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Desktop analysis to inform the design for megafauna monitoring within the Reef 2050 Integrated Monitoring and Reporting Program:

Final Report of the Shorebirds Team in the Megafauna Expert Group

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The Great Barrier Reef Marine Park Authority acknowledges the continuing sea country management and custodianship of the Great Barrier Reef by Aboriginal and Torres Strait Islander Traditional Owners whose rich cultures, heritage values, enduring connections and shared efforts protect the Reef for future generations.

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1.0 Executive Summary

There are two major components to current shorebird monitoring in the Great Barrier Reef (the Reef). These are ongoing counts of major mainland estuaries conducted by the Queensland Wader Study Group (a volunteer-led citizen science group) and counts of complementary mainland sites (Bowling Green, Shoalwater, Corio Bays) as well as a number of offshore islands and cays conducted by the Queensland Parks and Wildlife Service.

At the time of writing, shorebird monitoring by the Queensland Parks and Wildlife Service is performed under the Coastal Bird Monitoring and Information Strategy (2011) and consists primarily of counts of shorebirds at major sites where shorebirds are the main value, and at sites visited primarily for seabird monitoring. The Queensland Wader Study Group, by virtue of their volunteer-driven surveyor base, performs surveys that are neither structured in a way that samples the full range of important wetlands in the Reef region, nor frequent enough at every site to achieve sufficient power to detect trends in the desired timeframe across the region as a whole. As a result, existing data are too sparse in space and time to make any robust conclusions about trends in shorebird populations in the Reef beyond a few isolated locations.

Analysis of simulated time-series from multiple sites suggests that conducting two counts per summer (Nov.-Feb.) is the optimal strategy for maximising statistical power to detect population trends. The absolute level of statistical power to detect trends for a given time series length and magnitude of decline under the proposed survey intensity will depend on heterogeneity in trends among sites.

However, even under high levels of heterogeneity, high power (≥ 80 per cent) to detect declines that meet the criteria for VU and EN threat statuses is achievable with 15-20 years of annual monitoring.

Currently, summer counts are prioritised for almost all islands on the basis of coinciding with seabird breeding times, which is fortunate since the national standard for Shorebirds 2020 data collection is a single summer count between November and February. As such, a formal integration of shorebird monitoring into the seabird monitoring timetable would probably have relatively little impact on the latter, and would appear to serve as a reasonable basis going forward for the new shorebirds strategy for Reef islands and mainland.

We recommend that:

- The Department of Environment and Science initiate the design and implementation of a closer operational arrangement with citizen science groups, most notably the Queensland Wader Study Group, which extends the existing limited coordination activity to facilitate (i) enhanced coordination to ensure all major sites are identified, and surveyed at least twice per summer, (ii) full alignment of survey methods, (iii) integration of shorebird survey data into a single database permitting robust analysis of trends, and

(iv) regular submission of a combined dataset to the Shorebirds 2020 program, enabling data to be integrated in national and international analyses of shorebird population trends.

- For offshore islands and cays, the numerically important and distinctive species are determined, and a set of essential sites specifically for shorebirds is derived with this in mind. Key species are likely to include ruddy turnstone, Pacific golden plover, whimbrel, wandering tattler, and possibly grey-tailed tattler.

- Enhanced observer training and error-checking is conducted.

- Data on disturbance and major changes to roost sites (for example, severe erosion from storms, mangrove expansion) are formally and consistently collected as part of all shorebird surveys.

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2.0 Introduction

2.1 Shorebird subgroup: Desktop Analysis Phase

The shorebird subgroup of the larger Megafauna Expert Group was tasked with evaluating the adequacy of existing shorebird monitoring activities, and suggesting indices to achieve the objectives and requirements of the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP). This evaluation was undertaken by directly addressing the specific objectives and outcomes provided for the 'Desktop Analysis Phase' of the RIMReP process as applicable to shorebirds. These five objectives are detailed below.

2.2 Shorebird objectives (terms of reference)

Provide a synopsis of all current monitoring and modelling activities relevant to shorebirds, identifying potential sources of data describing proposed indicators.

Describe the current status of shorebird communities and define the desired environmental or social state and develop potential thresholds for each proposed indicator (i.e. for each proposed indicator, is there a credible number that defines a healthy state/condition that we should be aiming to achieve/maintain and that we can track progress toward? How might this number vary between locations/regions?)

Evaluate the adequacy of current monitoring and modelling of proposed indicators to achieve the objectives of the RIMReP. The evaluation should consider:

- The accuracy of monitoring and modelling
- The power to detect change in proposed indicators at magnitudes and spatial and temporal scales that are relevant for managers, stakeholders and for assessing the effectiveness of the *Reef 2050 Long-Term Sustainability Plan* (Reef 2050 Plan)
- The adequacy of sampling methods
- The adequacy of the spatial and temporal resolution of current monitoring and modelling

Identify gaps in (or issues with) current monitoring and modelling of proposed indicators. Gaps might be spatial (i.e. where an indicator is not measured), temporal (i.e. when indicators are not measured with sufficient frequency to maintain adequate knowledge of condition) or, in some cases, indicators might not be measured at all.

Evaluate new monitoring technologies for their potential to increase efficiency or statistical power and their compatibility with long-term datasets.

3.0 Section 1

Provide a synopsis of all current monitoring and modelling activities relevant to shorebirds, identifying potential sources of data describing proposed indicators.

3.1 What is the current monitoring strategy?

The current shorebird monitoring scheme for the Great Barrier Reef Marine Park (the Marine Park) is outlined in the 2011 Coastal Bird Monitoring and Information Strategy (CBMIS-2011; McDougall et al., 2011). The CBMIS-2011 covered both seabirds and shorebirds up until 2015 when a separate monitoring scheme for seabirds was developed and implemented (CBMIS-2015; Hemson et al., 2015). The monitoring strategy for shorebirds is currently being revised by the Queensland Government's Department of Environment and Science.

Although the CBMIS-2011 is the official monitoring strategy for shorebirds, the timing and frequency of site visits, especially to offshore islands and cays, are presently driven by the site visitation strategy outlined in the CBMIS-2015, which is designed with seabird monitoring as a priority. Therefore, our evaluation of shorebird monitoring on the Reef also considers elements of the CBMIS-2015 monitoring strategy that are relevant to the way in which shorebirds are monitored. Given that the monitoring strategy for shorebirds is currently being revised, we focus our review on providing recommendations for the upcoming strategy, rather than critiquing specific aspects of the CBMIS- 2011 which will soon be obsolete.

3.2 What are the existing data sources?

Shorebird surveys are being undertaken by the Queensland Parks and Wildlife Service on a regular basis at three mainland estuarine systems (Bowling Green Bay, Shoalwater Bay and Corio Bay), and at a range of offshore islands and cays (see analyses below). These surveys involve counting the numbers of shorebirds of all species present, usually on a rising or high tide, and confirming species identification and some counts with photographic evidence. A small number of sites have been monitored continuously for a long period, but for many locations the surveying is inevitably sparse over time (Figure 1, 2).

The majority of additional existing shorebird monitoring data for the mainland Reef region have been collected by volunteers under the umbrella of the Queensland Wader Study Group (a special interest group of Birds Queensland). The Queensland Wader Study Group was established in 1992 to monitor and help conserve shorebird populations in Queensland. Run entirely by volunteers, like most shorebird monitoring in Australia (Hansen et al., 2018), close interaction between organisers and surveyors has been key to the accuracy, precision, coverage and longevity of shorebird monitoring. Unlike many other shorebird monitoring programs around the country, which count birds once or twice per year, the Queensland Wader Study Group conducts monthly counts at a number of sites across the state. This notable feature of monitoring in some parts of Queensland helps to reduce within-year count variability and increase statistical power to detect trends compared with less frequent monitoring elsewhere (Fuller et al., 2009; Wilson et al., 2011). The Queensland Wader Study Group shorebird count data for selected regions are stored in WildNet, the state government database, and underlying data collected by the Group's volunteers are owned by the Group. Access is arranged for ongoing reporting on shorebird status and trends as negotiated.

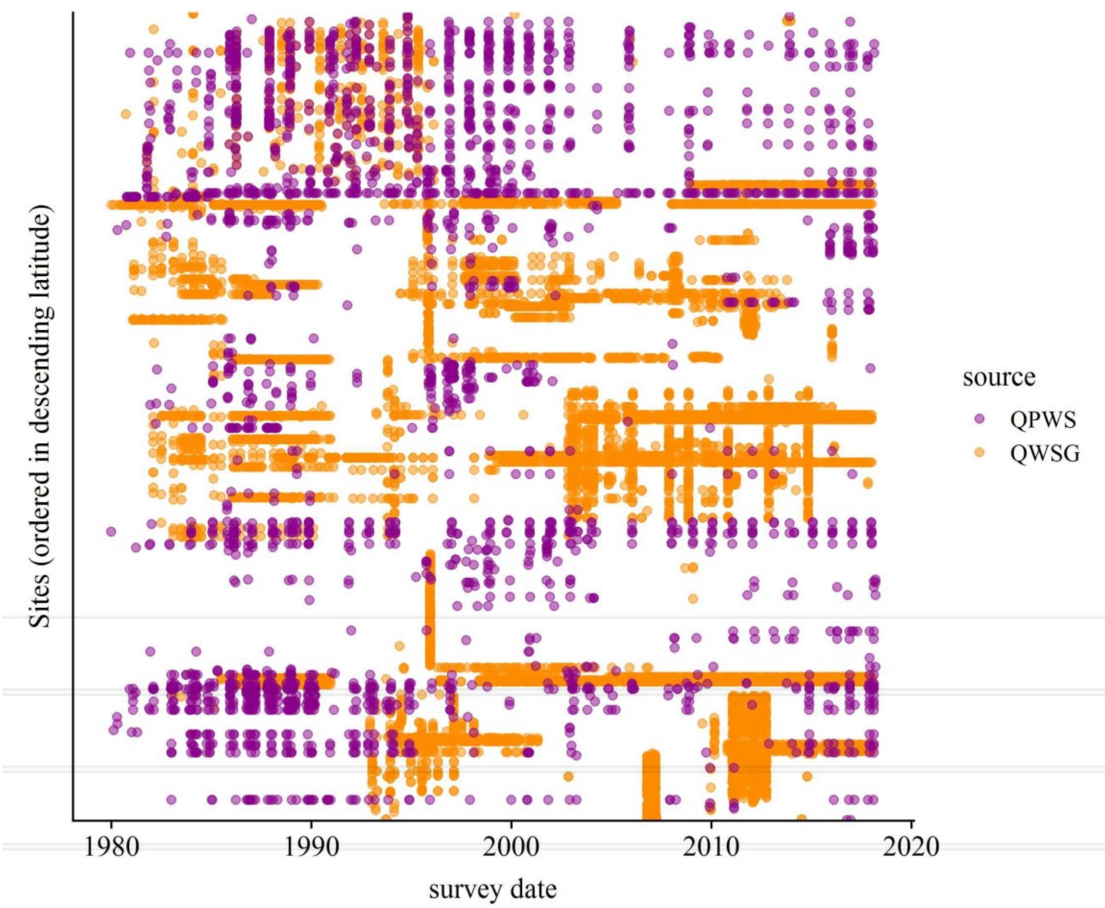

Figure 1. Visualisation of surveys conducted by The Queensland Wader Study Group (orange) and the Queensland Parks and Wildlife Service (purple) in the Great Barrier Reef region since 1980. Each row corresponds to a single site and each point represents a single site visit; sites are arranged on the y-axis in descending latitude (north to south; see Figure 2 for a map of study sites included). Only sites that have been surveyed at least three times since 1980 are shown.

