)
Percent annual change in abundance between 1993 and 2012:	1.56 (95%CI: -4.91, 7.76)
Percent annual change in abundance between 2012 and 2021:	-6.58 (95%CI: -19.19, 8.54)
Change in annual growth rate between 1993-2012 and 2012-2021:	-0.084 (95%CI: -0.25, 0.086)

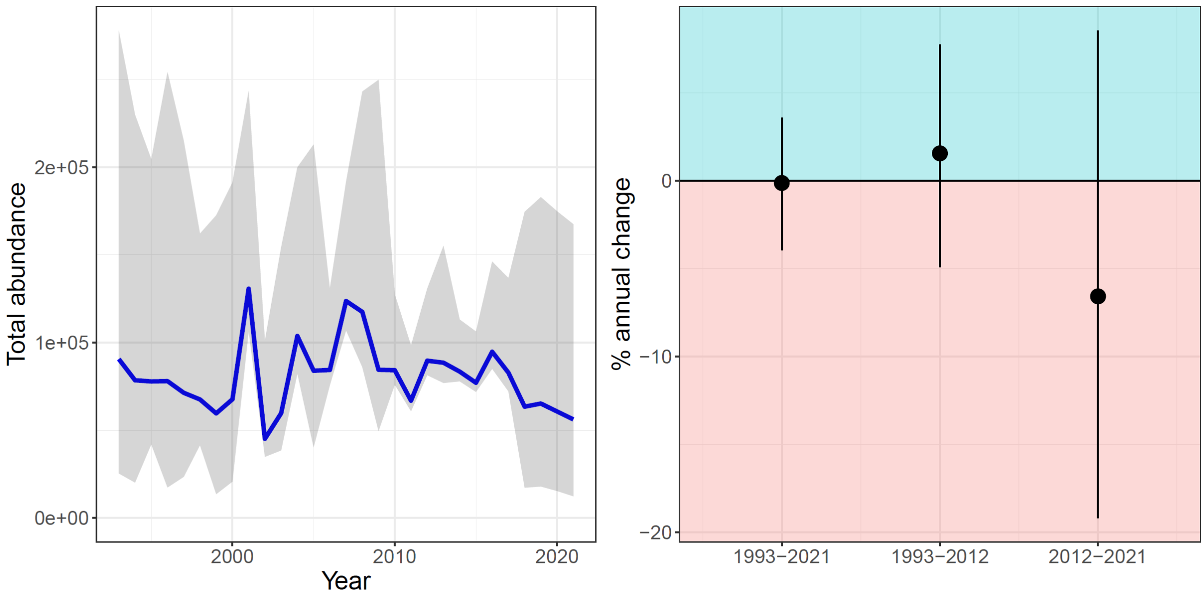

Figure 11. Left: Population trend for Northern Siberian Bar-tailed Godwit from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Nunivak Bar-tailed Godwit

The Action Plan for Australian Birds 2020 status: Endangered

Global Status (IUCN Red List 2022.2): Near Threatened (entire species)

EPBC Act status: Vulnerable (2016), Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	39
Generation time:	8.4 years (Bird et al. 2020)
Percent change in abundance over three generations:	-47.19 (95%CI: -64.56, -23.20)
Percent change in abundance between 1993 and 2021:	-49.14 (95%CI: -65.83, -26.58)
Percent annual change in abundance between 1993 and 2021:	-2.39 (95%CI: -3.76, -1.10)
Percent annual change in abundance between 1993 and 2012:	-1.50 (95%CI: -4.01, 0.83)
Percent annual change in abundance between 2012 and 2021:	1.23 (95%CI: -2.80, 5.03)
Change in annual growth rate between 1993-2012 and 2012-2021:	0.027 (95%CI: -0.021, 0.073)

