Review of long-term shorebird monitoring in north Western Australia

D.I. Rogers, M.P. Scroggie and C.J. Hassell

July 2020

Arthur Rylah Institute for Environmental Research
Technical Report Series No. 313

Arthur Rylah Institute for environmental research

VICTORIA State Government | Environment, Land, Water and Planning

Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

Arthur Rylah Institute for Environmental Research
Department of Environment, Land, Water and Planning
PO Box 137
Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.ari.vic.gov.au

Technical Report for: Department of Biodiversity, Conservation and Attractions
Western Australia.

Citation: Rogers, D.I., Scroggie, M.P. and Hassell, C.J. (2020). Review of long-term shorebird monitoring in north Western Australia. Arthur Rylah Institute for Environmental Research Technical Report Series No. 313.

Front cover photo: Shorebird flock on Eighty Mile Beach (Jan van de Kam).

ISSN 1835-3827 (print)
ISSN 1835-3835 (pdf))
ISBN 978-1-76105-157-9 (Print)
ISBN 978-1-76105-158-6 (pdf/online/MS word)

Accessibility

If you would like to receive this publication in an alternative format, please telephone the DELWP Customer Service Centre on 136 186, email customer.service@delwp.vic.gov.au or contact us via the National Relay Service on 133 677 or www.relayservice.com.au. This document is also available on the internet at www.delwp.vic.gov.au

Review of long-term shorebird monitoring in north Western Australia

Danny I. Rogers[1], Michael P. Scroggie[1] and Chris J. Hassell[2]

[1] Arthur Rylah Institute for Environmental Research
123 Brown St, Heidelberg VIC 3084

[2] Global Flyway Network and Australasian Wader Studies Group.
PO Box 3084, Broome, WA 6725

Arthur Rylah Institute for Environmental Research
Technical Report Series No. 313

Acknowledgements

The report was commissioned by the Department of Biodiversity, Conservation and Attractions (DBCA). We thank Chris Nutt, Naomi Findlay and Andy Halford of DBCA for help during report preparation.

The Australasian Wader Studies Group (ASWG) and Birdlife Australia have long supported the Monitoring Yellow Sea Migrants in Australia (MYSMA) project which generated most of the count data on which this report is based. Funding for the MYSMA program over the years has come from a number of agencies, including DBCA, the Commonwealth Government (through the Department of Environment and Heritage, 2004-2006), Woodside Energy, the Western Australian Marine Science Institute, Monash University and Birdlife Australia. Logistic support has been provided by DBCA, Broome Bird Observatory, Birdlife Australia, the Stoate family of Anna Plains Station and John and Trish Grey of Thangoo Station. We acknowledge the Yawuru People via the offices of Nyamba Buru Yawuru Limited for permission to monitor shorebirds on the shores of Roebuck Bay, traditional lands of the Yawuru people. We acknowledge the Karajarri and Nyangumarta people for permission to survey birds on the shores of 80 Mile Beach, traditional lands of the Karajarri and Nyangumarta people.

We are indebted to the many volunteers who have made the MYSMA counts possible. An especially prominent role has been played by Adrian Boyle, George Swann and staff of Broome Bird Observatory, who have collectively been part of all surveys. It is not possible to name all other participants here, but prominent figures have included Rob Clemens, John Graff, Connie Grohmann, Kerry Hadley, Maarten Hulzebosch, Nigel Jackett, Arthur Keates, Nyal Khwaja, Emelia Lai, Jan Lewis, Amanda Lilleyman, Grace Maglio, Clare and Grant Morton, Jo Oldland, Franky O'Connor, Maurice O'Connor, Kim Onton, Margot Ooerbeek, Ken Rogers, Liz Rosenberg, Matt Slaymaker, Andrea Spencer, Jane Taylor, Ray Turnbull, Nick Ward, and Hazel Watson.

The report also considers data from demographic monitoring projects. We thank the Global Flyway Network for access to their publications and results; Theunis Piersma and Ying Chi (Ginny) Chan also provided satellite tag tracks. We thank the AWSG for access to their banding data and satellite-tagging tracks from north-western Australia; access to this data was facilitated by Clive Minton, Joris Driessens and Katherine Leung. Amanda Lilleyman provided summaries of Eastern Curlew remote tracking data from the National Environment Science Program Threatened Species Recovery Hub research project 'Strategic planning for the Far Eastern Curlew' (a project also supported by Darwin Port, Charles Darwin University, Larrakia Rangers and the University of Queensland).

The report was improved by discussion or comments from Ben Fanson, Peter Menkhorst, Clive Minton and Chris Nutt.

We thank Rebekah Kington for help with formatting and presentation of the report.

Contents

Summary

Background

This report was commissioned by the Department of Biodiversity, Parks and Attractions Western Australia (DBCA). The key objective was to investigate variance of shorebird counts in north Western Australia and compare subsampling strategies in order to identify modifications to the monitoring program that could make it less costly, and thus easier to maintain long-term.

Context

The coast of north Western Australia is the most important non-breeding site for migratory shorebirds in the entire East Asian – Australasian Flyway (EAAF). Monitoring shorebirds in north Western Australia is critical to understanding shorebird trends in the EAAF, provides valuable information for management of shorebird habitats on this coastline, and is desirable or necessary in order to comply with several government agreements and legislative acts. This report focuses most heavily on current shorebird count programs in north Western Australia, but also considers demographic monitoring by several non-government organisations and research groups.

Aims

1. Overview shorebird monitoring in north Western Australia
2. Assess current status of shorebird populations in north Western Australia;
3. Examine temporal trends in shorebird numbers at regional scale, at sites and at individual roosts;
4. Identify causes of variation in counts
5. Subsample from the shorebird count database from north Western Australia to identify ways to reduce the costs of the shorebird count program with minimal loss of our capacity to detect changes

Methods

We analysed data collected by the "Monitoring Yellow Sea Migrants in Australia" (MYSMA) program since 2004: a systematic series of one annual winter count and two annual summer counts from major shorebird sites in northern Roebuck Bay, Bush Point and a 60 km section of Eighty Mile Beach. In addition, there is annual assessment of age ratios (an index of breeding success collected since the late 1990s) and banding-resighting projects (since the early 2000s) enabling ongoing estimation of shorebird survival. Disturbance of roosting shorebirds in northern Roebuck Bay has been monitored infrequently through behavioural observations. Trends at each of these sites, and in the region as a whole, were analysed by species using a non-linear approach (Generalised Additive Models). We compared the count results with national trends, and with published and unpublished data on annual age ratios and site fidelity, to better understand the causes of variation in the count data.

Finally, we identified a series of logistically feasible approaches to reducing the cost of the shorebird count program, either by reducing the area counted or by reducing the frequency of surveys and comparing these with results from the full program to identify the most suitable strategy for future monitoring.

Results

1. Between 2004 and 2016, compiled summer counts across the survey area demonstrated declines in 6 shorebird species (5 of which are known to also be in decline in the remainder of Australia), increases in five species (1 of which is declining Australia-wide) and no detectable change in ten species. Trends were non-linear in a number of species, with peaks and troughs in abundance over the years. Compared to Australia-wide trends, north Western Australia has fewer shorebird species in decline and more species with reasonably stable numbers.
2. Trends in summer counts were not consistent across Eighty Mile Beach, the northern shores of Roebuck Bay and Bush Point. Most noticeably, Bush Point had more increasing species, and fewer decreasing species, than Eighty Mile Beach and the northern shores of Roebuck Bay.
3. At small scales (individual roost sites), count variation was generally too high to assess whether changes in abundance were occurring over time. There were clear differences between usage of roost sites in summer and winter counts, and some evidence of declines at roost sites in Roebuck Bay that are experiencing mangrove encroachment.

4. Variance in counts in north Western Australia was quite high. Much of this variation was driven by shorebird movements within the non-breeding season, resulting in some individuals moving into or out of the study area between surveys; to minimise this problem counts should be carried out over a large spatial scale during a short time frame.
5. Substantial annual variation in the number of immature birds in the study area occurs, probably caused by annual variation in breeding success in the northern hemisphere. As a result, variance of winter counts (carried out when only immatures remain in Australia) was much higher than variance of summer counts. While winter counts are not therefore as suitable as summer counts for detecting long-term trends, they are important (along with annual monitoring of age ratios) to enable interpretation of fluctuations in summer counts.
6. We considered a variety of potential efficiencies for the count program. Five approaches were rejected because they were logistically impractical, did not obtain required data, or would not save money. A further 12 scenarios were modelled using subsets from the full data set. We considered reduction of the count program to one winter and one summer count annually (instead of two annual summer counts) to provide the best compromise between cost and the capacity to detect change.

Conclusions and implications

1. By the standards of wildlife monitoring, migratory shorebirds are monitored unusually well in north-western Australia.
2. Adequate shorebird count data are collected in north Western Australia to detect long term changes and to identify peaks and troughs in abundance of ~20 shorebird species.
3. North Western Australia remains a region of enormous importance to migratory shorebirds. Compared to Australia-wide trends, north Western Australia has fewer shorebird species in decline and more species with reasonably stable numbers. However national declines are being reflected for several species.
4. Subsampling from the count data collected between 2004-2016, we conclude that the current survey area should be maintained. If the current shorebird count program was reduced to one winter and one summer count annually (instead of two summer counts annually), monitoring costs would be ~60% of their current level with little loss in our capacity to detect changes in abundance.
5. Identification of the causes of changes in shorebird abundance in north Western Australia requires comparison of trends with other shorebird populations, and collection of additional demographic data. This additional information is important if changes caused by local conditions (potentially controllable through local conservation actions) are to be distinguished from changes driven by factors elsewhere in the migration route (the responsibility of other agencies or countries)
6. Demographic monitoring is therefore a valuable component of shorebird monitoring in north Western Australia. Excellent, relevant data are being collected by the AWSG (annual assessment of age ratios in ~10 species) and by the Global Flyway Network (detailed survival studies in four species). Issues of potential concern are:
7. lags between data collection and analysis
8. monitoring of survival is heavily dependent on continued overseas funding of the Global Flyway Network program in Australia
9. If some of the money saved from a reduced counting program could be allocated to demographic monitoring, priorities would include:
10. Integrated Population Model analyses, combining count, age-ratio and survival data into a single model to identify the factors driving population changes.
11. Identifying and implementing measures to ensure the continuity of demographic monitoring.
12. High variation in counts at individual roost sites makes the count program insufficient to detect deterioration of roost sites in a timely manner. Independent assessments of disturbance levels on the Northern Beaches of Roebuck Bay, preferably at 3 years intervals or less, are recommended to track changes in roost quality. Another potential approach is also proposed.
13. Grassland shorebird species that roost on Eighty Mile Beach in mid-day heat are not currently monitored adequately; we propose an approach to monitor them repeatedly.

1 Introduction

1.1 Scope of this report

This report was commissioned by the Department of Biodiversity, Parks and Attractions Western Australia (DBCA). The key objective was to investigate variance of shorebird counts in north Western Australia and compare subsampling strategies in order to identify modifications to the monitoring program that could make it less costly, and thus easier to maintain long-term.

Extensive background and some analyses of existing data are provided to examine the drivers behind count variation and to put the subsampling analysis in context. The report provides:

1. an overview of current shorebird monitoring in north Western Australia (which includes demographic monitoring in addition to direct monitoring of shorebird numbers through counts), drawing comparisons with shorebird monitoring practices in other parts of the world (Section 2);
2. a review of current shorebird populations in north-western Australia, updating previous work on the basis of a complete count from Eighty Mile Beach to the Dampier Peninsula carried out in 2015 (Section 3);
3. an investigation of temporal trends in shorebird numbers in north-western Australia at several scales: regional, site-based and at individual roosts (Section 4).
4. an examination of variance in counts in north Western Australia, causes of variation and its relationship to scale of survey area (Section 5)
5. an examination of the assumption of site fidelity of migratory shorebirds on the non-breeding grounds, and whether local movements may contribute to variance in shorebird counts (Section 5)
6. Using a systematic shorebird count database from north Western Australia 2004-2016, we subsample potential scenarios for a reduced shorebird count program, assessing how well the trends from these subsamples correspond with rends revealed by the full data set; and
7. finally, on the basis of this review we make recommendations for future shorebird monitoring in north West Australia.

1.2 Why monitor shorebirds in north Western Australia?

The extensive tidal flats and beaches of Eighty Mile Beach and Roebuck Bay, on the north coast of Western Australia (Figure 1), are of great importance to migratory shorebirds. No other region in Australia, or indeed anywhere else in the East Asian Flyway, supports such large and diverse nonbreeding populations (Bamford et al. 2008, Hansen et al. 2016). Reports of extraordinarily high shorebird numbers in Roebuck Bay and on the shores of Eighty Mile Beach first emerged in the early 1980s (Minton 2006). Follow-up surveys (reviewed by Rogers et al. 2011) revealed that between them Eighty Mile Beach and Roebuck Bay support 21 shorebird species in internationally significant numbers (i.e. >1% of the entire population of the East Asian Australasian Flyway), that almost 3.5 million shorebirds in total occur on these sites, and they include ~580,000 shorebirds that forage on tidal flats.

The importance of Eighty Mile Beach and Roebuck Bay to migratory shorebirds is now widely known; indeed the shorebird roosts in Northern Roebuck Bay are an internationally famous spectacle, and attract many tourists to Broome. Monitoring these populations is desirable or necessary in order to comply with various government agreements and legislation, including:

- Australia has entered several international agreements to conserve migratory birds, including: the Japan – Australia Migratory Bird Agreement (JAMBA); the China-Australian Migratory Bird Agreement (CAMBA); the Republic of Korea – Australia Migratory Bird Agreement (ROKAMBA); The Convention on the Conservation of Migratory Species of Wild Animals (the Bonn Convention). All encourage member parties to support conservation and conservation-related research on migratory species.
- Migratory shorebirds are treated as matters of national significance under the EPBC Act 1999.
- Both sites are recognized as Wetlands of International Significance under the Ramsar Convention. Member countries are obliged to promote the conservation of Ramsar wetlands and wise use of all wetlands and work to ensure that Ramsar sites are managed to protect their ecological character.
- Both sites were recently listed as marine parks. Waterbirds, including migratory shorebirds, and the intertidal sand and mudflat communities upon which they depend, are key performance indicators for both the Eighty Mile Beach Marine Park and Roebuck Bay Marine Park.

1.3 Requirements for long-term shorebird monitoring in north Western Australia

A recent overview of the monitoring of threatened biodiversity in Australia (Legge et al. 2018) concluded with a succinct summary (Robinson et al. 2018) of the key elements to programs monitoring threatened biodiversity. A key recommendation was to "plan, design and implement a fit-for-purpose monitoring program"; they noted that generic approaches to monitoring threatened species were likely to be ill-fitting and emphasised that the design and methods need to be tailored to the monitoring objectives and the species being monitored. This target is the main focus of this report, though we also touch on the other key elements of monitoring emphasised by Robinson et al.: (1) Engage people; (2) integrate monitoring and management; (3) ensure good data management; (4) communicate the value. We consider the following objectives to be of high importance to the specific requirements of monitoring shorebirds in north Western Australia:

1.3.1 Retain continuity with existing data

Shorebirds have been monitored in north Western Australia for some time. The shorebird count program has been carried out in systematic fashion since 2004; monitoring of age ratios began in the early 1990s and individual colour-marking of birds for mark-resighting estimates of annual survival began in 2003 (engraved leg-flags) and 2005 (colour-bands). This work represents a very substantial investment by both volunteers and funding agencies, and it has resulted in some of the most complete shorebird monitoring data in Australia; the count data, for example, are potentially the largest monitoring data set from the southern hemisphere in terms of shorebird numbers counted. Future monitoring data should be comparable with the data already collected.

1.3.2 Multiple species coverage

When doing ground-based shorebird counts in north Western Australia, shorebirds are identified to species level. This has been the practice since the first opportunistic counts were carried out the region in the 1980s. We consider it an essential part of effective shorebird monitoring in the region because:

1. The shorebird fauna is diverse (42 species recorded on our study sites during MYSMA surveys) and the species differ in many respects, including their preferred foraging and roosting distribution, diet, and population trends. No single species or guild can be considered an indicator for the status of all other species.
2. Overall numbers of shorebirds, and their trends, are most strongly influenced by the most numerous species; population changes in less numerous species would be overlooked if shorebirds were not identified to species level.
3. All migratory species are EPBC-listed as matters of National Significance, several species are also listed as Vulnerable or Endangered, and three (Curlew Sandpiper, Eastern Curlew and Great Knot) are listed as Critically Endangered.

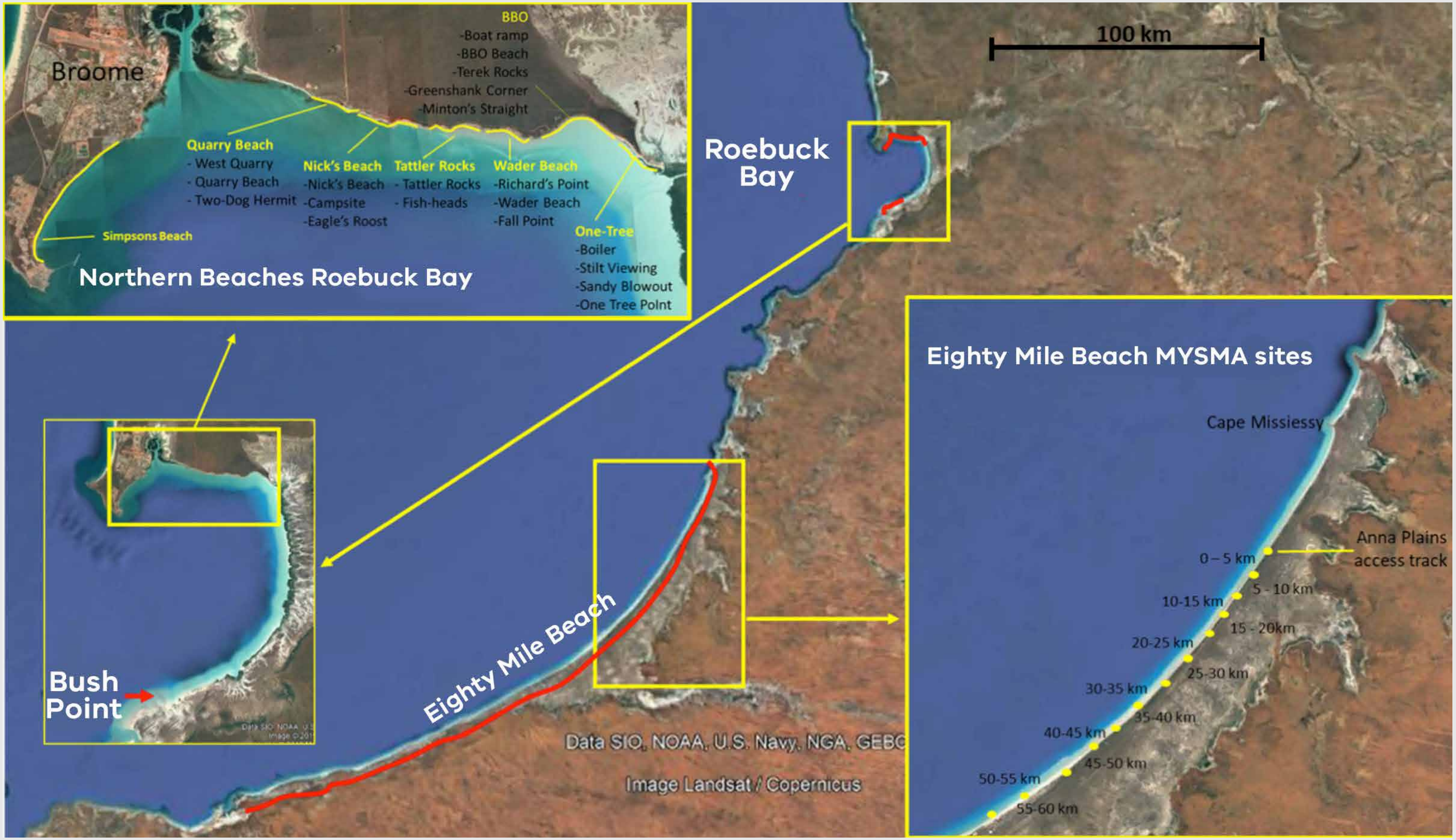


Figure 1. Map of the study area.

Red lines and text indicate the coastal areas where shorebirds are counted annually. The insets show the details of these count areas, including the nicknames given to individual roosts by shorebird counters (black typeface) and roost blocks (yellow typeface) discussed in Section 4.

1.3.3 Detect change at broad scale

Shorebird conservation is an international challenge, and the most important driver of ongoing declines is thought to be loss of migratory stopover habitat on the coast of Asia (Studds et al. 2017, Murray et al. 2018). Shorebird counts on the non-breeding grounds (especially in Australia) are considered the most effective and practical method to monitor populations of most shorebird species in the East Asian – Australasian Flyway (Gosbell and Clemens 2006; Melville and Battley 2006; Milton and Driscoll 2006; Hansen et al. 2016) and a large network of sites is monitored nationwide. The resultant dataset has been key to estimating population trends (e.g. Clemens et al. 2016, Studds 2017) and shorebird population size in the flyway (Hansen et al. 2016) and this information has in turn shaped threatened species listings and international conservation efforts (e.g. IUCN 2019; https://www.environment.gov.au/biodiversity/threatened/species). Collectively Eighty Mile Beach and Roebuck Bay support more shorebirds than any other site in Australia and are thus key to national estimates of populations and trends. Monitoring sites in north-western Australia is therefore important to shorebird conservation efforts on national and international scales. Beyond this consideration, an awareness of shorebird population trends at a broad scale is important to interpretation of trends at smaller scales at which management is most likely to occur.

1.3.4 Detect changes caused by local conservation issues

In a flyway where there is grave concern about broad-scale declines in shorebirds driven by loss of habitat on Asian stopover sites (MacKinnon et al. 2012, Ma et al. 2014, Studds et al. 2017), it is easy to lose sight of the fact that migratory shorebirds also face threats on their Australian non-breeding grounds. Some Australian shorebird sites have experienced much greater declines than others, with local drivers that have been proposed including loss of foraging habitats to pollution or urbanisation, loss of roosts due to construction, mangrove encroachment or human disturbance, and loss of water to non-tidal shorebird sites (Straw and Saintillan 2006, Clemens et al. 2016). Issues such as these could potentially be addressed through conservation actions on the non-breeding grounds that are quite local in scale – provided the driving forces can be identified. However distinguishing local-scale declines from declines happening on a continental scale is problematic, requiring a national benchmark against which local changes can be assessed. A national shorebird database is held and maintained by Birdlife Australia. There are however substantial lags between completion of shorebird counts and data submission, and between data submission and analysis. For the time being formal comparisons of local and national trends involve large analysis projects (e.g. Clemens et al. 2016, Studds et al. 2017), though Birdlife Australia and others are working towards more frequent and regular updates on national shorebird trends.

While most of the Kimberley coast is remote and sparsely populated, human populations and economic development in the region are increasing, notably in tourist destinations such as Broome (adjacent to Roebuck Bay). A key reason for monitoring shorebird numbers in the region is the prospect of detecting changes driven by local-scale threats that can be corrected or at least ameliorated by conservation actions within the Kimberley region. Ongoing changes in the region that have been considered of particular concern by shorebird biologists are listed below, and later in this report we consider whether data from the MYSMA count program is consistent with these threats impacting shorebird numbers. All these threats have the potential to cause declines in shorebird numbers, at least at local scales. Whether or not they would also cause declines in overall shorebird populations in the flyway is a question that is difficult to answer, but they could certainly impact the spectacle of very large shorebird flocks in relatively accessible areas, an attraction that brings many visitors to Broome.

Threats to shorebirds within north Western Australia include:

(1) increased pollution, which is thought to be driving increases in the incidence of *Lyngbya* blooms and resultant declines in the diversity and abundance of infauna in the intertidal mudflats (the food source of shorebirds) of Roebuck Bay (Estrella et al 2011);

(2) increased disturbance of roosts causing increases to the energy costs faced by shorebirds. Modelling of these costs indicates that disturbance could potentially make some sections of Roebuck Bay unsuitable for shorebirds (Rogers et al. 2006b);

(3) mangrove encroachment along some beaches of northern Roebuck Bay (Figure 1). The causes of these increases are unclear. Similar increases in mangrove extent in other regions are considered to have partly anthropogenic causes, and can cause at least local declines in numbers of shorebirds (Straw and Saintilan 2006). Most shorebird species have a strong preference for open tidal flats and beaches, probably because they offer clear views in all directions and hence lower the risk of predation (Piersma et al. 1883, Rogers et al. 2006d). They therefore avoid tall or dense vegetation such as mangroves, which can be used as cover by by hunting predators, especially birds of prey.

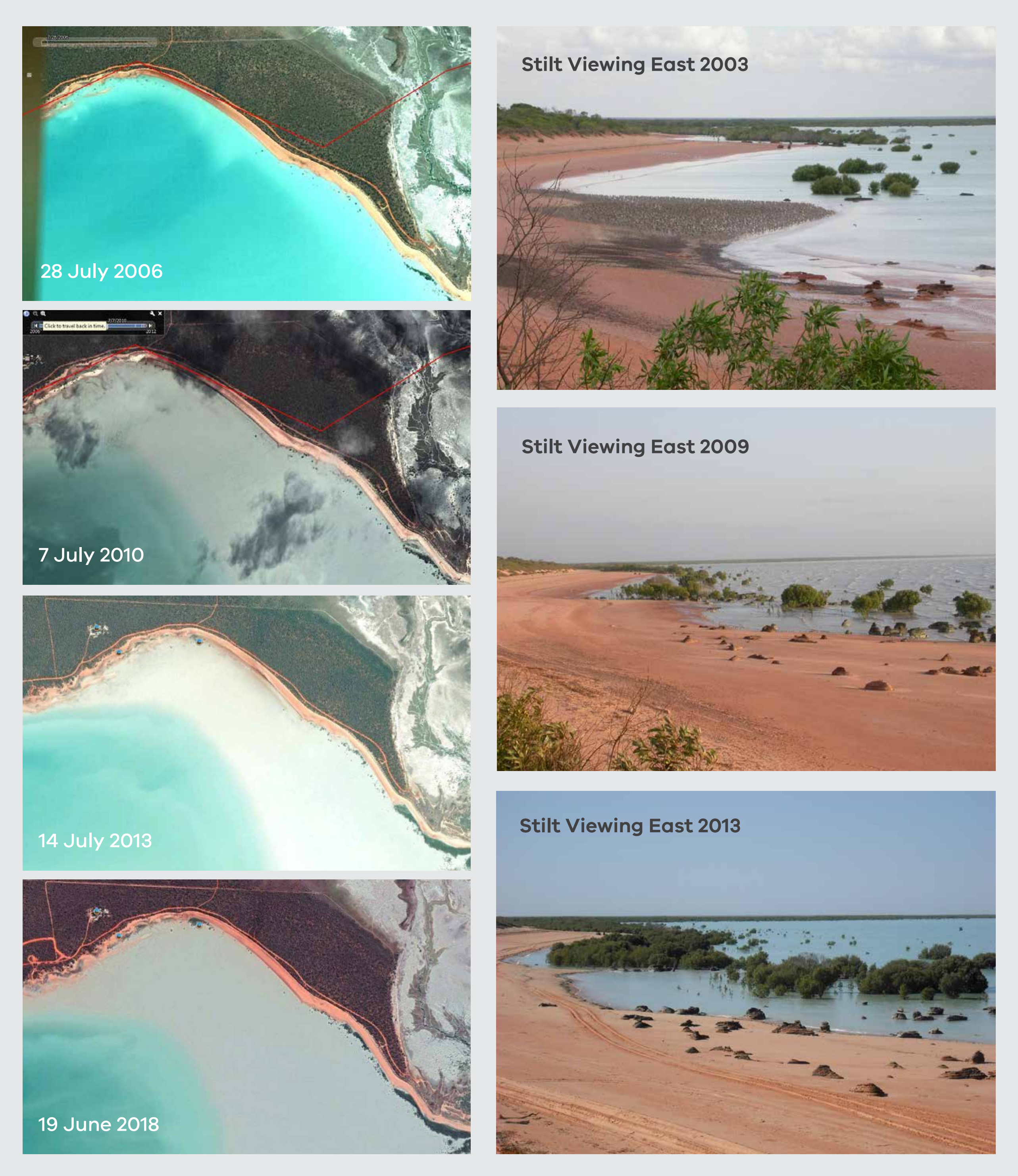


Figure 2. Mangrove encroachment on to shorebird roosts in North-eastern Roebuck Bay.
Google Earth images on left show increasing density of the mangrove line along the coast from Broome Bird Observatory to One Tree Point. Images on right show increasing extent of mangroves over time at a specific roost, Stilt Viewing.

2 Overview of current monitoring

2.1 Shorebird counts

2.1.1 Coastal shorebirds

Shorebird counts have been conducted in north-western Australia since 1980, when exploratory visits to the area for the Atlas of Australian Birds (Blakers et al. 1981) revealed that the area had enormous shorebird populations (Minton and Martindale 1982, Minton 2006). Initial surveys focussed on documenting the numbers and distribution of shorebirds in the region (Lane and Davies 1987), rather than attempting to monitor change over time. They included funded aerial surveys of the entire coastline supplemented by ground counts (largely conducted by volunteers) in more accessible regions to assess species composition. This approach succeeded in documenting areas of key importance and assessing their international significance. However subsequent surveys demonstrated that this approach led to inaccurate estimates of numbers of some species which are patchily distributed (Rogers et al 2011), because unrepresentatively high or low proportions occurred in the areas covered by the restricted ground counts.

From 1998 to 2001, the Australasian Wader Studies Group (AWSG) carried out three complete ground counts of the shorebirds of Eighty Mile Beach (Minton et al. 2013). Attempts to monitor shorebirds annually in the region began in 1993, with counts on the northern beaches of Roebuck Bay, a 10km stretch of Eighty Mile Beach and (irregularly, when resources allowed) visits to Bush Point. These counts were made in June and February to correspond seasonally with counts carried out (largely in southern and eastern Australia) for the AWSG's Population Monitoring Project. All previous counts in the region are in databases held at Birdlife Australia, and some of them have been used in previous assessments of shorebird trend in Australia (Clemens et al. 2016, Studds et al. 2017).

This count program was reappraised by the AWSG, following studies of roosting behaviour of shorebirds in Roebuck Bay (Rogers 2003; Rogers et al 2006a, 2006b, 2006c) and a smaller study on Eighty Mile Beach (Rogers 2005). Key findings from these studies included:

- Shorebird roosting distribution in north-western Australia is limited by their intolerance of hot microclimates; by day most species need to roost on wet substrates to avoid heat stress (see also Battley et al. 2003)
- Shorebirds prefer open roost settings and avoid sites where the tide pushes them close to tall features (e.g. mangroves, sand dunes) that can be used as cover by hunting birds of prey
- At Roebuck Bay, different roosts are used on daytime and night-time high tides.
- At Roebuck Bay, shorebirds roost at the closest acceptable roost to their preferred foraging grounds; in species in which the location of preferred feeding areas is not static over time, roost location also varies over time (see also Rogers 1999).
- At Roebuck Bay, availability of suitable roosts is strongly affected by tidal conditions, with different high tide roosts being suitable during periods of neap tides, spring tides and tides of intermediate height.
- At Roebuck Bay wet season rains and spring create temporary supratidal wetlands which are very difficult for humans to access; many coastal shorebirds roost in these sites when they available and are therefore overlooked when shorebird surveys are restricted to easily accessed beach roosts.
- At Eighty Mile Beach density of shorebirds on tidal flats at low tide is strongly correlated with high tide counts on the adjacent beaches, suggesting shorebirds there typically roost on beaches close to their preferred foraging sites.

In addition to the behavioural insights obtained from these studies, the practical experience of counts in the region obtained in previous surveys was important in reappraising tactics for shorebird counts in north Western Australia. It was recognised that monitoring in this large and complex area was beyond the capacity of volunteers alone, and that annual funding was required. Ideal tide conditions for counting at each site were identified (Rogers et al. 2003; Rogers et al. 2011): tides of intermediate height (6.8-9.1 m) at Roebuck Bay, spring tides (8.8-9.7 m) at Bush Point and lower tides (6.8-7.9 m) at Eighty Mile Beach. In surveys since 2004 the tidal range for surveys has been tightened further to increase repeatability of counts, and surveys are held on tides of 8.5-9.1 m in Roebuck Bay, 9.0-9.3m at Bush Point and 7.4 – 8.5 m at Eighty Mile Beach. Counting on rising tide series reduces the chances of birds using alternate saltpan roosts flooded by previous spring tides, and also enables counts at Eighty Mile Beach to be carried out in optimal light conditions, in the morning with the sun behind the observer and with less heat-haze than in afternoon surveys. Importantly, the decision was made to move summer counts to the period between late October and early December, before the onset of wet season rains: previous summer counts had been carried out in February and varied considerably due to undocumented variation in the extent of alternate roosting habitat in remote flooded saltpans.

The resultant count program, called Monitoring Yellow Sea Migrants in Australia (MYSMA), began in 2004 and has been maintained until present. From 2004 to 2017 it comprised two annual summer counts held between late October and early December, each taking almost a week to carry out. Each count comprises a single day counting at Bush Point, a single day counting at Roebuck Bay, and three days counting at Eighty Mile Beach. The counts are carried out by a combination of Broome-based volunteers, a few highly experienced volunteers flown in from Perth or interstate, and three contractors to lead the count teams. Two or three teams count concurrently. On Eighty Mile Beach, three teams are deployed, each team in a separate vehicle, each surveying a 10 km stretch of beach in a single high tide. At Bush Point three count teams walk to different sections of a single roost 4 km long. Usually three teams are deployed on the northern beaches of Roebuck Bay, one team covering Simpson's Beach on foot, and the other two vehicle-based teams visiting all other beaches (sometimes, according to local shorebird distribution, it is logistically easier to break the Roebuck Bay team into two teams). Tactics are similar during the single annual winter count (held in June or early July), but with the smaller number of shorebirds present at that time of year, it is possible to carry out the surveys with Broome-based volunteers and contractors, without flying in additional primary counters from interstate.

A 60 km stretch of Eighty Mile Beach is surveyed on each Eighty Mile Beach count, starting at the Anna Plains access track and heading south from there. This section of beach has held larger numbers of shorebirds than other parts of Eighty Mile Beach in all four surveys in which all of Eighty Mile Beach was counted (Minton et al. 2013; Section 4). Eighty Mile Beach counts are done on rising tide series. On the first day counts are done of the stretch from 0-30 km south of the Anna Plains access point; on the second day counts, when the tides are higher and half an hour later, counts are done from 0 to 50-60 km south; often it proves necessary to count the stretch from 50-60 km south on a third morning, when the high tide is higher still, and peaks another half-hour later.

Additional stretches of Eighty Mile Beach are now also counted on the third morning. On most surveys since 2010 it has also been possible to count the 20km stretch of coast from the Anna Plains access point to the northern end of Eighty Mile Beach at Cape Missiessy; this area has been surveyed in recent years because (1) sometimes there is a concentration of birds at the Anna Plains access point, and there was avoidable variation in count totals caused by their local movements into and out of their regular count area; (2) Lesser Sand Plovers occur regularly at Cape Missiessy; this species is uncommon elsewhere on Eighty Mile Beach and therefore difficult to monitor. From 2008 to 2013 the stretch of beach 60-70 km S of the Anna Plains access point was also counted, again because a concentration of birds at the limit of the regular count area made local movements into and out of the study area, and thus introduced variation in the counts. The stretch of beach from 60-70 km S has not been surveyed since 2014, in part because with local changes in beach morphology there is no longer such a large concentration of birds at 60km S; moreover, this section of beach is difficult to access because it is far from access tracks, has some deep creek lines and very soft sand.

Shorebird counts are written onto data sheets on the field. Copies of the completed datasheets are kept in both Broome and Melbourne. The datasheets are used to prepare quick summaries of each survey, including manually added count totals, which are circulated to interested stakeholders soon after every survey but are not formally published. The count sheets are then entered into an Excel database; a number of data validation procedures are built into the data entry template, including checks in all cases where entered totals differ from those added up manually in the field, and direct contact with the counters if details on the sheets are unclear. The completed data files are maintained by the project leaders (Danny Rogers and Chris Hassell), copies are also held by Birdlife Australia and a copy will be provided to DBCA with this report. The data from MYSMA surveys have been used in a number of scientific publications (e.g. Rogers et al. 2006, 2011, Clemens et al. 2016, Studds et al. 2017). Summaries of findings from MYSMA surveys are summarised later in this report (Sections 4 and 5).

Figure 3. Shorebird counting in north Western Australia.

Top left: Vehicles are used as hides, allowing closer approach to shorebirds than would otherwise be possible (Photo LIz Rosenberg). Top Right: Counts on the northern beaches of Roebuck Bay can usually be made from the cover of vegetation on cliff tops or dunes (Photo: Theunis Piersma). Lower panel: There is no cover at Bush Point, so teams aim to arrive early and wait for rising tides to push birds within identification range (Photo: Maarten Hulzebosch).

2.1.2 Grassland shorebirds

During shorebird counts on the coast of north-western Australia, three shorebird species characteristic of grasslands are sometimes seen roosting in very large numbers on beaches, especially on Eighty Mile Beach. Oriental Pratincole has been seen in spectacular numbers, with 2.88 million recorded along the full 225-km length of Eighty Mile Beach in February 2004 (Sitters et al. 2004). In a smaller scale survey in February 2010, Piersma and Hassell (2010) reported 514,900 Oriental Pratincoles and 144,300 Oriental Plovers along a 75 km stretch of Eighty Mile Beach, and two days later recorded 14,200 Little Curlew along a 45 km stretch of Eighty Mile Beach.

Although these three species occur on the beaches where MYSMA surveys are conducted, they cannot be monitored adequately during MYMSA counts. All three species forage on the near-coastal grasslands that border Eighty Mile Beach, especially in early mornings and late evenings; Oriental Plover and Little Curlew probably forage there through the night as well. These plains are bare and exposed, and can become extremely hot by day. This is why all three species move onto the beaches during the hottest part of the day, exploiting the relatively cool microclimate of surf-dampened sand or mud to avoid thermal stress during mid-day heat (Piersma and Hassell 2010; Rogers et al. 2011).

MYSMA surveys on Eighty Mile Beach were designed to count coastal shorebirds which forage on tidal flats at low tide, and roost on the beach when the tide is high. They are conducted on morning tides, and largely occur before the hottest part of the day – a deliberate tactic enabling counts to be made with the sun behind the observers, in the absence of strong heat haze. Much of the fieldwork is done before the grassland species move onto the beaches; it is usual for Oriental Plovers to be absent from the beach when counts begin, but to be present in their thousands when the count ends. Another issue is that the October-December period may not be the ideal time of year to monitor the grassland species; observations of huge concentrations of Oriental Pratincole have usually occurred in February, after the onset of wet season-rains has resulted in very large numbers of grasshopper prey on the plains (Sitters et al. 2004; Piersma and Hassell 2010).

MYMSA surveys therefore occur at the wrong time of year, and the wrong time of day, for adequate monitoring of grassland shorebirds. In early years of the program some attempts were made to count these three species, but numbers varied enormously according to time of survey and how quickly the temperature rose. In recent years no attempt to count the grassland species has been made at all, as it did not produce repeatable data, and considerably reduced the time available to count coastal shorebirds, the main target of the count program. Even in October-December the grassland species can be almost as numerous as coastal shorebirds, and when in peak numbers in February the numbers of Oriental Pratincoles can be so overwhelming that it would probably be impossible to count coastal shorebirds in the same survey.

Although Oriental Plover, Little Curlew and Oriental Pratincole cannot be monitored adequately on MYSMA surveys, it would be possible to monitor them in discrete surveys (see section 7).

Oriental Plover

2.2 Demographic monitoring: age ratios

The Australasian Wader Studies Group (AWSG) has been carrying out banding studies of shorebirds in north Western Australia since 1981. Expeditions have been held almost annually. In the 1980's and 1990's key objectives were to band and flag large number of birds to identify their migration routes, and to obtain samples from all months in order to document seasonal changes in weight and moult condition. Most birds were (and still are) captured by cannon-netting at high tide roosts of Roebuck Bay and Eighty Mile Beach. Every captured bird is aged in the hand using a combination of moult and plumage characters. All migratory species in their first year can be reliably aged on this basis. As the number of young and adult birds is recorded, it is possible to calculate age ratios on every banding expedition. Only birds captured with cannon-nets are used in estimation of sex ratios, as age-ratios in samples caught with other methods such as mist-netting may differ.

In 2000 documentation of age-ratios became one of the core objectives of AWSG banding expeditions, and since then the fieldwork program has been planned so that the annual expeditions are held during the austral summer when all non-breeding adult and immature migratory shorebirds are present (Minton 2006). These conditions were met on some previous AWSG expeditions back to 1980, but regular, annual documentation of age-ratios in the middle of the non-breeding season began in the 2000/2001 wader season. During the early 2000's most expeditions were centred on November, but this clashed with other fieldwork commitments, and since 2010, expeditions have been held in February. There are therefore 18 years of systematically recorded age ratios in north West Australian shorebirds. Seven species (Red-necked Stint, Curlew Sandpiper, Great Knot, Red Knot, Bar-tailed Godwit, Greater Sand Plover, Terek Sandpiper and Grey-tailed Tattlers) are captured in large enough numbers to document annual age ratios in samples of >50 individuals (usually >100); in some other species adequate samples are obtained in some years but not others.

The main reason for documenting age ratios is that they are thought to provide an index of breeding success in the previous breeding season. Annual variations in breeding success are thought to be driven by a combination of climate conditions in the Arctic (melt dates and especially mid-summer temperatures, Aharon-Rotman et al. 2015) and annual variation in nest predation on the breeding grounds, especially by Arctic Foxes (in turn influenced by cycles in abundance of lemmings (Underhill et al. 1993, Blomquist et al. 2002)). Annual variation in the proportion of first-year birds that survive their first migration to the non-breeding grounds could also influence age ratios observed in Australia. There is no information to inform on variation in survival on the first southwards migration. We consider it likely to have smaller effects on annual variations in age ratios than breeding success, as the southward migration of first year birds tends to be dispersed geographically (the birds do not know exactly where they are going) and in time (Cresswell 2014).

Whatever the causes of variation in age ratios of migratory shorebirds, the scale of variation is such that it can have a substantial effect on the number of shorebirds counted in any particular season. Within a species, first year birds can comprise fewer than 5% of the non-breeding population following poor breeding seasons, >40% following very good breeding seasons (Minton 2003; Minton et al. 2005; Minton et al. 2018). To put this in context, in a hypothetical species in which there were 1000 adults with consistent annual survival, annual counts (including first year birds) would range from <1050 in a year of low breeding success to >1400 in a year of high breeding success.

Temporal variation in age ratios can also play a powerful role in interpreting observed population changes, because a series of consecutive poor or good breeding seasons can alter the trajectory of population changes. In Victoria, for example, declines in Curlew Sandpiper populations coincided with several consecutive years of poor breeding success, while increases in Red-necked Stint populations coincided with several consecutive years of high breeding success (Rogers and Gosbell 2006). It is not unusual for some species to have 'good' breeding seasons while others have poor breeding seasons (Minton et al. 2005); all migratory shorebird species in the East Asian – Australasian Flyway differ to some extent in breeding distribution (Hansen et al. 2016), and neither climate fluctuations or lemming cycles are closely synchronised across the entire arctic (Aharon-Rotman et al. 2015).

Annual reports on age ratios in Australia, and breeding conditions in the arctic, are published in Arctic Birds (www.arcticbirds.net). There have been several publications describing the methodology and insights from the monitoring approach (Minton 2003, Minton 2004, Minton et al. 2005), discussions of the analysis challenges associated with the age-ratio data obtained (Rogers et al. 2004, Rogers 2006b, McCaffery et al. 2006) and loss of three-year periodicity in pulses of breeding success (Aharon-Rotman et al. 2015). However there is still a need for analyses linking fluctuations in annual breeding success to annual and long-term variation in shorebird counts in north Western Australia.

2.3 Demographic monitoring: Annual survival

Survival, the probability that an individual bird will survive from one year to the next, is one of the four basic variables of life tables. In combination with age of maturity, annual fecundity and pre-reproductive survival, it defines the demography and population dynamics of animal species and can have a profound effect on whether populations increase, remain stable or slide to extinction. The age of maturity of shorebirds in north Western Australia is reasonably well understood (Rogers et al. 2006), and the annual monitoring of age ratios (Section 2.2), along with winter counts (section 5.2), provides measures of annual fecundity and pre-reproductive survival. If survival can also be measured, there are realistic prospects of a much more complete understanding of population dynamics of shorebirds in north Western Australia. Integrated Population Models are becoming an increasingly popular approach to combine count and demographic data in a single analysis that provides insight into the processes that drive key demographic rates, in additional to improved understanding of how monitoring can be improved (e.g. (Schaub and Abadi 2011; Weegman et al. 2016). Integrated Population Models have yet not been developed for any north Western Australian shorebirds, but it is desirable that these analyses should be carried out in future and that the data required for them is collected.

Annual survival can be estimated with mark-recapture studies. Estimation of apparent annual survival rates of shorebirds is achievable (Sandercock 2003), but it is undoubtedly labour-intensive. In addition to an ongoing banding program and ongoing effort to recapture or resight individually marked birds, the analyses are challenging and time-consuming, generally beyond the capacity of volunteers. On the positive side, analytical tools to estimate annual survival and associated error are well developed and readily available (e.g. Program Mark, White and Burnham 1999, www.phidot.org/software/mark). In mobile species like shorebirds, it is important to be aware that apparent survival rate is not identical to true survival rate; rather, it is equivalent to true survival minus emigration from the study area. Few estimates of true survival rates of shorebirds are available (Mendez et al. 2018), but Weiser et al. (2018) show that in some species true survival may be markedly higher than apparent survival.

2.3.1 Global Flyway Network study

The Global Flyway Network is a partnership between researchers worldwide who are devoted to long term – usually demographic – work on long distance migrating shorebirds. Championed by Professor Theuis Piersma (University of Groningen and Netherlands Institute of Sea Research), the GFN initiated a demographic study of three shorebird species (Bar-tailed Godwit, Great Knot and Red Knot) in Roebuck Bay in 2006. Black-tailed Godwit was subsequently included in the program. The program, led locally by Chris Hassell, involves annual catches of the four species, with each captured individual being given a unique combination of colour-bands and leg-flags. These combinations can be read at long-range by observers with telescopes, and intensive searches for all four species are carried out in Roebuck Bay throughout the year. There is also regular, if less intensive, resighting effort on Eighty Mile Beach, and intensive annual resighting effort (focussed on Red Knot) in Bahai Bay, a critical staging area in the northern Yellow Sea. There are often opportunistic sightings of "GFN" birds elsewhere on their migration route, in part because the colour-band codes used for them are highly visible and legible at long range.

The first major analysis of the survival data from this study (Piersma et al. 2016, using data from 2006-2013) demonstrated very high survival rates (>95%) during the first half and second half of the non-breeding season in north Western Australia, but lower survival during the period that the birds were migrating or breeding. In Red Knot, there was no mortality during the northward migration from north Western Australia to intensively monitored staging grounds in the Yellow Sea; most mortality must therefore be occurring while breeding or on southwards migration. There were worrying declines in annual apparent survival of Bar-tailed Godwit, Great Knot and Red Knot from 2011 onwards; these declines were driven by reduced survival when migrating or breeding, while survival during the non-breeding season in north Western Australia remained very high.

The declining survival of all three species from 2011 onwards is not consistent with trends in population counts seen during the same time period. The paradox is puzzling; a possible interpretation is that increased mortality of adults was offset by high recruitment of immatures, especially in 2009-2010 (Section 5.2) – a question that might be resolved with integrated population modelling. It is noteworthy that a similar paradox was found in an analysis of survival of Bar-tailed Godwits in New Zealand, in which survival declined 2011-2012 while population counts on the non-breeding grounds remained stable (Conklin et al. 2016). In both studies, survival rates at the end of the study period were insufficient to maintain population levels without a long-term increase in recruitment rates. Annual survival rates may therefore offer an early warning of incipient population declines, and as Conklin et al. (2016) concluded, "monitoring a single index of population stability is insufficient for predicting future trends".

Figure 4. Black-tailed Godwit (top) and Great Knot (below) in Roebuck Bay, marked by the Global Flyway Network project with unique combination of yellow flag and colour bands *Photo: Nigel Jackett*

2.3.2 AWSG: Banding and Engraved leg flags

The AWSG started banding studies of shorebirds in Eighty Mile Beach and Roebuck Bay in 1980, and have held approximately annual banding expeditions to the region ever since. In the first 20-30 years annual timing of expeditions varied in order to obtain moult and weight samples from all months of the year, but since 2000 the expeditions have been consistently held during the austral summer. This has been done in large part to document age ratios (section 2.2), but also with survival estimates considered; the regular banding and recapture effort at consistent times of year since 1998 is well suited to long-term studies of survival. In addition, smaller catches at other times of year are carried out by local teams from Broome under the AWSG project; birds captured for the GFN project are also captured under the AWSG licence. In total over 140,000 shorebirds have been banded by the AWSG in north West Australia since 1980.