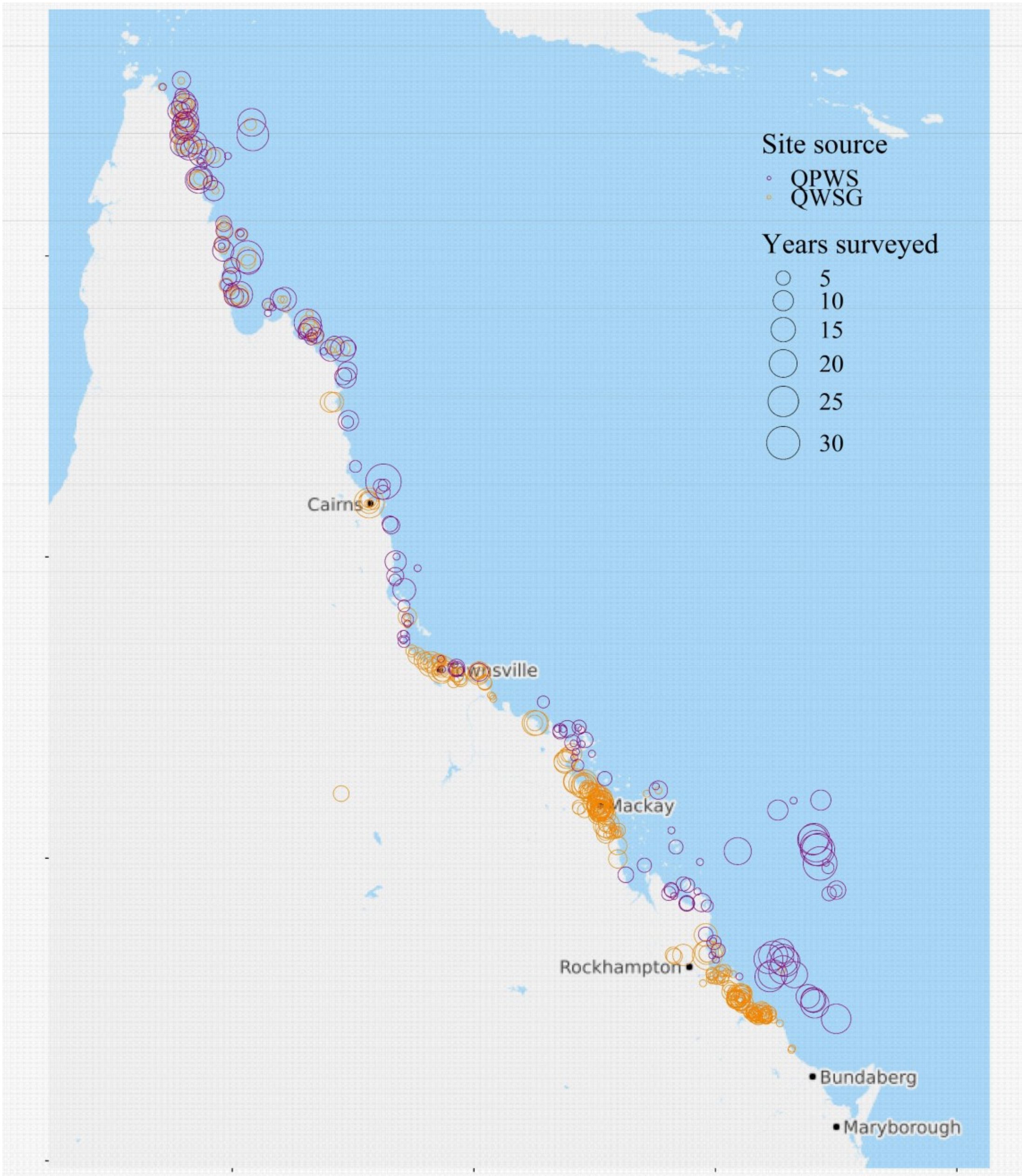

Figure 2. Map of shorebird sites surveyed by the Queensland Wader Study Group (orange) and the Queensland Parks and Wildlife Service (purple) in the Great Barrier Reef region since 1980. The size of the points is scaled according to the number of years in which each location was visited; only sites that have been surveyed at least three times since 1980 are shown. The Queensland Wader Study Group primarily surveys coastal mainland locations, whereas the majority of surveys of offshore islands and cays are conducted by the Queensland Parks and Wildlife Service, highlighting the complementarity of the two monitoring

programs. The base map was accessed at www.openstreetmap.org (© OpenStreetMap contributors).

A number of other citizen science programs hold data on shorebird occurrence and numbers in the Reef region, and perhaps among the most significant of these are BirdLife Australia's Birdata program (http://birdata.birdlife.org.au), and eBird Australia (http://ebird.org/australia). Birdata contains many observations of shorebirds collected by volunteers, collected outside organised shorebird monitoring efforts. Although many of the surveys are formally structured protocols, these are typically optimised for terrestrial habitats, and are generally not useful for monitoring shorebirds or conducting comparative analyses of abundance or trends. However, Birdata contains a structured subset of shorebird monitoring data, known as Shorebirds 2020. This dataset encompasses the Queensland Wader Study Group data described above, but it merits separate mention here because of the curation of their data alongside structured surveys from around the nation, enabling analysis of the data in a broader context (which is critical particularly for the migratory species), and also for small amounts of additional incidental data from the Reef region beyond the data. Shorebirds 2020 was initiated in 2007 with support from WWF-Australia to provide professionalised resources to support the appointment of a national monitoring coordinator and assistant. This program now houses the majority of state and national shorebird count data, with a focus on migratory species (Hansen et al., 2017). Data are accessible by arrangement with BirdLife Australia, and subsidiary data custodians where necessary.

eBird comprises more informal bird observations from volunteer observers, with about 200,000 checklists submitted for Queensland up to June 2018. A range of survey protocols are possible within eBird, but the unstructured nature of much of the data mean that they are generally not useful for monitoring shorebirds or conducting comparative analyses of abundance or trends, given the availability of more structured data from the Queensland Wader Study Group and Shorebirds 2020.

In sum, the only two existing datasets relevant to this report are those structured data collected by the Queensland Parks and Wildlife Service and the Queensland Wader Study Group.

3.3 What are the currently monitored species/foraging guilds and rational?

All breeding and non-breeding shorebirds are monitored, namely species in the families Burhinidae, Pluvialidae, Recurvirostridae, Haematopodidae, Charadriidae, Rostratulidae, Jacanidae, Scolopacidae and Glareolidae (McDougall et al., 2011). Migratory shorebirds take on particular significance, with all of the 37 regularly occurring species being listed under the Environment Protection and Biodiversity Conservation Act 1999, as matters of national environmental significance owing to their migratory habit (Hansen et al., 2018). Several species occur only in very small numbers in the Reef, and the monitoring is primarily relevant to those species listed in Table 1.

3.4 What is the current spatial and temporal pattern of monitoring and rationale?

The Queensland Parks and Wildlife Service visits to mainland shorebird sites and the offshore islands and cays are mostly concentrated in the November – February period, and so they align well with the time when migratory shorebirds are present on the non-breeding grounds (Figure 3). This suggests great potential for synergy between seabird and shorebird monitoring.

The most consistent, structured shorebird monitoring in the Reef is the surveys conducted by the Queensland Wader Study Group along the Mackay coast over a several day period approximately once every two years. However, there is no overarching programmatic or funding strategy to deliver shorebird monitoring in the Reef region, with much of the available data arising from volunteer efforts by the Queensland Wader Study Group, or isolated examples of intensive surveys in particular places and times. For example, migratory shorebirds have been monitored in the Port of Gladstone area intensively since 2010 under the Ecosystem Research and Monitoring Program (http://www.gpcl.com.au/environment/ermp), but this will end when the ten-year program ends in 2020. This has provided a great deal of robust monitoring information for that area, but its long term utility will diminish if the area once again ceases to be monitored.

Beyond particular projects, much of the shorebird monitoring in the Reef has been done by the Queensland Wader Study Group, as described above. Yet since it is a volunteer-run program without a funding directive, the monitoring schedule arises primarily from availability of counters, and as such the populous south east corner of the state is well monitored, with more intermittent and fragmented monitoring occurring further north in the state, including in the Reef region (Fuller et al., 2009). For the same reason, offshore islands and cays are not monitored by the Queensland Wader Study Group, and this is where the Queensland Parks and Wildlife Service data provides a key complement to the ongoing surveying efforts (Figure 2).

Importantly, a number of sites known to support significant numbers of shorebirds are not regularly monitored either by the Queensland Parks and Wildlife Service or the Queensland Wader Study Group. Examples include the Gladstone region, which supports approximately 15,000 shorebirds (Wildlife Unlimited 2018), and many sites in the Mackay and Great Sandy Strait regions that are not sampled annually, substantially reducing statistical power (see section 3). This highlights the need for enhanced integration of the monitoring strategies of the Queensland Wader Study Group and the Queensland Parks and Wildlife Service, and we envisage substantial benefit from a specific partnership agreement designed to achieve it.