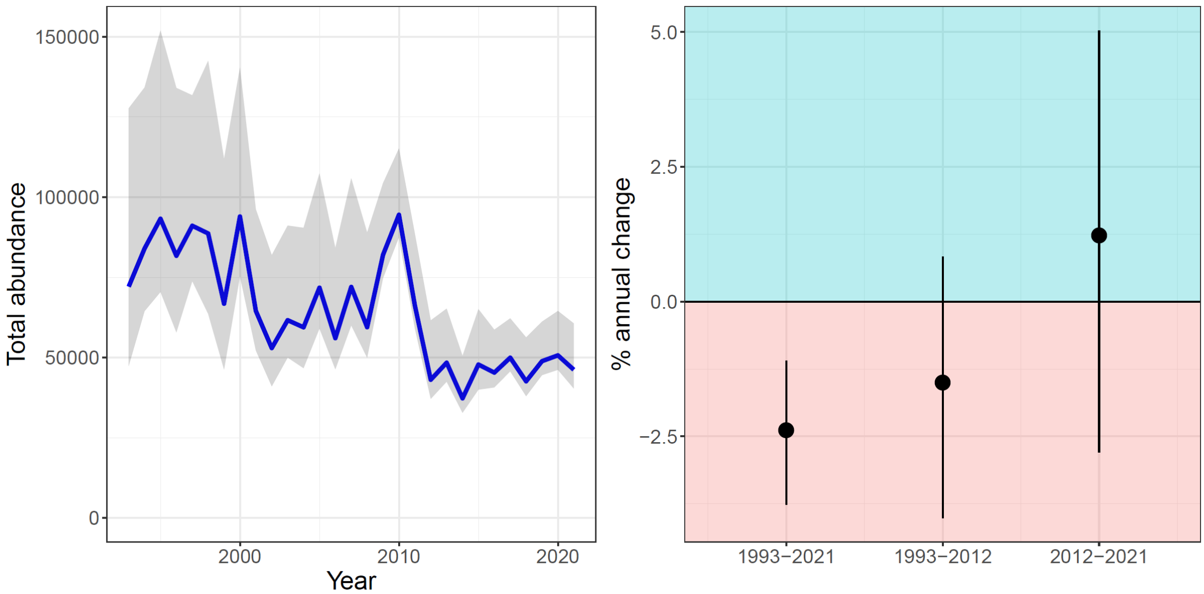

Figure 12. Left: Population trend for Nunivak Bar-tailed Godwit from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Red Knot

The Action Plan for Australian Birds 2020 status: Vulnerable

Global Status (IUCN Red List 2022.2): Near Threatened

EPBC Act status: Endangered (2016), Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	14
Generation time:	6.9 years (Bird et al. 2020)
Percent change in abundance over three generations:	6.11 (95%CI: -63.93, 207.40)
Percent change in abundance between 1993 and 2021:	-7.78 (95%CI: -68.38, 160.90)
Percent annual change in abundance between 1993 and 2021:	-0.29 (95%CI: -4.03, 3.48)
Percent annual change in abundance between 1993 and 2012:	-1.85 (95%CI: -7.85, 4.02)
Percent annual change in abundance between 2012 and 2021:	1.38 (95%CI: -10.81, 18.24)
Change in annual growth rate between 1993-2012 and 2012-2021:	0.032 (95%CI: -0.12, 0.20)