In 2003 it became standard practice to deploy engraved leg flags (Figure 5) on the tibia (upper leg) of nearly all shorebird species banded by the AWSG in Roebuck Bay; shorebirds banded on Eighty Mile Beach have been marked with engraved flags since 2015. These engraved flags can be read in the field through telescope views, and numbers of resightings far exceed number of recaptures of banded birds in cannon-net catches. Resighting effort has not been as systematic as it is for the Global Flyway Network project, but many AWSG engraved flags are documented in GFN surveys and vice versa. There are however some differences in field practices when attempting to read colour-band combinations vs engraved flags. In some settings engraved flags can be easier to read in the field (e.g. when shorebirds are standing in water that conceals their lower legs, it is possible to read engraved flags, but not possible to read submerged colour bands). On the other hand, colour-band combinations can be read at much longer range than engraved flags. On the northern beaches of Roebuck Bay, where viewing conditions are excellent, the differences in field legibility of engraved leg flags and colour bands is modest. In most other sites (including Eighty Mile Beach, and staging sites in the Yellow Sea) shorebirds are typically viewed in inferior conditions and colour-band combinations are easier to read than leg flags.

While the GFN and AWSG colour-marking programs have much in common, there are some important differences. The colour-banding protocols and intensive search effort associated with the GFN project result in 'cleaner' data which is more likely to detect annual changes. The GFN project has stronger academic support, and has resulted in extensive analysis and publication; the AWSG has struggled to find analysts for their data set and analysis lags behind. On the other hand the AWSG engraved leg-flag project has a longer history; the larger number of birds marked help to offset lower resighting rates, the study includes more species. Unpublished analyses (A. Ewing, K.G. Rogers) indicate that survival estimates could probably be made for more than 10 north Western Australian shorebird species on the basis of engraved leg-flag resighting data.

Figure 5. Curlew Sandpiper banded by the AWSG, with engraved leg flag. *Photo: Adrian Boyle*

2.4 Monitoring disturbance

Shorebirds take flight in response to real or perceived danger (Rogers 2003). The energetic costs of the resultant alarm flights are high (Rogers et al. 2006b), and the flights can also increase the risk of heat stress in tropical settings (Battley et al. 2003). Increased frequency of alarm flights caused by disturbance can potentially make roosts so unsuitable that they are abandoned (Rogers et al. 2006c).

Disturbance of roosts on the northern beaches of Roebuck Bay has caused concern among shorebird biologists for some time. These roosts are used by thousands of shorebirds, and the spectacle is internationally renowned, attracting many visitors to Broome. However the roosts have high rates of disturbance, both from birds of prey and humans, and in some tide conditions, the only alternate roosts are situated some 30km away at Bush Point.

Three previous assessments of disturbance levels on the northern shorebirds of Roebuck Bay have been carried out, on the basis of fieldwork in 1997-2001 (D Rogers. PhD studies, published in part in Rogers et al. 2006b), in 2006 (Rogers et al. 2006d) and in 2007-2008 (Sitters et al. 2012). The studies have followed the same basic approach: prolonged observation by stationary observers at key roost sites, in which the number of disturbance events and the duration of alarm flights is recorded. The 2006 survey was accompanied by interviews with beach-users, in part to improve understanding of the drivers of disturbance and in part to raise awareness of the disturbance issue. The 2007-08 study initiated a systematic approach to documenting numbers of birds of prey on the beaches. The fieldwork has been carried out largely by volunteers, keeping the costs of the surveys modest.

All three completed studies demonstrated high disturbance levels on the northern shores of Roebuck Bay, with birds of prey being the most frequent cause of disturbance, and disturbance from humans and their dogs also occurring frequently. Some beaches experienced heavier rates of disturbance than others, and both birds of prey and humans were most abundant on the beaches during the dry season (when migratory shorebird numbers are lowest). Disturbance levels increased slightly between 1997-2001 and 2006; further minor increases in 2007-08 were not statistically significant.

The roost-disturbance studies on Roebuck Bay prompted some management responses to lower disturbance, including signage, attempts to raise public awareness, and alterations to access of some beaches. There has been no recent assessment of the success or otherwise of these initiatives, and disturbance levels have not been measured systematically since 2007-2008. However another study of disturbance was being initiated by Broome Bird Observatory at the time of writing (2019). The findings from this study will be of considerable interest, as there are anecdotal reports of increase in numbers of both birds of prey and human visitors to the beaches of Roebuck Bay in the past decade.

2.5 Shorebird monitoring practices in other sites

2.5.1 Shorebird count approaches

Counts during the non-breeding season are the main tool used to identify population trends in shorebirds that migrate to Australia (Hansen et al. 2018). A national counting program was initiated by the Royal Australasian Ornithologists Union in 1981 (in a handful of south-eastern Australian sites counts were established earlier, in the 1960's or 1970s). From 1985 to 2006 the shorebird count was conducted almost exclusively by volunteers from the AWSG and many regional groups, and coordinated by volunteers from the AWSG. Recognising that the magnitude of the task was beyond the capacity of volunteers alone, the AWSG and Birdlife Australia partnered to initiate the 'Shorebirds 2020' program, resulting in paid Birdlife Australia staff coordinating volunteers and compiling and maintaining national databases since 2006. Birdlife Australia continues to play this role now, though the Shorebirds 2020 program has now been rebranded as the "National Shorebird Monitoring Program".

A review of the data collated and maintained by Shorebirds 2020 (Clemens et al. 2012) noted that shorebirds have become among the best-monitored taxa in Australia, and concluded that the data were of sufficiently high quality and spatial coverage to permit robust analysis of shorebird trends across much of the continent – a conclusion subsequently borne out by important analyses and publications (e.g. Clemens et al. 2016, Studds et al. 2017).

The fieldwork involved in monitoring shorebirds in Australia is still carried out largely by volunteer counters. This has resulted shorebird populations being monitored relatively intensively on the coasts of eastern, south-eastern and south-western Australia. On the northern Australian coast, where shorebird populations are considerably larger, relatively few sites are monitored regularly – partly because the low human population is correlated with a low population of shorebird counters, and partly because a large proportion of the relatively remote coastline is difficult to access by road. In north Western Australia the MSYMA program was initiated in 2004 because it was recognised that effective monitoring of the huge shorebird populations in this remote area was beyond the capacity of unsupported volunteers.

In more densely settled parts of Australia, the minimum standard aimed at has been one summer survey per year (between mid-January and early February) and one winter survey per year (between mid-June and early July). This approach (maintained for almost 40 years in over 30 sites around Australia) has generated a large proportion of the data that has been used in estimation of national shorebird trends. Additional surveys are undertaken at many sites. Survey approaches vary regionally, due to a combination of volunteer availability, coastal topography and access, and in some cases, because of local management issues (e.g. Christie 2006). For example, the Queensland Wader Study Group (QWSG) places considerable emphasis on monthly counts at major roosts in south-east Queensland (Milton and Driscoll 2006), but has rarely been able to carry out complete counts of some key sites (e.g. Moreton Bay) because while many major roosts within these are readily accessed, some are difficult to reach without expensive support (e.g. boats). The local decision was therefore made to focus on monthly surveys of readily accessed major roosts, because (1) it was an achievable objective for QWSG members; (2) the more readily accessible roosts were also those considered most threatened; (3) more frequent monitoring to detect change was considered important in a region with rapid coastal development; (4) in this region, monthly counts reduced within-year count variability and increased statistical power to detect changes (Milton and Driscoll 2006; Wilson et al. 2011).

Regular counts during the non-breeding season appear to be the main approach to shorebird monitoring in other countries where non-breeding shorebirds occur. In New Zealand there are two annual counts (June-July, and January-February), both carried out at all known shorebird sites in the country (Melville and Battley 2006; www.osnz.org.nz/national-wader-count). A similar approach underpins the Coordinated Waterbirds Counts programme in South Africa, where some 370 wetlands are counted twice per year, once in mid-wummer (January) and once in June-July (Taylor et al. 1999; Henry and O'Connor 2019). Non-breeding counts have been used to identify trends in a number of South African sites (Spearpoint et al. 1988, Harebottle et al. 2006, Essig et al. 2016). Counts during the boreal winter/austral summer (December – February) have been recommended as suitable approach for monitoring non-breeding shorebirds in the Americas (Reiter et al. 2011, PRISM 2018).

The best-resourced count programs worldwide are probably those in western Europe. In the United Kingdom, the Wetland Bird Survey was established in 1947; it involves counting wetland sites once a month, and with enormous volunteer input (over 3000 counters) there are over 40,000 surveys per year in 2,800 sites (Austin et al. 2000, 2007; www.bto.org/our-science/projects/webs). In the Wadden Sea, Dutch, Danish and German research institutes coordinate two complete waterbird counts of the Wadden Sea annually, including one in January (the middle of the non-breeding season); in addition there are bimonthly to monthly counts at a subset of sites, and additional surveys for geese and two duck species (Blew et al. 2016; https://qsr.waddensea-worldheritage.org/reports/migratory-birds).

In both the UK and the Wadden Sea multiple surveys per year are desirable in part because many shorebird and waterbird species numbers peak during migratory passage rather than in the middle of the non-breeding season.

Shorebird counts during the non-breeding season at the Banc d'Arguin (Mauritania, West Africa), have some parallels with counts at Eighty Mile Beach. The Banc d'Arguin is a larger site with larger numbers of shorebirds. However, both areas support enormous numbers of shorebirds, large teams are needed to count them in their entirety, and this, in combination with their remoteness, has resulted in few complete surveys being carried out. In the Banc dArguin, seven complete counts have been carried out during the non-breeding season since 1980; four complete counts of Eighty Mile Beach during the non-breeding season have been carried out since 1998. A recent review of the count program in Mauritania (Oudman et al. 2017) concluded that count frequency needed to be increased to detect temporal trends.

Although there are differences between the fieldwork components of count programs worldwide, there are some common elements. Count frequency is often dependent on resources, but it is usual to monitor annually, if not more frequently, and efforts are made to survey as large an area as possible during the middle of the non-breeding season. Counts are nearly always carried out at high tide, in conditions where shorebirds from larger foraging areas gather in flocks at a small number of roosts. Definition of count sites is influenced by topography of the sites in question, but it is usual practice to define sites carefully, with the pragmatic approach of breaking large count areas into smaller subsites that can be counted by a team in a single day; shorebird behaviour also influences selection of count sites, with areas being selected to minimise the risk of individual shorebirds being overlooked or double-counted (Rappoldt et al. 1985; Smit 1989). In these respects the count program in north Western Australia is consistent with standard practice worldwide.

There are substantial differences between frequency of counts in different count programs – ranging from once annually during the non-breeding season to once monthly. In some regions monthly counts are simply not an option because of limited resources. In other cases choice of frequency of counts may involve site-specific decisions about the best way to reduce count variance: increasing count area or increasing count frequency are both likely to result in lower count variance, but it is often not possible to do both concurrently.

2.5.2 Analysis

A variety of statistical approaches have been used to analyse shorebird trends. In part this reflects variation in the datasets available and the number of sites from which data is analysed. It also reflects the increasing range of statistical techniques available to analysts as statistical software develops and computing power increases. Important recent analyses of Australian data, such as the multilevel linear regressions of Clemens et al. (2016) and the N-mixture modelling of Studds et al. (2017), would have been beyond the reach of most biologists twenty years ago. There will surely be further evolution of analysis techniques in future, and techniques are likely to become more complex, requiring greater involvement of trained analysts. We therefore see little point in making restrictive recommendations about analytical approaches that should be followed in analysing north Western Australian data, beyond the obvious point that they should be developed in consultation with the observers responsible for collecting the data, given their familiarity with field conditions and data recording practices.

The Generalised Additive Modelling approach used in this report was advocated by Atkinson et al. (2006) and underpins shorebird trend analysis by the British Trust for Ornithology in their annual reports of what is probably the largest shorebird monitoring dataset in the world (BTO 2017). The approach has the advantage that it can be used to identify non-linear trends, and that it generates smoothed indices of abundance that are robust to missing data or large short-term fluctuations. A recent study of South African site monitored on a monthly bases used generalised additive mixed-models (a similar approach to that used in this report) to investigate trends; it concluded that monthly and biannual surveys generated similar conclusions about trends, though monthly surveys generally reduced uncertainty and provided more detail relevant to applied management (Henry and O'Connor 2019).

2.5.3 Reporting

Most of the shorebird monitoring projects mentioned in section 2.5.1 have a mechanism for simple annual reporting, with species totals and commentary circulated reasonably soon after the survey. A notable exception to this generalisation is Australia-wide reporting of shorebird counts. Until the early 2000's annual summaries were published in the journal Stilt, but Birdlife Australia has struggled to maintain this practice as the Australian count program expanded, with resultant delays in data submission and vetting. Birdlife Australia is currently working on this issue but for the time being, contemporary comparison of north Western Australian trends with national trends is not straightforward or rapid.

Some shorebird monitoring projects generate simple but formal, publicly available reports. Reports for MYSMA surveys in north Western Australia are regular but informal: count totals (added up in the field, before final vetting) and brief commentary are circulated to stakeholders and volunteers within a week of completing surveys.

Full analyses of monitoring data rarely appear annually. As count analysis methods become more complex, it is becoming increasingly necessary for analyses and resultant publications to be prepared professionally, so the appearance of complete, published analyses tends to be linked to irregular funding availability. This is not an ideal scenario when there is a need or desire for adaptive management based on monitoring outcomes. The British Trust for Ornithology's (BTO) reporting system for their Wetland Bird Survey was evidently designed with this issue in mind, with automation to ensure analyses, tables and graphics are prepared in a consistent fashion year to year; in addition the BTO provides detailed annual reports (probably essential given the large number of volunteers they need to engage) and a website from which many other analyses and data summaries can be extracted. A key part of the UK reporting system is identify 'alerts' – species or populations in which declines have exceeded a threshold value. In the UK alerts are raised for rapid declines (>50% in 25 years) or moderate declines (25-49% in 25 years), and they are used as an advisory tool to trigger further investigation (Atkinson et al. 2006).

3 Complete shorebird counts of north Western Australian coastline

3.1 Complete surveys of Eighty Mile Beach

The first estimates of total shorebird numbers on Eighty Mile Beach were published in the 1980's (Lane et al. 1987), on the basis of partial ground counts (to assess species composition) and complete aerial surveys (to assess total number of shorebirds by species). However the first complete ground counts of Eighty Mile Beach did not take place until the end of the 1990s, when complete counts were undertaken by the Australasian Wader Studies Group in October 1998, November 2001 and June 2003 (Minton et al. 2011). These surveys clarified shorebird numbers on Eighty Mile Beach, and showed some shorebird species preferred different areas of Eighty Mile Beach to others. Accordingly, extrapolating from incomplete ground counts to estimate total shorebird numbers on Eighty Mile Beach could be misleading, if some species were under or over-represented in the areas where ground counts occurred. This is probably why estimates from the 1980's proved quite inconsistent with counts in the period 1998-2001 for several species, and we regard the 1998-2003 surveys as more accurate estimates of shorebird numbers on Eighty Mile Beach.

The next complete survey of Eighty Mile Beach (December 2008) was rather alarming, with declines in many species (Rogers et al. 2008; Table 1). Most worryingly, four species had declined to less than 50% of their levels in 1998-2001: Bar-tailed Godwit, Terek Sandpiper, Curlew Sandpiper and Greater Sand Plover. This survey also covered the coastline between Eighty Mile Beach and Bush Point, and sites on the western shores of Dampier Peninsula north to Coulomb Point. These additional sites held far fewer birds than Eighty Mile Beach or Roebuck Bay, but nevertheless some shorebird species occurred in internationally significant numbers.

The same area was surveyed again in 2015. Reassuringly, counts in 2008 and 2015 were quite similar. Overall shorebird numbers were lower by ~ 5% but declines were considerably more modest than those between 2001 and 2008. Among the more numerous migratory shorebirds, the most substantial declines were in Ruddy Turnstone (45.2%), Red-necked Stint (38.2% and Great Knot (24.6%). The most substantial increases occurred in Eastern Curlew (54.5%), Whimbrel (47.7%), Greater Sand Plover (39.4%) and a few other species that are uncommon and difficult to count accurately at Eighty Mile Beach.

In several species, counts in both 2008 and 2015 were considerably lower than previous counts in 1998 and 2001: Bar-tailed Godwit, Curlew Sandpiper, Great Knot, Greater Sand Plover and Terek Sandpiper (Table 1). In Bar-tailed Godwit, Curlew Sandpiper and Terek Sandpiper, the declines are consistent with declines also observed in the annual MYSMA surveys 2004-2016. In Greater Sand Plover and Great Knot they are not. It is possible that in these species slight differences in field methods influenced totals recorded. Although the AWSG surveys 1998-2003 and MYSMA surveys 2008-2015 used similar approaches, the surveys were done by different teams. AWSG teams attempted to cover longer stretches of beach per day; they often counted overall numbers in flocks and then estimated percentage of each species within each flock (Minton et al. 2011). In MYSMA surveys this is sometimes necessary, especially when flocks of birds are flying past the observers, but most birds are counted in standing flocks in which each species is counted individually. Alternatively differences in totals between 1998/2003 and 2008/2015 might have been influenced by the cyclical nature of non-breeding shorebird counts, with peaks following years of high breeding success, troughs following years of low breeding success. When sampling at sampling at long intervals it is difficult to assess if short-term variations of these kind distort assessment of longer-term trends.

The number of migratory coastal shorebirds recorded on each 5 km stretch of Eighty Mile Beach during complete surveys (Figure 7) showed some consistent elements in each complete survey of the beach. In all surveys, the largest number of shorebirds occurred in along a stretch from 20 – 80 km S of Cape Missiessy (i.e. 0-60 km S of the Anna Plains access point); this area corresponds well with the MYSMA survey area where counts are done annually. In all surveys shorebird numbers were relatively low from ~ 80-150 km S of Cape Missiessy, but a little higher in the southernmost 50 km of the beach (Figure 6).

Table 1. Total number of coastal shorebirds recorded in complete ground counts of Eight Mile Beach.

Species	Jun-03	Oct-98	Nov-01	Dec-08	Nov-15	Apparent change in summer
MIGRATORY SHOREBIRDS						
Asian Dowitcher		1		2	3	
Bar-tailed Godwit	13767	109512	97403	51719	51720	decrease since 1998 & 2001
Black-tailed Godwit	7	16	6	52	99	
Broad-billed Sandpiper		12	3	35	71	
Common Greenshank	152	1738	2432	2534	2735	gradual increase
Common Redshank		5				
Common Sandpiper		3	2	6	3	
Curlew Sandpiper	363	2859	7984	3292	3734	decline since 2001
Eastern Curlew	163	709	552	423	930	increase since 2008
Eurasian Curlew				1		
Great Knot	10665	157940	169044	128653	103276	decrease since 1998 & 2001
Greater Sand Plover	3597	63200	64584	22885	37757	decrease since 1998 & 2001
Grey Plover	138	1400	1585	1146	1289	
Grey-tailed Tattler	124	10334	14647	7950	10376	
Lesser Sand Plover	1	162		7	29	
Marsh Sandpiper	2	76	171	127	50	
Pacific Golden Plover		24	12	73	154	
Red Knot	2316	24891	29679	23123	26336	
Red-necked Stint	5094	16766	24005	28443	20576	
Ruddy Turnstone	227	3359	1649	2433	1676	
Sanderling	1001	2133	3219	3605	3455	
Sharp-tailed Sandpiper		9	193	205	213	
Terek Sandpiper	296	7989	9820	4628	4769	decrease since 1998 & 2001
Unidentified Waders				3000	50	
Whimbrel	9	181	148	363	694	
Total migratory shorebirds	**37922**	**403319**	**427138**	**284705**	**269995**	
NON-MIGRATORY SHOREBIRDS						
Australian Pied Oystercatcher	615	635	694	809	866	increasing
Australian Pratincole		9	1	1	43	
Beach Stone-Curlew		1			2	
Black-fronted Dotterel			1			
Black-winged Stilt	2	1		10		
Red-capped Plover	2965	2469	3077	6752	4280	increase since 2001
Sooty Oystercatcher	1	3	13	25	2	
Total resident shorebirds	**3583**	**3118**	**3786**	**7597**	**5193**	

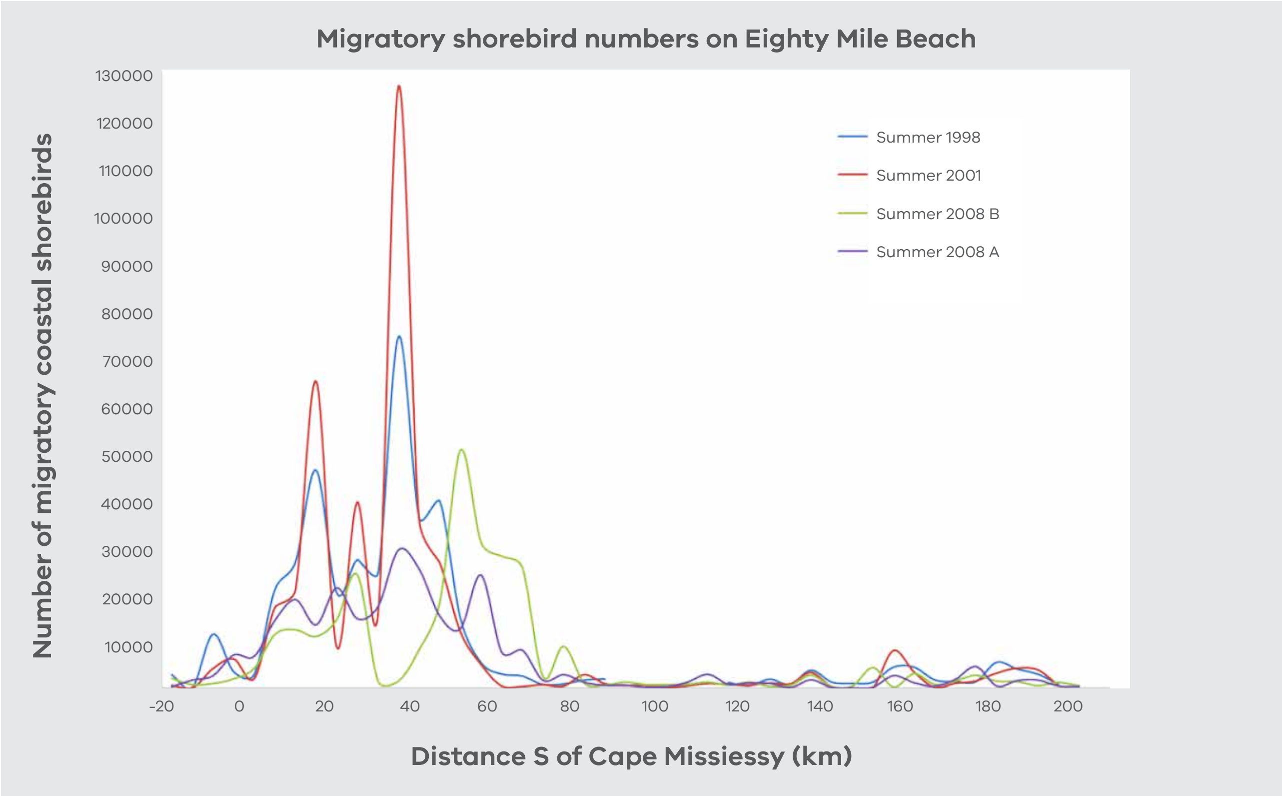


Figure 6. Number of coastal migratory shorebirds on each 50 km stretch of Eighty Mile Beach

While similar in these broad distributional senses, there were some notable differences in shorebird distribution in different complete surveys of Eighty Mile Beach (Figure 6). For example, in the section of beach from 55-65 km S, higher totals were observed in 2008 and 2015 than in previous complete counts of Eighty Mile Beach. We consider this consistent with changes in beach morphology observed in this period; in the early years of the MYSMA surveys (2004 - ~2010) there were large numbers of shorebirds in these areas, many of them concentrated along a 2-3 km section at 60km S where a tidal creek line met a sandy basin in the lower beach where still shallow water ideal for roosting (and some foraging) shorebirds was present through much of the high tide period. In recent years the sands have shifted and this section of beach now has an even shoreline; it now appears similar to the rest of the beach, and is not clearly a focal point for shorebirds.

Most noticeably, in the sector from 30-40 km S, there were very high counts in 1998 and 2001 (70,000 – 130,000 shorebirds) that have never been replicated in MYSMA surveys from 2004 to 2018. Similarly in the sector 15-20 km S, totals observed in 1998 and 2001 were 2-3 times higher than those observed in MYSMA surveys from 2004-2018. We have some trouble interpreting these observations, and suspect there might have been problems with overcounting, especially if birds had been displaced by disturbance (e.g. helicopters or sea-eagles) on a rising tide. Nevertheless, it is likely that the bird numbers on these stretches far exceeded numbers recorded in more recent surveys, perhaps reflecting the potential mobility of shorebirds on a dynamic coastal shoreline where there may be sudden changes in local beach width following the passage of cyclones.

3.2 Current Shorebird populations in north-western Australia

Maximum shorebird counts from north Western Australian coastal sites in the past 20 years are presented in Table 2. Since Rogers et al. (2011) provided a similar compilation, there has been an additional (2015) complete count of the coastline from Cape Keraudren (southern end of Eighty Mile Beach) to Coulomb Point (west side of the Dampier Peninsula); there have been nine years of MYSMA surveys in Roebuck Bay and >60 km of Eighty Mile Beach; there has also been a reappraisal of total shorebird numbers in the East Asian– Australasian Flyway population (Hansen et al. 2016).

Shorebird numbers at a site are considered of international importance if they exceed 1% of the flyway total. On the entire north Western Australian coast from 23 shorebird species have been recorded in internationally significant numbers. 19 species have been recorded in internationally significant numbers on Eighty Mile Beach; 20 species have been recorded in internationally significant numbers in Roebuck Bay (i.e northern Beaches and Bush Point counts combined). Five species have been recorded in internationally significant numbers on the coast between Eighty Mile Beach and Roebuck Bay (i.e. from Cape Missiessy and Jack's Creek) and a further 7 species have been reported in the same region in nationally significant numbers (>0.1% of the flyway population).

Table 2. Maximum counts of shorebirds at coastal north Western Australian sites since 1999

Counts in **boldface** were internationally significant (i.e. >1% of the flyway population, or >20,000)

Species	Eighty Mile Beach	Roebuck Bay	Cape Missiessy to Jacks Creek	Broome Port to Pt Coulomb	Total	1% threshold
COASTAL MIGRANTS						
Asian Dowitcher	2	**414**			**416**	140
Bar-tailed Godwit	**110290**	**32503**	**3414**	52	**146259**	3250
Black-tailed Godwit	99	**6780**			**6879**	1600
Broad-billed Sandpiper	71	196	1		268	300
Common Greenshank	**2735**	533	22	4	**3294**	1100
Common Redshank	5	3			8	750
Common Sandpiper	6	95	24	43	168	1900
Curlew Sandpiper	**7984**	**1990**	4	4	**9982**	900
Eastern Curlew	**930**	**783**	96	15	**1824**	350
Eurasian Curlew	*1*	*1*			2	*400*
Great Knot	**169044**	**30361**	2240	212	**201857**	4250
Greater Sand Plover	**64584**	**22318**	**3775**	1423	**92100**	2000
Grey Plover	**1585**	697	209	55	**2546**	800
Grey-tailed Tattler	**14647**	**2173**	**964**	169	**17953**	700
Lesser Sand Plover	162	155	104	75	496	1800
Marsh Sandpiper	171	53			224	1300
Nordmann's Greenshank	*1*				1	*10*
Pacific Golden Plover	154	103	29	35	321	1200
Red Knot	**29679**	**4683**	710	27	**35099**	1100
Red-necked Stint	**28443**	**16397**	998	817	**46655**	4750
Ruddy Turnstone	**3480**	**1081**	**754**	196	**5511**	300
Sanderling	**3605**	**3235**	**556**	274	**7670**	300
Sharp-tailed Sandpiper	213	520	17	8	758	850
Terek Sandpiper	**9820**	**1522**	56	6	**11404**	500
Whimbrel	694	**1100**	477	65	**2336**	650
GRASSLAND MIGRANTS						
Oriental Plover	**144300**	**6431**	1931	2	**152664**	2300
Little Curlew	**14200**	**1297**	149	17	**15663**	1100
Oriental Pratincole	**2880000**	**21041**	9		**2901050**	28800
RESIDENT SHOREBIRDS						
Beach Stone-curlew	1	2	6	5	14	250
Australian Pied Oystercatcher	**866**	**931**	105	52	**1954**	110
Sooty Oystercatcher	25	34	3	39	**101**	75
Black-winged Stilt	10	**1047**		13	**1070**	250
Red-necked Avocet		145			145	1100
Red-capped Plover	**6752**	**6531**	509	159	**13951**	950
Black-fronted Dotterel	1			2	3	160
Masked Lapwing		4	1	4	9	10000
Australian Pratincole	43		3		46	600
Total shorebirds	**3494603**	**165159**	17166	3773	**3680701**	
Total coastal migrants	**448405**	**127696**	14450	3480	**594031**	
Total grassland migrants	**3038500**	**28769**	2089	19	**3069377**	
Total residents	7698	8694	627	274	17293	

3.3 Interspecific differences in roost distribution

There were interspecific differences in the distribution of shorebirds on Eighty Mile Beach (Table 3). While most species were most abundant in the stretch of coast from 0-60 km S of the Anna Plains access track, some species (e.g. Australian Pied Oystercatcher, Ruddy Turnstone, Sanderling) were most abundant on more southerly stretches of beach. In these species, a large proportion of the north Western Australian population occurs outside the area that is monitored annually. Some species were more patchily distributed than others; for example Common Greenshank has a strong preference for the coastal stretch from 0-20 km S, while species such as Grey Plover were quite evenly distributed along the beach. Variability in these distributions from year to year, and their implications for monitoring, is considered in sections 4 and 5.

Table 3. Average percentage of shorebirds in 5km stretches of Eighty Mile Beach during complete summer counts.

Colour shading indicates proportion of birds: most favoured blocks in red (used by >50% of birds), through orange, yellow and green to light blue (least favoured blocks, used by <10% of birds); cells left white if the species was absent from the block.

Distance (km) from Anna Plains access (mid-point of 5km block)	Asian Dowitcher	Aus Pied Oystercatcher	Bar-tailed Godwit	Black-tailed Godwit	Black-winged Stilt	Broad-billed Sandpiper	Common Greenshank	Curlew Sandpiper	Eastern Curlew	Great Knot	Greater Sand Plover	Grey Plover	Grey-tailed Tattler	Lesser Sand Plover	Marsh Sandpiper	Pacific Golden Plover	Red Knot	Red-capped Plover	Red-necked Stint	Ruddy Turnstone	Sanderling	Sharp-tailed Sandpiper	Sooty Oystercatcher	Terek Sandpiper	Whimbrel
-17.5	0.0	0.9	0.6	0.0	0.0	0.0	0.1	0.0	2.4	0.0	0.6	2.3	1.3	1.5	0.0	1.5	0.0	3.5	0.7	6.0	2.4	0.2	0.0	0.0	13.8
-12.5	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.5	0.1	0.3	0.7	0.0	0.5	0.0	1.1	0.0	2.0	0.3	0.3	1.3	0.2	0.0	0.0	4.6
-7.5	0.0	0.6	4.5	2.9	0.0	0.0	2.2	0.0	1.6	0.6	0.3	2.2	0.1	5.1	4.0	0.0	0.1	2.4	0.5	0.2	0.2	0.5	0.0	0.0	7.5
-2.5	0.0	0.5	2.2	8.1	0.0	0.0	9.2	0.1	0.3	1.1	0.3	2.1	0.4	13.6	0.0	0.8	2.4	3.0	0.7	0.1	0.8	1.9	0.0	0.3	1.9
2.5	0.0	0.2	0.9	8.7	0.0	0.8	13.7	1.3	0.3	1.0	0.8	1.9	1.1	0.5	17.5	0.8	1.6	5.2	2.0	0.4	0.1	31.9	0.0	0.5	0.2
7.5	33.3	0.0	3.8	17.9	0.0	2.5	28.1	5.1	2.3	4.1	2.9	4.6	4.0	1.5	27.4	1.1	13.1	10.6	3.1	0.6	0.2	17.3	0.0	2.9	0.9
12.5	33.3	0.1	4.0	4.0	0.0	0.8	11.7	23.3	2.6	3.4	13.3	2.9	10.0	27.3	9.2	3.4	3.5	7.1	4.8	1.3	1.0	26.0	0.0	11.5	2.0
17.5	16.7	0.2	3.5	2.9	0.0	4.1	15.6	22.3	3.9	9.4	22.3	2.8	20.1	1.5	9.7	3.4	4.4	3.5	5.0	1.4	0.8	7.4	0.0	18.9	0.9
22.5	0.0	0.1	4.3	0.0	0.0	7.4	5.0	5.0	14.6	4.6	4.8	3.7	8.3	0.5	0.0	5.7	0.6	8.9	7.8	0.9	4.0	0.2	0.0	7.1	2.1
27.5	0.0	0.1	6.7	0.0	0.0	9.1	2.6	5.7	11.2	8.5	7.1	3.3	17.3	2.0	0.2	7.2	2.4	6.1	7.8	1.4	1.3	0.2	0.0	12.7	3.1
32.5	0.0	0.2	5.3	22.5	90.9	0.0	1.0	6.1	2.9	3.1	3.8	2.5	8.1	2.5	0.2	0.4	6.4	2.5	4.0	3.1	0.5	0.0	0.0	6.5	1.2
37.5	0.0	0.1	22.7	5.2	0.0	43.8	5.0	2.1	7.7	18.3	8.5	6.8	11.8	10.1	28.3	9.9	24.4	4.7	6.9	3.8	0.4	0.6	0.0	14.6	0.2
42.5	0.0	0.3	4.9	0.0	0.0	9.1	2.4	9.1	10.1	8.5	11.8	2.6	6.9	27.8	1.2	1.9	3.5	6.6	9.0	1.1	0.0	0.2	0.0	7.5	1.7
47.5	0.0	0.4	7.7	0.6	0.0	9.9	0.4	2.7	10.4	7.8	7.1	3.7	3.6	0.0	0.0	2.3	4.0	5.3	11.6	0.2	1.3	0.3	0.0	2.4	4.3
52.5	16.7	0.4	3.4	25.4	0.0	8.3	0.2	7.7	8.5	8.4	4.1	2.2	1.5	0.0	0.0	0.0	8.4	2.2	12.5	0.2	0.8	2.9	2.3	5.1	4.5
57.5	0.0	0.1	3.3	0.0	0.0	0.0	0.1	3.2	4.9	3.2	3.3	1.8	0.4	0.5	0.0	0.0	19.8	3.5	7.6	0.1	7.4	7.4	0.0	3.3	5.2
62.5	0.0	0.2	2.4	0.0	0.0	0.0	0.1	2.7	6.4	3.8	1.1	1.2	0.1	0.5	0.0	2.7	4.4	4.6	1.8	0.1	2.9	0.2	0.0	2.5	2.4
67.5	0.0	1.1	4.3	0.0	0.0	0.0	0.1	0.9	5.2	3.3	0.6	3.2	0.1	0.0	2.4	3.8	0.1	2.3	1.8	0.4	5.1	0.6	0.0	2.1	3.2
72.5	0.0	0.9	0.4	0.0	0.0	0.0	0.2	0.1	0.5	0.4	0.3	1.1	0.0	0.0	0.0	1.9	0.1	0.7	0.4	0.4	6.3	0.3	0.0	0.4	3.0
77.5	0.0	1.3	1.5	0.0	0.0	0.0	0.2	0.2	0.0	0.5	0.9	2.0	0.0	1.5	0.0	6.1	0.0	1.4	2.1	0.5	11.0	0.0	0.0	0.4	2.0
82.5	0.0	2.2	0.5	0.6	0.0	0.0	0.1	0.1	0.0	0.1	0.4	3.0	0.1	0.5	0.0	4.2	0.0	1.4	2.4	1.3	10.0	0.0	0.0	0.1	3.0
87.5	0.0	2.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.9	0.0	0.0	0.0	0.4	0.0	0.8	0.5	0.4	5.4	0.0	0.0	0.0	0.8
92.5	0.0	2.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	1.6	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.7	3.8	0.0	0.0	0.0	0.2
97.5	0.0	3.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	1.1	0.0	0.0	0.0	9.1	0.0	0.5	0.0	1.2	1.8	0.0	0.0	0.0	0.1
102.5	0.0	4.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.5	0.0	0.4	0.0	0.5	0.0	1.8	1.7	0.0	0.0	0.0	0.1
107.5	0.0	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	2.2	0.5	0.0	0.0	9.1	0.0	0.8	0.2	3.1	2.9	0.0	9.3	0.1	0.5
112.5	0.0	1.8	0.4	0.0	0.0	0.0	0.1	0.0	0.0	0.4	0.2	1.7	0.4	0.0	0.0	11.0	0.0	0.3	0.1	8.2	0.3	1.0	0.0	0.0	0.6
117.5	0.0	2.3	0.3	0.0	0.0	0.0	0.6	0.1	0.0	0.2	0.2	1.8	0.2	0.0	0.0	0.8	0.0	0.5	0.0	5.7	0.2	0.2	30.2	0.0	1.2
122.5	0.0	2.4	0.3	0.0	9.1	0.0	0.0	0.0	0.0	0.2	0.2	1.8	0.1	0.5	0.0	2.7	0.0	0.9	0.1	4.6	1.4	0.0	0.0	0.0	1.3
127.5	0.0	4.0	0.4	0.0	0.0	0.0	0.5	0.2	0.2	0.3	0.4	1.7	0.1	1.0	0.0	1.5	0.0	0.4	0.1	4.7	1.4	0.0	4.7	0.1	0.4
132.5	0.0	5.2	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.2	0.2	1.8	0.1	0.0	0.0	0.4	0.0	0.1	0.0	5.7	2.4	0.0	0.0	0.0	1.4
137.5	0.0	4.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.3	1.7	0.5	0.0	0.0	0.8	0.1	0.1	0.0	7.1	1.0	0.0	0.0	0.1	1.4
142.5	0.0	2.8	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.6	0.0	0.0	0.0	0.8	0.0	0.3	0.0	0.9	0.5	0.0	0.0	0.1	0.7
147.5	0.0	3.9	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.4	0.0	0.0	0.0	1.1	0.0	0.3	0.0	0.4	0.2	0.0	0.0	0.0	1.2
152.5	0.0	11.0	0.9	0.6	0.0	0.0	0.1	0.0	0.2	0.4	0.1	1.7	0.3	0.0	0.0	1.9	0.0	0.2	0.0	4.2	0.3	0.6	20.9	0.1	2.0
157.5	0.0	6.0	1.9	0.6	0.0	0.0	0.0	0.1	0.3	1.3	0.2	1.2	0.4	0.5	0.0	0.8	0.3	0.2	0.2	5.0	0.5	0.0	14.0	0.1	1.0
162.5	0.0	2.9	0.8	0.0	0.0	0.0	0.0	0.4	0.2	0.9	0.1	1.9	0.3	0.0	0.0	0.0	0.0	0.3	0.3	3.8	0.4	0.0	4.7	0.0	1.3
167.5	0.0	3.2	0.3	0.0	0.0	0.0	0.0	0.1	0.3	0.2	0.2	3.1	0.2	0.0	0.0	0.0	0.0	0.6	0.4	1.3	0.4	0.0	4.7	0.1	0.9
172.5	0.0	3.7	0.9	0.0	0.0	0.0	0.1	0.2	0.1	0.3	0.2	1.3	0.0	0.0	0.0	0.0	0.0	0.8	0.4	0.8	5.1	0.0	0.0	0.0	0.1
177.5	0.0	4.8	1.1	0.0	0.0	0.8	0.0	1.0	0.2	0.7	0.4	3.4	0.7	0.0	0.0	0.8	0.0	0.6	0.6	4.4	2.1	0.0	0.0	0.1	6.1
182.5	0.0	3.0	0.7	0.0	0.0	3.3	0.0	0.0	0.8	0.9	0.7	3.8	0.3	0.0	0.0	0.0	0.0	0.7	1.0	6.1	1.8	0.0	0.0	0.2	0.9
187.5	0.0	5.4	0.9	0.0	0.0	0.0	0.0	0.1	0.2	0.9	0.4	4.1	0.2	0.0	0.0	0.0	0.0	0.9	1.0	4.0	4.7	0.0	0.0	0.1	5.6
192.5	0.0	6.8	1.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.3	3.2	0.1	0.0	0.0	0.0	0.0	1.2	1.8	1.0	3.1	0.0	0.0	0.0	3.5
197.5	0.0	2.4	0.3	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	1.7	0.0	0.0	0.0	0.0	0.0	1.0	0.4	1.1	1.0	0.0	4.7	0.0	0.5
202.5	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	4.7	0.0	0.4

There were also interspecific differences in the distribution of shorebirds on the northern beaches of Roebuck Bay (Table 4). A number of relatively large, long-legged species occurred in large numbers on the more easterly beaches abutting very large tidal flats (e.g, both godwit and both knot species, Eastern Curlew, Whimbrel and Asian Dowitcher). Smaller species (e.g. Greater Sand Plover, Red-necked Stint) tended to prefer more westerly beaches opposite sandier tidal flats.

Table 4. Average percentage of shorebirds in roosts of Northern Roebuck Bay during complete summer counts.

Roosts are sorted from westernmost (1) to easternmost (26). Colour shading proportion of birds: most favoured blocks in red (used by >50% of birds), through orange, yellow and green to light blue (least favoured blocks, used by <10% of birds); cells left white if the species was absent from the block.

	Asian Dowitcher	Aus Pied Oystercatcher	Bar-tailed Godwit	Black-tailed Godwit	Black-winged Stilt	Broad-billed Sandpiper	Common Greenshank	Curlew Sandpiper	Eastern Curlew	Great Knot	Greater Sand Plover	Grey Plover	Grey-tailed Tattler	Lesser Sand Plover	Marsh Sandpiper	Pacific Golden Plover	Red Knot	Red-capped Plover	Red-necked Stint	Ruddy Turnstone	Sanderling	Sharp-tailed Sandpiper	Sooty Oystercatcher	Terek Sandpiper	Whimbrel
1 Simpson's Beach	0.0	2.2	7.9	0.2	4.6	0.9	6.7	14.4	0.8	7.2	10.8	7.8	19.8	22.1	5.3	24.0	3.9	0.0	0.0	0.2	0.1	0.0	0.0	0.1	0.0
2 West Quarry	0.0	0.0	7.0	0.0	0.0	0.0	4.2	0.4	0.0	2.9	2.7	2.3	5.7	0.0	0.0	0.0	0.4	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.1
3 Quarry Beach	0.0	5.6	3.7	0.6	0.0	0.8	3.8	1.0	1.4	2.1	6.6	2.0	5.3	4.9	0.0	0.9	4.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.1
4 Two Dog Hermit	0.0	9.2	4.5	0.9	0.1	1.0	1.0	1.7	1.5	2.3	10.4	2.9	1.0	2.9	0.0	1.8	5.2	0.0	0.1	0.1	0.0	0.0	0.3	0.0	0.0
5 Nick's Beach	0.0	3.5	1.7	1.1	0.0	2.0	1.7	0.6	0.6	0.9	2.8	3.0	1.2	2.1	0.0	0.9	1.2	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0
6 Campsite	0.0	0.8	1.5	2.3	0.0	1.7	1.8	1.1	0.7	2.8	3.6	3.8	3.8	4.7	0.0	1.1	6.9	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.0
7 Eagles Roost	0.0	2.8	3.2	1.5	0.0	4.9	0.8	3.2	0.9	2.4	5.3	1.5	3.9	4.0	0.0	1.2	3.2	0.1	0.1	0.1	0.2	0.1	0.1	0.0	0.0
8 Tattler Rocks	0.0	1.8	1.0	0.5	0.0	13.5	1.9	6.9	1.3	1.2	10.3	2.9	3.4	4.4	3.5	0.9	5.9	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0
9 Fish Heads	0.0	0.0	3.0	0.9	0.0	1.0	0.6	5.3	0.8	3.2	3.9	3.2	1.2	1.2	0.0	0.9	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10 Rocky Area	0.0	0.0	3.8	0.0	0.0	0.0	2.5	0.7	0.0	1.0	2.6	0.6	1.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
11 Richard's Point	12.8	7.2	5.5	0.9	0.0	9.9	1.3	5.9	1.4	6.6	7.8	4.8	1.3	3.9	0.0	1.8	2.6	0.0	0.1	0.0	0.2	0.1	0.0	0.0	0.0
12 Wader Beach	12.8	5.3	3.1	3.0	0.0	10.8	1.4	6.4	3.9	7.3	15.5	12.6	1.6	8.2	0.0	3.7	2.4	0.2	0.1	0.0	0.2	0.1	0.0	0.0	0.0
13 Fall Point	0.0	0.0	4.0	4.5	0.0	6.6	0.0	22.4	3.2	11.4	7.7	1.8	2.8	6.3	0.0	1.8	9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 Boat Ramp	0.0	7.6	0.3	11.8	0.0	16.5	0.1	10.4	0.5	1.9	1.4	1.0	0.7	11.8	0.0	12.0	1.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0
15 False Boat Ramp	0.0	0.0	3.8	0.1	0.0	21.7	6.2	3.4	4.2	1.1	4.7	0.5	1.8	10.0	0.0	3.2	0.9	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.0
16 Front of BBO	12.8	11.0	0.8	5.1	0.0	7.2	4.0	4.1	2.4	1.7	2.3	1.3	12.2	8.8	0.0	18.6	2.4	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0
17 Terek Rocks	0.0	1.5	0.0	0.0	1.9	0.0	8.4	0.6	19.4	0.0	0.0	0.0	8.5	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 Greenshank Corner	0.0	5.7	0.3	0.0	0.5	0.0	13.3	1.4	21.0	0.2	0.1	1.2	7.5	1.2	0.0	2.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
19 Boiler	12.8	12.3	9.2	24.8	11.6	0.0	9.8	2.3	6.9	14.2	0.0	11.8	0.5	1.2	0.0	2.3	22.5	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
20 Minton's Straight	17.0	16.8	25.8	23.2	11.0	0.6	17.3	6.6	23.7	18.9	1.4	18.6	9.6	2.4	0.0	3.5	17.9	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.1
21 Stilt Viewing	31.9	2.3	4.0	4.7	33.1	0.8	6.4	0.7	1.0	6.9	0.0	15.6	1.0	0.0	0.0	0.9	4.4	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
22 Sandy Blowout	0.0	4.6	0.8	10.0	20.4	0.0	1.7	0.3	1.8	2.1	0.0	0.0	0.0	0.0	0.0	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23 One Tree	0.0	0.0	3.0	3.0	13.5	0.0	2.6	0.2	1.0	1.4	0.0	0.9	0.1	0.0	91.2	7.4	3.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.2
24 Behind Mangroves	0.0	0.0	2.0	0.8	3.2	0.0	2.6	0.0	1.8	0.4	0.0	0.0	5.1	0.0	0.0	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3

4 Annual counts of shorebirds in north-western Australia (MYMSA)

4.1 Methods

Generalized additive models (GAMs) with quasi-poisson error distributions, logarithmic link functions and AR(1) autoregressive errors were fitted to the full time series data collected at Eighty Mile Beach, Bush Point and northern Roebuck Bay. A separate model was fitted to data for each species, and to data collected during the southern Summer and Winter periods

Unlike more conventional regression models such as generalized linear models (GLMs), GAMSs do not limit the functional form of the relationship between covariates and response variables to linear forms. Instead, GAMs estimate the shape of a "smooth function", which strikes a balance between the goodness of fit of more complex functions that better fit the observed data, and simpler models, which at the extreme level of simplicity will be equivalent to a GLM. In the current analysis, we modelled the relationship between the observed counts of each species of shorebird at the sites and time, to deduce underlying temporal trends in abundance. The shape of the fitted smooth function can be plotted to visualise the temporal trend in abundance (including associated measures of uncertainty), and thereby infer whether abundance is increasing or decreasing over time. GAMs were fitted to the data using the R package *mgcv* (Wood et al. 2018). Periods of increasing or decreasing abundance during the monitoring period were detected by computing numerical derivatives of the fitted smooth function, using R code based on that presented by Simpson et al (2014). To assess overall changes from the beginning to the end of the monitoring period, we used the fitted GAM to estimate average rates of change in abundance between the first and last monitoring period in the dataset. Structurally identical models were fitted to the different subsets of the data entailing the various proposed monitoring scenarios, and to the full data set to compare the extent to which the various modified monitoring programs would have recovered the population trends detectable in the full data set.

4.2 Population trends 2004-2018

Generalised Additive Models (GAMs) were prepared for the 21 most abundant migratory species in north-western Australia. We did not model Oriental Plover, Little Curlew or Oriental Pratincole because the survey program was not designed to count these species in a repeatable manner, and 18 other migratory species occurred too infrequently for the data to be modelled effectively.

Models for selected species that we consider illustrative of the patterns seen are shown in Figure 7. (Plots for all modelled species are provided in Appendix 1). The plots show that while changes over time appeared near-linear in some species (e.g. Bar-tailed Godwit and Curlew Sandpiper at Eighty Mile Beach), in some species changes over time were clearly not linear, with identifiable peaks and troughs occurring during the study period.

The GAMs indicated that summer counts of six migratory species had declined significantly in the study area overall between 2004 and 2016 (Table 5); five species had increased significantly; in the ten remaining species there was no significant difference between counts in 2004 and 2018, though examination of the models (plots provided in Appendix 1) indicated that some of the species had probably gone through peaks or troughs during this period.