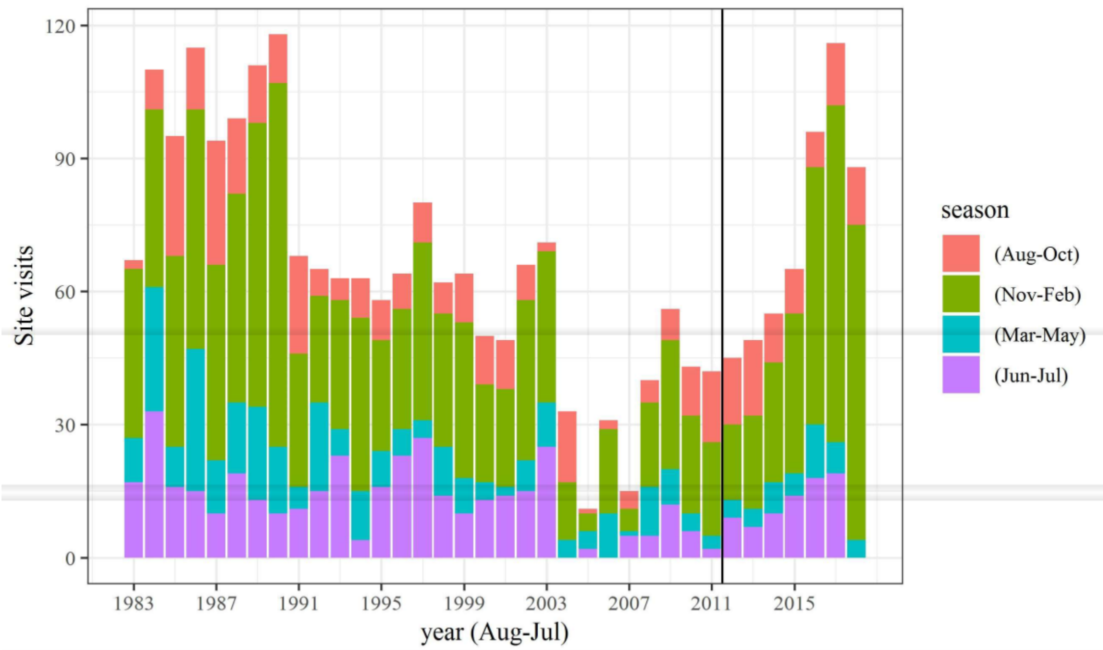

Figure 3. Summary of visits to essential seabird breeding site outlined in CBMIS-2015 (Hemson et al., 2015) as of March 2018. The stacked bar chart highlights that, since implementation of the CBMIS-2011 (vertical black line), and especially since implementation of CBMIS-2015 in 2015/16, the majority of visits to essential seabird sites coincide with the peak non-breeding period for migratory shorebirds (November to February). This suggests that, overall, the site visitation strategy for seabirds aligns well with the recommended counting period for migratory shorebirds. In the figure, only visits conducted since July 1980 are shown and years are defined from August to July (for example, 2016 ranges from Aug 2015 to Jul 2016) so as not to intersect the migration or non-breeding periods of shorebirds.

3.5 What are the currently monitored indices?

The Queensland Wader Study Group counts all shorebird species when a site is visited, with a focus on visits during the summer months, when numbers of the non-breeding migratory species are typically largest. Counts are conducted at roosting sites, enabling rapid assessment of the total numbers of individuals present at a site or group of sites, but no surveys are done at low tide, with two consequences. First, some species can be rather difficult to detect at high tide, since they roost in mangroves and other inaccessible places (Fuller et al., 2009; Wilson et al., 2011; Studds et al., 2017). Second, it is difficult to associate changes in intertidal habitat extent and quality with changes in shorebird numbers because the linkages between roosting and feeding sites are not easily estimable without low tide surveys. The Queensland Wader Study Group surveys are thus primarily aimed at indexing the number of birds present in the local area rather than documenting their behavior, movements, and low-tide foraging distributions. Any disturbances to the birds are also noted during the surveys, allowing for some potential analysis of this particular threat (Fuller et al 2009; Dhanjal-Adams et al., 2016; Stigner et al., 2016)

Breeding non-migratory species are recorded where and when observed by the Queensland Parks and Wildlife Service surveyors. However, timing for breeding on islands for species such as Australian pied oystercatchers does not usually coincide with either the regular winter or summer bird counts, and breeding timing can differ from year to year. Because bird monitoring is only one of many tasks scheduled into the Queensland Parks and Wildlife Service work program, it can be difficult if not impossible to cover all possibilities in this regard. The Queensland Parks and Wildlife Service is hoping to target monitoring for particular breeding species such as the beach stone-curlew at key locations including the Shoalwater and Corio Bays Ramsar site, although access permission to this area can be intermittent due to military exercises.

The Queensland Parks and Wildlife Service continuously searches for new, hitherto uncounted roost sites, especially those that are inaccessible to the Queensland Wader Study Group because they are on islands or cays, and counts at such roost sites of non-breeding migratory shorebird species are undertaken (McDougall et al., 2011). Yet there remain some significant gaps in the mainland site covered, for example, the Gladstone region where approximately 15,000 migratory shorebirds spend the non-breeding season (Wildlife Unlimited, 2018).

4.0 Section 2

Describe the current status of the relevant communities and define the desired environmental or social state and develop potential thresholds for each proposed indicator (i.e. for each proposed indicator, is there a credible number that defines a healthy state/condition that we should be aiming to achieve/maintain and that we can track progress toward? How might this number vary between locations/regions?)

4.1 What is the current status of the relevant communities based on the currently monitored indices?

Many migratory shorebird species are in rapid decline in the East Asian – Australasian Flyway (Amano et al., 2010, Clemens et al., 2016, Studds et al., 2017). While specific analyses from the Reef region are not available (and in many ways not possible with existing data; see below), at least six species of migratory shorebird were identified as in rapid decline by an analysis of monitoring data collected south of the Reef region in Moreton Bay by the Queensland Wader Study Group between 1992 and 2008 (red knot, Western Alaskan bar-tailed godwit, ruddy turnstone, common greenshank, great knot and whimbrel), and a further two were possibly in decline (greater sand plover, eastern curlew; Wilson et al., 2011). National level analysis gives some insight into the regional trends of many migratory and non-migratory species (Clemens et al., 2016; Studds et al., 2017). At a national level, 12 of 19 migratory shorebird species declined significantly between 1973 and 2014, all of which occur in the Reef region (Clemens et al., 2016). Of the seven non-migratory species occurring in the region whose populations were assessed at a national level, red-capped plovers, Australian pied oystercatchers, and sooty oystercatchers were found to be stable or increasing, whereas the other four species were declining (Clemens et al., 2016). In general, more species declined and declines were more rapid in southern and eastern Australia compared to northern and western Australia, although there were many exceptions. Within the region, one area appearing to be losing large numbers of multiple shorebird species is the Mackay area whereas Bushland Beach, Lucinda and Cape Bowling Green are areas of the most retention of shorebird species (Clemens et al., 2016) as are the Shoalwater and Corio bays with regards to eastern curlew, whimbrel, beach stone-curlew and Australian pied oystercatcher.

The Reef region probably warrants a focused analysis, as some local examples suggest the dynamics of populations might differ in this region from other parts of Australia. For example, although formal analysis of the ERMP monitoring from the Gladstone region is yet to be conducted, results so far suggest that while the overall numbers of migratory shorebirds using the area is not in rapid and obvious decline, some particular species that are in rapid decline elsewhere around the nation, such as the eastern curlew, are also declining precipitously in Gladstone (Wildlife Unlimited 2018). On the other hand, Terek sandpiper numbers remain stable or possibly increasing (Wildlife Unlimited 2018).

Combined with unambiguous national analyses demonstrating widespread declines in shorebird populations around Australia, including along the Queensland coast (Clemens et al., 2016), it is reasonable to assume that populations of several of the migratory shorebird species are undergoing rapid declines within the Reef region. As we describe elsewhere in this report (see Section 3), existing data are as yet insufficient to analyse and diagnose the causes of these declines across the Reef region, and in particular to partition local effects from those occurring elsewhere along the species' migratory routes.

The nationwide declines in many migratory shorebird species are thought to be driven mostly by habitat loss in the East Asian stopover areas where, for example, more than two-thirds of intertidal habitat has been lost in the Yellow Sea in the last 50 years primarily as a result of land reclamation for infrastructure development (Murray et al., 2014). Indeed, recent studies have shown that the Australian species declining most quickly are those that are highly dependent on the Yellow Sea while on migration (Studds et al., 2017), and that survival rates are declining for migratory shorebirds that depend on the Yellow Sea (Piersma et al., 2016). Yet migratory species depend on a complete chain of intact habitats along their migration routes (Runge et al., 2014), and habitat degradation anywhere along the chain can impact the birds (Iwamura et al., 2013). Thus, the proper management of important sites in the Reef region is crucial in the context of the birds' lengthy migration journeys, and the incidence of substantial local threats to shorebirds and their habitats.

A formal analysis of the current status of the Reef's shorebird populations is not yet possible because the count data are very sparse, with few sites being counted consistently over the years. There was substantial monitoring activity by the Queensland Parks and Wildlife Service in the 1990s, which then reduced in the following decade, at the same time as the Queensland Wader Study Group counts intensified (Figure 1). The two sources of data are largely complementary in their spatial location, with the Queensland Wader Study Group counts focusing on the mainland coast, and the Queensland Parks and Wildlife Service data deriving primarily from the offshore islands and cays (Figure 2). This spatial complementarity is potentially an asset, and it would especially be a strength if the onshore and offshore counts could be better coordinated so they occur at similar times of year.

Because the data do not yet permit formal analysis, we present some visualisations of the data, which begin to hint at some of the changes that might be revealed when a full analysis is possible.

Importantly, the vast majority of observations contributing to these data are from coastal mainland roost sites and not from the many islands and cays in the Marine Park. Figures 4 and 5 show the proportion of surveys in which each species was recorded in the Queensland Parks and Wildlife Service database, and figures 6 and 7 show reporting rate for the Queensland Wader Study Group data. Several observations are immediately apparent. A number of species are clearly in flux, with reporting rates increasing for many species being monitored in the Queensland Parks and Wildlife Service dataset (for example, wandering tattler, ruddy turnstone), although this probably arises from the fact there is now a focus on recording all birds on islands, not just seabirds, hence an increasing reporting rate. Additionally, better equipment is now available to the Queensland Parks and Wildlife Service and staff are generally more aware of monitoring requirements. In contrast, declines in reporting rate seem apparent for most species from the Queensland Wader Study Group data, suggesting either different dynamics of the species in the onshore and offshore counts, or some other artefact that is affecting the comparison between the two datasets. Detailed investigation would be needed to distinguish between these two possibilities.

Most counts have been done in the summer months (Figure 3). Indeed, summer counts are optimal for most species, ideally between November and February, when shorebird populations are thought to be at their most stable (Hansen et al., 2017). Yet some species are best surveyed at other times of year — for example, red knots are a passage migrant through the area, and probably best surveyed in September (Choi et al., 2016). Double-banded Plover is a winter visitor from breeding grounds in New Zealand, and is essentially absent from the region in summer.

