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Evaluating the impacts of local and international pressures on migratory shorebirds in Roebuck Bay and Eighty Mile Beach

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WAMSI Kimberley Marine Research Program

Final Report

Project 1.2.6

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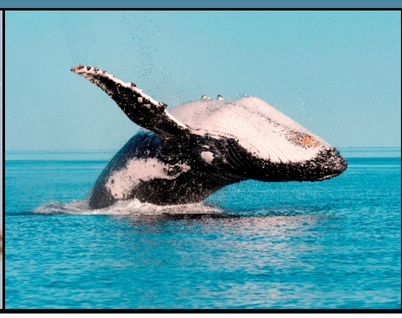


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WAMSI Kimberley Marine Research Program

Initiated with the support of the State Government, the Kimberley Marine Research Program is co-invested by the WAMSI partners to provide regional understanding and baseline knowledge about the Kimberley marine environment. The program has been created in response to the extraordinary, unspoilt wilderness value of the Kimberley and increasing pressure for development in this region. The purpose is to provide science based information to support decision making in relation to the Kimberley marine park network, other conservation activities and future development proposals.

Front cover images (L-R)

Image 1: Satellite image of the Kimberley coastline (Image: Landgate)

Image 2: Terek Sandpiper (*Xenus cinereus*) (Image: Danny Rogers)

Image 3: Humpback Whale (Image: Pam Osborn)

Image 4: Greater Sand Plovers (*Charadrius leschenualtii*) in the bottom row; Great Knot (*Calidris tenuirostris*) in the top row (one mostly hidden); Red Knot (*Calidris canutus*) at right centre. (Image: Danny Rogers)

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Contents

Executive Summary

Introduction

Migratory shorebirds are protected by a number of international conservation agreements and are treated as matters of national significance under the *EPBC Act 1999*. The tidal flats of Eighty Mile Beach and Roebuck Bay support the largest non-breeding populations of migratory shorebirds in Australia and the East Asian - Australasian flyway. Both sites are recognized as Wetlands of International Significance under the Ramsar Convention, and were recently listed as marine parks. Migratory shorebirds are key performance indicators for both the Eighty Mile Beach Marine Park and Roebuck Bay Marine Park.

Shorebird numbers in northwestern Australia have been monitored systematically since 2004 (Rogers et al. 2006a). 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 population changes driven by local-scale habitat changes that can be corrected or at least ameliorated by conservation actions within the Kimberley region. However, migratory shorebird numbers are also affected by external influences, such as loss of migratory stopover sites in Asia which they depend on when migrating to their breeding grounds in Siberia and Alaska. A key step to arresting the ongoing decline of migratory shorebird populations is to be able to distinguish changes caused by local factors (the responsibility of Australian governments, conservation agencies and land managers) and external factors (the responsibility of international agencies and governments).

Scope of study

WAMSI funded the shorebird monitoring program in northwestern Australia in the summer of 2013/14, enabling continuity of a program which has now been running for 13 years and provides one of the longest time-series of shorebird counts from tropical Australia; it is potentially the largest shorebird count data set from the southern hemisphere in terms of shorebird numbers counted. In addition, WAMSI funding supported two analyses: (1) An assessment of whether dramatic declines in Great Knot (*Calidris tenuirostris*) in Korea following large-scale reclamation operations (Moores et al. 2016) resulted in detectable effects on abundance and survival in northwestern Australia; (2) When high tide flood their intertidal foraging areas, shorebirds move to sites called roosts, where they loaf, preen or sleep until the tide ebbs. We assessed whether the roost-site preferences of shorebirds in Roebuck Bay and Eighty Mile Beach have changed, and whether any changes are associated with disturbance or mangrove encroachment.

Shorebirds on the Northern Beaches of Roebuck Bay, Bush Point (at the south of Roebuck Bay) and a 60 km stretch of Eighty Mile Beach were counted to species level from 2004 to 2017. These areas were counted twice each summer between mid-October and early December (during the non-breeding season for migratory shorebirds, when numbers peak in Australia) and once each winter (June-early July, when adults are breeding in the northern hemisphere and only immatures remain in Australia).

In the analysis of the coincidence of Korean reclamation (2006-2008) with changes in the northwestern Australian population of Great Knot, we also used mark-resighting data from northwestern Australian banding programs to estimate annual apparent survival of adult Great Knot. Annual breeding success was estimated from: (1) winter counts; (2) the proportion of immature shorebirds found in summer catches as part of a banding study by the Australasian Wader Studies Group.

The loss of a major Korean staging site for Great Knot (Saemangeum, Republic of Korea) in 2006 coincided with the disappearance of ~100,000 Great Knots from Korean staging grounds (about 20% of the world population). Counts of Great Knot, and annual apparent survival of Great Knots in northwestern Australia, also declined by ~20% at this time. Our data strongly suggest that the Korean reclamation caused rapid population decline in

northwestern Australian Great Knot, adding to a growing body of evidence demonstrating that declines in shorebird numbers in Australia are driven largely by loss of migratory stopover habitat in Asia.

Some changes of roost usage in northwestern Australia are consistent with disturbance and mangrove encroachment restricting their use of roosts. In winter, when disturbance from humans and birds of prey is highest, some roosts in Roebuck Bay (including those with encroaching mangroves) are abandoned by shorebirds. The birds relocate to other roosts on the shores of Roebuck Bay with less human disturbance. It is not clear whether this affects their survival, but it is noteworthy that counts of migratory shorebirds in Northern Roebuck Bay declined during the study, in contrast to less disturbed sites at Bush Point (where numbers increased) and Eighty Mile Beach (where numbers have been reasonably stable). In summer, no significant changes were found in relative numbers of birds at individual roosts in the period 2004-2017. This may indicate that roost protection measures in Roebuck Bay (largely public education) are succeeding, but it is also possible that the variability of counts at individual roosts has concealed slow changes.

Implications for management

In addition to addressing the management questions set for this project (see Appendix 1), the following implications for management should be considered.

1. Continued monitoring of shorebird populations in northwestern Australia is recommended. Our study shows roost usage and shorebird numbers in northwestern Australia to be dynamic, and we cannot predict what the future holds. Shorebird counts can provide direct evidence of local pressures on shorebird sites, and the success or otherwise of habitat management. Analyses are currently being carried out to assess whether the existing program can be improved, or maintained at lower cost.

2. It is helpful to monitor demographic parameters as well as shorebird numbers. Annual estimates of adult survival and recruitment of immatures enable understanding the causes of population changes shown by counts. Moreover, they may provide early warning of changes. In Great Knot, for example, annual adult survival is declining, but counts of Great Knot have not yet shown substantial decline. Our data indicate that this discrepancy has been driven by two years of exceptionally high breeding success, and is probably not representative of the long-term outlook.

3. Roost disturbance remains an issue in Roebuck Bay; it threatens the shorebird spectacle that attracts many tourists to Broome, and may cause shorebird population declines. Stakeholders who may be able to work together to control disturbance of shorebird roosts in Roebuck Bay include The Department of Biodiversity, Conservation and Attractions, The Conservation and Parks Commission, Broome Bird Observatory and traditional owners.

