Shorebird monitoring in Australia: a successful long-term collaboration among citizen scientists, governments and researchers

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Summary

From its beginnings in the 1960s, shorebird monitoring in Australia has grown into a national effort generating high quality information about a large group of migratory and non-migratory waterbirds. Robust information on trends, combined with detailed demographic monitoring and studies of bird movements, has revealed drastic declines, particularly among the migratory species. From the start, monitoring focused on a broad ecological assemblage meaning that the reasons for these declines could be understood through comparative analyses in partnership with researchers. Threats to migratory and non-migratory species, and the actions necessary for their recovery, are increasingly well resolved. Shorebird monitoring in Australia has been a largely decentralised, volunteer-driven effort, funded from both public and private sources. It exemplifies how the public and private sectors can work together to achieve long term monitoring.

Introduction

Migratory species pose a difficult conservation challenge, because management actions are required over vast areas, and comprehensive, broad scale monitoring is needed to provide data on population trends. Shorebirds (or waders) are a diverse group of waterbirds that exemplify this challenge. About 37 of the 55 regularly occurring shorebird species in Australia are migratory, mostly breeding at high latitudes in Russia and Alaska, and migrating to Australasia and New Zealand via stopover sites in East Asia (Geering *et al*. 2007). This collection of migratory routes through 22 countries is termed the East Asian-Australasian Flyway (EAAF; Figure 1). The remaining 18 species are non-migratory although many undertake nomadic, dispersive or irruptive movements especially among ephemeral inland wetlands. A few species undertake only locally dispersive movements (e.g. hooded plover *Thinornis cucullatus*), often occurring in sensitive coastal habitats where human disturbance is intense.

Figure 1 The East Asian-Australasian Flyway, showing schematic migratory movements of shorebirds (©Jen Dixon)

Recovering Australia's threatened shorebirds requires an understanding of their population trends and threats. Identifying causes of decline requires knowledge of their ecology, and in the case of migratory species, their movement patterns throughout their life cycle. On breeding grounds shorebirds occur at very low densities, hindering surveys. They spend several months at southerly non-breeding sites building fuel reserves for migration, often congregating in large numbers along the coast and making surveys much easier. Australia, being a large landmass at the end of the flyway with a largely coastal human population, has therefore been well placed to carry out robust population monitoring for many species on their non-breeding grounds.

Here we chart shorebird monitoring efforts in Australia and their contribution to conservation through policy and on-ground actions. Shorebirds are one of the best-monitored components of Australia's biodiversity; a fascinating case study of a largely decentralised, grass roots-driven effort funded from both public and private sources. Shorebird monitoring has required the capacity to count the birds, coordinate surveyors, manage datasets, and conduct complex

analyses. Lasting collaborations between citizen scientists, researchers, and increasingly, Indigenous communities, have determined population trends, identified key threats and habitats, and catalysed conservation concern and action.

Origins of shorebird monitoring in Australia

Shorebird monitoring began in the 1950s and 1960s in southern Tasmania (Wall 1953; Thomas 1970). The earliest formal survey efforts targeting non-migratory species commenced with hooded plover monitoring in Victoria in 1980, and in Tasmania in 1982 (Lane 1981; Newman and Patterson 1984). The Royal Australasian Ornithologists' Union launched the National Wader Count in 1981, in which coordination of volunteer counts was funded (initially) by the Australian National Parks and Wildlife Service. Monitoring at key sites identified though this project continued through the Australasian Wader Studies Group (AWSG) Population Monitoring Programme (PMP), sustained largely by volunteers from the mid–1980s to early 2000s (Wilson 2001; Gosbell and Clemens 2006). Shorebird monitoring shifted under the umbrella of BirdLife Australia's Shorebirds 2020 (S2020) programme in 2007; counts are still carried out largely by volunteers, but there is professional support for co-ordination and database maintenance, and extensive collaboration with universities to facilitate analysis and publication. Commonwealth Government support for shorebird monitoring has been largely underpinned by international environmental agreements such as the Ramsar Convention, the Convention on Migratory Species, and three bilateral agreements (with Japan, Republic of Korea and China) containing explicit provisions for conserving migratory birds. Currently, shorebird population monitoring covers the entire assemblage as broadly as possible, including surveying as many remotely located populations as possible (Clemens *et al*. 2012).

Dimensions of shorebird monitoring

Presently, there are three main facets to shorebird monitoring activity in Australia: (i) an ongoing regular count programme monitoring shorebird numbers at key sites, (ii) efforts to monitor beach-nesting shorebirds not well captured by the overall count programme, and (iii) ecological and migration studies, which, coupled with count data have led to key insights into the threats affecting the birds.