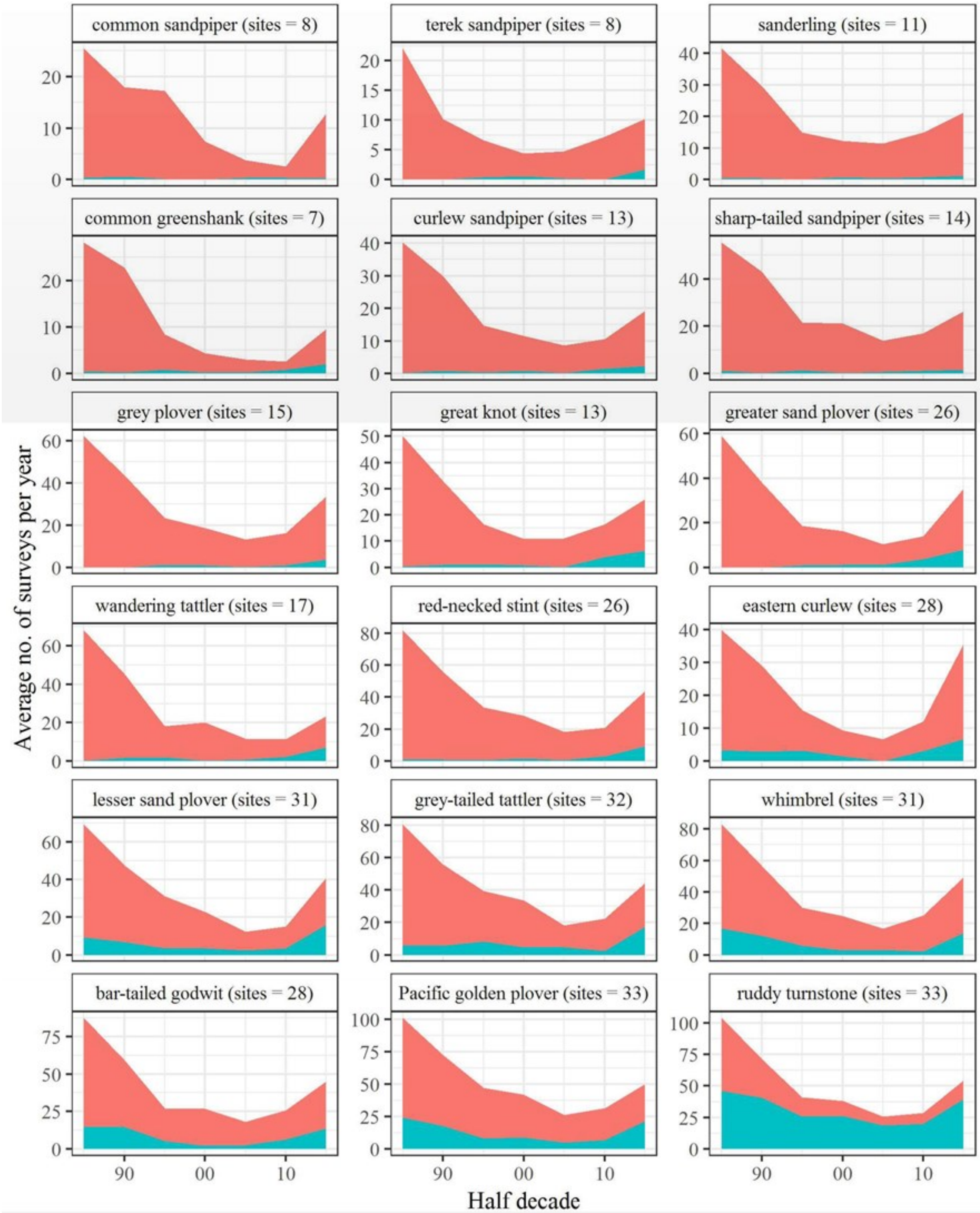

Figure 4. Number of surveys at which each species was observed and absent aggregated into 5-year intervals from essential sites identified in Hemson et al., (2015). Data are from surveys conducted between Sept. 1 and May 31; only species that were observed more than 10 times since Sept.1 1980 are shown. Year labels on the x-axis correspond to the first year of the five-year interval. Survey years were defined as beginning in

September and ending in April (i.e., the 1980 survey year consists of site visits from Sept.-Dec. 1979 and Jan.-May 1980).

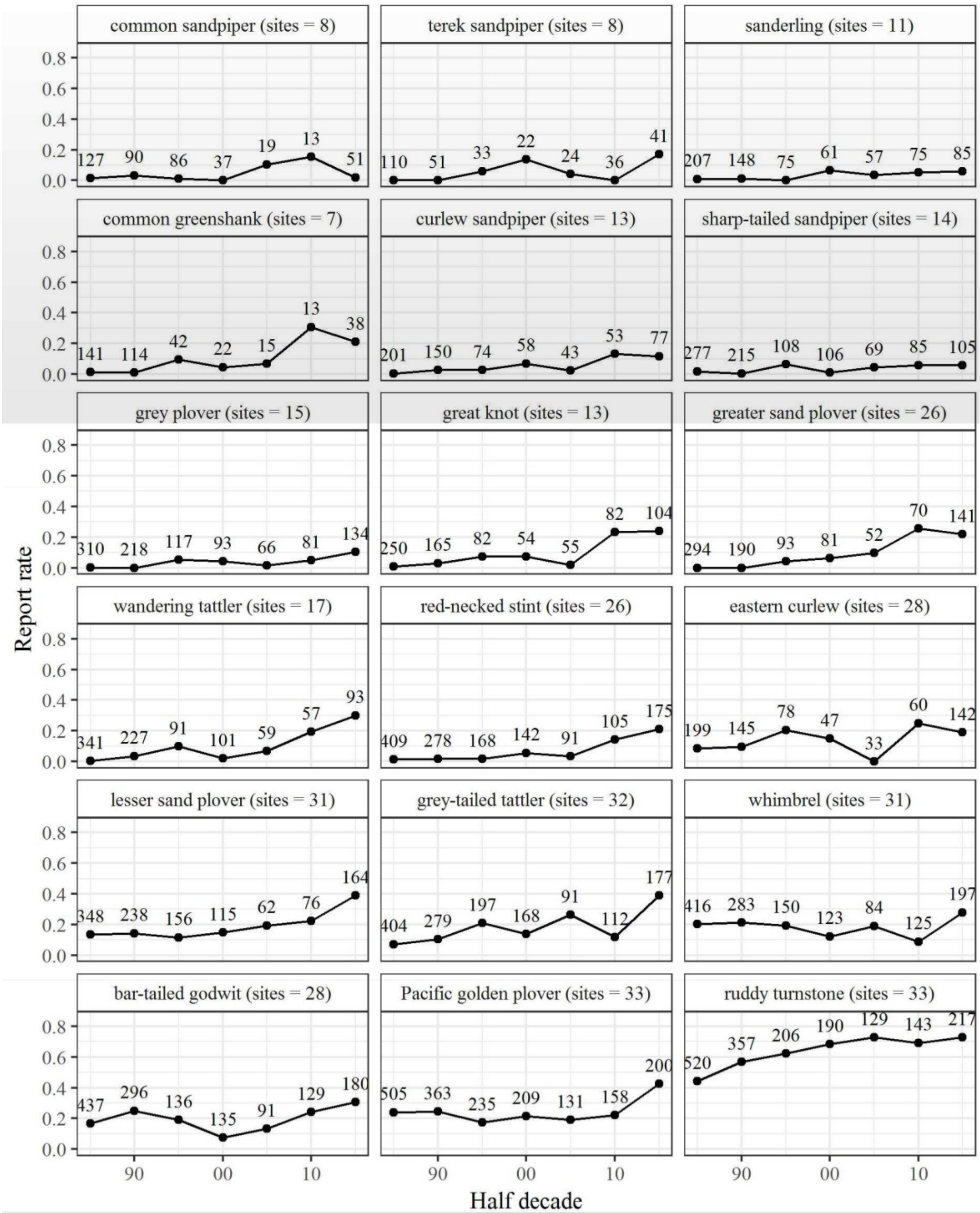

Figure 5. Reporting rates of migratory shorebirds by the Queensland Parks and Wildlife Service in the Great Barrier Reef region summarised at half decadal intervals since 1985. Reporting rates were calculated as the proportion of the total number of surveys conducted in each five-year interval in which each species was detected. As such it is only a crude measure of occurrence and must be interpreted with caution. More robust analysis methods are not possible based on the current data. Numbers above each point denote the number of surveys conducted in each half decade. Data used to generate this figure are the same as those used in Figure 2.1.

