

Waterbird metrics for the Coorong and Lakes Alexandrina and Albert Ramsar site

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Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
CHIEF EXECUTIVE
DEPARTMENT FOR ENVIRONMENT AND WATER

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Glossary

Annual waterbird census	The waterbird census conducted over the Lakes and Coorong each summer by the University of Adelaide (Associate Professor David Paton).
Change in ecological character	Defined as the human-induced adverse alteration of any ecosystem component, process and/or ecosystem benefit/service.
Coorong	The extent of the Ramsar site covered by the Coorong waterbird census, which runs from Goolwa Barrage to 42 Mile Crossing.
Ecosystem components, processes and services (CPS)	Criteria (see <i>Ecosystem components, Ecosystem processes and Ecosystem Services</i>) that determine the ecological character of the Ramsar site.
Ecosystem components	The physical, chemical and biological parts of a wetland (from large scale to very small scale, for example habitat, species and genes).
Ecosystem processes	The changes or reactions which occur naturally within wetland systems. They may be physical, chemical or biological. They include all those processes that occur between organisms and within and between populations and communities, including interactions with the non-living environment that result in existing ecosystems and bring about changes in ecosystems over time.
Ecosystem services	The benefits that people receive or obtain from an ecosystem. The components of ecosystem services are provisioning (for example, food and water), regulating (for example, flood control), cultural (for example, spiritual, recreational) and supporting (for example, nutrient cycling, ecological value).
Diversity	The number of species and abundance of each species in a particular location.
East Asian Australasian flyway	A flight path used by birds migrating between their breeding grounds and overwintering sites. The East Asian Australian flyway extends from southern Australia (overwintering site) to northern Asia and Alaska (breeding grounds).
Ecological character	The combination of the ecosystem components, processes and benefits and services that characterise the wetland at a given point in time.
Ecological Character Description (ECD)	A report that identifies and describes the critical components, processes and services (CPS) that determine the ecological character of the Ramsar site.
Filamentous algae	Colonies of microscopic plants that link together to form threads or mesh-like filaments.
Flyway species	Migratory shorebird species that have counts in the Ramsar site that regularly exceeded 1% of their total East Asian Australasian flyway population.
Herbivore	A group of waterbirds that primarily feed on aquatic plant material.
Large wader (waterbird)	Long-legged birds, such as an egrets, spoonbills and ibis, that often forage in shallow water.

Limit of Acceptable Change (LAC)	A condition or value set beyond the limit of variation under current management that, if reached or breached, indicates an undesirable condition that may mean a change in ecological character has occurred.
Macroinvertebrates	Animals without a backbone that can be seen without magnification, such as worms, insects and crabs.
Management Trigger	A pre-defined condition or value used to identify decision points to initiate a management response. Thresholds for Management Triggers are set at a value between the resource condition target and the LAC and are reflective of the limit of variation under current management.
Migratory shorebird (waterbird)	A group of waterbirds with long legs and bills relative to their body size, which forage in shallow water habitats and undergo international migrations.
Murray estuary	The extent of the Ramsar site below the Lakes barrages, which runs from the Goolwa Barrage to Pelican Point.
North Lagoon	The extent of the Ramsar site that runs from Pelican Point to near Parnka Point.
Piscivore (waterbird)	A group of waterbirds that primarily feed upon fish.
Priority species	Migratory shorebirds species that were present in numbers > 100 in at least four of the first five years of available data (1981, 1982, 1987, 1993 and 2000) in the Coorong.
Ramsar Management Plan (RMP)	A management plan that clearly specifies intended objectives for the Ramsar site, including clearly defined responsibilities, timelines, and milestones for accomplishing project tasks and management actions to maintain the ecological character of the Ramsar site.
Ramsar site	Refers to the Coorong and Lakes Alexandrina and Albert Wetland Ramsar site.
Resource Condition Target	A typical and contemporary (21 st century) state for the Ramsar site's critical CPS that takes into account variation under the current management.
<i>Ruppia tuberosa</i>	An aquatic plant that is the dominant species in the Coorong South Lagoon and an important habitat and food resource for fish and waterbirds.
Selected species	Species of waterbirds that met a series of conditions and were included in analyses.
Shorebird	A group of waterbirds with long legs and bills relative to their body size, which forage in shallow water habitats.
South Lagoon	The extent of the Ramsar site that runs from near Parnka Point to 42 Mile Crossing.
Threatened species	Nationally threatened waterbird species listed as either Vulnerable, Endangered or Critically Endangered under the <i>Environment Protection Biodiversity Conservation Act 1999 (Cth)</i> .
Waterfowl	Waterbirds belonging to the order Anseriformes that includes ducks, geese and swans. Most species have webbed feet.
Waterbird	Birds that live on or around waterbodies with the exception of passerines (songbirds).

Summary

The Department for Environment and Water (DEW) is updating the ecological character description (ECD) of the Coorong and Lakes Alexandrina and Albert Wetland to identify and describe the critical components, process and services (CPS) that determine the ecological character of the Ramsar site as at 2015. Each CPS has a Limit of Acceptable Change (LAC) that outlines the variation that is considered acceptable in a particular component, process or service of the ecological character of the wetland. The LAC in the ECD use the LAC thresholds identified in this report. The inference is that if the particular measure or parameter moves beyond the 'limit of acceptable change threshold' this *may* indicate a change that could lead to a reduction or loss of the values (criteria) for which the site was listed.

The ECD forms a reference for the development and implementation of a Ramsar Management Plan (RMP), which will outline the intended objectives and management actions that aim to maintain the ecological character of the Ramsar site. Underpinning the key objectives of the RMP are quantified Resource Condition Targets and Management Triggers, which describe the aims for site management and how and when to act to help achieve key objectives and prevent a change in ecological character.

Definitions for Resource Condition Targets, Management Triggers and LAC thresholds are provided below:

- **Resource Condition Target:** A typical and contemporary (21st century) state for the Ramsar site's critical CPS that takes into account variation under the current management. Resource Condition Targets are founded on the baselines identified in the ECD.
- **Management Trigger:** A pre-defined condition or value used to identify decision points to initiate a management response. Thresholds for Management Triggers are set at a value between the Resource Condition Target and the LAC threshold and are reflective of the limit of variation under current management.
- **LAC threshold:** A condition or value set beyond the limit of variation under current management that, if reached or breached, indicates an undesirable condition that may mean that a change in ecological character has occurred.

Waterbirds were identified as an ecosystem component, process and cultural service in the ECD. This technical report identifies and evaluates Resource Condition Targets, Management Triggers and LAC thresholds for the following waterbird CPS subcomponents:

- Waterbird abundance (including total waterbird abundance and abundance/presence of priority, important non-migratory and East Asian Australasian (EAA) flyway species)
- Waterbird diversity
- Nationally threatened species

This project built on previous work by O'Connor (2015) and Robinson (2017) to develop consistent Resource Condition Targets, Management Triggers and LAC thresholds.

Long-term annual waterbird census datasets from the Lakes and Coorong (collected by the University of Adelaide) were analysed to set Resource Condition Targets, Management Triggers and LAC thresholds for waterbird CPS. All metrics were set on a baseline including years of census up to 2015 (Coorong, 2000–15 & Lakes, 2009–15).

The statistical thresholds for each metric used across all waterbird CPS subcomponents were:

Resource Condition Target: Probability of target being met is 0.5 (positive outcome)

Management Trigger: Probability of trigger being breached is 0.1 (negative outcome)

LAC threshold: Probability of LAC threshold being exceeded is 0.01 (negative outcome)

Management actions are to be initiated where factors internal to the Ramsar site contributed significantly to the Management Trigger breach.

The compliance of Resource Condition Targets, Management Trigger and LAC thresholds were evaluated using annual Lakes and Coorong waterbird census data collected from 2000–20.

The key findings from evaluation were:

- Resource Condition Targets set incorporated variability and were considered to be reflective of a typical and contemporary state under current management.
 - Achievability of targets for certain migratory shorebirds may be affected by their declining populations in the EAA flyway.
- Management Trigger breaches from 2000–20 were most common during extreme hydrological events (i.e. prolonged low flows or high flows).
 - Management Trigger breaches for waterbird abundance and diversity CPS subcomponents occurred during periods of extreme drought (2008–10) and/or very high barrage flows and widespread flooding over the Murray-Darling Basin (2011 and 2017).
 - Management Triggers for individual species for the 1% EAA flyway abundance, important non-migratory species, priority species and threatened species were breached over a range of hydrological conditions, however, were most common during periods of high barrage flows (2011, 2012 and 2017) and widespread flooding over the Murray-Darling Basin (2011 and 2017).
- LAC thresholds were exceeded on 13 occasions over ten unique events (*events marked with an asterisk breached multiple LAC thresholds*):
 - Waterbird diversity: Murray estuary (2010–12), North Lagoon (2010–11) and South Lagoon (2008–11)
 - 1% EAA flyway species: Curlew Sandpiper (2011–12*) and Red-necked Stint (2017–20*)
 - Important non-migratory species: Red-capped Plover (2010–11)
 - Priority species: Black-tailed Godwit (2011–14), Common Greenshank (2011–12), Curlew Sandpiper (2011–12*), Pacific Golden Plover (2011–12) and Red-necked Stint (2017–20*)
 - Threatened species: Curlew Sandpiper (2011–12*) and Eastern Curlew (2000–01).

An investigation to determine whether local, national or international factors (or combination thereof) led the exceedance of each LAC threshold has not been conducted. Going forward, it is recommended that LAC assessments be complemented by investigations to determine the cause of the exceedance of the LAC threshold.

The metrics developed in this technical report will help to assess the condition of the Ramsar site, provide signals for the need of management actions to maintain ecological character and also serve to identify changes in ecological character.

1 Introduction

The Coorong, and Lakes Alexandrina and Albert (referred to herein as Lakes) (Figure 1.1) supports nationally and internationally significant populations of waterbirds (Paton et al. 2009). In 2015 the Ramsar site was assessed as meeting eight of the nine current Ramsar criteria, including all five Ramsar criteria that relate to waterbirds (criteria 2-6) (DEW 2021a). A total of 100,000 to 300,000 waterbirds are typically supported each summer over the Lakes and Coorong, with numbers highest during drought when the system provides a refuge for Australian waterbirds (Paton et al. 2018). The Lakes and Coorong supports a diverse waterbird community, including threatened species and > 1% of the total East Asian Australasian (EAA) flyway population of three migratory shorebird species. The site also provides significant and regular nesting habitat for thousands of colonial-nesting waterbirds from at least 10 species, and at least three beach-nesting waterbird species (O'Connor et al. 2013).

Under the Ramsar Convention, contracting parties are expected to manage their Ramsar sites to maintain the ecological character of the site (Ramsar Convention 2005). The Department for Environment and Water (DEW) is updating an ecological character description (ECD) of the Coorong and Lakes Alexandrina and Albert Wetland, which describes the critical components, processes and services (CPS) of the Ramsar site as at 2015. Each CPS has associated Limit of Acceptable Change (LAC) thresholds. The inference is that if the particular measure or parameter moves beyond the 'limit of acceptable change threshold' this *may* indicate a change that could lead to a reduction or loss of the values (criteria) for which the site was listed. The ECD forms a reference for the development and implementation of a Ramsar Management Plan (RMP) for the site, which will outline the intended objectives and management actions that aim to maintain the ecological character of the Ramsar site. Underpinning the key objectives of the RMP are quantified Resource Condition Targets and Management Triggers, which describe the aims for site management and how and when to act to help achieve key objectives and prevent a change in ecological character.

Waterbirds were identified as an ecosystem component, process and cultural service in the ECD, and therefore, this technical report aims to:

- Develop a methodology that enables Resource Condition Targets, Management Triggers and LAC thresholds to be set consistently between different waterbird CPS subcomponents (i.e. building on methodologies described in O'Connor 2015 and Robinson 2017)
- Set Resource Condition Targets, Management Triggers and LAC thresholds for the following waterbird CPS subcomponents to inform the RMP:
 - Waterbird abundance (including total waterbird abundance, priority species, important non-migratory and flyway species)
 - Waterbird diversity
 - Nationally threatened species (selected species only)

These metrics will help to assess the condition of the Ramsar site, provide signals for the need of management actions to maintain ecological character and also serve to identify changes in ecological character.

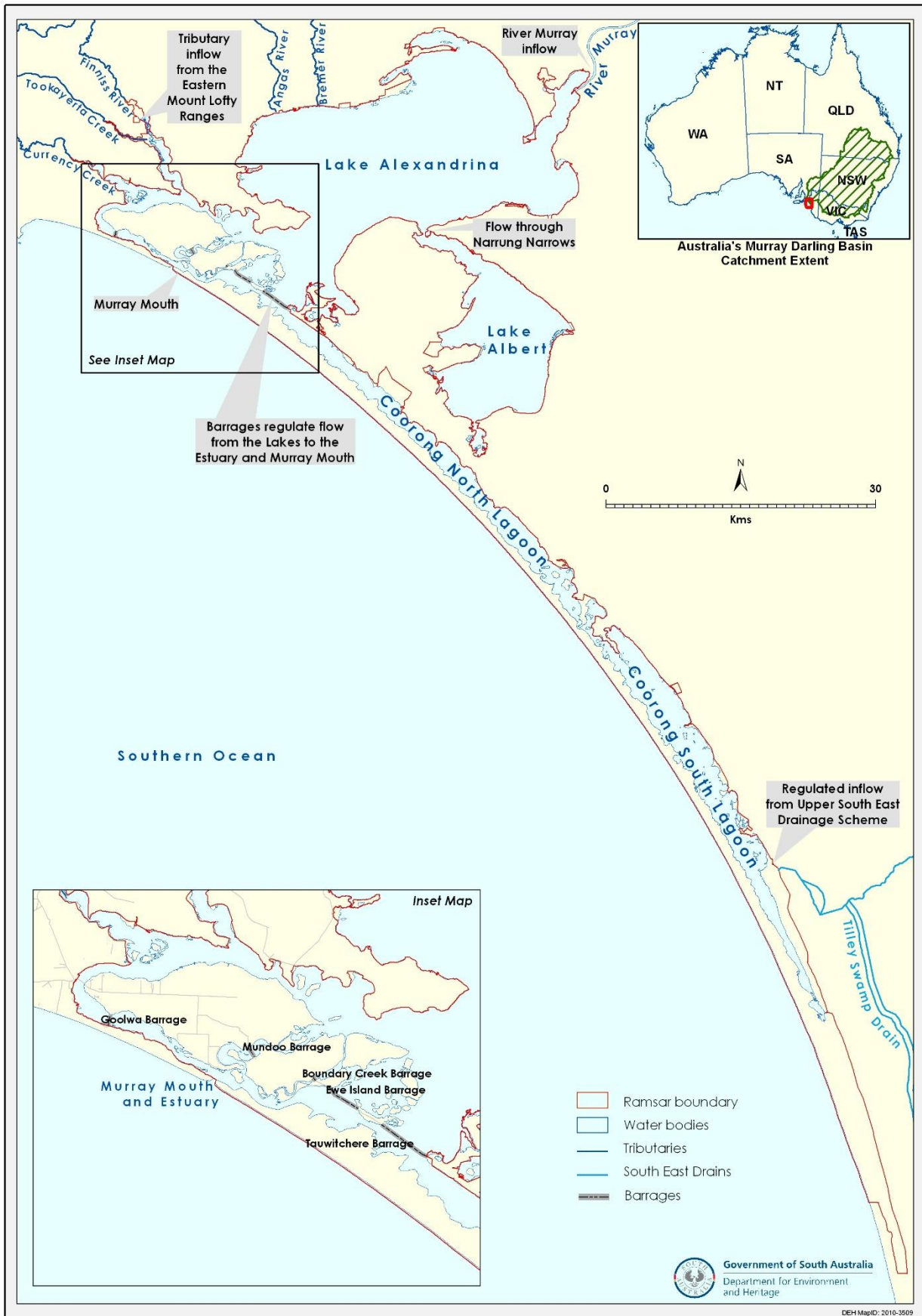


Figure 1.1. Extent of the Lakes (Alexandrina and Albert), Murray estuary and Coorong North and South Lagoons inside the Ramsar site boundary.

2 Background

2.1 Ecological Character Description

ECDs identify, describe and, where possible, quantify the critical components, processes and services (CPS) of the site which determine its character and ultimately allow detection and monitoring of change in that character. South Australia is updating the ECD for the Coorong and Lakes Alexandrina and Albert Ramsar site to describe its baseline conditions as at 2015.

Waterbirds are identified as an ecosystem component, process and cultural service in the revised ECD based upon the definitions in Table 2.1. Several waterbird CPS sub-components were also identified as shown in Table 2.2. Each of these CPS sub-components are to be quantified in order to describe the ecological character of the site and allow detection and management in response to undesirable change. The ECD includes a quantitative description of the Limits of Acceptable Change (LAC) for critical CPS. LAC describe undesirable condition thresholds that are set beyond the limit of variation under the current management regime. A breach of LAC *'indicates that a component, process or benefit/service has changed beyond its natural variability and the breach of this feature, by definition, requires a remedial response'* (DEWHA 2009). Given the variability of waterbird populations at the site, this report proposes an investigation process when LAC thresholds are breached to determine the relative impact of local, national or international (for migratory species) conditions on waterbird declines.

Table 2.1. Definitions by which ecosystem components, processes and services were identified for the Coorong and Lakes Alexandrina and Albert wetland in the Ecological Character Description (ECD). Source: DEW (2021b).

Criteria	Definition
Ecosystem component	The physical, and biological parts of a wetland (from large scale to very small scale, for example habitat, species and genes) (Millennium Ecosystem Assessment 2005).
Ecosystem process	The changes or reactions which occur naturally within wetland systems. They may be physical, chemical or biological (Ramsar Convention 1996, Resolution VI.1 Annex A). They include all those processes that occur between organisms and within and between populations and communities, including interactions with the non-living environment that result in existing ecosystems and bring about changes in ecosystems over time (Australian Heritage Commission 2002).
Ecosystem services	The benefits that people receive or obtain from an ecosystem. The components of ecosystem services are provisioning (for example, food and water), regulating (for example, flood control), cultural (for example, spiritual, recreational) and supporting (for example, nutrient cycling, ecological value) (Millennium Ecosystem Assessment 2005).

Table 2.2. Critical components, processes and services (CPS) and their sub-components identified for waterbirds in the Ecological Character Description (ECD).

Critical CPS	Sub-component
Waterbirds	Diversity (species richness and abundance)
	Abundance (including total waterbird abundance, important non-migratory species, priority migratory shorebird and flyway species)
	Breeding
	Threatened species

2.2 Ramsar Management Plan

The Ramsar Management Plan (RMP) is used to develop and implement planning to promote the wise and sustainable use and conservation of wetlands. The RMP describes Resource Condition Targets, Management Triggers and management actions designed to maintain the ecological character of the site.

In this project, Resource Condition Targets are set to be reflective of a typical and contemporary (21st century) state for the Ramsar site’s critical CPS and takes into account variation under current management. Management Triggers are set at a pre-defined condition or value used to raise an alert and act as decision points to initiate a management response. Both Resource Condition Targets and Management Triggers were founded on the 2015 baselines identified in the ECD.

2.3 Summary of metrics

LAC thresholds for each waterbird CPS subcomponent are quantified in the ECD and Resource Condition Targets and Management Triggers for each waterbird CPS subcomponent are quantified in the RMP (Figure 2.1). Definitions for each metric are provided below:

- **Resource Condition Target:** A typical and contemporary (21st century) state for the Ramsar site’s critical CPS and takes into account variation under the current management.
- **Management Trigger:** A pre-defined condition or value used to identify decision points to initiate a management response. Thresholds for Management Triggers are set at a value between the Resource Condition Target and the LAC threshold and are reflective of the limit of variation under current management.
- **Limit of Acceptable Change (LAC) threshold:** A condition or value set beyond the limit of variation under current management that, if reached or breached, indicates an undesirable condition that may mean a change in ecological character has occurred.

A schematic diagram of the relationship between Resource Condition Targets, Management Triggers and LAC thresholds with respect to an underlying dataset is shown in Figure 2.2.

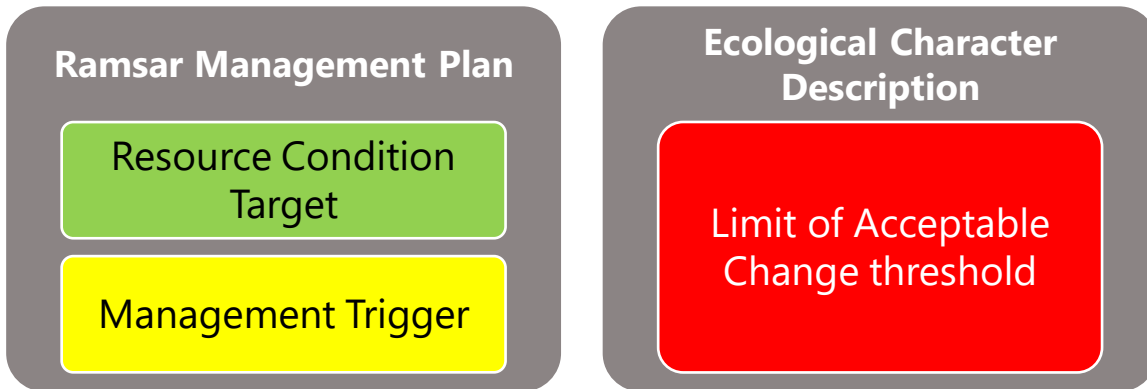


Figure 2.1. Metrics required to be quantified for the Ramsar Management Plan (RMP) and the Ecological Character Description (ECD) for the Coorong and Lakes Alexandrina and Albert wetland.