Counting shorebirds

The AWSG PMP began revealing decreases in population sizes for some shorebird species as long ago as the early 1980s (Close and Newman 1984; Barter 1992). A decade after these first reports of declines in south-eastern Australia, counting efforts expanded particularly across the eastern states of Victoria, South Australia, New South Wales and Queensland. The Queensland Wader Study Group (QWSG; a special interest group of Birds Queensland) was established in 1992 to monitor and conserve shorebird populations. Run entirely by volunteers (like most shorebird monitoring in Australia), close interaction between organisers and surveyors has been key to the accuracy, precision, coverage and longevity of shorebird monitoring in Queensland. One notable feature of monitoring in parts of Queensland is monthly counts, which reduce within-year count variability and increase statistical power to detect trends compared with less frequent monitoring elsewhere (Wilson *et al*. 2011).

Key challenges in the first decades of national shorebird monitoring included taxonomic and geographic bias in count coverage, variability in repeatability of count methods, and the limited capacity for data analysis and research. Monitoring suffered because the time required for co-ordination (including data-entry, feedback to counters, recruitment and training of new counters) exceeded volunteer capacity. S2020 was initiated in 2007 with support from WWF-Australia to reinvigorate shorebird monitoring, and received funding of approximately $1 million over a 10 year period from the Commonwealth Government. This strategic injection of funding was crucial for maintaining the continuity of the monitoring effort. Rolling the AWSG PMP into S2020 provided professionalised resources to support the appointment of a national monitoring coordinator and assistant. This programme now houses the majority of state and national shorebird count data, with a focus on migratory species.

Statistics extracted from S2020 in January 2017 reveal the scale of the shorebird monitoring effort. Since the first record on 15 March 1971, the monitoring network has grown to encompass 1 142 215 counts of 44 010 168 shorebirds from 96 621 surveys. Nationally, 3010 count areas are aggregated into 437 shorebird areas for reporting (Figure 2). There are 1437 registered volunteers, with many more helping informally. These local experts determine how birds use each site, and how best to achieve repeatable counts. S2020 has mapped these count areas nationally (Figure 2). In Queensland, the QWSG has mapped high tide roosts along

much of the coast at a precision relevant to development proposals, and is called upon regularly to assess potential impacts of developments. Combined with information on suitable buffers for shorebirds (e.g. Guay *et al*. 2016), or protected area zoning advice (Stigner *et al*. 2016), shorebird monitoring has matured into an impressive planning tool.

Figure 2 Shorebird monitoring across Australia (Shorebirds 2020 database). Although biased toward coastal and the more accessible inland sites, the national reach of shorebird monitoring is striking. See Clemens *et al*. (2012) for a detailed discussion of this dataset.

Shorebird monitoring has typically been biased toward the main population centres in south-eastern Australia (Figure 2; Clemens *et al*. 2012). One major exception is a series of aerial surveys covering about a third of the continent's wetlands each October for waterbirds (> 50 species), using aerial surveys of up to 2000 wetlands across eastern Australia (Kingsford and Porter 2009). Shorebirds are counted, with only the more distinctive identified to species (e.g. red-necked avocet *Recurvirostra novaehollandiae*). Migratory shorebirds are not specifically identified (Kingsford 1999), but instead grouped into large and small species (Nebel *et al*. 2008). These aerial surveys are among the longer-term large-scale surveys in the world, providing data for more than three decades on shorebird abundance (Nebel *et al*. 2008). Long-term trend data on individual wetlands is providing valuable information on specific threats affecting shorebirds and their habitats in Australia (Bino *et al*. 2015, 2016; Nebel *et al*. 2008). There are also systematic annual aerial surveys of waterbirds (2010–present), including shorebirds, on all major wetlands in the Murray-Darling Basin.

Shorebird monitoring is challenging in remote northern Australia due to large expanses of suitable habitat, few locally-based volunteers, difficult field conditions, poor accessibility and little prior information on bird movements. Aerial surveys of the northern Australian coast were undertaken in the 1980s, identifying large populations of shorebirds across the Northern Territory and southern Gulf of Carpentaria, and further aerial surveys in 1997 and 1999 confirmed the international importance of the south-east Gulf of Carpentaria region for shorebirds.

