Biodiversity and Conservation Science

Waterbird usage of Lake Warden and Lake Gore Ramsar sites 2006 to 2023

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April 2023

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The recommended reference for this publication is:

Pinder A, Venarsky M, Felton F, Barrett A, Cale D, Barrat, P and Bucktin, H (2023), *Waterbird usage of Lake Warden and Lake Gore Ramsar sites from 2006 to 2023*, Department of Biodiversity, Conservation and Attractions, Perth.

Cover image: Kubich Lake looking towards Lake Gore, Adrian Pinder © DBCA

Acknowledgements. Thanks to Stephen Butler (DBCA Esperance) for logistical support and Dave Thornburg (DBCA, Stokes Inlet) for assisting with the surveys of Lake Quallilup and the flow-through system in 2020-21. Operational funds for this project were provided by South Coast NRM through funding from the Australian Government's National Landcare Program. Thanks to BirdLife Wa for supporting Plaxy Barrat to participate in one of the surveys. Thanks to Tom Parkin for allowing us to access two wetlands on his property, Tom Murray for access to wetlands on his property and access to the east shore of Lake Gore and Rohan Marold for allowing us to survey the Carbul Suite wetlands west of Lake Gore. Surveys between Oct 2006 and Feb 2008 were undertaken by Stuart Halse and colleagues. John Lizamore played a pivotel role in organising and participating in surveys up to 2015.

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Summary

- Ground-based surveys of waterbirds using the Warden and Gore wetland systems were undertaken in November and February in 2020/21 and 2022/23, continuing surveys of these systems commenced in 2006.
- Climatic and hydrological conditions for these two pairs of surveys were very different. Rainfall across southern Western Australia was average to below average for the year prior to the Nov 2020 survey, albeit with some significant rains in August, and very little rain fell between the spring 2020 and summer 2021 surveys. The spring survey came after the largest decline in cumulative monthly mean rainfall since 2004. Depths in gauged Warden wetlands were comparatively low, with average depths in Nov 2020 only 15cm above the minimum recorded during any of the previous surveys and average depth in Feb 2021 was the lowest for any survey thus far. The 2022/23 surveys followed much wetter conditions, with average to above average rains over the south coast in the previous year and slightly above average rainfall over the 2022/23 summer period. Depths were correspondingly higher than during 2020/21, representing the fourth deepest conditions in spring and the deepest conditions in summer since 2008.
- There has been a decline in the number of species using the Warden wetlands over the past five spring surveys, from a peak of 48 in 2013 to 32 in 2022, with richness for the last two surveys lower than all previous spring surveys other than the partial Oct 2006 survey. Richness has not declined for summer surveys.
- The counts of 3807 and 2068 for November 2020 and 2022 respectively were the lowest spring counts for the current survey program. For the Nov 2022 survey this result is surprising since depths were comparable to 2008 and 2018 when total abundance was more than three times as high. Numbers of most duck species (which together represent most waterbird abundance in the system) were particularly low in both surveys. Numbers of Black Swan and Straw-necked Ibis were also notably low in Nov 2020. The low depth of Lake Warden meant that there were almost no Banded Stilt and very few Red-necked Avocet in Nov 2020, but numbers of most migratory shorebirds across the system were not unusual, except for relatively low numbers of Common Greenshank and the presence of two Black-tailed Godwits. In Nov 2022, almost all species had lower than average abundance. While Lake Warden had become substantially deeper in Nov 2022 it still supported very few shorebirds. It is possible that some species, such as Grey Teal, which was represented by just 92 individuals compared to >1000 for most surveys, had migrated to eastern Australia in response to the exceptionally wet 2021-22, but other species are more likely to have found (or not returned from) alternative habitat elsewhere in south-west WA.
- In contrast to the very low abundance of waterbirds in the Warden system in Nov 2020, total abundance increased over summer to 11370 in Feb 2021, which is well within the range recorded in those summer surveys without large numbers of Banded Stilt. This was only the second time since 2006 that Banded Stilt, Red-necked Avocet and Black-winged Stilt have been absent, but Lake Warden, which normally supports the largest numbers of these species, was nearly dry. The count of 621 smaller

shorebirds was also low compared to recent years (1003 to 1995 for summer counts between 2012 and 2019). The number of Pacific Black Duck (3190) was the highest summer count for the 2006+ surveys (previous range 188 to 2676 and the 1543 Eurasian Coot was the third highest summer count. Large numbers of waterbirds returned to the Warden system over the 2022/23 summer, resulting in the 4th highest summer count (14968) of the current survey program. A few species had their highest counts in Feb 2023 (2005 Red-necked Avocets, 199 White-faced Heron) or second highest counts (3654 Black Swan, 149 Red-capped Plover, 508 Silver Gulls). Red-necked Stint were absent whereas there have been 420 to 1221 during previous surveys.