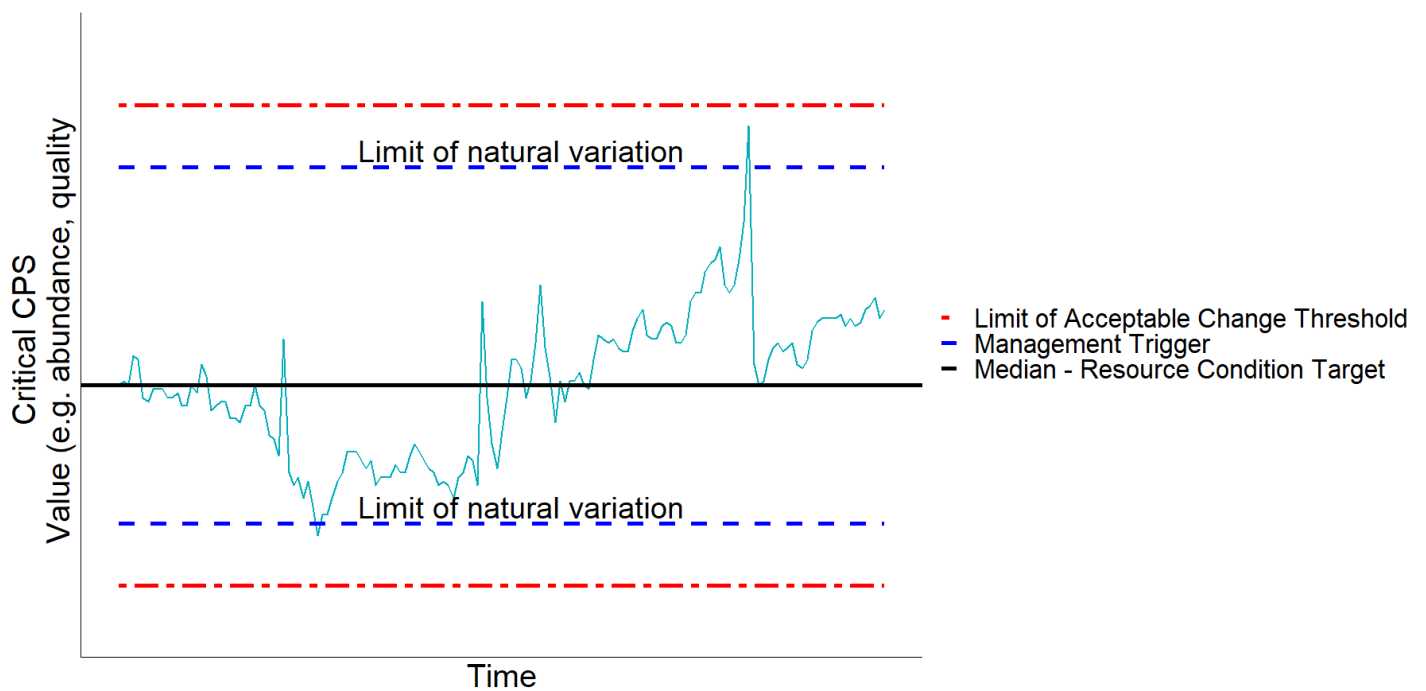


Figure 2.2. The relationship between Resource Condition Target, Management Triggers and Limits of Acceptable Change (LAC) thresholds for a given component, process or service (CPS).

3 Methodology

3.1 Databases

Resource Condition Targets, Management Triggers and LAC thresholds for each CPS subcomponent were set using data collected during annual waterbird censuses of the Lakes and Coorong led by the University of Adelaide (Associate Professor David Paton). Waterbird censuses in the Coorong commenced in 2000 and were expanded to include the Lakes in 2009. The data collected during censuses are made available in the Australian National Data repository, available at: <https://data.gov.au/data/dataset/coorong-and-lower-lakes-waterbird-census-data>. The methodology of the annual waterbird census of the Lakes and Coorong are detailed in Paton et al. (2017a) and summarised below.

Lakes census: The shoreline of Lake Alexandrina, Lake Albert and Goolwa Channel were divided into 1 km × 1 km cells. Within each 1 km² cell, waterbirds were counted by surveyors on foot or by boat. The Lakes census is conducted on an annual basis in late January and February.

Coorong census: The Coorong and the Murray estuary was divided into 1 km sections that run perpendicular to the wetland direction. Within each 1 km section, waterbirds are counted on the eastern and western shorelines, around islands and over open water in the centre of the wetland. Waterbird counts in each 1 km section are conducted by a minimum of two surveyors on foot or by boat. The Coorong census is conducted on an annual basis in January.

3.2 Baseline

The ECD uses baselines developed with data collected prior to and including 2015. As such, metrics for the Lakes and Coorong in this report use baseline years from 2009–15 and 2000–15, respectively. In the RMP data collected up to 2020 were used to evaluate the performance of metrics for each critical CPS subcomponent.

The hydrological and ecological conditions of the Lakes and Coorong were highly variable over the baseline years (2000–15), which greatly affected the waterbird community (Paton et al. 2018). The Millennium Drought prevailed in the Coorong and Lakes from 2001–10, and therefore, coincided with two of seven waterbird censuses in the Lakes and nine of the 16 baseline waterbird censuses in the Coorong. The extremely low water levels and greatly elevated salinities recorded during the Millennium Drought, especially from 2007 onwards, contributed to the following key changes to waterbird food resources and habitat in the Lakes and Coorong:

- Disconnection of the waterline from fringing vegetation in the Lakes (DEW 2020)
- Low species richness and biomass of benthic invertebrates in the Murray estuary and North Lagoon (Dittmann et al. 2017)
- Extirpation of key food resources from the South Lagoon, including *Ruppia tuberosa*, chironomid larvae (*Tanytarsus barbitarsus*) and Small-mouthed Hardyhead (Paton 2010)
- Extremely high abundance of brine shrimp (*Parartemia zietziana*) in the South Lagoon when salinities exceeded 150 ppt, despite not previously having been recorded in the Coorong (Paton 2010).

Waterbird numbers are greatest in the Lakes and Coorong during drought (Paton 2010; Paton et al. 2018; Porter et al. 2019), however, due to the severity of the Millennium Drought, abundances and distributions of numerous waterbird species were greatly affected, especially from 2007–10 (Paton 2010; Prowse 2020). One exception was the Banded Stilt, with over 200,000 individuals recorded in the Coorong during the 2009 census in response to significant increases in food availability (i.e. brine shrimp) (Paton 2010).

Extensive flooding over the Murray-Darling Basin ended the Millennium Drought and greatly improved flow to the Lakes and Coorong in 2010-11. The 2010-11 flow event restored water levels (>+0.4 m AHD) and reduced elevated salinities in Lake Alexandrina (Lake Albert salinities remained elevated until November 2017) and increased water levels and restored salinities to those more typical for the system in the Coorong (DEW 2020). Despite this, the abundance and diversity of waterbirds in the Lakes and Coorong were particularly low in 2011, likely due to a combination of national and local scale factors, including the exodus of waterbirds to re-filling inland waterbodies (Bino et al. 2020) and limited extent of accessible mudflat due to high water levels and a dampened tidal signal (Paton and Bailey 2012b). High flows continued in 2011-12 and 2012-13, and were succeeded by moderate flows in 2013-14, and further reductions in flow in 2014-15 (DEW 2020). These flows contributed to the following key changes to waterbird food resources and habitat:

- Re-connection of the waterline with fringing vegetation in the Lakes in 2010/11 (DEW 2020)
- Recovery of the distribution and abundance of chironomid larvae in the South Lagoon within half a year of flows in 2010-11 (Paton and Bailey 2012a)
- Recovery of the distribution and abundance of Small-mouthed Hardyhead in the South Lagoon following a one year lag of flows in 2010-11 (Ye et al. 2012)
- Brine shrimps remained abundant in 2011, however, were completely absent in 2012 (Paton and Bailey 2012b)
- Recovery of the extent of *R. tuberosa* to its 43 km historic distribution in 2013 (Paton and Bailey 2013a)
- Recovery of the distribution, diversity and biomass of the benthic macroinvertebrate community in the Murray estuary and North Lagoon in 2015 (Dittmann et al. 2019)
- A slow and limited recovery of *R. tuberosa* area of occupation and seed bank density by 2015 (Paton et al. 2019a).

Over this post drought period (up to 2015), the abundances and distributions of waterbirds in the Lakes improved and were considered to have recovered from the Millennium Drought (Paton et al. 2015). However, in the Coorong, while abundances of most species improved following the Millennium Drought, species such as Chestnut Teal, Common Greenshank, Fairy Tern and Pied Oystercatchers failed to recover or continued to decline (Paton and Bailey 2013b; Prowse 2020).

3.3 Guiding principles for setting metrics

The setting of Resource Condition Targets, Management Triggers and LAC thresholds for each critical waterbird CPS subcomponent were guided by the schematic diagram in Figure 2.2 that illustrates the relationship between each metric and a dataset with inherent variability. Resource Condition Targets, Management Triggers and LAC thresholds are set using statistical thresholds that inferred the probability of the metric succeeding (for Resource Condition Target evaluation) or being breached (Management Trigger and LAC threshold evaluation). The statistical thresholds for each metric were:

Resource Condition Target: Probability of target being met is 0.5 (positive outcome)

Management Trigger: Probability of trigger being breached is 0.1 (negative outcome)

LAC threshold: Probability of LAC being exceeded is 0.01 (negative outcome)

Resource Condition Targets were set at a conditional probability of 0.5, and therefore, were expected to represent “typical” conditions for the system in a contemporary (21st century) context. This metric was validated against the full dataset of waterbird censuses over the Lakes (2009–20) and Coorong (2000–20) (see section 6.1.1).

Management Triggers were set at a conditional probability of at 0.1, which was determined to be broadly reflective of the limits of variation for waterbird CPS subcomponents (i.e. abundance and diversity) under current (21st century) management when the metric was validated against the full dataset of waterbird censuses over the Lakes (2009–20) and Coorong (2000–20) (see section 6.1.2).

As the abundances of waterbirds in the Lakes and Coorong are likely affected by factors outside of the Ramsar site, including the extent and condition of wetland habitat over Australia (Porter et al. 2020) and internationally for migratory species (Clemens et al. 2016), Management Triggers could be breached irrespective of the condition and performance of the Lakes and Coorong as waterbird habitat. Therefore, once a Management Trigger is breached, a process will be conducted to determine whether factors internal or external to the system led to the Management Trigger breach. Lines of evidence to be considered during the investigation may include but are not limited to:

- Habitat suitability modelling for key waterbird species in the Coorong to be conducted under the *Healthy Coorong, Healthy Basin Program* (Prowse 2020). The habitat suitability model will capture how the distribution and abundance of key waterbird species change in response to location conditions within the Coorong and potentially external factors.
- Condition monitoring assessments of key waterbird food resources in the Murray estuary and Coorong, including *R. tuberosa* (e.g. Paton et al. 2020a), macroinvertebrates (e.g. Dittmann et al. 2020, Paton et al. 2020b) and fish, especially Small-mouthed Hardyhead (e.g. Ye et al. 2020, Paton et al. 2020b) to evaluate food resource availability for waterbirds.
- Wetland area index as calculated during the *Aerial Survey of Wetland Birds in Eastern Australia* (Porter et al. 2020) or the 'wet observations' derived from *Water Observations from Space* (Mueller et al. 2016) to evaluate wetland availability over Eastern Australia for nomadic waterbirds.
- Comparison in the rates of decline for migratory shorebirds populations in the Coorong with rates recorded at a national scale (see published values in Clemens et al. 2016 and Studds et al. 2018) to evaluate whether migratory shorebirds in the Coorong are declining at a disproportionately high rate.
- Studies regarding the movement of waterbird species, including those being conducted under the *Healthy Coorong, Healthy Basin Program* for key waterbirds species in the Coorong (Aldridge et al. 2020) and under the *Waterbird Project* as part of the *Murray-Darling Basin Environmental Water Knowledge and Research Project* (McGinness et al. 2019).

Management actions are to be initiated where factors internal to the Ramsar site contributed significantly to a Management Trigger breach.

LAC thresholds were used to identify negative outcomes with a probability of occurrence of 0.01. A negative outcome had to be recorded for at least two consecutive years in order to exceed the LAC threshold. Once a LAC threshold is exceeded an investigation will be initiated to determine the relative contribution of local, national and international (for migratory species) conditions to the event (following the process detailed above for the breach of a Management Trigger). The influence of external factors on the exceedance of a LAC threshold for waterbirds was identified by Hansen et al. (2021) as not being accounted for at other Ramsar sites in Australia and New Zealand, and therefore, the approach detailed in these guiding principles is considered to align with best practice.

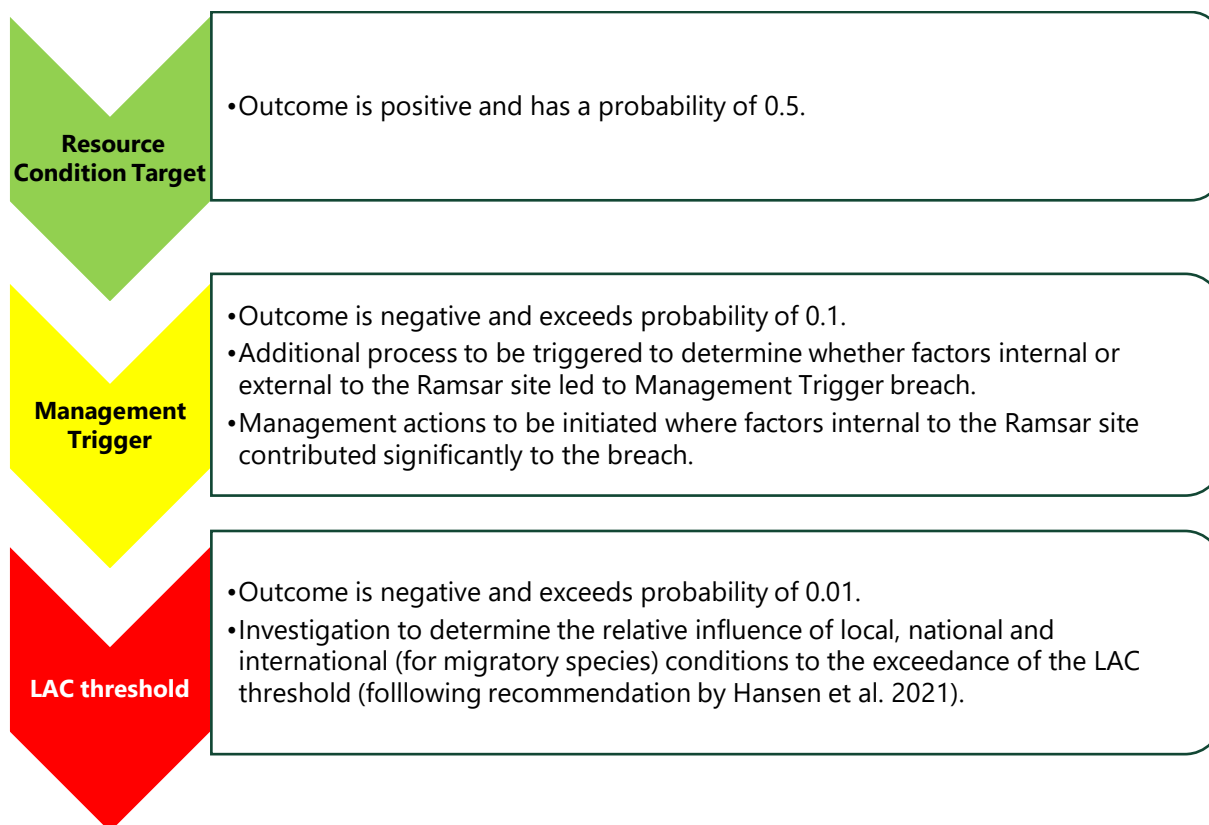


Figure 3.1. Schematic of the flow down process used to determine whether a waterbird CPS subcomponent has met its Resource Condition Target, breached its Management Trigger or exceeded its Limit of Acceptable Change (LAC) threshold.

3.4 Data manipulation

The Lakes and Coorong databases were subset to exclude data collected outside of the Ramsar site boundary, such as Morella Basin. Moreover, to ensure consistency in the spatial extent and temporal resolution of data collected, data with the location 'other' (indicative of fringing wetlands) in the Lakes dataset were removed as counts were not conducted on an annual basis. Counts from the creek at Salt Creek (cell: S36SC) were also removed from the Coorong dataset as its brackish waters provide habitat for species that are not characteristic of the Coorong lagoons, especially the South Lagoon.

The Lakes and Coorong databases included records of non-waterbird species (e.g. Little Grassbird, Swamp Harrier) as well as domesticated waterfowl, introduced species (e.g. Mallard) and hybrids (e.g. Mallard x Pacific Black Duck). Such records were excluded from analyses to ensure metrics were set based upon the abundance and presence of native waterbird species.

3.5 Metric calculation

The method used to calculate metrics was adapted and expanded from Robinson (2017).

3.5.1 Total waterbird abundance

The Lakes and Coorong databases were subset to data collected from 2009–15 and then aggregated to derive an annual measure of total waterbird abundance over the Lakes and Coorong. An assessment of waterbird

abundance included all native waterbird species that were not excluded during data manipulation (see section 3.4). The species list set in O'Connor (2015) was not followed as it was limited to Coorong species only.

Resource Condition Target: The Resource Condition Target for waterbird abundance over the Lakes and Coorong was set at the median abundance from 2009–15.

Management Trigger: The Management Trigger for waterbird abundance over the Lakes and Coorong was set at the 10th percentile measure for waterbird abundance from 2009–15.

LAC threshold: The LAC threshold was set to be exceeded if the Management Trigger was breached for two consecutive years. The probability of an event that exceeds the LAC threshold is $(0.1 \times 0.1 =) 0.01$.

3.5.2 Waterbird diversity

The Lakes and Coorong datasets were aggregated or segregated into the following spatial units as per Figure 1.1:

- Ramsar site (inclusive of the Lakes, Murray estuary and Coorong North and South Lagoons)
- Lakes (Lake Alexandrina, Lake Albert and Goolwa Channel)
- Murray estuary
- North Lagoon
- South Lagoon

The Murray estuary, North Lagoon and South Lagoon were spatially delineated based upon the location cell identifier, with the Murray estuary ranging between Goolwa Barrage and Pelican Point (cells N46 to N62), North Lagoon ranging between Pelican Point to near Parnka Point (cells N01 to N45) and South Lagoon ranging between near Parnka Point and 42 Mile Crossing (cells S01 to S54).

The selected species used for the waterbird diversity (except for the Ramsar site) were identified by O'Connor (2015) as having met a series of selection criteria. Although these selection criteria differed between spatial units assessed, in general they used presence/absence and count data to select species that either regularly occurred or that were regularly abundant in the first five years of data collection.

This technical report developed criteria to select species for analysis of the waterbird diversity – Ramsar site CPS subcomponent. The selection criteria were:

- Detection in the Ramsar site on five or more annual baseline censuses.
- At least five annual baseline counts of 30 or more individuals in the Ramsar site.
- Both the Lakes and Coorong held more than 50% of the total Ramsar site count in baseline years (2009–15) of census **or** more than 5,000 individuals were recorded on one or more census in the habitat (i.e. Lakes or Coorong) that supported fewer individuals.

The criteria used for the waterbird diversity – Ramsar site identified species that could have important habitat in the Lakes and Coorong depending on the prevailing water regime.

Resource Condition Target: Resource Condition Targets for each spatial unit were set at half of all selected species are at or above their median abundance. Median abundances were calculated using censuses from 2009–15 in the Ramsar site and Lakes and censuses from 2000–15 in the Murray estuary, North Lagoon and South Lagoon. The Resource Condition Target was set on the principle that only half (0.5) of the selected species would be expected to be at or above their median abundance in a given year.

Management Trigger: Management Triggers were set at the lower 80% confidence limit of compliant species (i.e. those with abundances at or above their 10th percentile), which has a probability of being breached of 0.1. Selected species that have a 10th percentile abundance of 0 were not included in this assessment as they are not

expected to be present on an annual basis. The lower 80% confidence limit was calculated using the following equation:

Confidence Limit: $CL = \mu - (z \times \sigma)$

Where μ = the mean number of annual species (i.e. species with 10th percentiles ≥ 1) above their 10th percentile abundance in any given year

z = standard score (1.282) for the 80% confidence limit

σ = standard deviation

The mean (μ) was calculated using the following equation:

Mean: $\mu = n \times 0.90$

Where n = the number of annual species (with 10th percentile abundances ≥ 1)

0.90 = the proportion of annual species that are expected to be at or above their 10th percentile abundance in a given year.

The standard deviation (σ) was calculated using the following equation:

Standard deviation: $\sigma = \sqrt{npq}$

Where n = number of annual species

p = probability of success (event occurring, i.e. 9/10)

q = probability of failure (event not occurring, i.e. 1/10)

The probability of success (p) represents the probability that a selected annual species has an annual count greater than its 10th percentile abundance, while the probability of failure (q) represents the probability that a selected annual species has an annual count below its 10th percentile abundance.

A worked example of the Management Trigger calculation for waterbird diversity is provided in Appendix A.

LAC threshold: LAC thresholds were set to be exceeded if the Management Trigger was breached for two consecutive years. The probability of an event that exceeds the LAC threshold is $(0.1 \times 0.1 =) 0.01$.

3.5.3 Priority species

Seven commonly encountered migratory shorebird species were identified by O'Connor (2015) as priority species. Species were identified as priority species by O'Connor (2015) if they were present in numbers > 100 individuals in at least four of the first five years (1981, 1982, 1987, 1993 and 2000) of available waterbird data in the Coorong.

The priority species identified were:

- Black-tailed Godwit
- Common Greenshank
- Curlew Sandpiper
- Pacific Golden Plover
- Red-necked Stint
- Sanderling
- Sharp-tailed Sandpiper

Sanderling was listed as a priority species in this report; however, the Murray estuary and Coorong lagoons are not considered to be important habitat for the species, which forages on the beaches of the Youngusband Peninsula and only at times uses the Murray estuary and Coorong to shelter and roost (D Paton 2021, pers. comm., 24 March).