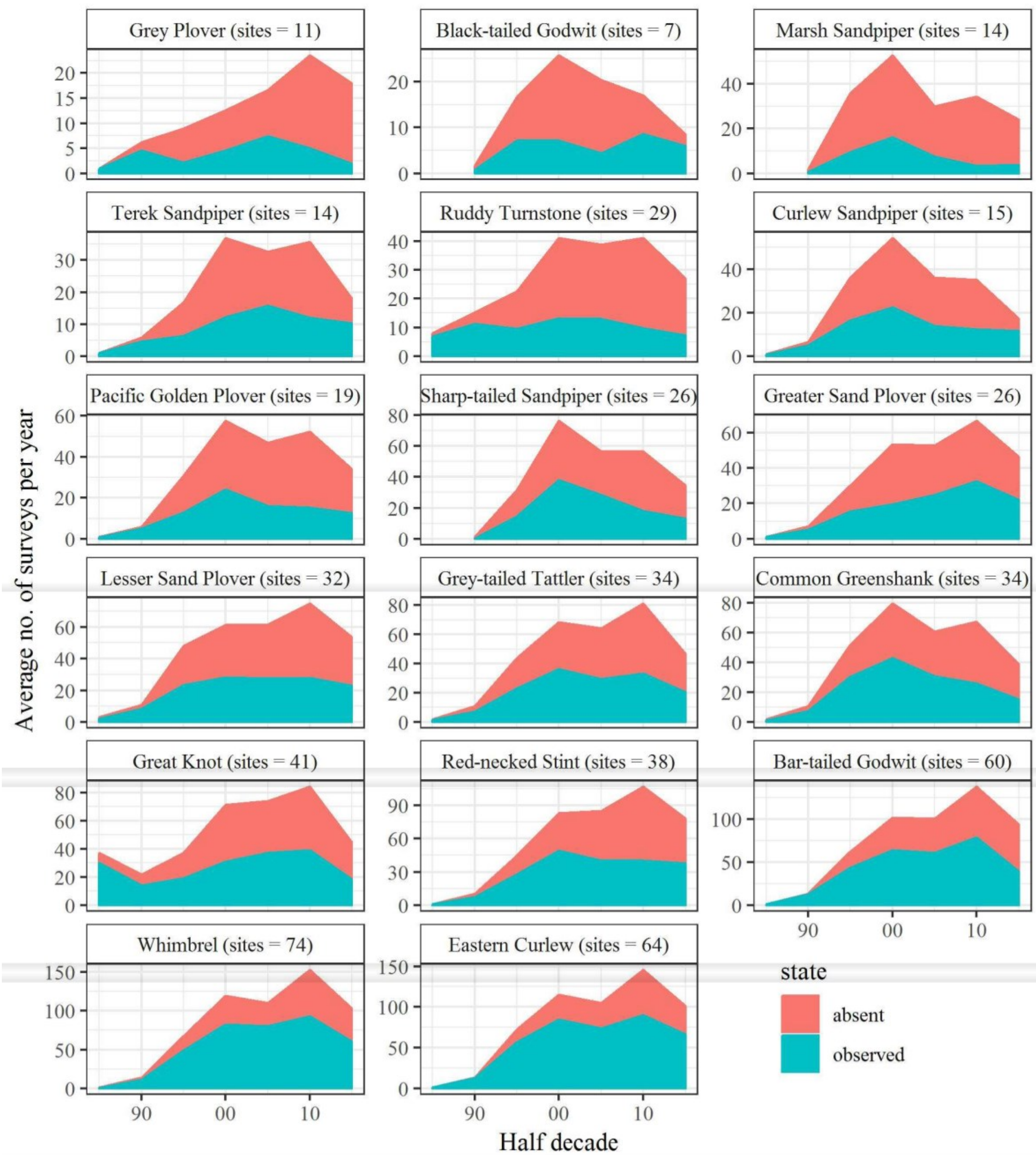

Figure 6. Average number of surveys per year at which each species was observed (blue) and absent (pink) aggregated into five-year intervals. Data are from surveys conducted primarily at mainland sites between Sept. 1 and May 31 by the Queensland Wader Study Group. Year labels on the x-axis correspond to the first year of each five-year interval. Survey years were defined as beginning in Sept.r and ending in May (i.e., the 1985 survey year consists of site visits from Sept.-Dec. 1984 and Jan.-May 1985).

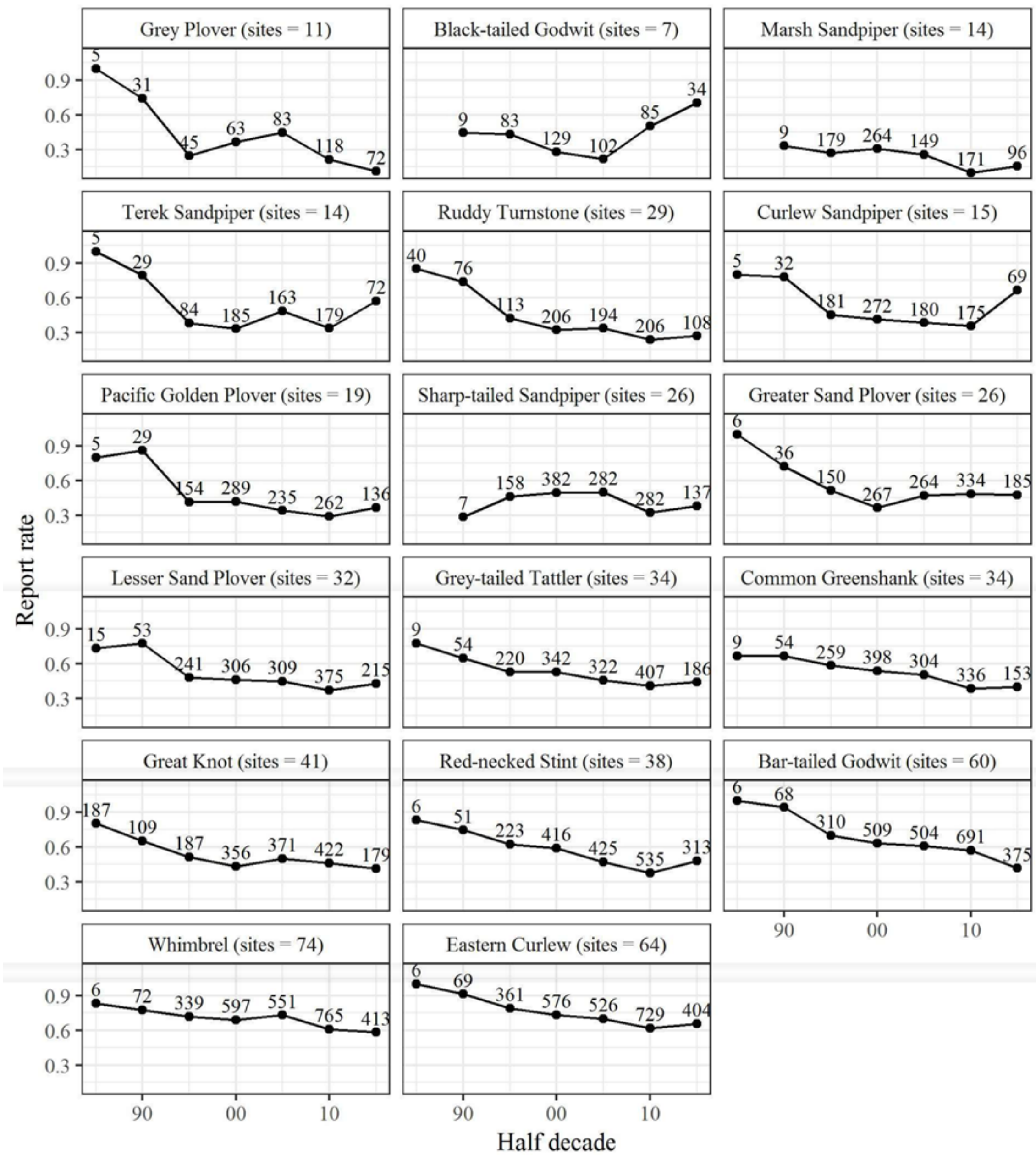

Figure 7. Reporting rates of migratory shorebirds by Queensland Wader Study Group volunteers in the Great Barrier Reef region summarised at half decadal intervals since 1985. Reporting rates were calculated as the proportion of the total number of surveys conducted in each five-year interval in which each species was recorded. Summaries were restricted to species that have been observed at least five sites since 1985 and observed on least five surveys per half decade (number of surveys where species was present divided by the total number of surveys). Numbers above each point denote the number of surveys conducted in each half decade.

4.2 What magnitude of change/criteria needs to be detected to identify problems/trigger management actions?

Accurately assessing shorebird population trends for management purposes requires identifying the level of decline/change considered ecologically significant and the statistical power required for detecting a trend of this magnitude. No required level of trend detection is specified in any of the previous management plans or strategies, and this is an important priority for future plans, to ensure the strategy can meet the needs of the Reef 2050 Plan. The assessment criteria required stem from the desired management outcomes and/or the need to raise flags for management intervention at appropriate times. Therefore, to aid the RIMReP process we have attempted to develop appropriate criteria against which to undertake this assessment.

The Reef 2050 Plan focuses on the Reef maintaining the Outstanding Universal Values for which the World Heritage Convention listed it as a World Heritage Area in 1981. Maintaining World Heritage status requires an assessment process undertaken against a set of internationally developed criteria. Consequently, internationally developed and accepted criteria on what constitutes significant, or undesirable, ecological change in avian populations are also likely to be the most appropriate criteria for detecting change in shorebird populations of the Reef. A number of international and regional criteria associated with detecting significant negative trends in other avian systems have been developed. Most of these are in some way linked to, or developed from, the International Union for Conservation of Nature (IUCN) criteria for communicating the risk of extinction and the listing of species/populations threatened with extinction (Table 1). These include but are not limited to:

- IUCN, International Union for Conservation of Nature, Red List of Threatened Species criteria. Birdlife International use these criteria.
- NCA, Nature Conservation Act, is the legislation used in Queensland. This Act lists species in Queensland using criteria similar to those adopted by the IUCN.
- EPBC, Environmental Protection and Biodiversity Conservation Act. This Act also lists Australian species using IUCN criteria.
- BoT, Back on Track species prioritisation framework is a Queensland species prioritisation process. This process is not statutory but assesses whether recovery is likely and other factors to prioritise recovery actions.

Table 1 Summary of IUCN population reduction criteria for the evaluation of the risk of extinction (IUCN 2012).

Category	Criteria
Critically Endangered (CR)	Population size reduction of ≥ 90% over the last 10 years or three generations, whichever is the longer, where the causes of the reduction are clearly reversible AND understood AND ceased OR Population size reduction of ≥ 80% over the last 10 years or three generations, whichever is the longer, where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible
Endangered (EN)	Population size reduction of ≥ 70% over the last 10 years or three generations, whichever is the longer, where the causes of the reduction are clearly reversible AND understood AND ceased OR Population size reduction of ≥ 50% over the last 10 years or three generations, whichever is the longer, where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible
Vulnerable (VU)	Population size reduction of ≥ 50% over the last 10 years or three generations, whichever is the longer, where the causes of the reduction are clearly reversible AND understood AND ceased OR Population size reduction of ≥ 30% over the last 10 years or three generations, whichever is the longer, where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible

The Australian Government Department of Environment and Energy as well as the Queensland Department of Environment and Science currently use IUCN criteria for assessing total species status under the NCA, EPBC, and The Action Plan for Australian Birds 2000. The adoption of these criteria by multiple Australian government agencies implies that they are also the most appropriate internationally recognised criteria for assessing the risk of extinction of shorebird species at critical sites on the Reef. Note that several species/population characteristics are used by the ICUN including geographic range etc. but for the purposes of this review we have focused on changes in population size as this is the population index closest to the value estimated by the monitoring activities of the Queensland Parks and Wildlife Service and Queensland Wader Study Group.

We have applied the IUCN criteria specifically to shorebird populations on the Reef. The current IUCN status of each species and the per cent population decline required to move a particular species from one IUCN category to another over a specific time period are given in Table 2.2. To generate Table 2.2 we calculated the average annual per cent declines required using generation times provided by the Birdlife International Portal (http://datazone.birdlife.org/species/spcpop, last accessed 23 May 2018) based on available life-history data. Calculations of annual average per cent declines assumed exponential population growth (see section 3 for details).

Table 2 EPBC and IUCN threat levels of all 37 migratory shorebirds that regularly occur in Australia. Species list derived from Hansen et al., 2016. IUCN status from the IUCN Red List of Threatened Species 2017. Per cent declines for species for which generation length was not provided by IUCN are specified as 30 per cent for Vulnerable, 50 per cent for Endangered, and 80 per cent for Critically Endangered (Table 1). The two sub-species for bar-tailed godwit (baueri and menzbieri) are listed separately under EPBC but not under IUCN.