Key residual knowledge gaps

There is a need for integrated population modelling of existing count and demographic data to fully understand the interactions between annual survival, recruitment, immature dispersal and population counts.

Disturbance levels of shorebirds in Roebuck Bay need to be re-appraised; they were last measured in 2009, and it is not known if public education measures undertaken since then (e.g. signposting, public meetings) have succeeded in lowering disturbance rates.

Existing shorebird monitoring data should be compared with data from benthos surveys in northwestern Australia, to assess whether any of the observed changes in roost location can be associated with changes in local food supplies.

1 Introduction

The tidal flats of the Kimberley coast support the largest populations of migratory shorebirds in Australia. Eighty Mile Beach and Roebuck Bay are the most important shorebird sites in the region, regularly supporting more than 550,000 migratory shorebirds (Rogers et al. 2011, Minton et al. 2003). Both sites are recognized as Wetlands of International Significance under the Ramsar Convention, and 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. Moreover, these sites are among the most important non-breeding sites for these spectacular trans-equatorial migrants in the entire East-Asian Australasian Flyway, and are therefore of international importance to shorebird conservation. Australia has entered several international agreements to conserve migratory birds and migratory shorebirds are treated as matters of national significance under the *EPBC Act 1999*. The shorebird roosts in Northern Roebuck Bay are an internationally famous spectacle, and attract many tourists to Broome.

Shorebird numbers in northwestern Australia have been monitored systematically since 2004 (Rogers et al. 2006a), with the long-term objective of developing a dataset suitable for assessment of changes in shorebird diversity, numbers and distribution over time. 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 population changes driven by local-scale habitat changes that can be corrected or at least ameliorated by conservation actions within the Kimberley region. Ongoing changes in the region that could potentially cause declines in shorebird populations 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. 2006c);
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, presumably because they offer clear views in all directions and hence lower the risk of predation (Rogers et al. 2006d).

On the other hand, shorebird counts at a local scale can also be influenced by external factors. The strongest driver of declining shorebird populations through the entire East Asian – Australasian Flyway is thought to be habitat loss in migratory stopover sites on the Asian coast (e.g. Studds et al. 2017). In addition, migratory shorebirds experience marked annual fluctuations in breeding success on their near-arctic breeding grounds. Although these fluctuations are driven by distant factors (e.g. arctic summer temperatures and lemming cycles), they have observable effects on the number of juvenile shorebirds reaching Australasian non-breeding grounds each year (Aharon- Rotman et al. 2014, Minton et al. 2003, Summers and Underhill 1987)

Conservation issues such as habitat loss in Asia or reduced breeding success in the Arctic can only be addressed through international actions involving agencies and governments working overseas. In contrast, local pressures on shorebird populations, such as human disturbance, habitat alteration and pollution, can be controlled with local conservation actions such as alterations to recreation zoning, public education, vegetation management and runoff management. It is therefore important to understand the extent to which shorebird populations in the Kimberley are influenced by local factors, and by factors outside Australia. Shorebird count data from the Kimberley coast are essential for solving this question, especially when they can be compared with shorebird trend data in other parts of Australia (e.g. Clemens et al. 2016), and with additional demographic parameters such as annual breeding success (Minton et al. 2005) and annual survival (e.g. Piersma et al 2016).

WAMSI funding enabled continuation of systematic shorebird counts in northwestern Australia through the summer of 2012/2013 (it has since been maintained with other funding sources). The funding also contributed to two ongoing analyses, both related to the issue of distinguishing changes caused by local versus external factors. These analyses are:

1. An assessment of whether dramatic declines in shorebird abundance in Korea following large-scale reclamation operations (Moores et al. 2016) resulted in detectable effects in abundance and survival of shorebirds in northwestern Australia.

   The analysis focuses on one species, the Great Knot Calidris tenuirostris. It is one of the most numerous shorebird species in northwestern Australia during the non-breeding season October-March. Banding and tracking studies confirm that Australia's Great Knot stage in the Yellow Sea on their northward migration. In Korea numbers of Great Knot declined dramatically between 2006 and 2008 when the Saemangeum reclamation project destroyed the most important staging site for Great Knot in the East Asian Australasian Flyway (Rogers et al. 2006b, Moores et al. 2016). Great Knot counts in Korea declined by ~100,000 during this period (~20% of the world population), and detectable declines were therefore expected in Australia.

2. When high tide flood their intertidal foraging areas, shorebirds move to sites called roosts, where they loaf, preen or sleep until the tide ebbs. We assessed whether the roost-site preferences of shorebirds in Roebuck Bay and Eighty Mile Beach have changed, and whether any changes are associated with disturbance. Shorebird roosts in the area range from sites in Roebuck Bay where disturbance from humans and birds of prey is frequent, to remote and tree-less sites on Eighty Mile Beach where there is little disturbance from humans or birds of prey. There are also roosts in Roebuck Bay known to be influenced by mangrove encroachment (Figure 1). Comparisons of consistency of use of pristine and disturbed roosts on the Kimberley coast should therefore shed some light on whether local habitat issues affect shorebird numbers.

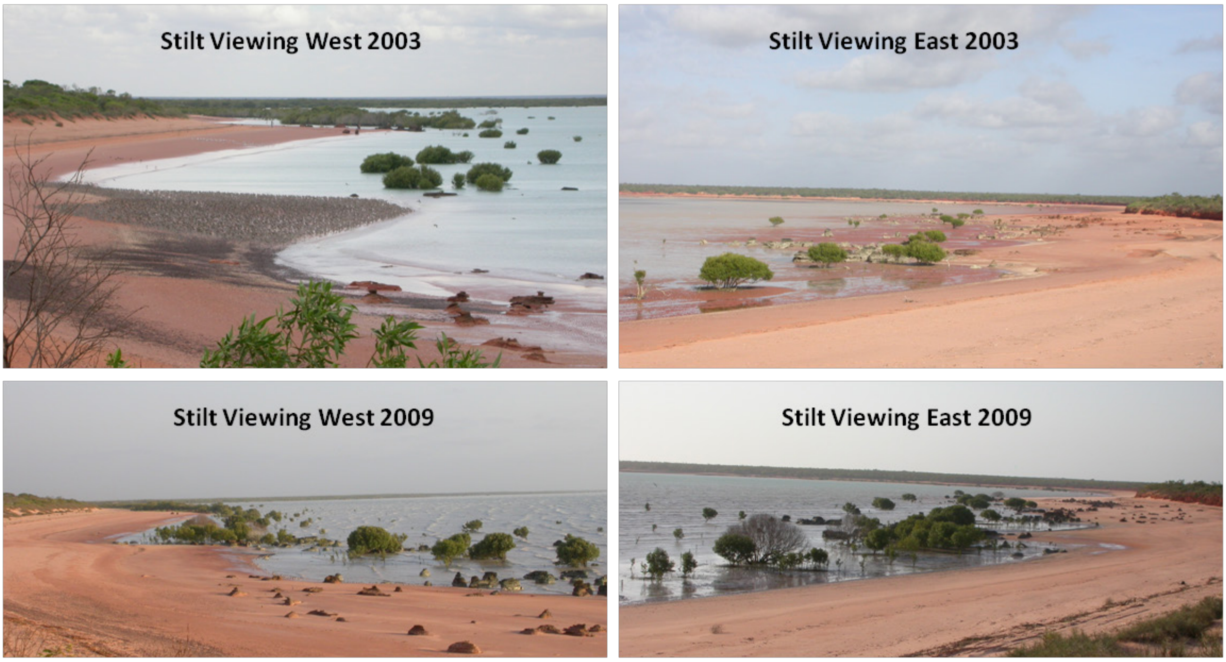

Figure 1. Shorebird roosting sites at Stilt Viewing, Northern Roebuck Bay, in 2003 and 2009. Note the increase in mangrove cover in the 2009 images, both to the west (left hand panels) and east (right hand panels).