The Ramsar site is considered to be an important area for migratory shorebirds in Australia (Dutson et al. 2009), and as each of the priority species were recorded in abundances greater than 100 individuals in four of the first five years of available data (1981, 1982, 1987, 1993 and 2000) in the Coorong (O'Connor 2015), the system provides important habitat for each priority species. Therefore, species are assessed on an individual basis rather than as a community to ensure that management actions are initiated when any priority species experiences a negative outcome with a probability of <0.1. This approach ensures that no priority species that perform poorly are overlooked.

Only the Coorong dataset was used to set Resource Condition Targets, Management Triggers and LAC thresholds for each priority species as comparatively few shorebirds use the Lakes. Moreover, the sole use of the Coorong dataset enabled a greater range of baseline data (i.e. 2000–15) to be used to set each metric, as aggregating the Coorong and Lakes datasets would have limited the baseline data range (i.e. 2009–15) if the spatial area of census were to be consistent between years.

Resource Condition Target: Resource Condition Targets were set for each priority species at their median abundance from 2000–15.

Management Trigger: Management Triggers were set for each priority species at their 10th percentile abundance from 2000–15. However, if a priority species had a 10th percentile abundance of 0, then the Management Trigger was set based upon the number of consecutive annual censuses in the Coorong that the species was not detected. As Management Triggers are set at a probability of 0.1, the number of consecutive years of failed detection equal to a probability of 0.1 were calculated using the following equation for conditional probability of an event series:

$$y^x = z$$

Where x = number of consecutive years of failed detection

y = probability of failed detection in a given year

z = probability of event series occurring (i.e. 0.1 for trigger)

Logarithms were used to solve the exponential (x, i.e. number of consecutive years of failed detection) using the following equations:

$$y^x = z$$

$$x \cdot \ln(y) = \ln(z)$$

$$x = \frac{\ln(z)}{\ln(y)}$$

A worked example of the Management Trigger calculation for certain priority and threatened species is provided in Appendix C.

Limit threshold: LAC thresholds were set for each priority species and followed the processes outlined for Management Trigger calculations, and as such, were set in one of two ways dependent upon whether the species had a 10th percentile abundance of 0 or ≥1.

Species with a 10th percentile abundance of ≥1 had their LAC thresholds set at two consecutive years of abundances less than their 10th percentile abundance, i.e. the LAC thresholds was set to be exceeded if the Management Trigger was breached for two consecutive years.

Species that had a 10th percentile abundance of 0 used the equation for conditional probability of an event series to set their LAC threshold, with (z) the probability of the event series occurrence set at 0.01 (rather than 0.1 for a Management Trigger).

3.5.4 East Asian Australasian flyway species

East Asian Australasian (EAA) flyway species (referred to herein as flyway species) were identified by O'Connor (2015) as migratory shorebird species with counts in the Ramsar site that regularly exceeded 1% of their total EAA flyway population. Flyway species identified were:

- Curlew Sandpiper
- Red-necked Stint
- Sharp-tailed Sandpiper

As counts of Curlew Sandpiper, Red-necked Stint and Sharp-tailed Sandpiper in the Ramsar site regularly exceed 1% of their total EAA flyway population, the site is considered to be of international importance (Commonwealth of Australia 2015). Each flyway species is assessed on an individual basis rather than as a community to ensure that management actions are initiated when any flyway species experiences a negative outcome with a probability of <0.1. This approach ensures that no flyway species that perform poorly are overlooked.

Only data from the Coorong was used to set Resource Condition Targets, Management Triggers and LAC thresholds for reasons detailed in section 3.5.3.

Resource Condition Target: Resource Condition Targets for each species were set at their median abundance in the Coorong from 2000–15.

Management Trigger: Management Triggers for each species were set at their 10th percentile abundance in the Coorong from 2000–15.

LAC threshold: LAC thresholds for each species were set to be exceeded if the Management Trigger was breached for two consecutive years. The probability of an event that exceeds the LAC threshold is $(0.1 \times 0.1 =) 0.01$.

3.5.5 Non-migratory species where the site regularly supports 1% or more of the Australian population

Non-migratory flyway species were identified by O'Connor (2015) as species with counts in the Ramsar site that regularly exceeded 1% of their Australian population estimate. Non-migratory species identified were:

- Australian pied oystercatcher
- Chestnut teal
- Fairy tern
- Red-capped plover

Populations of other non-migratory flyway species such as banded stilts and red-necked avocets that fluctuate greatly in response to off-site conditions have not been included.

Each species is assessed on an individual basis rather than as a community to ensure that management actions are initiated when any species experiences a negative outcome with a probability of <0.1. This approach ensures that no non-migratory flyway species that perform poorly are overlooked.

Only data from the Coorong was used to set Resource Condition Targets, Management Triggers and LAC thresholds as comparatively few individuals of each of the non-migratory flyway species use the Lakes. Resource

Condition Targets, Management Triggers and LAC thresholds were set using the same methodology as for EAA flyway species (see section 3.5.5).

3.5.6 Threatened species

This technical report developed criteria to select species for analysis of the threatened species CPS subcomponents. The selection criteria were:

- Must be listed as nationally threatened under the *Environment Protection Biodiversity Conservation (EPBC) Act 1999* (available at: [EPBC Act list of threatened fauna](#)) as of 12 February 2021.
- Must be easily detectable if present during waterbird censuses over the Lakes and Coorong, and therefore, cannot be a cryptic species (e.g. Australasian Bittern)
- Must not have important habitat that is not surveyed during the waterbird censuses over the Lakes and Coorong (e.g. Hooded Plover that uses the beaches of Youngusband Peninsula).
- Must have been recorded on a minimum of 25% of waterbird censuses in the Lakes and/or Coorong.

Resource Condition Targets, Management Triggers and LAC thresholds were set using the same methodology as for priority species (see 3.5.3).

3.6 Software

R studio (version 3.5.0, R Core Team 2018) was used calculate median and 10th percentile abundances with the dplyr package (Wickham et al. 2019) and summarise function. Results were graphed with the ggplot2 package (Wickham 2016). Microsoft Excel 2016 was used to calculate the lower 80% CL for the waterbird diversity subcomponent (see section 5.2) and integral values for the priority and threatened species subcomponent (see section 5.4 and 5.6).

4 Assumptions and Limitations

The following assumptions and limitations were considered when developing metrics for waterbird CPS subcomponents.

Assumptions:

- Statistical thresholds were used to set Management Triggers and LAC thresholds in the absence of known thresholds or tipping points for an abrupt and/or sustained change in waterbird diversity and species abundances.
- Abundances of individual species were assumed to be independent when setting metrics for waterbird diversity, however, it is recognised that there would be some correlation in abundances between species, especially those with similar life histories.
- Metrics are set based on the assumption that they can be evaluated with of the continuation of annual waterbird censuses of the Lakes and Coorong led by the University of Adelaide (Associate Professor David Paton).

Limitations:

- Baseline years (2000–15) for the Coorong had significant overlap with the Millennium Drought, which persisted over the region from 2001–10, and therefore, “typical conditions” used to set Resource Condition Targets were likely reflective of the Coorong in drought.
- Annual censuses of waterbirds in the Coorong in January and the Lakes in late January/early February has largely been sufficient to represent change of the waterbird community from 2000–20. However, as these wetland systems are important habitat for waterbirds over autumn, spring and summer (Paton 2010), the absence of both autumn and spring data with which to set Resource Condition Targets, Management Triggers and LAC thresholds is considered a weakness.

5 Results

5.1 Total waterbird abundance

5.1.1 Ramsar site

The median and 10th percentile total abundance of waterbirds recorded over the Ramsar site (Lakes and Coorong) from 2009–15 are shown in Table 5.1. The median abundance of waterbirds recorded over the Ramsar site from 2009–15 was 282 212 individuals, and therefore, the Resource Condition Target was set at 282 212 or more waterbirds are counted over the Ramsar site in the annual census (Table 5.2). The 10th percentile abundance of waterbirds recorded over the Ramsar site was 190 122 individuals from 2009–15, and therefore, the Management Trigger was set at fewer than 190 122 waterbirds counted over the Ramsar site in the annual census (Table 5.2). If this event were to occur for two consecutive years then the LAC threshold would be exceeded (Table 5.2).

Table 5.1. Median and 10th percentile total annual abundance of waterbirds over the Ramsar site (Coorong and Lakes) from 2009–15. Data source: University of Adelaide (Associate Professor David Paton).

10 th percentile (2009–15)	Median abundance (2009–15)
190 122	282 212

Table 5.2. The Resource Condition Target, Management Trigger and Limit of Acceptable Change (LAC) threshold for waterbird abundance in the Ramsar site.

Metric	Measure
Resource Condition Target	282 212 or more waterbirds are counted over the Ramsar site in the annual census.
Management Trigger	Fewer than 190 122 waterbirds counted over the Ramsar site in the annual census.
LAC threshold	Fewer than 190 122 waterbirds counted over the Ramsar site in the annual census over two consecutive years.

Compliance

The total abundance of waterbirds over the Ramsar site met the Resource Condition Target in four of 12 (33%) and breached the Management Trigger in two of 12 (17%) annual censuses from 2009–20 (Table 5.3; Figure 5.1). The LAC threshold was not exceeded at any time from 2009–20 as the Management Trigger was not breached in two consecutive years.

Table 5.3. Compliance success of the Resource Condition Target (Target) and Management Trigger (Trigger) for waterbird abundance in the Ramsar site.

Year	Target	Trigger
2009	Yes	Yes
2010	Yes	Yes
2011	No	No
2012	No	Yes
2013	Yes	Yes
2014	Yes	Yes
2015	No	Yes
2016	No	Yes
2017	No	No
2018	No	Yes
2019	No	Yes
2020	No	Yes

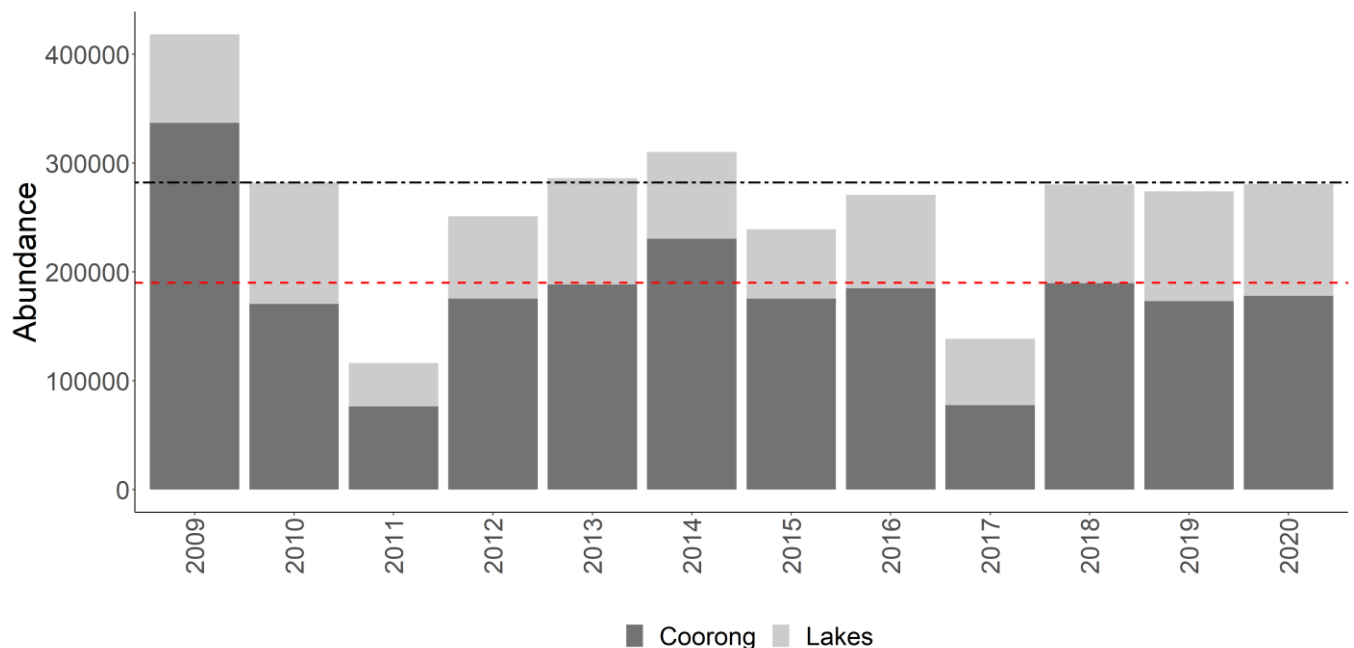


Figure 5.1. Aggregated total number of waterbirds in the Ramsar site during annual summer waterbird censuses conducted from 2009–20. Management Triggers (red dashed line) are set at the 10th percentile abundance and Resource Condition Targets (black dashed line) are set at the median abundance of waterbirds from 2000–15. Data source: University of Adelaide (Associate Professor David Paton).

5.2 Waterbird diversity

5.2.1 Ramsar site

The medians and 10th percentile abundances of selected waterbird species during annual censuses over the Ramsar site from 2009–15 are shown in Table 5.4. As half (n=10) of the 20 selected species are expected to be at or above their median abundance in a given year, the Resource Condition Target was set to be '*at least 10 selected waterbird species have counts at or above their median abundance during the annual census*' (Table 5.5).

Table 5.4. The 10th percentiles and median abundances of selected waterbird species counted over the Ramsar site (Lakes and Coorong) from 2009–15 during annual summer waterbird censuses. Data source: University of Adelaide (Associate Professor David Paton).

#	Common name	10 th percentile (2009–15)	Median (2009–15)
1	Australian Pelican	6523	8904
2	Australian Shelduck	25 175	31 805
3	Australian White Ibis	522	1188
4	Black-winged Stilt	241	473
5	Black Swan	2363	4372
6	Caspian Tern	512	1263
7	Curlew Sandpiper	150	938
8	Eurasian Coot	167	3643
9	Great Cormorant	5052	15 336
10	Great Egret	92	117
11	Grey Teal	12 184	22 765
12	Little Black Cormorant	1500	3458
13	Little Pied Cormorant	94	237
14	Masked Lapwing	774	1106
15	Red-capped Plover	828	1474
16	Red-necked Stint	15 494	41 964
17	Sharp-tailed Sandpiper	3493	14 285
18	Straw-necked Ibis	359	833
19	Whiskered Tern	5536	11 711
20	White-faced Heron	227	306

All of the selected waterbird species for the Ramsar site had a 10th percentile abundance greater than 0 and therefore all 20 selected species were used to calculate the lower 80% confidence limit for the number of compliant species in a given year equal to a probability of 0.1 (*see calculation below*). The lower 80% confidence limit of the expected number of selected species to be above their 10th percentile abundance in a given census was 16.28. Therefore, the Management Trigger was set at '*Less than 17 selected waterbird species have counts above their 10th percentile abundance during the annual census*' (Table 5.5). If this event were to occur for two consecutive years then the LAC threshold would be exceeded.

Calculation of 80% confidence limit:

$$\begin{aligned} \text{Mean: } \mu &= 20 \times 0.90 \\ &= 18.00 \end{aligned}$$

$$\begin{aligned} \text{Standard deviation: } \sigma &= \sqrt{20 \times 0.1 \times 0.9} \\ &= 1.34 \end{aligned}$$

$$\begin{aligned} \text{Lower 80\% CL} &= 18.00 - (1.282 \times 1.34) \\ &= 16.28 \end{aligned}$$

Table 5.5. The Resource Condition Target, Management Trigger and Limit of Acceptable Change (LAC) threshold for waterbird diversity in the Ramsar site.

Metric	Measure
Resource Condition Target	At least 10 selected waterbird species have counts above their median abundance during the annual census.
Management Trigger	Less than 17 selected waterbird species have counts above their 10 th percentile abundance during the annual census.
LAC threshold	Less than 17 selected waterbird species have counts above their 10 th percentile abundance for two consecutive annual censuses.

Compliance

The Ramsar site waterbird community met the Resource Condition Target in nine of 12 (75%) and breached the Management Trigger in three of 12 (25%) annual censuses from 2009–20 (Table 5.6; Figure 5.2). The LAC threshold was not exceeded at any time from 2009–20 as the Management Trigger was not breached in two consecutive years.

The abundances of selected species during annual censuses from 2009–20 with respect to their 10th percentile and median abundances are shown in Figure 5.3.

Table 5.6. Compliance success of the Resource Condition Target (Target) and Management Trigger (Trigger) for waterbird diversity in the Ramsar site.

Year	Target	Trigger
2009	Yes	No
2010	No	Yes
2011	No	No
2012	Yes	Yes
2013	Yes	Yes
2014	Yes	Yes
2015	Yes	Yes
2016	Yes	Yes
2017	No	No
2018	Yes	Yes
2019	Yes	Yes
2020	Yes	Yes

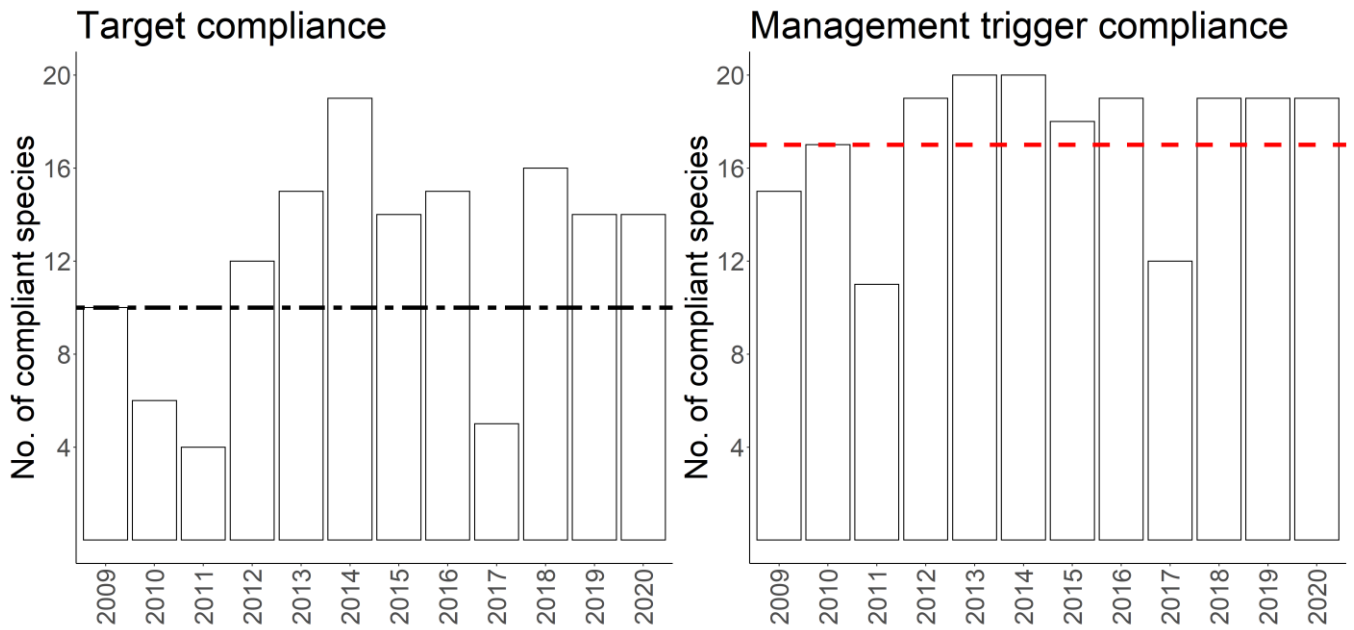


Figure 5.2. The number of selected species in the Ramsar site that met their Resource Condition Target (Target) (max 20) and Management Trigger (max 20) (based upon baselines from 2009–2015) on an annual basis from 2009–20. Data source: University of Adelaide (Associate Professor David Paton).

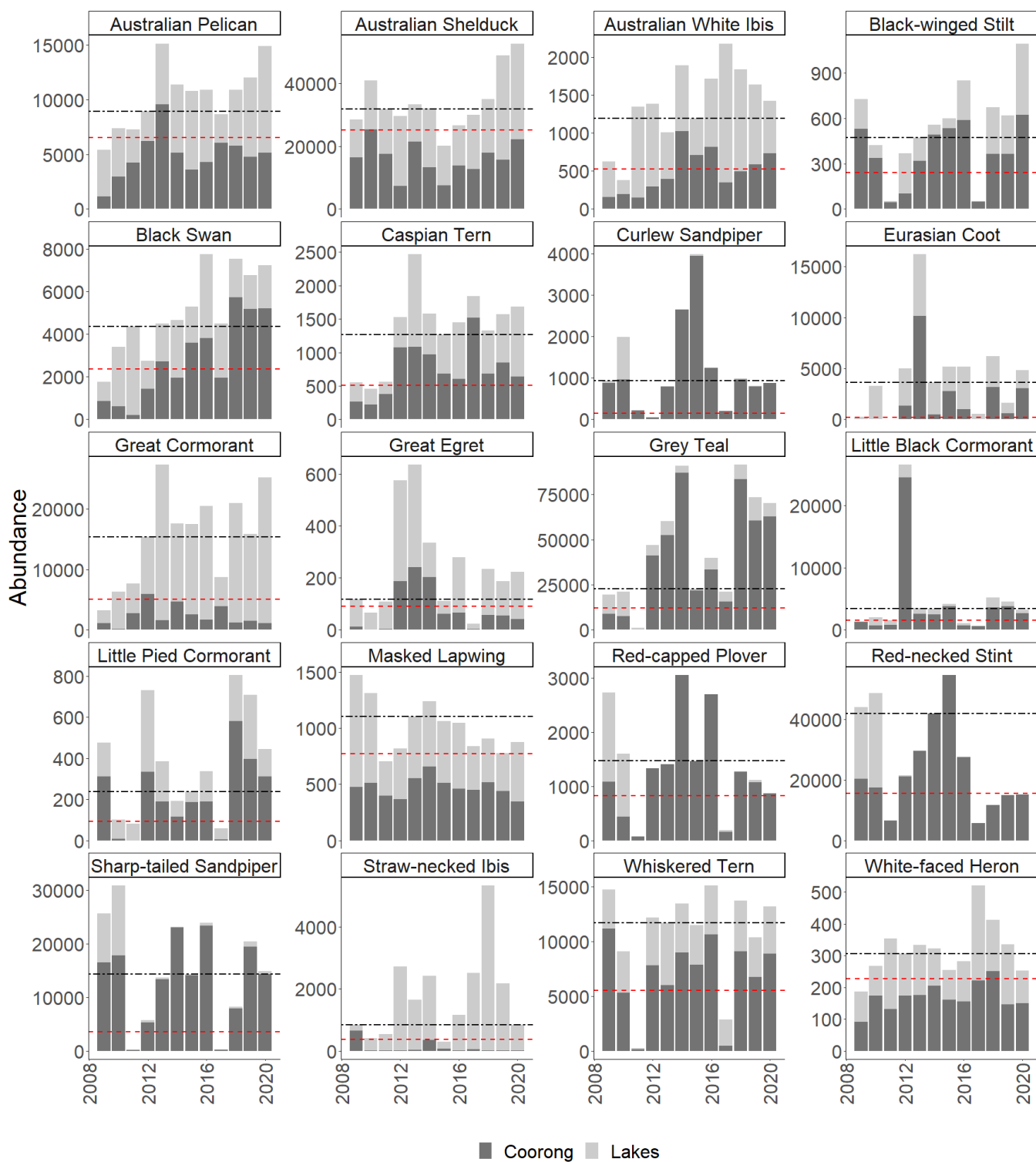


Figure 5.3. Annual abundances of selected species in the Ramsar site during annual summer waterbird censuses from 2009–20 with respect to their baseline (2009–15) median abundance (black dashed line) and 10th percentile abundance (red dashed line). Data source: University of Adelaide (Associate Professor David Paton).