Trends in summer counts were not consistent across sites. Only one species (Whimbrel) underwent significant concurrent increases at Eighty Mile Beach, northern Roebuck Bay and Bush Point; no species declined concurrently at all three sites. Five species decreased at both Eighty Mile Beach and northern Roebuck Bay, three decreased on the northern beaches of Roebuck Bay, and only one (Pacific Golden Plover) was decreasing at Bush Point. In contrast, ten species increased significantly at Bush Point, compared to only three increasing at Eighty Mile Beach and three increasing on the northern shores of Roebuck Bay.

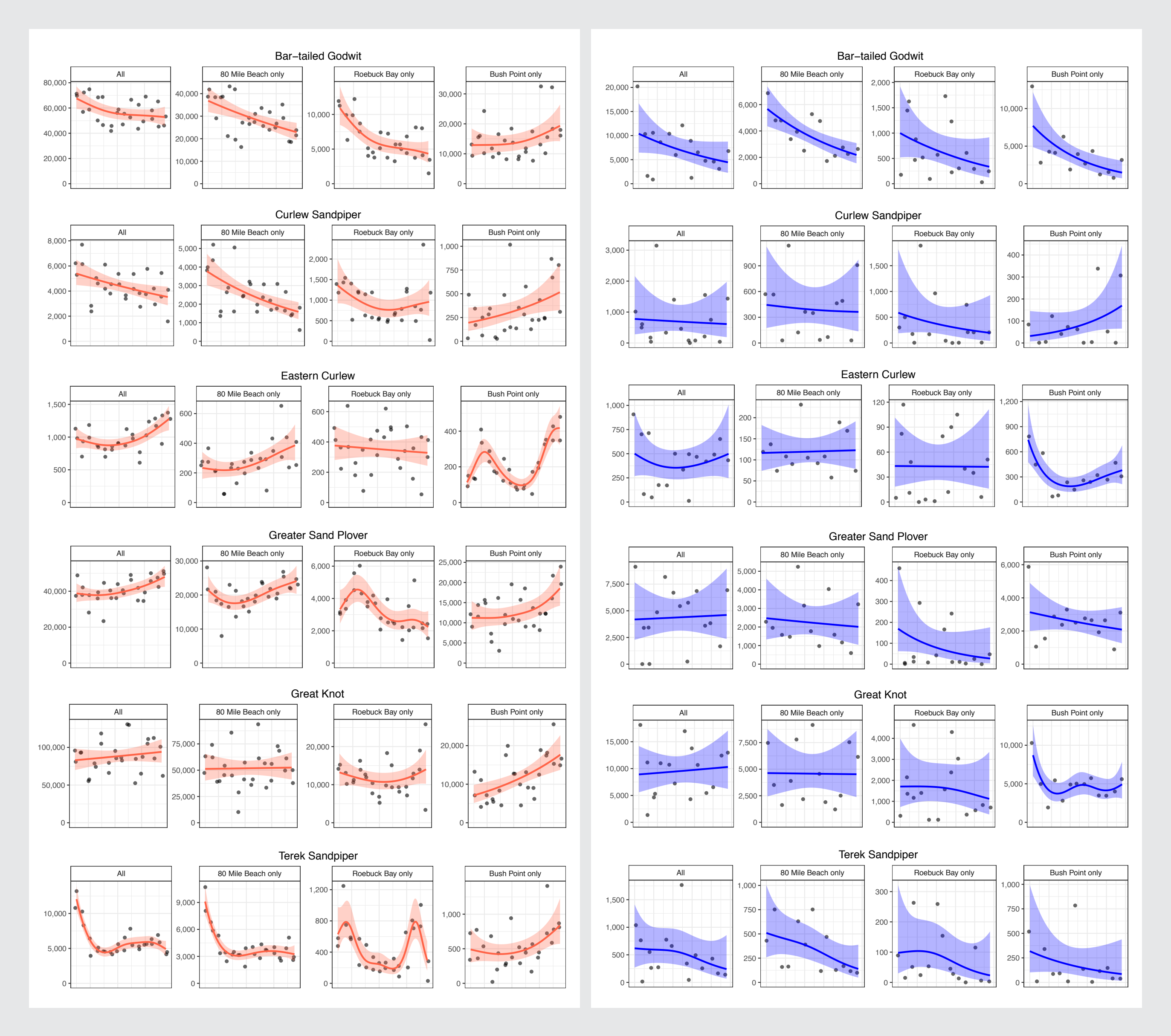


Figure 7. Generalised additive models of change over time in summer counts of selected species in north Western Australia.

Summer counts in red (left); winter counts in blue (right). Trend lines represent GAMs; shading represents 95% error of the line; black dots are individual counts. In both panels, counts from Eighty Mile Beach are shown in the 2nd column, northern Beaches of Roebuck Bay in the 3rd and Bush Point in the 4th; the first column (overall count) is based on the sum of these counts. Number of birds (Y axis) differs between graphs; Year (X axis) is consistent between graphs. These graphs are shown at larger scale in Appendix 1 and 2.

Table 5. Trends in shorebird summer counts at Eighty Mile Beach, Roebuck Bay (northern beaches), Bush Point and overall

Annual rate of change in shorebird populations (expressed as a percentage) during the period 2004-2016. Inferences about the rate of change are derived from the fitted GAM, rather than being taken directly from the raw data. Significant decreases shown in **Red Boldface**, significant increases in **Underlined Black Boldface**. Cells left blank at sites where the species occurred too infrequently for modelling.

1) Species	2) Eighty Mile Beach	3) Roebuck Bay (northern beaches)	4) Bush Point	5) Overall (shorebird areas combined)
Asian Dowitcher	108.9	108.4	**127.9**	**124.3**
Bar-tailed Godwit	**96.5**	**93.0**	103.1	**98.1**
Black-tailed Godwit	103.1	98.0	**194.9**	100.6
Broad-billed Sandpiper	104.7	93.1	**118.4**	102.8
Common Greenshank	99.2	**104.1**	98.3	99.8
Curlew Sandpiper	**93.6**	97.4	**107.7**	**96.8**
Eastern Curlew	**104.0**	99.0	**110.5**	**102.1**
Great Knot	100.2	100.4	**107.2**	101.1
Greater Sand Plover	101.0	97.1	**103.8**	**101.7**
Grey Plover	**98.0**	97.5	99.4	98.5
Grey-tailed Tattler	101.1	100.0	103.5	100.4
Lesser Sand Plover	97.8	**88.2**	98.2	94.4
Marsh Sandpiper	**92.8**	78.4		**93.1**
Pacific Golden Plover	104.5	**93.0**	101.0	**92.1**
Red Knot	98.9	**116.3**	**109.0**	100.8
Red-necked Stint	**95.6**	102.1	98.5	**97.3**
Ruddy Turnstone	**103.9**	99.1	101.7	101.7
Sanderling	96.6	103.0	**105.8**	**106.7**
Sharp-tailed Sandpiper	110.9	107.0	94.8	91.5
Terek Sandpiper	94.5	103.9	**94.3**	**92.4**
Whimbrel	**106.9**	**118.5**	**108.2**	**108.7**

Variation in winter counts was proportionately higher than that in summer counts, as shown by the broad confidence limits to the GAMs (see Appendix 1). This made significant changes in numbers over time harder to detect than in summer counts. Across the entire study area, significant increases were only found in Whimbrel and significant decreases were only found in Terek Sandpiper (Table 6). Marsh Sandpiper and Red-necked Stint declined at Eighty Mile Beach, Eastern Curlew declined in Roebuck Bay and Bar-tailed Godwit decreased in both sites.

Table 6. Trends in shorebird winter counts at Eighty Mile Beach, Roebuck Bay (northern beaches), Bush Point and overall

Annual rate of change in shorebird populations (expressed as a percentage) during the period 2004-2016. Significant decreases shown in **Red Boldface**, significant increases in **Underlined Black Boldface**.
Cells left blank at sites where the species occurred too infrequently for modelling.

6) Species	7) Eighty Mile Beach	8) Roebuck Bay (northern beaches)	9) Bush Point	10) Overall (shorebird areas combined)
Asian Dowitcher		96.2	107.1	103.1
Bar-tailed Godwit	**92.3**	91.2	**87.3**	93.4
Black-tailed Godwit	110.2	95.2	123.4	98.2
Broad-billed Sandpiper	119.0	100.0	105.0	105.8
Common Greenshank	95.8	104.2	98.1	99.7
Curlew Sandpiper	98.1	92.1	115.5	98.4
Eastern Curlew	100.4	100.1	**92.6**	99.1
Great Knot	100.0	97.4	95.6	101.1
Greater Sand Plover	98.3	86.2	96.8	101.0
Grey-tailed Tattler	100.9	96.1	101.8	100.2
Grey Plover	100.4	103.6	96.2	102.7
Lesser Sand Plover	158.3		145.3	174.9
Marsh Sandpiper	**61.6**	96.0	100.0	85.8
Pacific Golden Plover	105.8		**74.9**	93.2
Red-necked Stint	**92.3**	104.5	90.2	100.1
Red Knot	92.2	101.4	105.5	96.7
Ruddy Turnstone	106.9	105.1	108.8	108.6
Sanderling	98.9		95.4	95.5
Sharp-tailed Sandpiper	0.0			100.0
Terek Sandpiper	93.2		90.0	**89.3**
Whimbrel	107.5		107.6	**109.9**

4.3 Comparison of national and north Western Australian trends

National trend analyses including count data from north-western Australia have been published by Clemens et al. (2016) and Studds et al. (2017). Results from these studies are compared with the results of MYSMA surveys in Table 7. The studies did not generate identical findings, in part because they used different modelling approaches, but probably still more because the analyses covered different time periods.

It is however noteworthy that the six species declining in MYSMA surveys (areas combined) were also declining nationally (except Marsh Sandpiper, for which there are no national trend estimates). Of the five species increasing in MYSMA surveys, one (Eastern Curlew) was decreasing Australia-wide while trends were not significant, or not estimated for the remainder. Those species in which no significant evidence of long-term change could be detected in MYSMA surveys 2004-2016 included several species that are declining nationally.

Overall the trend comparison suggests shorebirds are faring better in north Western Australia than they are faring Australia-wide, but there is nevertheless evidence that national declines are being reflected in declines of a number of species that occur in north Western Australia.

Table 7. Comparison of trends found in this study, and by Clemens et al. (2016) and Studds et al. (2017).

Downwards-pointing red arrows indicate significant decreases, upwards-pointing black arrows indicate significant increases, ns is an abbreviation for no significant change. No data were available for cells that have been left blank.

Species	2004 -2016. North Western Australia	Clemens et al. 2016. 1996-2014 Northern Australia	Clemens et al 2016. 1996-2014 Australia-wide	Studds et al 2017. 1993 to 2012, North Western Australia	Studds et al 2017. 1993 to 2012, Australia-wide
Asian Dowitcher	↑				
Bar-tailed Godwit	↓	↓	↓	↓	↓
Black-tailed Godwit	ns	↓	↓		
Broad-billed Sandpiper	ns				
Common Greenshank	ns	ns	↓		
Curlew Sandpiper	↓	ns	↓	ns	↓
Eastern Curlew	↑	↓	↓	↓	↓
Great Knot	ns	ns	ns	↓	↓
Greater Sand Plover	↑	ns	ns		
Grey Plover	ns	ns	↓		
Grey-tailed Tattler	ns	↑	ns	ns	ns
Lesser Sand Plover	ns	↓	↓		↓
Marsh Sandpiper	↓	ns	ns		
Pacific Golden Plover	↓	ns	↓		
Red Knot	ns	ns	ns	↓	↓
Red-necked Stint	↓	ns	↓		
Ruddy Turnstone	ns	ns	↓		
Sanderling	↑	↑	ns		
Sharp-tailed Sandpiper	ns	↑	↓		
Terek Sandpiper	↓	↓	↓	↓	ns
Whimbrel	↑	ns	ns		

4.4 Changes at specific roost sites

Concerns have been raised about threats to some individual shorebird roosts within the north Western Australian study area. All the sites of concern are on the northern shores of Roebuck Bay, where potential conservation issues include:

(1) increased pollution driving increases in the incidence of *Lyngbya* blooms and resultant declines in the diversity and abundance of shorebird food in the intertidal mudflats (Estrella et al 2011). As the most strongly affected tidal flats are those closest to Broome, this may cause declines in shorebird numbers at the more westerly roosts of Roebuck Bay (especially Simpson's Beach and Quarry Beach).

(2) increased disturbance of roosts causing increases to the energy costs faced by shorebirds. Resultant declines would be expected at the roosts experiencing the most frequent disturbance. In the early 2000's all shorebirds at all roosts on the northern shores were frequently disturbed by people or birds of prey; the most heavily disturbed single roost was Quarry Beach, the beach most often visited by people (Rogers et al. 2006e; Sitters et al. 2008). There is no quantitative data available on roost disturbance levels since then, though a study is now in progress. Our extensive field experience of the bay (notably that of CJH, who visits the roosts ~140 times per year) suggests that disturbance levels remain high, may be increasing, and that Quarry Beach remains one of the most heavily disturbed sites. There is also regular human disturbance at roosts near to One Tree Point (a popular fishing area), but human disturbance tends to be lower in other sites which are less easily accessed by vehicles.

(3) mangrove encroachment on the easternmost beaches of northern Roebuck Bay, at the roosts known to birdwatchers as One-Tree Point, Sandy Blowout, Stilt Viewing and The Boiler (Figure 8).

An examination of MYSMA counts to assess whether trends in counts at these individual roost sites were changing was inconclusive because of the highly variable counts obtained from individual sites. This variation did not surprise us, in view of our field experience of the roosts of Roebuck Bay. Shorebirds in Roebuck Bay often respond to disturbance when flushed by moving from one roost to another, and at a single roost, numbers often range from thousands of shorebirds to no shorebirds at all during a single high tide.

We attempted to get around this issue by aggregating data adjacent roosts into 'blocks' of similar length (Figure 8). We aggregated species, simply examining overall number of coastal shorebirds; this was considered reasonable as most shorebird species (including all of the more numerous species) roost in mixed flocks in Roebuck Bay. We examined the proportion of Roebuck Bay's shorebirds in each roost block, rather than absolute numbers at each site, because absolute numbers can be influenced by factors external to Roebuck Bay.

Linear regressions (Figure 8) showed gradients consistent with some of the expectations outline above. We interpret the results as follows:

1. Shorebird numbers have declined at the roosts in the east of the northern Beaches where there has been mangrove encroachment in addition to human disturbance.

2. There has been an increase in proportionate numbers of shorebirds roosting at Wader Beach and opposite Broome Bird Observatory. We consider this to represent birds displaced from beaches further east where mangrove encroachment has occurred. Often on rising tides we observe shorebirds initially gathering near One Tree Point, but then moving to Wader Beach as the tide rises.

3. There was no striking change in proportionate usage of roosts from Nick's Beach to Tattler Rocks, a stretch of coastline which is backed by cliffs, making the beaches relatively difficult for humans to access.

4. Shorebirds were declining at Quarry Beach (a heavily disturbed site) but stable at Simpson's Beach, a site where disturbance levels are lower in summer. Declines would have been expected at both sites had they been driven by Lyngbya blooms and diminished food resources on tidal flats near Roebuck Bay.

Other modelling approaches such as robust regression and GLMs resulted in long-term gradients consistent with the interpretation above. However, as was the case with the linear regression models in Figure 8, confidence intervals were broad, and apparent changes were not statistically significant. A much higher frequency of counts on the northern beaches of Roebuck Bay would be needed to reveal temporal patterns in usage of individual roosts, a challenge considered further in the discussion (Section 7).

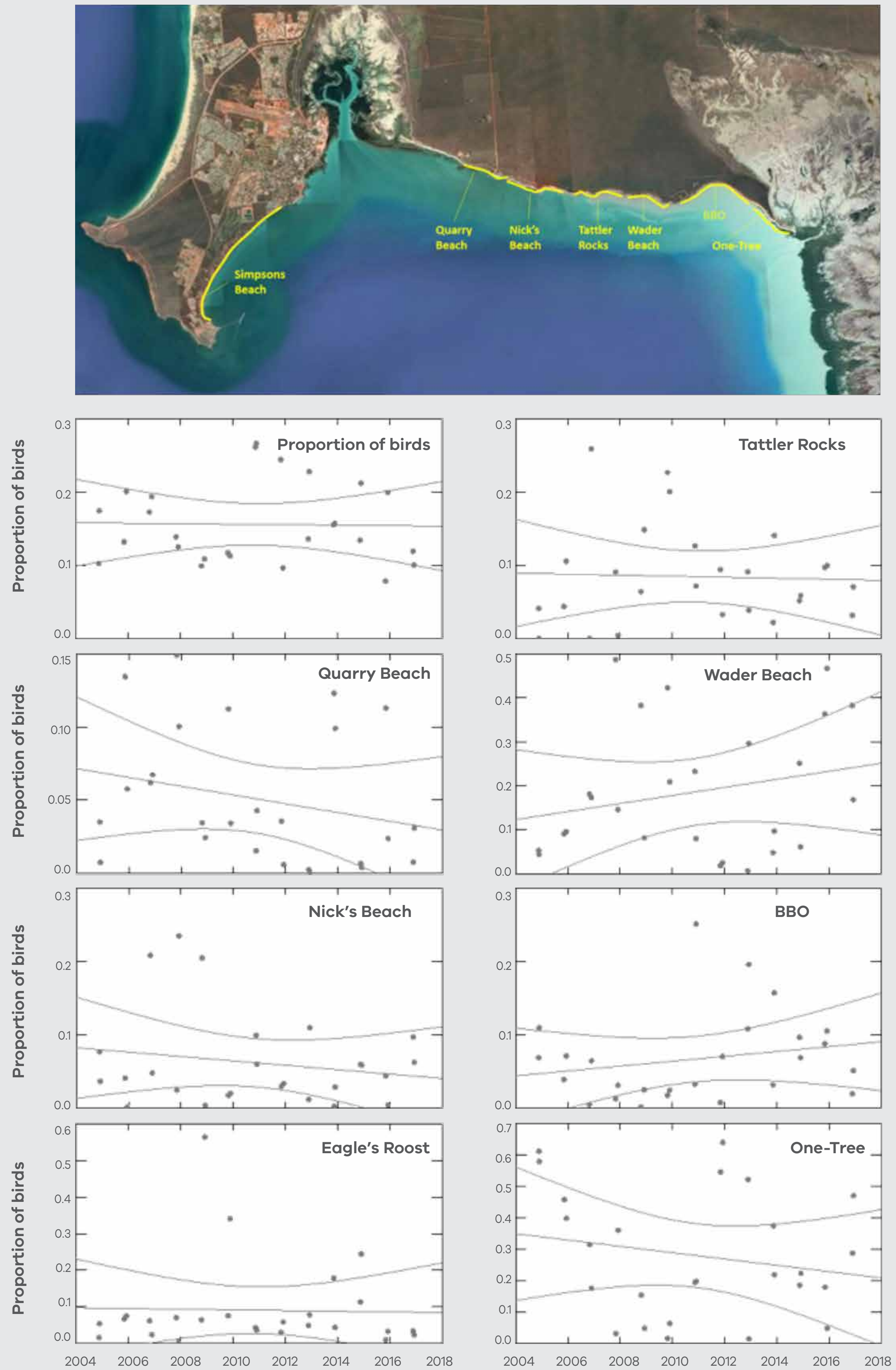


Figure 8. Summer counts: Proportion of the shorebirds in northern Roebuck Bay that roosted in each of the roost blocks indicated in the top panel.

Lines are least-squares linear regressions and their 95% confidence limits.

We also examined proportional use of roost blocks in Roebuck Bay in winter counts (when disturbance levels from birds of prey and raptors is highest) and in summer counts (when disturbance levels are relatively low). There was striking variation (Figure 9): Simpson's Beach, Tattler Rocks, and beaches from Broome Bird Observatory to One Tree Point were abandoned in winter. Shorebirds made substantially more use of roosts with cliffs behind them at this time of year, perhaps because these roosts are less accessible to human visitors.

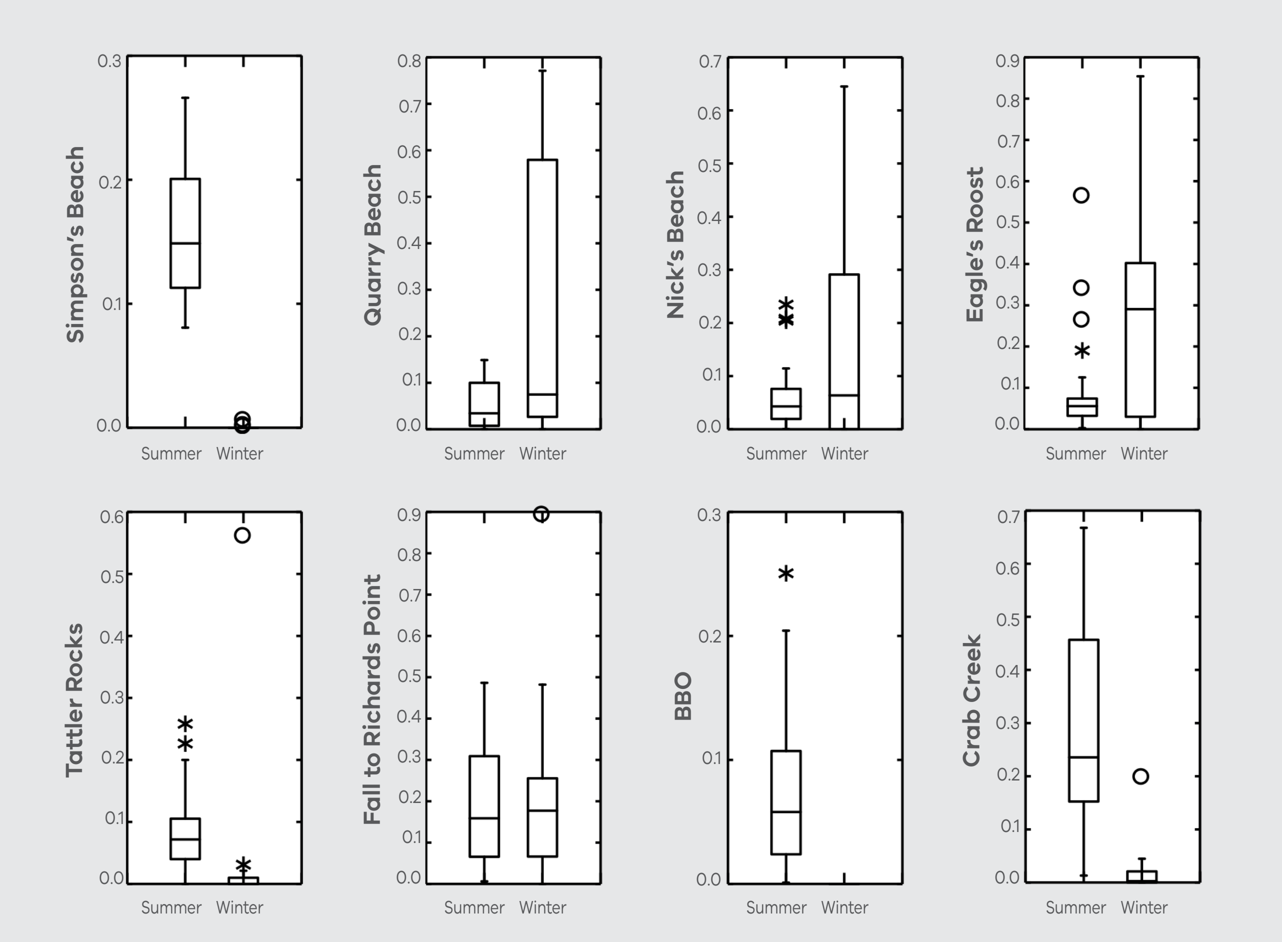


Figure 9. Proportionate shorebird use of different roost blocks in Roebuck Bay in summer counts (November-early December) and winter counts (June – early July).

5 Causes of variation in counts

5.1 Count error

Error in north Western Australian counts was examined by Rogers et al. (2006a) following the first two years of the MYSMA program. In the first two years of the program, the first and second summer count of each season were carried out in quick succession (in consecutive weeks), allowing the starting assumption that number of birds should have been similar in both surveys; the differences in count totals could therefore be examined in relation to site, species, observer, sub-site and number of component counts. Key conclusions closely corresponded with those from an independent study of shorebird count variation in the Dutch Wadden Sea by Rappoldt et al. (1985):

1. There were no systematic differences between observers (all of whom were experienced). This does not mean that there was no count error, but the error was not systematic: the counts by different observers were randomly scattered around the number of shorebirds present, with underestimates being as likely as overestimates.
2. There were between-site differences in error rates when counting individual flocks of shorebirds. The total stochastic error of counts of a shorebird flock was estimated as 30% in Roebuck Bay and Bush Point, and 80% on Eighty Mile Beach (Rogers et al. 2006a). While this error rate may seem high, it is important to note that the errors were not systematic and when combining a number of flock counts to calculate the number of shorebirds present in an area, the random counting errors will tend to neutralise one another.
3. Many component counts contribute to the final totals in MYSMA surveys, especially at Eighty Mile Beach, reducing the relative error considerably. It was estimated that if a significance level of 80% is considered acceptable, then changes in the order of 10-15% in shorebird numbers could be detected between one year and the next.

The capacity to detect such small changes from one year to the next may be useful in limited circumstances, for example when trying to assess if a particular event (such as an oil-spill) corresponds in time with significant changes in numbers of shorebirds. One of the reasons behind the establishment of the MYSMA program was to assess whether shorebird numbers in north-western Australia were affected by the destruction of Saemangeum (a major shorebird staging site in the Republic of Korea); Rogers and Hassell (2017) demonstrate that significant declines in north Western Australia, of the magnitude expected on the basis of Korean counts, coincided with the reclamation of Saemangeum.

It should be emphasised that Rogers et al. (2006a) only described an approach to estimate site-specific observer error in a single survey. Their study did not assess other factors that contribute to variation in counts of shorebirds in north-western Australia, and these are likely to have substantial effects on MYSMA counts. For example in the 13 years of paired MYMSA summer counts analysed in this study, there were eight years when the total number of coastal migratory shorebirds in the first and second count of each season differed by more than 15% (average difference 13.6%). The broad confidence limits of the GAMs, especially in winter counts (section 4), also suggest there is substantial variation in numbers recorded from survey to survey. GAMs do not lend themselves well to conventional power analysis, but it is clear that the statistical power of the MYMSA counts is not high.

The variation observed in shorebird counts in north-western Australia exceeds that expected from random counting error, indicating that much of the variation in counts is caused by genuine variation in the number of birds present. In the following section we consider two important potential causes of variation in north Western Australian shorebird counts: annual variation in breeding success, and local movements of shorebirds into and out of the study area.

5.2 Effects of annual age-ratio variation on counts

A summary of age-ratio data collected in north Western Australia since 1998 is provided in Figure 10. The graphs show that there is substantial variation in age ratios from year to year in all species. In most species the proportion of shorebirds in north Western Australia that are in their first year can be less than 5% in poor years (presumably following a year of poor breeding success), more than 40% in a good year (presumably following a year of high breeding success; Minton et al. 2005 and Aharon Rotman et al., 2015 discuss the link between breeding success and age-ratios). It is also clear that years of high and low breeding success occur at unpredictable intervals. Moreover, years of high and low breeding success are not closely synchronised between species; in many years breeding success is high in some species and low in others.

Figure 10. Annual percentage of first year birds (juveniles) in the most commonly captured shorebirds in north Western Australia.

Data from Minton et al. (2018).

In most coastal shorebird species, maturity is delayed and shorebirds remain in their non-breeding grounds through their first austral winter, not attempting their first northwards migration until they are older (Rogers et al. 2006f); in contrast almost all adult shorebirds migrate to the breeding grounds annually (Rogers et al. 2006f), with the very few that remain on the non-breeding grounds probably being injured or ill. Counts on the non-breeding grounds during the austral winter therefore consist almost entirely of immature birds, and we would therefore expect a strong positive relationship between age ratios during the austral summer and counts in the subsequent austral winter (Rogers and Gosbell 2006).

We examined the correlation between numbers counted in the austral winter, and the estimated number of first-year birds during the austral summer (i.e. summer count multiplied by the proportion of first-year birds within cannon-net catches (Table 8). Analyses were restricted to species captured most often in north Western Australia. Two of these species, Bar-tailed Godwit and Great Knot, have long-delayed maturity, and immatures remaining in Australia during the austral summer comprise a mixture of birds in their first, second and even third year of life. We did not anticipate a direct relationship between age ratio and winter counts in these species, as age ratio is only expected to be related to the number of first year birds (not second or third year birds) in the austral winter. Not surprisingly the relationship between age ratio and winter counts proved to be very weak in these two species. In contrast, in the remaining species, most or all immatures remaining in Australia in the austral winter are in their first year. A strong positive correlation was found in one of these species (Terek Sandpiper) and modest correlations were found in four others (Curlew Sandpiper, Greater Sand Plover, Grey-tailed Tattler and Red Knot). We were however surprised to find a negative correlation (albeit a weak one) between age ratios and winter counts of Red-necked Stint, a species in which there is strong evidence that immatures during the austral winter are all in their first year.

Overall, the relationship between numbers counted in the austral winter, and the estimated number of first-year birds during the austral summer, was far from perfect. A potential issue is imperfect estimation of age ratios during the austral summer; further research is needed on how to estimate the error associated with age-ratios, as there may be some 'bunching' of juveniles so they are not evenly distributed through flocks, and are thus likely to occur in higher proportions in some cannon-net catches than others. It is also possible that winter counts are affected by movements of immature shorebirds in the 4-6 months that elapse between measurement of age ratios in the austral summer, and counts in the austral winter. The different site usage by shorebirds in north Western Australia in summer and winter (section 4.4) suggests that this does occur. Moreover, it is possible that in some shorebird species there is an influx of southern Australian immatures into north-western Australia during the austral winter; for example, Rogers et al. (1996) showed that first year Red-necked Stints in Victoria put on sufficient weight to move to northern Australia during the austral winter. There is a need for more intensive analysis to resolve these issues. In the meantime, it would probably be imprudent to discontinue monitoring either age-ratios in summer, or shorebird numbers in winter. Neither in itself is a perfect measure of breeding success, but both have a positive relationship with breeding success. The magnitude of variation in age ratios from year to year considerably exceeds the magnitude of variation that can be attributed to observer error, so annual documentation of age ratios can play a large part in interpretation of long-term trends in summer count data.

Table 8. Correlations between estimated first-year population in summer and counts during the next austral winter in north Western Australia

Species	Correlation coefficient	Notes
Bar-tailed Godwit	-0.098	Very weak
Curlew Sandpiper	0.602	Modest
Great Knot	-0.056	Very weak
Greater Sand Plover	0.514	Modest
Grey-tailed Tattler	0.449	Modest
Red Knot	0.489	Modest
Red-necked Stint	-0.282	Weak
Terek Sandpiper	0.805	Strong

5.3 Relationship of variance and survey area

The coefficient of variation of counts summarises variability scaled by numbers present. We calculated coefficient of variation for counts of the most numerous shorebird species on Eighty Mile Beach the section 0-5 km S, 0-10 km S etc. Plots of these data (Figure 11) indicated that variability in count totals was high when only short stretches of beach were counted, but decreased as the extent of beach surveyed increased. The relationship was not linear, tending to level off as longer stretches of beach were surveyed. Thus counts confined to the northernmost 10 km of Eighty Mile Beach were considerably more variable than counts carried out in the northernmost 30 km of Eighty Mile Beach, but in general there were modest differences between variability of counts carried out between 0-30 km, and between counts carried out from 0-60 m. A notable exception to this generalisation was Red Knot, in which variance in counts was only modest (rather than high) if over 50 km of Eighty Mile Beach was surveyed.

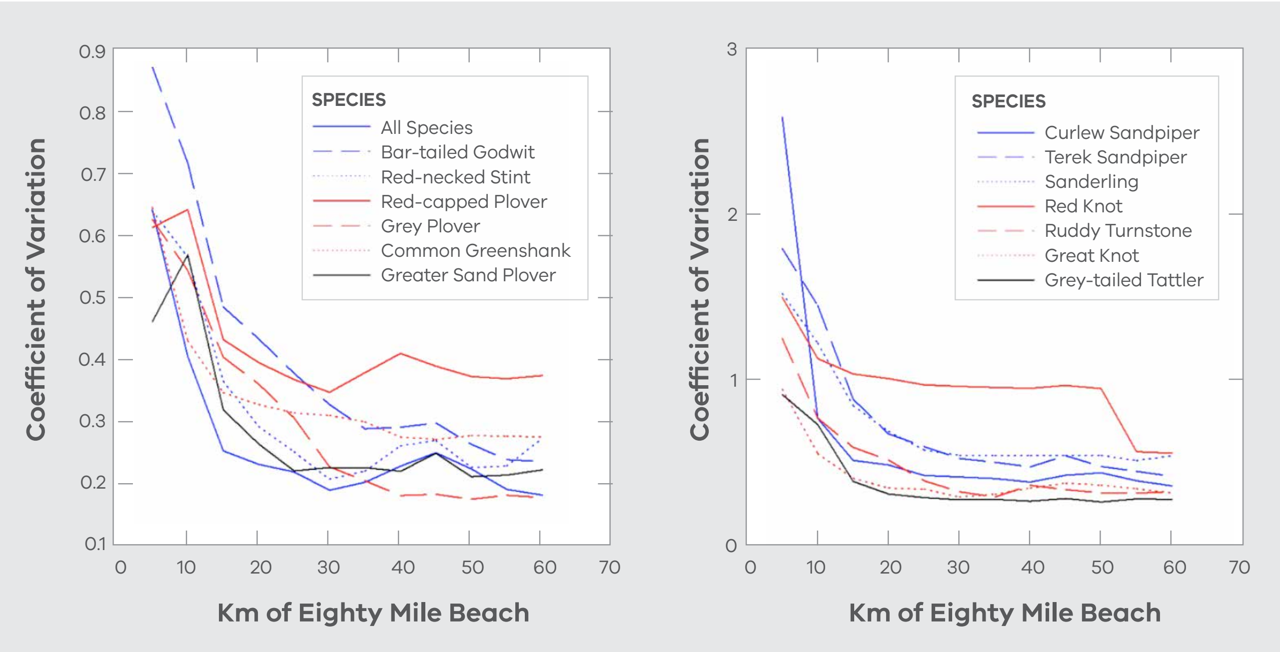


Figure 11. Coefficient of Variation of count plotted agains km of beach surveyed for the most numerous coastal shorebird species of Eighty Mile Beach.

5.4 Site fidelity and local movements

An assumption that underlies monitoring migratory shorebird numbers through counts on the non-breeding grounds is that shorebirds are site faithful through this period (Clemens et al. 2016; Studds et al. 2017). It is certainly true that during the ~7 month non-breeding period shorebirds are more site-faithful than they are during the migration seasons. Indeed, as they are carrying out a complete moult of wing feathers, and their body mass is low, they do not have the physiological capacity to make flights of thousands of kilometres. Banding studies show many of the same individuals returning to the same sites year after year (Leyrer et al. 2006). Estimates of annual apparent survival, based on resightings on the non-breeding grounds, are high in migratory shorebirds (Mendez et al 2018), including those in north-western Australia (Piersma et al. 2016).

These survival studies demonstrate that most individuals return to the same sites on the non-breeding grounds year after year. But they do not confirm that all individuals do so; when only apparent (rather than true) survival is estimated, it is not possible to distinguish birds that have died from birds that have emigrated from the study site. Moreover, while a resighting may demonstrate that a bird has returned to exactly the same site in which it was seen in a previous year, it is only one point in time. It does not prove that the bird was there throughout the non-breeding season. Individuals might make movements during the non-breeding season that are short by the standards of migration, but nevertheless long enough for the bird to move into and out of study areas where there is a chance that the individual will be resighted, or counted during surveys. We therefore explored data from banding and tracking studies for insights on the scale and frequency of local movements in shorebirds in north Western Australia.

5.4.1 Remote tracking studies

Remote tracking techniques are now available to record the position of tagged individual shorebirds over reasonably long periods of time. These have the potential to reveal the extent of local movements and whether they are relevant to monitoring shorebird populations through counts.

The first such studies in north Western Australia involved deployment of small VHF radio-tags on Red and Great Knots in Roebuck Bay; the birds were then tracked locally through a combination of an automatic radio-telemetry array and hand-held radio-tracking (Battley et al 2004, 2005; Rogers et al. 2006c). Battley et al. (2004) found considerable site-faithfulness in Great Knots in this study; 27 were radio-tagged and all remained in northern Roebuck Bay during the two-month study period. Most of these individuals were highly consistent in their diurnal routines, foraging on the same tidal flats day after day, and generally preferring to roost in the closest acceptable site to their feeding grounds (e.g. Figure 12). Roost usage varied according to tide height, whether it was day or night and sometimes because of disturbance, but in most individuals all roosts used were within the study area. A similar pattern occurred in 15 of the 21 Red Knots tracked, but 6 individuals were recorded infrequently, suggesting that at times they moved outside the study area.

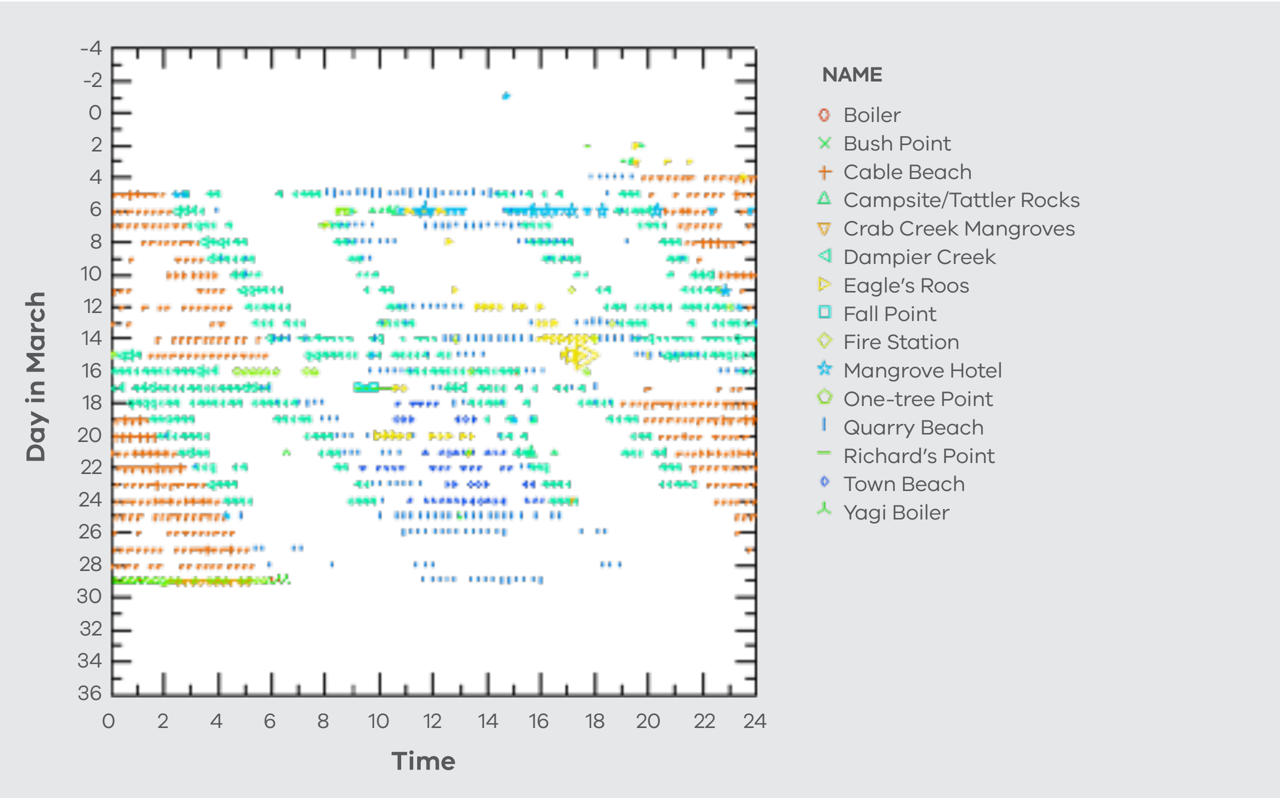


Figure 12. Movements of a Great Knot in Roebuck Bay, Feb-April 2010.

From Rogers et al. (2006c); a working graphic updated regularly during the field study in order to keep track of individual birds. This individual had consistent routines, foraging on the Dampier Creek flats at low tide, roosting at Cable Beach on night-time high tides, and roosting on Quarry Beach or Town (Simpsons) Beach on daytime high tides; on neap tides it moved to the mouth of Crab Creek for several days.

Maintaining a local radio-tracking array is resource-intensive, and the radio-tracking study in 2000 only tracked birds for two months Feb-Apr (during the pre-migratory mass gain period). Birds can be tracked for longer using geolocators, devices mounted on leg-flag that log location estimated on the basis of daylight records and time. Geolocator studies of Greater Sand Plovers (Minton et al. 2011) and Great Knots (Lisovski et al. 2016) tagged in north-western Australia showed that tracked individuals remained in north-western Australia for several months, but the precision of geolocators is insufficient to detect movements within this area.

Higher precision for relocations can be obtained from birds fitted with Platform Terminal Transmitters (PTT tags), which estimate position to a few hundred metres using doppler shifts and send the data to satellites, or from birds fitted with Groupe Spécial Mobile (GSM) tags, which estimate position with GPS precision and send the data to the mobile phone network. PTT or GSM tags have been deployed on several species in north-western Australia by the Global Flyway Network, AWSG and other researchers, but the full data is still being analysed for publication and was not available for this review. However, some tracks of individual birds are shown here as examples of the patterns seen (Figure 9):

1. At the sedentary extreme, the Eastern Curlew (Panel A) remained faithful to the same foraging area on the tidal flats of Roebuck Bay from 20th Feb to mid-March 2019 (note that this was during the wet season and the bird roosted on salt-pans; in dryer weather conditions such as those during surveys between October-December, we would expect the bird to roost on beaches where counts are conducted).
2. The Grey Plover map (Panel B) shows combined tracks of four individuals which were also rather site-faithful, making some local movements and shifts of foraging area during the study period in March 2016, but remaining within the area where they would be detected on MYSMA surveys.
3. The Grey-tailed Tattler map (Panel C) shows combined tracks of three individuals satellite-tagged on Eighty Mile Beach in April 2018. The majority of tracked locations were within the MYSMA survey area, but the birds made long-shore movements along a 100km stretch of Eighty Mile Beach, with some time spent both north and south of the MYSMA survey area (though Cape Missiessy has been added to the survey area since 2010).
4. At the itinerant extreme, the single Red Knot (Panel D) spent some time in Roebuck Bay (usually within the MYSMA survey area) and some time at Eighty Mile Beach during April 2011. While on Eighty Mile Beach it made substantial long-shore movements along a stretch of beach approximately 105km long, with a similar number of tracking records coming from within and outside the MYSMA survey area.

The remote tracking studies that have been carried out in north-western Australia were undertaken primarily to learn about the migrations of shorebirds. Most tracked birds were therefore tagged on AWSG banding expeditions in the departure season (February to March) rather than in the period when MYSMA counts are undertaken, and quantitative analyses of the local movements made by shorebirds before migration have not yet been published. Moreover, only a few species have been studied. The frequency of the movement patterns illustrated in Figure 13 during the period when counts are made is therefore unclear.

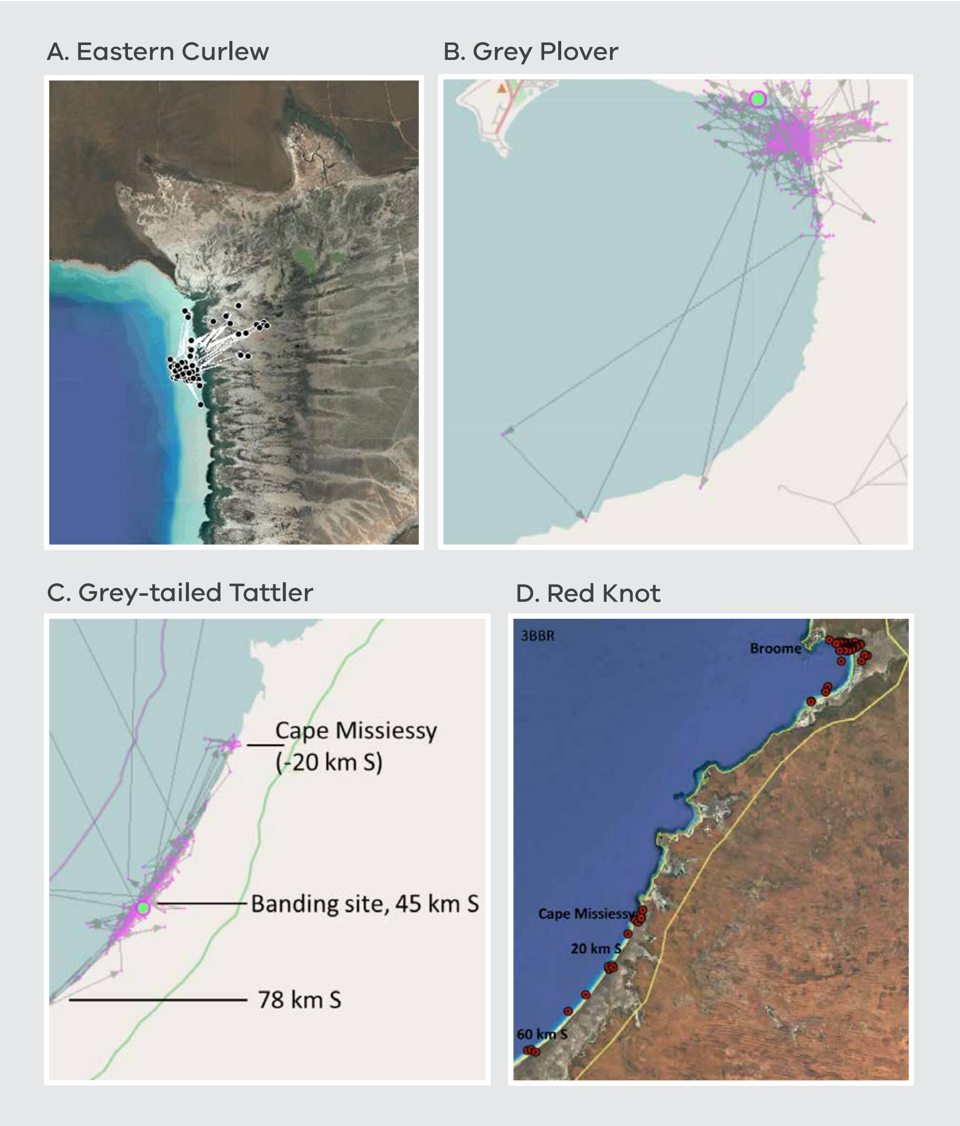


Figure 13. Examples of tracks observed from individual birds with PIT or GSM tags deployed in north-western Australia.

A: Eastern Curlew (Map prepared by Amanda Lilleyman using data from the National Environment Science Program Threatened Species Recovery Hub research project 'Strategic planning for the Far Eastern Curlew' (supported by Darwin Port, Charles Darwin University, Larrakia Rangers and the University of Queensland).

B: Grey Plover (based on data collected by the AWSG, map extracted from Movebank).

C: Grey-tailed Tattler (based on data collected by the AWSG, map extracted from Movebank).

D: Red Knot (based on data collected by the Global Flyway Network).

5.4.2 Band recoveries and flag resightings

We explored resighting and retrap data from north-western Australia to improve our understanding of the frequency of movements between discrete sites. The number of species that have been banded in large numbers in north Western Australia exceeds the number of species that have been studied with remote tracking techniques, so we used the banding dataset to assess whether some species are more sedentary than others. Data of this kind are skewed by observation effort, as resightings and recaptures can only occur in areas where observation or research is being undertaken. We therefore examined movements between Eighty Mile Beach (where some colour-band resighting work and banding is carried out annually) and Roebuck Bay (where there is an intensive resighting and banding program). There were resightings and retraps in other sites in north-western Australia, but these data were recorded opportunistically and irregularly and are not included in the summary in Table 10.

Recaptures of banded birds show that movements between Eighty Mile Beach and Roebuck Bay occurred in most species that were banded in large numbers (Table 10). There were some striking differences between species. A number of species rarely moved between Eighty Mile Beach and Roebuck Bay, notably Bar-tailed Godwit, Greater Sand Plover, Terek Sandpiper and Grey-tailed Tattler, all of which were retrapped in large numbers at the banding sites, but not at alternate sites. At the other extreme, Red and Great Knots often made movements between Eighty Mile Beach and Roebuck Bay, the likelihood of between-site movements being 5-10 times higher than it was in many of the more site-faithful species. We had expected site fidelity of Red and Great Knots to be relatively low, as both species primarily eat bivalves, targetting small and often immature individuals that are more easily digested (van Gils et al. 2005). This is a patchy and impermanent food source which would often be unavailable to individuals that remained in a single small foraging area. Studies overseas have shown that knots tend to be more mobile in the non-breeding season than other shorebird species, presumably because of their reliance on prey species with dynamic spatial distribution (Rehfisch et al. 1996, 2003). Rather to our surprise, Red-necked Stints also proved to be highly mobile, an observation for which we have no immediate explanation.