Recent efforts to monitor shorebirds on-ground in northern Australia have been spearheaded by Indigenous people through a range of community-based initiatives. Locally-based

Indigenous land and sea ranger programmes, drawing on traditional knowledge and often supported through government funding, are well-placed to monitor and research shorebirds. Partnerships involving Indigenous ranger programmes and shorebird scientists have yielded promising results in a number of sites. Two designations occurred on Indigenous lands in the south-east Gulf of Carpentaria in 2014 and 2016 under the Flyway Site Network of the East Asian-Australasian Flyway Partnership (EAAFP), to which Australia is a partner. This is a multi-actor voluntary, non-binding initiative for conserving migratory waterbirds and their habitats across the flyway. These site designations were driven by the Land and Sea Rangers of the Carpentaria Land Council Aboriginal Corporation, complemented by shorebird counts by the QWSG (Jaensch and Driscoll 2015). Surveys through a long-term collaborative partnership including the Mapoon Land and Sea Rangers, have also revealed that the greater Mapoon area of western Cape York is internationally significant for shorebirds (Jackson *et al*. 2016).

Beach-nesting birds

The surveys described above mostly focus on sites with large congregations of migratory shorebirds. Species occupying non-wetland habitats, or non-estuarine coastal environments such as sandy beaches are often underrepresented. Consequently, BirdLife Australia runs a nationwide Beach-nesting Birds project aimed at monitoring and management of shorebirds that breed on beaches. This is an example of integrated adaptive management, and hatching and fledging rates of breeding pairs, threats and on-ground management outcomes are monitored by > 750 citizen scientists. On-ground threat mitigation actions are initiated using an online data portal (> 4500 records per season) that relays alerts from volunteers to managers (http://portal.mybeachbird.com.au).

Monitoring measures the effectiveness of on-ground management actions, and a user manual to guide managers to implement nest and chick protection has been created (Maguire 2008). At beaches with high human visitation, protective signage and fencing around breeding sites have boosted the probability of chick fledging tenfold, equivalent to fledging rates of birds on remote, undisturbed beaches. In total, 244 hooded plover chicks were saved from mortality through this project, doubling- quadrupling the expected fledgling tally for Victoria and South Australia. Remarkably, despite increasingly high human usage of beaches in south-eastern Australia, the plover population has stabilised and birds are returning to sites from

which they had been absent for 15 years or more. It is likely that long-term persistence of hooded plover populations in south-eastern Australia is conservation-dependent.

A longer-term goal is to change behaviour of beach users, and foster community ownership of flagship species like hooded plovers. The project has a visible presence in primary schools and runs awareness-raising events such as 'Dog's Breakfasts'. Over 10 years, awareness has doubled with coastal communities embracing flagship species and establishing 12 'Friends of' groups (Dowling and Weston 1999; Maguire 2008; Maguire *et al*. 2013).

Banding, flagging and migration studies

The Victorian Wader Study Group (VWSG) formed in 1979 to enable 'the collection of information in a scientific manner as a basis for conservation activities' (Minton 2006). The development of markers on birds that could be read in the field (e.g. leg flags) allowed the VWSG and AWSG to study migration routes in detail, which is crucial to conservation of migratory species (Minton *et al*. 2006). This biological monitoring data would later be combined with count data to understand why many migratory shorebirds were in rapid decline. Tracking the migration of individual birds has also helped engage the public with epic stories of shorebird migrations, such as that of bar-tailed godwit *Limosa lapponica* E7, who migrated direct from Alaska to New Zealand in a single trans-Pacific flight (Gill *et al*. 2009). In collaboration with Deakin University, ongoing ruddy turnstone *Arenaria interpres* geolocator studies led by the VWSG and Friends of Shorebirds South East (FOSSE) have generated one of the few datasets on long-term migration patterns, yielding important information on how this species responds to habitat changes along its migratory route (Minton *et al*. 2013).

A key challenge has been the lack of progress analysing and publishing demographic data resulting from detailed population studies. The Global Flyway Network (GFN) has been leading the way in this area, funded from the Netherlands and led by Theunis Piersma of the University of Groningen. Large-scale counting and colour-banding in north-western Australia are combined with extensive resighting efforts in China. These activities have revealed (i) that red knots *Calidris canutus* depend heavily on one short stretch of the Luannan coastline on northward migration (Rogers *et al*. 2010), (ii) that declines in annual adult survival among several shorebird species were apparent before these declines had resulted in detectable

changes in population size (Piersma *et al*. 2016; Conklin *et al*. 2016), and (iii) the location of the majority of mortality in the annual cycle of red knot, great knot *Calidris tenuirostris* and bar-tailed godwit. In all three species, increased mortality is occurring outside Australia, either on migration (particularly in the Yellow Sea: Piersma *et al*. 2016) or on the breeding grounds.