- Multivariate analyses suggest that composition of Warden waterbird communities in both spring and summer has shifted over the 2006 to 2023 period, although few individual species have distinct population trends. Australian Shelduck, Hoary-headed Grebe and Yellow-billed Spoonbill have been less common in spring surveys in recent years. Some species, such as Black Swan, Sharp-tailed Sandpipers and Hooded Plover in spring, and Little Black Cormorant in summer, increased in abundance for several years after 2008 to 2010 but returned to earlier abundances in the most recent recent surveys. Some of these patterns are related to depths in Lake Warden in particular. Silver Gulls, Eurasian Coot and Red-capped Plovers have been particularly abundant during recent summer surveys.
- The composition of waterbird communities (the mix of species and their abundances) using the Warden system is strongly associated with rainfall. Spring composition is associated with cumulative deviation from the monthly mean (CDM) over the last 12 months for the Myrup weather station and the at 6 month CDM for the Esperance Station plus the number of days the pipeline was open in the previous three months ($r = 0.57$). Summer waterbird composition was less strongly associated with 6 month CDMs from the Esperance and Esperance Aerodrome weather stations but not with the number of days the pipeline was open ($r= 0.37$).
- Numbers of Chestnut Teal in the Warden system continue to exceed 1% of the estimated global population, other than in Feb 2021, although numbers of this species have been lower than average during recent surveys.
- Hooded Plover numbers increased substantially after 2009, especially in summer. This was mostly due to increased shorebird habitat at Lake Warden following installation of the Wheatfield pipeline. Numbers of this species have been lower in recent surveys, especially in spring, with this not easily explained by Lake Warden depths.
- Shorebird numbers on Lake Warden during the last four surveys have fallen within the previous concept of depth/shorebird relationships, with shorebirds mostly present when depths are between about 0.5 and 1.5 metres and greatest numbers in the middle of this range. Shorebirds were present on Lake Warden for three of the four most recent surveys, but richness was relatively low considering the depths. Shorebird abundance on Lake Warden in Feb 2023 was third highest for the present survey series and exceeded by only one summer survey in the 1980s.
- There is some indication that composition of waterbird communities using the Gore system has been more variable in recent years (from 2014), in both spring and

summer, but there is no general trend in number of species present or in total abundance. The 32 species using the Gore system wetlands in Nov 2020 was equal second highest, whereas the 27 species present in Nov 2022 was slightly below the previous low richness (28 species in Dec 2011). Richness for the Feb 2021 and Feb 2023 surveys were well within the range of previous summer surveys.

- Total abundance of waterbirds on the Gore system in Nov 2020 was within the range of previous surveys but abundance in Nov 2022 declined and lower than for all previous surveys. The Nov 2020 survey saw the return of large numbers of Little Black Cormorant in the flow-through system, after being absent or low in numbers for many years due to low water depths, and Sharp-tailed Sandpipers were recorded in record numbers.
- Total abundance during the Feb 2021 survey of the Gore system was exceptionally low at 2800. The very low abundance of Grey Teal and Australian shelduck was particularly notable, with only 6 Grey Teal (average 1208 for previous summer surveys) and 385 Australian Shelduck (average 1669). The Feb 2023 survey saw a return to a total abundance well within the range of past summer surveys, with the 6813 birds not far below the summer average of 7672. A notable record is the 267 Hooded Plover on Lake Gidon.
- The Gore and Warden systems continue to maintain distinct waterbird communities.

Background

Surveys of waterbirds using wetlands within the Lake Warden and Gore-Quallilup wetland systems (Figure 1 and Figure 2) in November and February 2020/21 and 2022/23 are the latest in a series of surveys that started in 2006, originally associated with the then Lake Warden Recovery Catchment, and that has been reported on previously, most recently by Pinder et al. (2019, 2021).

The surveys have aimed to comprehensively count waterbirds using the Lake Warden and Lake Gore wetland systems, including all wetlands within the Ramsar sites, to;

1. Describe spatial and temporal patterns in contemporary usage of wetlands by waterbirds within these systems, in order to better understand the relative conservation values of wetlands and trends in species abundances.

2. Provide data on waterbird populations for Ramsar Convention reporting.

3. Guide and measure the effectiveness of management actions on waterbird populations.

In this report we present summaries of the data collected to date, focussing on the four surveys undertaken between 2020 and 2023.