The proportion of retraps that were documented moving from one site to another were quite low (ranging from 5% in Red-necked Stint to 0.3% in Grey-tailed Tattler) but note that they underestimate of the number of movements that occur. The proportion of birds that are recaptured at the site where they were banded was about 10 - 20% in the most frequently captured species (Table 9). The proportion of birds that are recorded moving from one site to another is a fraction of that fraction. The proportion of birds that actually move between sites can be estimated coarsely by assuming that once an individual has moved, the probability of recapturing it at the new site is the same as the probability of recapturing individuals that were initially banded at the new site. Making this correction (Table 9) suggests that in some species more than 10% of individuals move between Roebuck Bay and Eighty Mile Beach. The number of individuals that sometimes move away from the banding site but are not resighted elsewhere is likely to be higher still, as there are many shorebird sites on the north Western Australian coast where banding is seldom or never carried out.

Table 9. Frequency of recaptures of birds banded at Eighty Mile Beach or Roebuck Bay.

Species	Total caught	Total retrapped	% retraps at banding site	% retraps at alternate site	Estimated % moving from Roebuck Bay to Eighty Mile Beach	Estimated % moving from Eighty Mile Beach to Roebuck Bay
Red-necked Stint	18241	3150 (17.3%)	92.5%	5.0%	15.6%	10.7%
Red Knot	9191	866 (9.4%)	95.7%	4.2%	18.4%	5.5%
Great Knot	31655	4066 (12.8%)	96.2%	3.7%	17.9%	2.9%
Curlew Sandpiper	11740	1569 (13.4%)	96.7%	1.2%	0.2%	2.7%
Ruddy Turnstone	2055	413 (20.1%)	97.6%	1.2%	4.4%	2.1%
Bar-tailed Godwit	14600	1960 (13.4%)	99.2%	0.6%	1.5%	0.8%
Greater Sand Plover	15900	3041 (19.1%)	99.3%	0.4%	0.9%	0.3%
Terek Sandpiper	7977	724 (9.1%)	99.3%	0.3%	1.3%	0.0%
Grey-tailed Tattler	8805	1096 (12.4%)	99.4%	0.3%	0.4%	0.3%
Pied Oystercatcher	277	57 (20.6%)	94.7%	0.0%		0.0%
Red-capped Plover	1307	77 (5.9%)	98.7%	0.0%	0.0%	0.0%
Broad-billed Sandpiper	627	79 (12.6%)	97.5%	0.0%	0.0%	0.0%
Lesser Sand Plover	440	130 (29.5%)	100.0%	0.0%	0.0%	0.0%
Pacific Golden Plover	21	1 (4.8%)	0.0%	100.0%		
Black-tailed Godwit	998	46 (4.6%)	97.8%	2.2%		100%
Common Greenshank	487	11 (2.3%)	100.0%	0.0%	0.0%	0.0%
Whimbrel	586	16 (2.7%)	100.0%	0.0%		0.0%
Grey Plover	359	19 (5.3%)	100.0%	0.0%		0.0%
Sharp-tailed Sandpiper	627	22 (3.5%)	95.5%	0.0%	0.0%	0.0%
Asian Dowitcher	97	1 (1.0%)	100.0%	0.0%		
Marsh Sandpiper	77	1 (1.3%)	100.0%	0.0%	0.0%	
Sanderling	240	3 (1.3%)	100.0%	0.0%	0.0%	

The frequency of movements between sites could be explored further by examining resightings of individual birds with unique engraved leg-flags or colour-band combinations. The probability of resighting leg-flagged or colour-banded birds is higher than the probability of recapturing them and reading their band numbers. Colour-band resightings by the Global Flyway Network show that of 322 Red Knots colour-banded on Eighty Mile Beach, 15.1% were subsequently resighted in Roebuck Bay. This estimate corresponds reasonably well with the 10.7% -15.6% of Red Knots estimated to move between Eighty Mile Beach and Roebuck Bay on the basis of retraps (Table 9). Less intensive resighting work on Eighty Mile Beach also indicates movements of leg-flagged birds between sites; 10% of Red Knots, 1.7% of Great Knots and 0.6% of Bar-tailed Godwits banded in Roebuck Bay have been resighted on Eighty Mile Beach. The AWSG leg-flag database would be a more suitable dataset to use in further exploration of movements of birds from Eighty Mile Beach to Roebuck Bay, as large numbers of many species have been leg-flagged on Eighty Mile Beach and resighting effort in Roebuck Bay is intensive. This dataset was not available when preparing this report.

5.4.3 Implications for monitoring

It is likely that some of the longer movements made by some shorebirds during the non-breeding season (e.g. movements between Roebuck Bay and Eighty Mile Beach) influence shorebird totals recorded on counts. We calculated Chi-squared in the 5 km stretches of Eighty Mile Beach in which shorebirds occurred:

$$\chi^2 = \Sigma \frac{(O - E)^2}{E}$$

Where

O = proportion of the birds on Eighty Mile Beach of birds observed each 5km stretch during a summer count

E = proportion of birds expected in each 5 km stretch, based on mean proportion over the MYSMA study period and assuming that their distribution is similar from year to year.

The sum of chi-squared values was considered an index of variability in distribution of each species on Eighty Mile Beach. In Table 10 species are listed from least to most variable in distribution. Red-necked Stint emerged as the species which varied least in distribution within Eighty Mile Beach – a surprising result given that this species often moves between Eighty Mile Beach and Roebuck Bay (section 5.4.2).

Table 10. Variability in annual distribution of shorebirds within Eighty Mile Beach during summer counts

Species	Chi-squared
Red-necked Stint	14.505
Whimbrel	27.263
Red-capped Plover	28.934
Bar-tailed Godwit	29.346
Greater Sand Plover	38.378
Grey-tailed Tattler	40.858
Terek Sandpiper	44.548
Sanderling	49.894
Common Greenshank	54.716
Pacific Golden Plover	59.410
Grey Plover	60.893
Broad-billed Sandpiper	66.523
Lesser Sand Plover	69.383
Red Knot	84.606
Curlew Sandpiper	91.208
Sharp-tailed Sandpiper	94.501
Ruddy Turnstone	112.386
Marsh Sandpiper	115.894
Great Knot	122.916
Australian Pied Oystercatcher	147.280

Excluding Red-necked Stint, in the most frequently captured species of Eighty Mile Beach there was a strong correlation (0.709, n = 9) between the index of variability in distribution with the frequency of movements between Eighty Mile Beach and Roebuck Bay (Figure 14). This indicates that movements during the non-breeding season make a substantial contribution to variability of counts in north Western Australia. There are some implications for design of count programs, considered further in Sections 5.3 and 7. In short, it suggests that:

1. the larger the count area, the better, because fewer shorebirds making non-breeding movements will move outside the surveyed area;
2. counts should be done in a short time-frame to reduce the chances of birds moving from one day to the next and therefore being missed or double-counted.

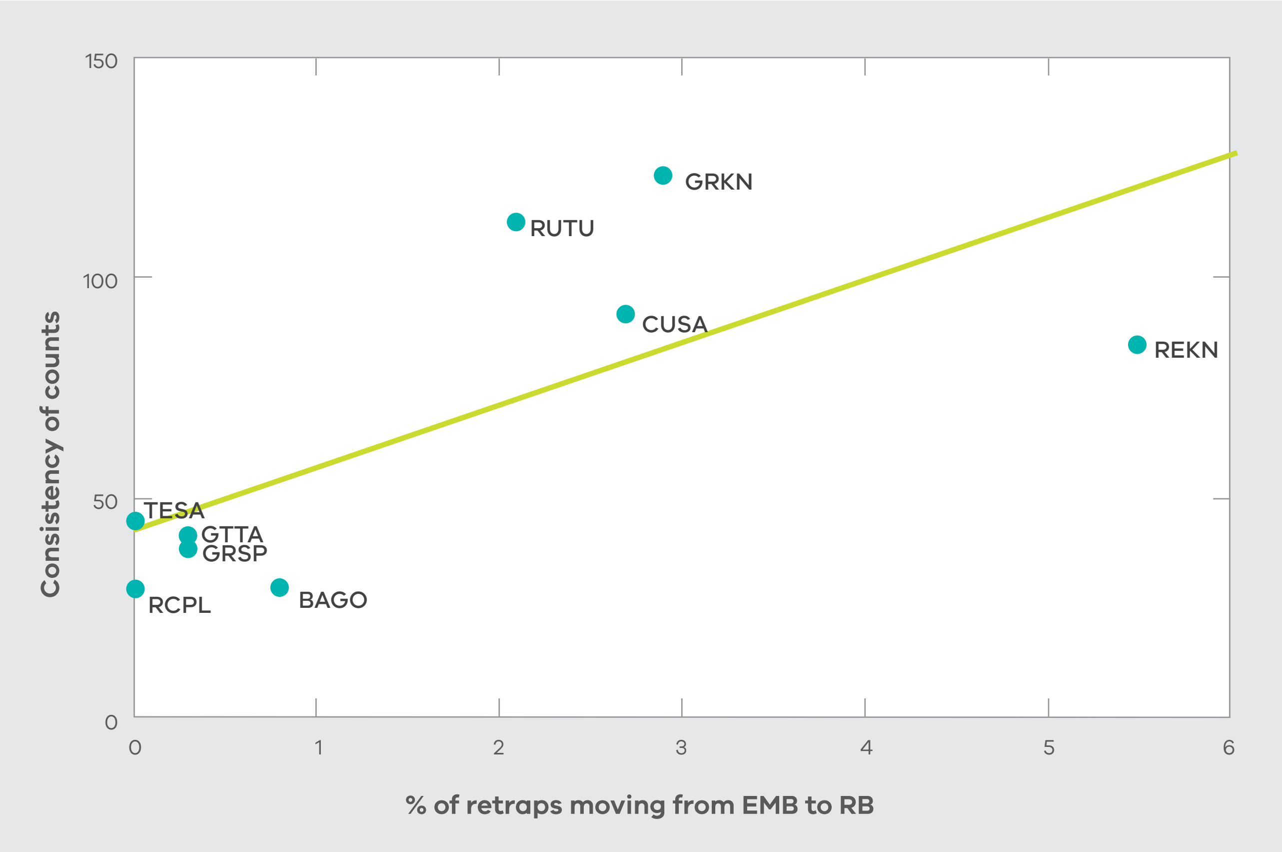


Figure 14. Consistency of counts in 5km stretches of Eighty Mile Beach plotted against the frequency of movements between Eighty Mile Beach and Roebuck Bay.

Chi-squared index of consistency of counts is described in text. Case labels are abbreviations for those species in which > 1000 individuals have been retrapped. The linear smoother is to guide the eye; the correlation between the indices of count consistency and mobility was 0.709

6 Potential cost efficiencies for count program

Shorebirds occur in open habitats, and at high tide they aggregate at roost sites where it is often possible to observe nearly all birds present in a local population. By the standards of wild animals they are therefore unusually easy to count directly, and high tide counts are the main approach for monitoring shorebirds in Australia. There is a wide network of sites in Australia where shorebirds are monitored in mid-summer (November-early February: peak of the non-breeding season for migratory species) and mid-winter (June- July; the breeding season for migratory species, when only immature birds remain in Australia). Shorebird monitoring Australia-wide is carried out by a number of regional groups. Birdlife Australia (currently under the Shorebirds 2020 project) plays a co-ordinating role and maintains the national database into which data are collated. MYSMA data from north Western Australia is vetted annually and imported into the Birdlife Australia national database

Most shorebird surveys in Australia are carried out by volunteers, but in north-western Australia funding support is essential for shorebird counts. Reasons for this include:

- The remoteness of key shorebird sites, most of which can only be accessed by 4WD; at one site (Bush Point) there are times when access is only possible by boat, hovercraft or helicopter.
- The very large numbers of shorebirds present. Organised teams are required to count them and volunteers are always a key part of the teams that monitor shorebirds at Eighty Mile Beach (preferred team size of 9), Bush Point and the northern beaches of Roebuck Bay (preferred team of at least 6). These volunteers are excellent, and carry out essential tasks such as scribing, and counting the more readily identified species. However only highly experienced shorebird-counters have the skills to act as 'primary counters' on Eighty Mile Beach, Roebuck Bay and Bush Point, counting those species that are difficult to identify and leading their counting teams to ensure counts are completed during the high tide period. The density of birds, the high species diversity, and the necessity to count quickly within the constraints of the tides make north-western Australia a particularly challenging area to survey.
- Limited personnel. Few people in Broome (or Australia overall) have the shorebird counting skills needed to carry out successful counts on Eighty Mile Beach, Roebuck Bay and Bush Point; teams can only be secured long term through a combination of providing payment to primary counters, or by flying in highly experienced counters from other parts of Australia.

Below we discuss some of the approaches that have been considered to lower costs of shorebird monitoring by counts in north-western Australia. The most expensive component of the MYSMA surveys is the counts at Eighty Mile Beach. Two important constraints need to be recognised in identifying cost efficiencies at this site:

(1) It is a remote site where temperatures are often very high, accessed by beach-driving. A minimum of two car-based teams is preferred for safety reasons.

(2) Counts at Eighty Mile Beach are spread over three days. Subsampling strategies that do not reduce the number of days spent at Eighty Mile Beach will not result in any cost-saving. Note that we cannot be confident of completing the counts from 0-60 km south of the Anna Plains access point (specifically the 10 km stretch from 50-60 km S) without a third day.

6.1 Alternative approaches

Several approaches that have been proposed for reducing costs of shorebird counts in north-western Australia were considered unsuitable for reasons of cost, impracticality or because they would not provide adequate data. These are summarised below.

6.1.1 Aerial survey

Aerial surveys from fixed-wing aircraft have been widely used to count waterbirds in large or remote areas. A well-known Australian example is the Eastern Australian Waterbird survey led by Richard Kingsford and his team at the University of New South Wales (www.ecosystem.unsw.edu.au/content/rivers-and-wetlands/waterbirds/eastern-australian-waterbird-survey). Aerial survey was also key to identifying significant shorebird sites in Australia during the 1980s and early 1990s (Lane 1987; Chatto 2003), and flights around the entire South American coastline were key to identifying significant shorebird sites in that region (Morrison et al. 1998). Methodology for aerial surveys in Australia has been described by Kingsford et al. (2008).

The use of aerial survey for Roebuck Bay and Eighty Mile Beach is likely to be cheaper than ground-based surveys, as much larger areas can be surveyed in a single day. However, the economies may be relatively small because of:

- Costs of chartering aircraft
- The need to pay three staff per day: one pilot, two counters highly experienced in aerial survey

- The likelihood that surveys would need to be spread over at least two days. In theory the coast from Broome to the southern end of Eighty Mile Beach could be flown in a single day, but shorebirds could only be counted in period of about four hours per day when the tide is high during daylight hours. At low tide when scattered over very large tidal flats, an unknown but large proportion would not take flight as the aircraft approached, and would therefore be overlooked.

Data obtained through aerial survey of the north Western Australian coast would be less well suited for monitoring than ground counts. A key issue is that migratory shorebirds cannot be identified to species level from aerial survey (Nebel et al. 2008), and it is necessary to aggregate shorebird species into coarse categories (e.g. "large Shorebirds", "small shorebirds") when counting them from the air. Earlier in this report (Section 5) we showed that population trends differ markedly between shorebird species in north Western Australia. This information would be lost if aerial survey was the only monitoring approach used, and any trends revealed in overall number of shorebirds seen from the air would be strongly influenced by a small number of relatively numerous species.

A related problem is that aerial surveys would not be able to distinguish migratory shorebirds that depend on tidal flats from other shorebird species. A large proportion of the shorebirds that roost on the north West Australian coast comprises "grassland species" (Oriental Plover, Oriental Pratincole, Little Curlew) that forage on inland grasslands and roost on beaches (with genuinely coastal shorebirds) to avoid high temperatures in the middle of the day (Rogers et al. 2011). At Eighty Mile Beach these species can outnumber the shorebird species that feed on tidal flats. Counts of unidentified shorebirds could therefore be so strongly skewed by grassland species that they provide no usable information on changes in the numbers of shorebirds that are dependent on the tidal flats within Eighty Mile Beach Marine Park.

A final issue is that there is a tendency for aerial surveys to underestimate the abundance and number of species seen during ground counts, especially when numbers are very large (Kingsford 1999, Kingsford et al. 2008). The magnitude of these underestimates differs from site to site, and according to the species being counted. There has been no detailed comparison of aerial counts with ground counts on the north Western Australian coast, but data collected in November 2015 indicate that while ground and aerial counts of total shorebird numbers corresponded well on one stretch of beach (from Jack's Creek to Eco Beach), in general aerial counts were far lower than those obtained on ground counts. If aerial survey were to become the tool used to monitor shorebirds in north Western Australia, aerial surveys and ground counts would need to be conducted concurrently for several years to assess whether conversion factors could be calculated to make aerial surveys comparable with the 15 years of ground count data that have already been collected.

Table 11. Comparison of concurrent ground counts and aerial counts of total shorebird numbers on the north Western Australian coast in November 2015.

All aerial surveys were completed by a highly experienced observer (Adrian Boyle) who also participated regularly in MYSMA ground counts.

Location	Ground Count	Aerial count (10 Nov 2015)
Bush Point (13 Nov 2015)	58512	40000
Jack's Creek to Eco Beach (10 Nov 2015)	5571	5612
Bidyadanga (10 Nov 2015)	4869	600
Port Smith (10 Nov 2015)	117	49
Desault Bay (10 Nov 2015)	1349	325

6.1.2 Drones and photography

Unmanned Aerial Vehicles ("drones") have become widely used by ecologists in recent years. Drones can be flown over habitats that are very difficult to access in other ways, and they can carry cameras or other remote sensing instruments to collect data on the habitat and fauna they fly over. Both drones and the equipment they can carry are getting cheaper, and they have been successful tools for monitoring birds in some settings. In large, colonially nesting birds, for example, imagery from drones has proved to be a cheaper and potentially less intrusive method of data collection than ground counts, and there is experimental evidence that in ground-nesting seabird colonies, the data obtained from drones are more accurate than those obtained from ground counts (Hodgson et al. 2018).

We do not consider drones well suited for monitoring shorebirds on the coast of north Western Australia. The key issues are that the shorebird flocks in north-western Australian hold many species of bird that are difficult to distinguish, the flocks are often spread over areas many hundreds of metres in diameter, and that shorebird flocks readily take flight in response to disturbance. In combination these attributes would make drome surveys challenging and costly. Specific issues that would need to be overcome include:

- Inadequate photograph resolution. We are not aware of any camera and lens combination that could provide adequate resolution of an entire shorebird flock, with all birds in clear enough focus to enable species identification. If any such lenses could be manufactured they would likely be heavier than the payload of any drone likely to be available for wildlife studies.
- As flocks could not be photographed in their entirety, adequate footage could only be obtained by low flights zig-zagging over a shorebird flock. Vas et al. (2015) found a variety of waterbird species surprisingly tolerant of close approach by drones, provided they approached flocks from a low angle (necessitating a low approach speed <8 m s-1, i.e. 22.6 km h-1). More often than not, notoriously flighty species such as Common Greenshank and Greater Flamingo showed no obvious response to close approaches (to 4-10m). Nevertheless, some birds took flight in some trials, and when attempting to count a large flock, any flights would compromise the data collected. Moreover, preliminary data collected by Vas et al. (2015) suggested there may be a positive correlation between size of flock and likelihood of birds taking flight when approached by a drone. Although this hypothesis awaits full testing, it could be highly problematic in north Western Australia, where most shorebird flocks are very much larger than the populations studied by Vas et al (2015), and where shorebirds are often restless in the first two hours of high tide. A final issue is that slow zig-zags over a shorebird flock by a low flying drone would probably be considerably more time consuming than ground counts by observers who can remain in one site and scan the entire flock with telescopes. Careful tests in a north-western Australian setting would be required to find out adequate drone footage for monitoring purposes could be collected.
- Drone piloting requires skills and permits not available to most volunteers – it would require paid personel. Moreover, line of sight is required to operate drones in Australian wildlife studies, and for safety reasons it would be unsuitable for drone pilots to operate alone on Eighty Mile Beach or at Bush Point. The costs of data collection are therefore unlikely to be much lower than the costs of ground counts.
- Ethics approval would be required for drone surveys, and these should be factored into costs.
- Analysis of footage collected from drones to obtain count data would require extensive post-processing work, likely to be considerably more time-consuming than the act of collecting the footage. In contrast, MYSMA ground counts need no post-processing time beyond data entry.
- It is unlikely that post-processing of drone footage would or could be carried out by volunteers; it would require special training, and persuading volunteers to spend hours or days in front of a computer screen is considerably more difficult than persuading them to do fieldwork on spectacular coastlines.
- At present there are no software tools to identify shorebirds automatically from photographs or video footage. It is possible that machine-learning procedures to do so could be developed, but this would require considerable development time by highly trained professionals.
- It would be necessary to run a calibration exercise to test comparability of counts from drone footage with field counts, at least doubling the costs of counts in north Western Australia for several years.

While it is worth keeping track of developments in this field, at present drone footage is not a viable alternative to direct counts of shorebirds in north Western Australia. We suspect the costs could be up to an order of magnitude higher than existing survey methods.

6.1.3 Count a smaller number of species

Some pragmatic reduction of species coverage on MYSMA surveys has already occurred. As discussed in section 2.1.2, the MYSMA program no longer attempts to monitor grassland species (Little Curlew, Oriental Pratincole, Oriental Plover) because the core survey methodology is unsuitable for them. There has also been some discussion within the counting teams about discontinuing counts of terns. The survey program is not ideal for monitoring most tern species, many of which may be foraging at sea when counts are taking place. Terns have not been removed from the count program because (1) it is nearly always possible to count them without disrupting the shorebird-focussed surveys; (2) the MYSMA surveys are the only source of monitoring data for these species in the region. There is now an understanding with the count teams that if they are unusually time-pressed, they can stop recording numbers of most species (making a note that they have done so on the data sheets). However, totals of Gull-billed Tern (both subspecies macrotarsa and affinis) are always recorded because the species forages on tidal flats and roosts with shorebird flocks; it is therefore considered a species that can be monitored effectively during shorebird surveys. Silver Gull numbers are also reported systematically on all surveys, because in many other parts of the world, gull numbers have increased in response to human activities, at times posing conservation problems for other species.

Further reduction of the number of species counted on MYSMA surveys would not reduce survey costs. Most field time on MYSMA surveys goes into counting species which are abundant and should not be removed from the count program because of their conservation importance. Even if MYSMA surveys were trimmed to only include those species listed as Critically Endangered by the Commonwealth Government (Great Knot, Curlew Sandpipers and Eastern Curlew), it would still be necessary to spend a day each at Bush Point and Roebuck Bay, and 2-3 days at Eighty Mile Beach.

Further drawbacks to reducing species coverage include the difficulty in identifying species which are of higher and lower priority, and those most representative of health of the study site. Seven foraging guilds of shorebirds have identified in Roebuck Bay (Rogers 2006), and at least four contain several abundant shorebird species. If monitoring was restricted to just a representative species from each guild, there would be a reduction in the number of species for which temporal trends can be examined. As shown in Section 5, different shorebird species in north Western Australia show quite different trends over time. “Migratory shorebirds” are often referred to collectively in conservation and popular media for simplicity, but they comprise many species that all differ in details of their diet, breeding location and migration route.

Finally, reducing species coverage would not eliminate the need for highly skilled counters as some of the key species in the region (e.g. Great and Red Knot in non-breeding plumage) are quite difficult to distinguish. When counting shorebirds in north western Australia it is essential to have experienced observers who can reliably identify shorebirds at long range using a combination of subtle identification characters.

6.1.4 Count alternate 5km stretches of Eighty Mile Beach

In theory this approach would allow the count area to be reduced without losing data on species that tend to be more common in some parts of Eighty Mile Beach than others. However, the approach is logistically impossible, as driving quickly for 5 km between two count areas would cause a great deal of disturbance, resulting in birds being double-counted or overlooked. Moreover, on much of Eighty Mile Beach the sand is too soft to drive quickly; it is unlikely that counting teams could count 10 km of coastline in a day if they had to interrupt the four-hour high tide period of potential high tide counts in order to drive 5 km to another site.

6.1.5 Discontinue winter counts

Shorebird numbers on the coast of north Western Australia are lowest during the austral winter (dry season) when adult migratory shorebirds are on their breeding grounds in the northern hemisphere. At this time only immatures remain in Australia, the number present each year being considerably more variable than in summer counts (Sections 4.2 and 5.2).

From the perspective of detecting long-term trends, winter counts are not as effective as summer counts. However, we recommend that they be continued because:

1. Discontinuation of winter counts would only provide a modest saving to the costs of the monitoring program in Australia. Winter counts are considerably cheaper than summer counts because there are fewer birds to count, reducing the need to have such large teams, and allowing counting teams to cover more ground per day on Eighty Mile Beach.
2. Winter counts are valuable for assessing breeding success in the previous season, and thus enable some examination of the factors driving long-term trends in summer counts (Section 4.2).
3. Site use of shorebirds differs between winter and summer counts, with higher levels of human disturbance during the winter counts likely to be an important driving factor (Section 4.4). Winter counts therefore provide information that is likely to be needed for effective control of roost disturbance in future.

6.2 Subsampling from MYSMA data to assess whether sampling effort can be reduced

We subsampled from the MYSMA dataset to assess approaches to reducing costs while minimising any loss in our ability to detect changes in shorebird numbers in north Western Australia. We assessed approaches that involved a reduction in sampling area, or a reduction in frequency of sampling. We only modelled scenarios that would reduce survey costs, and that were considered logistically achievable. Our benchmark in these analyses was the standard practice from 2004-2018: two summer counts and one winter count per year at each of Bush Point, northern Roebuck Bay, and the section of Eighty Mile Beach from 0-60 km S of the Anna Plains access point. Since 2010 we have also surveyed some extra sections of Eighty Mile Beach (notably the 20 km section between Anna Plains access point and Cape Missiessy). These additional beach sections have not been included in these analyses because the time series were relatively short.

To assess the likely impact of alternative scenarios for sampling, the full data sets were stripped back as if the data had been collected less thoroughly. The scenarios we modelled are described in section 6.2.4 and the appendix. We compared results of different subsamples using several criteria:

1 Annual cost (presented as a proportion of the cost of carrying out two summer and one winter counts with the existing survey approach)

2 Average number of migratory shorebirds counted per survey. We considered higher counts to be better than lower counts, because (a) they comprise a larger proportion of the population north-western Australia; (b) uncommon species are more likely to be seen in large enough numbers to be monitored.

3 Coefficient of Variation per survey: i.e. percentage variation in counts relative to the mean. Lower coefficients of variation were considered preferable, as they implied the subsampling approach was more repeatable.

4 Trend, assessed through estimated population at the start and end of the study period. We assumed results from the full count program to be 'true" (an assumption discussed more fully in Section 7) and assessed differences from this benchmark, considering the likelihood of making (a) Type 1 errors (false positives); (b) Type 2 errors (failing to detect significant changes); (c) bias in subsampling methods; (d) uncertainty in modelled estimates. Methods are described more fully in section 6.2.1.

5 Periods of negative or positive change in abundance. In some species changes over time were clearly non-linear, with periods of increase, decrease, peaks and troughs in numbers. In such cases, trend estimates over a set time period can be strongly influenced by the timing of study: in Pacific Golden Plover for example (see Appendix 1), trend analyses of summer counts would show clear decrease in a study conducted from 2004-2009, clear increase in a study from 2010-2014, but negligible change over the period 2004-2016. We calculated the first derivative of the GAMs (i.e. rate of change; Appendix 4) to formally identify periods in which significant increases and decreases occurred. Visual inspection of the plots of the GAMs (Appendix 1) is helpful for appreciating the differences observed in different subsampling scenarios; while it does not provide a rigorous statistical separation between subsampling approaches, it does draw attention to some subsampling approaches that produce very different results to the full data set.

6.2.1 Methods of comparing subsamples

We compared counts at the start and end of the study period. The full data set (one winter count and two summer counts from northern Roebuck Bay, Bush Point and 0-60 km S on Eighty Mile Beach) was assumed to be the 'truth' (an assumption discussed further in section 7.1) and differences from this benchmark were assessed. The index used to examine long-term trends was lambda (λ), the annual proportional rate of increase: for example λ = 1.1 means the overall change was consistent with 10% annual increase in population, λ = 0.9 is a 10% annual decrease.

The estimated mean annual rate of increase (lambda) was calculated as follows:

$$r = \frac{logN_t - logN_o}{t}$$

where

$\lambda = \exp(r)$

By calculating lambda for each of the 500 random draws from the parameters of the GAM, the uncertainty in lambda conditional on the fitted model could be calculated; the 95 % confidence interval on lambda was then calculated by computing the 2.5 and 97.5 % quantiles of the 500 estimates. This process was repeated for each data subset based on the alternative sampling scenarios. Graphs were then prepared showing the estimates of lambda +/- the CI for each species, and each sampling scenario (Appendix 3).

Bias and variance in the estimated of lambda derived from the different sampling scenarios were assessed relative to those derived from the full dataset (i.e. we assumed that the estimate of lambda derived from the full dataset was the "truth"

For each scenario, we calculated the bias as:

$Bias\ (\lambda) = \lambda_{scenario} - \lambda_{full}$

A negative bias implies that the scenario in question underestimated the population rate of increase, relative to the inferences of the full model.

The Root-mean square error (RMSE) was calculated from the set of 500 random estimates of lambda for each scenario, and the estimate of λfor the full model:

$$RMSE = \sum \sqrt{\frac{(\lambda - \lambda_{full})^2}{500}}$$

The estimates of RMSE for each scenario are plotted on graphs for each species and scenario to illustrate the accuracy with which each subsampling scenario estimates the assumed "true" lambda derived from the full model (Appendix 3).

The scenarios modelled are summarised in Table 7, and GAMs of the subsampled datasets are graphically in Appendix 1 (summer counts) and Appendix 2 (winter counts). Further discussion of each modelled scenario is provided in section 6.2.2.

We also examined inflection points in the graphs to assess whether peaks and troughs visible in the full dataset were represented in the subsampled data sets. To distinguish periods of increasing or decreasing abundance we examined plots of first derivatives (equivalent to rate of change) against year (Appendix 4).

6.2.2 Comments on specific subsampling approaches

Comments on the advantages and disadvantages of each subsampling approach are given below, including commentary on their cost, logistic considerations and their statistical performance. Overview tables and graphs are provided in section 6.3.

Scenario 1: Discontinue counts of Eighty Mile Beach

Discontinuation of counts at Eighty Mile Beach would lower costs of shorebird counts in north-western Australia to 53.6% of their current level, and would be logistically easy to achieve. However, the monitoring data obtained would be considerably inferior to those currently collected. About 67% of the shorebirds in the study area occurred on Eighty Mile Beach (range in summer surveys 58-77%; in winter surveys 46-58%), and for 14 of the 21 shorebird species modelled, Eighty Mile Beach was the main site in north-western Australia. One species (Marsh Sandpiper) could not be monitored at all without count data from Eighty Mile Beach as it occurs too infrequently in other coastal sites.

Not surprisingly, Eighty Mile Beach drove a considerable part of the temporal variation seen in the study area overall (see section 5.2). However, trends on Eighty Mile Beach were different to those in other sites (especially Roebuck Bay) in many species, and in several species (including numerous species such as Greater Sand Plover, Grey Plover, Ruddy Turnstone, and Terek Sandpiper), trends and inflections in the GAMs detected on Eighty Mile Beach differed from those of the full survey area. Correlations between counts in Roebuck Bay, Eighty Mile Beach and Bush Point could be either positive or negative, and were weak (r<0.19) to very weak (0.20 - <0.39) in most species (Table 11). In other words, counts at Bush Point or Roebuck Bay would not provide an adequate index of shorebird numbers at Eighty Mile Beach.

Scenario 2: Discontinue counts of Bush Point

Discontinuation of counts at Bush Point would lower costs of shorebird counts in north-western Australia to 73.6% of their current level, and would be logistically easy to achieve. About 18% of the shorebirds in the study area occurred on Bush Point (range in summer surveys 9-27%; in winter surveys 28-46%), and for 2 of the 21 shorebird species modelled, Bush Point was the main site in north-western Australia. One species (Asian Dowitcher) could not be monitored at all without count data from Bush Point as it occurs too infrequently in other coastal sites. Trends at Bush Point were different to those in other sites in many species; Type 1 Errors (false positives) were uncommon if Bush Point was excluded from analysis (only observed in 2 of 20 compared species) but Type 2 Errors (failure to detect change) occurred in 6 of 20 compared species when Bush Point was excluded from analysis. A number of species underwent increases in summer counts at Bush Point while decreasing in the northern section of Roebuck Bay (Section 5.2.1). We suspect this to be caused to birds moving roosting habitat in response to mangrove encroachment into roost sites on the northern beaches of Roebuck Bay (Section 4), a strong incentive to ensure that counts at both sites are continued. Moreover, correlations between counts in Roebuck Bay, Eighty Mile Beach and Bush Point were generally weak (Table 11), indicating that counts at Eighty Mile Beach or Roebuck Bay would not provide an adequate index of shorebird numbers at Bush Point.

Scenario 3: Discontinue counts of Roebuck Bay

Discontinuation of counts at Roebuck Bay would lower costs of shorebird counts in north-western Australia to 80% of their current level, and would be logistically easy to achieve. About 11% of the shorebirds in the study area occurred on the northern shorebird of Roebuck Bay (range in summer surveys 7– 9 %; in winter surveys 4-23%), and for 5 of the 21 shorebird species modelled, Roebuck Bay was the main site in north-western Australia. One species (Black-tailed Godwit) could not be monitored at all without count data from northern Roebuck Bay as it occurs too infrequently in other coastal sites. In many species trends on the northern beaches of Roebuck Bay were different to those in other sites (Section 5), and if Roebuck Bay was excluded, Type 1 Errors (i.e. incorrect conclusions that changes had occurred over time) occurred in 11 of 21 species: in this respect, excluding Roebuck Bay was the worst-performing scenario. Correlations between counts in Roebuck Bay, Eighty Mile Beach and Bush Point could be either positive or negative, and were weak (r<0.19) to very weak (0.20 - <0.39) in most species (Table 11).

Scenario 4: Reduce count area on Eighty Mile Beach to 0-30 km

If counts on Eighty Mile Beach were reduced to the 30 km stretch of coast directly south of the Anna Plains access track, only one day of fieldwork would be required at Eighty Mile Beach, and costs would be reduced to 53.3% of their current level. The total number of birds counted per survey in this reduced area was 63% of that seen in the total area. Counts of some species were reduced still further, notably Red Knot: on average, over half the Red Knot in the north Western Australia study area occurred on the 30 – 60 km S sector of Eighty Mile Beach, a stretch of coast that would be excluded in this scenario. On eight of 26 summer surveys over 90% of the Red Knot on Eighty Mile Beach occurred in the sector 30-60 km S (outside the area modelled in this scenario), and on four of the surveys, the Red Knots between 30-60 km S comprised >80% of the Red Knot in the entire study area.

Variation in count totals performed well under this scenario; Relative Mean Square Error was fairly low and the coefficient of variation (variation relative to number of birds counted) was 13.8%, lower than any other count scenario. The scenario was also one of the more accurate in detecting trends (2 Type 1 errors and three Type 3 errors among the 21 species modelled). However, non-linear periods of increase and decrease in the full data set were not reflected so well in the reduced data set, differing from the full model in 9 of 21 modelled species.

Table 11. Correlation coefficient (Pearson's r) between summer counts at Eighty Mile Beach, northern Shores of Roebuck Bay and Bush Point in the period 2004-2016 (n = 26 comparisons for each species).

Species	Eighty Mile Beach - Bush Point	Eighty Mile Beach - Roebuck Bay	Roebuck Bay - Bush Point
Asian Dowitcher	-0.174	0.544	-0.158
Bar-tailed Godwit	-0.403	0.373	0.148
Black-tailed Godwit	-0.1	0.338	-0.254
Broad-billed Sandpiper	0.077	0.214	-0.152
Common Greenshank	-0.194	0.062	0.264
Curlew Sandpiper	-0.067	0.163	0.078
Eastern Curlew	0.082	-0.218	-0.263
Great Knot	-0.031	0.108	0.053
Greater Sand Plover	-0.091	-0.248	-0.297
Grey-tailed Tattler	0.095	-0.087	0.044
Grey Plover	-0.212	-0.139	-0.058
Lesser Sand Plover	-0.415	0.353	0.086
Pacific Golden Plover	0.039	-0.126	-0.294
Red-necked Stint	0.482	0.271	-0.148
Red Knot	0.463	0.428	0.341
Ruddy Turnstone	0.059	0.147	0.139
Sanderling	0.279	0.381	-0.005
Sharp-tailed Sandpiper	-0.42	0.236	-0.0062
Terek Sandpiper	0.033	0.212	0.364
Whimbrel	0.463	0.331	0.418

Scenario 5: Reduce count area on Eighty Mile Beach to 0-50 km

If counts on Eighty Mile Beach were reduced to the 50 km stretch of coast directly south of the Anna Plains access track, two days of fieldwork would be required at Eighty Mile Beach, and costs would be reduced to 76.2% of their current level. The total number of birds counted per survey in this reduced area was 84% of that seen in the total area. As in the previous scenario, Red Knot was undercounted, because on average 89% (annual range 31 – 99 %) of the Red Knots occurring from 30 – 60 km S occur in the final 10 km from 50-60 km S.

By most statistical criteria, this was one of the most suitable subsampling criteria, with low variance, and a low incidence of incorrectly estimating trends. However it only performed moderately well in detecting briefer periods of negative or positive change in abundance shown by the full data set.

Scenario 6: Count alternate 10 km stretches of Eighty Mile Beach

This scenario was considered because some species show a clear preference for northern sections of Eighty Mile Beach while others have a preference for more southerly sections (Section 3). In theory, by counting in alternate 10km stretches there is a greater chance of encountering all species in large numbers. The approach would also allow a three-vehicle team to carry out fieldwork at Eighty Mile Beach in a single day, lowering costs to 53.3% of their current level.

Logistically this approach poses challenges. It would involve each vehicle on Eighty Mile Beach operating 20km from the nearest vehicle, increasing the amount of time needed for one team to assist another if an emergency arose (such as a vehicle getting bogged on a rising tide). Eighty Mile Beach counts are done on rising tide series, in which the tides are higher and later each day: typically the stretch from 0-30 km is counted on the first day, from 30 to ~50-60 km S on the second day, 50-60 km S on the third day. It is convenient that the more distant sites are counted on later days of the tide series, as the long beach drive to these sites can be carried out in daylight. Much of it would need to be driven in darkness if the southernmost sites were also counted on the first day, potentially increasing the risk of bogging vehicles or disturbing nesting turtles. Moreover, the southernmost sites would be counted in on slightly lower tides than in previous surveys. There would be some loss in repeatability of methods, and technical difficulties in the sectors from 40-60 km S, where the beach is very broad and some tidal flat areas remain exposed for much of the tide cycle; the effective duration of high tide (when tidal flats are submerged and birds are close enough to the beach to be identified) would be shorter, making it extremely difficult to complete counts before the tide ebbed.

Two approaches could be used in counting alternate 10km stretches of beach. "Alternative A" involves counting the sectors from 0-10, 20-30 and 40-50 km S of the Anna Plains access point. "Alternative B" would theoretically involve counting the sectors from 10-20, 30-40 and 50-60 km S of the Anna Plains access point. In practice, past experience has shown that it is not always possible to count the stretch from 50-60 km S in a single day, because shorebirds on this section of beach are numerous and restless, sometimes failing to settle before the tide peaks and forcing teams to start their counts half-way through the high tide period. For this reason, in the "Alternative B" subsampling scenario, we assumed that the area counted would comprise sections 10-20, 30-40 and 50-55 km S of the Anna Plains access point.

Perhaps for this reason, the "Alternative B" subsampling scenario was one of the least effective scenarios that we modelled. The total number of birds counted per survey in this reduced area was 61% of that seen in the total area, but some species were strongly under-represented: notably Common Greenshank and Marsh Sandpiper, which are consistently most abundant in the northern 10km section of Eighty Mile Beach (section 4). Alternative B was more likely to generate Type 1 errors in trend than any other scenario, and also the scenario most likely to fail to detect periods of increase and decrease visible in the full data set.

"Alternative A" was more satisfactory. The total number of birds counted per survey in this reduced area was 63% of that seen in the total area, and most species were counted in reasonable numbers, though Red Knot were under-represented. Variance in counts, as demonstrated by coefficient of variation and RMSE, was relatively low and the incidence of Type 1 errors (false positives) in estimating trends was very low. It was also one of the better subsampling scenarios in terms of detecting periods of increase and decrease visible in the full data set, and in terms of the incidence of Type 2 errors.

Scenario 7: Carry out complete MYSMA surveys every second year

If one summer and two winter surveys of the complete MYMSA area were conducted every second year, costs would reduce to 50% of their current level, and the number of birds seen per survey would not be expected to change. Logistically this scenario would be relatively easy to achieve. A possible concern is that it may be more difficult to maintain a committed team of volunteers without annual surveying activity. It is also possible that this schedule might not fit well with funding cycles, increasing the risk of a survey being missed.

Statistically this was one of the better subsampling scenarios examined, performing moderately well by most criteria; the magnitude of bias and incidence of Type 1 errors were among the lowest in the subsampling scenarios we modelled.

A final concern is that if a catastrophic change should occur to part of the study area (such as an oil spill, or substantial changes in beach morphology following a cyclone), it could remain undetected for almost two years before any local conservation action was taken. No such event has occurred since MYSMA surveys began, making it a difficult scenario to model, but we cannot assume that no such events will occur in future.

Scenario 8: Carry out one full summer count per year

Reducing the summer count program from two surveys to one survey per year (while retaining winter counts) would bring annual costs to 61.3% of their current level. There would be no change in the number of birds counted per survey. Logistically this scenario would be easy to achieve, and it would indeed be convenient for the field teams. The October-December period when MYSMA surveys occurs is a busy time of year for shorebird biologists and involvement in MYSMA surveys often involves rescheduling or cancelling other work.

Statistically this was one of the better subsampling scenarios examined, performing moderately well by most criteria; the magnitude of bias and incidence of Type 1 errors were among the lowest in the subsampling scenarios we modelled. It performed particularly well at detecting periods of increase and decrease shown in the full data set, and was one of the scenarios least likely to result in Type 1 errors (detecting false positives).

6.2.3 Overview of subsampling approaches

Table 12 presents 7 statistical indices of each subsampling scenario modelled: number of birds counted, coefficient of variation, number of species in which inflections in GAMs were inconsistent with the full model, number of species in which Type 1 errors occurred, number of species in which Type 2 errors occurred, Bias and Relative Mean Standard Error. In Table 13 these are presented as ranks, with the lowest rank assigned to the best scenario. In Figure 15 these ranks are summed, to give a single index of statistical quality for each subsampling scenario; this is plotted against the cost of each subsampling scenario to give a visual impression of their merits or otherwise. Note that each component of the statistical rank was treated as equally important in this plot: for example the number of birds counted was treated as being of equal importance to the likelihood of making Type 1 errors when interpreting trends. It would be possible to weight each criteria according to their importance if this was subsequently decided to be a better approach for the management needs in north-western Australia.

Scenarios which involved dropping one or more monitoring sites (Roebuck Bay, Eighty Mile Beach or Bush Point) were considered poor because (1) they resulted in a small proportion of the birds in the MYSMA study area being counted; (2) correlations between sites were weak, indicating that number of birds at one site cannot be adequately predicted from numbers at another site; (3) trends over time differed between sites, something important to document in itself, and also affecting assessments of trend in the broader study area. One scenario involving reduced count effort at Eighty Mile Beach (Alternative B) also performed poorly.

None of the remaining five subsampling scenarios wholly replicated findings from the full data set, but for most species they did detect similar patterns and magnitude of change over time. The choice of which of these scenarios is preferable cannot be based wholly on statistical criteria. It is not possible to foresee exactly what questions may be asked of the data in the long-term future, so there is unavoidable subjectivity in assessing whether some criteria (e.g. repeatability of surveys) are more important than others (e.g. detection of peaks and troughs in shorebird numbers over time). Moreover there are other important considerations including cost, logistical difficulty and flexibility of use of the resultant data.

We consider the final scenario, carrying out one winter and one summer count per year, to be the most suitable subsampling scenario. Statistically it was one of the most suitable scenarios modelled, logistically it is the easiest to achieve, and it would achieve a substantial reduction in costs (to 60.1% of current levels). It also has the advantage that the entire MYSMA study area would be surveyed annually (increasing the likelihood of rapid detection of catastrophic local changes if they should occur), and that the dataset could be subsampled further if that was considered desirable (e.g. only using data from 0-30 km of Eighty Mile Beach for analyses in which low coefficients of variation are considered the highest priority).

Table 12. Comparison of subsampling scenarios

Scenario	No. of migratory shorebirds (excluding grassland species)	Co-efficient of Variation	No. of species in which inflections incorrect	Trend: Type1 errors	Trend: Type 2 errors	Bias	RMSE (relative mean square error)
All sites	271311	15.8	0	1	0	0	0
80 Mile Beach only	184648	20.3	9	2	5	0.003	0.004
Bush Point only	53452	28.9	12	7	3	0.087	0.087
Roebuck Bay only	33209	18.6	10	3	8	-0.004	-0.004
No Bush Point	217858	17.7	6	2	6	-0.006	-0.006
No Roebuck Bay	238101	17.7	6	5	1	0.027	0.0266
30 km only	170595	13.8	9	2	3	0.009	0.009
50 km only	227503	17.0	8	1	3	-0.005	-0.005
Alternating A	171207	15.2	7	0	5	-0.016	-0.0155
Alternating B	166347	17.5	13	4	6	0.024	0.0235
Every 2nd year	280215	17.5	8	2	4	0.012	0.011
Single count	260537	16.1	5	2	5	0.012	0.011

Table 13. Comparison of subsampling scenarios, expressed as ranks (the lower the rank the better).

Scenario	No. of migratory shorebirds (excluding grassland species)	Co-efficient of Variation	No. of species in which inflections incorrect	Trend: Type1 errors	Trend: Type 2 errors	Bias	RMSE (relative mean square error)
All sites	2	3	1	1	1	1	1
80 Mile Beach only	7	11	8.5	2	8	9	9
Bush Point only	11	12	11	7	4	12	12
Roebuck Bay only	12	10	10	3	12	11	11
No Bush Point	6	8	3.5	2	10.5	6	6
No Roebuck Bay	4	9	3.5	5	2	5	5
30 km only	9	1	8.5	2	4	7	7
50 km only	5	5	6.5	1	4	3	3
Alternating A	8	2	5	0	8	8	8
Alternating B	10	7	12	4	10.5	10	10
Every 2nd year	1	6	6.5	2	6	2	2
Single count	3	4	2	2	8	4	4

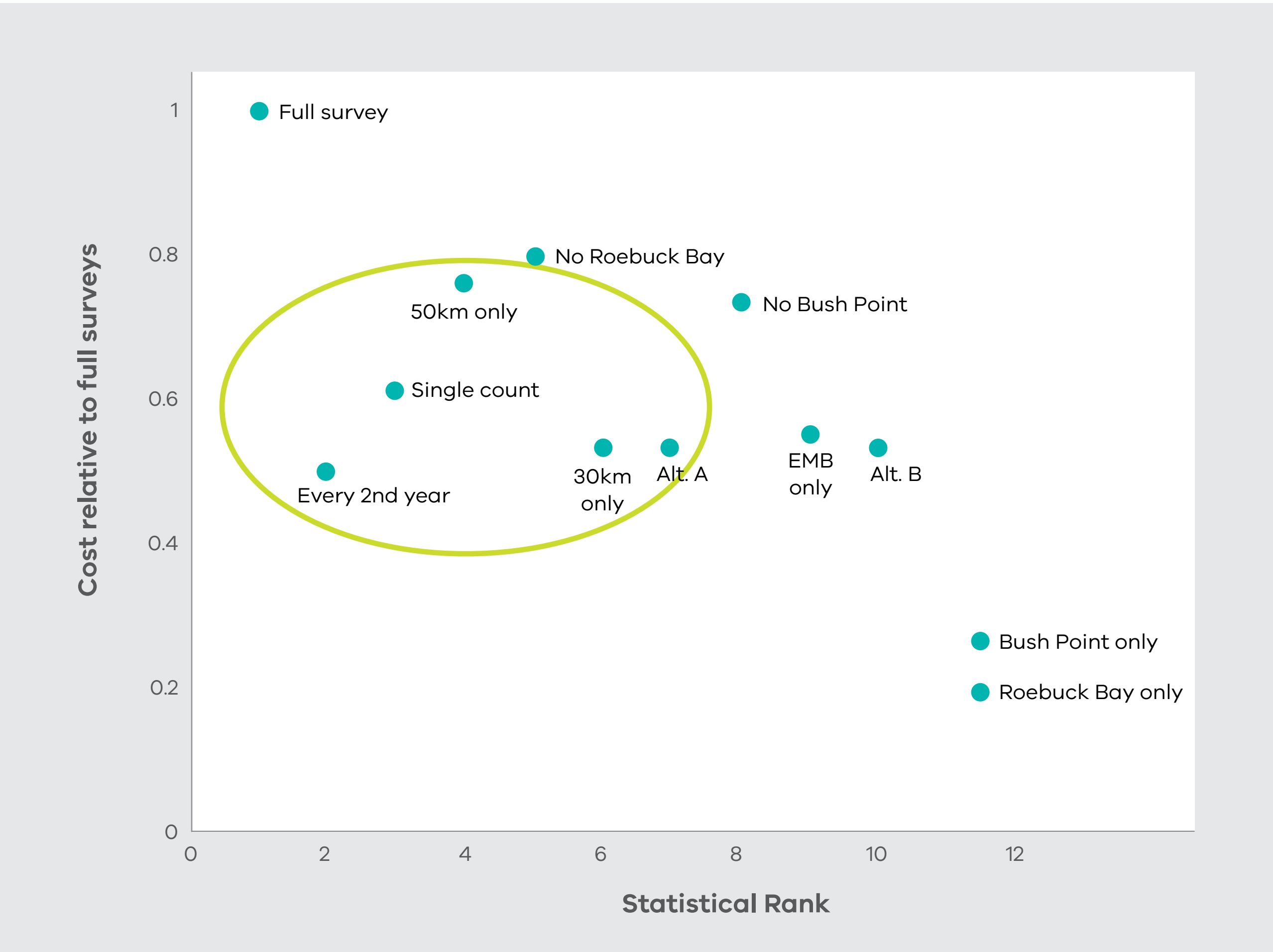


Figure 15. Statistical rank of subsampling approaches (1 = best, 12 = poorest) plotted against cost relative to full MYSMA surveys.