5.2.2 Lakes

The medians and 10th percentiles for the abundance of selected waterbird species during annual censuses over the Lakes from 2009–15 are shown in Table 5.7. As half (n=10) of the 20 selected species are expected to be at or above their median abundance in a given year, the Resource Condition Target was set to be '*at least 10 selected waterbird species have counts at or above their median abundance during the annual census*' (Table 5.8).

Table 5.7. The 10th percentiles and median abundances of selected waterbird species counted over the Lakes from 2009–15 during annual summer waterbird censuses. Data source: University of Adelaide (Associate Professor David Paton).

#	Common name	10 th percentile (2009–15)	Median (2009–15)
1	Australasian Shoveler	7	17
2	Australian Pelican	2877	4460
3	Australian Shelduck	11 952	14 296
4	Australian White Ibis	349	611
5	Black Swan	1159	1799
6	Cape Barren Goose	939	1303
7	Eurasian Coot	167	3165
8	Great Cormorant	3831	9375
9	Great Crested Grebe	19	108
10	Greater Crested Tern	311	335
11	Grey Teal	932	5780
12	Hardhead	2	44
13	Little Black Cormorant	290	907
14	Little Pied Cormorant	67	96
15	Masked Lapwing	394	553
16	Pacific Black Duck	1485	4408
17	Pied Cormorant	1198	3955
18	Silver Gull	1558	2819
19	Straw-necked Ibis	206	532
20	Whiskered Tern	2154	3744

All of the selected waterbird species over the Lakes had a 10th percentile abundance greater than 0 and therefore all 20 selected species were used to calculate the lower 80% confidence limit for the number of compliant species in a given year equal to a probability of 0.1 (*see calculation below*). The lower 80% confidence limit of the expected number of selected species to be above their 10th percentile abundance in a given census was 16.28. Therefore, the Management Trigger was set at '*less than 17 selected waterbird species have counts above their 10th percentile abundance during the annual census*' (Table 5.8). If this event were to occur for two consecutive years then the LAC threshold would be exceeded.

Calculation of 80% confidence limit:

$$\text{Mean: } \mu = 20 \times 0.90$$

$$= 18.00$$

$$\text{Standard deviation: } \sigma = \sqrt{20 \times 0.1 \times 0.9}$$

$$= 1.34$$

$$\text{Lower 80\% CL} = 18.00 - (1.282 \times 1.34)$$

$$= 16.28$$

Table 5.8. The Resource Condition Target, Management Trigger and Limit of Acceptable Change (LAC) threshold for waterbird diversity in the Lakes.

Metric	Measure
Resource Condition Target	At least 10 selected waterbird species have counts above their median abundance during the annual census.
Management Trigger	Less than 17 selected waterbird species have counts above their 10 th percentile abundance during the annual census.
LAC threshold	Less than 17 selected waterbird species have counts above their 10 th percentile abundance for two consecutive annual censuses.

Compliance performance

The Lakes waterbird community met their Resource Condition Target in eight of 12 (67%) and breached their Management Trigger in three of 12 (25%) annual censuses from 2009–20 (Table 5.9; Figure 5.4). The LAC threshold was not exceeded at any time from 2009–20 as the Management Trigger was not breached in two consecutive years.

The abundances of selected species during annual censuses from 2009–20 with respect to their 10th percentile and median abundances are shown in Figure 5.5.

Table 5.9. Compliance success of the Resource Condition Target (Target) and Management Trigger (Trigger) for waterbird diversity in the Lakes.

Year	Target	Trigger
2009	No	No
2010	Yes	Yes
2011	No	No
2012	Yes	Yes
2013	Yes	Yes
2014	Yes	Yes
2015	No	Yes
2016	Yes	Yes
2017	No	No
2018	Yes	Yes
2019	Yes	Yes
2020	Yes	Yes

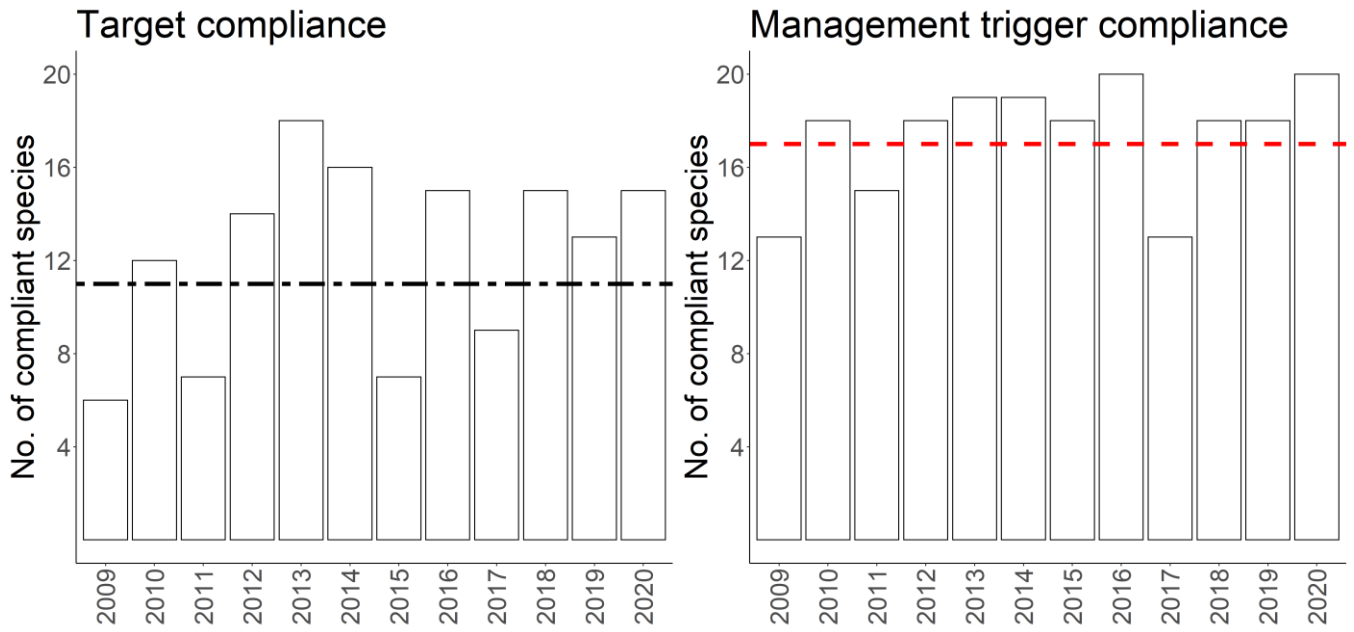


Figure 5.4. The number of selected species in the Lakes that met their Resource Condition Target (Target) (max 20) and Management Trigger (max 20) (based upon baselines from 2009–15) on an annual basis from 2009–20. Data source: University of Adelaide (Associate Professor David Paton).

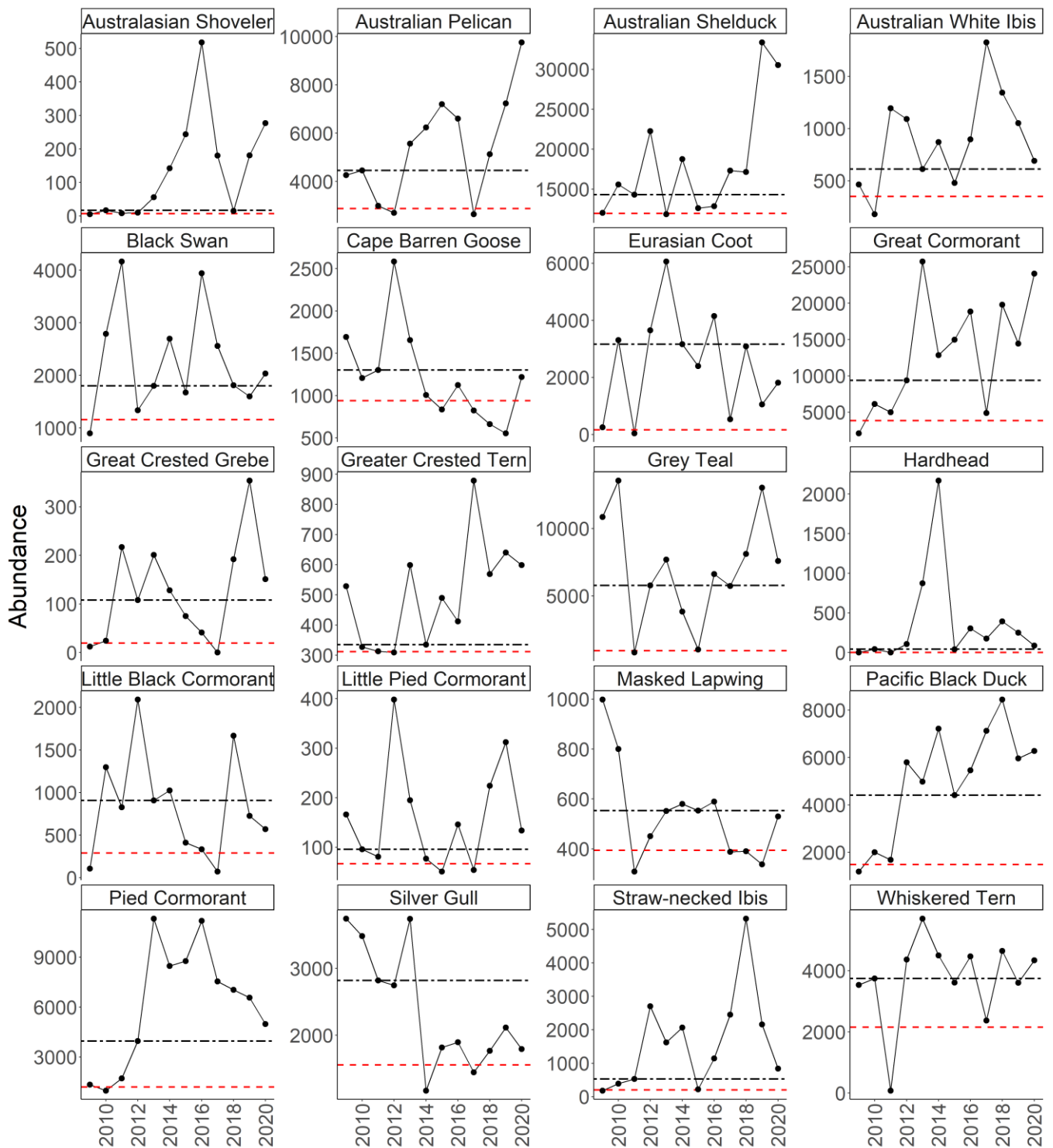


Figure 5.5. Annual abundances of selected species in the Lakes during annual summer waterbird censuses from 2009–20 with respect to their baseline (2009–15) median abundance (black dashed line) and 10th percentile abundance (red dashed line). Data source: University of Adelaide (Associate Professor David Paton).

5.2.3 Murray estuary

The medians and 10th percentiles for the abundance of selected waterbird species during annual censuses over the Murray estuary from 2000–15 are shown in Table 5.10. As half (n=12) of the 24 selected species are expected to be at or above their median abundance in a given year, the Resource Condition Target was set to be '*at least 12 selected waterbird species have counts at or above their median abundance during the annual census*' (Table 5.11).

Table 5.10. The 10th percentile and median abundance of selected waterbird species counted over the Murray estuary from 2000–2015 during annual summer waterbird censuses. Data source: University of Adelaide (Associate Professor David Paton). *Species with 10th percentiles of 0 were omitted from compliance calculations to set a Management Trigger.

#	Common name	10 th percentile (2000–15)	Median abundance (2000–15)
1	Australian Pelican	236	577
2	Black-tailed Godwit*	0	21
3	Black-winged Stilt	52	157
4	Black Swan	215	820
5	Caspian Tern	48	209
6	Common Greenshank	113	194
7	Curlew Sandpiper	24	877
8	Eastern Curlew	2	12
9	Greater Crested Tern	183	330
10	Grey Teal	528	1682
11	Hoary-headed Grebe	1	30
12	Little Black Cormorant	19	116
13	Little Pied Cormorant	19	138
14	Masked Lapwing	53	97
15	Pacific Black Duck	34	173
16	Pacific Golden Plover	3	18
17	Pied Oystercatcher	34	52
18	Red-capped Plover	12	94
19	Red-necked Avocet*	0	206
20	Red-necked Stint	719	4234
21	Sanderling*	0	1
22	Sharp-tailed Sandpiper	740	4289
23	Silver Gull	985	1612
24	Whiskered Tern	338	865

Black-tailed Godwit, Red-necked Avocet and Sanderling had 10th percentile abundances of 0 in the Murray estuary. As three of the 24 selected waterbird species for the Murray estuary had a 10th percentile abundance of 0, 21 selected species were used to calculate the lower 80% confidence limit for the number of compliant species in a given year equal to a probability of 0.1 (*see calculation below*). The lower 80% confidence limit of the expected number of selected species to be above their 10th percentile abundance in a given census was 17.14. Therefore, the Management Trigger was set at '*less than 18 selected waterbird species have counts above their 10th percentile abundance during the annual census*' (Table 5.11). If this event were to occur for two consecutive years then the LAC threshold would be exceeded.

Calculation of 80% confidence limit:

Mean: $\mu = 21 \times 0.90$

$= 18.9$

Standard deviation: $\sigma = \sqrt{21 \times 0.1 \times 0.9}$

$= 1.37$

Lower 80% CL = $18.90 - (1.282 \times 1.37)$

$= 17.14$

Table 5.11. The Resource Condition Target, Management Trigger and Limit of Acceptable Change (LAC) threshold for waterbird diversity in the Murray estuary.

Metric	Measure
Resource Condition Target	At least 12 selected waterbird species have counts above their median abundance during the annual census.
Management trigger	Less than 18 selected waterbird species have counts above their 10 th percentile abundance during the annual census.
LAC threshold	Less than 18 selected waterbird species have counts above their 10 th percentile abundance for two consecutive annual censuses.

Compliance

The Murray estuary waterbird community met the Resource Condition Target in 13 of 21 (62%) and breached the Management Trigger in four of 21 (19%) annual censuses from 2000–20 (Table 5.12; Figure 5.6). The Management Trigger was breached for three consecutive years from 2010–12, and therefore, the LAC threshold was exceeded.

The abundances of selected species during annual censuses from 2000–20 with respect to their 10th percentile and median abundances are shown in Figure 5.7.

Table 5.12. Compliance success of the Resource Condition Target (Target) and Management Trigger (Trigger) for waterbird diversity in the Murray estuary.

Year	Target	Trigger
2000	Yes	Yes
2001	No	Yes
2002	Yes	Yes
2003	Yes	Yes
2004	Yes	Yes
2005	No	Yes
2006	Yes	Yes
2007	Yes	Yes
2008	No	Yes
2009	No	Yes
2010	No	No
2011	No	No
2012	No	No

Year	Target	Trigger
2013	Yes	Yes
2014	Yes	Yes
2015	Yes	Yes
2016	Yes	Yes
2017	No	No
2018	Yes	Yes
2019	Yes	Yes
2020	Yes	Yes

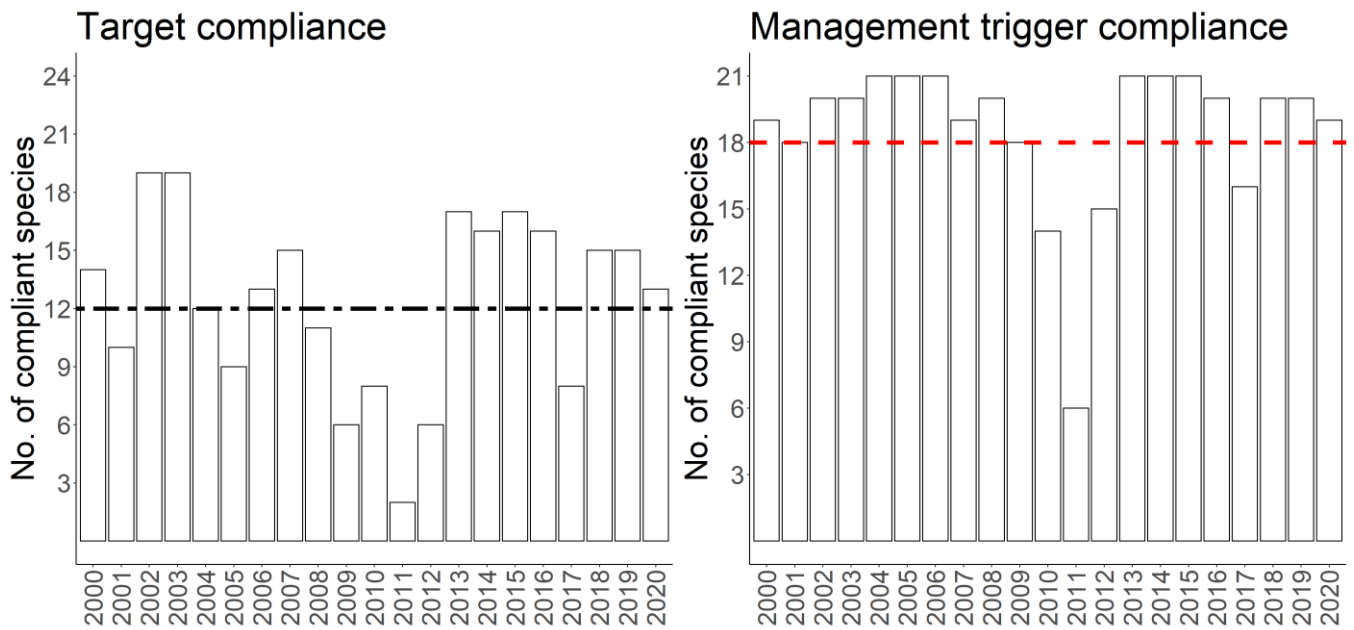


Figure 5.6. The number of selected species in the Murray estuary that met their Resource Condition Target (Target) (max 24) and Management Trigger (max 21) (based upon baselines from 2000–15) on an annual basis from 2000–20. Data source: University of Adelaide (Associate Professor David Paton).

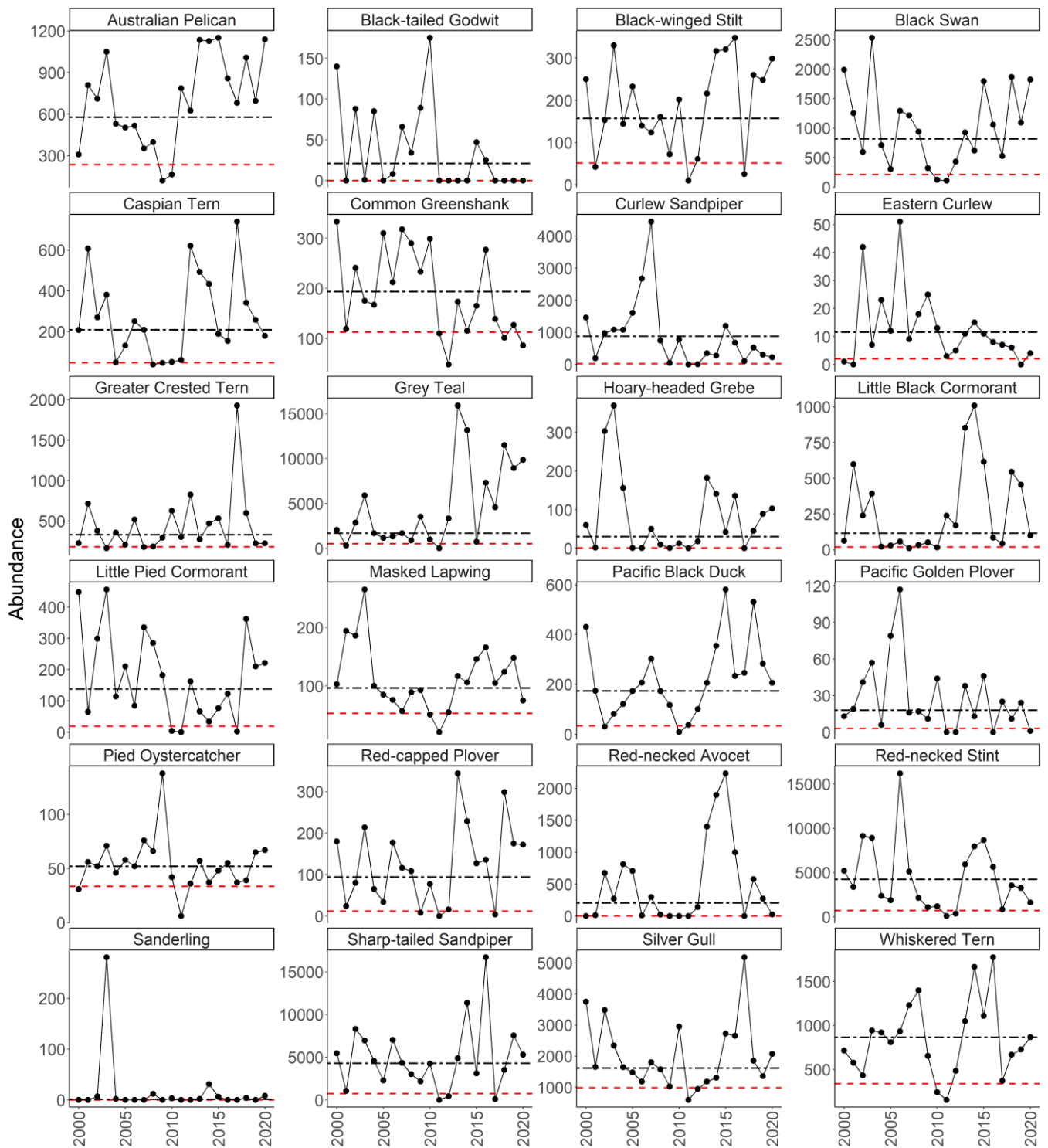


Figure 5.7. Annual abundances of selected species in the Murray estuary during annual summer waterbird censuses from 2000–20 with respect to their baseline (2000–15) median abundance (black dashed line) and 10th percentile abundance (red dashed line). Data source: University of Adelaide (Associate Professor David Paton).