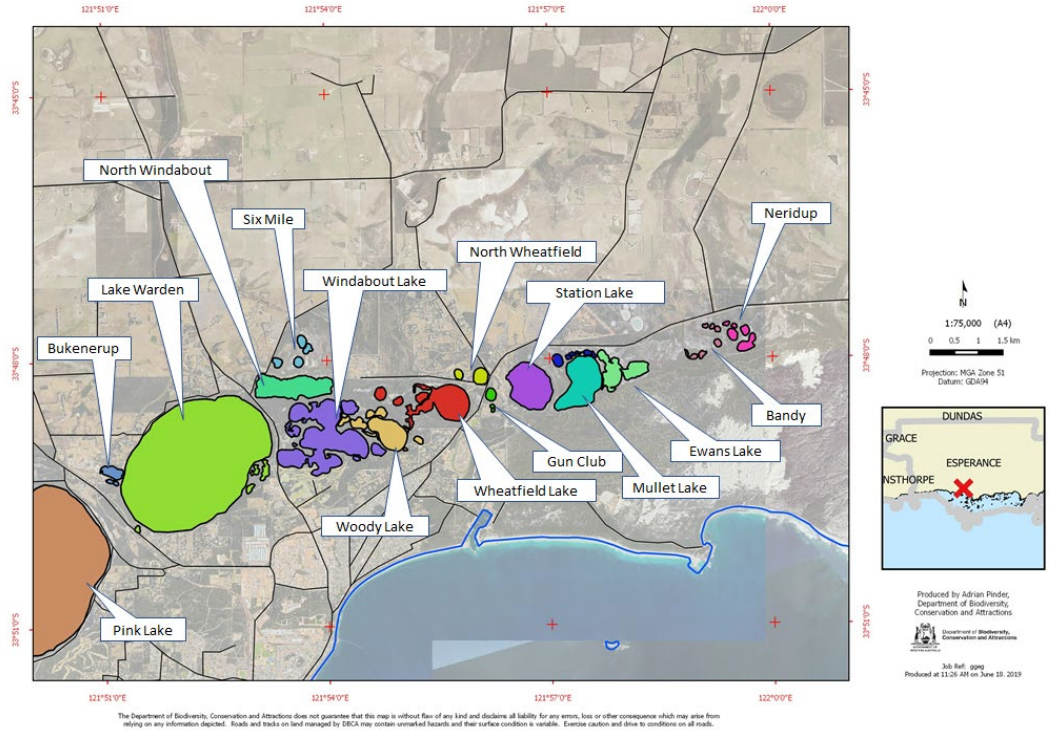

Figure 1. Map showing the Warden system. Colour of wetland polygons indicates suite.

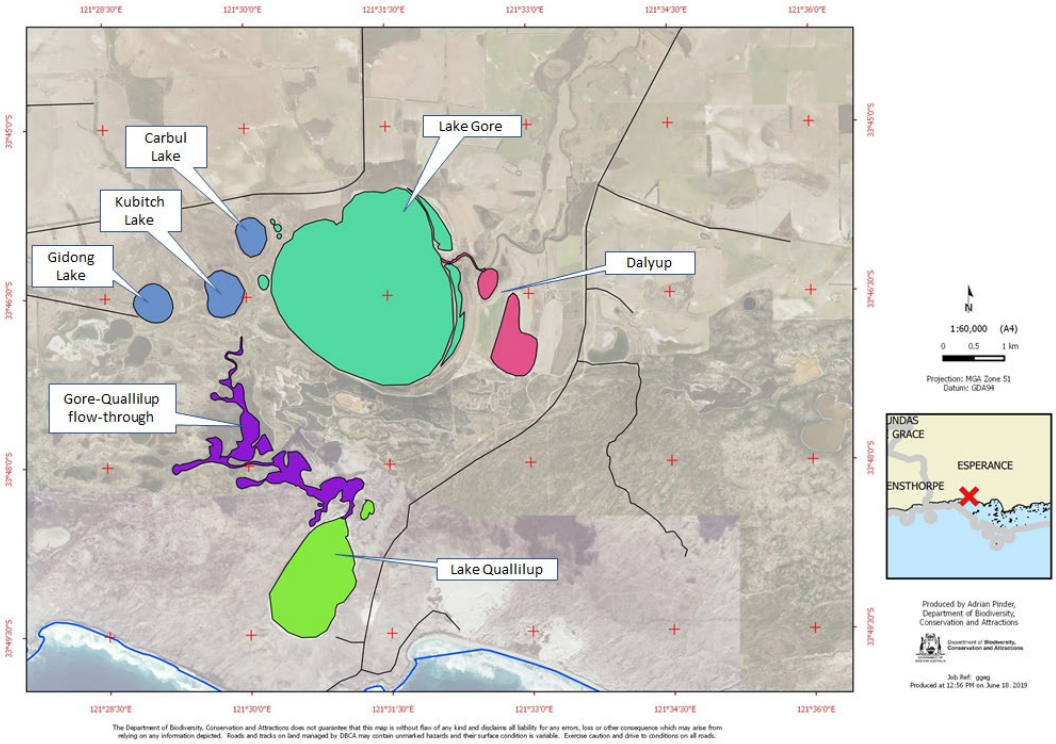

Figure 2. Map showing Gore-Quallilup system. Colour of wetland polygons indicates suite.