The scenarios within the red oval are considered statistically adequate and cheaper than existing survey methods.

In Table 14 we present a one-table summary of the subsampling scenarios considered for quick reference when making decisions about funding allocations for future shorebird surveys in north Western Australia.

Table 14. Comparison of subsampling scenarios

Scenario	Cost as % current levels	Logistic notes	Statistical notes
Retain current program	100	Achievable	Benchmark for scenarios below
Eighty Mile Beach only	54.8	Achievable	Unsatisfactory – trends differ in other sites, so trends for the full survey area could not be assessed when only using data from one site
Roebuck Bay only	20.0	Achievable	
Bush Point only	26.4	Achievable	
No Eighty Mile Beach	53.6	Achievable	Unsatisfactory – due to differences in trends between sites, trends for full area can only be assessed if all are sampled
No Roebuck Bay	80.0	Achievable	
No Bush Point	73.6	Achievable	
Reduce Monitored Eighty Mile Beach area to 0-30 km S	53.3	Achievable	Reasonably good count repeatability. Only 63% of birds in MYSMA area counted; in 13 species fewer than half of EMB's birds monitored.
Reduce Monitored Eighty Mile Beach area to 0-50 km S	76.2	Achievable	Good count repeatability – statistically the closest scenario to full data set. Key species (notably Red Knot) would be under-represented.
Reduce Monitored Eighty Mile Beach area to alternating 10km stretches (Alternative A)	53.3	Very difficult time constraints in S. OH&S challenges, problems with comparisons of existing data	Reasonably good in terms of repeatability, detection of trends and inflections in data. Only 63 % of birds in area counted and some species under-represented.
Reduce Monitored Eighty Mile Beach area to alternating 10km stretches (Alternative B)	53.3	Very difficult time constraints in S. OH&S challenges, problems with comparisons of existing data	Quite poor in terms of repeatability, detection of trends and inflections in data. Only 63 % of birds in area counted and some species under-represented.
Survey every second year	50.0	Achievable. Some challenges retaining skill levels of team	Reasonably good in terms of repeatability and detection of trends, moderate in detecting inflections in data. Two-year gap between survey periods might cause slow detection of catastrophic change.
One winter count and only one summer count each year	61.3	Achievable – most convenient option for field teams	Best subsampling scenario for detecting inflections in data, reasonable in terms of repeatability and good at detection of long-term trends.

7 Discussion

7.1 Trends in shorebird populations of north Western Australia

Generalised Additive Models showed that numbers of many shorebird species in north Western Australia changed or fluctuated between 2004 and 2016 (Section 4.2). While changes over time appeared near-linear in some species (e.g. Bar-tailed Godwit and Curlew Sandpiper at Eighty Mile Beach), in some species changes over time were clearly not linear, with identifiable peaks and troughs occurring during the study period.

Over the entire survey area, summer counts of six species declined significantly between 2004 and 2016. Five of these species were also declining in other parts of Australia (no Australian estimates were available for the sixth species). It is very likely that the declines were driven by factors outside Australia, such as loss of staging habitat in the Yellow Sea (Studds et al. 2017), given the improbability of the alternative explanation that north Western Australia and other Australian sites were undergoing concurrent, unnoticed environmental deterioration (Clemens et al. 2016).

Clemens et al. (2016) and Studds (2017) found Australia-wide declines in eight shorebird species that did not undergo detectable declines in north Western Australia between 2004 and 2016. This suggests that shorebirds in north Western Australia are faring relatively well, though it is possible that north Western Australian declines in some of these species will become apparent as the data set becomes longer. A number of shorebird species showed non-linear changes in numbers over time, with peaks and troughs over abundance. It is therefore likely that in some species, assessments of whether or not there have been long-term trends in numbers will be influenced by the timing of study.

Temporal trends in shorebird numbers were not consistent between Eighty Mile Beach, Roebuck Bay and Bush Point, and in several species increases at one site coincided with declines at another. The factors driving these differences between sites remain unclear. We suspect that increases in several species at Bush Point may have been caused by displacement of birds from the northern beaches of Roebuck Bay, where there is evidence suggesting that shorebird numbers are decreasing in several roost sites with encroaching mangroves. There is more compelling evidence that some roosts on the northern shores of Roebuck Bay are abandoned during winter months where disturbance levels are highest (Section 4.4). While these suspicions are difficult to confirm, it is clear that it is necessary to monitor shorebirds at all three sites to assess trends in the north Western Australian population.

7.2 Causes of variation in counts

Shorebird counts on the coast of north Western Australia are quite variable. Variation caused by observer error was examined by Rogers et al. (2006a), who concluded that if a significance level of 80% is considered acceptable when counting flocks, then changes in the order of 10-15% in shorebird numbers could be detected between one count and the next (section 5.1). This apparent contrast between errors in counting individual flocks and error in overall counts results from flock count errors not being systematic; when combining a number of flock counts to calculate the number of shorebirds present in an area, the random counting errors will tend to neutralise one another

The level of count variation that can be attributed to error is exceeded by the variation from year to year caused by annual fluctuations in breeding success, and the consequent number of immature birds (in their first year) that reach north Western Australian breeding grounds (Section 5.2). The proportion of birds present that are immature can comprise less than 5% of the north Western Australian population in a poor year, and over 40% of the population in a good year. It is not possible to predict when 'poor' and 'good' years will occur, but it is possible to estimate the proportion of immatures present annually. This can be done using age-ratios in cannon net catches during the austral summer, or by examining winter counts (when only immatures remain in Australia). Although there are strong positive correlations between age-ratios in winter counts, there are also some puzzling anomalies; these anomalies require further examination, and would be better understood if an integrate population model could be developed (Section 7.4). In the meantime it is desirable to maintain annual assessments of age ratios, and winter counts, so that the role that breeding success plays in population changes in north Western Australia can be assessed.

Band recoveries, colour-band resightings and (largely unpublished) tracking studies show that shorebirds are not wholly sedentary during the non-breeding season. Regular "commuting" movements between roosting and foraging sites are reasonably well understood, and the MYSMA counting program was designed in such a way that they do not have large effects on numbers counted (section 2.1). However, it is now clear that some shorebirds make longer movements within the non-breeding season (section 5.4), at times relocating many kilometres to new feeding areas that are within reach of different roost sites. The magnitude of variation in counts caused by these movements is difficult to quantify. However, it is clear that some species move more often during the non-breeding season than others (section 5.4.2), and that there is a strong correlation between the mobility of a species and the variance in their counts (section 5.4.3). Movements during the non-breeding season are therefore likely to make a substantial contribution to variability of counts. Too little is known about movements during the non-breeding season to predict when they will occur, or where mobile birds will move too. Perhaps ongoing analyses of tracking data will solve some of these problems, but in the absence of such information, it is prudent to carry out shorebird counts over a large spatial scale in a short time frame. The shorter the survey the period, the smaller the proportion of count birds that will be double-counted or overlooked when moving to new sites. The larger the survey area, the more likely it is that local non-breeding movements will result in mobile birds re-settling in another part of the survey area rather than straying outside the area that is monitored.

7.3 Future monitoring: counts

The trend analyses in this report, and the modelling of subsets of the full shorebird count data set to identify efficiencies in the future count program, both assume the full MYSMA data set to be the 'truth' – i.e. representative of trends of shorebird numbers on the north Western Australia coastline. However spatial coverage of the MYSMA surveys is not complete; it comprises about 85 km of the full coastline of ~470 km that was surveyed during complete surveys of the north Western Australian coast in 2008 and 2015.

The complete surveys demonstrate that the MYSMA surveys cover those parts of the north Western Australian coast that hold most shorebirds; 75.5% of the coastal migrants counted in the full survey of 2008 occurred within the annual MYSMA survey area, and 71.3% of the coastal migrants in the full survey of 2015 occurred within the annual MSYMA survey area. It would not be possible to increase the proportion of north Western Australian shorebirds monitored annually without increased resources.

It is possible that if shorebird declines occur in north Western Australia, they will first affect shorebird numbers in suboptimal sites and that shorebird numbers in the best sites (where largest numbers occur) will be more resilient as these sites presumable provide better habitat. We see no obvious solution to this issue. There is unlikely to be enough funding, or enough volunteers, to undertake annual counts of the shorebirds of the entire north Western Australian coastline. Discontinuing counts in part of the current survey area to initiate surveys in areas known to have fewer shorebirds would be illogical, especially given the desirability of continuity of data collection. At present we consider it best to maintain annual MYSMA surveys and carry out complete counts of the north Western Australian coast every few years as funding opportunities allow. It would also be desirable to be alert for opportunities to monitor 'lesser' sites. For example there may be Broome-based volunteers who could monitor sites that are near Broome but not within the MYSMA survey area, such as Reddell and Cable Beach.

We subsampled from the MYSMA dataset to assess approaches to reducing costs while minimising any loss in our ability to detect changes in shorebird numbers in north Western Australia. Effectiveness of each scenario was compared with cost, logistic achievability and a number of statistical criteria. Statistical criteria cannot be considered a wholly objective approach to identification of the most suitable monitoring scenario, as the weight given to each criterion depends on decisions made about the objectives of the monitoring. Several of the scenarios modelled did a reasonably good job of detecting change while lowering costs, and there is inevitably some subjectivity involved in choosing the most appropriate.

Our preference was for reducing the existing program (one winter and two summer counts annually) to one summer count and one winter count annually. Statistically it was one of the most suitable scenarios modelled, logistically it is the easiest to achieve, and it would achieve a substantial reduction in costs (to 60.1% of current levels). It also has the advantage that the entire MYSMA study area would be surveyed annually (increasing the likelihood of rapid detection of catastrophic local changes if they should occur), and that the dataset could be subsampled further if that was considered desirable (e.g. only using data from 0-30 km of Eighty Mile Beach for analyses in which low coefficients of variation are considered the highest priority). Finally, an appealing feature of this scenario is that it is effective for a species of particular interest, the Red Knot. The demographic studies carried out by the Global Flyway Network are especially complete on Red Knot; in additional to the intensive resighting effort carried out in north Western Australia, there is also intensive resighting work at a key staging site in China (Lok et al. 2019); in combination with the north Western Australian resighting data it offers the potential for more detailed identification of when mortality occurs in the annual cycle (Piersma et al. 2017) and to estimate true (rather than apparent) survival. It is a particularly suitable species for integrated population monitoring, so maintaining capacity to track population trends is highly desirable.

7.4 Future monitoring: demography

Three shorebird projects in north Western Australia monitor aspects of shorebird demography important to interpretation of changes in shorebird populations:

- The Australasian Wader Studies group assesses age-ratios annually in seven species of migratory shorebird by AWSG. The project is carried out by volunteers and largely self-funded, but there is some logistic support from DBCA and Broome Bird Observatory for the annual banding expeditions in which data are collected.
- Survival studies carried out by the Global Flyway Network (GFN), involving colour-banding of four species and intensive resighting effort. Data is analysed by a research team in the analysis and has resulted in several important publications. The program requires considerable funding input, largely through Dutch funds raised by Theunis Piersma. The sustained effort required to fund this project has been remarkable but is unlikely to last indefinitely. In the long term there will probably be a need for Australian funding input to continue the project, or investment to ensure results are published
- Deployment and resighting of engraved leg flags deployed as most coastal shorebird species in north-western Australia by the AWSG; a number of species are resighted in large enough numbers for survival analyses. The project is largely carried out by volunteers who carry out the fieldwork and (with considerable difficulty) manage to maintain data entry. A new system for data-handling is currently being developed

All three projects were designed to collect data relevant to interpretation of changes in shorebird populations, and the fieldwork has been running successfully since the early-mid 2000s. The projects conducted by the AWSG and GFN are separate, but they support and depend on one another to some extent; for example AWSG equipment and volunteers are important to deployment of colour bands on GFN birds, and a very large proportion of resightings, both of colour-banded and leg-flagged shorebirds, are made by GFN staff during funded fieldwork.

Analysis and publication of data from these studies lags behind data collection, especially for the AWSG leg-flagging project. There is a need for integrated population modelling, tying together survival, age-ratio data and population counts for a much complete understanding of the causes of population changes in north Western Australian shorebirds. Ideally work of this kind should also generate scripts allowing analyses to be repeated readily as further data comes in year by year; this would greatly enhance capacity to assess the extent to which changes in north Western Australian are influenced by local factors.

There is also a need for strategic thought on how to maintain long-term monitoring of survival of shorebirds in north Western Australia. The GFN project depends on ongoing funding; the AWSG project has lower funding requirements but struggles with maintaining data entry and analyses. It would be prudent to test the comparability of survival estimates derived from GFN data (colour-banded birds) and AWSG data (birds with engraved leg flags) to ensure continuity is possible should one of the projects come to an end. In the meantime, it is desirable to maintain both AWSG and GFN programs until integrated population analyses have been carried out and regular reporting tools have been developed.

7.5 Future monitoring: disturbance

The three previous studies of shorebird disturbance on the northern beaches of Roebuck Bay (Rogers et al. 2006d, Sitters et al. 2012) have followed the same general approach: prolonged observation by stationary observers at key roost sites, in which the number of disturbance events and the duration of alarm flights is recorded. The studies have been effective, demonstrating high and increasing levels of disturbance on northern beaches of Roebuck Bay, with seasonal variation in disturbance levels and higher disturbance at some beaches than others. The work has prompted some management responses (e.g. signage, public awareness, alterations to access) but there has been no recent assessment of success; the last survey was carried out in 2007/08. Broome Bird Observatory's recent initiation of a repeat disturbance study (a year-long study commencing August 2019) is therefore a welcome development.

Disturbance studies on the northern beaches of Roebuck Bay have been modestly priced, though they required some funding support for analysis and reporting. However the studies have been brief (one year), in part because they place high demands on volunteers, probably making continuous monitoring in this way unachievable. We recommend more frequent surveys – perhaps every 3-5 years - but the frequency of surveys would need to be assessed according to volunteer capacity and funding availability.

Although data from the MYSMA count program suggest that disturbance and mangrove encroachment are causing some reduction in shorebird numbers on the northern shores of Roebuck Bay, the data are not wholly conclusive (Section 4.). The MYSMA count program is not well suited to detecting changes in roost usage because of high variation in counts at individual roosts (Section 5). Disturbance is such that during any single high tide there are usually periods when thousands of birds are present and periods when none are present; an impractically high frequency of counts would therefore be required to detect changes in site use.

We suggest that a potential supplement to disturbance studies on Roebuck Bay would be more effective capture of the observations of birdwatchers. Skilled birdwatchers, including Broome Bird Observatory staff, tour guides and researchers, visit most roosts of northern Roebuck Bay on a regular basis – most roosts are probably visited near-daily during the tourist season. It would not be reasonable or achievable to ask the birdwatchers to record detailed disturbance information on these visits (tour-guiding and research are demanding activities in their own right). However, with near-daily roost visits, it should be possible to assess if roost quality is changing over time with only the following data recorded on each visit: location, time, date, a rough approximation of the number of shorebirds (e.g. to the nearest order of magnitude) and number of people on the beach. It should be possible to develop a mobile phone application so this information could be recorded on site in a few seconds, with automatic data upload to a central database. Developing such an application would require some initial investment but if the app was used regularly, if only by a relatively small number of birdwatchers who visit the bay regularly, in the long term it may prove a cheap and sustainable way to monitor disturbance.

7.6 Monitoring grassland shorebirds

Oriental Plover, Little Curlew and Oriental Pratincole occur in internationally significant numbers in north Western Australia. It is likely that the region is the non-breeding stronghold of Oriental Plover (Piersma and Hassell 2010), and at times supports most of the world population of Oriental Pratincole (Sitters et al. 2014). None of the three species are monitored adequately anywhere else in their range.

All three species forage on near-coastal grasslands, and roost on ocean beaches at the hottest part of day (section 2.1.2). As a result, they cannot be monitored adequately through the existing MYSMA program. They could, however, be monitored through bespoke monitoring on Eighty Mile Beach, with car-based observers recording numbers present on the beach when high tides coincide with the hottest part of day. The species are distinctive, and can be identified and counted by a team based in a moving vehicle. It is therefore possible for a team based in a car to count numbers of these species over stretches of coast up to 40 km long during a single high tide (Sitters 2004; Piersma and Hassell 2010; pers. obs).

It would be possible to design a program to count these species. We suggest such a program would best involve two counts per year. Counts would be most repeatable in November-December while the grasslands behind Eighty Mile Beach are dry. We also recommend a February count, as past experience suggests that this is when Oriental Pratincole numbers are most likely to peak.

Several Broome-based ornithologists would be capable of leading such a project. The proposed survey program may also be well suited to the talents of ranger groups, provided there was a budget for training and developing a mechanism to handle data.

7.7 Reporting

Reporting of shorebird monitoring in north Western Australia includes:

- A brief report prepared after every MYSMA survey. It includes preliminary totals from the survey (final vetting of these totals occurs later, during the data entry phase) and a table comparing the counts with previous MYSMA surveys. It is circulated to the shorebird counting team and other interested stakeholders, but is not circulated publicly.
- Annual assessments of age ratios are published in journal Arctic Birds (http://www.arcticbirds.net/), an online journal read mainly by shorebird biologists. They include tables comparing age ratios over the years but there is no formal analysis of temporal trends. There are also reports on the annual banding expeditions in which the catches for age-ratio measurement are made. They are circulated to expedition participants and other interested stakeholders. They include tables summarising totals caught but no formal analyses
- The Global Flyway Network sends informal reports to all participants and expeditions after all catching attempts and resighting expeditions.
- The data collected from the monitoring projects is used as a basis for publications in scientific journals (many of them listed in the references section of this report); these papers are directed at scientific audiences and in some cases at conservation managers. They appear irregularly as time and resources and time permit.

With the exception of scientific publications, the primary function of the monitoring reports is to keep volunteers and other supporters informed and engaged. While serving this purpose adequately, broader awareness of the work being done is limited, potentially increasing the difficulty of supporting the programs long term.

The annual reporting currently in place does not include detailed analyses, and there is therefore no formal mechanism to ensure that findings essential to conservation management are identified and released in a timely manner. This is not ideal, as a fundamental purpose for monitoring threatened species is to detect changes early enough to implement corrective conservation actions if necessary. In practice this may be achieved in an informal manner in north Western Australia, as the data compilations used in the existing report framework do involve some data exploration by team leaders with a deep knowledge of shorebirds and commitment to shorebird conservation. Catastrophic changes in count totals or age ratios would therefore be likely to be noticed. However, more subtle or localised changes could be overlooked without more detailed analysis. Changes in survival rates would not be be obvious through casual data inspection, and could only be detected through regular analysis.

A mechanism used in some monitoring programs to ensure regular review of data is an 'alerts' advisory tool: if declines exceed a pre-set level (e.g. a 50% decline over a five year period), this is considered a trigger requiring investigation of the causes (e.g. Atkinson et al. 2006, Loyn et al. 2014). In north Western Australia, this kind of investigation would inevitably need to focus on the question of whether the declines were only occurring in north Western Australia (implying a local conservation issue that could be addressed by local management) or whether they were occurring nationally (implying that the declines were driven by factors in other countries). At present addressing this kind of question would involve substantial and expensive analysis. In the foreseeable future, it may become considerably more achievable. With funding from the Commonwealth Government, Birdlife Australia is currently developing a tool to automate trend analyses from the national shorebird database, and to establish it in a portal where it can be interrogated at need.

Another likely focus of any investigation of detected declines in north Western Australia would be an assessment of whether they were driven by decreased recruitment of young birds, decreased survival of adult birds, or both. While data relevant to this question are collected in north Western Australia, a full analysis would be time-consuming in the absence of existing integrated population analyses (Section 7.4). Deakin University, in collaboration with the Victorian Wader Study Group and AWSG, is currently working on a project to program survival analyses and report regularly on them; when developed it should become a helpful tool for timely analyses of survival data.

With these analysis and reporting tools still in development, and in the absence of integrated population models, it would be premature to establish an 'alerts' system to trigger investigations of declines in north Western Australian shorebirds, though doing so would be a desirable long-term target. In the meantime, we suggest it would be helpful to generate more informative annual reports for the shorebird count program in north-western Australia, including graphical output of simple analyses (such as the GAMs used in this report). This would ensure some annual data inspection to detect emerging issues, and would make annual reports better suited for circulation beyond those directly involved in the monitoring project.

Conclusions

1. By the standards of wildlife monitoring, migratory shorebirds are monitored unusually well in north-western Australia.
2. Adequate shorebird count data are collected in north Western Australia to detect long term changes and to identify peaks and troughs in abundance of ~20 shorebird species.
3. North Western Australia remains a region of enormous importance to migratory shorebirds. Counts indicate that shorebirds of north Western Australia are faring well by modern standards, but national declines are being reflected in declines of a number of species.
4. Subsampling from the count data collected between 2004-2016, we conclude that the current survey area should be maintained, but that if the current shorebird count program was reduced to one winter and one summer count annually (instead of two summer counts annually), monitoring costs would be ~60% of their current level with little loss in our capacity to detect changes in abundance.
5. Identification of the causes of changes in shorebird abundance in north Western Australia requires comparison of trends with other shorebird populations, and collection of additional demographic data. This additional information is important if changes caused by local conditions (potentially controllable through local conservation actions) are to be distinguished from changes driven by factors elsewhere in the migration route (the responsibility of other agencies or countries)
6. Demographic monitoring is therefore a valuable component of shorebird monitoring in north Western Australia. Excellent, relevant data are being collected by the AWSG (annual assessment of age ratios in ~10 species) and by the Global Flyway Network (detailed survival studies in four species) Issues of potential concern are:

- lags between data collection and analysis
- monitoring of survival is heavily dependent on continued overseas funding of the Global Flyway Network program in Australia

7. If some of the money saved from a reduced counting program could be allocated to demographic monitoring, priorities would include:

- Integrated Population Monitoring analyses, combining count, age-ratio and survival data into a single model to identify the factors driving population changes.
- Identifying and implementing measures to ensure the continuity of demographic monitoring.

8. High variation in counts at individual roost sites makes the count program insufficient to detect deterioration of roost sites in a timely manner. Independent assessments of disturbance levels on the northern Beaches of Roebuck Bay, preferably at 3 years intervals or less, are recommended to track changes in roost quality. We also propose development of a system (probably a mobile phone) app to capture basic data from birdwatches who visit the area regularly.
9. Grassland shorebird species that roost on Eighty Mile Beach in mid-day heat are not currently monitored adequately; we propose an approach to monitor them repeatably.

References

Aharon-Rotman, Y., Soloviev, M., Minton, C., Tomkovich, P., Hassell, C. & Klaassen, M. (2015). Loss of periodicity in breeding success of waders links to changes in lemming cycles in Arctic ecosystems. *Oikos* **124**, 861–870.

Atkinson, P.W., Austin, E.E., Rehfish, M.M., Baker, H., Cranswick, P., Kershaw, M., Robinson, J., Lagnston, R.H.W., Stroud, D.A., van Turnhout, C. and Maclean, I.M.D. (2006). Identifying declines in waterbirds: the effects of missing data, population variability and count period on the interpretation of long-term survey data. *Biological Conservation* **130**, 549 – 559.

Austin, G.E., I. Peachel and M.M. Rehfisch. (2000). Regional trends in coastal wintering waders in Britain. *Bird Study*, **47**, 352-371.

Austin, G.E., Banks, A.N. and REhfisch, M.M. (2007). *The UK Wintering waterbird indicator: new developments towards a more comprehensive assessment of trends in the wintering waterbird assemblage*. BTO Research Report No. 479.

Bamford, M., Watkins, D., Bancroft, W., Tischler, G., and Wahl, J. (2008). *Migratory shorebirds of the East Asian- Australasian Fyway; Population Estimates and Internationally Important Sites.* Wetlands International – Oceania. Canberra, Australia.

Battley, P.F., D.I. Rogers, T. Piersma and A. Koolhaas. (2003). Behavioural evidence for heat-load problems in Great Knots in tropical Australia fuelling for long-distance flight. *Emu* **103**, 97-104.

Battley, P.F., T. Piersma, D.I. Rogers, A. Dekinga, B. Spaans and J. van Gils. (2004). Do body condition and plumage during fuelling predict northwards departure dates of great Knots (Calidris tenuirostris) from North West Australia? Ibis 146: 46-60.

Battley, P.F., D.I. Rogers, J.A. van Gils, T. Piersma, C.J. Hassell, A Boyle and Y Hong-Yan. (2005). How do red knots Calidris canutus leave Northwest Australia in May and reach the breeding grounds in June? Predictions of stopover times, fuelling rates and prey quality in the Yellow Sea. *Journal of Avian Biology* **36**, 494-500.

Blakers, M., Davies, S.J.J.F. and Reilly, P.N. (1984). *The Atlas of Australian Birds*. Melbourne Univesity Press, Melbourne).

Blew, J., K. Günther, B. Hälterlein, R. Kleefstra, K. Laursen, G. Scheiffarth 2016. *Trends of Migratory and Wintering Waterbirds in the Wadden Sea 1987/1988 - 2013/2014*. Wadden Sea Ecosystem No. 37., Common Wadden Sea Secretariat, Joint Monitoring Group of Migratory Birds in the Wadden Sea, Wilhelmshaven, Germany

Blomqvist, S., Holmgren, N., Åkesson, S., Hedenström, A., & Pettersson, J. (2002). Indirect Effects of Lemming Cycles on Sandpiper Dynamics: 50 Years of Counts from Southern Sweden. *Oecologia*, **133**, 146-158.

BTO (2017). *Wetland Bird Survey. Survey methods, analysis and interpretation*. Version 2. BTO, Norfolk. https://www.bto.org/sites/default/files/webs_methods.pdf

Chatto, R. (2003). *The distribution and status of shorebirds around the coast and coastal wetlands of the Northern Territory*. Parks and Wildlife Commission of the Northern Territory. Technical Report 73.

Christie, M. (2006). South Australian Wader Studies – an overview. *Stilt* **50**, 247-277.

Clemens, R.S., Kendall, B.E., Guillet, J. and Fuller, R.A. (2012). Review of Australian shorebird data, with notes on their suitability for comprehensive population trend analysis. *Stilt* **62**, 3-17.

Clemens, R.S., Rogers, D.I., Hansen, B.D., Gosbell, K.G., Minton, C.D.T., Straw, P, Bamford, M., Woehler, E.J., Milton, D, Weston, M.A., Venables, W., Weller, D., Hassell. C, Rutherford, W., Onton, K., Herrod, A.., Studds, C.E., Choi C-Y, Dhanjal-Adams, K., Murray, N.J., Skilleter, G. and Fuller, R.A. (2016). Continental-scale decreases in shorebird populations in Australia. **Emu 116**, 119-135

Cresswell, W. (2014). Migratory connectivity of Palaearctic-African migratory birds and their responses to environmental change: the seasonal residency hypothesis. *Ibis* **156**, 493-510.

Essig, E.C. (2016). *Long-term population trends and habitat preferences of waders at Strandfontein Wastewater Treatment Works.* MSc thesis, University of Cape Town.

Estrella, S. M., Storey, A.W., Pearson, G. and Piersma, T. (2011). Potential effects of Lyngbya majuscula blooms on benthic invertebrate diversity and shorebird foraging ecology at Roebuck Bay, Western Australia: preliminary results. *Journal of the Royal Society of Western Australia* **94**, 171-179.

Estrella, S. M. (2013). *Effects of nutrient enrichment and toxic Lyngbya blooms on benthic invertebrates- and migratory shorebird communities of Roebuck Bay Ramsar site*. Final report to the NRM Office, WA. May 2013.

Hansen B. D., Fuller R. A., Watkins D, Rogers D. I,. Clemens R. S., Newman, M., Woehler, E. J. and Weller D.R. (2016) *Revision of the East Asian-Australasian Flyway Population Estimates for 37 listed Migratory Shorebird Species*. Report for the Department of the Environment. Birdlife Australia, Melbourne. http://www.environment.gov.au/biodiversity/publications/revision-east-asian-australasian-flyway-population-2016

Hansen, B.D., Clemens, R.S, Gallo-Cajiao, E., Jackson, M.V., Kingsford, R.T., Maguire, G.S., Maurer, G., Milton, D.A., Rogers, D.I., Weller, D.R., Weston, M.A., Woehler, E.J. and Fuller, R.A. (2018). Shorebird monitoring in Australia: a successful long-term collaboration among citizen scientists, governments and researchers. Chapter 11 in Legge, S., Lindenmayer, D., Robinson, N., Scheele, B., Southwell, D. and Wintle, B. (Eds). *Monitoring threatened species and ecological communities.* CSIRO Publishing, Clayton.

Harebottle, D.M., Navarro, R.A., Underhill, L.G. and Waltner, M. (2006). *Trends in numbers of migrant waders (Charadrii) at Langebaan Lagoon, South Africa, 1975-2003*. Waterbirds around the world. Eds. G.C. Boere, C.A. Galbraith & D.A. Stroud. The Stationery Office, Edinburgh, UK. pp. 376-378.

Henry, D.A.W. and O'Connor, T.G. (2019). Survey frequency affects the estimates and coclusions of long-term changes in waterbird populations: a case study from a South African Wetland. Biodiversity and Conservation. https://doi.org/10.1007/s10531-019-01828-2

Hodgson, J.C. Mott, R., Baylis, S.M., Phan, T.T., Wotherspoon, S., Kilpatrick, A.D., Segaran, R.R., Ried, I., Teruads, A. and Koh, L.P. (2018). *Drones count sildlife more accurately precisely than humans. Methods in Ecology and Evolution* **2018**;00:1–8. https://doi.org/10.1111/2041-210X.12974

IUCN 2019. *The IUCN Red List of Threatened Species*. Version 2019-1. http://www.iucnredlist.org.

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

Kingsford, R.T., Halse, S.A. & Porter, J.L. (2008). *Aerial surveys of waterbirds - assessing wetland condition. Final report to the National Land & Water Resources Audit.* 60pp. University of New South Wales, Sydney.

Lane, B.A. 1987. *Shorebirds in Australia*. Nelson, Melbourne.

Laursen, K., J. Blew, B. Ens, K. Eskildsen, K. Günther, B. Hälterlein, K. Koffijberg, P. Potel, M. van Roomen (2009). *Migratory Birds. Thematic Report No. 19*. In: Marencic, H. & Vlas, J. de (Eds), 2009. Quality Status Report 2009. WaddenSea Ecosystem No. 25. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Wilhelmshaven, Germany.

Legge, S., Lindenmayer, D. B., Robinson, N. M., Scheele, B. C., Southwell, D. M. and Wintle, B. A. (Eds) (2018). Monitoring Threatened Species and Communities. CSIRO Publishing, Clayton South.

Leyrer J., Spaans B., Camara M., and Piersma, T. (2006). Small home ranges and high site fidelity in red knots (Calidris c. canutus) wintering on the Banc d'Arguin, Mauritania. *Journal of Ornithology* **147**, 376–384

Lisovski, S., Gosbell, K., Hassell, C. & Minton, C. (2016). Tracking the full annual-cycle of the Great Knot Calidristenuirostris, a long-distance migratory shorebird of the East Asian-Australasian Flyway. *Wader Study* **123**, 177–189.

Lisovski, S., Schmaljohann, H. Bridge, E.S., Bauer, S., Farnsworth, A, Gauthreaux, S.A., Hahn, S., Hallworth, M.T., Hewson, C.M., Kelly, J.F., Liechti, F., Marra, P.P., Rakhimberdiev, E., Ross, J.D, Seavy, N.E., Sumner, M.D., Taylor, C.M., Winkler, D.W., Wotherspoon, S.J. and Wunder, M. (2018). Inherent limits of light-level geolocation may lead to over-interpretation. *Current Biology* **28**, 89-102. 10.1016/j.cub.2017.11.072.

Loyn, R. H., Rogers, D. I., Swindley, R. J., Stamation, K., Macak, P. and Menkhorst, P. (2014) *Waterbird monitoring at the Western Treatment Plant, 2000–12: The effects of climate and sewage treatment processes on waterbird populations*. Arthur Rylah Institute for Environmental Research Technical Report Series No. 256. Department of Environment and Primary Industries, Heidelberg, Victoria

Ma, Zhijun & Melville, David & Liu, Jianguo & Chen, Ying & Yang, Hongyan & Ren, Wenwei & Zhang, Zheng-Wang & Piersma, Theunis & Li, Bo. (2014). Rethinking China's new great wall. *Science*, **346**, 912-914. 10.1126/science.1257258.

MacKinnon, J., Verkuil, Y.I. & Murray, N.J. (2012) *IUCN situation analysis on East and Southeast Asian intertidal habitats, with particular reference to the Yellow Sea (including the Bohai Sea)*. Occasional Paper of the IUCN Species Survival Commission No. 47. . In, p. ii + 70pp. IUCN, Gland, Switzerland and Cambridge, UK.

Méndez, V., Alves, J. A., Gill, J. A. and Gunnarsson, T. G. (2018), Patterns and processes in shorebird survival rates: a global review. *Ibis* **160**, 723-742. doi:10.1111/ibi.12586

Milton, D. and Driscoll, P. (2006). An assessment of shorebird monitoring in Queensland by the Queensland Wader Study Group. *Stilt* **50**, 242-248.

Minton C.D.T. (2003) The importance of long-term monitoring of reproduction rates in waders. *Wader Study Group Bulletin* **100** ,178-182.

Minton, C.D.T. (2006). The history of wader studies in North-West Australia. *Stilt* **50**, 223-234.

Minton, C.D.T., Jessop, R., Collins, P. and Gosbell, K. (2005). Monitoring shorebird productivity by the percentage of first year birds in populations in S.E. Australian non-breeding areas. *International Wader Studies* **17**, 73-85.

Minton, C., Gosbell, K., Johns, P., Christie, M., Klaassen, M., Hassell, C., Boyle, A., Jessop, R. & Fox, J. (2011). Geolocator studies on Ruddy Turnstones Arenaria interpres and Greater Sandplovers Charadrius leschenaultii in the East Asian–Australasia Flyway reveal widely different migration strategies. *Wader Study Group Bull*. **118**, 87–96.

Minton C, Connor M, Price D, Jessop R, Collins P, Sitters H, Hassell C, Pearson and Rogers D. (2013). Wader numbers and distribution on Eighty Mile Beach, north-west Australia: baseline counts for the period 1981-2003. *Conservation Science W. Aust*. **8**, 345-366

Minton, C., Jessop, R., Hassell, C., Patrick, R. and Marks, I. (2018). Wader breeding success in the 2017 Arictic summer, based on juvenile ratios of birds which spend the non-breeding season in Australia. *Stilt* **72**, 62-65.

Morrison, R.I.G. and Ross, R.K. 1989. *Atlas of nearctic shorebirds on the coast of South America*. Canadian Wildlife Servie, Ottowa, Canada.

Murray, N. J., Marra, P. P., Fuller, R. A., Clemens, R. S., Dhanjal-Adams, K., Gosbell, K. B., Hassell, C. J., Iwamura, T., Melville, D., Minton, C. D. T., Riegen, A. C., Rogers, D. I., Woehler, E. J. and Studds, C. E. (2018). The large-scale drivers of population declines in a long-distance migratory shorebird. *Ecography* **41**, 867–876. doi:10.1111/ecog.02957

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

Oudman, T., Schekkerman, H., Kidee, A., van Roomen, M., Tentij, M. & Piersma, T. (2017). *The waterbirds of Parc National du Banc d'Arguin: evaluation of all complete winter counts, workshop proceedings and an evaluation.* Report for Programme towards a Rich Wadden Sea.

Piersma, T. & Hassell, C. (2010). Record numbers of grasshopper-eating waders (Oriental Pratincole, Oriental Plover, Little Curlew) on coastal west-Kimberley grasslands of NW Australia in mid February 2010. *Wader Study Group Bull.* **117**, 103–108.

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

Program for Regional and International Shorebird Monitoring (PRISM). (2018). *Standards for Monitoring Nonbreeding Shorebirds in the Western Hemisphere. Unpublished report, Program for Regional and International Shorebird Monitoring (PRISM).* Available at: https://www.shorebirdplan.org/science/program-for-regional-andinternational-shorebird-monitoring/.

Rappoldt, C., Kersten, M. and Smit, C. (1985). Errors in large-scale shorebird counts. *Ardea* **73**, 13–24.

Rehfisch, M.M., Clark, N.A., Langston, R.H.W. and Greenwood, J.J.D. (1996). A guide to the provision of refuges for waders: an analysis of 30 years of ringing data from the Wash, England. *Journal of Applied Ecology* **33**, 673–687.

Rehfisch, M.M., Insley, H. and Swann, B. (2003). Fidelity of overwintering shorebirds to roosts on the Moray Basin, Scotland: implications for predicting impacts of habitat loss. *Ardea* **91**, 53–70.

Riecke, T.V., Williams, P.J., Behnke, T.L., Gibson, D., Leach, A.G., Sedinger, B.S., Street, P.A. and Sedinger, J.S. (2019). Integrated population models: Model assumptions and inference. *Methods Ecol Evol.* 00: 1072 – 1082. https://doi.org/10.1111/2041-210X.13195

Reiter, M. E., C. M. Hickey, G. W. Page, W. D. Shuford, and K.M. Strum. (2011). *A monitoring plan for wintering shorebirds in the Central Valley of California, version 1.0.* Report to the California Landscape Conservation Cooperative. PRBO Conservation Science, Petaluma, California.

Robinson, N. M., Legge, S., Scheele, B. C., Lindenmayer, D. B., Southwell, D. M., Wintle, B. A., Bickerton, D., Brooks, L., Carter, O., Dickman, C., Gillespie, G., Kanowski, J., Koleck, J., Lahoz-Monfort, J. J., Lintermans, M., Marsh, H., Paltridge, R., Radford, J., Skorblin, A. and Wayne, A. (2018). Essential principles to guide monitoring of threatened biodiversity. Chapter 35 in Legge, S., Lindenmayer, D. B., Robinson, N. M., Scheele, B. C., Southwell, D. M. and Wintle, B. A. (Eds) (2018). *Monitoring Threatened Species and Communities*. CSIRO Publishing, Clayton South.

Rogers, D.I. (1999). What determines shorebird feeding distribution in Roebuck Bay? Capter 9 (Pp 145-179) in M. Pepping, T. Piersma, G. Pearson and M. Lavaleye (Eds). *Intertidal sediments and benthic animals of Roebuck Bay, Western Australia*. NIOZ Report 1999-3, Texel.

Rogers, D.I. (2003). High-tide roost choice by coastal waders. *Wader Study Group Bulletin* **100**, 73-79.

Rogers, D.I. (2005). The distribution of shorebirds along Eighty-mile Beach. Chapter 10 in G.P. Pearson, T. Piersma, M. Lavaleye and R. Hickey (Eds). *The long mud: Benthos and shorebirds of the foreshore of Eighty-mile Beach, Western Australia.* NIOZ-Report 2005-2.

Rogers D.I., Rogers K.G., Gosbell K.B. and Hassell C.J. (2006a). Causes of variation in population monitoring surveys: insights from non-breeding counts in north-western Australia, 2004-2005. *Stilt* **50**, 176-193

Rogers D. I., Piersma, T. and Hassell, C. (2006b). Roost availability may constrain shorebird distribution: Exploring the energetic costs of roosting and disturbance around a tropical bay. *Biological Conservation* **133**, 225-235

Rogers, D.I., Battley, P.F., Piersma, .T, van Gils, J. and Rogers, K.G. (2006c) High-tide habitat choice: modelling the roost selection of shorebirds around a tropical bay. *Animal Behaviour* **72**, 562-575.

Rogers D., Hassell, C. and Lewis, J. (2006e) *Shorebird disturbance on the beaches of Roebuck Bay, 2005-2006: Conservation implications and recommendations.* Broome Bird Observatory Report

Rogers, D.I., Minton, C.D.T., Boyle, A.N., Hassell, C.J. and Silcocks, A. (2006f). Growing up slowly by the sea-side: age at first northwards migration of shorebirds from Australian non-breeding grounds. Chapter 10 in Rogers, D. I. (2006). *Hidden costs: challenges faced by migratory shorebirds living on intertidal flats.* PhD Thesis, Charles Sturt University.

Rogers D.I., Yang H-Y, Hassell C.J., Boyle A.N., Rogers K.G., Bing Chen, Zhang. Z-W, and 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

Rogers, D.I., C.J. Hassell, A. Boyle, K. Gosbell, C. Minton, K.G. Rogers and R.H. Clarke. (2011). Shorebirds of the Kimberley Coast – Populations, key sites, trends and threats. *Journal of the Royal Society of Western Australia* **94**, 377-391.

Rogers, K.G. (2006). A note on estimating the variance of a juvenile proportions from a number of subsamples. *Wader Study Group Bulletin* **110**, 59-62.

Rogers, K. and Gosbell, K. (2006). Demographic models for Red-necked Stint and Curlew Sandpiper in Victoria. *Stilt* **50**, 205-214.

Rogers D. and Hassell, C. (2017) *Evaluating the impacts of local and international pressures on migratory shorebirds in Roebuck Bay and Eighty Mile Beach*. Report of 1.2.6 prepared for the Kimberley Marine Research Program, Western Australian Marine Science Institution, Perth, Western Australia, 23 pp

Sandercock, B.K. (2003). Estimation of survival rates for wader populations: a review of mark-recapture methods. *Wader Study Group Bulletin* **100**, 163-174.

Schaub, M. and Abadi, F. (2011). Integrated population models: a novel analysis framework for deeper insights into population dynamics. *Journal of Ornithology* **152 Suppl.**, 227. https://doi.org/10.1007/s10336-010-0632-7

Simpson, G. (2014). Identifying periods of change in time series with GAMs. Blog post: https://www.fromthebottomoftheheap.net/2014/05/15/identifying-periods-of-change-with-gams/

Sitters, H., C. Minton, P. Collins, B. Etheridge, C. Hassell & F. O'Connor (2004). Extraordinary numbers of Oriental Pratincoles in nw Australia. *Stilt* **45**, 43-49.

Sitters, H., Minton, C., Collins, P., Etheridge, B., Hassell, C. & O'Connor, F. 2004. Extraordinary numbers of Oriental Pratincoles in NW Australia. *Wader Study Group Bull.* **103**, 26-31.

Sitters H.P., Sitters H.F., Collins, P.C., King, A and King, J. (2009) *Birds of Prey Numbers and shorebird disturbance in Roebuck Bay*. Broome Bird Observatory Issues Paper No. 2

Smit, C. (1989). Perpectives in using shorebird counts for assessing long-term changes in wader numbers in the Wadden Sea. *Helgoländer Meeresuntersuchungen* **43**, 367-383

Spearpoint, J.A., Every, B. and Underhill, L.G. (1988). Waders (Charadrii) and other shroebirds at Cape Recife, Algoa Bay, South Africa: seasonality, trends, conservation, and reliability of surveys. *Ostrich* **59**, 166-177.

Straw, P. and Saintilan, N. (2006). Loss of shorebird habitat as a result of mangrove incursion due to sea-level rise and urbanization. In Boere G.C., Galbraith, C.A. and Stroud, D.A. *Waterbirds around the world*. Eds The Stationery Office, Edinburgh, UK. pp. 717-720

Studds C.E., Kendall B.E., Wilson H.B., Clemens R.S., Murray N.J., Gosbell K., Hassell C.J., Rogers, D.I., Woehler, E.J., Jessop, R., Possingham, H.P. and Fuller, R.A. (2017). Reliance on the Yellow Sea predicts population collapse in a migratory flyway. *Nature Communications* **8**, 14895

Summers, R.W. and Underhill, L.G. (1987). Factors related to breeding production of brent geese Branta b. bernicla and waders (Charadrii) on the Taimyr Peninsula. *Bird Study* **34**, 161–171.

Taylor PB, Navarro RA, Wren-Sargent M et al (1999) TOTAL CWAC Report: co-ordinated waterbird counts in South Africa, 1992–1997. University of Cape Town, Cape Town, Avian Demography Unit

Underhill, L.G., Prys-Jones, R.P., Syroechkovsk, E.E.J., Groen, N.M., Karpov, V., Lappo, H.G., Van Roomen, M.W.J., Rybkin, A., Schekkerman, H., Spiekman, H., and Summers, R.W. (1993). Breeding of waders (Charadrii) and Brent Geese Branta bernicla bernicla at Pronchishcheva Lake, northeastern Taimyr. Russia, in a peak and a decreasing lemming year. *Ibis* **135**, 277–292.

van Gils, J. A., Battley, P. F., Piersma, T., & Drent, R. (2005). Reinterpretation of gizzard sizes of red knots world-wide emphasises overriding importance of prey quality at migratory stopover sites. Proceedings. *Biological sciences*, **272**, 2609–2618. doi:10.1098/rspb.2005.3245

Vas, E., Lescroël, A., Duriez, O., Boguszewski, G., and A Grémillet, D. (2015). Approaching birds with drones: first experiments and ethical guidelines. *Biology letters*, **11**, 20140754. doi:10.1098/rsbl.2014.0754

Weegman, M. D., S. Bearhop, A. D. Fox, G. M. Hilton, A. J. Walsh, J. L. McDonald, and D. J. Hodgson (2016). Integrated population modelling reveals a perceived source to be a cryptic sink. *Journal of Animal Ecology* **85**, 467–475.

Weiser E.L., Lanctot, R.B., Brown, S.C., Gates, H.R., Bentzen, R.L., Bêty J., Boldenow, M.L., English, W.B., Franks, S.E., Koloski, L., Kwon, E., Lamarre, J-F., Lank, D.B., Liebezeit, J.R., McKinnon, L., Nol, E., Rausch, J., Saalfeld, S.T., Senner, N.R., Ward, D.H., Woodard, P.F., and Sandercock, B.K. (2018). Environmental and ecological conditions at Arctic breeding sites have limited effects on true survival rates of adult shorebirds. *Auk* **135**, 29–43.

White, G.C. and Burnham, K.P. (1999). Program MARK: survival estimation from populations of marked animals. *Bird Study* **46**, S120–S139.