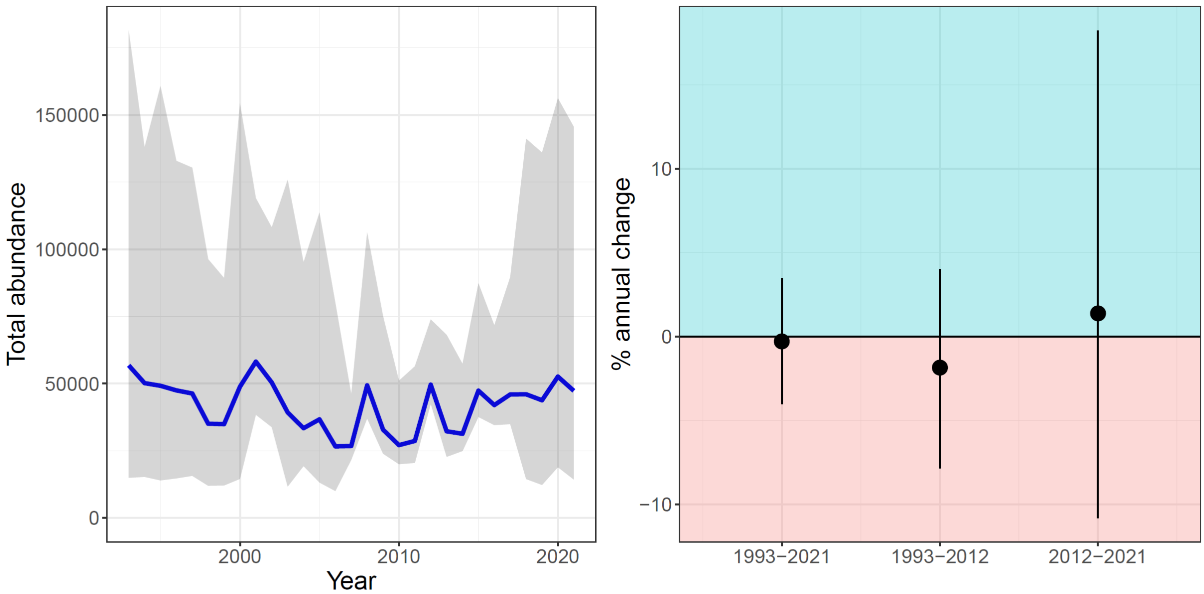

Figure 13. Left: Population trend for Red Knot from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Ruddy Turnstone

The Action Plan for Australian Birds 2020 status: Endangered

Global Status (IUCN Red List 2022.2): Least Concern

EPBC Act status: Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	20
Generation time:	6.2 years (Bird et al. 2020)
Percent change in abundance over three generations:	-26.11 (95%CI: -53.57, 21.81)
Percent change in abundance between 1993 and 2021:	-52.76 (95%CI: -69.21, -26.52)
Percent annual change in abundance between 1993 and 2021:	-2.64 (95%CI: -4.12, -1.09)
Percent annual change in abundance between 1993 and 2012:	-4.36 (95%CI: -6.60, -2.07)
Percent annual change in abundance between 2012 and 2021:	2.46 (95%CI: -4.09, 9.50)
Change in annual growth rate between 1993-2012 and 2012-2021:	0.069 (95%CI: -0.0037, 0.14)