Table 1. Wetlands surveyed during the 2020-2023 surveys.

SiteCode	Site name	Subsite	Spring 2020	Dry?	Summer 2021	Dry?	Spring 2022	Dry?	Summer 2023	Dry?
WRP001	Neridup Suite	A	16/11/2020		23/02/2021		31/10/2022		06/02/2023	dry
WRP001	Neridup Suite	B	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	dry
WRP001	Neridup Suite	C	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	dry
WRP001	Neridup Suite	D	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	dry
WRP001	Neridup Suite	E	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	dry
WRP002	Bandy Creek Suite	A	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	
WRP002	Bandy Creek Suite	B	16/11/2020		23/02/2021		31/10/2022		06/02/2023	
WRP002	Bandy Creek Suite	C	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	
WRP002	Bandy Creek Suite	D	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	
WRP002	Bandy Creek Suite	E	16/11/2020	dry	23/02/2021	dry	31/10/2022		06/02/2023	
WRP003	Ewens Lake	A	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP004	Mullet Lake	A	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP005	Station Lake	A	17/11/2020		24/02/2021	dry	01/11/2022		07/02/2023	
WRP005	Station Lake	B	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP005	Station Lake	C	17/11/2020		24/02/2021	dry	01/11/2022		07/02/2023	
WRP006	Gun Club Suite	A	16/11/2020		23/02/2021		31/10/2022		06/02/2023	
WRP006	Gun Club Suite	B	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	
WRP007	Lake Wheatfield	A	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP007	Lake Wheatfield	BC	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP007	Lake Wheatfield	D	16/11/2020		not surveyed		31/10/2022		06/02/2023	
WRP007	Lake Wheatfield	E	16/11/2020		not surveyed		31/10/2022		06/02/2023	
WRP008	North Wheatfield Suite	A	17/11/2020		23/02/2021		01/11/2022		07/02/2023	
WRP008	North Wheatfield Suite	B	not surveyed		23/02/2021	dry	01/11/2022		07/02/2023	
WRP008	North Wheatfield Suite	C	17/11/2020		23/02/2021		01/11/2022		07/02/2023	
WRP009	Woodie Lake Suite	A	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP009	Woodie Lake Suite	C	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP009	Woodie Lake Suite	D	17/11/2020		not surveyed		01/11/2022		07/02/2023	
WRP009	Woodie Lake Suite	E	19/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP009	Woodie Lake Suite	F	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP009	Woodie Lake Suite	G	19/11/2020		24/02/2021	dry	01/11/2022		07/02/2023	
WRP010	Windabout Suite	A	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP010	Windabout Suite	B	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP010	Windabout Suite	C	not surveyed		not surveyed		01/11/2022		07/02/2023	
WRP010	Windabout Suite	D	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP010	Windabout Suite	E	17/11/2020		24/02/2021		01/11/2022		07/02/2023	
WRP010	Windabout Suite	F	17/11/2020		24/02/2021	dry	01/11/2022		07/02/2023	
WRP011	North Windabout Suite	A	17/11/2020		24/02/2021		31/10/2022		06/02/2023	
WRP012	Six Mile Hill Suite	A	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	
WRP012	Six Mile Hill Suite	B	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	
WRP012	Six Mile Hill Suite	C	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	
WRP012	Six Mile Hill Suite	D	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	
WRP012	Six Mile Hill Suite	E	16/11/2020		23/02/2021	dry	31/10/2022		06/02/2023	
WRP013	Lake Warden Suite	A	19/11/2020		23/02/2021		03/11/2022		09/02/2023	
WRP013	Lake Warden Suite	B	not surveyed		not surveyed	dry	03/11/2022		09/02/2023	
WRP013	Lake Warden Suite	C	not surveyed		not surveyed		03/11/2022		09/02/2023	
WRP013	Lake Warden Suite	D	19/11/2020		23/02/2021		03/11/2022		09/02/2023	
WRP013	Lake Warden Suite	E	not surveyed		not surveyed		03/11/2022		09/02/2023	
WRP014	Burkenup Suite	A	19/11/2020		24/02/2021	dry	03/11/2022		09/02/2023	
WRP015	Pink Lake	A	19/11/2020		not surveyed		not surveyed		09/02/2023	
WRP016	Lake Gore Suite	A	18/11/2020		25/02/2021		02/11/2022		08/02/2023	
WRP016	Lake Gore Suite	B	18/11/2020		25/02/2021	dry	02/11/2022		08/02/2023	
WRP016	Lake Gore Suite	C	18/11/2020		25/02/2021	dry	02/11/2022		08/02/2023	
WRP016	Lake Gore Suite	D	18/11/2020		25/02/2021		02/11/2022		08/02/2023	
WRP016	Lake Gore Suite	E	18/11/2020		25/02/2021	dry	02/11/2022		08/02/2023	
WRP016	Lake Gore Suite	F	18/11/2020		25/02/2021		02/11/2022		08/02/2023	
WRP017	Carbul Lakes	A	18/11/2020		25/02/2021	dry	02/11/2022		08/02/2023	
WRP017	Carbul Lakes	B	19/11/2020		25/02/2021		02/11/2022		08/02/2023	
WRP017	Carbul Lakes	C	19/11/2020		25/02/2021	dry	02/11/2022		08/02/2023	
WRP018	Dalyup Suite	A	18/11/2020		25/02/2021		02/11/2022		08/02/2023	
WRP018	Dalyup Suite	B	18/11/2020		25/02/2021	dry	02/11/2022		08/02/2023	
WRP018	Dalyup Suite	C	18/11/2020		25/02/2021	dry	02/11/2022		08/02/2023	
WRP019	Qualilup Lake	A	18/11/2020		25/02/2021		02/11/2022		08/02/2023	
WRP019	Qualilup Lake	B	18/11/2020		25/02/2021	dry	02/11/2022		08/02/2023	
WRP020	Qualilup-Gore Flowthrough	A	18/11/2020		25/02/2021		02/11/2022		08/02/2023	
WRP021	Merrivale Suite	A	17/11/2020		24/02/2021	dry	01/11/2022		07/02/2023	