Wilson, H. B., Kendall, B. E., Fuller, R. A., Milton, D. A., and Possingham, H. P. (2011a). Analyzing variability and the rate of decline of migratory shorebirds in Moreton Bay, Australia. *Conservation Biology* **25**, 758–766. doi:10.1111/j.1523-1739.2011.01670.x

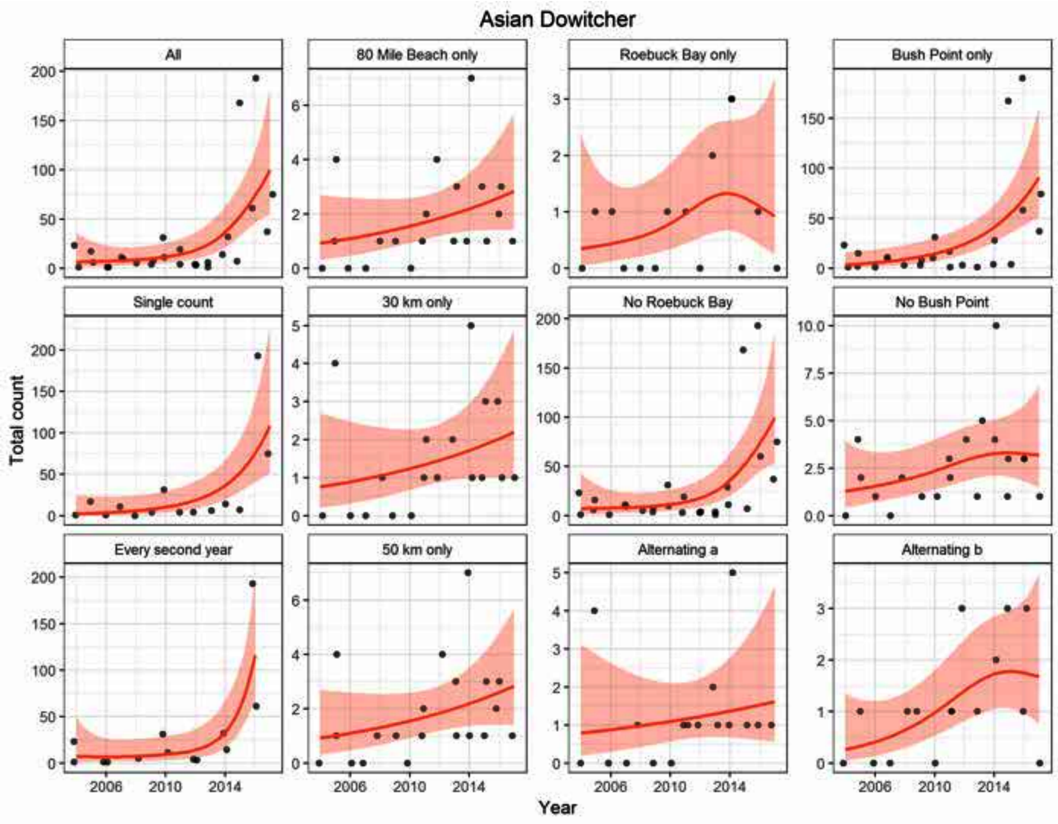
Wood, S.N. (2018) mgcv: Mixed GAM Computation Vehicle with Automatic Smoothness Estimation. R package version 1.8. https://cran.r-project.org/web/packages/mgcv/index.html

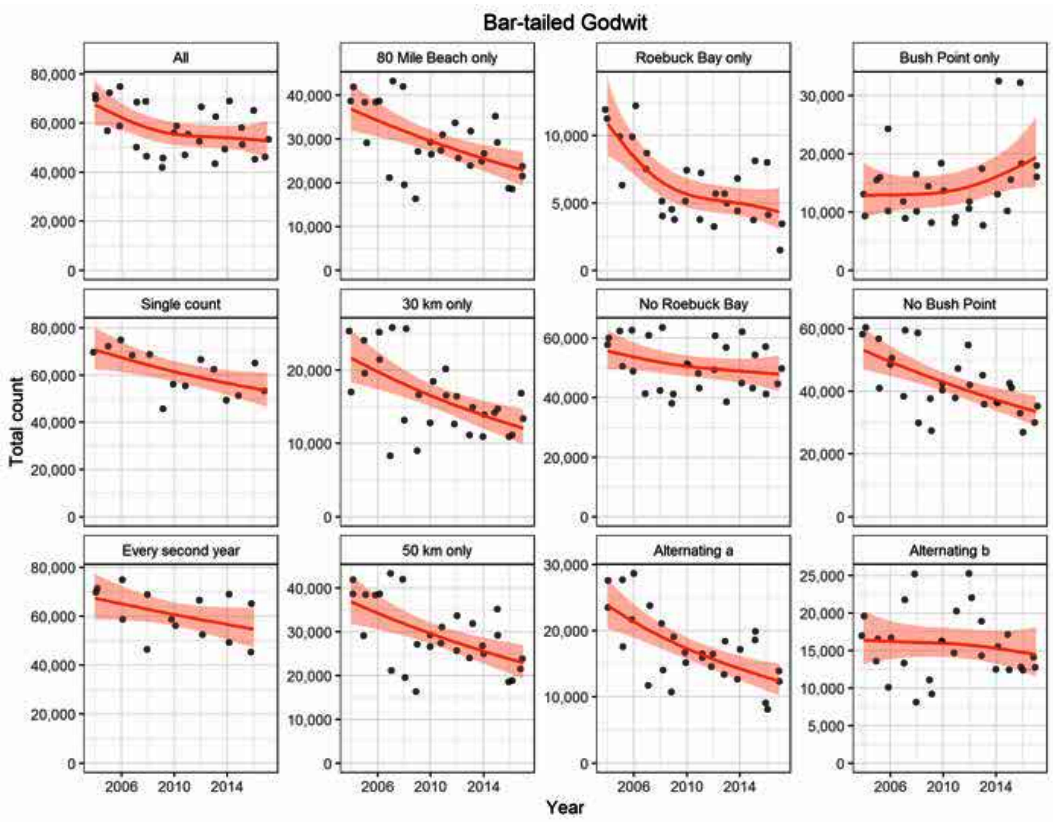
Appendices

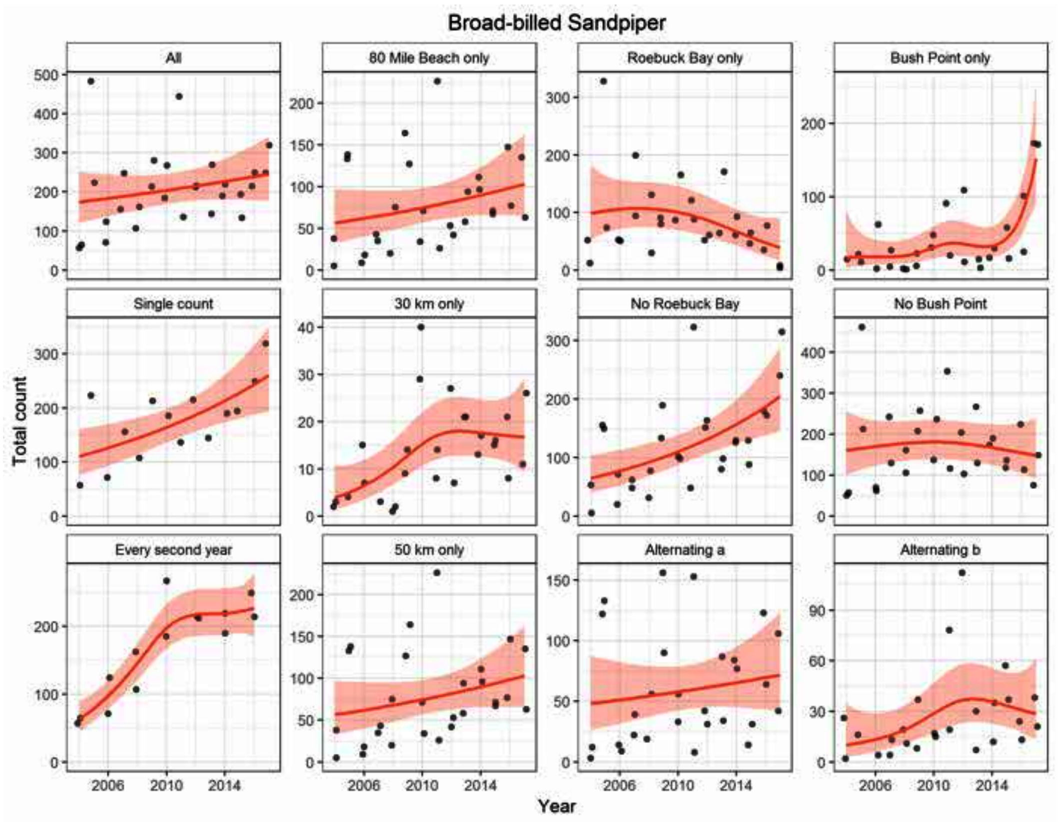
Appendix 1: GAMs of summer subsamples

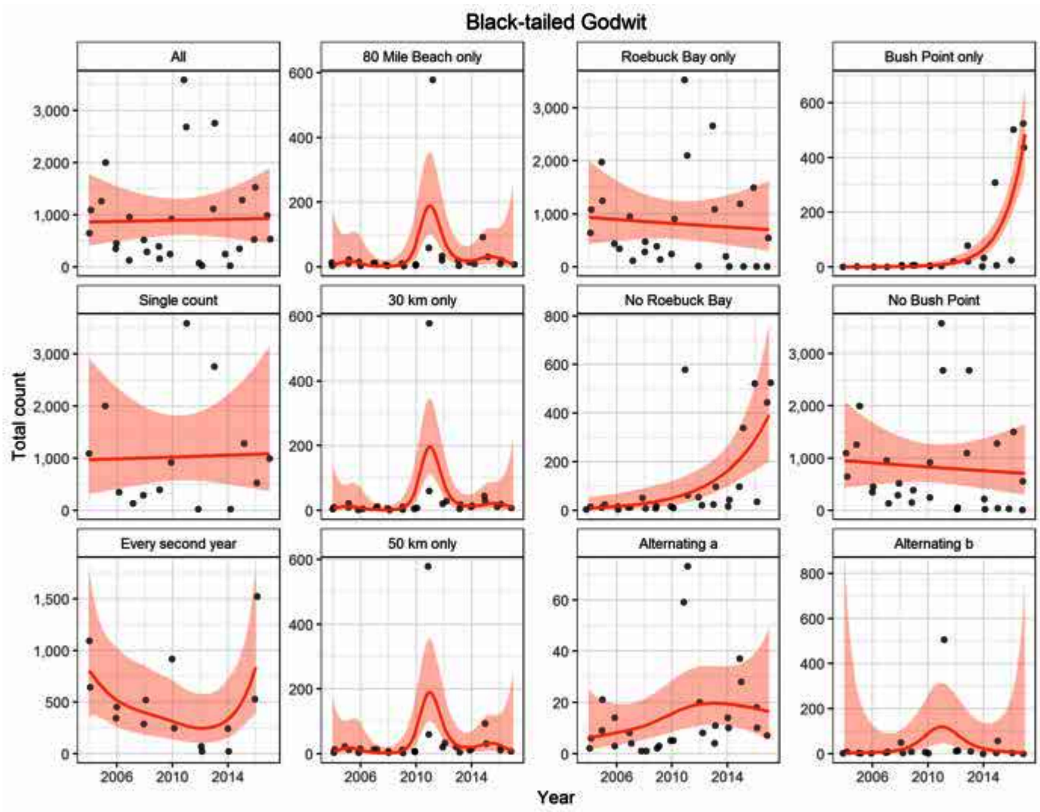
The MYSMA count database was subsampled to represent a variety of sampling scenarios that would be less costly than carrying out the full surveys. GAMs generated from these subsampled scenarios are illustrated in the figures that follow. For each of the most numerous 21 migratory shorebird species we show models for the scenarios summarised in the Table below. Results for summer counts are presented in this appendix; winter counts are presented in Appendix 2.:

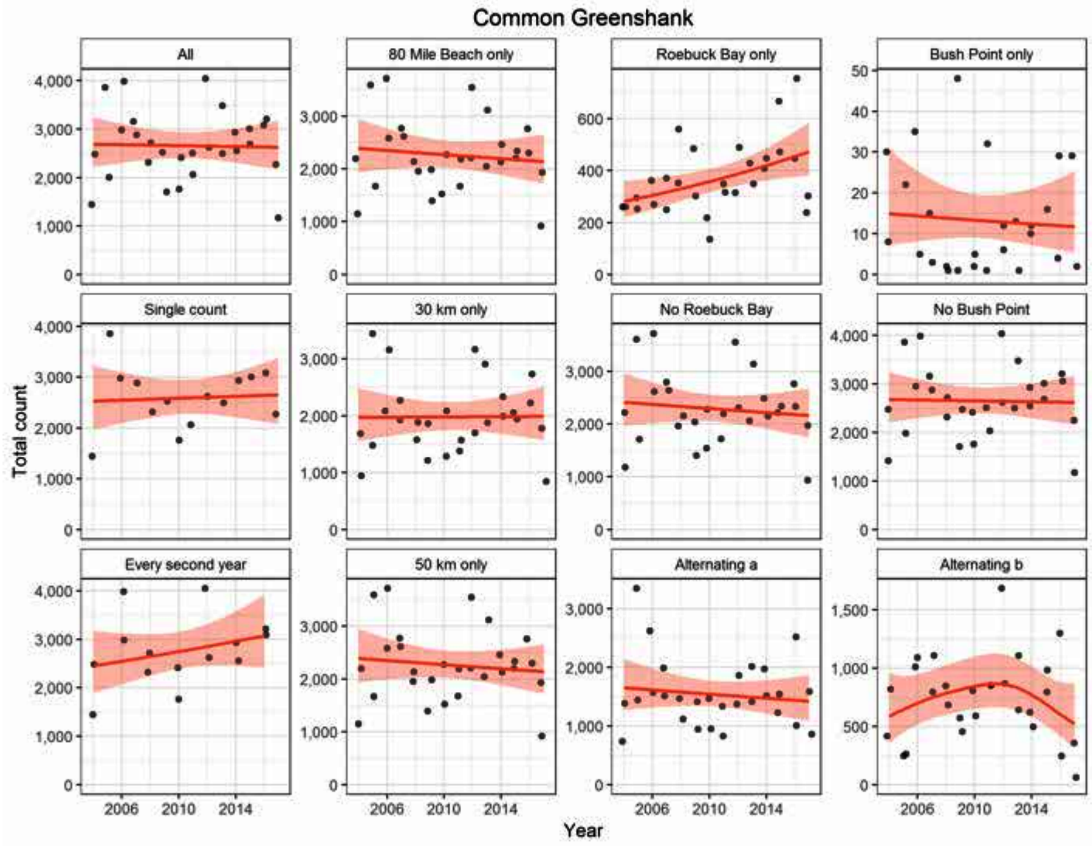
Abbreviation in figure	Description of subsampling
All	Based on two summer counts per year: totals from Eighty Mile Beach, Roebuck Bay and Bush Point combined in each survey
Single count	One summer count per year: totals from all sites combined
Every second year	Paired summer counts and a single winter count, carried out every second year
80 Mile Beach only	Paired summer counts and a single winter count, only carried out at Eighty Mile Beach
30 km only	Paired summer counts and a single winter count at all sites; at Eighty Mile Beach only count from 0-30 km S of Anna Plains access track
50 km only	Paired summer counts and a single winter count at all sites; at Eighty Mile Beach only count from 0-50 km S of Anna Plains access track
Roebuck Bay only	Paired summer counts and a single winter count, only carried on the northern beaches of Roebuck Bay
No Roebuck Bay	Paired summer counts and a single winter count, at Eighty Mile Beach and Bush Point (Roebuck Bay excluded)
Aternating a	Paired summer counts and a single winter count at all sites; at Eighty Mile Beach count alternate 10 km stretches of beach (0-10 km S, 20-30 km S, 40-50 km S)
Bush Point only	Paired summer counts and a single winter count, only carried out at Bush Point
No Bush Point	Paired summer counts and a single winter count, at Eighty Mile Beach and Bush Point (Roebuck Bay excluded)
Alternating b	Paired summer counts and a single winter count at all sites; at Eighty Mile Beach count alternate 10 km stretches of beach (10-20 km S, 30-40 km S, 50-55 km S)

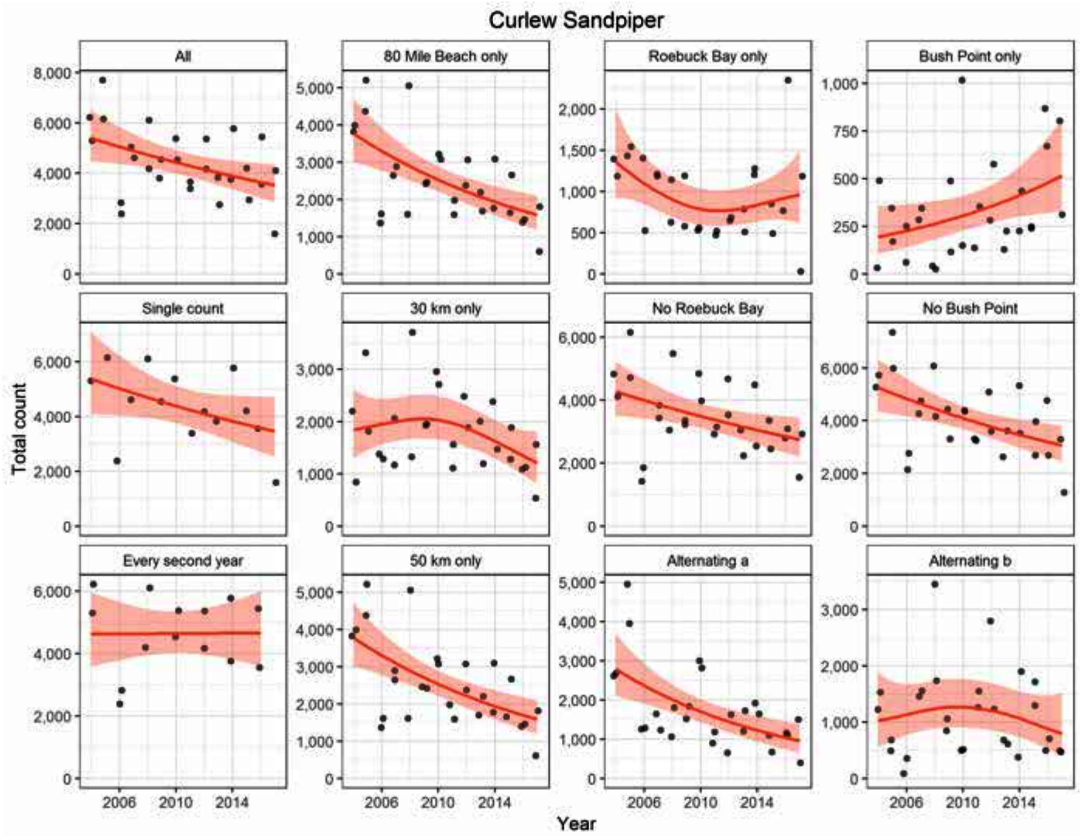

Asian Dowitcher
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

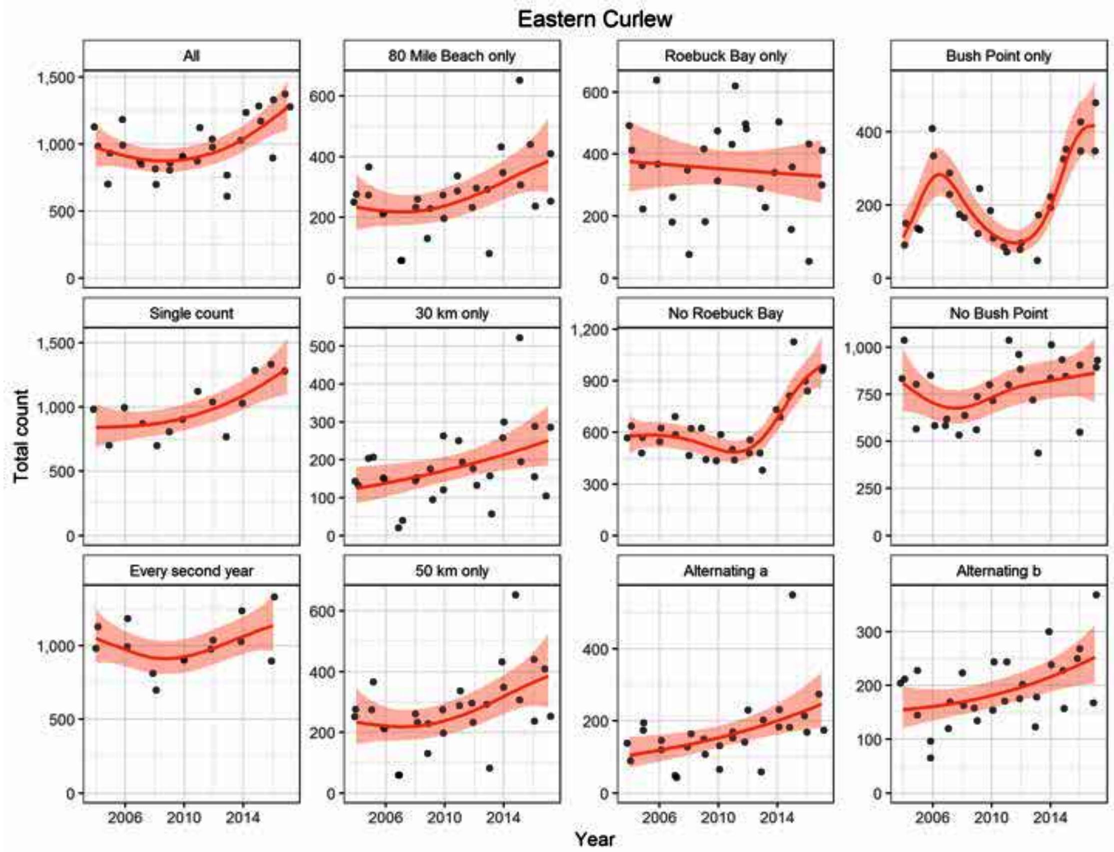

Bar-tailed Godwit
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year


Broad-billed Sandpiper
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

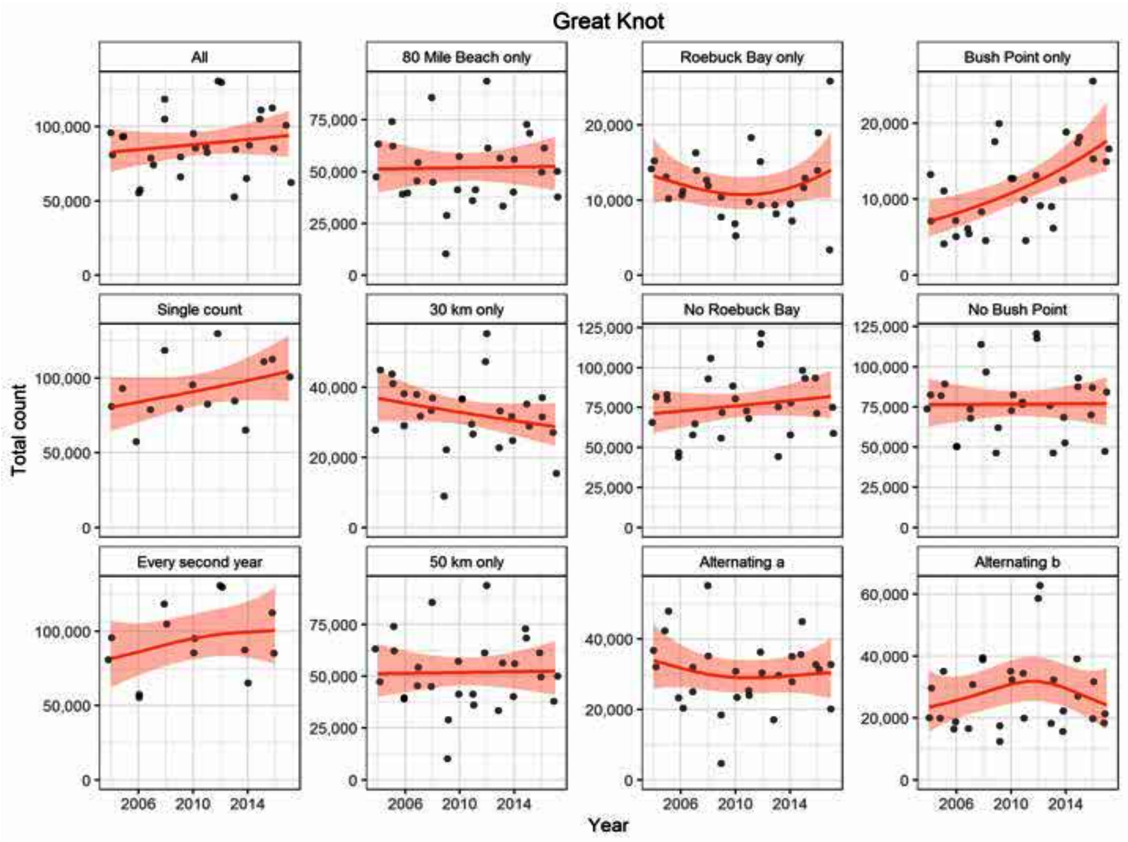

Black-tailed Godwit
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year


Common Greenshank
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

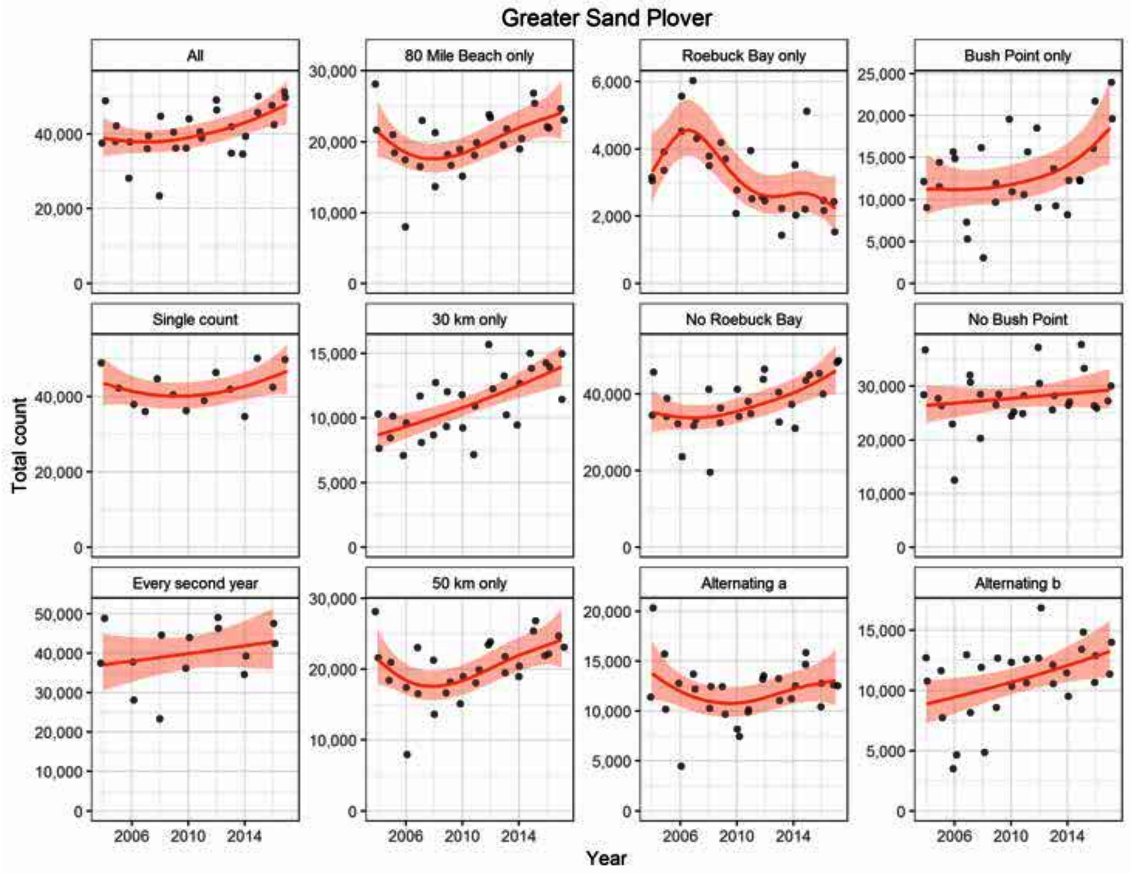

Curlew Sandpiper
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

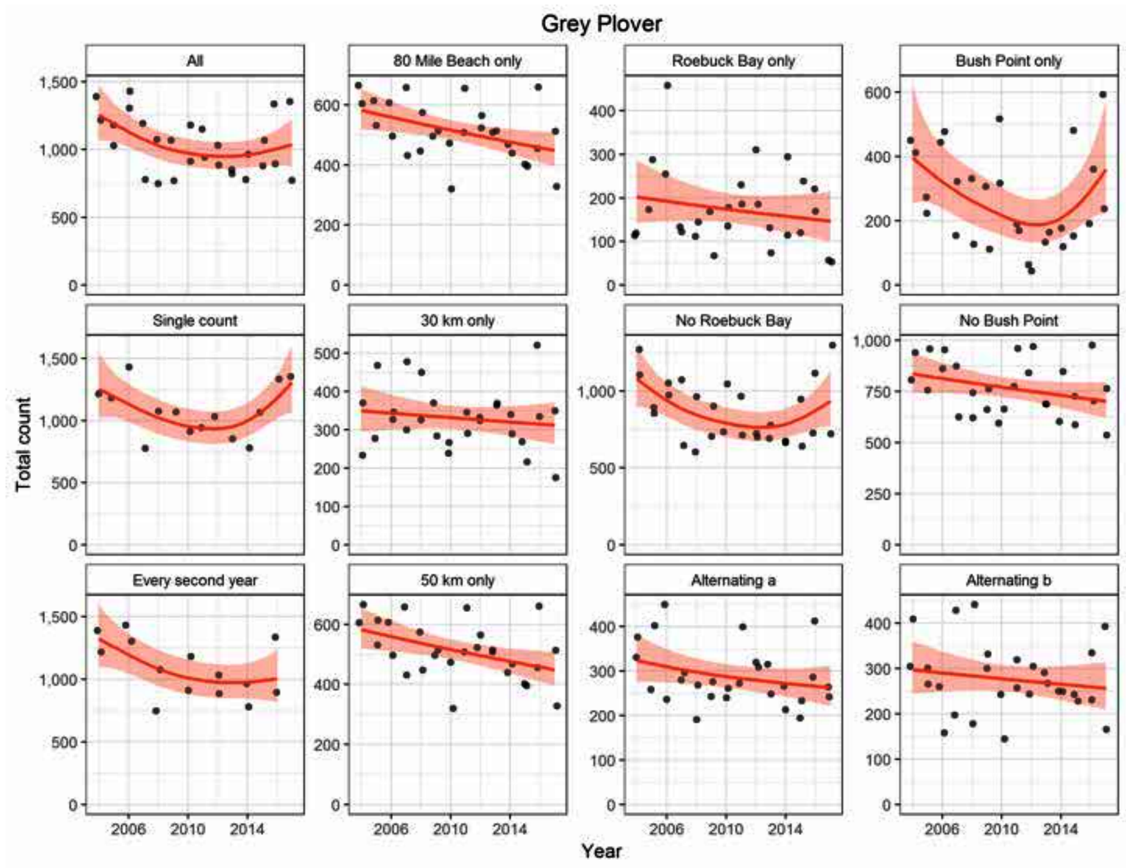


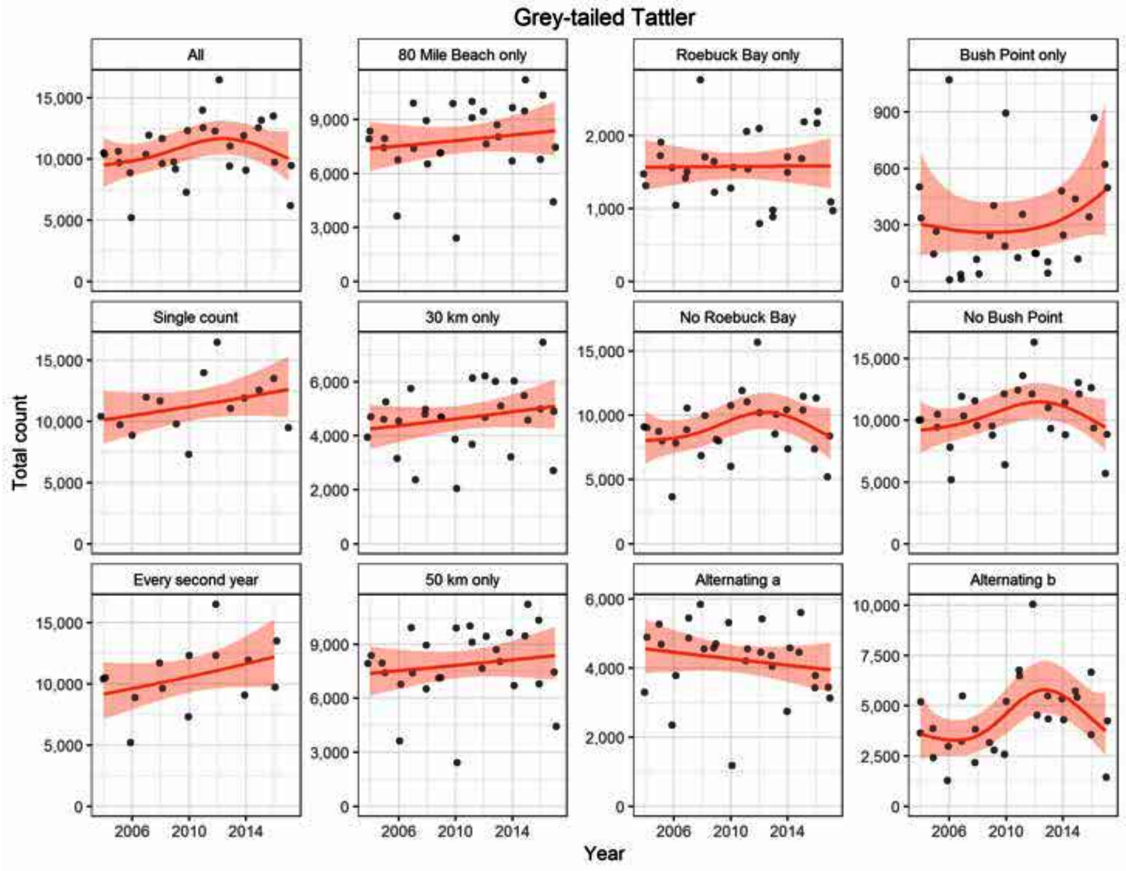
Eastern Curlew
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

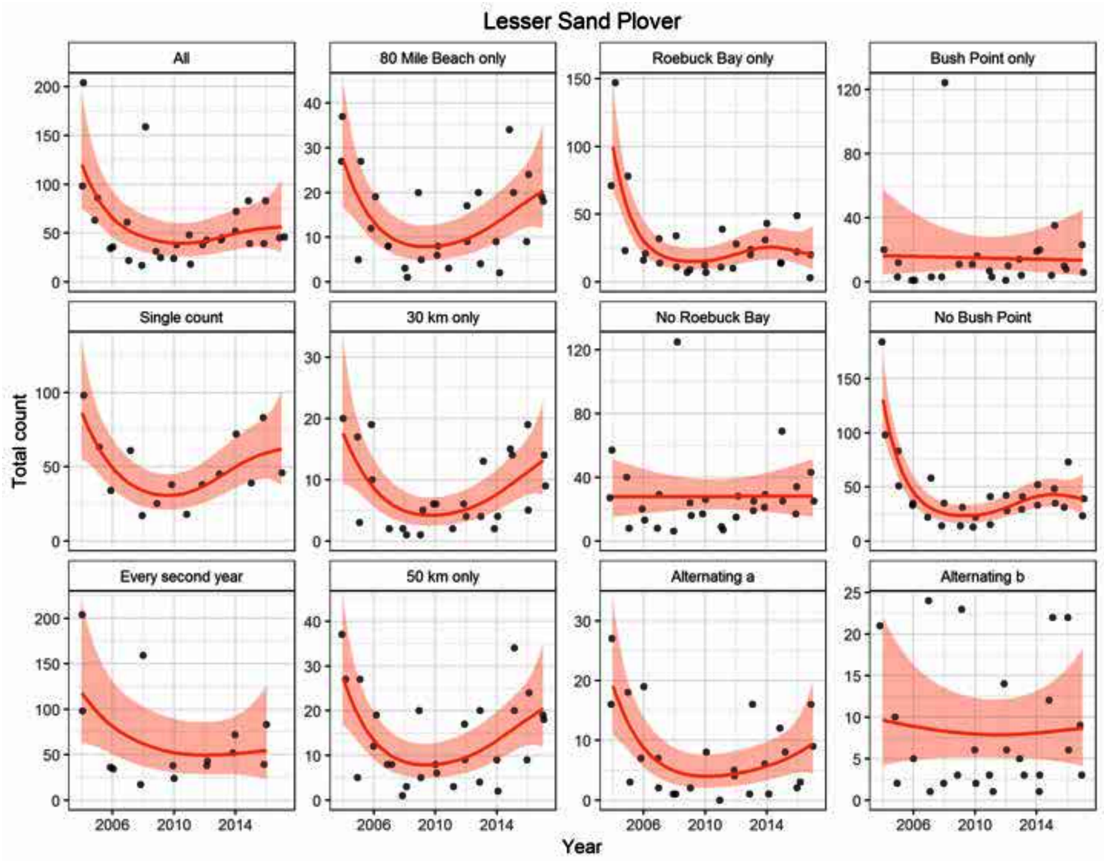


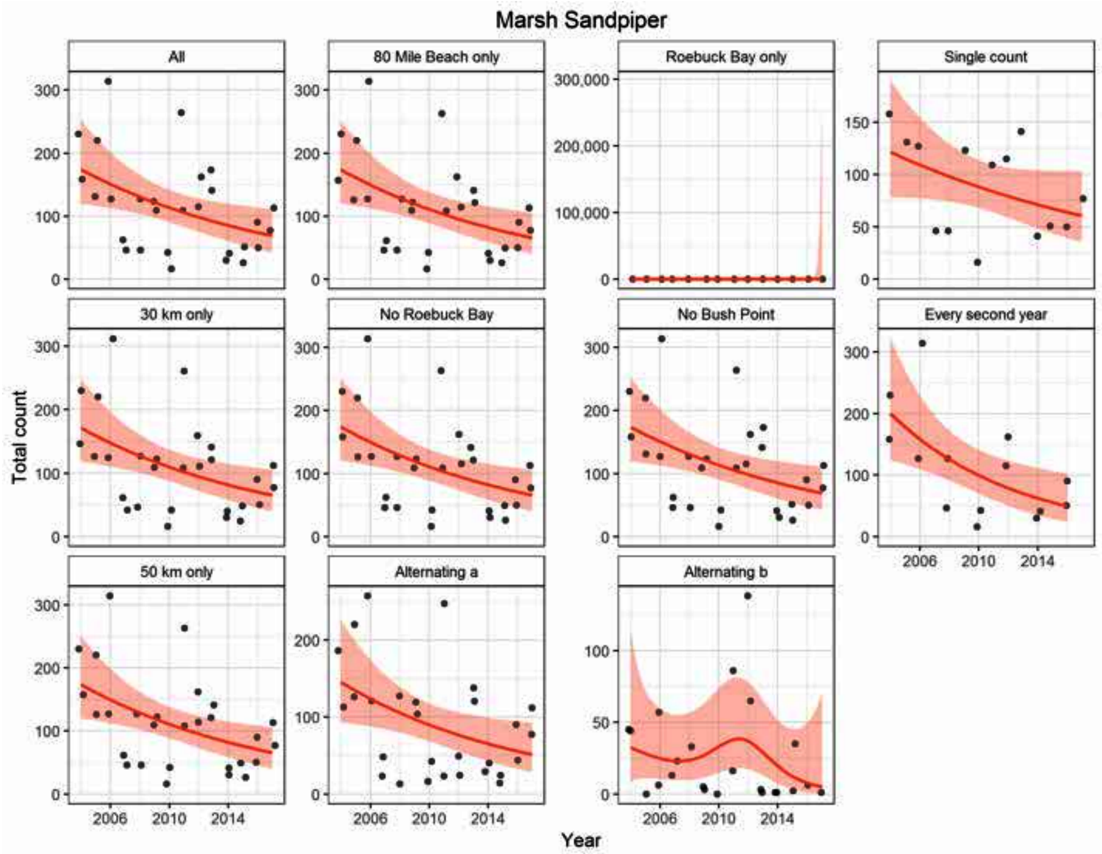
Great Knot
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

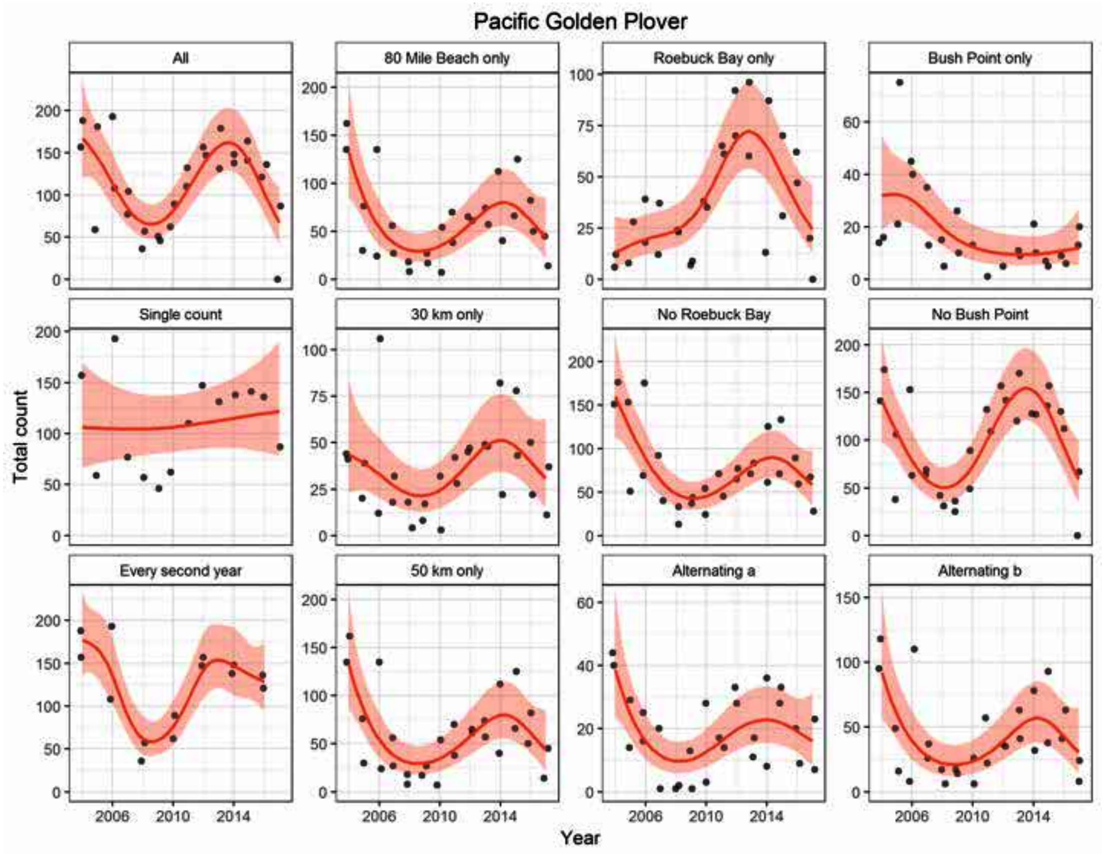

Greater Sand Plover
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

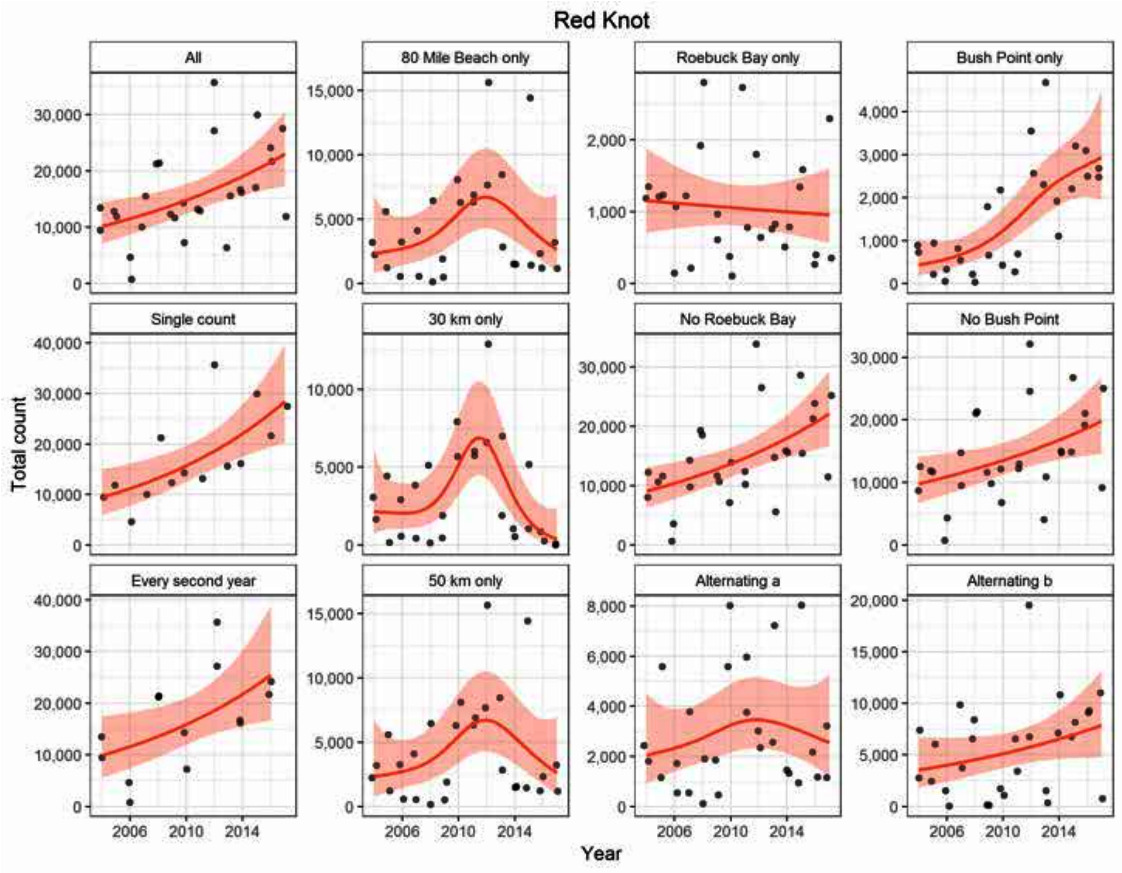

Grey Plover
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

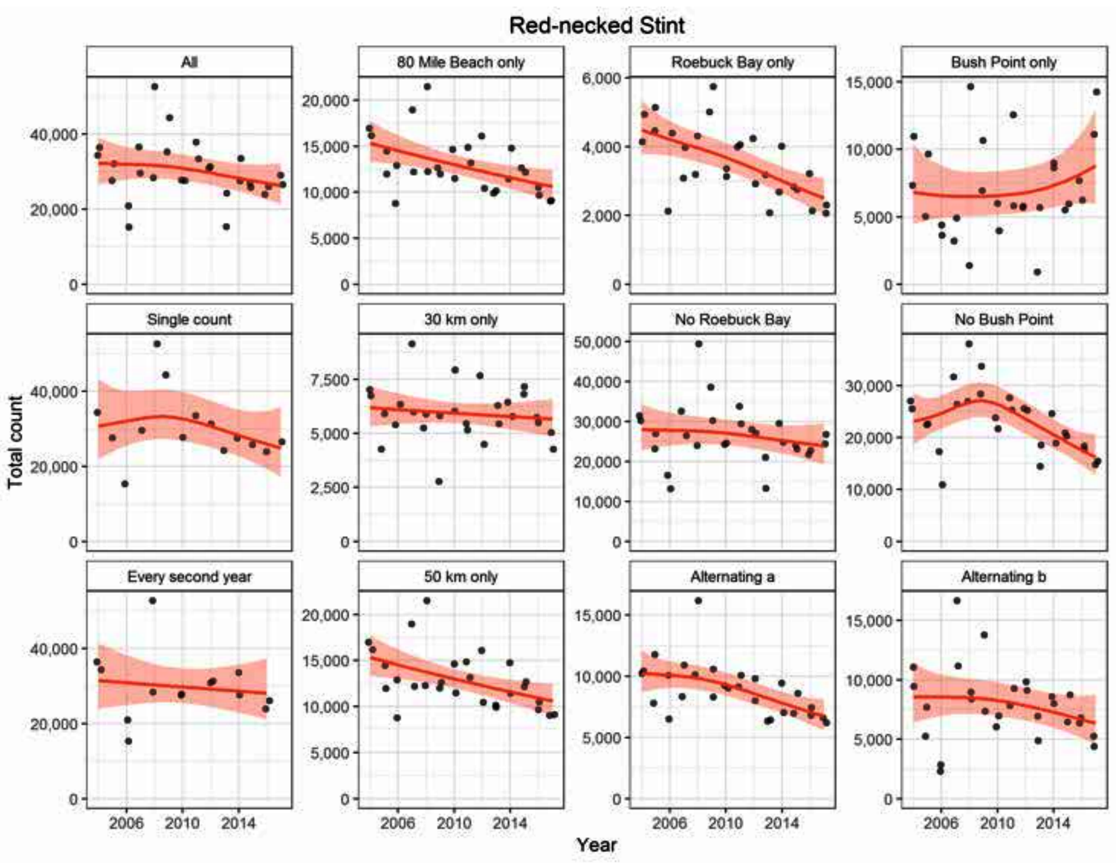

Grey-tailed Tattler
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

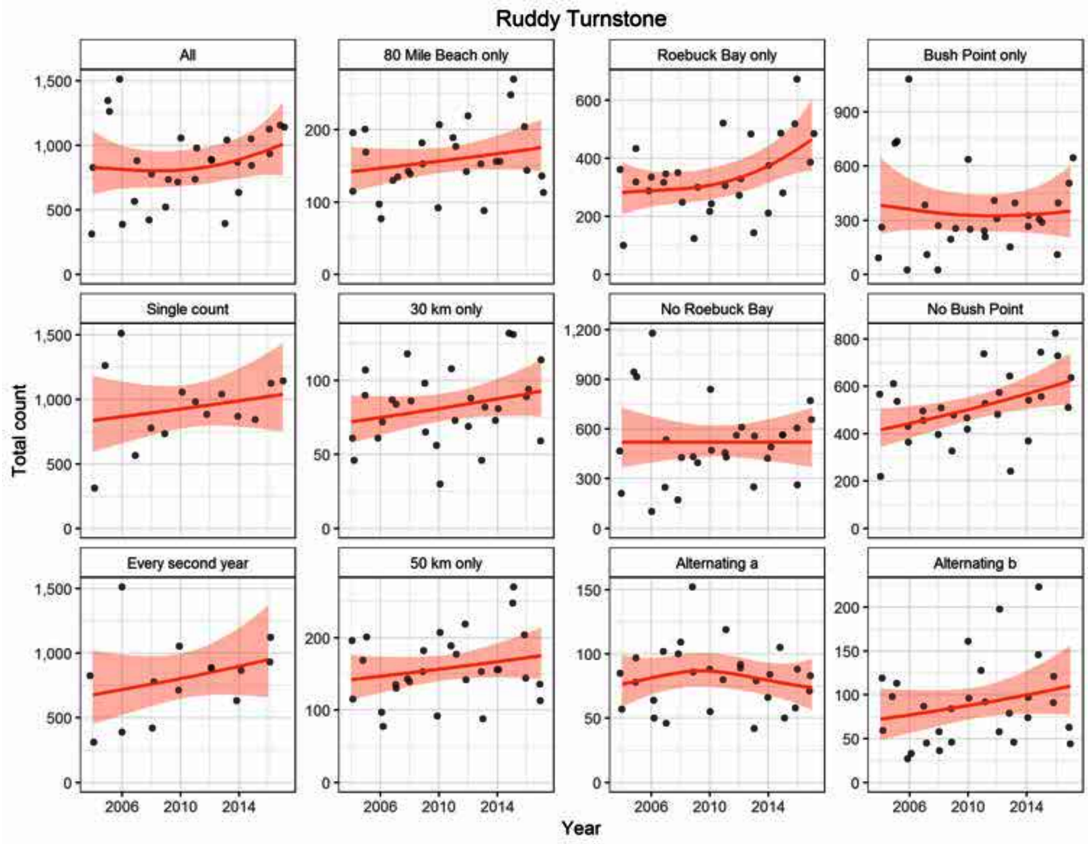

Lesser Sand Plover
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

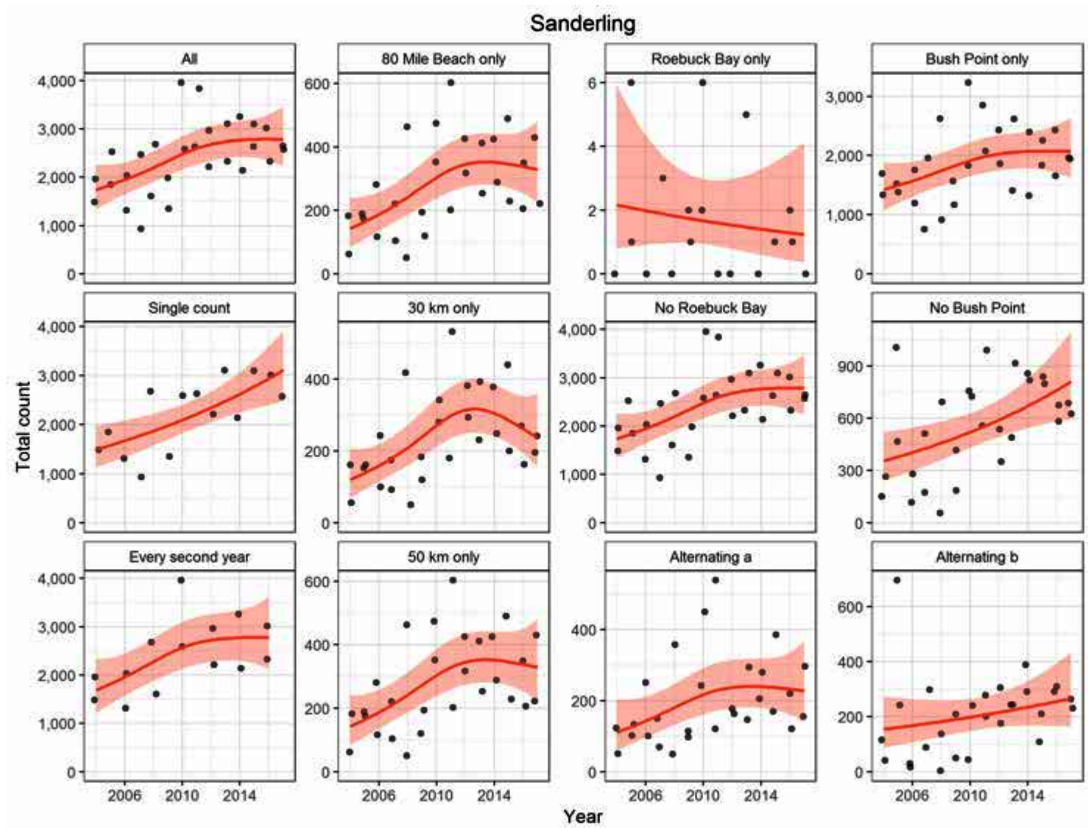

Marsh Sandpiper
All
80 Mile Beach only
Roebuck Bay only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