5.2.4 North Lagoon

The medians and 10th percentiles for the abundance of selected waterbird species during annual censuses over the Coorong North Lagoon from 2000–15 are shown in Table 5.13. As half (n=12) of the 24 selected species are expected to be at or above their median abundance in a given year, the Resource Condition Target was set to be *'at least 12 selected waterbird species have counts at or above their median abundance during the annual census'* (Table 5.14).

Table 5.13. The median and 10th percentile abundance of selected waterbird species in the Coorong North Lagoon.
Data source: University of Adelaide (Associate Professor David Paton). *Species with 10th percentiles of 0 that therefore were omitted from compliance calculations to set a Management Trigger.

#	Common name	10 th percentile (2000–15)	Median abundance (2000–15)
1	Australian Pelican	916	1413
2	Australian Shelduck	905	4342
3	Black Swan	171	483
4	Black-winged Stilt	37	122
5	Cape Barren Goose	3	26
6	Caspian Tern	109	295
7	Common Greenshank	83	186
8	Curlew Sandpiper	178	752
9	Great Cormorant	92	544
10	Greater Crested Tern	139	303
11	Grey Teal	1448	6499
12	Hoary-headed Grebe	266	1410
13	Little Black Cormorant	169	861
14	Little Pied Cormorant	21	116
15	Masked Lapwing	141	213
16	Pacific Golden Plover*	0	7
17	Pied Cormorant	84	211
18	Pied Oystercatcher	23	53
19	Red-capped Plover	185	458
20	Red-necked Avocet	77	646
21	Red-necked Stint	7009	12 448
22	Sharp-tailed Sandpiper	2806	5622
23	Silver Gull	2204	3179
24	Whiskered Tern	1236	3439

Pacific Golden Plover was the only selected species in the North Lagoon to have a 10th percentile abundance of 0. As one of the 24 selected waterbird species for the North Lagoon had a 10th percentile abundance of 0, the remaining 23 selected species were used to calculate the lower 80% confidence limit for the number of compliant species in a given year equal to a probability of 0.1 (*see calculation below*). The lower 80% confidence limit of the expected number of selected species to be above their 10th percentile abundance in a given census was 18.85. Therefore, the Management Trigger was set at *'less than 19 selected waterbird species have counts above their 10th percentile abundance during the annual census'* (Table 5.14). If this event were to occur for two consecutive years then the LAC threshold would be exceeded.

Calculation of 80% confidence limit:

$$\begin{aligned}\text{Mean: } \mu &= 23 \times 0.90 \\ &= 20.7\end{aligned}$$

$$\begin{aligned}\text{Standard deviation: } \sigma &= \sqrt{23 \times 0.1 \times 0.9} \\ &= 1.44\end{aligned}$$

$$\begin{aligned}\text{Lower 80\% CL} &= 20.70 - (1.282 \times 1.44) \\ &= 18.85\end{aligned}$$

Table 5.14. The Resource Condition Target, Management Trigger and Limit of Acceptable Change (LAC) threshold for waterbird diversity in the Coorong North Lagoon.

Metric	Measure
Resource Condition Target	At least 12 selected waterbird species have counts above their median abundance during the annual census.
Management Trigger	Less than 19 selected waterbird species have counts below their 10 th percentile abundance during the annual census.
LAC threshold	Less than 19 selected waterbird species have counts below their 10 th percentile abundance for two consecutive annual censuses.

Compliance

The North Lagoon waterbird community met the Resource Condition Target in nine of 21 (43%) and breached the Management Trigger in four of 21 (19%) annual censuses from 2000–20 (Table 5.15; Figure 5.9). The Management Trigger was breached for two consecutive years (2010–11) and therefore, the LAC threshold was exceeded.

The abundances of selected species during annual censuses from 2000–20 with respect to their 10th percentile and median abundances are shown in Figure 5.9.

Table 5.15. Compliance success of the Resource Condition Target (Target) and Management Trigger (Trigger) for waterbird diversity in the Coorong North Lagoon.

Year	Target	Trigger
2000	No	Yes
2001	Yes	Yes
2002	No	Yes
2003	Yes	Yes
2004	No	Yes
2005	No	Yes
2006	Yes	Yes
2007	No	Yes
2008	No	No
2009	Yes	Yes
2010	No	No
2011	No	No
2012	Yes	Yes

Year	Target	Trigger
2013	No	Yes
2014	No	Yes
2015	Yes	Yes
2016	No	Yes
2017	No	No
2018	Yes	Yes
2019	Yes	Yes
2020	Yes	Yes

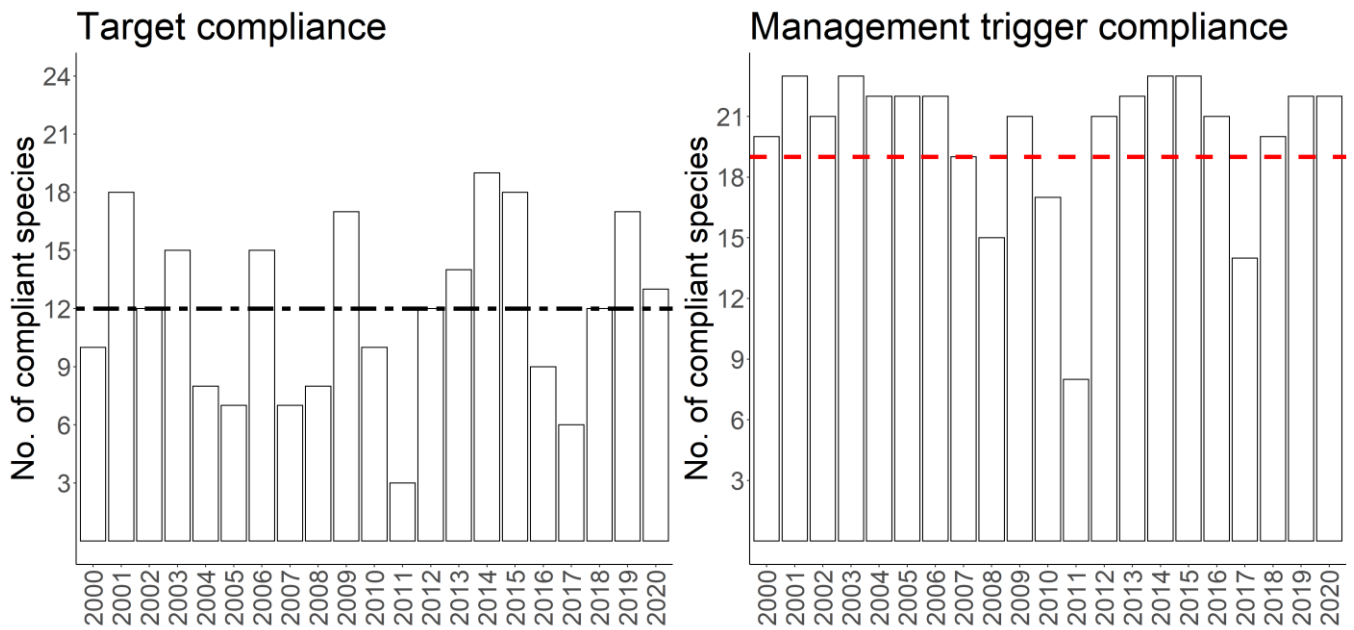


Figure 5.8. The number of selected species in the North Lagoon that met their Resource Condition Target (Target) (max 24) and Management Trigger (max 23) (based upon baselines from 2000–15) on an annual basis from 2000–20. Data source: University of Adelaide (Associate Professor David Paton).

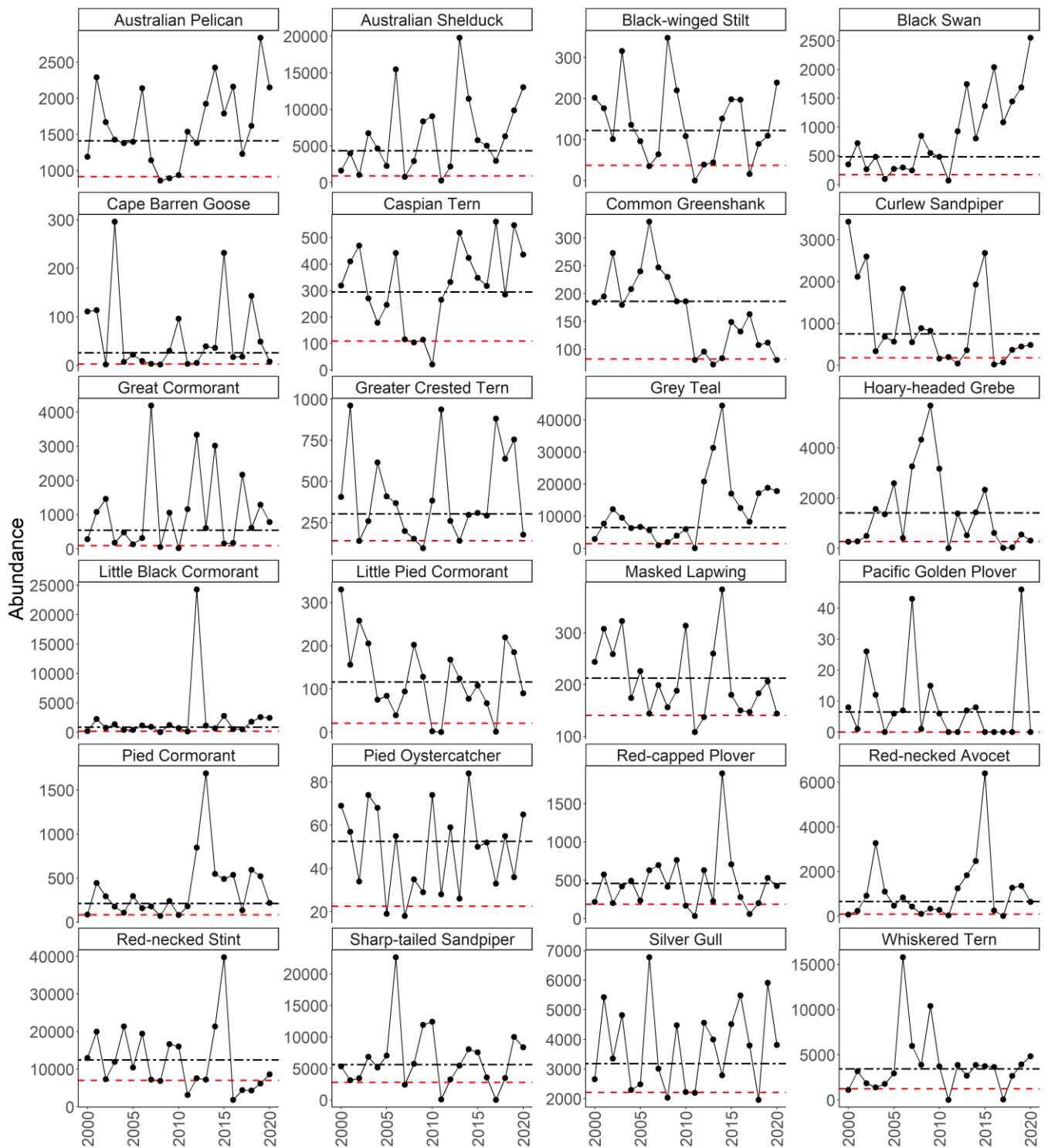


Figure 5.9. Annual abundances of selected species in the Coorong North Lagoon during annual summer waterbird censuses from 2000–20 with respect to their baseline (2000–15) median abundance (black dashed line) and 10th percentile abundance (red dashed line). Data source: University of Adelaide (Associate Professor David Paton).

5.2.5 South Lagoon

The medians and 10th percentiles for the abundance of selected waterbird species during annual censuses over the Coorong South Lagoon from 2000–15 are shown in Table 5.16. As half (n=12) of the 23 selected species are expected to be at or above their median abundance in a given years, the Resource Condition Target was set to be *'at least 12 selected waterbird species have counts at or above their median abundance during the annual census'* (Table 5.17).

Table 5.16. The median and 10th percentile abundance of selected waterbird species in the Coorong South Lagoon.
Data source: University of Adelaide (Associate Professor David Paton). *Species with 10th percentiles of 0 were omitted from compliance calculations to set a Management Trigger.

#	Common name	10 th percentile (2000–15)	Median abundance (2000–15)
1	Australian Pelican	354	1600
2	Australian Shelduck	1473	3205
3	Banded Stilt	848	8179
4	Black Swan	7	148
5	Caspian Tern	7	62
6	Chestnut Teal	334	2757
7	Common Greenshank	13	39
8	Curlew Sandpiper	7	44
9	Fairy Tern	6	128
10	Great Crested Grebe*	0	13
11	Greater Crested Tern	1409	2989
12	Grey Teal	941	4267
13	Hoary-headed Grebe	63	2263
14	Little Black Cormorant*	0	26
15	Masked Lapwing	115	177
16	Pied Oystercatcher	17	48
17	Red-capped Plover	198	529
18	Red-necked Avocet	69	945
19	Red-necked Stint	2089	6781
20	Sharp-tailed Sandpiper	301	2304
21	Silver Gull	1193	1960
22	Whiskered Tern	118	1058
23	White-faced Heron	10	23

Great Crested Grebe and Little Black Cormorant were the only selected species in the South Lagoon to have a 10th percentile abundance of 0. As two of the 23 selected waterbird species for the South Lagoon had a 10th percentile abundance of 0, the remaining 21 selected species were used to calculate the lower 80% confidence limit for the number of compliant species in a given year equal to a probability of 0.1 (*see calculation below*). The lower 80% confidence limit of the expected number of selected species to be above their 10th percentile abundance for a given census was 17.14. Therefore, the Management Trigger was set at *'Less than 18 selected waterbird species have counts above their 10th percentile abundance during the annual census'* (Table 5.17). If this event were to occur for two consecutive years then the LAC threshold would be exceeded.

Calculation of 80% confidence limit:

Mean: $\mu = 21 \times 0.90$

= 18.9

Standard deviation: $\sigma = \sqrt{21 \times 0.1 \times 0.9}$

= 1.37

Lower 80% CL = $18.90 - (1.282 \times 1.37)$

= 17.14

Table 5.17. The Resource Condition Target, Management Trigger and Limit of Acceptable Change (LAC) threshold for waterbird diversity in the Coorong South Lagoon.

Metric	Measure
Resource Condition Target	At least 12 selected waterbird species have counts above their median abundance during the annual census.
Management Trigger	Less than 18 selected waterbird species have counts below their 10 th percentile abundance during the annual census.
LAC threshold	Less than 18 selected waterbird species have counts below their 10 th percentile abundance for two consecutive annual censuses.

Compliance

The South Lagoon waterbird community met their Resource Condition Target in 12 of 21 (57%) and breached the Management Trigger in five of 21 (24%) annual censuses from 2000–20 (Table 5.15; Figure 5.10). The Management Trigger was breached for four consecutive years from 2008–11, and therefore the LAC threshold was exceeded.

The abundances of selected species during annual censuses from 2000–20 with respect to their 10th percentile and baseline abundances are shown in Figure 5.11.

Table 5.18. Compliance success of the Resource Condition Target (Target) and Management Trigger (Trigger) for waterbird diversity in the Coorong South Lagoon.

Year	Target	Trigger
2000	Yes	Yes
2001	Yes	Yes
2002	Yes	Yes
2003	Yes	Yes
2004	No	Yes
2005	No	Yes
2006	Yes	Yes
2007	No	Yes
2008	No	No
2009	No	No
2010	No	No
2011	No	No

Year	Target	Trigger
2012	Yes	Yes
2013	Yes	Yes
2014	Yes	Yes
2015	Yes	Yes
2016	Yes	Yes
2017	No	No
2018	Yes	Yes
2019	No	Yes
2020	Yes	Yes

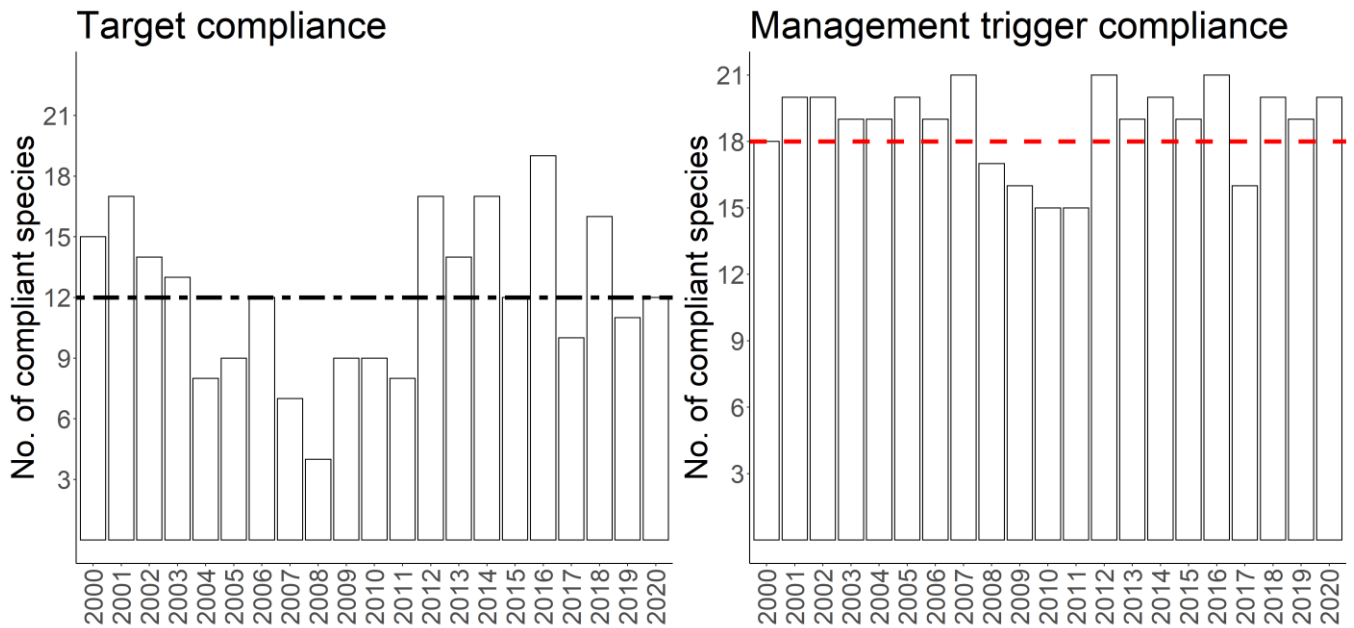


Figure 5.10. The number of selected species in the Coorong South Lagoon that met their Resource Condition Target (Target) (max 23) and Management Trigger threshold (max 21) (based upon baselines from 2000–15) on an annual basis from 2000–20. Data source: University of Adelaide (Associate Professor David Paton).