Methods

Surveys of waterbirds using 65 wetland areas (Table 1) in the Lake Warden and Lake Gore-Quallilup wetland systems was undertaken between 16th and 19th November 2020, 23rd to 25th February 2021, 31st Oct to 3rd Nov 2022 and 6th to 9th February 2023, continuing the series of surveys commenced in 2006. Brief descriptions of these wetlands are provided in Pinder et al. (2019).

The surveys attempted to count all birds present on every wetland. The order, survey effort and methods were the same as for other recent surveys in these systems carried out by DBCA (e.g. Pinder *et al.*, 2019), except that for the first 3 of the above 2020-2023 surveys Lake Warden was only surveyed by spotting from a number of points around the shore as the lake was very shallow and not supporting large numbers of waterbirds in either season. Pink Lake was incompletely surveyed in Nov 2020 and not surveyed at all in Feb 2021 and Nov 2022, but this lake has always been excluded from analyses. To minimise effects of waterbird movement most of the larger lakes in the Warden system, except for Lake Warden) are surveyed on the same day, with one team surveying Ewans, Mullet and Station and a second team surveying the central suite wetlands. At lake Gore the survey attempts to survey the whole system in one day but for some surveys the Carbul Suite wetlands have to be completed the following day.

Lake Wheatfield, Woodie Lake, Windabout Lake, Quallilup Lake and the Quallilup to Gore flowthrough were surveyed by boat (or a combination of boat and on foot for the flow-through). Other wetlands were surveyed on foot. Most surveys involved two observers and there are usually two teams, each working on a different set of wetlands. In 2020-21 observers were Adrian Pinder, Fiona Felton and Mike Venarsky in both seasons, with David Cale in November and Plaxy Barratt from Birdlife WA in February. In 2022-23 observers were Adrian Pinder and Mike Venarsky in both seasons, with Fiona Felton in November and Heidi Bucktin and Adrian Barrett in February.

Weather for the November 2020 survey was fine, warm and clear with light winds. In February 2021 weather was fine, warm and clear but windy on most days. In November 2022 weather was warm, fine and often windy. In February 2023 weather was fine, warm to hot and clear with light winds.

Analyses

Analyses of Warden system waterbirds in this report use data from ground surveys except that aerial data was used where ground surveys were not undertaken as follows:

- Neridup, Bandy Creek and North Wheatfield wetlands in 2006, 2007 and 2008.
- Ewans Lake in 2006 and Ewans Lake and Mullet Lake combined in 2008.

This means some richness and abundance graphs will be slightly different to those presented for ground data in Pinder et al. (2015) and previous reports where aerial data was presented separately.