2 Materials and Methods

Shorebird monitoring in northwestern Australia has been carried out by a combination of volunteers and contractors since 2004, and funding is essential to cover travel costs, transport and payment of contractors. A number of agencies have supported the surveys over this time and WAMSI funding enabled us to maintain the annual count surveys in a lean year in 2012/13.

The field methodology and statistical approaches to estimate the error associated with shorebird counts in northwestern Australia have been described in detail elsewhere (Rogers et al. 2006a, Rogers et al. 2011). In brief, our surveys involve ground-based counts of shorebirds viewed through tripod-mounted telescopes (30 – 60 x magnification). Numbers of terns are recorded in the same surveys, but the tern data are not considered in this report. One winter survey (June-July) and two summer surveys (Nov-Dec) are carried out each year, in which shorebirds of Roebuck Bay (including Bush Point) and the northern 80km of Eighty-mile Beach (see Appendix 2 for a map of the study area reprinted from Rogers et al 2011) are identified to species level and their numbers counted by an experienced team of professional and volunteer shorebird experts (see Appendix 3 for a list of species recorded). Surveys are carried out at high tide roosts, at times when the tidal flats are submerged and shorebirds are forced into relatively small roosts where it is possible for a team of experienced surveyors to count all birds of each species. Survey dates and times are carefully selected so that particular sites are visited at consistent tide heights (± ~75 cm) in every survey; this is important to increase repeatability, and to avoid neap and spring tide extremes. Neap tides do not rise high enough to force all birds from the tidal flats and spring tides can inundate mangrove clearings and salt-pans, providing alternate roost sites for shorebirds that are inaccessible to humans.

Shorebirds sometimes move from one roost site to another during high tide, and in Roebuck Bay in particular, they are often disturbed several times during a high tide. In the field great care was taken to avoid double-counting or overlooking birds, and often when major disturbance caused birds from already-counted roosts to fly into other roosts, it was necessary to discard the recorded data and start again. Shorebird counts over such a large geographical area are based on component counts from many different shorebird roosts. Each component count is entered into a long term database, enabling an assessment of whether local roost usage changes over time.

In addition to using Northwestern shorebird count data, the analysis of Korean reclamation effects on Great Knot numbers includes Mark-recapture analysis of Great Knots, individually marked in northwestern Australia with engraved leg-flags (by the Australasian Wader Studies Group since 2003) or with colour-bands (by the Global Flyways Network since 2005) with intense and systematic resighting effort. Resighting data were used in Cormack-Jolly-Seber Models (e.g. Sandercock 2003 and Sandercock 2006) to estimate apparent annual survival (with associated error) and assess whether survival has changed over time. We are also examining a data set on age-ratios within cannon-net catches by the Australasian Wader Studies Group, an index of annual breeding success (Minton 2003). The final part of this analysis is still in progress: we are working towards integrated population models that combine data on changes in shorebird numbers (from counts), annual survival (from the Mark-recapture analyses) and breeding success (from winter counts, and from age-ratio data on birds captured in the northwestern Australian summer) to assess whether populations underwent changes coinciding with the reclamation of Saemangeum, and the extent to which these changes were driven by adult mortality and annual breeding success.

3 Results

3.1 Maintaining continuity of shorebird monitoring in northwestern Australia

WAMSI funding was used to carry out two summer shorebird counts, 24-30 Nov 2012 and 9-14 Dec 2012, maintaining the continuity of a 14-year series of systematic counts from Eighty Mile Beach, Roebuck Bay and

Bush Point. Copies of the database are held by the Australasian Wader Studies Group and Birdlife Australia, and metadata is available on the PAWSEY database. A list of the bird species recorded during the surveys is in Appendix 2.

3.2 Did the Saemangeum reclamation in Korea affect Australian shorebird populations?

Analysis of South Korean data (Moores et al. 2016) indicated that ~100,000 Great Knots had been lost from migratory staging grounds at Saemangeum and adjacent estuaries in 2006 and 2007, immediately following the closure of the Seamangeum sea-wall in April 2006. This total comprised ~20% of the estimated world population of Great Knot (Hansen et al. 2016). At the same time, counts of Great Knot declined by ~20% in our study area, the most important non-breeding site for this species. Moreover, on the basis of mark-recapture analyses, estimates of apparent annual survival of adults in 2006/07 and 2007/08 were ~70%, low by migratory shorebird standards, and 20% lower than apparent annual adult survival in what we perceived as 'normal' years in 2009/10 and 2010/11 (Figure 2).