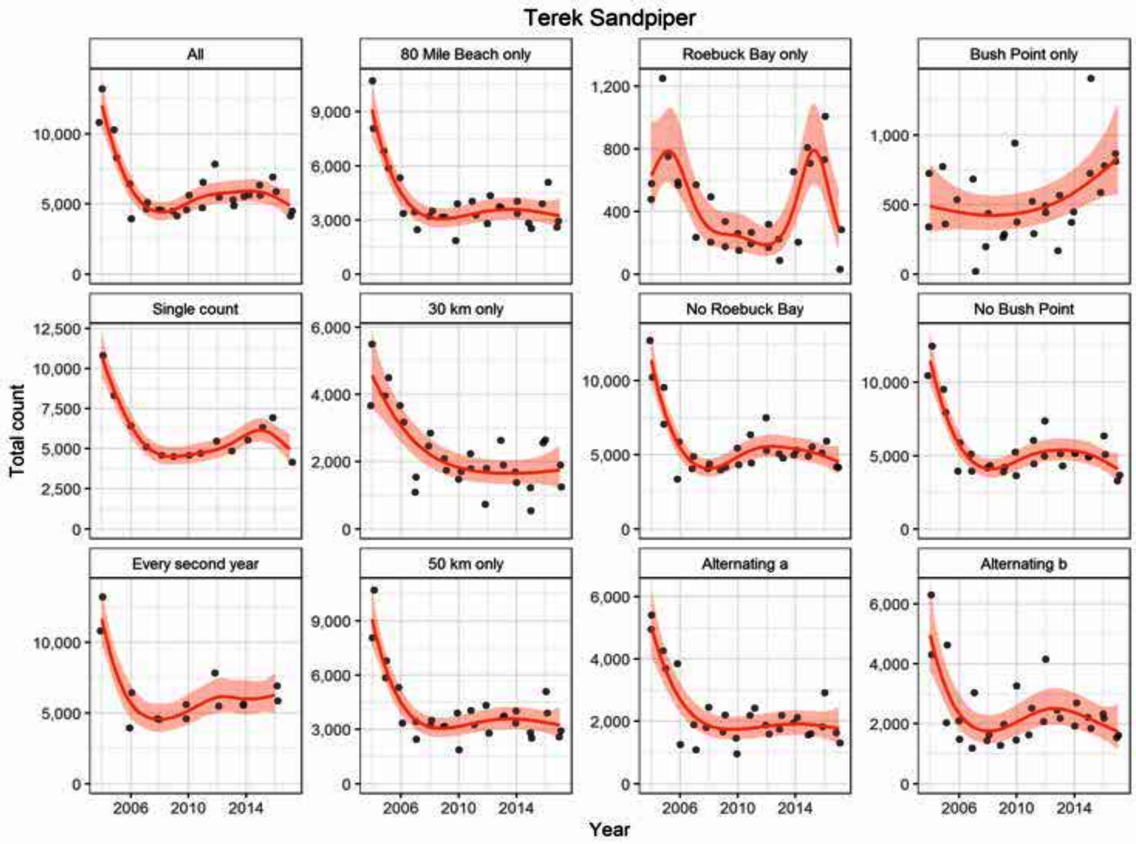

Pacific Golden Plover
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

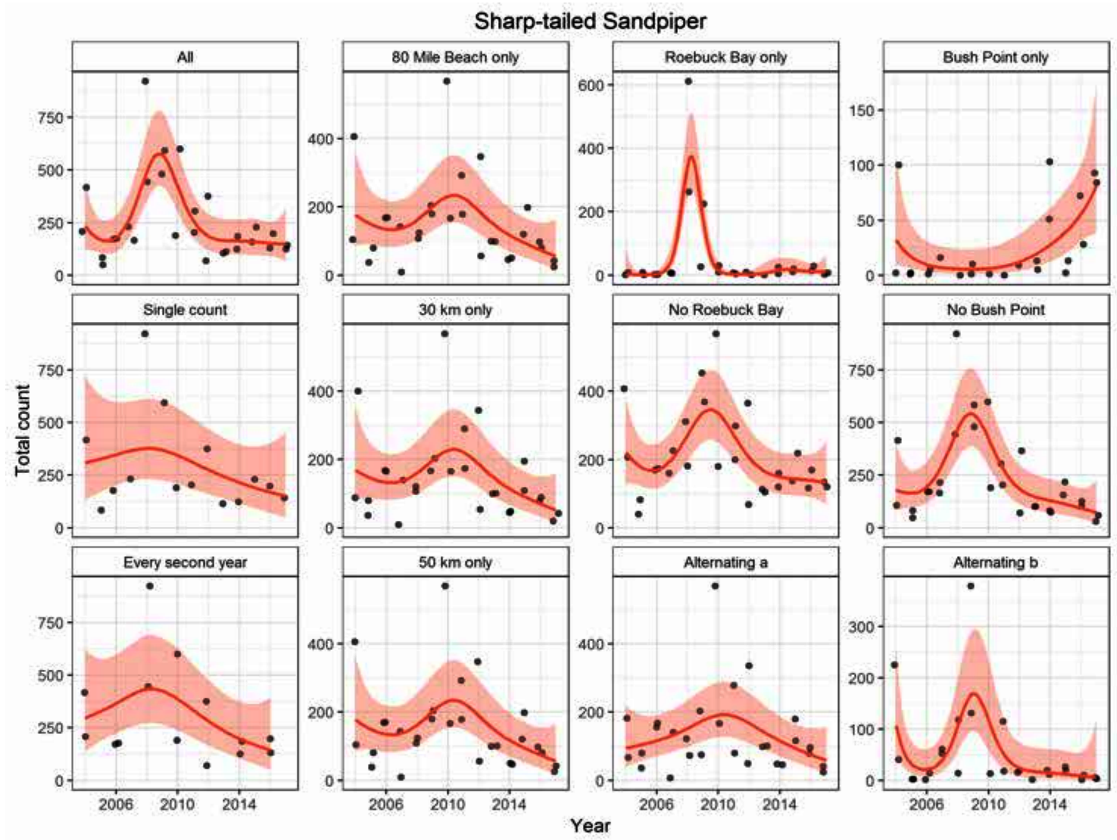

Red Knot
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year
2006
2010
2014

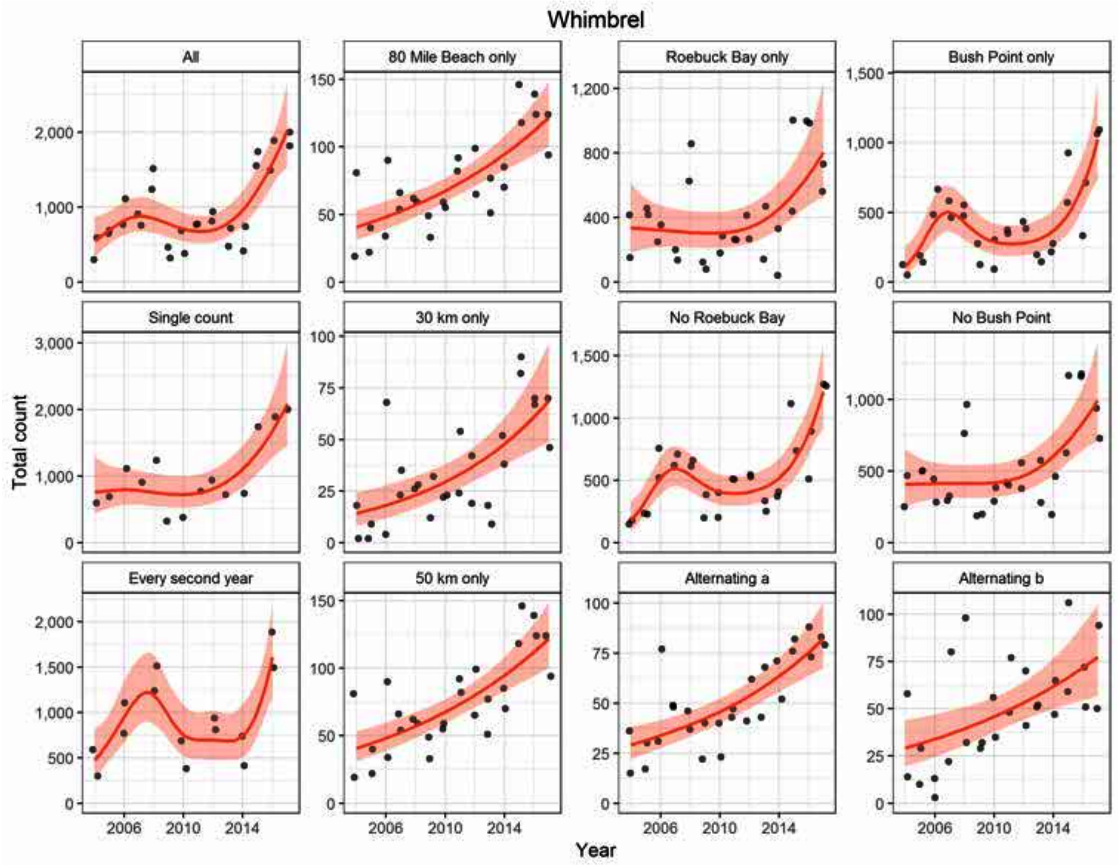

Red-necked Stint
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year
2006
2010
2014


Ruddy Turnstone
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year
2006
2010
2014


Sanderling
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year
2006
2010
2014


Terek Sandpiper
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

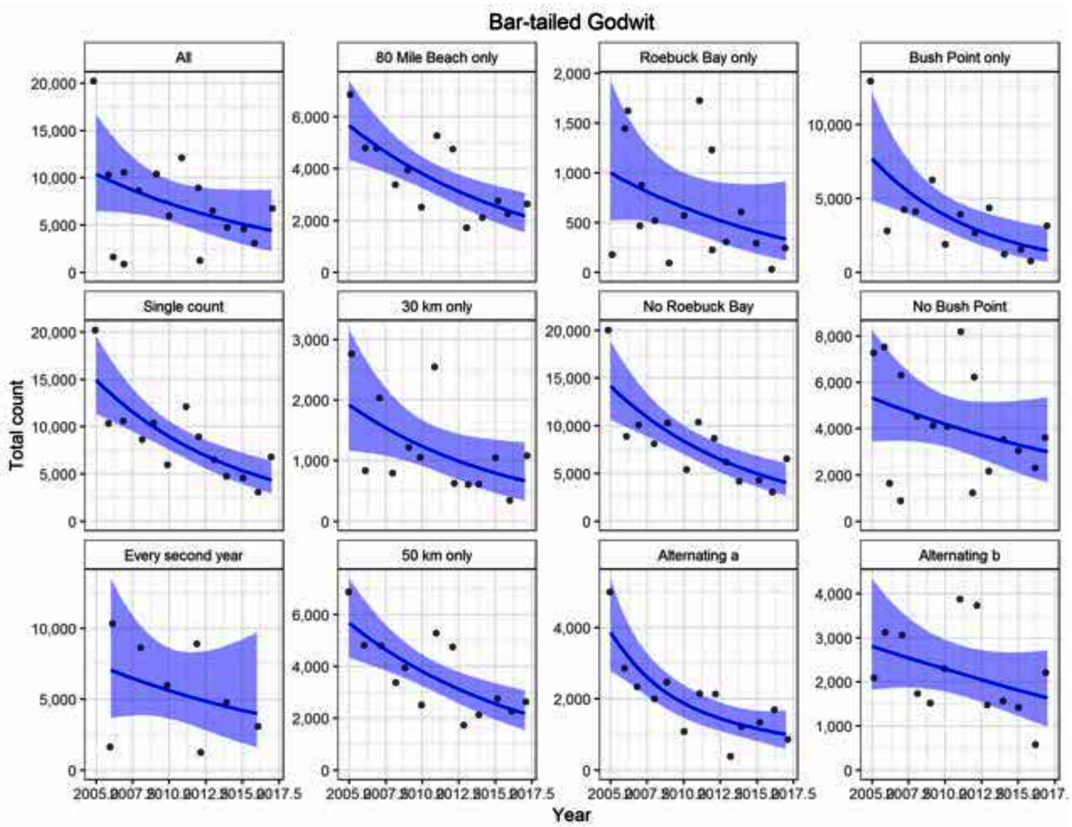

Sharp-tailed Sandpiper
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

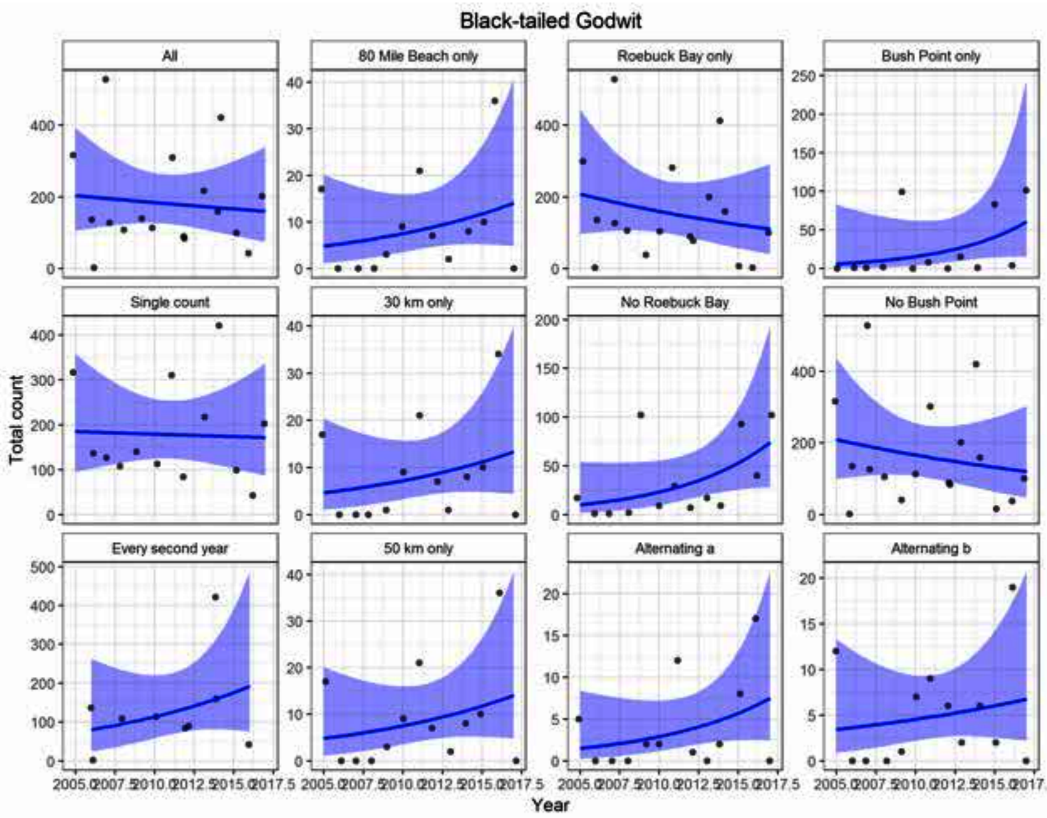


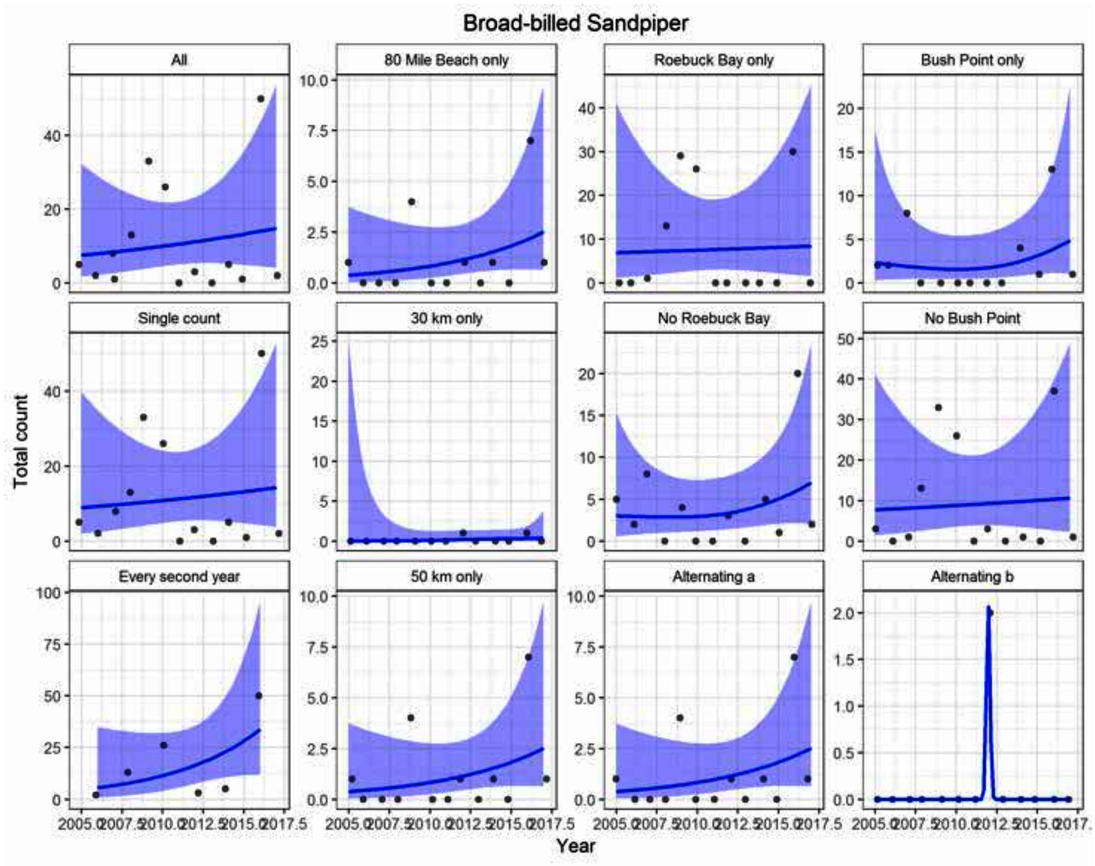
Whimbrel
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

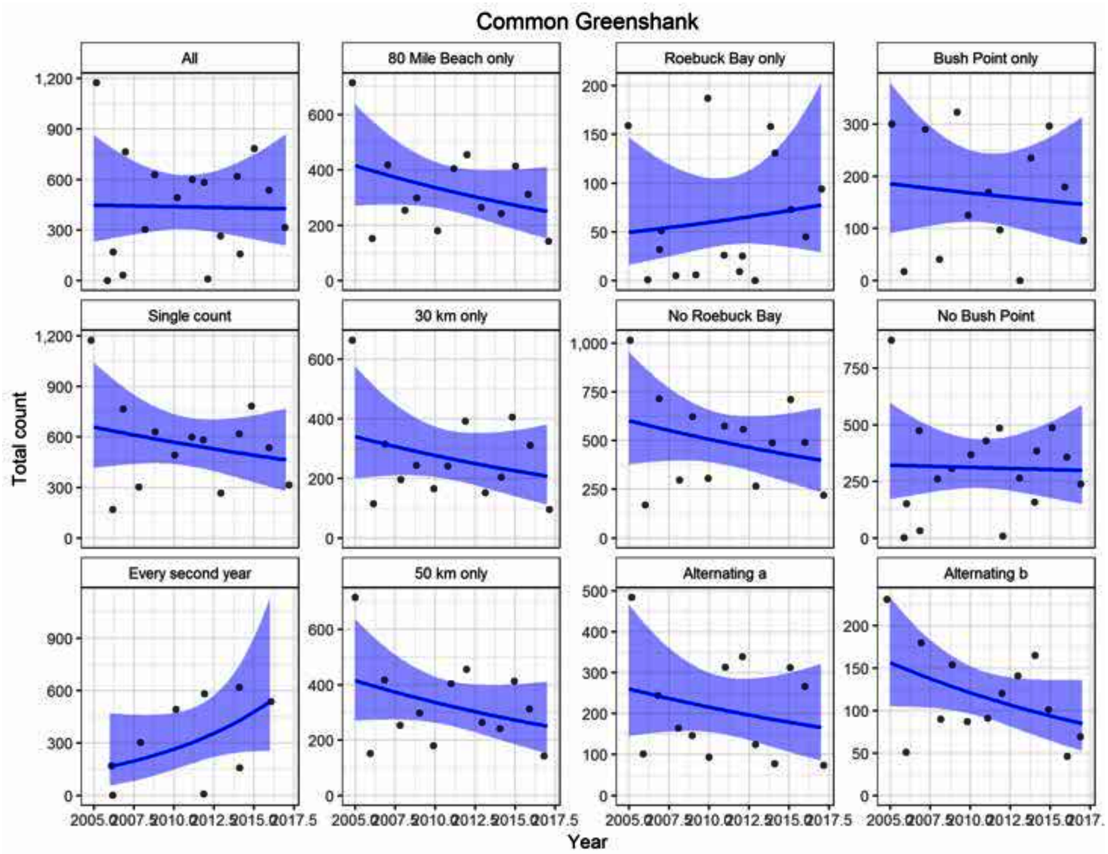
Appendix 2: GAMs of winter subsamples

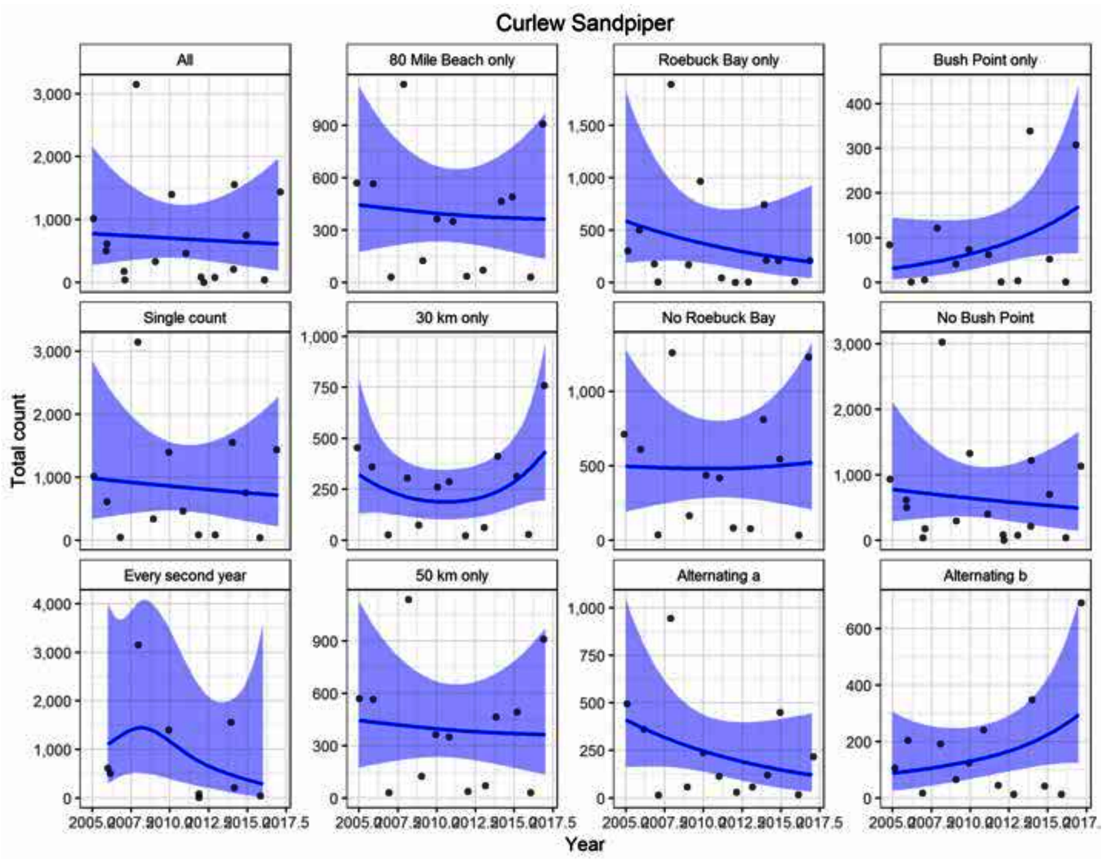
Subsampling strategies are as described in Appendix 1 and section 6.2. Winter populations of some species (Asian Dowitcher, Sharp-tailed Sandpiper) were too small to be modelled with GAMs.