Discoveries, policy development and on-ground actions for shorebird conservation arising from monitoring efforts

Scientific analysis of monitoring data

Shorebird monitoring was revealing declines in migratory populations as long ago as the 1980s, when Close and Newman (1984) observed of eastern curlews in Tasmania that "there has been well-documented systematic decline over 30 years in the south-east". They suggested prophetically that the species might be threatened by "land reclamation and clearance of mangroves in China, where the species is a passage migrant". Close and Newman made the point that before the Tasmanian declines could be properly understood, "the species' status in the rest of Australia" needed to be assessed. They were highlighting a concern that declines in one place might represent a redistribution of populations elsewhere in Australia, rather than an overall decline. More papers documenting worrying local and regional declines of several migratory shorebird species appeared over the ensuing years (see Hansen 2011 for a review), all hampered by the same issue of a cloudy national picture.

A full scale national analysis of shorebird declines got underway in 2010, led by the University of Queensland and funded by the Commonwealth Government, Queensland State Government, Port of Brisbane, and QWSG. The project discovered that populations of at least 12 migratory shorebird species were declining nationally (Figure 3; Clemens *et al*. 2016; Studds *et al*. 2017). In an example of rapid and responsive action by the Commonwealth Government, on 26 May 2015, even before these studies were published, the far eastern curlew *Numenius madagascariensis* and curlew sandpiper *Calidris ferruginea* were listed as Critically Endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and the following year another six migratory shorebird taxa were also listed as threatened. All these listings were founded on robust continental-scale monitoring

data. An international single-species action plan for far eastern curlew conservation was approved by the 9th Meeting of the Partners of the EAAFP in 2017, which includes state and non-state actors working across its entire migratory range.

Figure 3 National population change in 19 migratory shorebird species. Twelve species are significantly declining across Australia. Data span from 1973 to 2014, and error bars indicate the 95% confidence interval. See Clemens *et al*. (2016) for full details of the analysis.

By the 1990s, the decades of research on migration instigated by the VWSG, AWSG and QWSG, had documented the migration routes of many species and it had now become possible to see the declines observed in Australia in the context of the places visited by the birds during migration. Pioneering work by David Melville, the late Mark Barter and others, had documented habitat loss across vast tracts of the Yellow Sea (Barter 2005), and work by Nick Murray showed that two-thirds of the intertidal habitat in the Yellow Sea had disappeared since the 1950s (Murray *et al*. 2014). While it had long been suspected that this habitat loss in the Yellow Sea was the main driver of the declines of Australian migratory shorebirds, concrete evidence began to emerge in 2010, when Amano *et al*. (2010) showed that populations of shorebird species specialising in the Yellow Sea while on migration were declining more rapidly in Japan than those that do not. Most recently, Studds *et al*. (2017) showed that species with a greater reliance on the Yellow Sea while on migration have been declining the fastest in Australia, suggesting that the epicentre of the declines of many species can be confidently located in the Yellow Sea. This line of evidence is fundamentally important for influencing policy nationally and internationally, as it emphasises the need for coordinated conservation. As Paul Sullivan, CEO of BirdLife Australia said at the launch of the Commonwealth Government's *Wildlife Conservation Plan for Migratory Shorebirds* in Melbourne in April 2016, "the science is in". Urgent action is needed to save these birds from sliding further toward extinction.

Action resulting from the monitoring effort

Organisations monitoring shorebirds work hard to identify and advocate for the protection of shorebird habitats, and their efforts draw upon the vast repository of data generated by counters. To facilitate habitat protection, wetlands of international conservation importance are typically identified using Ramsar criteria, two of which relate to waterbird population

sizes. Shorebird monitoring data have contributed to the listing of 36 of Australia's 66 Ramsar sites and its 24 EAAFP Flyway Sites. Sites identified as nationally important under these designations are also afforded additional conservation protection through the EPBC Act (Department of the Environment 2015). On a species level, Australian monitoring efforts have also been critical in developing and maintaining population estimates, with the most recent revision for 37 migratory shorebird species drawing almost exclusively on the monitoring effort outlined in this chapter (Hansen *et al*. 2016). These population estimates, plus information on population trends, underpin the listing of particular species under the EPBC Act and International Union for the Conservation of Nature (IUCN) Red List.

Recognition of all migratory shorebirds as matters of national environmental significance has also occurred under the EPBC Act, triggering development of the *Wildlife Conservation Plan for Migratory Shorebirds* in 2006. An updated version of the plan founded on data from the national shorebird monitoring effort was released in 2016, and includes objectives pertaining to habitat protection in Australia and throughout the EAAF. The listing of these species and release of the plan is catalysing conservation action and applied research around the nation.

Successes, challenges and lessons for the future

Although it seems an obvious truism, detecting declines requires long-term data. This is a key strength of volunteer-based programs: the passion of a volunteer can (and often does) last a lifetime, while funding cycles rarely last more than a few years. Moreover, threatened species monitoring must ideally start *before* species become threatened. One of the important innovations in Australian shorebird monitoring was to monitor the entire ecological assemblage, rather than focus on particular species thought to be at risk. This strategy has not only allowed the detection of population declines, but also helped to identify threats. For instance, demonstrating the link between population declines in Australia and habitat loss in the Yellow Sea was only possible because the range of species monitored present a gradient of reliance on this region (Studds *et al*. 2017). Few shorebird specialists in the early 1980s would have predicted that common species such as bar-tailed godwit and curlew sandpiper would be listed as nationally threatened just 30 years later.