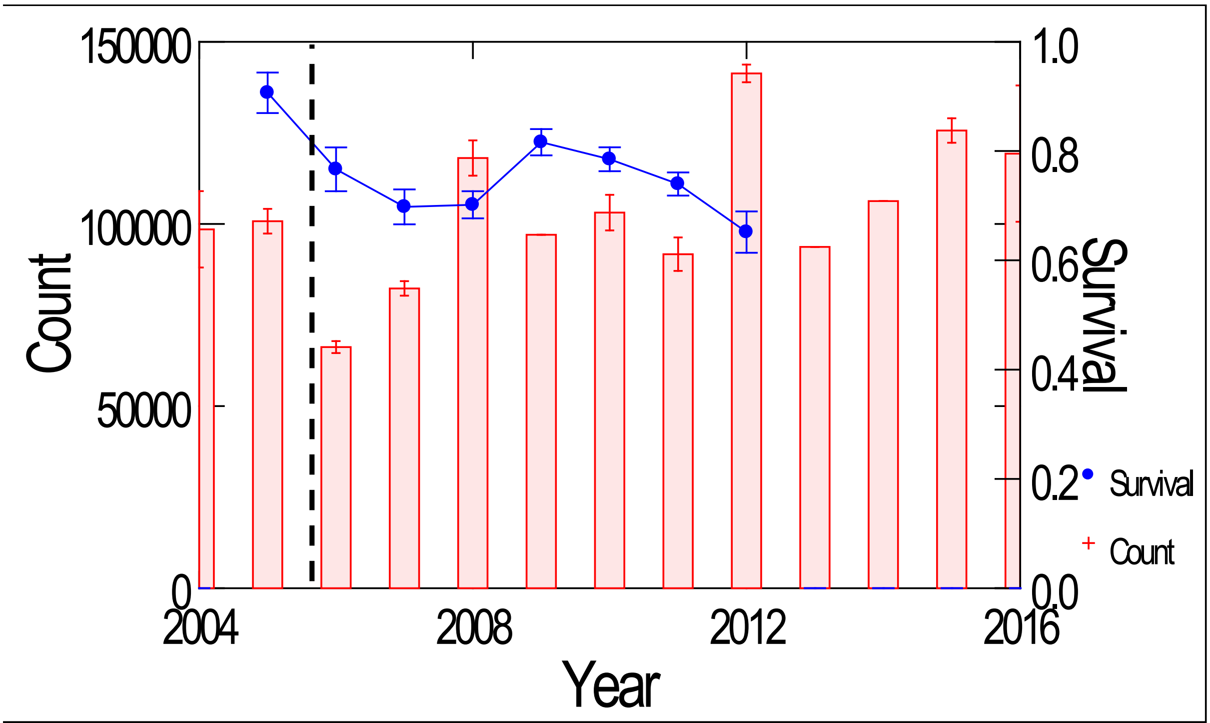

Figure 2. Average summer counts of Great Knot in northwestern Australia (red bars, plotted against the left Y axis; error bars indicate observed range of 2 counts). Apparent annual survival of adult Great Knots in northwestern Australia is indicated by the blue points and lines, plotted against the right Y axis; error bars indicate 95% confidence limits. The dotted line indicates the time when the Saemangeum sea-wall was closed

However, as monitoring has continued since 2011, the relationship between adult annual survival and non-breeding counts in northwestern Australia has become less easy to interpret. Annual apparent survival of colour-banded Great Knots in northwestern Australia (Piersma et al. 2016) declined steadily from 2010 to at least 2012, a trend also demonstrated by our independent analyses of apparent survival of adult Great Knots in northwestern Australia marked by engraved leg-flags. Confusingly, these declines in survival are not matched by declining population counts, which have fluctuated from year to year without showing consistent decline in recent years.

It is likely that the discrepancies between counts and mark-recapture estimates of survival in recent years can be explained by pulses in breeding success. The number of one-year old Great Knots that migrate to northwestern Australia varies considerably from year to year, probably because of conditions on the Siberian breeding grounds. These fluctuations in breeding success influence the proportion of immature birds within catches of Great Knots during the Australian summer (the non-breeding season of migratory shorebirds), and they also influence northwestern Australian shorebird counts in our winter (when adults have returned to Australia and only non-breeding birds remain). In northwestern Australia, summers when immature ratios are high (indicating good breeding success) are typically followed by winters when shorebird counts are high (Figure 3). However the relationship is imperfect, and there is a need for integrated population modelling of the data to fully understand the interactions between annual survival, recruitment, immature dispersal and population counts.

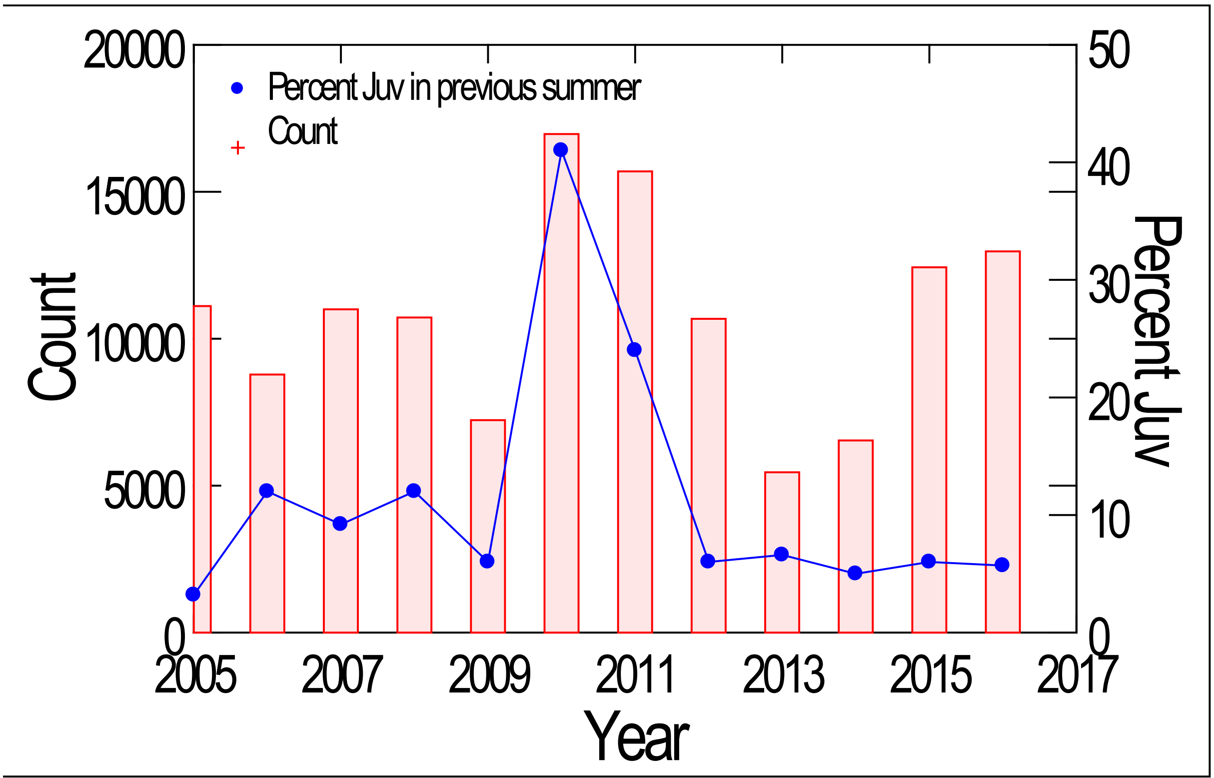

Figure 3. Annual variation in winter counts (red bars) and the proportion of birds in northwestern Australia in their first year of life in the preceding summer count (blue line).

3.3 Have shorebirds changed their patterns of high tide roost usage on the Kimberley coast?

Summer counts of migratory shorebirds at roosts in Roebuck Bay affected by mangrove incursion did not decrease significantly during the period from 2004 to 2017 (Figure 4). Scatter in the counts at individual roosts was so substantial that only very striking trends could have been detected. Similar variation in counts occurred at all individual roost sites in Roebuck Bay, and no significant changes could be detected at any single roost. Pooling all roosts removed some of the scatter, and revealed significant declines in summer counts of migratory shorebirds in Northern Roebuck Bay (Least Squares Regression; coefficient = -770.95 ± 301.269; R^2 = 0.182, P = 0.0172), significant increases in summer counts at Bush Point (Least Squares Regression; coefficient = 18952.524 ± 739.619; R^2 = 0.174, P = 0.0195). There were no significant changes in winter counts at any site, or in summer counts at Eighty Mile Beach or the entire region combined (Figure 5). Similar results were obtained with robust regression using the Least Absolute Deviation procedure (Systat Software 2009). Proportionate use of the sites (i.e. percentage of Northwestern Australian shorebirds at Eighty Mile Beach, Roebuck Bay and Bush Point) varied over the time in the same manner.