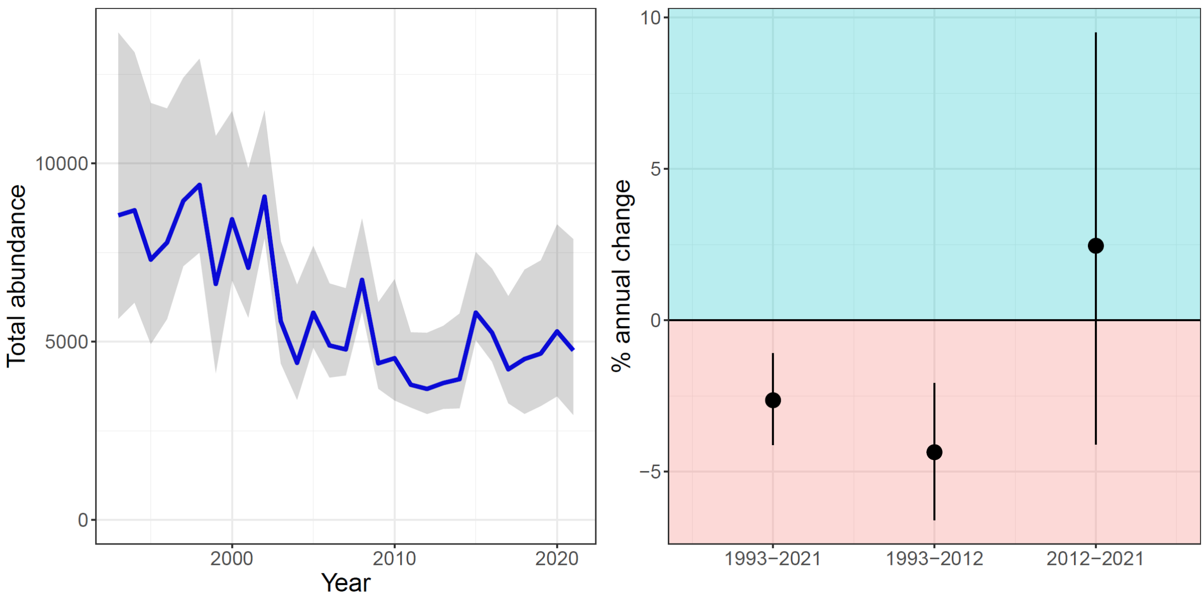

Figure 14. Left: Population trend for Ruddy Turnstone from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Sharp-tailed Sandpiper

The Action Plan for Australian Birds 2020 status: Vulnerable

Global Status (IUCN Red List 2022.2): Vulnerable

EPBC Act status: Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	34
Generation time:	5.1 years (Bird et al. 2020)
Percent change in abundance over three generations:	19.77 (95%CI: -51.86, 235.20)
Percent change in abundance between 1993 and 2021:	4.08 (95%CI: -57.46, 151.80)
Percent annual change in abundance between 1993 and 2021:	0.14 (95%CI: -3.01, 3.35)
Percent annual change in abundance between 1993 and 2012:	0.23 (95%CI: -5.17, 5.56)
Percent annual change in abundance between 2012 and 2021:	1.89 (95%CI: -9.14, 16.77)
Change in annual growth rate between 1993-2012 and 2012-2021:	0.016 (95%CI: -0.11, 0.17)

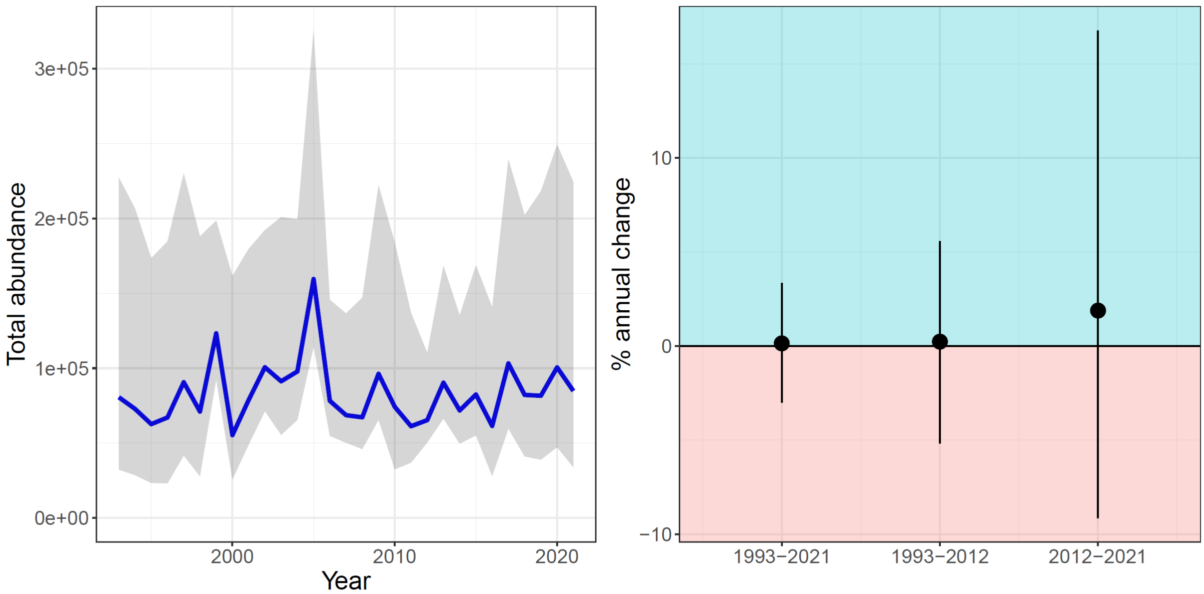

Figure 15. Left: Population trend for Sharp-tailed Sandpiper from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Terek Sandpiper