The Six Mile Hill wetlands were not included in the survey program until 2007 and the 2006 to 2008 surveys did not involve counting at all the satellite wetlands around Wheatfield, Woody, Windabout Lakes and Lake Warden. This means richness and abundance may have

been underestimated compared to later surveys, although the Six Mile Hill Suite and the peripheral wetland rarely contain significant numbers of birds.

Most analyses and graphing were performed in R (R Development Core Team, 2023) within RStudio 2022.12.0 (RStudio Team, 2022). R markdown code, including details of packages used, and the raw data for these analyses can be viewed at https://github.com/AdrianMP62/Warden-Gore-2023.git.

Non-metric multidimensional ordinations were performed using the metaMDS function in vegan (Oksanen *et al.*, 2022). Analyses of Gore system and of Gore and Warden system combined are based on the ground counts undertaken since 2009. Ordinations are performed on raw abundance data rather than square root transformed data. While this means that high abundance species more strongly influence the ordinations than rare species, this is considered appropriate since high numbers of some waterbirds are as important as the presence of particular species.

Ordinations attempt to create a unitless graphic in which surveys with similar composition are placed nearer together than surveys with dissimilar composition. The extent to which the graphic represents actual similarities in composition is measured by a 'stress' value which should be minimised. Three dimensional ordinations have lower stress values than two dimensional ordinations based on the same data and are used when 2D ordination stress was considered too high (<~0.12).

Rainfall data from three weather stations, Esperance (station 9789), Esperance Aero (9542) and Myrup (9584), was downloaded from the Bureau of Meteorology. Cumulative deviations from the monthly mean rainfall values are calculated using the mean monthly rainfall for all years available for each of these sites. CDM was calculated for periods of 3, 6 and 12 months prior to the month of the survey. A small number of missing values were filled by using a regression of one weather stations data against the other two. The number of days that the Wheatfield pipeline was open during the three months prior to each survey, and the number of days since the start of spring (for spring surveys) or start of January (for summer surveys), were also used in the Bio-env analyses below, as was the average depth of gauged Warden system wetlands (Warden, Windabout, Woody, Wheatfield, Station, Mullet and Ewans).

Bio-env in the vegan R package (Oksanen *et al.*, 2022) was used to identify subsets of environmental variables (rainfall, pipeline, timing, as above) that create (Euclidean) survey x survey similarity matrices best correlated with Warden system waterbird (Bray-Curtis) dissimilarity matrices. That is, sets of environmental variables that change between surveys in ways that best match changes in waterbird communities. Strengths and significance of the resulting model were determined by Pearson matrix correlation (between the environmental and biological matrices).Antecedent rainfall

2020/21

Rainfall across southern WA was average to below average for the year prior to the Nov 2020 survey with the 464 mm[1] recorded at the Esperance weather station 11% below average for

[1] Includes 14.5 mm for April 2020 modelled using linear regression from the Myrup (22.8 mm) and Esperance Aerodrome (21.2 mm) values for the same month. BoM data is not otherwise available for April 2020.

this period. Nov 2019 to July 2020 had consistently below average monthly rainfall (Figure 3), with a deficit of 145 mm at the Esperance station, but this was followed by a very wet August along the south-east coast (164 mm compared to an average of 80 mm) (Figure 4). September and October also had below average rainfall (Figure 5), with the Esperance station recording rainfall 45% and 25% lower than average respectively, although 85.8 mm fell during the two weeks preceding the mid-Nov survey. Very little rain fell in south-western Australia between the spring 2020 and summer 2021 surveys (Figure 6), with just 15.4 mm recorded for Dec 2020 and Jan 2021 at the Esperance Station. While there were above average rains in inland WA (100-300 mm) over summer this is unlikely to have created significant inland waterbird habitat.