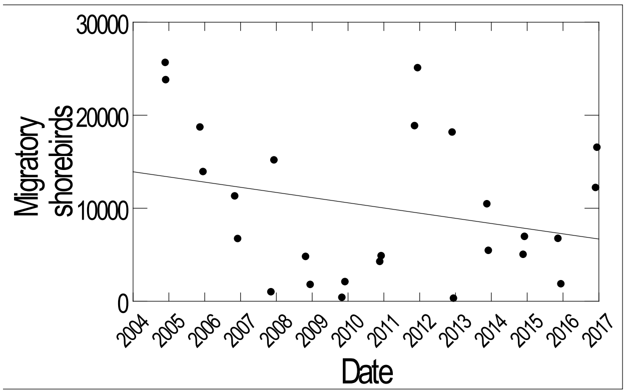

Figure 4. Summer counts of migratory shorebirds (species pooled) at roosts affected by mangrove incursion in Northern Roebuck Bay. The linear smoother shows a least-squares regression; it was not statistically significant.

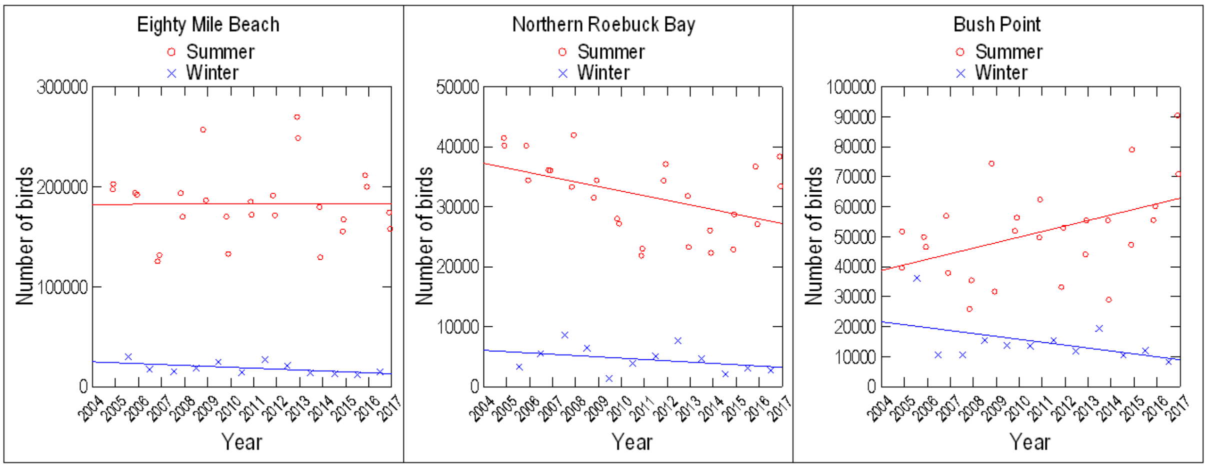

Figure 5. Summer counts of migratory shorebirds (species pooled) at all roosts of a 60km stretch of Eighty Mile Beach (left panel), Northern Roebuck Bay (centre) and Bush Point (right). The smoothers were calculated with least-squares regression, see text for results.

There were striking differences in seasonal usage of sites. At Bush Point, the proportion of Northwestern Australian migratory shorebirds present was higher in winter than in summer; the reverse applied at Eighty Mile Beach, while the proportion occurring in Roebuck Bay was similar in summer and winter (Figure 6).

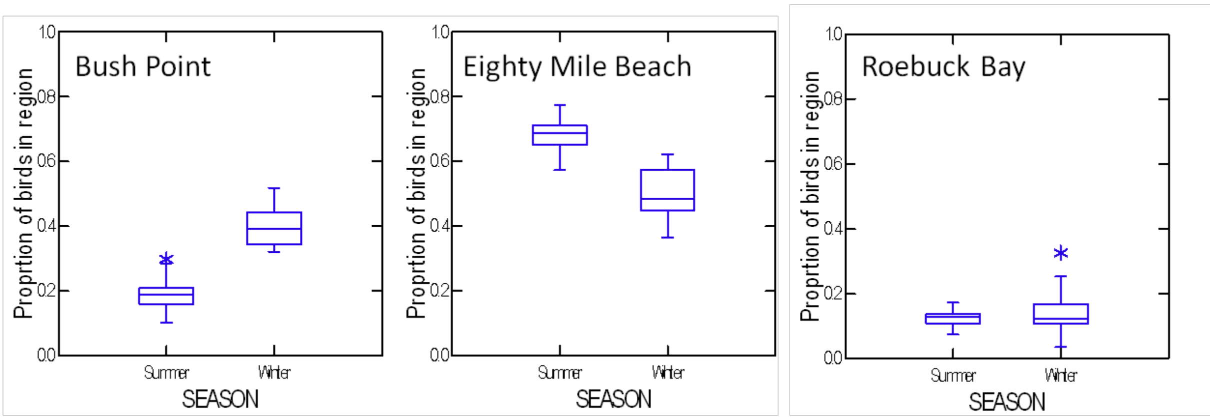

Figure 5. Boxplots illustrating the proportion of migratory shorebirds in the NWA region at Bush Point, Eighty Mile Beach and Roebuck Bay in summer and winter counts.

Within Roebuck Bay, the proportion of birds present that occurred in specific roost sites differed between summer and winter (Figure 6). In four roost clusters (each comprising several adjacent roost sites), the proportion of birds occurring in winter was significantly lower than the proportion occurring in summer; indeed in winter shorebirds were virtually absent from these four roost-clusters. One of these roost clusters ("Crab Creek" comprises all the shorebird roosts in Roebuck Bay where local observers have noted mangrove incursion. Like the other three roost clusters where shorebirds were usually absent in winter, it has been noted to experience high levels of disturbance from humans and birds of prey, especially during the austral winter, which coincides with peak tourist season. The proportion of shorebirds roosting at less disturbed roost-clusters ("Eagles Roost", Quarry Beach and "Nick's Beach") increased during winter counts (Figure 6).