Collaborations among expert volunteers (some of whom are also professional scientists) and university researchers have been crucial in unlocking the power of the monitoring effort. Careful data sharing agreements, and long-term working relationships built on mutual trust, have led to insights that neither the expert volunteers nor the university researchers could possibly have achieved alone. This has resulted in high quality collaborative science that has assisted conservation decision-making by Commonwealth and state governments, regional and local site managers, and the integration of the results of shorebird monitoring into international agreements. It has also raised the public profile of shorebirds, with many more people aware of (and amazed by) their feats of migration. This demonstrated application of the data is critical to engaging both funders and contributors in the longer term.

As citizen science continues to grow in Australia, this example of a hugely successful grass-roots movement for monitoring shorebirds shows that it is imperative the motivations and needs of volunteers are foremost in planning new programmes. A lot of trust and careful design would be needed to ensure that a top-down designed citizen science-driven monitoring effort had a realistic chance of achieving the multi-decadal longevity that the shorebird movement has achieved. Continuous recognition of volunteer contributions through publications, news articles, social media, email circulars, *State of Australia's Birds* reports, and changes to government policy have played an important part in maintaining and expanding shorebird monitoring programmes. As the success of these programmes hinges on volunteer goodwill, passion, and belief they are helping the birds, it is critical that volunteers get due inclusion, acknowledgement, attribution and feedback: it can be a major disincentive if they don't feel the data they collect are going to be used.

Despite the central importance of volunteers in the history and development of shorebird monitoring in Australia, funding has also been key to the growth of the movement. The advent of Shorebirds 2020, funded over a decade by the Commonwealth Government, was crucial in organising and curating the data, paving the way for national analyses and a full understanding of the species' status and threats. It is hard to find funding to support spatial planning and database management, yet if this sort of work is not supported, an enormous amount of data can be vastly underutilised by not feeding through into analysis and decision-making. Collaborative discussions can identify when such funding is needed. For example, the shorebird monitoring movement is currently suffering from a lack of technological capacity to house and curate the burgeoning datasets. Databases have reached the point where

they cannot be managed by a single individual nor housed on a desktop computer. The server space and technological support to manage these now almost exclusively resides with organisations, but the longevity of funding programmes and sometimes even the organisations themselves, pose risks to long-term data storage and retrieval.

Dedicated coordination of monitoring efforts is central to their conduct and without this, surveys may become misdirected, experience loss of methodological rigour and eventually risk foundering. The current scale of shorebird monitoring in Australia precludes an absolute reliance on volunteers. Continued strategic funding will be critical to the future of what has become one of the longest-running, largest and arguably most successful citizen science programmes in Australia.

Lessons learnt

- Multi-species and habitat monitoring, combined with robust ecological information, facilitated discovery of the causes of shorebird population declines;
- Community-driven monitoring can mature into large programmes providing robust, long-term, large-scale data;
- Public sector funding can assist citizen science efforts, especially at critical junctures in their history;
- Partnerships between community groups and researchers can be crucial to achieving the full potential of threatened species community-based monitoring efforts;
- Monitoring species before they become threatened makes it easier to identify declines and understand the reasons for these before it is too late.

References

Amano T, Szekely T, Koyama K, Amano H, Sutherland WJ (2010) A framework for monitoring the status of populations: An example from wader populations in the East Asian–Australasian Flyway. *Biological Conservation* **143**, 2238–2247.

Barter MA (1992) Changing wader numbers in Swan Bay, Victoria - a cause for concern? *Stilt* **21**, 8–12.

Barter MA (2005) Yellow Sea-driven priorities for Australian shorebird researchers. In *Status and Conservation of Shorebirds in the East Asian-Australasian Flyway*. (Ed P Straw) pp. 158–160. Proceedings of the Australasian Shorebirds Conference 13-15 December 2003, Canberra, Australia. Wetlands International Global Series 18, International Wader Studies 17. Sydney, Australia.

Bino G, Kingsford RT, Brandis K (2016) Australia's wetlands – learning from the past to manage for the future. *Pacific Conservation Biology* **22**, 116–129.

Bino G, Kingsford RT, Porter J (2015) Prioritizing wetlands for waterbirds in a boom and bust system: Waterbird refugia and breeding in the Murray-Darling Basin. *PLOS ONE* **10**, e0132682.