Common Name	Scientific Name	Generation Length	EPBC status	IUCN status	Per cent decline over 10-years to meet IUCN threat category criteria		
					VU	EN	CR
Pacific golden plover	*Pluvialis fulva*	5.6	Secure	LC	18.9	33.5	61.2
Grey plover	*Pluvialis squatarola*	6	Secure	LC	18	32	59.1
Little ringed plover	*Charadrius dubius*	5	Secure	LC	21.2	37	65.8
Double-banded plover	*Charadrius bicinctus*	Unknown	Secure	LC	30	50	80
Lesser sand plover	*Charadrius mongolus*	5.2	EN	LC	20	35.2	63.4
Greater sand plover	*Charadrius leschenaultia*	5.8	VU	LC	18	32	59.1
Oriental plover	*Charadrius veredus*	Unknown	Secure	LC	30	50	80
Latham's snipe	*Gallinago hardwickii*	Unknown	Secure	LC	30	50	80
Pintail snipe	*Gallinago stenura*	4.8	Secure	LC	21.2	37	65.8
Swinhoe's snipe	*Gallinago megala*	4.8	Secure	LC	21.2	37	65.8
Black-tailed godwit	*Limosa*	8.6	Secure	NT	12.8	23.4	46.2

Bar-tailed godwit	*Limosa lapponica*	8.9	--	NT	12.4	22.6	44.9
Western Alaskan bar-tailed godwit	*Limosa lapponica baueri*	8.9	VU	--	12.4	22.6	44.9
Bar-tailed godwit menzbieri	*Limosa lapponica menzbieri*	8.9	CR	--	12.4	22.6	44.9
Little curlew	*Numenius minutus*	10.1	Secure	LC	10.9	20	40.5
Whimbrel	*Numenius phaeopus*	9.1	Secure	LC	12	21.9	43.7
Eastern curlew	*Numenius madagascariensis*	10.1	CR	EN	10.9	20	40.5
Terek sandpiper	*Xenus cinereus*	6.4	Secure	LC	16.3	29.3	55.3
Common sandpiper	*Actitis hypoleucos*	6.8	Secure	LC	15.6	28.1	53.5
Grey-tailed tattler	*Tringa brevipes*	5.7	Secure	NT	18	32	59.1
Wandering tattler	*Tringa incana*	Unknown	Secure	LC	30	50	80
Common greenshank	*Tringa nebularia*	6.3	Secure	LC	17.1	30.6	57.1
Marsh sandpiper	*Tringa stagnatilis*	5.6	Secure	LC	18.9	33.5	61.2
Common redshank	*Tringa totanus*	6.2	Secure	LC	17.1	30.6	57.1
Wood sandpiper	*Tringa glareola*	5.2	Secure	LC	20	35.2	63.4
Ruddy turnstone	*Arenaria interpres*	7.3	Secure	LC	15	27	51.9
Asian dowitcher	*Limnodromus semipalmatus*	5.8	Secure	NT	18	32	59.1
Great knot	*Calidris tenuirostris*	7.4	CR	EN	14.4	26	50.3
Red knot	*Calidris canutus*	6.8	EN	NT	15.6	28.1	53.5
Sanderling	*Calidris alba*	8.1	Secure	LC	13.3	24.2	47.5
Red-necked stint	*Calidris ruficollis*	7.5	Secure	NT	14.4	26	50.3
Long-toed stint	*Calidris subminuta*	7.4	Secure	LC	14.4	26	50.3

Pectoral sandpiper	*Calidris melanotos*	Unknown	Secure	LC	30	50	80
Sharp-tailed sandpiper	*Calidris acuminata*	Unknown	Secure	LC	30	50	80
Curlew sandpiper	*Calidris ferruginea*	7.6	CR	NT	14.4	26	50.3
Broad-billed sandpiper	*Calidris falcinellus*	4.8	Secure	LC	21.2	37	65.8
Ruff	*Calidris pugnax*	5.3	Secure	LC	20	35.2	63.4
Red-necked phalarope	*Phalaropus lobatus*	4.9	Secure	LC	21.2	37	65.8
Oriental pratincole	*Glareola maldivarum*	Unknown	Secure	LC	30	50	80

Table 3. EPBC and IUCN threat levels of 10 non-migratory shorebirds that occur in Queensland, Australia. IUCN status from the IUCN Red List of Threatened Species 2017. Per cent declines for species for which generation length was not provided by IUCN are specified as 30 per cent for Vulnerable, 50 per cent for Endangered, and 80 per cent for Critically Endangered (Table 1).

					Per cent decline over 10-years to meet IUCN threat category criteria		
Common Name	Scientific Name	Generation Length	EPBC status	IUCN status	VU	EN	CR
Masked lapwing	*Vanellus miles*	Unknown	Secure	LC	30	50	80
Beach stone-curlew	*Esacus magnirostris*	10.5	Secure	NT	10.5	19.5	39.5
Black-winged stilt	*Himantopus*	7.3	Secure	LC	15	27	51.9
Bush stone-curlew	*Burhinus grallarius*	10.5	Secure	LC	10.5	19.5	39.5
Australian Pied oystercatcher	*Haematopus longirostris*	Unknown	Secure	LC	30	50	80

Sooty oystercatcher	*Haematopus fulignosus*	Unknown	Secure	LC	30	50	80
Red-capped plover	*Charadrius ruficapillus*	Unknown	Secure	LC	30	50	80
Red-kneed dotterel	*Erythrogonys cinctus*	Unknown	Secure	LC	30	50	80
Black-fronted Dotterel	*Elseyornis melanops*	Unknown	Secure	LC	30	50	80
Red-necked avocet	*Recurvirostra novaehollandiae*	Unknown	Secure	LC	30	50	80

For migratory species (excluding those for which generation lengths are unknown), Table 2 shows that monitoring needs to be able to detect declines of, on average, 16.5 per cent (range = 10.9 per cent - 21.2 per cent) over a 10 year period to identify species or populations that are Vulnerable and 29.4 per cent (range = 20.0 per cent- 37 per cent) over 10 years for Endangered. Detecting declines that qualify for Critically Endangered status requires identifying declines of, on average, 55.0 per cent (range = 40.5 per cent - 65.8 per cent) over 10 years.

Generation lengths were unknown for all non-migratory species, excluding beach stone-curlew, bush stone-curlew, and black-winged stilt (Table 3). For the two stone-curlew species, monitoring needs to be able to detect declines of 10.5 per cent (VU), 19.5 per cent (EN), and 39.5 per cent (CR) over 10 years, whereas for the black-winged stilt, monitoring needs to be able to detect declines of 15 per cent (VU), 27 per cent (EN), and 52 per cent (CR) over the same time period. Converted from 10-year to annual percentages, Tables 2 and 3 suggest that monitoring needs to be capable of detecting annual average declines of 1.8 per cent (range = 1.1 per cent - 2.4 per cent), 3.4 per cent (range = 2.1 per cent - 4.5 per cent), and 7.6 per cent (range= 4.9 per cent - 10.2 per cent) to identify species and populations declining at rates that meet Vulnerable, Endangered, and Critically Endangered criteria, respectively. The smaller the changes the strategy can detect the more useful it is for triggering management aimed at stabilising trends in populations before they undergo significant or irreversible decline.

4.3 Statistical power required to detect a trend of a specified magnitude

The stability of a population at any point in time is assessed against accumulated baseline data on “normal” intrinsic year-to-year variation in the total numbers. Importantly, these baseline data are assumed to not reflect variation associated with major ecological perturbations, other possible external influences (such as anthropogenic disturbance) and/or variation introduced due to the sampling strategy of the monitoring program itself. These data also need to be collected over a sufficient period and at appropriate sampling intervals so as to provide a robust ability to project future population trends.

In practice the choice of statistical power thresholds depends on the purpose of the monitoring program and is often influenced by the needs of a range of stakeholders and funders. In general, standard scientific analyses attempt to reject a null hypothesis of no change. This requires very strong statistical evidence that an observed effect is real. However, in the case of diagnosing threats it is usually more prudent to take a precautionary approach, such that a population might be considered to be in decline unless it is certain that it is stable or increasing. This is precisely the approach recommended by IUCN (2012) for assessing species for admission to the Red List of Threatened Species. The IUCN (2012) also recommend that the attitude to risk (precautionary versus evidentiary) should be explicitly documented. The downside of more liberal thresholds is the cost of management actions that are inevitably triggered more frequently at lower statistical thresholds. The costs of this potentially unnecessary management can be explicitly estimated to help decide on appropriate thresholds, noting that a threshold of being 95 per cent confident is almost always too high for most environmental management decisions (Field et al., 2004).

For these reasons we recommend that shorebird monitoring on the Reef take an appropriate precautionary approach favouring a lower threshold for declaring a statistically significant trend, such as greater than or equal to approximately 90 per cent statistical likelihood of decline, over the more standard 95 per cent significance threshold. This has the effect of favouring action over statistical certainty.

5.0 Section 3

Evaluate the adequacy of current monitoring and modelling of proposed indicators to achieve the objectives of RIMReP. The evaluation should consider:

- *The accuracy of monitoring and modelling*
- *The power to detect change in proposed indicators at magnitudes and spatial and temporal scales that are relevant for managers, stakeholders and for assessing the effectiveness of the Reef 2050 Plan.*
- *The adequacy of sampling methods, and the adequacy of the spatial and temporal resolution of current monitoring and modelling.*

We evaluated statistical power to detect trends in abundance of three migratory shorebirds: eastern curlew, Pacific golden plover, and ruddy turnstone. We focused our analyses on these three species for three reasons. First, all three species rank among the most highly reported species in the region based on the Queensland Wader Study Group surveys of the Mackay region and the Queensland Parks and Wildlife Service surveys at seabird island/cay sites and select coastal mainland locations (Figure 2). Secondly, these three species represent a mix of habitats; ruddy turnstone are frequently reported at island sites in the Reef region, eastern curlew are most common at coastal mainland sites, and Pacific golden plover occur at both island and mainland sites. Thirdly, these species span a range of short (5.6 years) to long (10.1 years) generation lengths, and thus encompass a range of average annual decline levels to meet IUCN population reduction criteria (Tables 2, 3).

Because there is no explicit, documented site visitation strategy beyond the suggested monitoring schedules for The Queensland Parks and Wildlife Service -monitored Ramsar sites for shorebirds for the Reef region, we parameterised power analyses based on the high tide roost site survey strategies employed by Queensland Wader Study Group in the Mackay region and the BirdLife Shorebirds 2020 monitoring protocol as well as the site visitation strategy for essential seabird sites as outlined in Hemson et al., 2015 and described in section 1. For each species, we simulated time-series of abundance for all combinations of five time periods (10-30 years in five-year intervals) and three levels of decline (30 per cent, 50 per cent, and 80 per cent over three generations) across multiple sites. Numbers of sites, average abundance, and variation in abundance across sites were simulated to match count data collected by the Queensland Wader Study Group for the Mackay region and from the Queensland Parks and Wildlife Service count data from island and selected coastal mainland sites. We then analysed time-series of true abundances and observed counts (described below) to evaluate power to detect trends from a single survey per year (as per the BirdLife Shorebirds 2020 protocol) and every second year (approximate frequency of the Queensland Wader Study Group's Mackay surveys). Using eastern curlew as an example, we also evaluated implications of different levels of spatial autocorrelation in temporal trends among sites and for multiple surveys per year (ranging from a single survey up to five surveys per Austral summer) for power to detect trends.