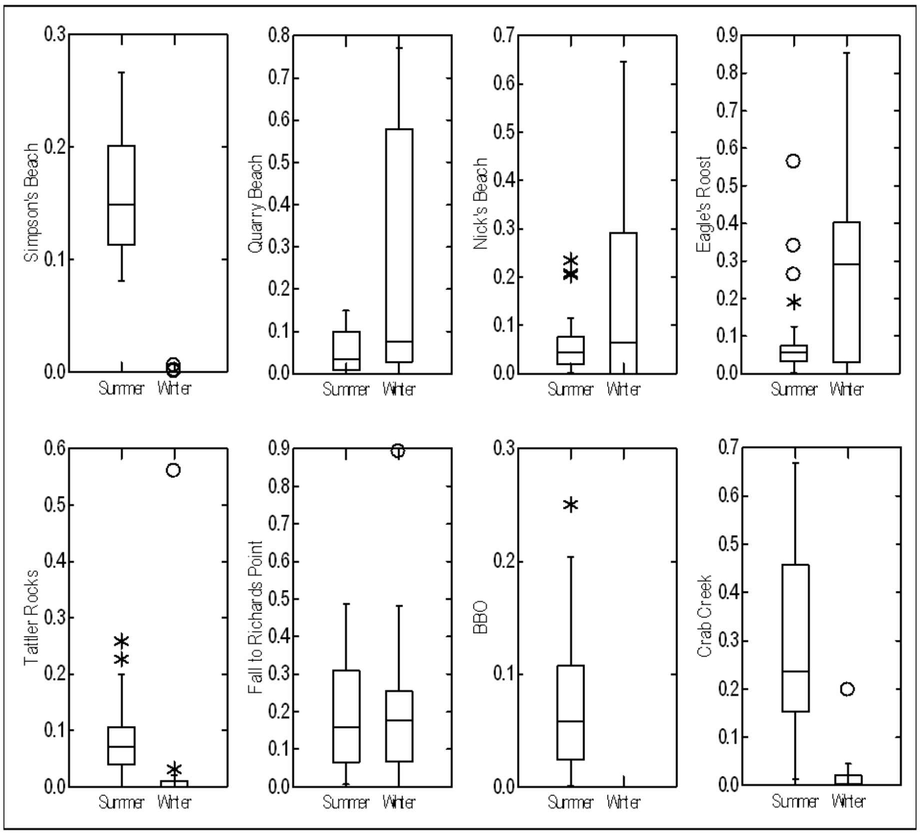

Figure 6. Boxplots illustrating the proportion of migratory shorebirds in eight roost-blocks within Northern Roebuck Bay.

4 Discussion and Conclusions

4.1 Maintaining continuity of shorebird monitoring in Northwestern Australia

Despite the remoteness of much of the Kimberley coastline, shorebird monitoring data from northwestern Australia is some of the most complete in Australia. It is one of the longest time-series of shorebird counts from tropical Australia, and it is potentially the largest data set from the southern hemisphere in terms of shorebird numbers counted. Data from the shorebird count program on the Kimberley coast have been important to a series of recent publications revising population estimates of shorebirds in the East Asian – Australasian Flyway, and examining population trends in shorebirds throughout Australia. These studies have shown that while the Kimberley coast still holds very large numbers of shorebirds (Rogers et al. 2010, Rogers et al. 2011, Hansen et al. 2016), many of its migratory species are declining in numbers (Clemens et al. 2016, Studds et al. 2017). Similar declines are occurring throughout continental Australia (Clemens et al. 2016) and the species in fastest decline are those that depend most on staging areas in the Yellow Sea when migrating (Studds et al. 2017); rates of decline in the northwestern Australian Bar-tailed Godwit subspecies *menzbeiri* are also related to climate conditions on their Siberian breeding grounds (Murray et al. 2017).

In addition to systematic annual counts since 2004 (and some comparable counts back to the late 1990s), there are concurrent demographic monitoring projects in place. The Australasian Wader Studies Group (AWSG) has been monitoring age ratios in non-breeding flocks in northwestern Australia since ~2000, and mark-resighting projects by the Global Flyways Network (colour-bands) and AWSG (engraved leg-flags) allow annual apparent adult survival to be monitored in a number of species. Collectively these datasets offer the rare opportunity to not only detect long-term trends, but to identify their causes, and distinguish changes caused by external factors from those caused by within-site factors that may be modified with local management.

Although the volume of the data offers exciting possibilities, it also gives analysts a large task. Although much progress has been made, analyses are not yet complete. Much of this analytical work is currently being carried out under a contract from the Department of Biodiversity Conservation and Attractions (DBCA), with a focus on reviewing shorebird monitoring practices in northwestern Australia and assessing if they can be made more powerful and cost-effective.

4.2 Did the Saemangeum reclamation in Korea affect Australian shorebird populations?

Outcomes from this investigation are not yet fully analysed. Nevertheless, there is clear evidence that changes in northwestern Australian shorebird populations are strongly influenced by factors outside Australia:

1. Declines observed in many migratory species in northwestern Australia are matched by concurrent declines in many sites elsewhere in Australia (Clemens et al. 2016), suggesting they must have a common driver. This driver (or drivers) is unlikely to be in Australia, as the monitored sites are independent; it must therefore operate either on migratory stopover sites or on the breeding grounds.
2. Rates of decline are related to extent of habitat loss in Asian staging areas, with the strongest declines occurring in those species most reliant on staging sites in the Yellow Sea (Studds et al. 2017)
3. Fluctuations in Australian counts are related to the proportion of juvenile birds on the non-breeding grounds, which is in turn likely to be driven by conditions on the breeding grounds in th northern hemisphere (Aharon-Rotman 2015).
4. Mark-recapture analyses of shorebirds banded in northwestern Australia indicate that most mortality occurs outside Australia, either on migration to the breeding grounds or southwards migration back to Australia (Piersma et al. 2016).
5. The Saemangeum reclamation caused huge declines in the numbers of Great Knot staging on the coast of Korea in 2006-2008. Concurrent declines in counts and adult survival of Great Knot in northwestern Australia were consistent in magnitude with expectations from Korean population declines.

Most of these findings have been driven by research carried out in Australia. Given the strong external influences on shorebird numbers in Australia, it is clear that Australian-based monitoring serves an important purpose as a barometer of shorebird populations throughout the East Asian – Australasian Flyway. As the most important non-breeding region for shorebirds in Australia, Kimberly coastline monitoring is a very important part of this monitoring effort.

A challenge that remains is to tie together the various kinds of monitoring data (summer and winter counts; age-ratio in summer; annual survival estimates; band-resighting data on local movements) into a single integrated model. This would clarify the relative importance of changes in adult survival and annual fluctuations in breeding success on population size in northwestern Australia. The capacity to account for these effects would make it easier to assess whether local habitat changes in northwestern Australia also affect our non-breeding shorebird populations.

4.3 Have shorebirds changed their patterns of high tide roost usage on the Kimberley coast?

The evidence of external factors influencing Australian shorebird populations does not rule out the possibility that shorebird populations in Australia are also influenced by habitat conditions and management within Australia. Identifying whether local influences in northwestern Australia also contribute to shorebird declines is difficult. Rogers et al. (in prep.) examines this issue in detail, and extracts from this study are provided here.