Clemens RS, Kendall BE, Guillet J, Fuller RA (2012) Review of Australian shorebird survey data, with notes on their suitability for comprehensive population trend analysis. *Stilt* **62**, 3–17.

Clemens RS, Rogers DI, Hansen BD, Gosbell K, Minton CDT, Straw P, Bamford M, Woehler EJ, Milton DA, Weston MA, Venables B, Weller D, Hassell C, Rutherford B, Onton K, Herrod A, Studds CE, Choi CY, Dhanjal-Adams KL, Murray NJ, Skilleter GA, Fuller RA (2016) Continental-scale decreases in shorebird populations in Australia. *Emu* **116**, 119–135.

Close D, Newman OMG (1984) The decline of the eastern curlew in south-eastern Australia. *Emu* **84**, 38–40.

Conklin JR, Lok T, Melville DS, Riegen AC, Schuckard R, Piersma T, Battley PF (2016) Declining adult survival of New Zealand Bar-tailed Godwits during 2005–2012 despite apparent population stability. *Emu* **116**, 147–157.

Department of the Environment (2015) *EPBC Act Policy Statement 3.21 - Industry guidelines for avoiding, assessing and mitigating impacts on EPBC Act listed migratory shorebird species*. Commonwealth of Australia, Canberra, Australia.

Dowling B, Weston MA (1999) Managing a breeding population of the hooded plover *Thinornis rubricollis* in a high-use recreational environment. *Bird Conservation International* **9**, 255–270.

Geering A, Agnew L, Harding S (2007) *Shorebirds of Australia*. CSIRO Publishing, Clayton, Victoria.

Gill RE, Tibbitts TL, Douglas DC, Handel CM, Mulcahy DM, Gottschalck JC, Warnock N, McCaffery BJ, Battley PF, Piersma T (2009) Extreme endurance flights by landbirds

crossing the Pacific Ocean: Ecological corridor rather than barrier? *Proceedings of the Royal Society B: Biological Sciences* **276**, 447–457.

Gosbell K, Clemens R (2006) Population monitoring in Australia: Some insights after 25 years and future directions. *Stilt* **50**, 162–175.

Guay P-J, van Dongen WFD, Robinson RW, Blumstein DT, Weston M (2016) AvianBuffer: An interactive tool for characterising and managing wildlife fear responses. *Ambio* **7**, 841–851.

Hansen B (2011) A brief overview of literature on waders in decline. *Stilt* **60**, 6–8.

Hansen BD, Fuller RA, Watkins D, Rogers DI, Clemens RS, Newman M, Woehler EJ, Weller DR (2016) *Revision of the East Asian-Australasian Flyway Population Estimates for 37 listed Migratory Shorebird Species*. Unpublished report for the Department of the Environment. BirdLife Australia, Melbourne.

Jackson MV, Blackwood J, Maurer G, Weller D, Barkley S, Booth L, Dejersey J, Ling E, Mamoose G, Kennett R, Stone L (2016) Establishing the importance of the Greater Mapoon Area for waterbirds through collaboration with Indigenous Land and Sea Rangers. *Stilt* **69/70**, 66–73:

Jaensch R, Driscoll P (2015). International recognition for the SE Gulf of Carpentaria – at last! *Tattler* **36**, 9–10.

Kingsford RT (1999) Aerial survey of waterbirds on wetlands as a measure of river and floodplain health. *Freshwater Biology* **41**, 425–438.

Kingsford RT, Porter JL (2009) Monitoring waterbird populations with aerial surveys - what have we learnt? *Wildlife Research* **36**, 29–40.

Lane BA (1981). The Hooded Plover survey, October 1980. *Victorian Wader Study Group Bulletin* **3**, 6–8.

Maguire GS (2008) *A practical guide for managing beach-nesting birds in Australia*. Birds Australia, Melbourne.

Maguire GS, Rimmer JM, Weston MA (2013) Stakeholder perceptions of threatened species and their management on urban beaches. *Animals **3***, 1002–1020

Minton C (2006) The history and achievements of the Victorian Wader Study Group. *Stilt* **50**, 285–294.

Minton C, Wahl J, Jessop R, Hassell C, Collins P, Gibbs H (2006) Migration routes of waders which spend the non-breeding season in Australia. *Stilt* **50**, 135-157.

Minton C, Gosbell K, Johns P, Christie M, Klaassen M, Hassell C, Boyle A, Jessop R, Fox J (2013) New insights from geolocators deployed on waders in Australia. *Wader Study Group Bulletin* **120**, 37–46.

Murray NJ, Clemens RS, Phinn SR, Possingham HP, Fuller RA (2014) Tracking the rapid loss of tidal wetlands in the Yellow Sea. *Frontiers in Ecology and the Environment* **12**, 267–272.