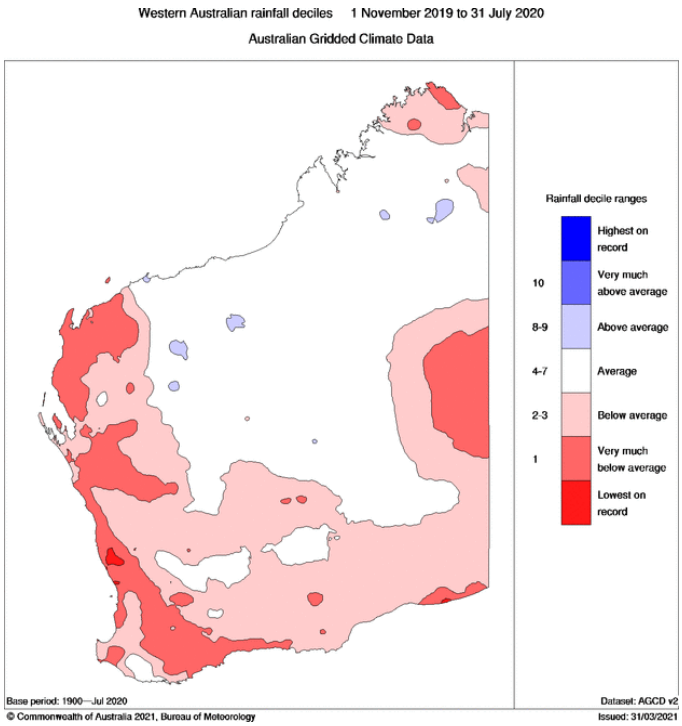

Figure 3. Rainfall deciles for Western Australia for 1 Nov 2019 to 31 July 2020.

A similar pattern of rainfall was recorded at The Myrup and Esperance Aerodrome rainfall gauges. Rainfall at these stations during the 12 months prior to the Nov 2020 survey was 466 mm and 480 mm, or 23% and 16% below average respectively. As for the Esperance station, August was the only above average month for rainfall at Myrup and Esperance Aerodrome, with 124 and 111 mm respectively (51% and 52% above average).

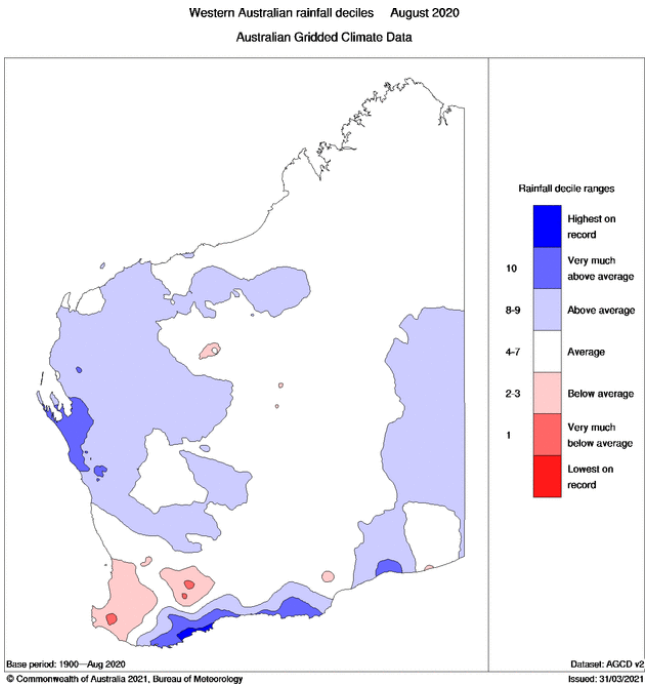

Figure 4. Rainfall deciles for Western Australia for August 2020

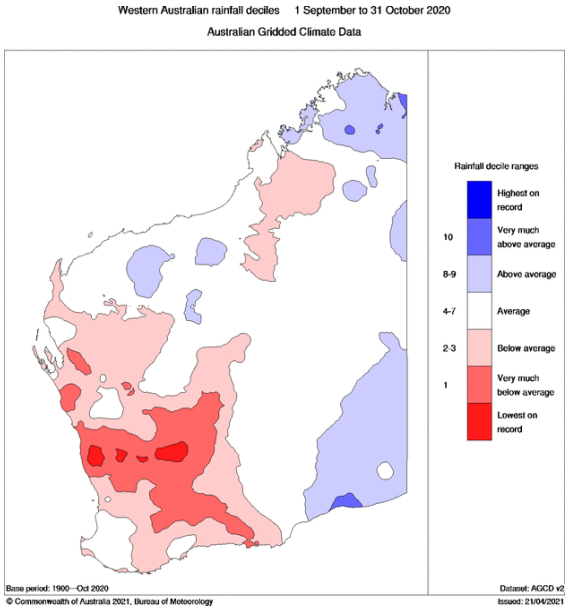

Figure 5. Rainfall deciles for Western Australia for 1 September to 31 October 2020.