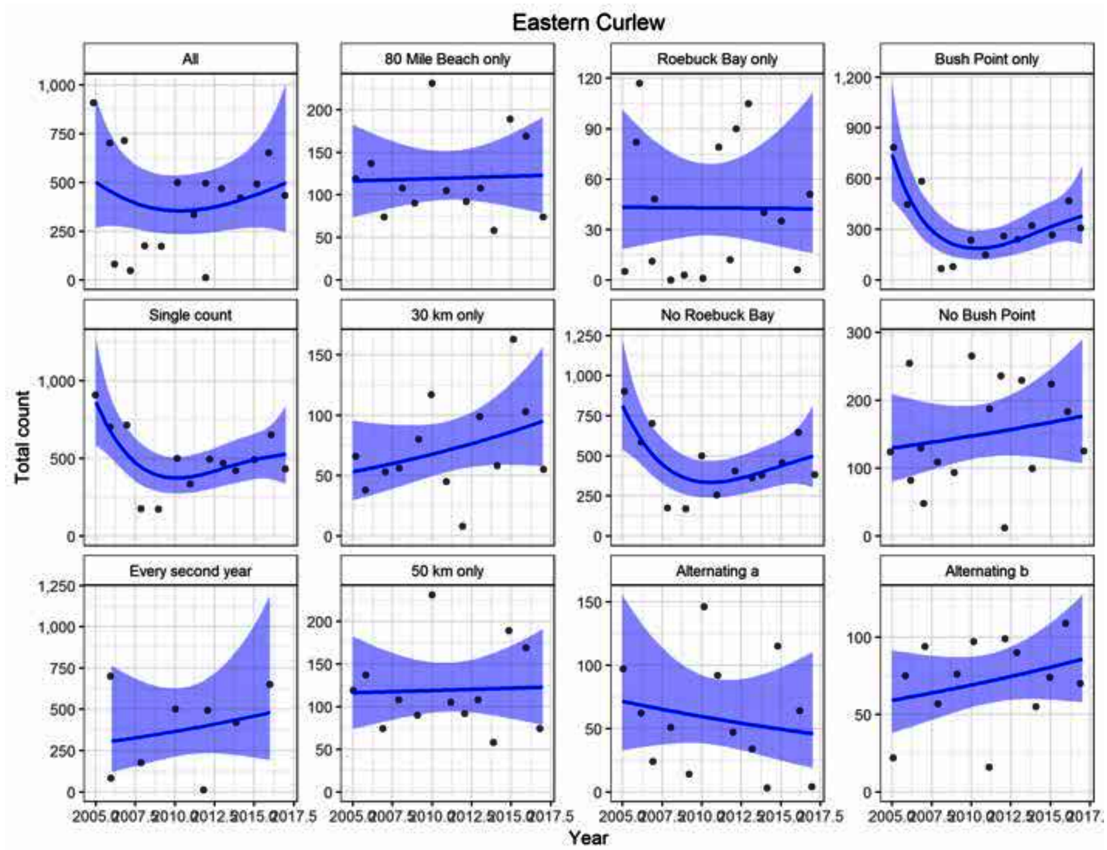


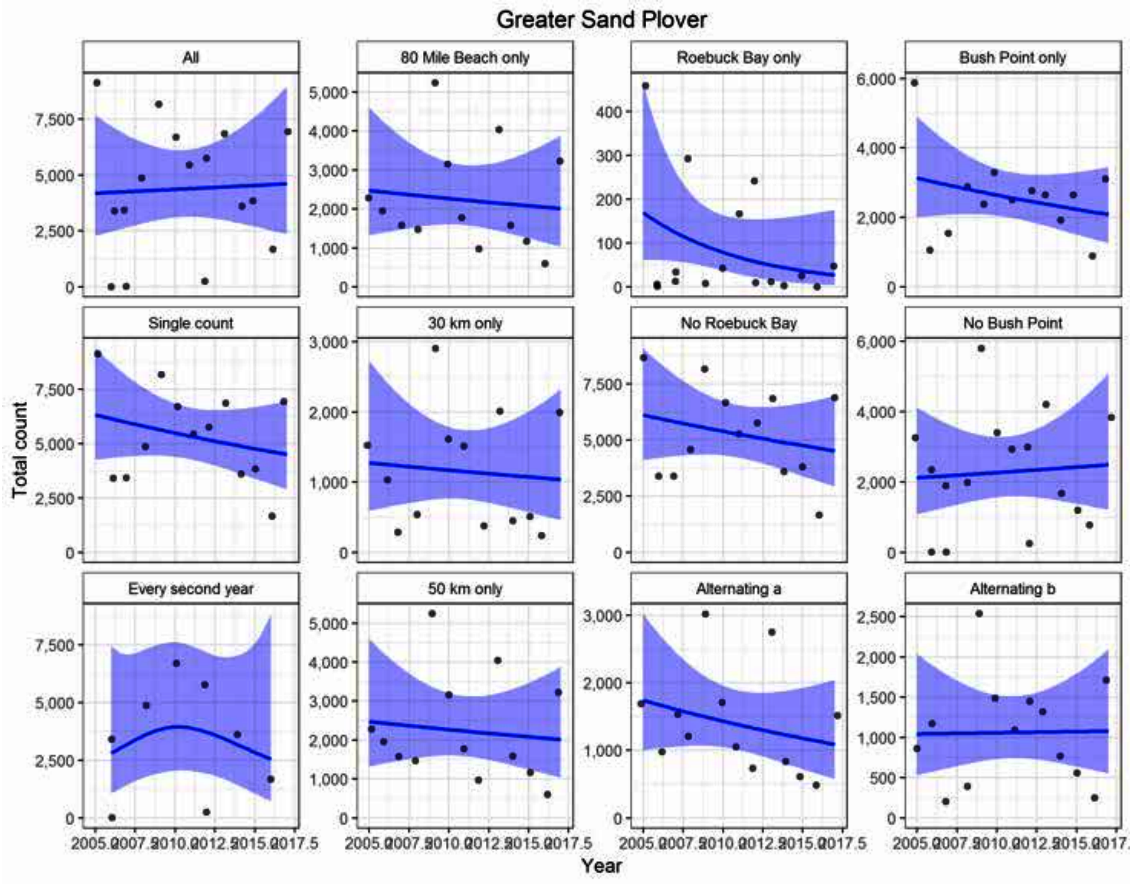


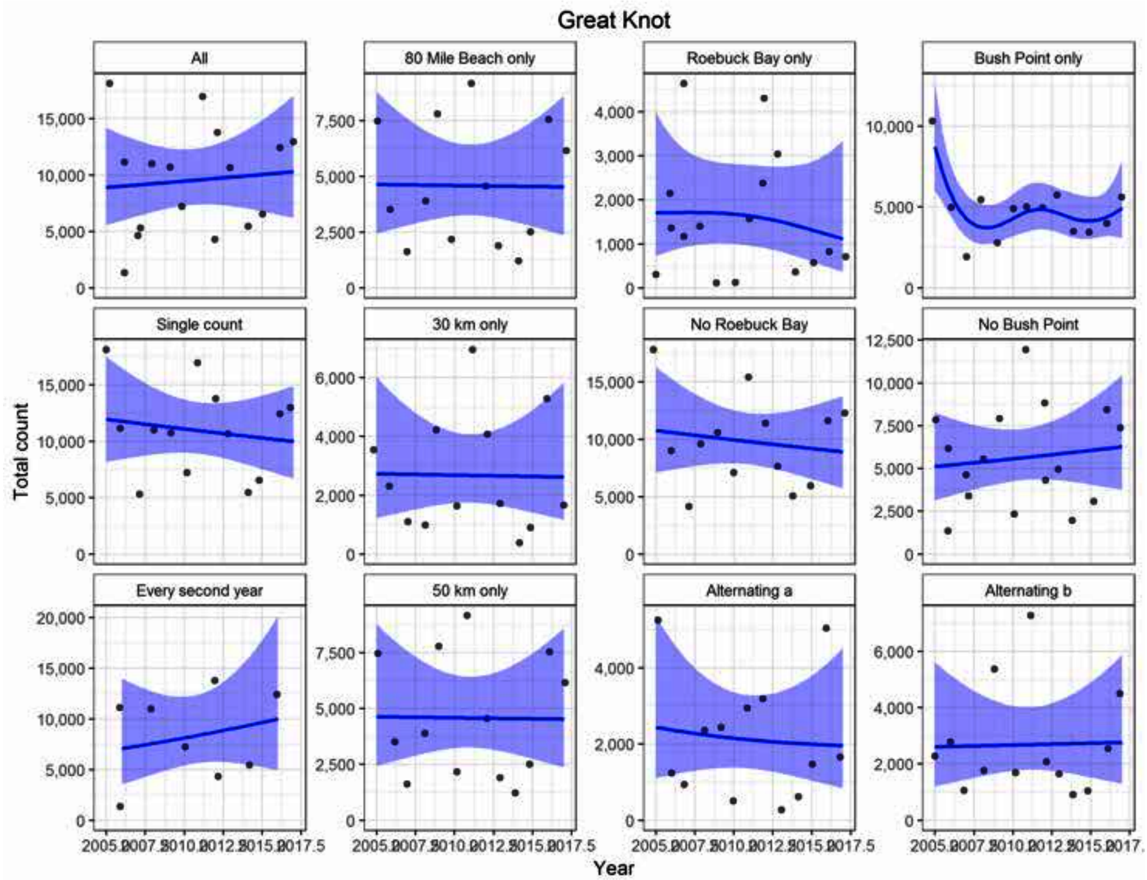

Broad-billed Sandpiper
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

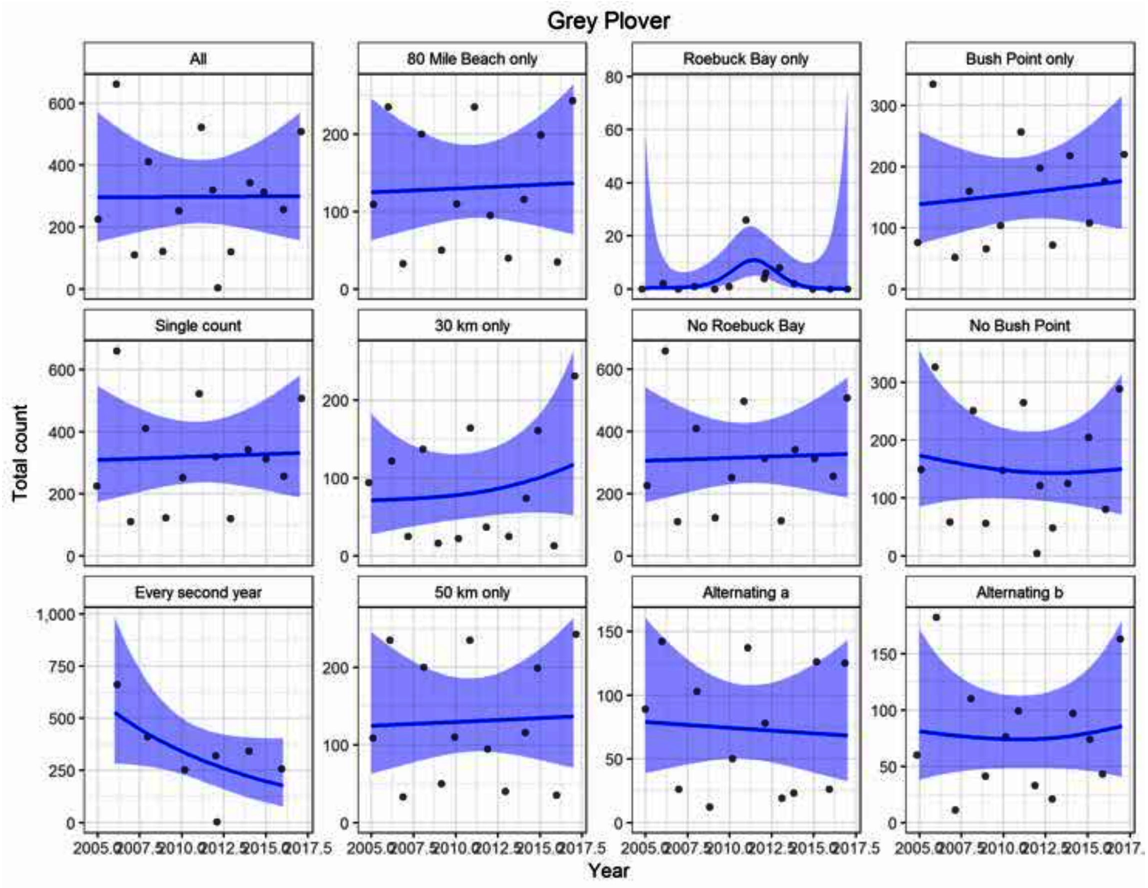

Common Greenshank
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

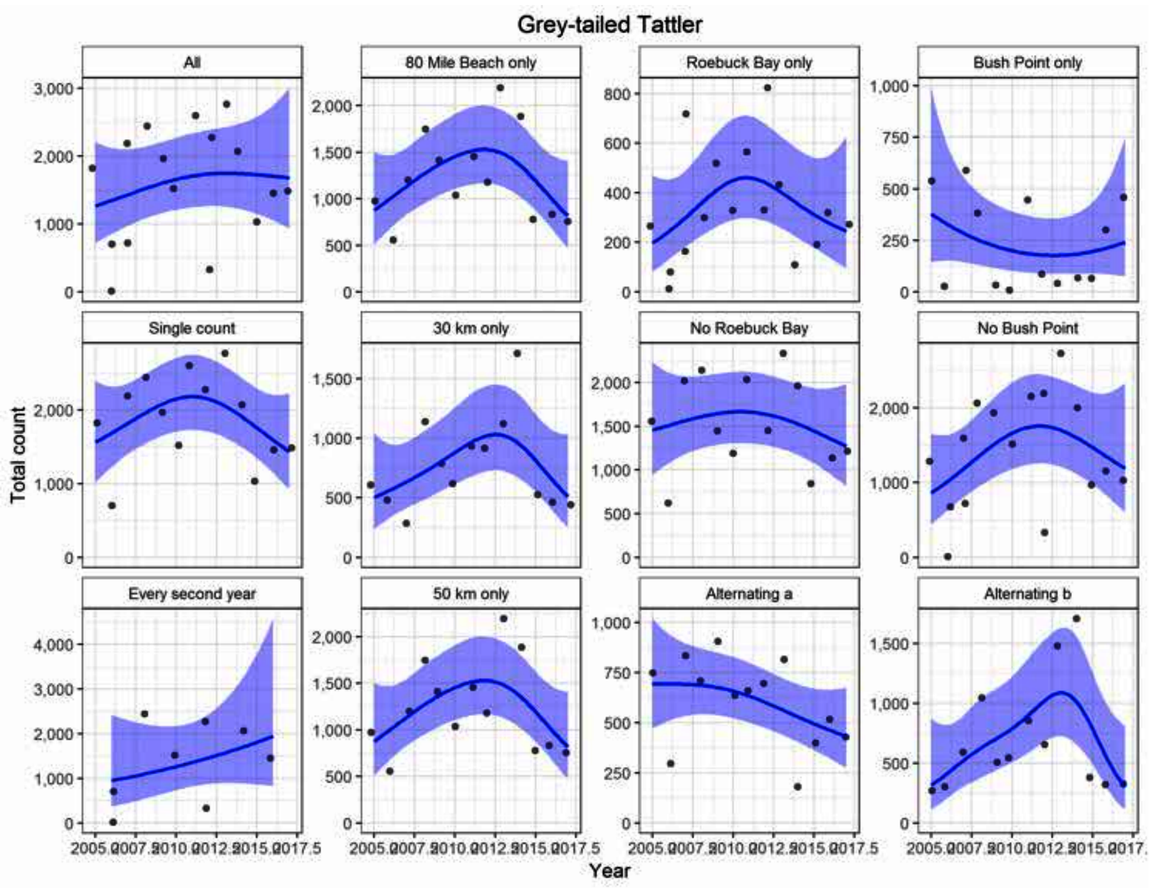

Curlew Sandpiper
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

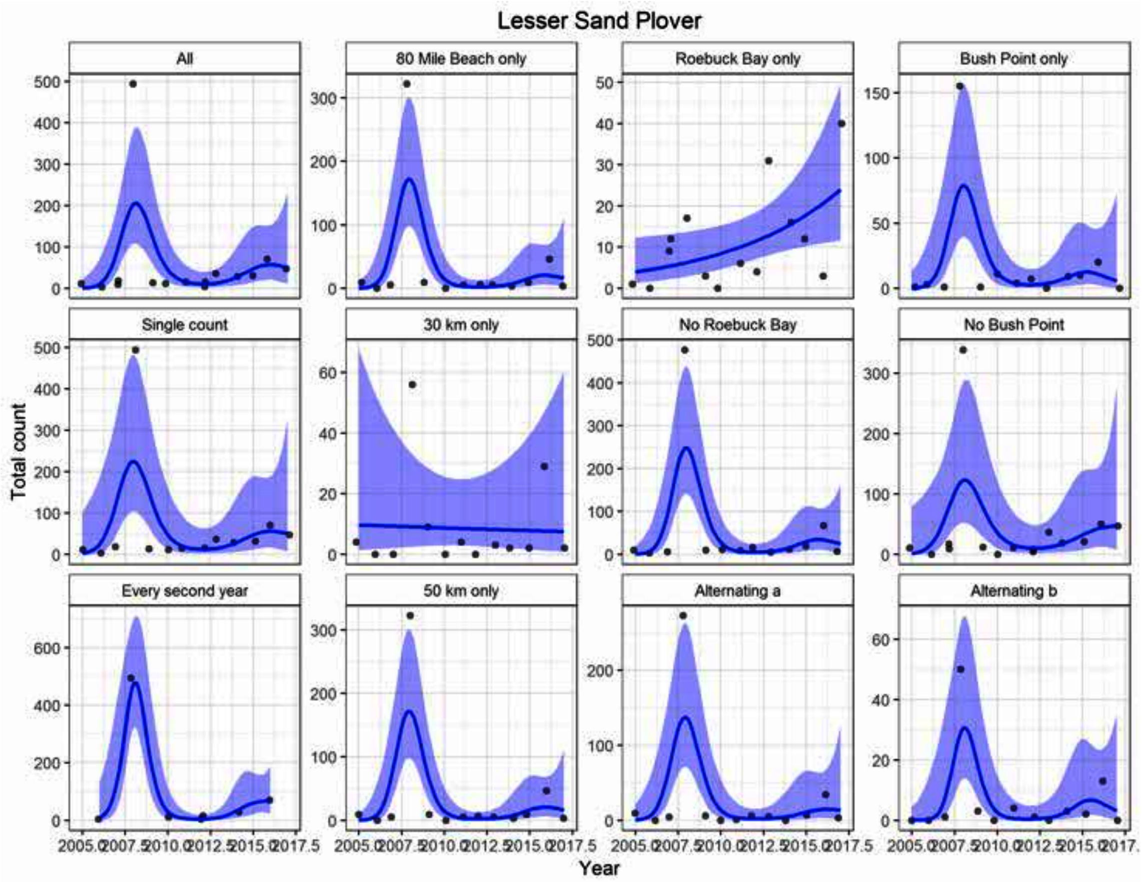

Eastern Curlew
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

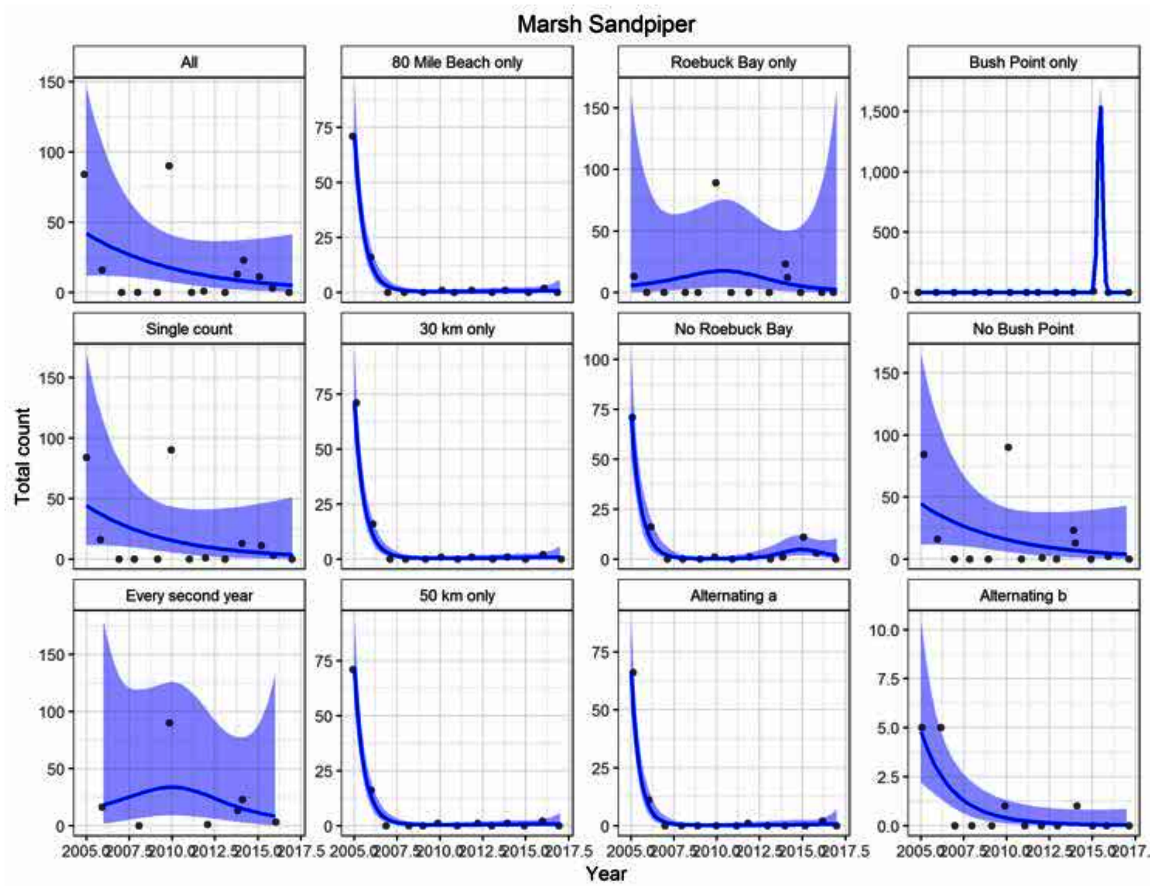

Greater Sand Plover
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

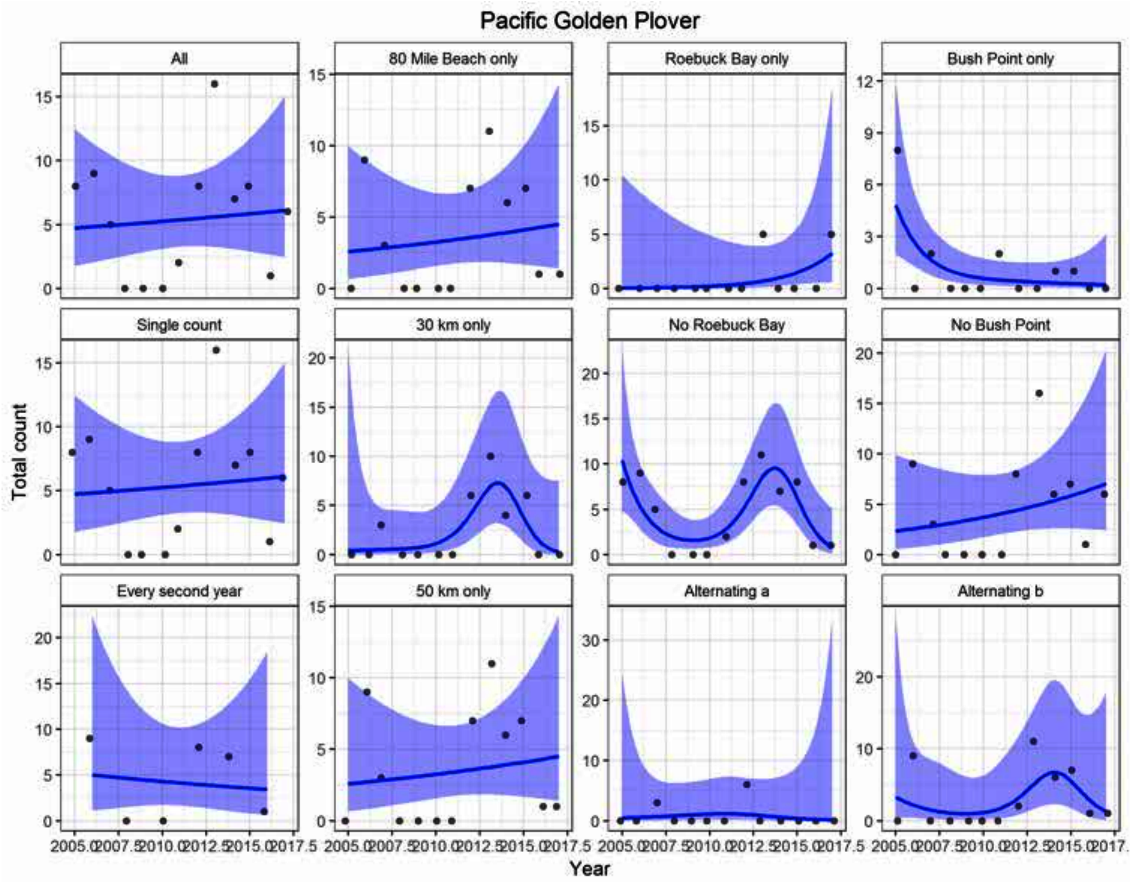

Great Knot
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

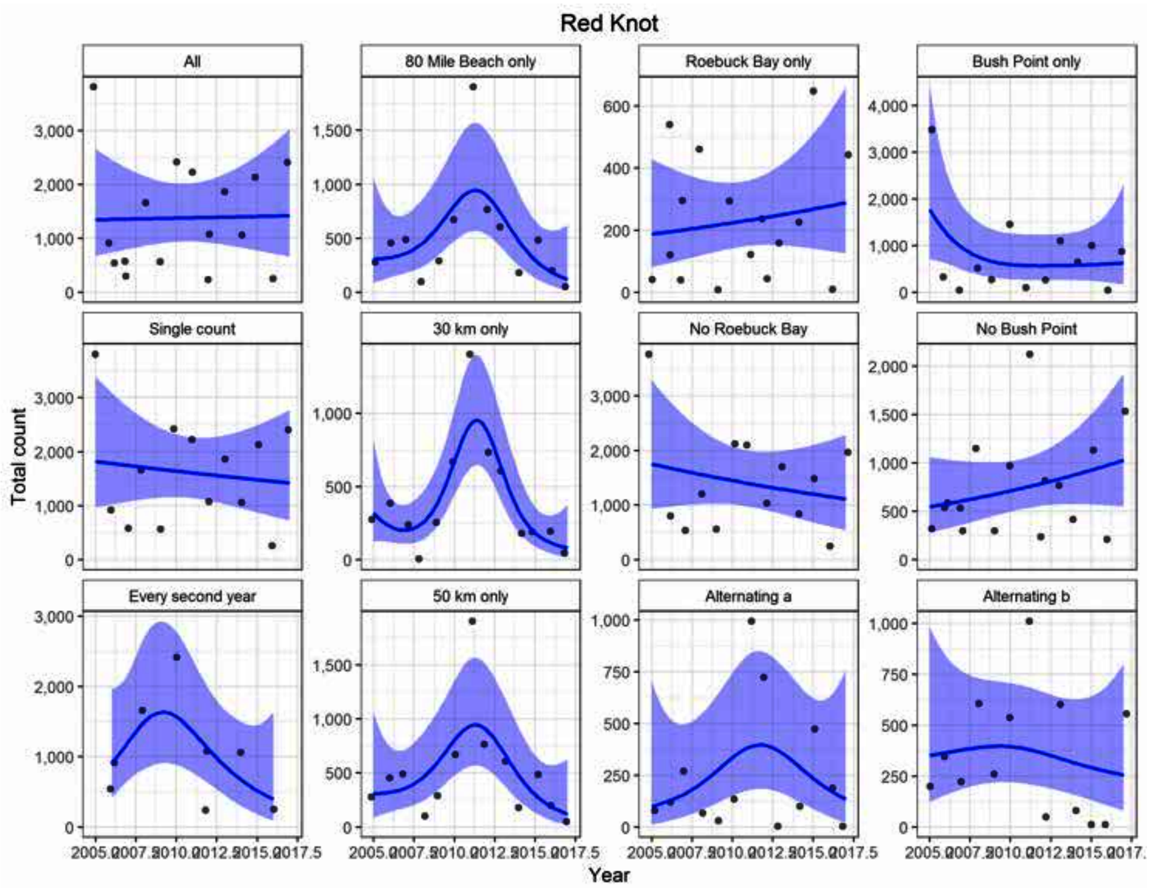

Grey Plover
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

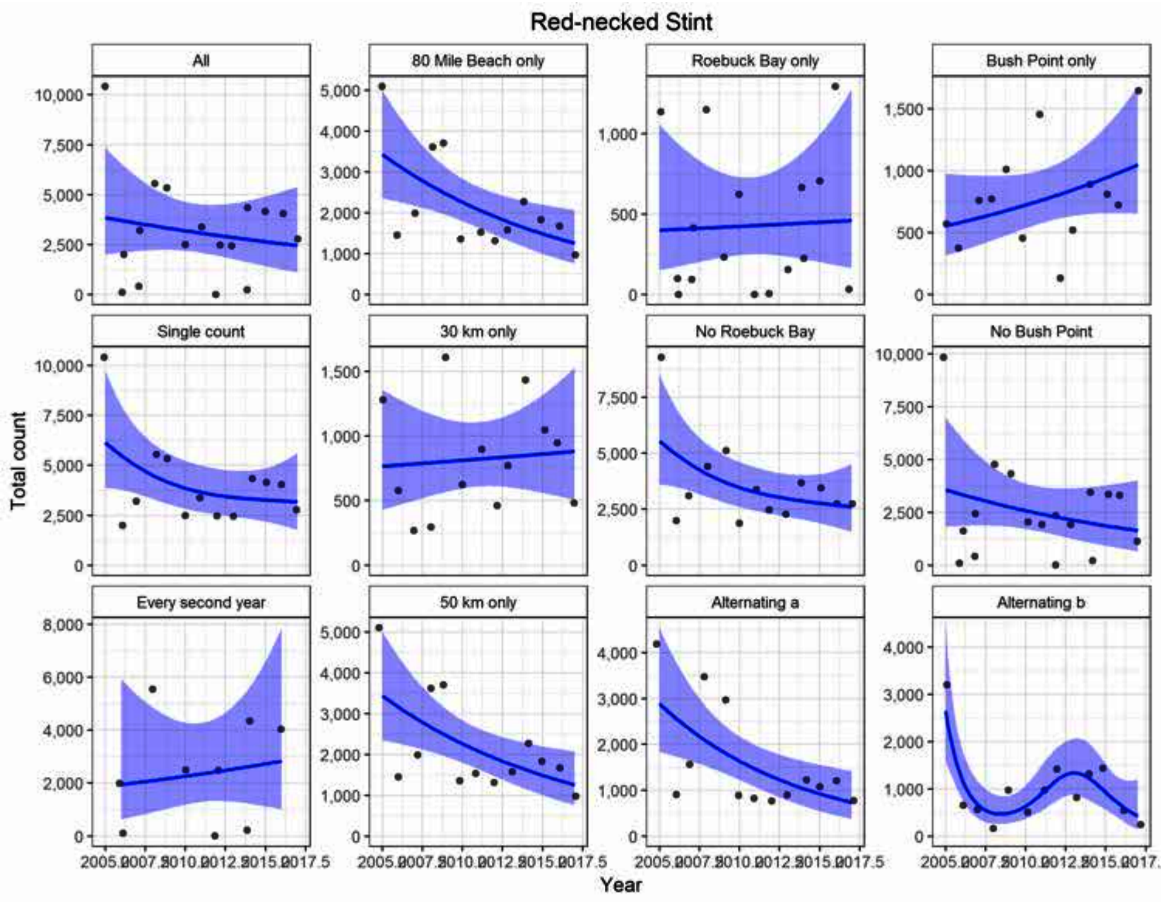

Grey-tailed Tattler
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

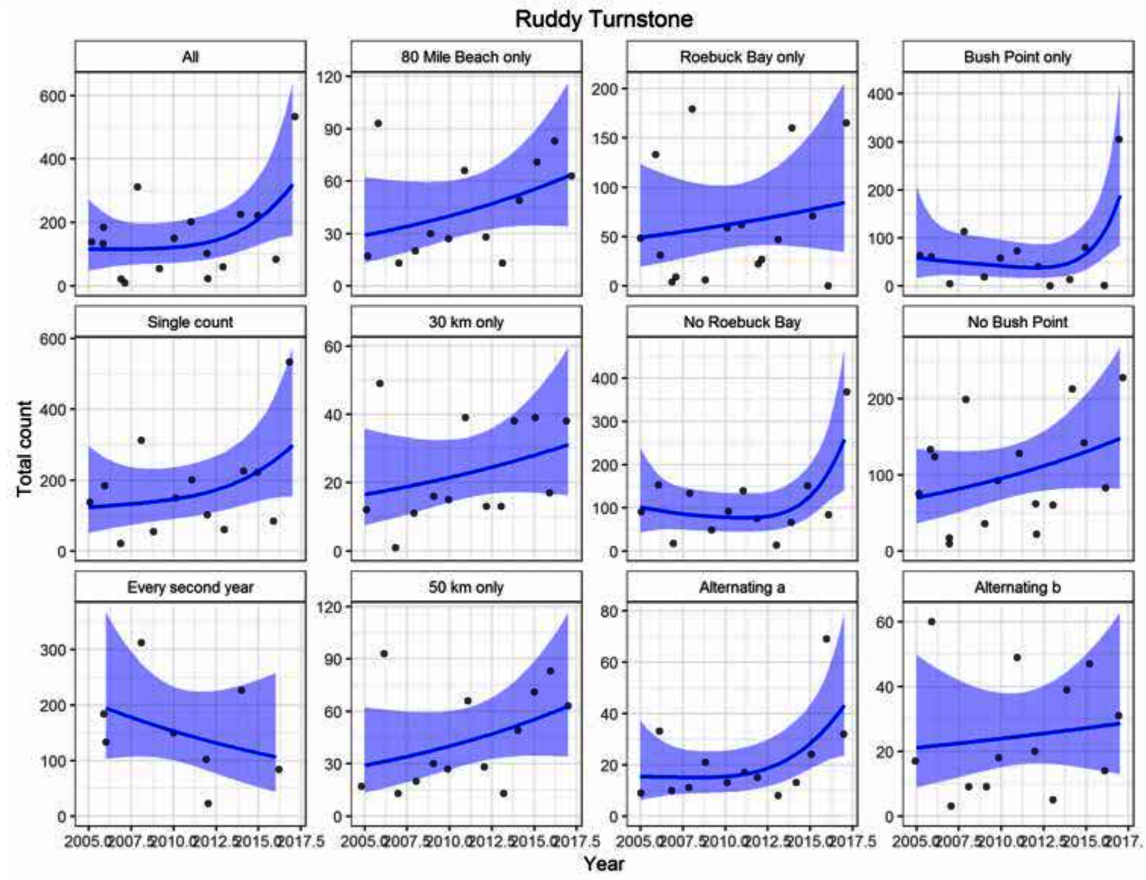

Lesser Sand Plover
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

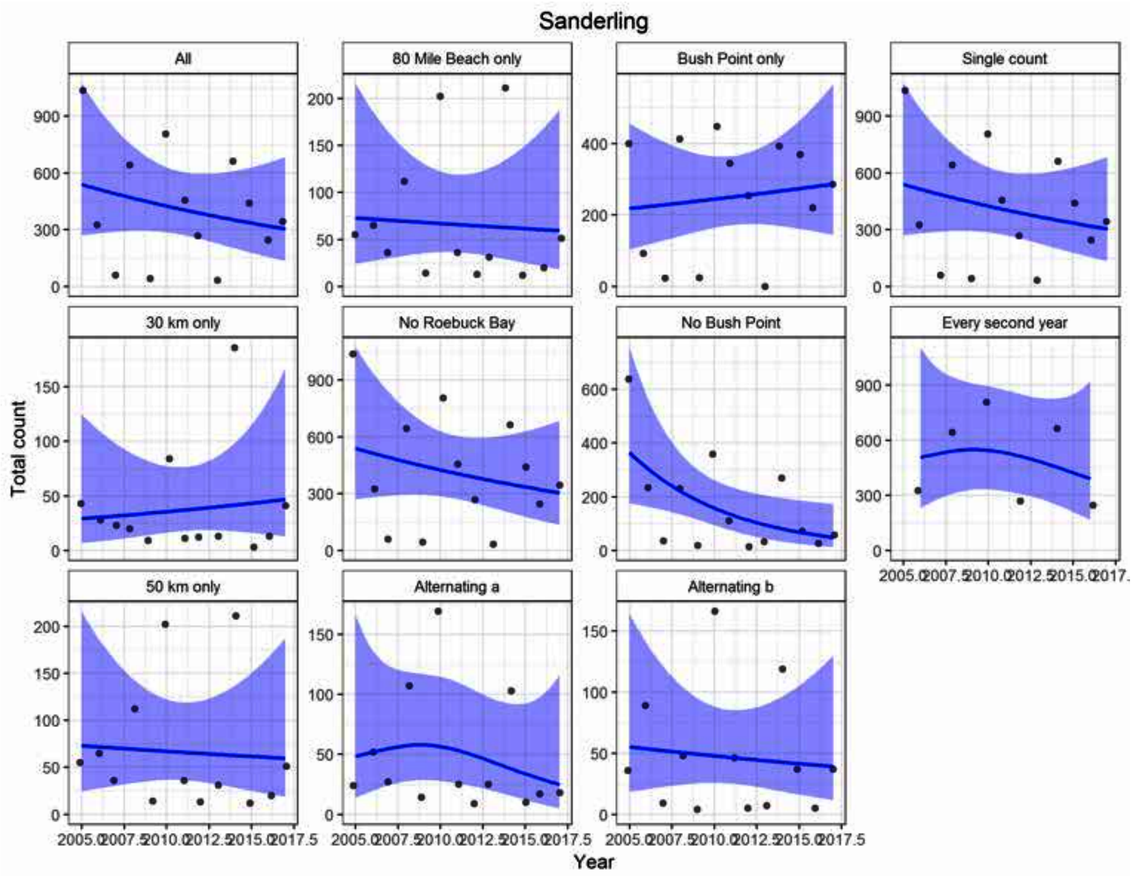

Marsh Sandpiper
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

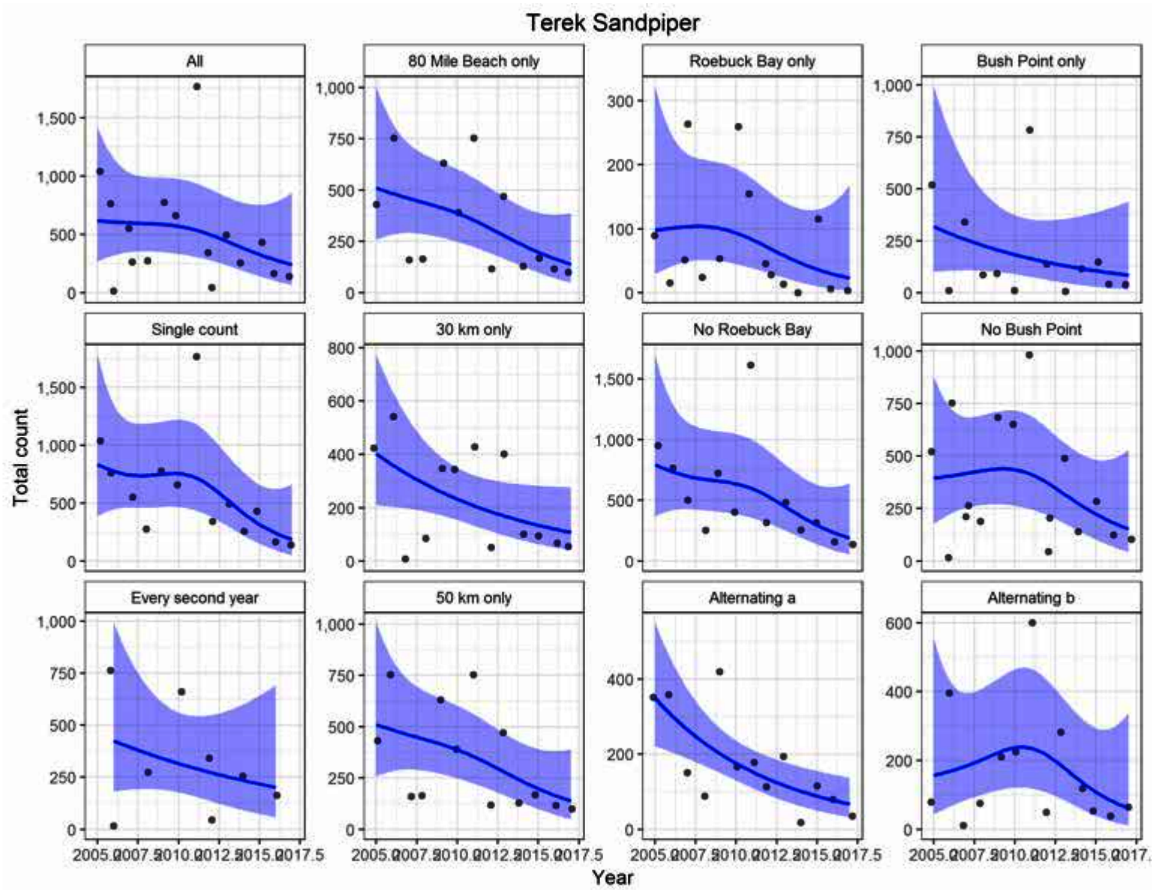

Pacific Golden Plover
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

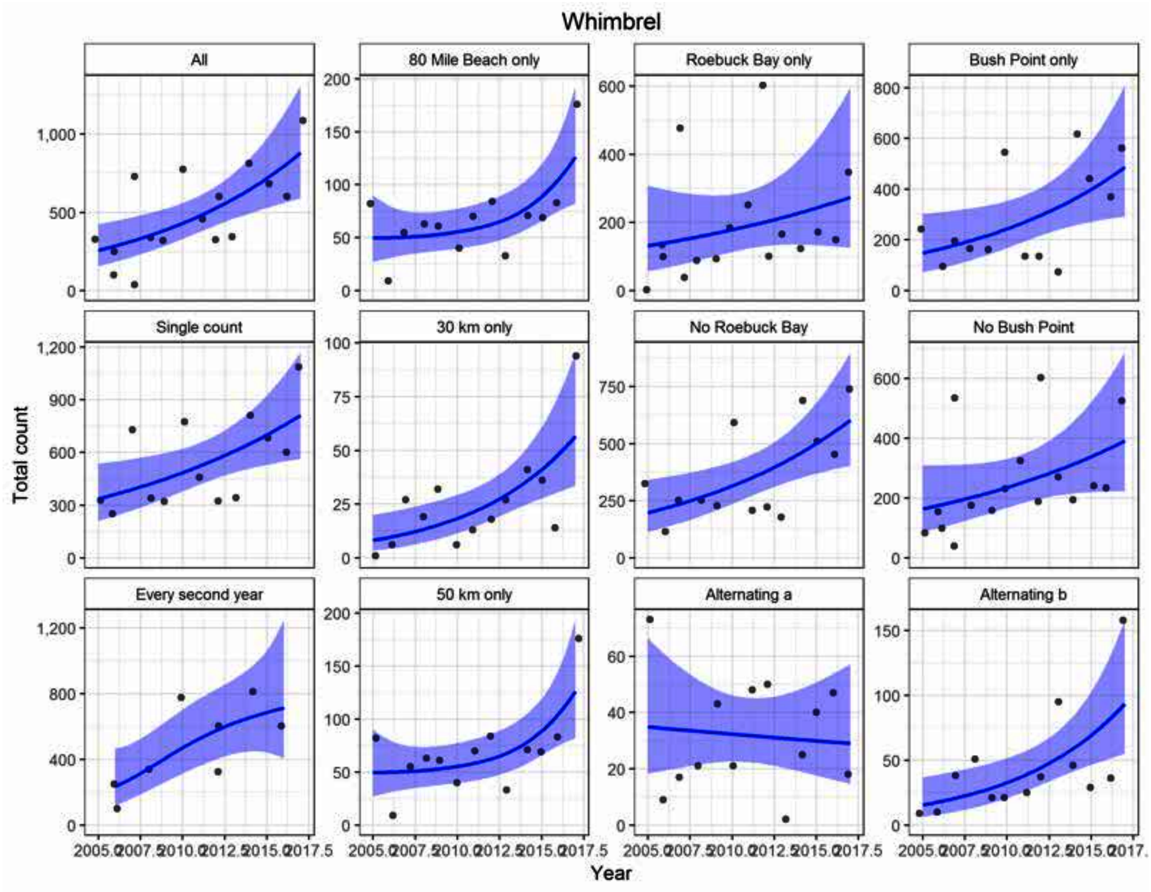

Red Knot
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year


Red-necked Stint
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year


Ruddy Turnstone
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year


Sanderling
All
80 Mile Beach only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year


Terek Sandpiper
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

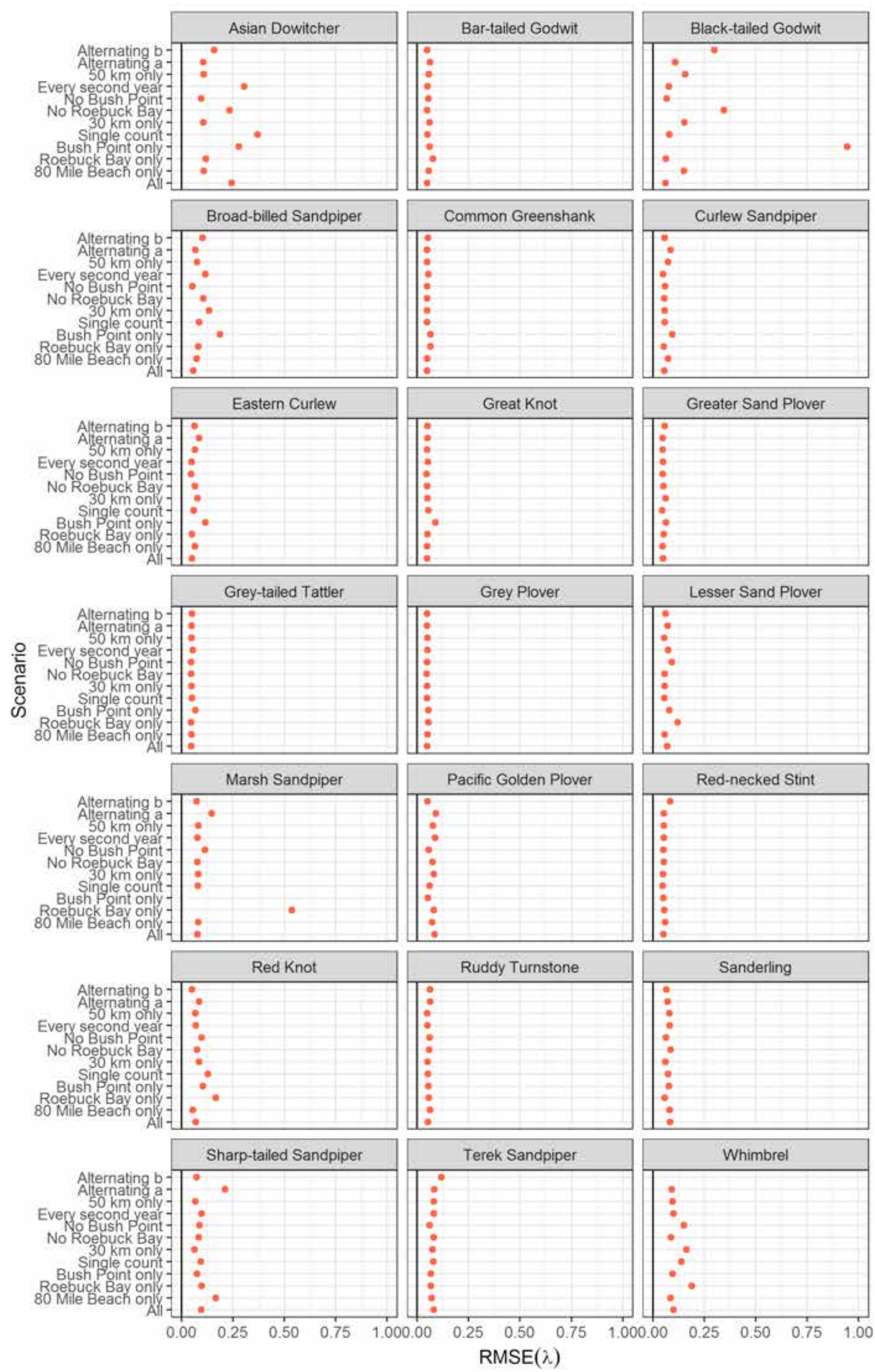

Whimbrel
All
80 Mile Beach only
Roebuck Bay only
Bush Point only
Single count
30 km only
No Roebuck Bay
No Bush Point
Every second year
50 km only
Alternating a
Alternating b
Total count
Year

Appendix 3: Trends in GAMs 2004-2016

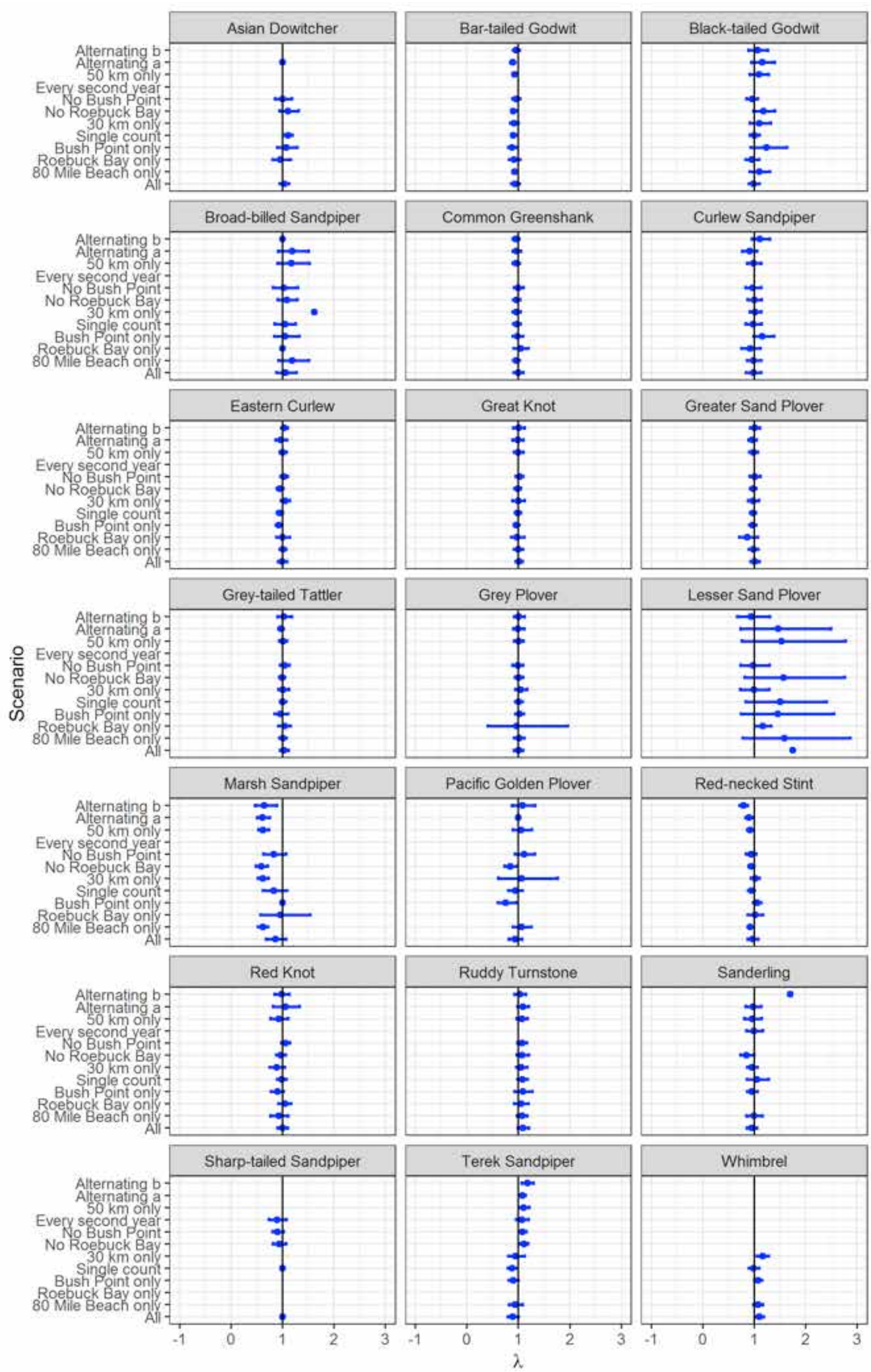
Bias of Lambda and 95% confidence intervals for summer subsampling scenarios.

Bias in lambda for summer subsamples.

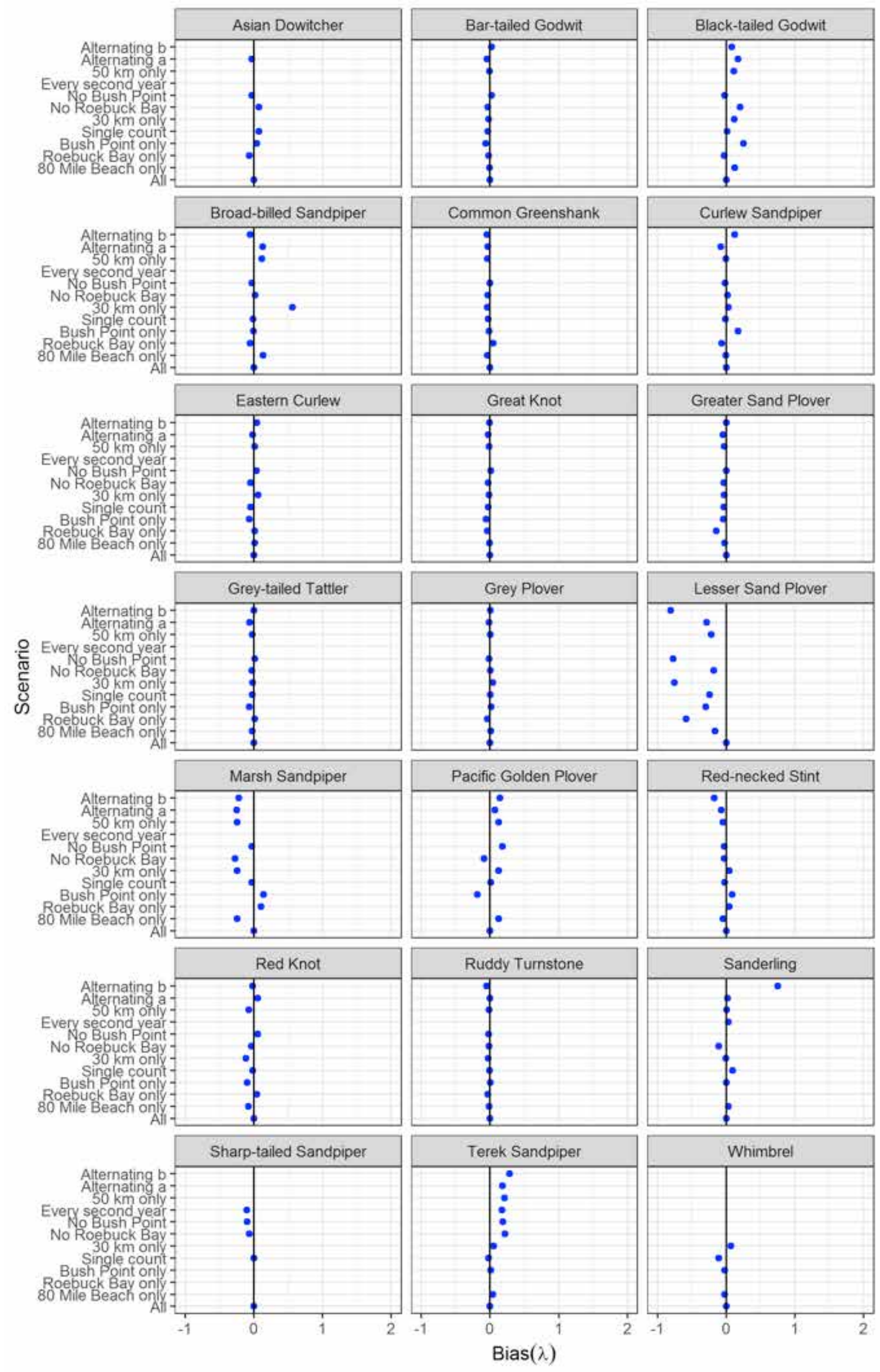
Root-Mean Square Error of lambda for summer subsamples.



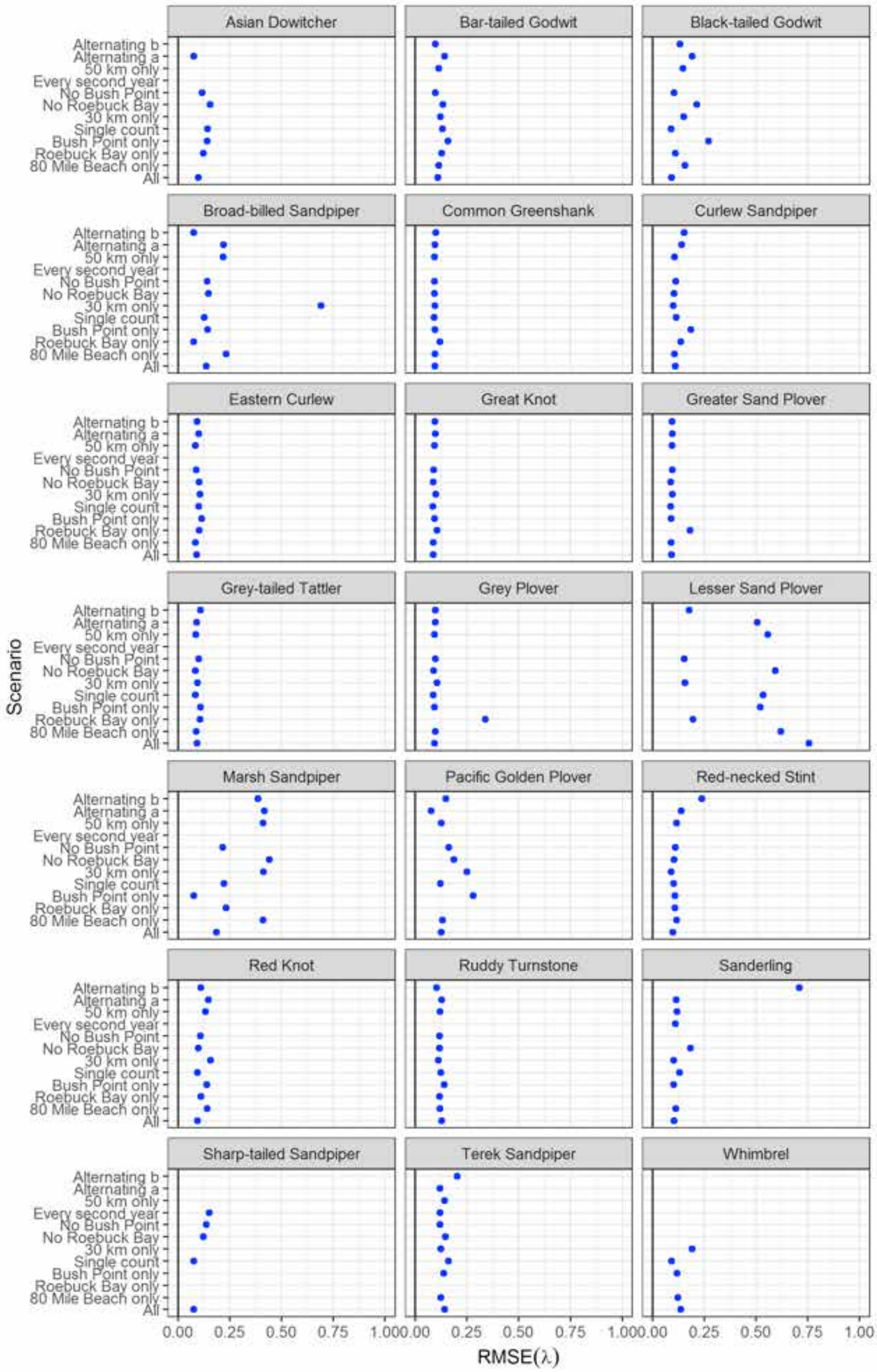
Lambda and 95% confidence intervals for winter subsampling scenarios.



Bias in lambda for winter subsamples.



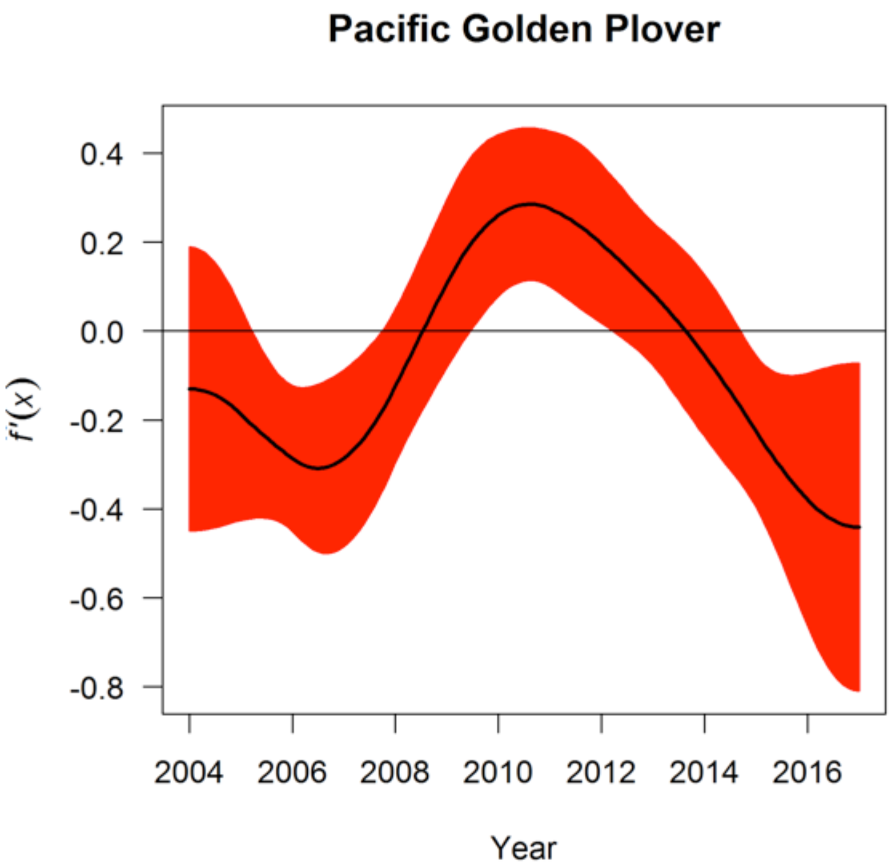
Root-Mean Square Error for lambda in winter subsamples.



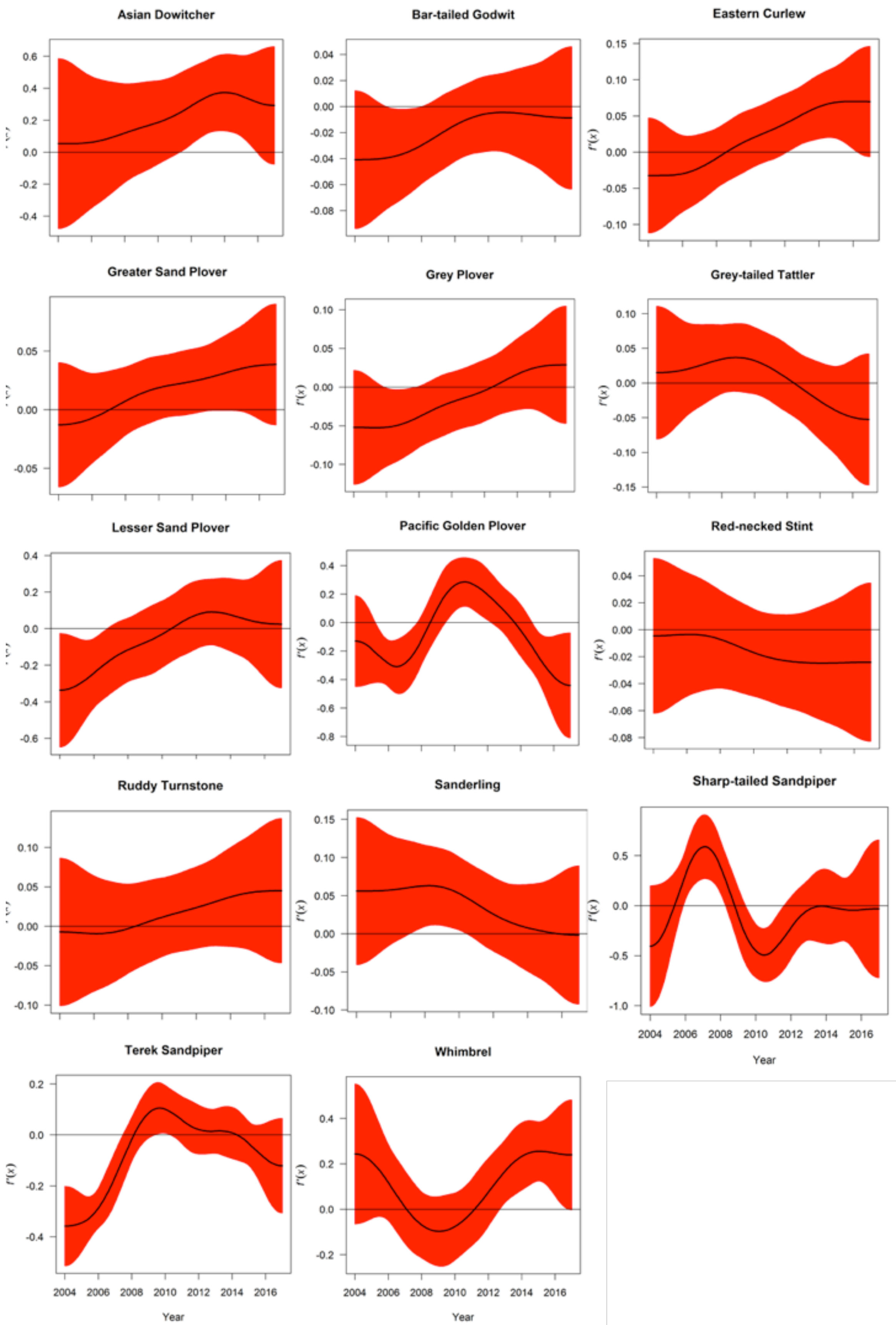
Appendix 4: First derivatives of GAMs

This appendix includes plots of the first derivatives (rate of change) over time for the GAMs presented in Appendix 1. An example is provided below. When the line and confidence limits were less than zero, the population was declining significantly, when the line and confidence limits were greater than zero the population was increasing significantly. Pacific Golden Plover went through a period of significant decline 2005-2007, increased significantly 2009-2012, and has been decreasing significantly since 2015.

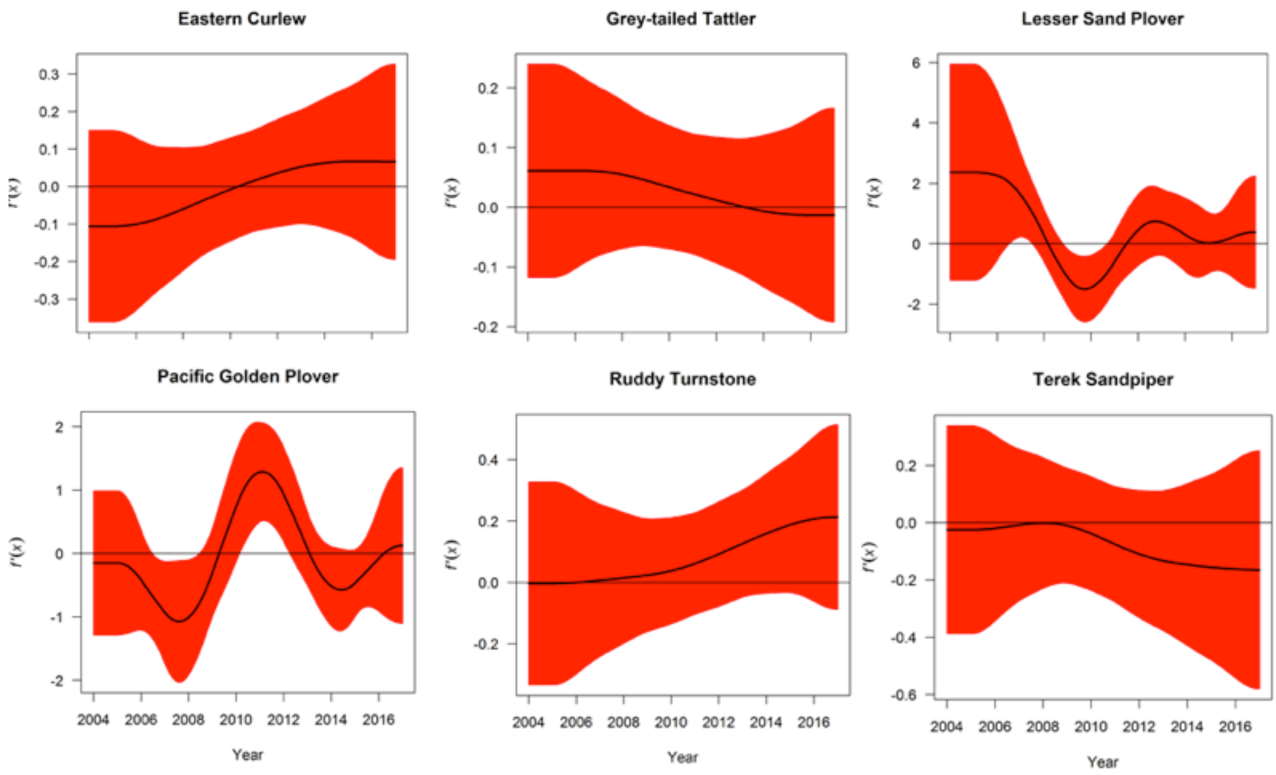
First derivatives are plotted for all species on the subsequent two pages, except for species in which the GAMs were unable to detect periods of increase or decrease.



First derivatives of GAMs for summer subsamples.



First derivatives of GAMs for winter subsamples.



www.delwp.vic.gov.au

www.ari.vic.gov.au