Nebel S, Porter JL, Kingsford RT (2008) Long-term trends in shorebird populations in eastern Australia and impacts of freshwater extraction. *Biological Conservation* **141**, 971–980.

Newman OMG, Patterson RM (1984) A population survey of the hooded plover *Charadrius rubricollis* in Tasmania, October 1982. *An Occasional Stint* **3**, 1–6.

Piersma T, Lok T, Chen Y, Hassell CJ, Yang HY, Boyle A, Slaymaker M, Chan YC, Melville DS, Zhang ZW, Ma Z (2016) Simultaneous declines in summer survival of three shorebird species signals a flyway at risk. *Journal of Applied Ecology* **53**, 479–490.

Rogers DI, Yang H-Y, Hassell CJ, Boyle AN, Rogers KG, Bing C, Zhang Z-W, Piersma T (2010) Red Knots (*Calidris canutus piersmai* and *C. c. rogersi*) depend on a small threatened staging area in Bohai Bay, China. *Emu* **110**, 307-315.

Stigner MG, Beyer HL, Klein CJ, Fuller RA (2016) Reconciling recreational use and conservation values in a coastal protected area. *Journal of Applied Ecology* **53**, 1206–1214.

Studds CE, Kendall BE, Murray NJ, Wilson HB, Rogers DI, Clemens RS, Gosbell K, Hassell CJ, Jessop R, Melville DS, Milton DA, Minton CDT, Possingham HP, Riegen AC, Straw P, Woehler EJ, Fuller RA (2017) Rapid population decline in migratory shorebirds relying on Yellow Sea tidal mudflats as stopover sites. *Nature Communications*.

Thomas DG (1970) Fluctuation of numbers of waders in south-eastern Tasmania. *Emu* **70**, 79–85.

Wall LE (1953) Some notes on migrant waders in southern Tasmania. *Emu* **58**, 80–86.

Wilson HB, Kendall BE, Fuller RA, Milton DA, Possingham HP 2011. Analyzing Variability and the Rate of Decline of Migratory Shorebirds in Moreton Bay, Australian. *Conservation Biology* **25**, 758–766.

Wilson JR (2001) The Australasian Wader Studies Group Population Monitoring Project: Where to now? Perspectives from the Chair. *Stilt* **39**, 13–26.

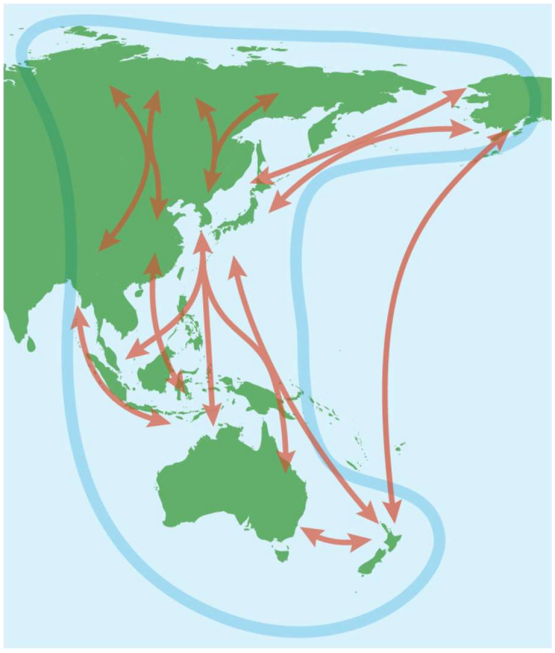

Figure 1 The East Asian-Australasian Flyway, showing schematic migratory movements of shorebirds (©Jen Dixon)