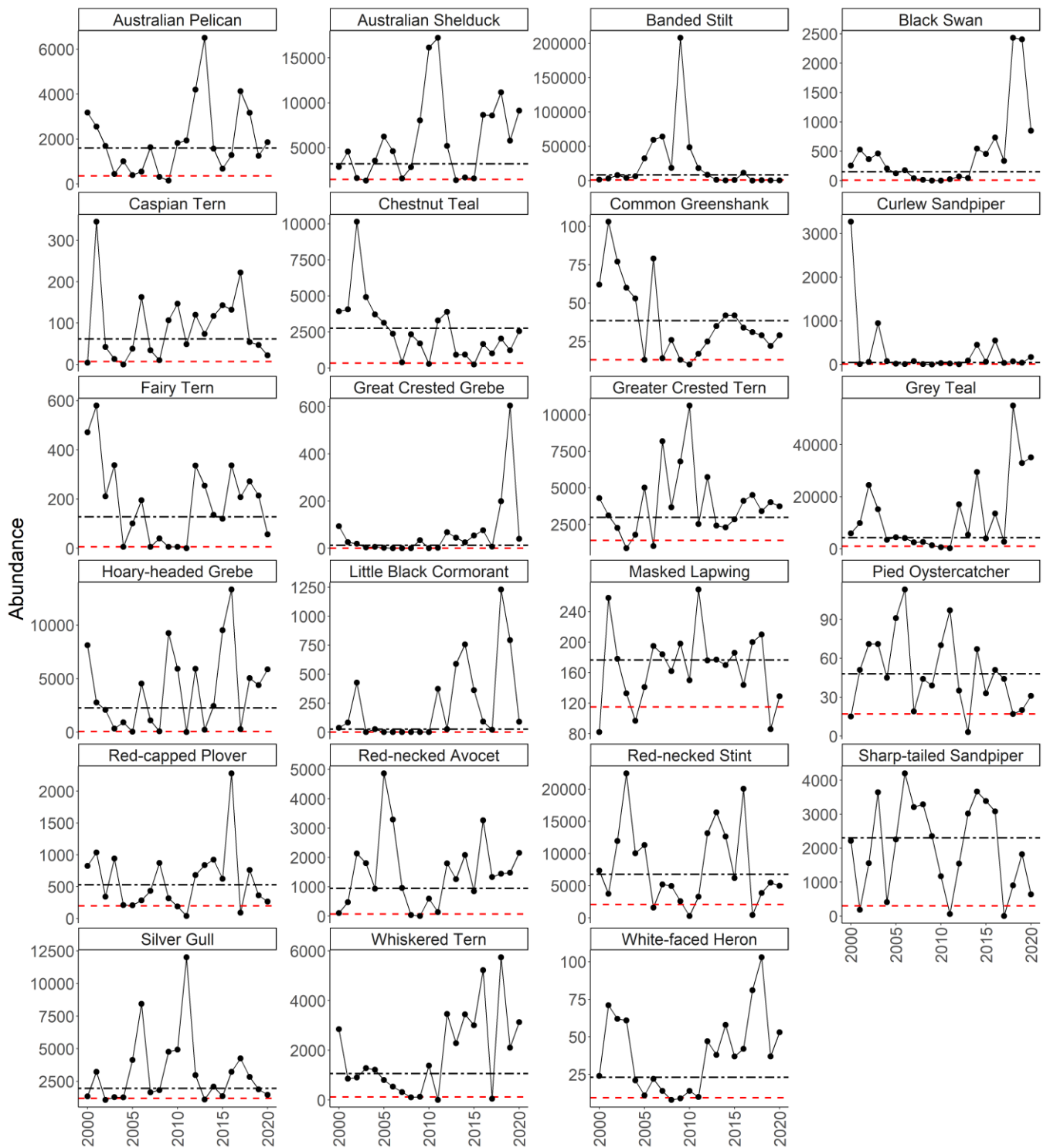


Figure 5.11. Annual abundances of selected species in the Coorong South Lagoon during annual summer waterbird censuses from 2000–20 with respect to their baseline (2000–15) median abundance (black dashed line) and 10th percentile abundance (red dashed line). Data source: University of Adelaide (Associate Professor David Paton).

5.3 1% East Asian Australasian flyway abundance

Flyway species are assessed against management metrics on a species-by-species basis rather than across all flyway species.

The median abundance of Curlew Sandpipers, Red-necked Stints and Sharp-tailed Sandpipers present in the Coorong during annual censuses from 2000–15 was 2252, 26 286 and 13 179, respectively (Table 5.19). Median values for each flyway species have a probability of 0.5 of being exceeded on an annual basis, and therefore, the Resource Condition Target was set to be '*Counts of each flyway species in the Coorong during an annual census are at or above their median abundance (2000–15)*' (Table 5.20).

The 10th percentile abundance of Curlew Sandpipers, Red-necked Stints and Sharp-tailed Sandpipers present in the Coorong during annual censuses from 2000–15 were 508, 15 703 and 4823, respectively (Table 5.19). Tenth percentile values for each flyway species have a probability of 0.1 of not being met on an annual basis, and therefore, the Management Trigger was set at '*Counts of each flyway species in the Coorong during an annual census are below their 10th percentile abundance (2000–15)*' (Table 5.20). If Curlew Sandpipers, Red-necked Stints and Sharp-tailed Sandpipers were to occur below their 10th percentile abundance in the Coorong for two consecutive years then the LAC threshold would be exceeded (Table 5.20).

Table 5.19. Median and 10th percentile abundances of each flyway species present in the Coorong during annual censuses from 2000–15. Data source: University of Adelaide (Associate Professor David Paton).

Common name	10 th percentile (2000–15)	Median (2000–15)
Curlew Sandpiper	508	2252
Red-necked Stint	15 703	26 286
Sharp-tailed Sandpiper	4823	13 179

Table 5.20. The Resource Condition Target, Management Trigger and Limit of Acceptable Change (LAC) threshold for flyway species in the Coorong. The evaluation of each metric is based on a species-by-species basis rather than across all flyway species.

Metric	Measure
Resource Condition Target	Counts of each flyway species in the Coorong during an annual census are at or above their median abundance (2000–15).
Management Trigger	Counts of each flyway species in the Coorong during an annual census are at or above their 10 th percentile abundance (2000–15).
LAC threshold	Counts of each flyway species in the Coorong during an annual census are below their 10 th percentile abundance (2000–15) for two consecutive years.

Compliance

The Resource Condition Target was met for Curlew Sandpiper, Red-necked Stint and Sharp-tailed Sandpiper in eight (38%), nine (43%) and 11 (52%) of 21 annual censuses from 2000–20 (Table 5.14; Figure 5.12). The Management Trigger was breached for Curlew Sandpiper, Red-necked Stint and Sharp-tailed Sandpiper in three (14%), six (29%) and three (14%) of annual censuses from 2000–20. The Management Trigger was breached for two or more consecutive years for Curlew Sandpiper (2011–12) and Red-necked Stint (2017–20), and therefore, the LAC thresholds for these species were exceeded.

Table 5.21. Compliance success of the Resource Condition Target (RCT) and Management Trigger (MT) for flyway species in the Coorong.

Year	Curlew Sandpiper		Red-necked Stint		Sharp-tailed Sandpiper	
	RCT	MT	RCT	MT	RCT	MT
2000	Yes	Yes	No	Yes	No	Yes
2001	Yes	Yes	Yes	Yes	No	No
2002	Yes	Yes	Yes	Yes	Yes	Yes
2003	Yes	Yes	Yes	Yes	Yes	Yes
2004	No	Yes	Yes	Yes	No	Yes
2005	No	Yes	No	Yes	No	Yes
2006	Yes	Yes	Yes	Yes	Yes	Yes
2007	Yes	Yes	No	Yes	No	Yes
2008	No	Yes	No	No	No	Yes
2009	No	Yes	No	Yes	Yes	Yes
2010	No	Yes	No	Yes	Yes	Yes
2011	No	No	No	No	No	No
2012	No	No	No	Yes	No	Yes
2013	No	Yes	Yes	Yes	Yes	Yes
2014	Yes	Yes	Yes	Yes	Yes	Yes
2015	Yes	Yes	Yes	Yes	Yes	Yes
2016	No	Yes	Yes	Yes	Yes	Yes
2017	No	No	No	No	No	No
2018	No	Yes	No	No	No	Yes
2019	No	Yes	No	No	Yes	Yes
2020	No	Yes	No	No	Yes	Yes

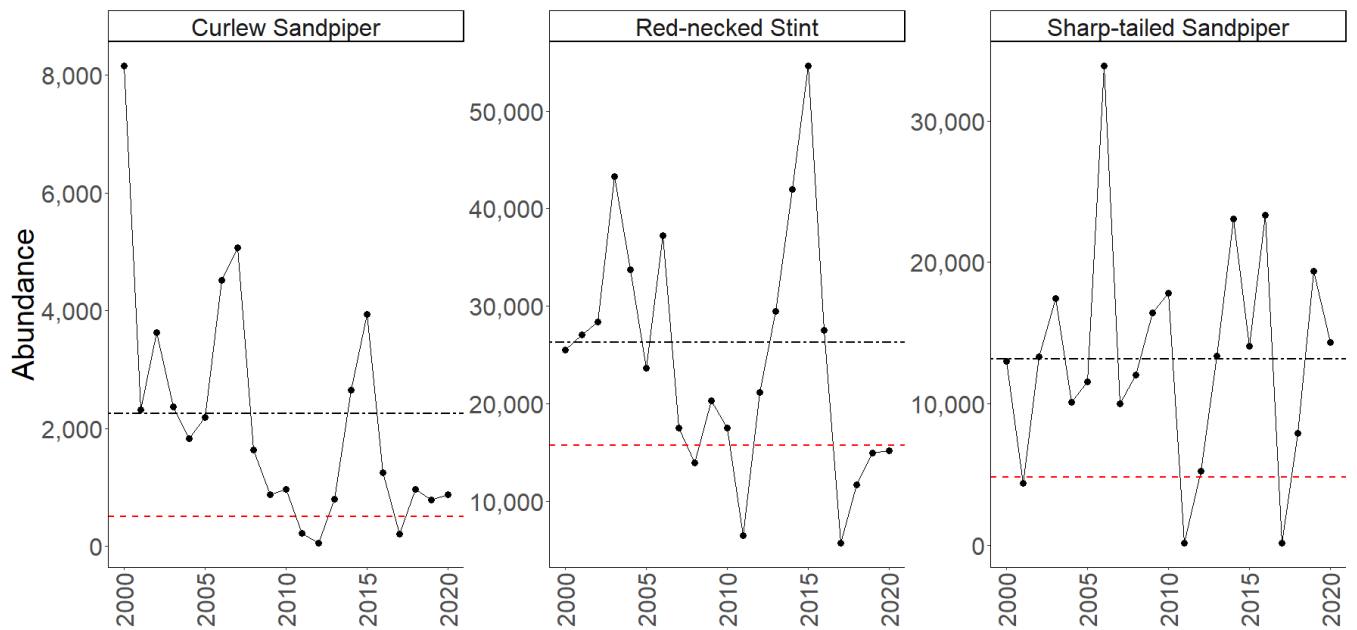


Figure 5.12. Abundance of Curlew Sandpipers, Red-necked Stints and Sharp-tailed Sandpipers present in the Coorong during annual censuses from 2000–20 with respect their Resource Condition Target (black dashed line) and Management Trigger (red dashed line). Resource Condition Targets for each species are set at their median abundance in the Coorong from 2000–15. Management Triggers for each species are set at their 10th percentile abundance in the Coorong from 2000–15. Data source: University of Adelaide (Associate Professor David Paton).

5.4 Non-migratory species where the site regularly supports 1% or more of the Australian population

Non-migratory (1% Australian population) species are assessed against management metrics on a species-by-species basis rather than across all non-migratory (1% Australian population) species.

The median abundance of Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plover present in the Coorong during annual censuses from 2000–15 were 158, 7216, 336 and 1234, respectively (Table 5.22). Median values for each species have a probability of 0.5 of being exceeded on an annual basis, and therefore, the Resource Condition Target was set to be '*Counts of Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plovers in the Coorong during an annual census are at or above their median abundance (2000–15)*' (Table 5.23).

The 10th percentile abundance of *Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plovers* present in the Coorong during annual censuses from 2000–15 were 114, 4332, 226 and 456, respectively (Table 5.22). Tenth percentile values for each species have a probability of 0.1 of not being met on an annual basis, and therefore, the Management Trigger was set at '*Counts of Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plovers in the Coorong during an annual census are below their 10th percentile abundance (2000–15)*' (Table 5.23). If *Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plovers* were to occur below their 10th percentile abundance in the Coorong for two consecutive years then the LAC threshold would be exceeded (Table 5.23).

Table 5.22. The median and 10th percentile abundances of important non-migratory species (1% Australian population species) in the Coorong for each species during annual censuses from 2000–15. Data source: University of Adelaide (Associate Professor David Paton).

Common name	10 th percentile (2000–15)	Median (2000–15)
Australian Pied Oystercatcher	114	158
Chestnut Teal	4332	7216
Australian Fairy Tern	226	336
Red-capped Plover	456	1234

Table 5.23. The Resource Condition Target, Management Trigger and Limit of Acceptable Change (LAC) threshold for important non-migratory (1% Australian population) species in the Coorong. The evaluation of each metric is based on a species-by-species basis rather than across all non-migratory (1% Australian population) species.

Metric	Measure
Resource Condition Target	Counts of Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plovers in the Coorong during an annual census are at or above their median abundance (2000–15).
Management Trigger	Counts of Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plovers in the Coorong during an annual census are below their 10 th percentile abundance (2000–15).
LAC threshold	Counts of Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plovers in the Coorong during an annual census are below their 10 th percentile abundance (2000–15) for two consecutive years.

Compliance

The Resource Condition Target was met for Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plover in ten (48%), nine (43%), 12 (57%) and ten (48%) of 21 annual censuses from 2000–20 (Table 5.24, Figure 5.13). The Management Trigger was breached for Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plover in three (14%), three (14%), two (10%) and three (14%) of annual censuses from 2000–20. The Management Trigger was breached for two consecutive years for Red-capped Plover in 2010–11, and therefore, the LAC threshold for this species was exceeded.

Table 5.24. Compliance success of the Resource Condition Target (RCT) and Management Trigger (MT) for non-migratory species (1% Australian population species) in the Coorong.

Year	Australian Pied Oystercatcher		Chestnut Teal		Australian Fairy Tern		Red-capped Plover	
	RCT	MT	RCT	MT	RCT	MT	RCT	MT
2000	No	Yes	Yes	Yes	Yes	Yes	No	Yes
2001	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2002	No	Yes	Yes	Yes	Yes	Yes	No	Yes
2003	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2004	Yes	Yes	Yes	Yes	No	No	No	Yes
2005	Yes	Yes	No	Yes	No	Yes	No	Yes
2006	Yes	Yes	Yes	Yes	No	Yes	No	Yes
2007	No	No	No	No	No	Yes	Yes	Yes
2008	No	Yes	No	Yes	Yes	Yes	Yes	Yes
2009	Yes	Yes	No	Yes	No	Yes	No	Yes
2010	Yes	Yes	No	Yes	No	Yes	No	No
2011	No	Yes	No	Yes	No	No	No	No
2012	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2013	No	No	Yes	Yes	No	Yes	Yes	Yes
2014	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
2015	No	Yes	No	No	Yes	Yes	Yes	Yes
2016	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
2017	No	Yes	No	No	Yes	Yes	No	No
2018	No	No	Yes	Yes	Yes	Yes	Yes	Yes
2019	No	Yes	No	Yes	No	Yes	No	Yes
2020	Yes	Yes	No	Yes	Yes	Yes	No	Yes

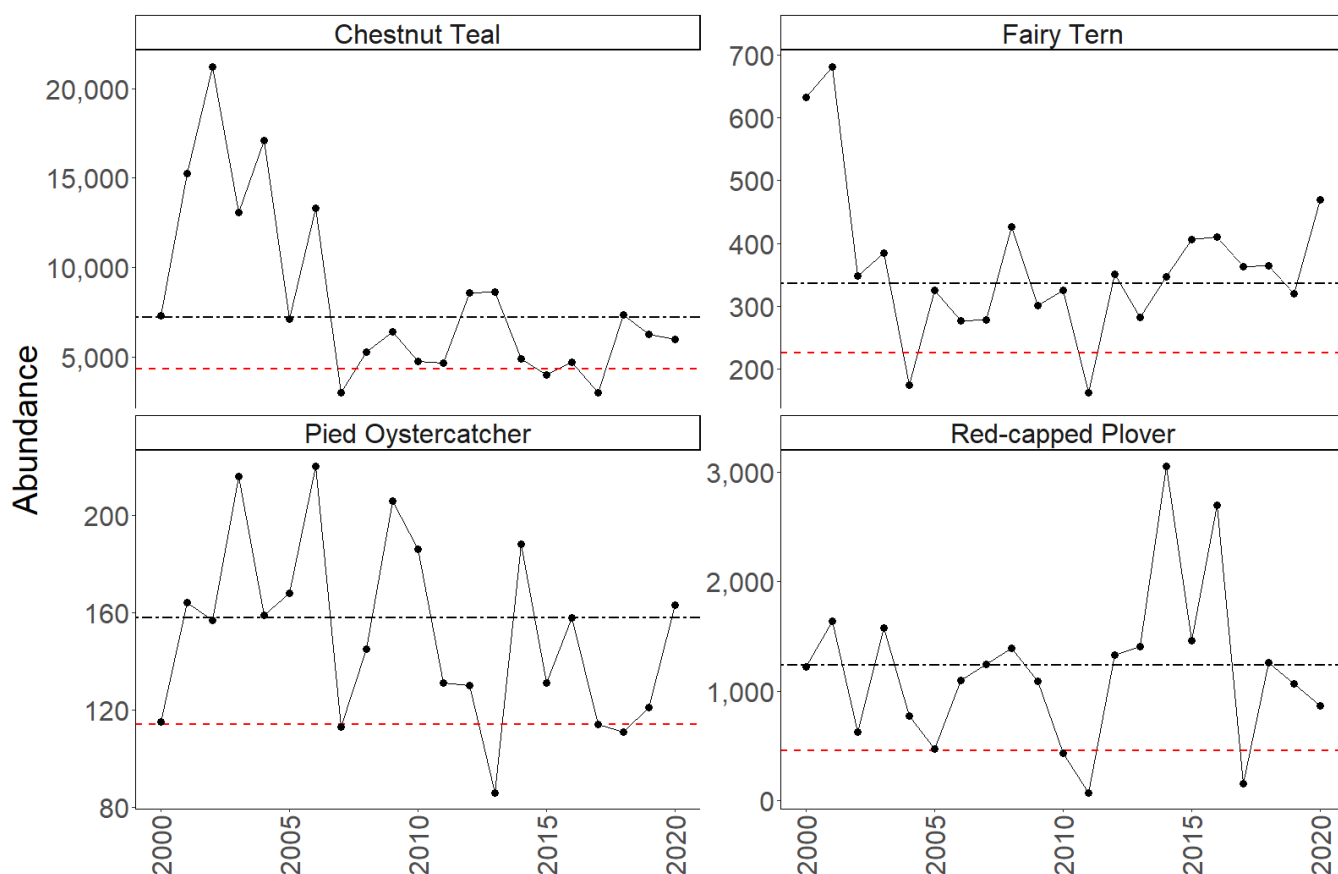


Figure 5.13 Abundance of Australian Pied Oystercatcher, Australian Fairy Tern, Chestnut Teal and Red-capped Plover present in the Coorong during annual censuses from 2000-20 with respect their Resource Condition Target (black dashed line) and Management Trigger (red dashed line). Resource Condition Targets for each species are set at their median abundance in the Coorong from 2000-15. Management Triggers for each species are set at their 10th percentile abundance in the Coorong from 2000-15. Data source: University of Adelaide (Associate Professor David Paton).

5.5 Presence of priority species – migratory shorebirds

Priority waterbird species are assessed against management metrics on a species-by-species basis rather than across all priority waterbird species.

The median abundances of priority species in the Coorong during annual censuses from 2000–15 are shown in Table 5.25. The probability of each priority species being recorded at or above their median abundance in a given annual census is 0.5, and therefore, the Resource Condition Target was set to be '*Counts of each priority species in the Coorong during an annual census are at or above their median abundance (2000–15)*' (Table 5.27).

All priority species had 10th percentile abundances of ≥ 1 in the Coorong during annual censuses from 2000–15, with the exception of Black-tailed Godwit (Table 5.25). Therefore, the Management Trigger for Common Greenshank, Curlew Sandpiper, Pacific Golden Plover, Red-necked Stint and Sharp-tailed Sandpiper are set at their 10th percentile abundance (Table 5.25). As such, the Management Trigger for aforementioned priority species was set to be '*Counts of each priority species in the Coorong during an annual census are below their 10th percentile abundance (2000–15)*' (Table 5.27). If this event were to occur for two consecutive years for an individual species then the LAC threshold would be exceeded (Table 5.27).

Management Triggers and LAC thresholds for Black-tailed Godwit and Sanderling were set based upon the number of consecutive years of failed detection during annual censuses that equated to a probability of 0.1 and 0.01, respectively, based upon the proportion of years that the species was present from 2000–15 (Table 5.26).

Management Triggers for Black-tailed Godwit and Sanderling were set at two and three consecutive years of failed detection during annual censuses in the Coorong, respectively (Table 5.27). LAC thresholds for Black-tailed Godwit and Sanderling were set at four and six consecutive years of failed detection during annual censuses in the Coorong, respectively (Table 5.27).

Table 5.25. The 10th percentiles and median abundances of priority waterbird species counted over the Coorong from 2000–15 during annual summer waterbird censuses. Data source: University of Adelaide (Associate Professor David Paton).

Common name	10 th percentile (2000–15)	Median abundance (2000–15)
Black-tailed Godwit	0	38
Common Greenshank	225	430
Curlew Sandpiper	508	2252
Pacific Golden Plover	3	36
Red-necked Stint	15 703	26 286
Sanderling	0	6
Sharp-tailed Sandpiper	4823	13 179

Table 5.26. The number of consecutive years of Black-tailed Godwit and Sanderling failed detection during annual censuses equal to an event probability of 0.1 and 0.01 based upon the proportion of censuses that the species was not detected from 2000–15.

Common name	0.1 probability of occurrence	0.01 probability of occurrence	Prop. of years present (2000–15)
Black-tailed Godwit	2 (1.97)	4 (3.96)	0.69
Sanderling	3 (2.79)	6 (5.57)	0.56

Table 5.27. The Resource Condition Target, Management Trigger and Limit of Acceptable Change (LAC) thresholds for priority waterbird species in the Coorong. Priority waterbird species are assessed against management metrics on a species-by-species basis rather than across all priority waterbird species.