The Action Plan for Australian Birds 2020 status: Vulnerable

Global Status (IUCN Red List 2022.2): Least Concern

EPBC Act status: Marine, Migratory

Population trends:

Number of shorebird areas used in the trend analysis:	10
Generation time:	4.5 years (Bird et al. 2020)
Percent change in abundance over three generations:	-19.59 (95%CI: -77.44, 222.20)
Percent change in abundance between 1993 and 2021:	1.85 (95%CI: -70.03, 243.90)
Percent annual change in abundance between 1993 and 2021:	0.065 (95%CI: -4.21, 4.51)
Percent annual change in abundance between 1993 and 2012:	2.94 (95%CI: -4.67, 10.76)
Percent annual change in abundance between 2012 and 2021:	-0.60 (95%CI: -14.37, 18.65)
Change in annual growth rate between 1993-2012 and 2012-2021:	-0.035 (95%CI: -0.21, 0.16)

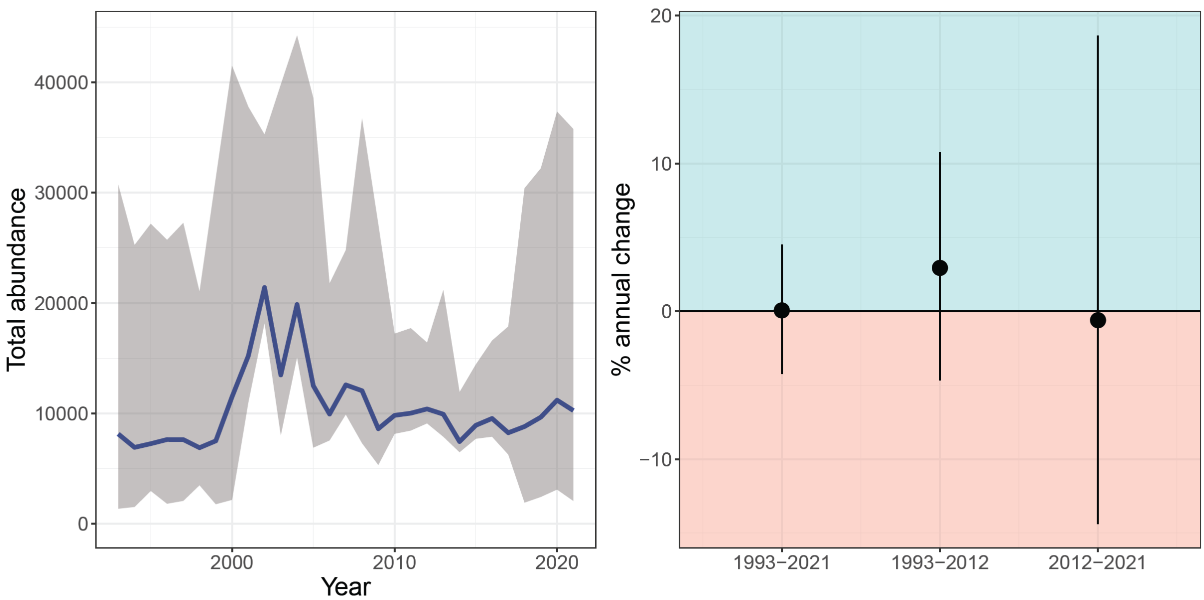

Figure 16. Left: Population trend for Terek Sandpiper from 1993 to 2021. The blue line indicates the posterior mean and the shaded area indicates 95% credible intervals. **Right**: The mean % annual changes (95% confidence intervals shown with the bars) in total abundance over 28 years (1993-2021), between 1993 and 2012, and between 2012 and 2021.