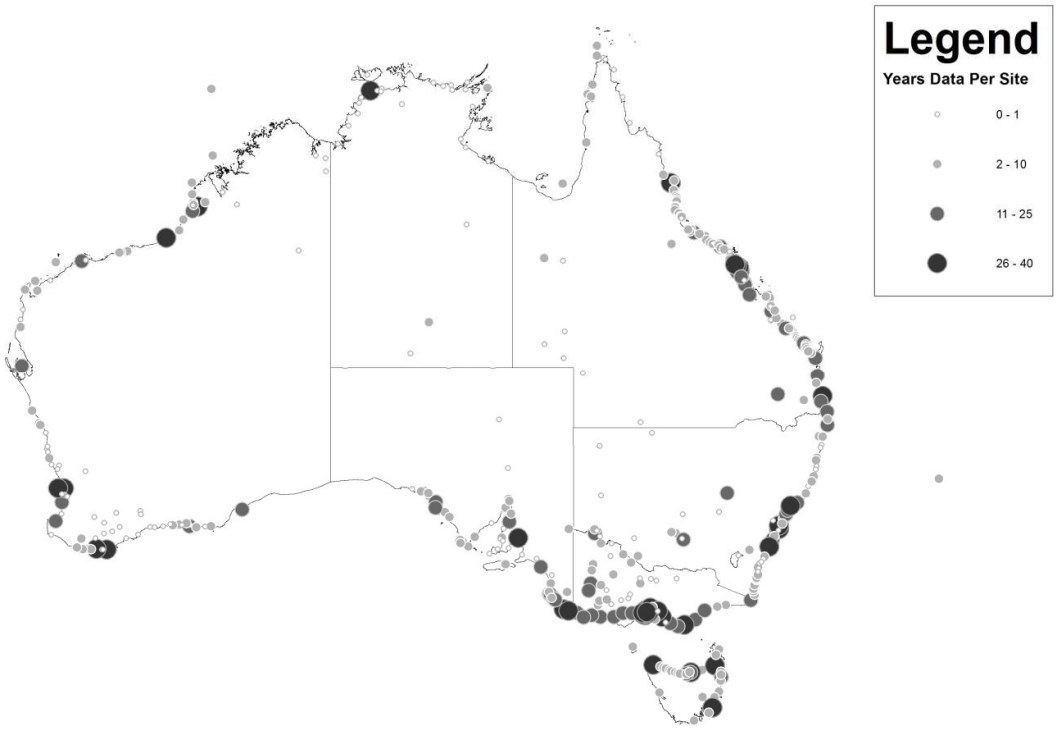

Figure 2 Shorebird monitoring across Australia (Shorebirds 2020 database). Although biased toward coastal and the more accessible inland sites, the national reach of shorebird monitoring is striking. See Clemens *et al*. (2012) for a detailed discussion of this dataset.

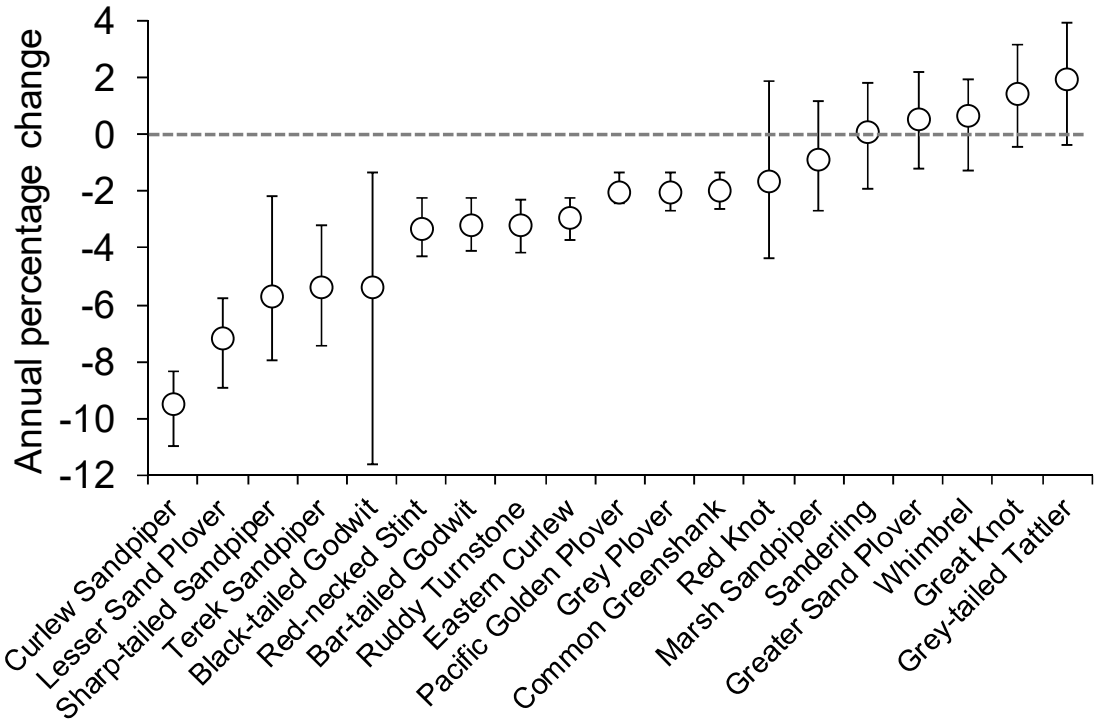

Figure 3 National population change in 19 migratory shorebird species. Twelve species are significantly declining across Australia. Data span from 1973 to 2014, and error bars indicate the 95% confidence interval. See Clemens *et al*. (2016) for full details of the analysis.