Metric	Measure
Resource Condition Target	Counts of each priority species in the Coorong during an annual census are at or above their median abundance (2000–15).
Management Trigger	<p>Common Greenshank, Curlew Sandpiper, Pacific Golden Plover, Red-necked Stint and Sharp-tailed Sandpiper: Counts of each priority species in the Coorong during an annual census are below their 10th percentile abundance (2000–15).</p> <p>Black-tailed Godwit: Black-tailed Godwit are not detected over two consecutive years of census in the Coorong.</p> <p>Sanderling: Sanderling are not detected over three consecutive years of census in the Coorong.</p>
LAC threshold	Counts or detection for any of the seven priority species are at the following levels <p>Common Greenshank, Curlew Sandpiper, Pacific Golden Plover, Red-necked Stint and Sharp-tailed Sandpiper: Counts of each priority species in</p>

Metric	Measure
	the Coorong during an annual census are below their 10 th percentile abundance (2000–15) for two consecutive years.
	Black-tailed Godwit: Black-tailed Godwit are not detected for four consecutive years of census in the Coorong.
	Sanderling: Sanderling are not detected for six consecutive years of census in the Coorong.

Compliance

The Resource Condition Target for Common Greenshank, Curlew Sandpiper and Pacific Golden Plover were met in nine (43%), eight (38%) and nine (43%) of 21 annual censuses from 2000–20 (Table 5.28). The Management Trigger for Pacific Golden Plover, Common Greenshank and Curlew Sandpiper were breached in four (19%), three (14%) and three (14%) censuses, respectively, from 2000–20. The Management Triggers were breached in two consecutive years (2011–12) for Common Greenshank, Curlew Sandpiper and Pacific Golden Plover, and therefore, the LAC thresholds were exceeded.

The Resource Condition Target for Red-necked Stint and Sharp-tailed Sandpiper were met in nine (43%) and 11 (52%) of 21 annual censuses, respectively, from 2000–20 (Table 5.28). The Management Trigger for Red-necked Stint and Sharp-tailed Sandpiper were breached in six (29%) and three (14%) of 21 annual censuses, respectively, from 2000–20. The Management Trigger was not breached in consecutive years for Sharp-tailed Sandpiper; however, the Management Trigger for Red-necked Stint was breached for four consecutive years from 2017–20. Therefore, the LAC threshold for Red-necked Stint was exceeded.

The Resource Condition Target for Black-tailed Godwit and Sanderling were met in nine (43%) and 11 (52%) of 21 annual censuses, respectively, from 2000–20 (Table 5.28). The Black-tailed Godwit was not detected for four consecutive censuses from 2011–14, and therefore, the Management Trigger was first breached in 2012 (two consecutive years of absence) and the LAC threshold was exceeded in 2014 (four consecutive years of absence). The Management Trigger and LAC threshold for Sanderling were not breached from 2000–20.

Table 5.28. Compliance success of the Resource Condition Target (RCT) and Management Trigger (MT) for each priority species in the Coorong.

Year	Black-tailed Godwit		Common Greenshank		Curlew Sandpiper		Pacific Golden Plover		Red-necked Stint		Sharp-tailed Sandpiper		Sanderling	
	RCT	MT	RCT	MT	RCT	MT	RCT	MT	RCT	MT	RCT	MT	RCT	MT
2000	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	No	Yes
2001	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No	Yes
2002	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2003	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2004	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes
2005	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes
2006	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
2007	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
2008	No	Yes	Yes	Yes	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes
2009	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes
2010	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
2011	No	Yes	No	No	No	No	No	No	No	No	No	No	No	Yes

Year	Black-tailed Godwit		Common Greenshank		Curlew Sandpiper		Pacific Golden Plover		Red-necked Stint		Sharp-tailed Sandpiper		Sanderling	
	RCT	MT	RCT	MT	RCT	MT	RCT	MT	RCT	MT	RCT	MT	RCT	MT
2012	No	No	No	No	No	No	No	No	No	Yes	No	Yes	No	Yes
2013	No	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2014	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2015	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2016	No	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
2017	No	Yes	No	Yes	No	No	No	Yes	No	No	No	No	No	Yes
2018	Yes	Yes	No	Yes	No	Yes	No	Yes	No	No	No	Yes	No	Yes
2019	No	Yes	No	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
2020	No	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes

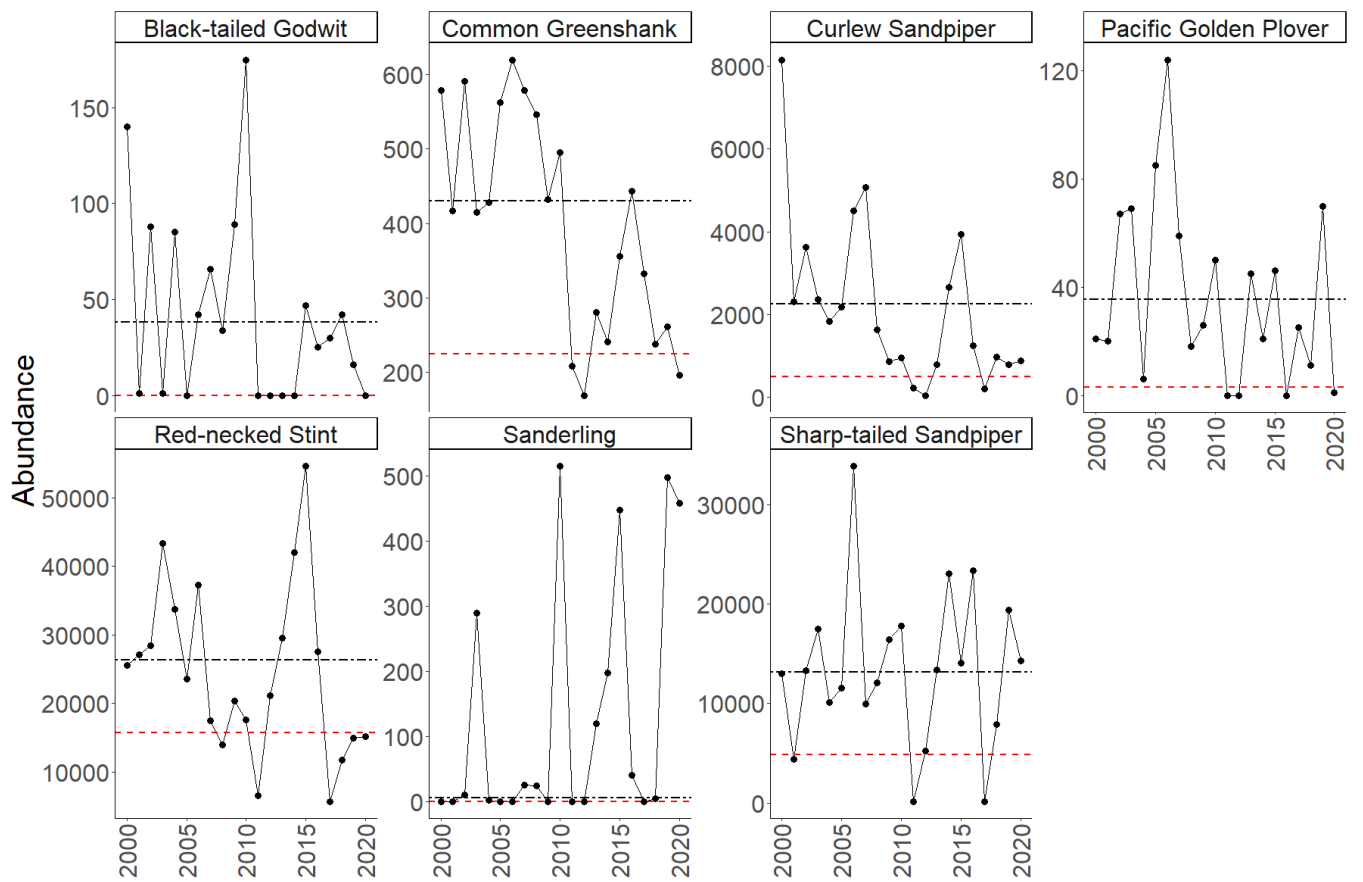


Figure 5.14. Annual abundances of priority species in the Coorong from 2000–20 with respect to their median (black dashed line) and 10th percentile (red dashed line) abundance based on a 2000–15 baseline. All data was collected during annual summer waterbird censuses. Data source: University of Adelaide (Associate Professor David Paton).

5.6 Threatened species

Threatened species are assessed against management metrics on a species-by-species basis rather than across all threatened species.

Six threatened waterbird species met the selection criteria detailed in section 3.5.5. The six species were: Bar-tailed Godwit, Curlew Sandpiper, Eastern Curlew, Fairy Tern, Great Knot and Red Knot. As the vast majority of records for each species were recorded in the Coorong, the Coorong census dataset was used to set all metrics.

The median abundance of the six threatened waterbird species over the Coorong during annual censuses from 2000–15 are shown in Table 5.29. Four of the six species had a median abundance of ≥ 1 , and two species had a median abundance of 0, which means that they were not detected in more than half of the baseline annual censuses. Resource Condition Targets were set at the median abundance of each threatened species if they had a median abundance ≥ 1 , i.e. Bar-tailed Godwit, Curlew Sandpiper, Eastern Curlew and Fairy Tern. The probability of a threatened species being recorded at or above its median abundance in a given annual census is 0.5, and therefore, the Resource Condition Target for aforementioned species was set to be '*Counts of each threatened species in the Coorong for an annual census are at or above their median abundance (2000–15)*' (Table 5.31). Great Knot and Red Knot had median abundances of 0 in the Coorong during annual censuses from 2000–15. Resource Condition Targets for Great Knot and Red Knot were therefore set based upon the number of consecutive years of failed detection during annual censuses that equated to a probability of 0.5 based upon the proportion of years that the species was detected from 2000–15 (Table 5.30). As such, the Resource Condition Target for Great Knot was detection each census and for Red Knot was detection one in two censuses (Table 5.31).

Curlew Sandpiper, Eastern Curlew and Fairy Tern were the only threatened species with 10th percentile abundances ≥ 1 during annual censuses from 2000–15 (Table 5.29). Tenth percentile values for each threatened species have a probability of 0.1 of not being met on an annual basis, and therefore, the Management Trigger for the aforementioned threatened species was set to be '*Counts of each threatened species in the Coorong during an annual census are below their 10th percentile abundance (2000–15)*' (Table 5.31). If this event were to occur for two consecutive years for an individual species then the LAC threshold was exceeded (Table 5.31).

Management Triggers and LAC thresholds for Bar-tailed Godwit, Great Knot and Red Knot were set based upon the number of consecutive years of failed detection during annual censuses that equated to a probability of 0.1 and 0.01, respectively, based upon the proportion of years that the species was not detected from 2000–15 (Table 5.30). Management Triggers for Bar-tailed Godwit, Great Knot and Red Knot were set at one, five and eight consecutive years of failed detection during annual censuses, respectively (Table 5.31). LAC thresholds for Bar-tailed Godwit, Great Knot and Red Knot were set at three, 10 and 16 consecutive years of failed detection during annual censuses, respectively (Table 5.31).

Table 5.29. The 10th percentile and median abundance of threatened waterbird species counted over the Coorong from 2000–2015 during annual summer waterbird censuses. Data source: University of Adelaide (Associate Professor David Paton).

Common name	10 th percentile (2000–15)	Median abundance (2000–15)	Prop. of years present (2000–15)
Bar-tailed Godwit	0	27	0.81
Curlew Sandpiper	508	2252	1.00
Eastern Curlew	2	13	1.00
Fairy Tern	226	337	1.00
Great Knot	0	0	0.38
Red Knot	0	0	0.25

Table 5.30. The number of consecutive years of failed detection required to equal a probability of 0.5, 0.1 and 0.01 for Black-tailed Godwit, Great Knot and Red Knot based upon the proportion of years of failed detection during annual censuses from 2000–15.

Common name	0.5 probability of occurrence	0.1 probability of occurrence	0.01 probability of occurrence
	Used median		
Bar-tailed Godwit	Abundance	1 (1.38)	3 (2.75)
Great Knot	1 (1.47)	5 (4.90)	10 (9.80)
Red Knot	2 (2.41)	8 (8.00)	16 (16.00)

Table 5.31. The Resource Condition Target, Management Trigger and Limit of Acceptable Change (LAC) threshold for threatened species. Threatened species are assessed against management metrics on a species-by-species basis rather than across all threatened species.

Metric	Measure
Resource Condition Target	<p>Bar-tailed Godwit, Curlew Sandpiper, Eastern Curlew and Fairy Tern: Counts of each threatened species in the Coorong for an annual census are at or above their median abundance (2000–15).</p> <p>Great Knot: Great Knot are detected during the annual census.</p> <p>Red Knot: Red Knot are detected at least once in every two annual censuses.</p>
Management trigger	<p>Curlew Sandpiper, Eastern Curlew and Fairy Tern: Counts of each threatened species in the Coorong for an annual census are below their 10th percentile abundance (2000–15).</p> <p>Bar-tailed Godwit: Bar-tailed Godwit are not detected during the annual census.</p> <p>Great Knot: Great Knot are not detected in the Coorong for five consecutive years of census.</p> <p>Red Knot: Red Knot are not detected in the Coorong for eight consecutive years of census.</p>
LAC threshold	<p>Curlew Sandpiper, Eastern Curlew and Fairy Tern: Counts of each threatened species in the Coorong for an annual census are below their 10th percentile abundance (2000–15) for two consecutive years.</p> <p>Bar-tailed Godwit: Bar-tailed Godwit are not detected for three consecutive years of census.</p> <p>Great Knot: Great Knot are not detected in the Coorong for 10 consecutive years of census.</p> <p>Red Knot: Red Knot are not detected in the Coorong for 16 consecutive years of census.</p>

Compliance

Resource Condition Targets for Bar-tailed Godwit, Curlew Sandpiper, Eastern Curlew and Fairy Tern were met in 12 (57%), eight (38%), eight (38%) and 12 (57%) of 21 annual censuses, respectively, from 2000–20 (Table 5.32). Annual abundances of Bar-tailed Godwit, Curlew Sandpiper, Eastern Curlew and Fairy Tern are shown in Figure 5.15.

Resource Condition Targets for Great Knot and Red Knot were met in nine (43%) and 11 (52%) of 21 annual censuses, respectively, from 2000–20 (Table 5.32). Annual abundances of Great Knot and Red Knot are shown in Figure 5.15.

Management Triggers for Curlew Sandpiper, Eastern Curlew and Fairy Tern were breached in three (14%), three (14%) and two (10%) of 21 annual censuses, respectively, from 2000–20 (Table 5.32). The Management Trigger was breached in two consecutive years for Curlew Sandpiper and Eastern Curlew, and therefore, the LAC thresholds for these species were exceeded.

Management Triggers for Bar-tailed Godwit, Great Knot and Red Knot, which were based upon absence, were breached in three (14%), four (19%) and zero (0%) of the 21 annual censuses, respectively, from 2000–20 (Table 5.32). The LAC thresholds for these species were not exceeded.

Table 5.32. Compliance success of the Resource Condition Target (RCT) and Management Trigger (MT) for each priority species in the Coorong. Compliance success of the Management Trigger for Great Knot and the Resource Condition Target and Management Trigger for Red Knot could not be determined (N/A) until the species were detected during a census or the number of censuses required for metric evaluation had elapsed. Great Knot and Red Knot were first detected during a census in 2001 and 2004, respectively.

Year	Bar-tailed Godwit		Curlew Sandpiper		Eastern Curlew		Fairy Tern		Great Knot		Red Knot	
	RCT	MT	RCT	MT	RCT	MT	RCT	MT	RCT	MT	RCT	MT
2000	No	Yes	Yes	Yes	No	No	Yes	Yes	No	N/A	N/A	N/A
2001	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	N/A
2002	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	N/A
2003	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	N/A
2004	No	No	No	Yes	Yes	Yes	No	No	Yes	Yes	No	N/A
2005	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes
2006	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
2007	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes
2008	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
2009	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes
2010	No	No	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
2011	Yes	Yes	No	No	No	Yes	No	No	No	Yes	Yes	Yes
2012	Yes	Yes	No	No	No	Yes	Yes	Yes	No	Yes	No	Yes
2013	Yes	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
2014	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
2015	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
2016	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes
2017	Yes	Yes	No	No	No	Yes	Yes	Yes	No	No	Yes	Yes
2018	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2019	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes
2020	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

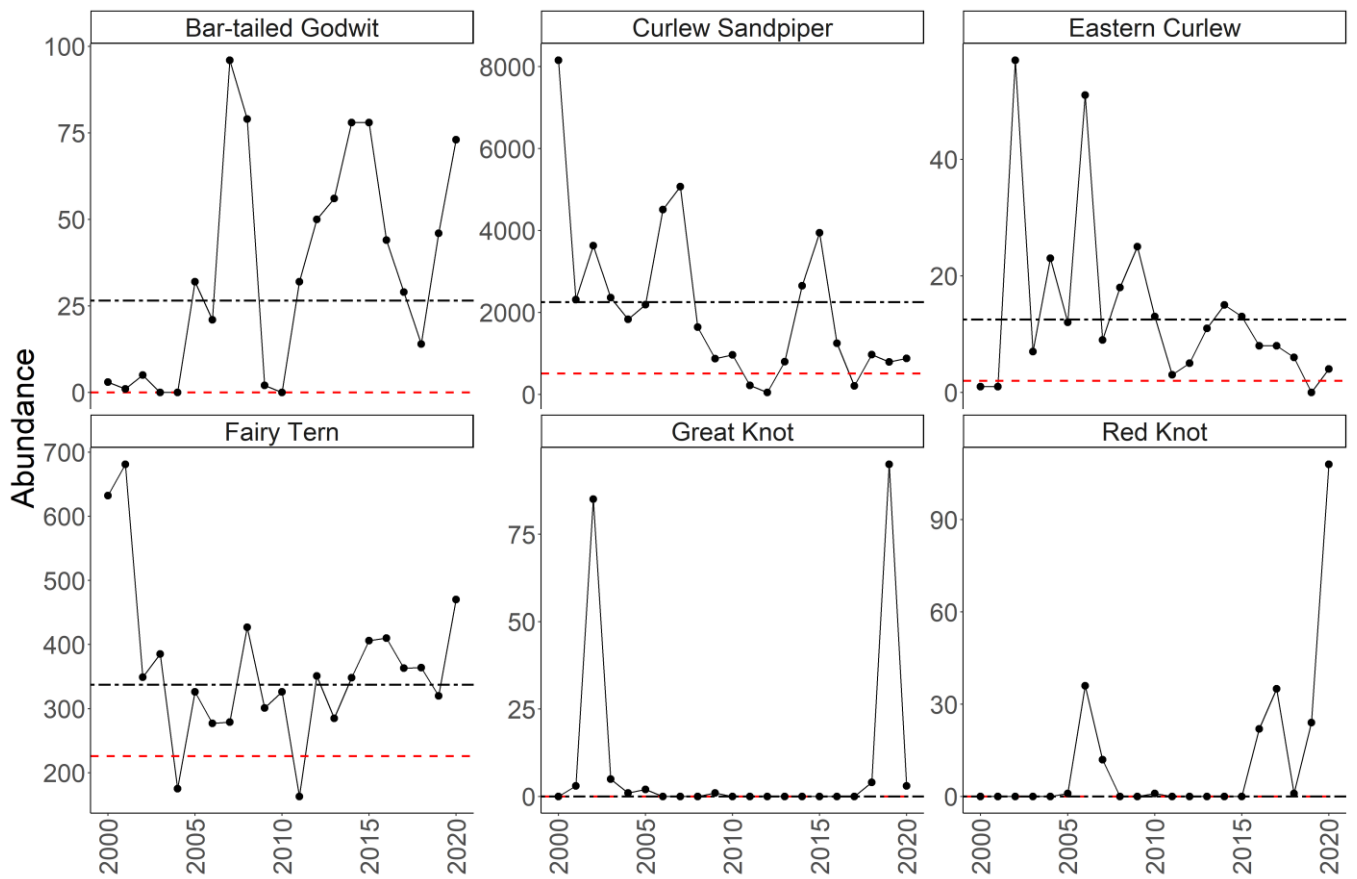


Figure 5.15. Annual abundances of threatened species in the Coorong from 2000–20 with respect to their median (black dashed line) and 10th percentile (red dashed line) abundance based on a 2000–15 baseline. All data was collected during annual summer waterbird censuses. Data source: University of Adelaide (Associate Professor David Paton).

6 Discussion

6.1 Validation

Metrics in this technical report were set using statistical thresholds that were expected to align with the prescribed definitions for a Resource Condition Target, Management Trigger and LAC threshold in the RMP and ECD. A summary of waterbird Resource Condition Target (see 6.1.1), Management Trigger (see 6.1.2) and LAC threshold (see 6.1.3) evaluation is detailed below.

6.1.1 Resource Condition Target

The abundance and diversity of waterbirds in the Lakes and Coorong are variable and likely respond to conditions at local (Paton et al. 2020b), national (Bino et al. 2020) and international scales (for migratory species) (Rogers and Gosbell 2006; Minton et al. 2014). To account for this variability, Resource Condition Targets were set at a probability of 0.5 and often used the median of a dataset rather than the arithmetic mean, which is affected by outliers. The statistical threshold used to set Resource Condition Targets therefore aligned with the definition for a Resource Condition Target in the RMP of being “*reflective of a typical and contemporary (21st century) state for the Ramsar site’s critical CPS*”.

There was one event for the Waterbird diversity CPS subcomponent for the Ramsar site where the Resource Condition Target was met and the Management Trigger was breached in the same year. This event occurred in 2009, when abundances of shorebird species (e.g. Black-winged Stilt, Masked Lapwing and Sharp-tailed Sandpiper) were relatively high, while piscivores (e.g. Australian Pelican, Caspian Tern and Little Black Cormorant), waterfowl (e.g. Black Swan and Grey Teal) and large waders (e.g. Australian White Ibis and White-faced Heron) were typically in relatively low abundances. These contrasting results between species of shorebirds and those from other waterbird guilds were considered to be largely in response to the extremely low lake level, which greatly increased the extent of foraging habitat for shorebirds (Paton and Bailey 2011a), however, was likely detrimental to the habitat and food resources of piscivores, waterfowl and large waders (DEW 2020).