Discussion

There were sufficient data to model the population trend for 14 of the 15 species currently under assessment. We found that four species have declined more than 50%, and three have declined more than 30% but less than 50% over three generations. Five other species have declined less than 30% while Red Knot and Sharp-tailed Sandpiper have increased. Asian Dowitcher did not have sufficient data to model its population trends with this modelling approach. The changes in abundance we found for the declining taxa showed some consistencies with previous assessments, and some differences. We consider that differences have arisen in large part because we were able to apply the most robust available modelling techniques to the data, and our analyses included about a decade of additional data beyond those employed by Studds et al. (2017) and Clemens et al. (2016). Our criteria for determining which sites should be included in the analysis was based on our judgement about which approach would create the most robust dataset, and resulted in a slightly different set of sites being analysed than previous studies. We believe our approach represents the best available analyses so far of national migratory shorebird population trend estimates in Australia, having built upon the excellent approaches developed by previous authors. In turn, we expect that future analyses will improve on our work.

Analysis of the entire time series has shown that for five of the seven species with declines exceeding 30% declines, the rate of decline has slowed in the last nine years (2012-2021) compared to the previous 19 years (1993-2012), although the change was significant only for one species, the Eastern Curlew. These changes in the rate of decline may be the first sign that the crash in population may be slowing for many species, particularly the Eastern Curlew. Changes in population trends may be the result of widespread conservation efforts in the last decade, however the drivers of ongoing declines and current threats need to be mapped at a flyway level to explain the observed changes in population trends. Importantly, the magnitude and direction of the change in the rate of decline was not consistent among species. For example, two of the seven species with more than 30% declines have been declining at a faster rate over the last nine years compared to the first 19 years, although the change in the growth rate was not significant in those species. Determining why some species are doing better than others will be critical for identifying priorities for conservation action in the next decade of shorebird conservation.

The long-term data in Birdlife Australia's Birdata shorebird database collected by Indigenous observers and other citizen scientists around Australia are critical for producing robust population assessments. While there is now 28 years of reasonably consistent survey data present in the database there is still much variation in survey effort that limits our understanding of species trends. Some species, such as Sharp-tailed Sandpiper and Terek Sandpiper, exhibit large fluctuations in the number of individuals detected across years, probably a combination of detection error and movements of birds into and out of surveyed sites. The high natural variation in species numbers coupled with the variation in survey effort as a result of inconsistent funding and the difficulty in reaching remote sites reduced the total number of sites with sufficient data for many species (Hansen et al. 2018). The modelling approach we used required multiple counts of a species at each site per season to account for differences in detectability. This approach is the most robust option for assessing population trends but requires a relatively large amount of data collected consistently over a long period of time.

The national population trends presented here represent the most sound approach for assessing changes in population at the national scale. This approach requires specific data quality that was not present at all shorebird areas. This means that the total abundance that we report is indicative of abundance at the sites we examined (see the methods for rules for shorebird area inclusion). This number will always be a subset of the national abundance for a species. There still remains important spatial bias in these records; for example, some species had data from fewer than ten shorebird areas. There have been significant differences in the rates of declines in different regions of Australia (Studds et al. 2017; Clemens et al. 2016, 2021) and there are still large areas of the north and northwest of the continent that haven't been surveyed consistently for long periods. It is of the utmost importance to continue regular surveys of northern Australia going forward as these places are underrepresented in the current dataset and may not be experiencing the same levels of decline as the shorebird areas in the south of the continent (Clemens et al. 2016).

Many of the species we assessed remain of urgent conservation concern. We found evidence of extraordinary declines in total abundance, in agreement with previous assessments, and evidence of ongoing declines for many species. However, the conservation efforts of the last decade may be starting to turn things around for at least some species of migratory shorebird. This is evident in the rate of declines slowing for five of the seven species with more than 30% declines we assessed. While a smaller rate of decline is noteworthy as it signals an important change relative to the rate of dramatic declines early in the time series, none of the taxa is yet showing signs of recovery. This suggests that the efforts to conserve shorebird habitat around Australia, and elsewhere in the flyway, over the last few decades must intensify if we want to halt the ongoing declines and commence recovery. Careful analyses of the threats along the flyway need urgently to be made so that species-specific conservation actions can be identified, especially in a post-reclamation era where a broader range of threats now needs to be tackled.

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