5.1 General methods

5.1.1 Simulating abundance and population counts

Non-breeding abundance was simulated for all combinations of five time periods (10-30 years in five-year intervals), three levels of decline [based on the IUCN 2012 criteria for critically endangered (CR), endangered (EN), and vulnerable (VU)] across multiple roost sites. Population declines were simulated following an exponential model of population growth:

$$Nt = N1 * ert \qquad (1)$$

In equation 1, Nt is the population size at time t, N1 is the initial population size, r is the exponential rate of increase, and e is the mathematical constant equal to 2.78128. From the equation 1, the average annual rate of increase r was derived using the following equation:

$$r = [loge(Nt / N0)] / t \qquad (2)$$

Declines were simulated over three generation lengths at levels of 30 per cent, 50 per cent, and 80 per cent in concert with IUCN 2012 criteria for vulnerable, endangered, and critically endangered threat statuses, respectively (Table 2.1). We introduced inter-annual variation in abundance following a Poisson distribution:

$$N_{s,t} \sim \text{Poisson}(\lambda_{s,t})$$

$$\log_e(\lambda_{s,t}) = N_1 + \beta_s * t + \eta_s \quad \eta_s \sim \text{Normal}(0, 1)$$

$$\beta_s \sim \text{Normal}(r, \sigma) \qquad (3)$$

In equations 3, s denotes sites, η_s denotes a normally-distributed random site intercept, and β_s denotes the site-specific slope drawn from a normal distribution with a mean of r and standard deviation σ.

For all three species, time-series were simulated with σ equal to the absolute value of the mean exponential rate of increase (r), which hereafter is considered to represent high levels of correlation in trends across sites. For eastern curlew, we also simulated time-series where site-specific slopes were drawn from a normal distribution with σ equal to 1.5 * |r| and 2 * |r| to simulate moderate and low levels of correlation in trends across sites. From time-series of true abundances, we generated observed counts ($C_{s,t}$) for each site following a binomial distribution:

$$C_{s,t,n} \sim \text{Binomial}(N_{s,t}, p_{s,t,n}) \qquad (4)$$

In equation 4, n denotes count number and p denotes the detection probability for each count. For ruddy turnstone and Pacific golden plover we simulated a single count per Austral summer (n = 1), but for eastern curlew we simulated up to five counts, equivalent to a single monthly count for Nov- Mar, to examine the extent to which repeated counts influence power to detect trends. Detection probabilities were drawn from a normal distribution with a mean of 0.75 and standard deviation of 1.5.

We simulated 100 replicates for each combination of time-series length and minimum average annual decline to qualify for vulnerable, endangered, and critically endangered under IUCN. For eastern curlew, we also simulated 100 replicate surveys for different levels of spatial correlation in temporal trends across sites and number of counts per austral summer. Comparison of coefficients of variation from simulated time-series of population counts to actual counts conducted by the Queensland Wader Study Group in the Mackay region and selected island and coastal mainland sites surveyed by the Queensland Parks and Wildlife Service suggested a close match between simulated and actual population variability.

5.1.2 Power analysis

We evaluated power to detect trends from time-series of observed population counts. For all three species, we analysed time-series of observed abundances from a single survey. For eastern curlew we also analysed time-series of observed counts from 1, 2, 3, 4, and 5 surveys conducted each Austral summer. For estimating trends from time-series of observed counts, we fitted generalised linear mixed-effects models with negative binomial error structures to account for over-dispersion in population counts introduced by the observation process. Models included a single fixed effect of year, a random site intercept, and random slopes for the year effect to account for variance in temporal trends across sites. For simulations where two or more counts were conducted in a single season, we modelled the average of the counts. All simulation and analysis of time-series was conducted in R 2.5.0. Generalised linear mixed-effects models were fitted using the package 'glmmTMB'.

In all subsequent results, power is defined as the proportion of models where the slope estimate for the fixed year effect was both negative and statistically significant ($\alpha = 0.1$).

5.1.3 Results

Power analyses of simulated time-series suggested high power (≥ 0.8) to detect average annual declines for Critically Endangered from single summer counts conducted over 10 years or longer for all three focal species when trends were highly correlated among sites (Figure 8). High power was also achieved for less severe declines but required longer time-series (approximately 12 to 15 years for endangered and approximately 18 to 25 years for vulnerable). For a given sampling frequency and time-series length, power averaged higher for Pacific golden plover than for the other two species (Figure 8). This is because Pacific golden plovers have the shortest generation length of the three species (5.4 years; Table 2). Thus, the minimum average annual decline that monitoring is required to detect to qualify for vulnerable, endangered, and critically endangered status is steeper than for ruddy turnstone (generation length = 7.3 years) and eastern curlew (generation length = 10.1 years).

Sampling frequency, spatial correlation in roost-level trends, and the number of surveys per season all influenced power. Power gained from sampling every year vs. every other year was substantial, with gains as high as 0.3-0.35 for vulnerable and endangered levels of decline over medium length time periods (15 to 25 years; Figure 8) when correlation in temporal trends among sites was high. This suggests that sampling every year is important for detecting declines over shorter time periods (less than 20 years) and before a species reaches a more severe rate of decline when it may be too late. However, sampling every other year is adequate for detecting declines equivalent to critically endangered in a 15-year time horizon. Using eastern curlew as an example, we found that power averaged approximately 15 to 20 per cent lower when heterogeneity in temporal trends among sites was high (or correlation was low; Figure 9). Finally, and again using eastern curlew as an example, the power to detect declines increased with the number of surveys conducted each season, particularly when average annual declines were small (-1.1 to -2.2%) and time-series were short (less than 20 years; Figure 10). However, the effect of additional counts was most pronounced for adding a second count, and in particular for detecting low to moderate rates of decline over short to mid-length time series. This suggests that adding second summer count could be useful in situations where declines of vulnerable or endangered need to be detected over a 10 to 15-year time horizon. In all cases, almost no additional power was gained by counting more than three times per season.

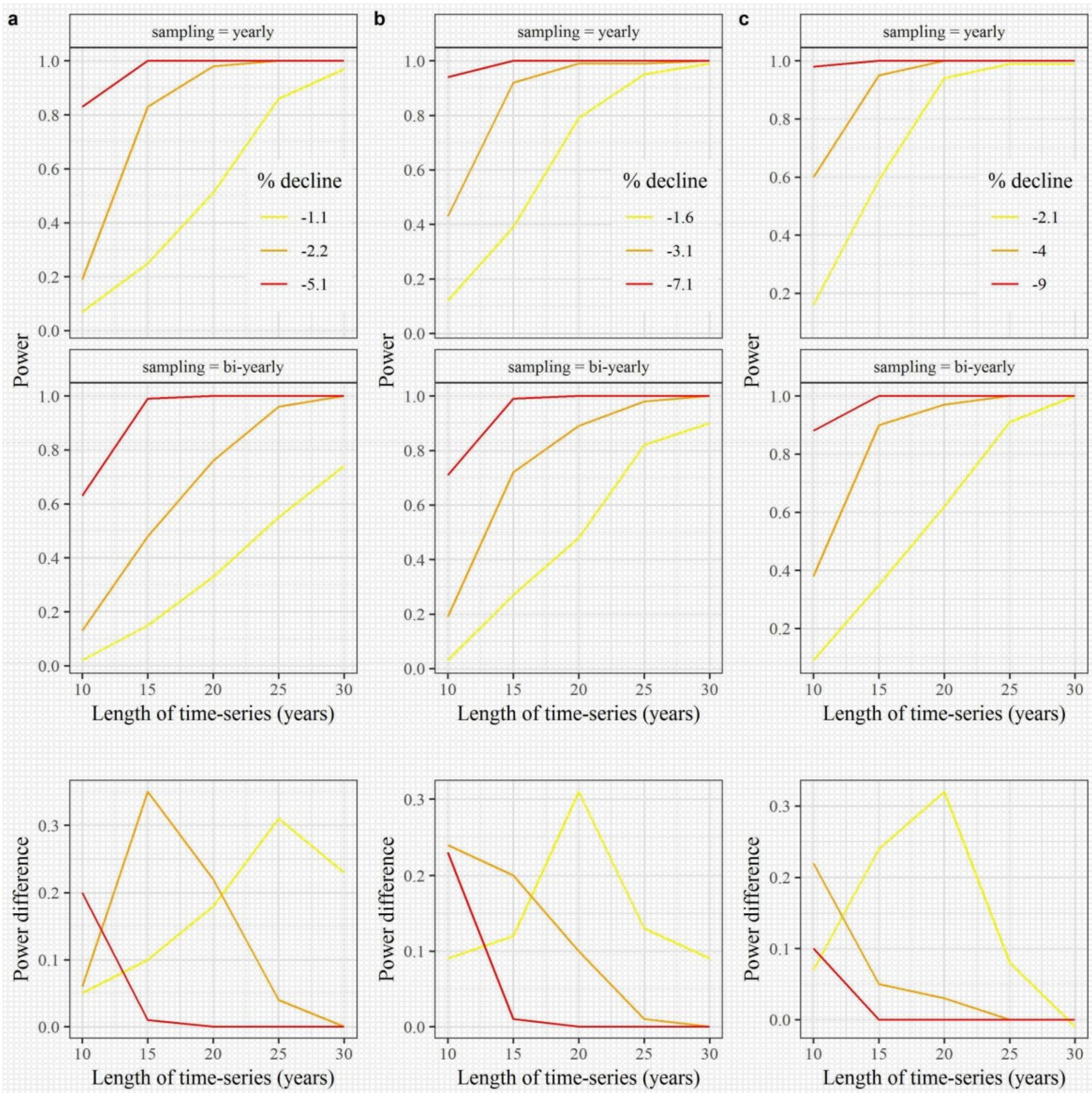

Figure 8. Influence of time-series length and sampling frequency on power to detect trends in populations of (a) eastern curlew, (b) ruddy turnstone, and (c) Pacific golden plover from simulated time-series of summer counts high tide roost sites in the Great Barrier Reef region. The upper two rows show power to detect trends when counts are conducted every year (top row) vs. every second year (middle row), and the bottom panel shows the difference in power between the two sampling frequencies (power yearly – power bi-yearly). Time-series were simulated with high levels of correlation in temporal trends across roost sites. Power gains from sampling every year vs. every other year peaked at approximately 0.3 for small to moderate declines (-1.1 per cent to -2.2 per cent) and at intermediate time-series lengths (15 to 25 years).