Comparing the proportion of migratory shorebirds in northwestern Australia occurring at individual sites provides an indication of site usage that is not directly influenced by external influences on population size. By this measure, there was no evidence of significant change in usage of any individual roost site during the study period. This result was perhaps unexpected, given that studies of shorebird disturbance at the roosts of Roebuck Bay (Rogers et al. 2006e, Sitters et al. 2009) showed that levels of shorebird disturbance (from people and from increasing populations of birds of prey) were high, and increased between surveys in the late 1990s, 2005-06, and 2007-08. However, our count data would only have been suitable for detection of striking changes, because there was so much variation in shorebird counts at individual roosts from one survey to the next. We consider much of this variability in roost counts (especially in Roebuck Bay) to be caused by disturbance. Shorebirds at roosts in Roebuck Bay are often disturbed several times per high tide, and often move from one roost to a nearby alternate roost when disturbed. The site where they finally settle (and get counted) varies unpredictably depending on the behaviour of the people, dogs or birds that have disturbed them, and on disturbance levels at alternate roosts.

Pooling data from multiple roosts reduces the observed scatter in counts, because birds disturbed from one roost usually resettle in another roost that is monitored by our surveys. Treating the data in this way we found significant declines in the summer counts of shorebirds in Roebuck Bay over time, coinciding with significant increases in summer counts of shorebirds at Bush Point. We also found significant seasonal differences in roosting distribution of shorebirds in northwestern Australia. A relatively higher proportion of shorebirds roosted at Bush Point in winter; a relatively lower proportion of shorebirds occurred on Eighty Mile Beach in winter. About 15% of the migratory shorebirds in northwestern Australia were counted in Northern Roebuck Bay in both summer and winter, but within Northern Roebuck Bay, there were a number of roosts that were used by shorebirds in summer (when disturbance levels are low) but not in winter (when disturbance levels are high).

A possible interpretation of these observations is that disturbance is causing changes in the shorebird populations of Roebuck Bay, with birds having abandoned a number of winter roost sites before this study began, and ongoing increases in disturbance levels causing a gradual reduction in the number of shorebirds occurring in Roebuck Bay in summer, with some of these birds relocating to Bush Point (where counts are increasing). While we consider this scenario plausible, we note that other interpretations are possible. For example, declines in Roebuck Bay may be linked to increased incidence of *Lyngbya* blooms on the tidal flats influencing food supplies (*Lyngbya* is absent or far less common at Bush Point and Eighty Mile Beach), or the changes might be related to natural fluctuations in food resources which are not yet fully understood.

Further investigations are needed for a more complete understanding of the factors driving the changes in Roebuck Bay, including a more current assessment of disturbance levels, and comparison of count trends with data on benthic food supplies in the region. As a precautionary measure it would be prudent to prevent further deterioration of roosts in Roebuck Bay, and discussions with DBCA and the Yawuru NagulagunRoebuck Bay Marine Park joint management body about how to achieve this are under way, informed by the count data collected in this project.

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6 Communication

6.1 Students supported

No students were supported directly by WAMSI funding, but the count data collected were a major part of analyses included in PhD chapters and resultant publications by Nick Murray and Rob Clemens (University of Queensland; see reference list), and were (or are) being used to some extent by Mo Verhoeven (Verhoeven et al 2016) and Ying Chi Chan (University of Groningen).

6.2 Journal Publications

The two journal publications originally intended as part of the WAMSI funding are nearing completion but are not yet published. Data from the shorebird count program on the Kimberley coast have formed a major part of several journal publications since WAMSI provided a year of support in 2012-13: Clemens et al 2016, Murray et al 2017, Studds et al 2017

6.3 Proceedings/Technical Reports

Data from the shorebird count program on the Kimberley coast since WAMSI provided a year of support in 2012-13 were used heavily by Hansen et al. (2016).

6.4 Submitted manuscripts.

None at present. Two drafts still in preparation, provisionally entitled "Changes in roost distribution of shorebirds in north-western Australia, 2004-2017" and " Trans-hemispheric effects of a Yellow Sea land claim on a migratory shorebird". Presentations

(1) Onton K (2013) Migratory shorebird research in north west Australia. WAMSI North West Australian Symposium Program, 21 Feb 2013;

(2) Rogers D (2013) How did the destruction of the Saemangeum tidal flats affect the Great Knot? Australian Shorebird Conference, Darwin, September 2014;

(3) Rogers D (2013) What effect did the destruction of the Saemanguem tidal flats have on the great knot? Australasian Ornithological Conference, Auckland, December 2013.

(4) Rogers D (2015) Shorebird Monitoring in north-western Australia. WAMSI Research Conference 2015, Perth.

6.5 Other communications achievements

Much engagement with the local birding community, some of whom play a important voluntary roles in this project. Ongoing discussions with DBCA and other local agencies about the importance of roost protection.

Since the WAMSI funding for this project came to an end, the shorebird surveys have been maintained with funding from the Department of Biodiversity, Conservation and Attractions (DBCA). DBCA has also funded analysis of the data and two resultant reports are in preparation. In addition to being made available to DBCA, we intend to publish these reports and bring them to the attention of land-owners, site managers and the broader community.

7 Appendices

Appendix 1.

Management questions

This project directly addresses the following questions outlined in the Kimberley Marine Research Program Science Plan and in the project Agreement for the Shorebird project.

Key Question Informed response
What are the distribution, abundance and movement patterns of these populations? Migratory shorebirds breed at high latitudes in the northern hemisphere, mainly in the arctic or near-arctic. They carry out long-distance annual migrations to non-breeding grounds such as the Kimberley coast. During their non-breeding season, migratory shorebirds are broadly distributed along those parts of the north Western Australian coast with extensive tidal flats, with especially large concentrations in Roebuck Bay and the northern 80 km of Eighty Mile Beach. Of the 41 shorebird species occurring regularly along this coastline, 18 species occur in internationally significant numbers (>1% of the population in the East Asian – Australasian Flyway); over 635,000 migratory shorebirds depend on the tidal flats of the northwestern Australian coast. During the non-breeding season migratory shorebirds are reasonably site-faithful, though small-scale movements (10's of km) are now being revealed by colour-banding studies and satellite telemetry.
What environmental factors are 'driving' the above distribution patterns and population characteristics – in particular factors outside Australia? The strongest driver of declining shorebird populations in Australia is thought to be habitat loss on staging grounds in Asia, especially on the coast of the Yellow Sea.
What cost-effective methods can be developed to enable effective condition monitoring of priority species? An analysis to answer this question is in progress, and a report will be prepared for the Department of Biodiversity, Conservation and Attractions.
What are the local pressures on shorebird populations, such as human disturbance, habitat alteration (e.g. mangrove incursion removing significant roost sites) and pollution? There is some evidence suggesting that local habitat preferences of shorebirds in northwestern Australia have changed in response to human disturbance of roost sites, mangrove incursion on some beaches in northern Roebuck Bay. Organic pollution of groundwater from Broome has contributed to Lyngbya blooms in Roebuck Bay which may have detrimental effects on the prey resources available to shorebirds. It is not yet clear whether these problems have only resulted in local relocation of shorebirds, or whether it affects their survival rates and population counts.

Appendix 2.

Shorebird species recorded during surveys

Appendix 2 Map of the study area, reprinted from Rogers et al 2011.