Declining flyway populations of certain migratory shorebird species may already be affecting the achievability of Resource Condition Targets. For example, Eastern Curlews and Curlew Sandpipers have failed to meet their respective Resource Condition Targets since 2015. The EAA flyway population declines of these species are significant, with Eastern Curlews estimated to have an annual population decline of 2–7% and Curlew Sandpipers estimated to have an annual population decline of 5–11% (Clemens et al. 2016; Studds et al. 2017). The declines of Eastern Curlews and Curlew Sandpipers were such that Hansen et al. (2021) found the species to no longer meet their Criterion 6 (1% of the EAA flyway) thresholds at multiple Ramsar sites over Australia and New Zealand. Despite the high rate of population decline of Eastern Curlews and Curlew Sandpipers in the EAA flyway, it must be recognised that migratory shorebirds are declining in the Coorong well above the national rate (Clemens et al. 2016), and that migratory shorebird species with relatively stable populations, such as Red-necked Stint (Studds et al. 2017), have also been recorded in exceedingly low numbers in recent years.

6.1.2 Management Triggers

Management Triggers prescribed for waterbird community related CPS subcomponents; total waterbird abundance (section 5.1) and waterbird diversity (section 5.2) led to breaches during periods of extreme drought (2008–10) and very high barrage flows and widespread flooding over the Murray-Darling Basin (2011 and 2017) (DEW 2020). The Management triggers prescribed for flyway species (section 5.3), important non-migratory species (section 5.4), priority species (section 5.5) and threatened species (section 5.6) were breached over a greater range of years, inclusive of a wide range of hydrological conditions, however, breaches were most common during periods of high barrage flows (2011, 2012 and 2017) and widespread flooding over the Murray-Darling Basin (2011 and 2017) (DEW 2020). Waterbird responses in the Lakes and Coorong during these times of

extremes in hydrology are well documented (Paton 2010, Paton and Bailey 2011a, 2011b, 2012b; Paton et al. 2017b), and are considered to be reflective of the limit of variation in the abundance and diversity of waterbirds under current management. Therefore, Management Triggers set in this technical report are considered to align with their definition in the RMP, which is to be reflective of the limit of variation under current management.

6.1.3 Limit of Acceptable Change threshold

LAC thresholds for waterbird CPS subcomponents were exceeded on 13 occasions over ten unique events (Table 6.1). An investigation to determine whether local, national or international factors (or combination thereof) led the exceedance of each LAC threshold has not been conducted. Going forward, it is recommended that LAC assessments be complemented by investigations to determine the cause of the exceedance of the LAC threshold.

Table 6.1. Events that exceeded the Limit of Acceptable Change (LAC) thresholds for waterbird CPS subcomponents.

* Denotes the same event over different CPS sub-components.

CPS sub-component	LAC threshold exceedance events
Waterbird diversity	Murray estuary: 2010–12 North Lagoon: 2010–11 South Lagoon: 2008–11
Waterbird abundance - 1% EAA flyway species	Curlew Sandpiper: 2011–12* Red-necked Stint: 2017–20*
Waterbird abundance – important non-migratory (1% Australian population) species	Red-capped Plover: 2010–11
Waterbird abundance - Priority species	Black-tailed Godwit: 2011–14 Common Greenshank: 2011–12 Curlew Sandpiper: 2011–12* Pacific Golden Plover: 2011–12 Red-necked Stint: 2017–20*
Threatened species	Curlew Sandpiper: 2011–12* Eastern Curlew: 2000–01

LAC thresholds set in this technical report are considered to be reflective of “undesirable condition thresholds set beyond the limit of variation under current management that, if reached or breached, indicate a change in ecological character may have occurred”. A brief description of the condition of the Coorong for waterbirds at the time of each LAC exceedance event is provided below.

Waterbird diversity

LAC threshold exceedance events for waterbird diversity in the Murray estuary (2010–12), North Lagoon (2010–11) and South Lagoon (2008–11) occurred at the end of the Millennium Drought (2001–10) and succeeding years (2011 and 2012) of high barrages flows. The impacts of the Millennium Drought on the waterbird food resources over the Coorong are documented in section 3.2, and describe a northward contraction in the distribution and reduction in the biomass of key food resources (*R. tuberosa*, Small-mouthed Hardyhead and macroinvertebrates), and ultimately their extirpation from the South Lagoon (Paton 2010).

Very high barrage flows occurred in 2011, however, the recovery of food resources for waterbirds from the Millennium Drought was limited. The only key food resource (for shorebirds and dabbling ducks) that recovered by the 2011 census was the salt-tolerant chironomid in the South Lagoon (Paton and Bailey 2011b). The remainder of the macroinvertebrate community remained in low abundance, diversity and biomass in the Murray estuary and North Lagoon (Dittmann et al. 2020). The abundance of Small-mouthed Hardyhead (prey for piscivores) also remained low (Paton and Bailey 2012b) and the availability of *R. tuberosa* (consumed by waterfowl) declined

following the high barrage flows, due to the loss of populations that colonised the central North Lagoon during the Millennium Drought and the negligible recovery of populations in the South Lagoon (Paton and Bailey 2013a). The accessibility of food resources was also impacted by high water levels and a dampened tidal signal, which restricted access to shallow areas for waterbirds to forage (Paton and Bailey 2011b).

Exceedance of the LAC threshold continued in the Murray estuary in 2012, largely due to the low counts of shorebird species. The low numbers of shorebirds may have been in response to the continued low abundance, diversity and biomass of macroinvertebrates (Dittmann et al. 2020) and barrage flows dampening the tidal signal (DEW 2020), which can reduce the extent of mudflat for shorebird foraging (Paton 2002).

Migratory shorebirds (assessed as flyway, priority and threatened species)

LAC threshold exceedance events for Curlew Sandpiper, Common Greenshank and Pacific Golden Plover occurred from 2011–12, although continued for Black-tailed Godwit from 2011–14. In 2011, high barrage flows greatly increased water levels throughout the Coorong lagoons and damped the tidal signal in the Murray estuary (DEW 2020), which limited the extent of suitable mudflat for migratory shorebirds to forage (Paton and Bailey 2011b). Although the extent of mudflat for migratory shorebird foraging increased in the Coorong lagoons in 2012 (Paton and Bailey 2012b), the tidal signal was dampened from continuing high flows (DEW 2020), and therefore, may have restricted foraging habitat in the Murray estuary. In association with restricted foraging habitat, the food resource availability for migratory shorebirds in the North Lagoon and Murray estuary was also limited, with low abundance, diversity and biomass of macroinvertebrates that continued to recover from the Millennium Drought (Dittmann et al. 2020).

The LAC threshold for Eastern Curlew was exceeded from 2000–01. Monitoring of macroinvertebrate food resources was not conducted at the time of the LAC threshold exceedance event, and therefore, it is unknown whether food resource availability was a contributing factor. However, the Murray Mouth was approaching closure at the time (Walker 2002), which reduced the tidal signal in the Murray estuary and may have reduced the extent of foraging habitat for Eastern Curlews.

The LAC threshold for the Red-necked Stint was exceeded from 2017–20. In 2017, the access to food resources was likely low due to high water levels associated with high barrage flows and extensive mats of filamentous algae over the shallow margins of the southern Coorong that prohibited access to the underlying sediment (Paton et al. 2017). The availability of food in 2017 may have also been a contributing factor, with chironomid larvae (an important prey item) found to be in low abundance throughout the North and South Lagoons, although they were abundant in the Murray estuary and near Parnka Point (Dittmann et al. 2017; Paton et al. 2017). Food resource availability for Red-necked Stint likely declined further in the Coorong from 2018–20, with densities of chironomid larvae greatly reduced from those recorded from 2011–17 (Paton et al. 2020b).

Important non-migratory species

The LAC threshold for Red-capped Plover was exceeded from 2010–11 at the end of the Millennium Drought (2010) and the succeeding year (2011) of high barrages flows. In 2010, food resource availability for Red-capped Plovers was likely limiting, with low biomass of benthic macroinvertebrates in the North Lagoon (Dittmann et al. 2017) and chironomid larvae becoming extirpated in the South Lagoon (Paton 2010). In 2011, high barrage flows greatly increased water levels throughout the Coorong lagoons (DEW 2020), which limited the extent of suitable mudflat for migratory shorebirds to forage (Paton and Bailey 2011b).

7 Conclusion

This technical report identifies and evaluates recommended Resource Condition Targets, Management Triggers and LAC thresholds for critical waterbird CPS subcomponents for the Coorong, Lakes Alexandrina and Albert Ramsar site. It also recommends a process be commenced following a Management Trigger breach to determine whether factors internal or external to the system led to the breach, with management actions initiated where factors internal to the Ramsar site contributed significantly to the outcome. Similarly, it is recommended that when a LAC threshold is exceeded that an investigation is initiated to determine the relative contribution of local, national and international (for migratory species) conditions to the event.

Validation of recommended metrics determined that:

- Resource Condition Targets were reflective of a typical and contemporary (21st century) state, however, the achievability of Resource Condition Targets for certain migratory shorebird species, such as Curlew Sandpipers and Eastern Curlews, may be impacted by their declining populations in the EAA flyway.
- Management Triggers were reflective of the limit of variation of waterbird CPS subcomponents under current management, with the majority of breaches occurring during periods of extreme drought and/or high barrage flows and flooding over the Murray-Darling Basin.
- LAC thresholds were considered to be adequate in identifying consecutive years (two or more) where waterbird CPS subcomponents were at concerning levels. An investigation is to be initiated following exceedance of a LAC threshold to determine the relative contribution of local, national and international conditions to the outcome.

The information presented within this technical report can be used to update the ECD and RMP for the Ramsar site. The metrics developed in this technical report (Appendix D) will help to assess the condition of the Ramsar site, provide signals for the need of management actions to maintain ecological character and also serve to identify changes in ecological character.

8 Appendices

A. List of waterbird species selected for assessment for each waterbird CPS subcomponent

Waterbird CPS sub-component	Selected species
Waterbird abundance	All true native waterbird species, following the selection criteria described in section 3.4.
Waterbird diversity – Ramsar site	Australian Pelican
	Australian Shelduck
	Australian White Ibis
	Black-winged Stilt
	Black Swan
	Caspian Tern
	Curlew Sandpiper
	Eurasian Coot
	Great Cormorant
	Great Egret
	Grey Teal
	Little Black Cormorant
	Little Pied Cormorant
	Masked Lapwing
	Red-capped Plover
	Red-necked Stint
	Sharp-tailed Sandpiper
	Straw-necked Ibis
	Whiskered Tern
	White-faced Heron
Waterbird diversity – Lakes	Australasian Shoveler
	Australian Pelican
	Australian Shelduck
	Australian White Ibis
	Black Swan
	Cape Barren Goose
	Eurasian Coot
	Great Cormorant
	Great Crested Grebe
	Greater Crested Tern
	Grey Teal
	Hardhead
	Little Black Cormorant
	Little Pied Cormorant
	Masked Lapwing

Waterbird CPS sub-component	Selected species
	Pacific Black Duck Pied Cormorant Silver Gull Straw-necked Ibis Whiskered Tern
Waterbird diversity – Murray estuary	Australian Pelican Black-tailed Godwit Black-winged Stilt Black Swan Caspian Tern Common Greenshank Curlew Sandpiper Eastern Curlew Greater Crested Tern Grey Teal Hoary-headed Grebe Little Black Cormorant Little Pied Cormorant Masked Lapwing Pacific Black Duck Pacific Golden Plover Pied Oystercatcher Red-capped Plover Red-necked Avocet Red-necked Stint Sanderling Sharp-tailed Sandpiper Silver Gull Whiskered Tern
Waterbird diversity – North Lagoon	Australian Pelican Australian Shelduck Black Swan Black-winged Stilt Cape Barren Goose Caspian Tern Common Greenshank Curlew Sandpiper Great Cormorant Greater Crested Tern Grey Teal Hoary-headed Grebe Little Black Cormorant Little Pied Cormorant

Waterbird CPS sub-component	Selected species
	Masked Lapwing Pacific Golden Plover Pied Cormorant Pied Oystercatcher Red-capped Plover Red-necked Avocet Red-necked Stint Sharp-tailed Sandpiper Silver Gull Whiskered Tern
Waterbird diversity – South Lagoon	Australian Pelican Australian Shelduck Banded Stilt Black Swan Caspian Tern Chestnut Teal Common Greenshank Curlew Sandpiper Fairy Tern Great Crested Grebe Greater Crested Tern Grey Teal Hoary-headed Grebe Little Black Cormorant Masked Lapwing Pied Oystercatcher Red-capped Plover Red-necked Avocet Red-necked Stint Sharp-tailed Sandpiper Silver Gull Whiskered Tern White-faced Heron
1% East Asian Australasian Flyway	Curlew Sandpiper Red-necked Stint Sharp-tailed Sandpiper
Non-migratory (1% Australian population) species	Australian Pied Oystercatcher Chestnut Teal Australian Fairy Tern Red-capped Plover
Presence of priority species	Black-tailed Godwit Common Greenshank Curlew Sandpiper

Waterbird CPS sub-component	Selected species
Threatened species	Pacific Golden Plover
	Red-necked Stint
	Sanderling
	Sharp-tailed Sandpiper
	Bar-tailed Godwit
	Curlew Sandpiper
	Eastern Curlew
	Fairy Tern
	Great Knot
	Red Knot

B. Management Trigger calculation – Waterbird diversity

Aim: Determine the minimum number of selected annual species that are at or above their 10th percentile abundance when an event with a probability of occurrence of 0.1 takes place.

Example data:

For this example, we are assuming that there are a total of 24 selected waterbird species of which 20 selected species have 10th percentile abundances ≥ 1 , and therefore, are referred to as annual species.

Calculation procedure:

Step 1. Determine the number of target species that are expected to occur on an annual basis, i.e. with 10th percentile values ≥ 1 , referred to herein as annual species.

Result: 20 selected species have 10th percentile abundances ≥ 1 , and therefore, are referred to as annual species.

Step 2. Determine the mean number of annual species that are expected to be at or above their 10th percentile abundance in any given year.

$$\text{Mean: } \mu = n \times 0.90$$

Where n = the number of annual species

$$\begin{aligned} \text{Result: } \mu &= 20 \times 0.90 \\ &= 18 \end{aligned}$$

Step 3. Determine the standard deviation for the number of annual species that are expected to be at or above their 10th percentile abundance in any given year.

$$\text{Standard deviation: } \sigma = \sqrt{npq}$$

Where n = number of target species (with 10th percentiles > 1)

p = probability of success (event occurring, i.e. 1/10)

q = probability of failure (event not occurring, i.e. 9/10)

$$\begin{aligned} \text{Result: } \sigma &= \sqrt{20 \times 0.9 \times 0.1} \\ \sigma &= 1.341 \end{aligned}$$

Step 4. Determine the lower 80% confidence limit for the number of annual species above their 10th percentile abundance in any given year.

Confidence Limit: $CL = \mu - (z \times \sigma)$

Where μ = the mean number of annual species above their 10th percentile abundance in any given year

z = standard score for the 80% confidence limit

σ = standard deviation

Note: A standard (z) score of 1.282 is used for the lower 80% confidence limit

Result: $CL = 18 - (1.282 \times 1.341)$
 $= 16.28$

C. Presence/absence Management Trigger and LAC threshold calculation – Priority and threatened species

Aim: Determine the number of years of absence from annual waterbird censuses that would be reflective of an event series with a probability of 0.1.

Example data:

A priority species was absent in 30% of baseline years and the probability of an event series is fixed at 0.1.

Calculation procedure:

Step 1. Plug in known parameters to the equation for the conditional probability of a series of events (i.e. absence during annual waterbird censuses):

$$y^x = z$$

Where x = number of consecutive years of absence

y = probability of absence in a given year

z = probability of event series occurring

Result: $0.3^x = 0.1$

As the priority species was absent in 30% of baseline years ($y=0.3$) and the probability set for management triggers is ($z=$) 0.1.

Therefore, $y = 0.3$ (% of baseline years absent) and $z = 0.1$ (probability set for management triggers)

Step 2. Solve the exponential (i.e. number of consecutive years of absence, shown as x) using logarithms.

Result: $0.3^x = 0.1$
 $x \cdot \ln(0.3) = \ln(0.1)$
 $x = \frac{\ln(0.1)}{\ln(0.3)} \approx 1.9$

There is a probability of 0.1 that the priority species will be absent from annual censuses for two (rounded from 1.9) consecutive years.

The calculation of a LAC threshold follows this process also, however, the probability of its occurrence is 0.01 rather than 0.1 for a Management Trigger.

D. Complete list of all Resource Condition Targets, Management Triggers and LAC Thresholds for Waterbird CPS considered in this technical report.

Waterbird CPS sub-component	Metric	Measure
Waterbird abundance	Resource Condition Target	282 212 or more waterbirds are counted over the Ramsar site in the annual census.
	Management Trigger	Fewer than 190 122 waterbirds counted over the Ramsar site in the annual census.
	LAC threshold	Fewer than 190 122 waterbirds counted over the Ramsar site in the annual census over two consecutive years.
Waterbird diversity – Ramsar site	Resource Condition Target	At least 10 selected waterbird species have counts above their median abundance during the annual census.
	Management Trigger	Less than 17 selected waterbird species have counts above their 10 th percentile abundance during the annual census.
	LAC threshold	Less than 17 selected waterbird species have counts above their 10 th percentile abundance for two consecutive annual censuses.
Waterbird diversity – Lakes	Resource Condition Target	At least 10 selected waterbird species have counts above their median abundance during the annual census.
	Management Trigger	Less than 17 selected waterbird species have counts above their 10 th percentile abundance during the annual census.
	LAC threshold	Less than 17 selected waterbird species have counts above their 10 th percentile abundance for two consecutive annual censuses.
Waterbird diversity – Murray estuary	Resource Condition Target	At least 12 selected waterbird species have counts above their median abundance during the annual census.
	Management Trigger	Less than 18 selected waterbird species have counts above their 10 th percentile abundance during the annual census.
	LAC threshold	Less than 18 selected waterbird species have counts above their 10 th percentile abundance for two consecutive annual censuses.
Waterbird diversity – Coorong North Lagoon	Resource Condition Target	At least 12 selected waterbird species have counts above their median abundance during the annual census.
	Management Trigger	Less than 19 selected waterbird species have counts below their 10 th percentile abundance during the annual census.
	LAC threshold	Less than 19 selected waterbird species have counts below their 10 th percentile abundance for two consecutive annual censuses.
Waterbird diversity – Coorong South Lagoon	Resource Condition Target	At least 12 selected waterbird species have counts above their median abundance during the annual census.
	Management Trigger	Less than 18 selected waterbird species have counts below their 10 th percentile abundance during the annual census.
	LAC threshold	Less than 18 selected waterbird species have counts below their 10 th percentile abundance for two consecutive annual censuses.
	Resource Condition Target	Counts of each flyway species in the Coorong during an annual census are at or above their median abundance (2000–15).

Waterbird CPS sub-component	Metric	Measure
1% East Asian Australasian Flyway population	Management Trigger	Counts of each flyway species in the Coorong during an annual census are at or above their 10 th percentile abundance (2000–15).
	LAC threshold	Counts of each flyway species in the Coorong during an annual census are below their 10 th percentile abundance (2000–15) for two consecutive years.
Non-migratory species where the sites regularly supports 1% or more of the Australian population	Resource Condition Target	Counts of Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plovers in the Coorong during an annual census are at or above their median abundance (2000–15).
	Management Trigger	Counts of Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plovers in the Coorong during an annual census are below their 10 th percentile abundance (2000–15).
	LAC threshold	Counts of Australian Pied Oystercatcher, Chestnut Teal, Australian Fairy Tern and Red-capped Plovers in the Coorong during an annual census are below their 10 th percentile abundance (2000–15) for two consecutive years.
Priority species – migratory shorebirds	Resource Condition Target	Counts of each priority species in the Coorong during an annual census are at or above their median abundance (2000–15).
	Management Trigger	Common Greenshank, Curlew Sandpiper, Pacific Golden Plover, Red-necked Stint and Sharp-tailed Sandpiper: Counts of each priority species in the Coorong during an annual census are below their 10 th percentile abundance (2000–15). Black-tailed Godwit: Black-tailed Godwit are not detected over two consecutive years of census in the Coorong. Sanderling: Sanderling are not detected over three consecutive years of census in the Coorong.
	LAC threshold	Counts or detection for any of the seven priority species are at the following levels Common Greenshank, Curlew Sandpiper, Pacific Golden Plover, Red-necked Stint and Sharp-tailed Sandpiper: Counts of each priority species in the Coorong during an annual census are below their 10 th percentile abundance (2000–15) for two consecutive years. Black-tailed godwit: Black-tailed Godwit are not detected for four consecutive years of census in the Coorong. Sanderling: Sanderling are not detected for six consecutive years of census in the Coorong.
Threatened species	Resource Condition Target	Bar-tailed Godwit, Curlew Sandpiper, Eastern Curlew and Fairy Tern: Counts of each threatened species in the Coorong for an annual census are at or above their median abundance (2000–15). Great Knot: Great Knot are detected during the annual census. Red Knot: Red Knot are detected at least once in every two annual censuses.

Waterbird CPS sub-component	Metric	Measure
	Management Trigger	<p>Curlew Sandpiper, Eastern Curlew and Fairy Tern: Counts of each threatened species in the Coorong for an annual census are below their 10th percentile abundance (2000–15).</p> <p>Bar-tailed Godwit: Bar-tailed Godwit are not detected during the annual census.</p> <p>Great Knot: Great Knot are not detected in the Coorong for five consecutive years of census.</p> <p>Red Knot: Red Knot are not detected in the Coorong for eight consecutive years of census.</p>
	LAC threshold	<p>Curlew Sandpiper, Eastern Curlew and Fairy Tern: Counts of each threatened species in the Coorong for an annual census are below their 10th percentile abundance (2000–15) for two consecutive years.</p> <p>Bar-tailed Godwit: Bar-tailed Godwit are not detected for three consecutive years of census.</p> <p>Great Knot: Great Knot are not detected in the Coorong for 10 consecutive years of census.</p> <p>Red Knot: Red Knot are not detected in the Coorong for 16 consecutive years of census.</p>

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