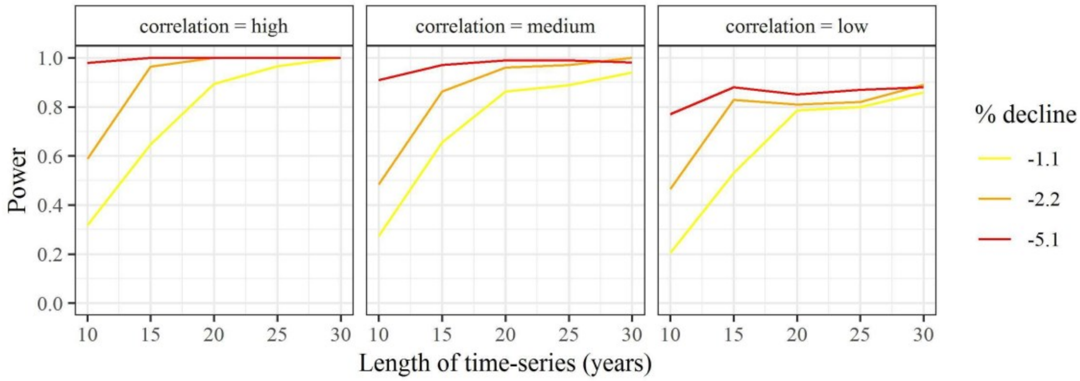

Figure 9. Influence of varying levels of spatial correlation in temporal trends across roost sites on power to detect population trends of eastern curlew from simulated time-series of single summer counts from 31 high tide roost sites in the Great Barrier Reef region. As similarity or correlation in temporal trends across roosts decreases so too does power to detect population declines, particularly at low levels of average annual decline (VU and EN) and short time periods (< 20 years).

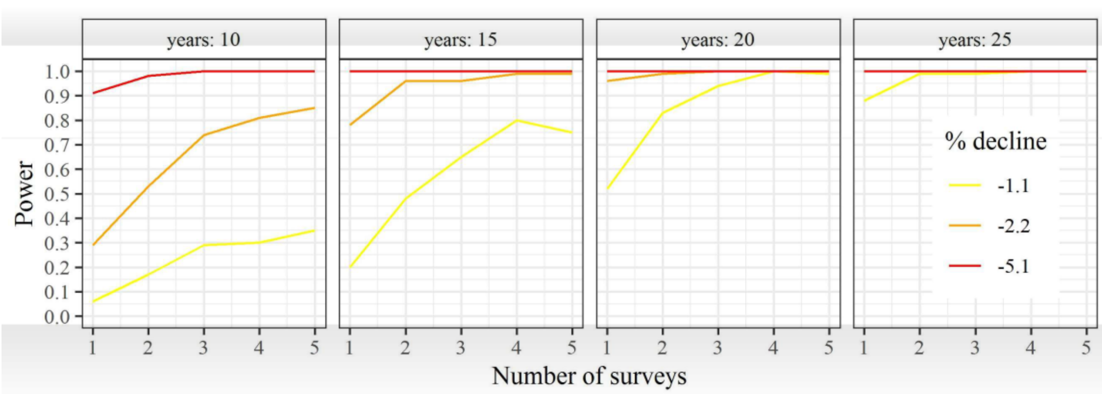

Figure 10. Influence of repeated surveys on power to detect trends in populations of eastern curlew from simulated time-series of population counts from 31 high tide roost sites in the Great Barrier Reef region. As the number of surveys conducted at each site per year increases, so too does the power to detect population declines, particularly when average annual declines are small (-1.1 to -2.2 per cent) and time-series are short (less than 20 years). However, power did not increase linearly with the number of surveys, resulting in minimal power gained from counting more than three times per season. Time-series were simulated with high levels of correlation in temporal trends across roost sites.

6.0 Section 4

Identify gaps in current monitoring and modelling of proposed indicators. Gaps might be spatial (i.e. where an indicator is not measured), temporal (i.e. when indicators are not measured with sufficient frequency to maintain adequate knowledge of condition) or, in some cases, indicators might not be measured at all.

6.1 What are the potential issues/problems with the current strategy?

Summarise any identified potential problems/issues with current strategy relative to the logistic constraints within which it was originally designed and/or based on the modelling results.

At the time of writing, shorebird monitoring is performed under the Coastal Bird Monitoring and Information Strategy (2011), and consists primarily of counts of shorebirds (i) by the Queensland Parks and Wildlife Service at major sites where shorebirds are the main value, (ii) by the Queensland Parks and Wildlife Service counts of shorebirds at sites visited primarily for seabird monitoring, and (iii) by the Queensland Wader Study Group, who by virtue of their volunteer-driven surveyor base, perform surveys that are neither structured in a way that samples the full range of important wetlands in the Reef region, nor frequent enough at all sites to achieve sufficient power to detect trends in the desired timeframe. As a result, the current situation is that existing data are too sparse in space and time to make any robust conclusions about trends in shorebird populations in the Reef beyond a few isolated locations.

6.2 Issues from Section 1.3: Are historic data compatible with data obtained in the CBMIS 2011 and 2015?

Existing data are similar to those currently being collected by the Queensland Parks and Wildlife Service and the Queensland Wader Study Group, but much of the historical Queensland Parks and Wildlife Service data are too sparse in space and time for trend analysis. There are also concerns around errors in the identification of similar species that may limit the utility of much of the historical count data to just a small number of easily identifiable species.

6.3 Issues from Section 1.4: What are the currently monitored species/foraging guilds and rationale?

Currently all shorebird species are monitored in both the Queensland Parks and Wildlife Service and the Queensland Wader Study Group datasets. This is generally appropriate, particularly since mechanisms are in place to screen the data for erroneous counts of identifications.

6.4 Issues from section 1.5: What is the current spatial and temporal pattern of monitoring and rationale?

The main issue with the current strategy is that it is built primarily for seabird surveying, meaning that visits are timed with seabird breeding events in mind, and without regard for the tidal state, which strongly influences shorebird distributions. In part this arises from the multi-dimensional role of the Queensland Parks and Wildlife Service monitoring, where the capacity is to survey key locations at times that coincide with either general coastal bird monitoring, as in the case of islands and cays, or the targeted shorebird sites which are sensitive to site access availability and weather. Submission of incidental records while staff are involved in other project work is encouraged, potentially leading to the identification of new sites or interesting species occurrences. As most of the Queensland Parks and Wildlife Service survey sites require boat transport, accessibility can limit coverage. In general, summer counts are prioritised for almost all islands on the basis of coinciding with seabird breeding times (Figure 3), which is fortunate since the national standard for the Shorebirds 2020 data collection is a single summer count between November and February. As such, a formal integration of shorebird monitoring into the seabird monitoring timetable would probably have relatively little impact on the latter, and would appear to serve as a reasonable basis going forward for the new shorebirds strategy for Reef islands and mainland. Our power analysis shows that a second annual summer count is worthwhile, and that monitoring is needed every year.

The current monitoring strategy for shorebirds for offshore islands results in rather few visits in comparison to the large number of islands and cays in the Reef, and it remains unclear whether important offshore sites for shorebirds are being missed. As a result, there are uncertainties about shorebird usage of offshore islands that would require more consistent and sustained effort to address — for example, determining how many shorebirds use small offshore islands and whether these islands are being used more during passage migration than during the stationary non-breeding period, as recent tracking data from several species might suggest.

7.0 Section 5

Evaluate new monitoring technologies and indices for their potential to increase efficiency or statistical power and their compatibility with long-term datasets.

7.1 What new monitoring strategies are possible for the current indices?

There are no new monitoring technologies available for the current index, which is shorebird abundance. While some remote methods such as video surveillance and drone surveys have been trialed for shorebirds, the reality is that shorebirds use wetlands in a highly dynamic way, and searching by experienced observers is the most reliable way to find and enumerate birds under variable field conditions.

7.2 What other indices could be monitored & what threatening processes could these indices detect?

Other possible indices include the proportion of juveniles present in migratory species, which gives an approximate measure of breeding success in the previous season, or habitat quality based on benthic sampling (see Choi et al., 2017). Both of these indices would require expert assessment, and are very expensive as a result, and don't yield a substantial amount of additional information beyond the counts themselves. Probably the best approach is the current one - if changes in numbers are detected, analysis of these changes with respect to covariates can shed light on possible causes and management responses.

8.0 Section 6

Outline the likely best practice versus likely most cost effective approach for combining the monitoring of additional indices so as to maximise information returns on population trends and/or specific potential threatening process.

8.1 Recommendations for the current strategy

General recommendations:

- Summer surveys for shorebirds are organised and implemented on an ongoing basis for all major mainland estuary systems, by working in close partnership with Queensland Wader Study Group. At least one survey per summer is necessary, but ideally two will be conducted.

- A closer operational arrangement in partnership with the Queensland Wader Study Group is designed and implemented, extending the existing coordination activity to facilitate (i) enhanced coordination to ensure all major sites are surveyed at least twice per summer, (ii) integration of data into a single database permitting robust analysis of trends, and (iii) submission of a combined dataset to the Shorebirds 2020 program, enabling data to be integrated in national analyses of shorebird population trends.

- Formally distinguish the mainland and offshore surveys. The habitats are different, and so the species are different. This means that different monitoring approaches are needed.

    a. Mainland — the expertise and frameworks for doing the counts exists, but there needs to be increased capacity to roll these methods out across more sites, and more frequently in time. One obvious solution is to work in closer partnership with the Queensland Wader Study Group to coordinate once- or twice-annual summer counts in key mainland sites that are not currently being monitored (for example, the Gladstone region). This will deliver appropriate expertise in (i) logistics of identifying and covering roost sites at appropriate times of the tide, (ii) robust identification of the shorebirds themselves, and (iii) accurate counting of large numbers of birds. Each major site complex needs to be carefully evaluated with respect to behavior of the birds, how many teams are needed, and how they need to be deployed.

   b. Offshore — to prioritise offshore sites, it is necessary to determine the numerically important and distinctive species occurring on the Reef islands, and focus the definition of essential sites with these in mind. From initial analysis of the data, key species are likely to be ruddy turnstone, Pacific golden plover, whimbrel, wandering tattler, and possibly grey-tailed tattler.

- Enhanced observer training and error-checking is conducted. For island / cay surveys, ensure that surveyors are well-trained in strategies for counting them in relation to tidal and light / dark cycles. Ideally ensure site visits occur during high tide and, where non-expert counters are deployed, clearly flag this in the resulting data.
- Data on disturbance are formally and consistently collected as part of the shorebird surveys.

8.2 Acknowledgements

Data used in this report were supplied, in part, by the Queensland Wader Study Group (a special interest group of the Queensland Ornithological Society Incorporated).

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