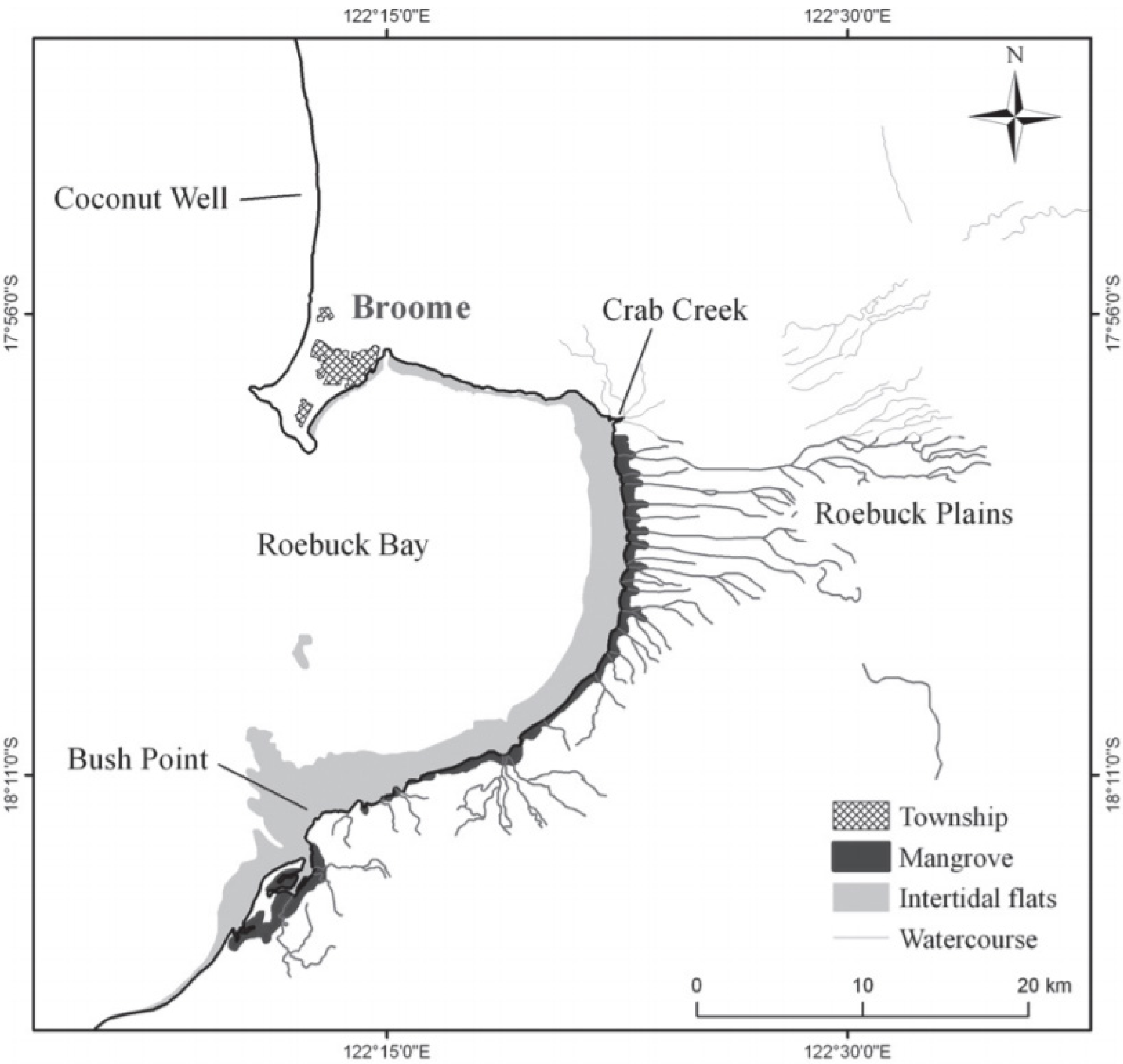

Figure 2. Shorebird sites in the Roebuck Bay area.

Appendix 3.

Shorebird species recorded during population monitoring surveys on the coast of northwestern Australia.

Common name	Scientific Name	Migratory?	Occurrence
Beach Stone-Curlew	*Esacus magnirostris*	Australian	1
Australian Pied Oystercatcher	*Haematopus longirostris*	Australian	2
Sooty Oystercatcher	*Haematopus fuliginosus*	Australian	2
White-headed Stilt	*Himantopus leucocephalus*	Australian	2
Red-necked Avocet	*Recurvirostra novaehollandiae*	Australian	3
Masked Lapwing	*Vanellus miles*	Australian	3
Red-kneed Dotterel	*Erythrogonys cinctus*	Australian	3
Pacific Golden Plover	*Pluvialus fulva*	Migrant	2
Grey Plover	*Pluvialus squatarola*	Migrant	2
Semipalmated Plover	*Charadrius semipalmatus*	Migrant	4
Red-capped Plover	*Charadrius ruficapillus*	Australian	2
Lesser Sand Plover	*Charadrius mongolus*	Migrant	2
Greater Sand Plover	*Charadrius leschenaultii*	Migrant	2
Oriental Plover	*Charadrius veredus*	Migrant	5
Black-fronted Dotterel	*Elseyornis melanops*	Australian	3
Asian Dowitcher	*Limnodromus semipalmatus*	Migrant	2
Black-tailed Godwit	*Limosa limosa*	Migrant	2
Bar-tailed Godwit	*Limosa lapponica*	Migrant	2
Little Curlew	*Numenius minutus*	Migrant	5
Whimbrel	*Numenius phaeopus*	Migrant	2
Eurasian Curlew	*Numenius arquata*	Migrant	4
Eastern Curlew	*Numenius madagascariensis*	Migrant	2
Common Redshank	*Tringa totanus*	Migrant	1
Marsh Sandpiper	*Tringa stagnatilis*	Migrant	2
Common Greenshank	*Tringa nebularia*	Migrant	2
Nordmann's Greenshank	*Tringa guttifer*	Migrant	4
Wood Sandpiper	*Tringa glareola*	Migrant	3
Grey-tailed Tattler	*Tringa brevipes*	Migrant	2
Terek Sandpiper	*Xenus cinereus*	Migrant	2
Common Sandpiper	*Actitis hypoleucos*	Migrant	2
Ruddy Turnstone	*Arenaria interpres*	Migrant	2
Great Knot	*Calidris tenuirostris*	Migrant	2
Red Knot	*Calidris canutus*	Migrant	2
Sanderling	*Calidris alba*	Migrant	2
Red-necked Stint	*Calidris ruficollis*	Migrant	2
Long-toed Stint	*Calidris subminuta*	Migrant	3
Pectoral Sandpiper	*Calidris melanotus*	Migrant	3
Sharp-tailed Sandpiper	*Calidris acuminata*	Migrant	2
Curlew Sandpiper	*Calidris ferruginea*	Migrant	2
Broad-billed Sandpiper	*Limicola falcinellus*	Migrant	2
Grey Phalarope	*Phalaropus fulicarius*	Migrant	4
Australian Pratincole	*Stiltia isabella*	Australian	5
Oriental Pratincole	*Glareola maldivarum*	Migrant	5