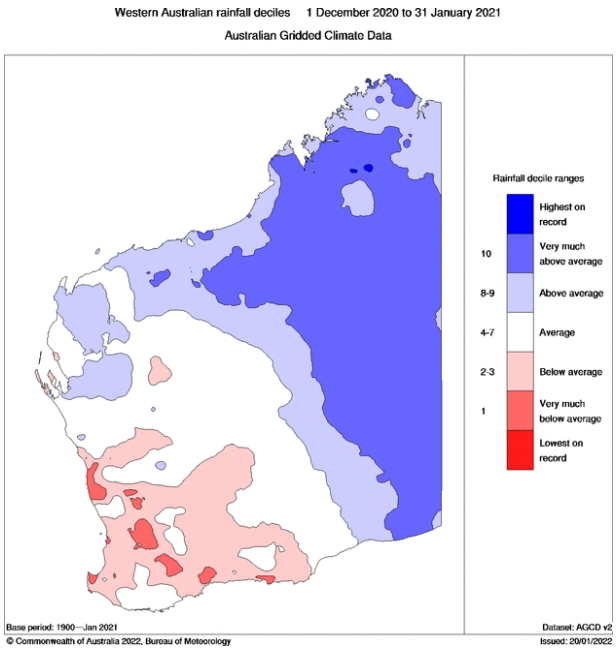

Figure 6. Rainfall deciles for Western Australia for the period 1 December 2020 to 31 Jan 2021.

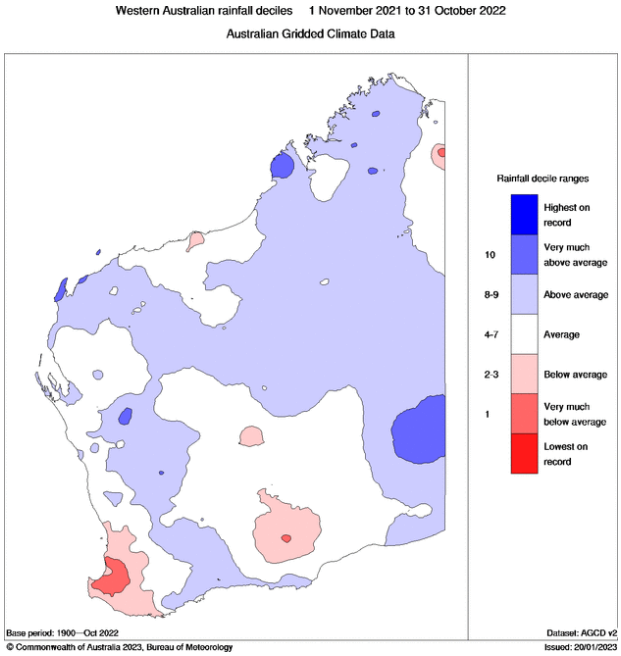

Figure 7. Rainfall deciles for Western Australia for the period 1 Nov 2021 to 31 Oct 2022.

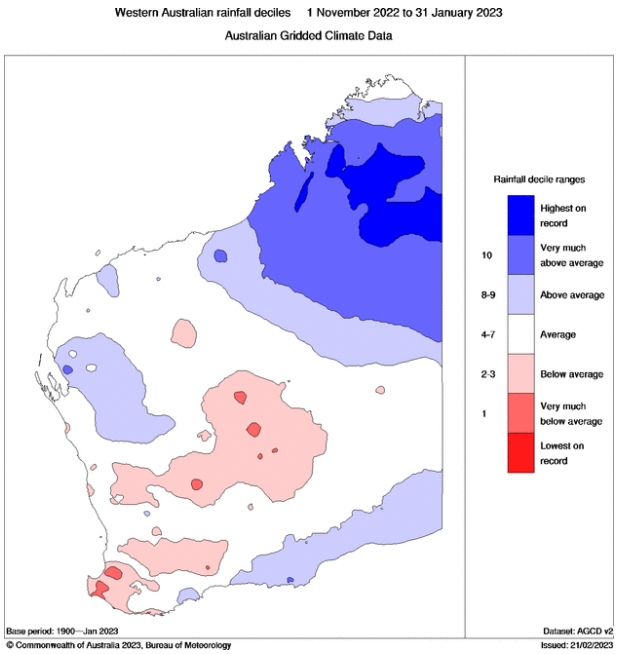

Figure 8. Rainfall deciles for Western Australia for the period 1 Nov 2022 to 31 Jan 2023.

2022/23

Average to above average rains fell across the south coast in the twelve months prior to the spring 2022 survey (Figure 7), with 688 mm, 638 mm and 597 mm recorded at the Esperance, Myrup and Esperance Aerodrome stations respectively. During this period only August and Oct 2022 had significant variation from the monthly mean (139 mm and 110 mm respectively at the Esperance station). Rainfall between the spring and summer surveys (Nov-Jan) was average to below average for most of the south west, but above average along the Esperance coast (Figure 8) primarily due to relatively high rainfall in November after the spring survey.

Wetland depths in the Warden system

Warden wetlands were relatively shallow during the Nov 2020 and Feb 2021 survey, with the Feb 2021 average depth the lowest since the summer surveys started in 2008 (Figure 9). Nov 2022 and Feb 2023 depths were higher, with the Feb 2023 average depth the second highest for the 2006+ summer surveys.

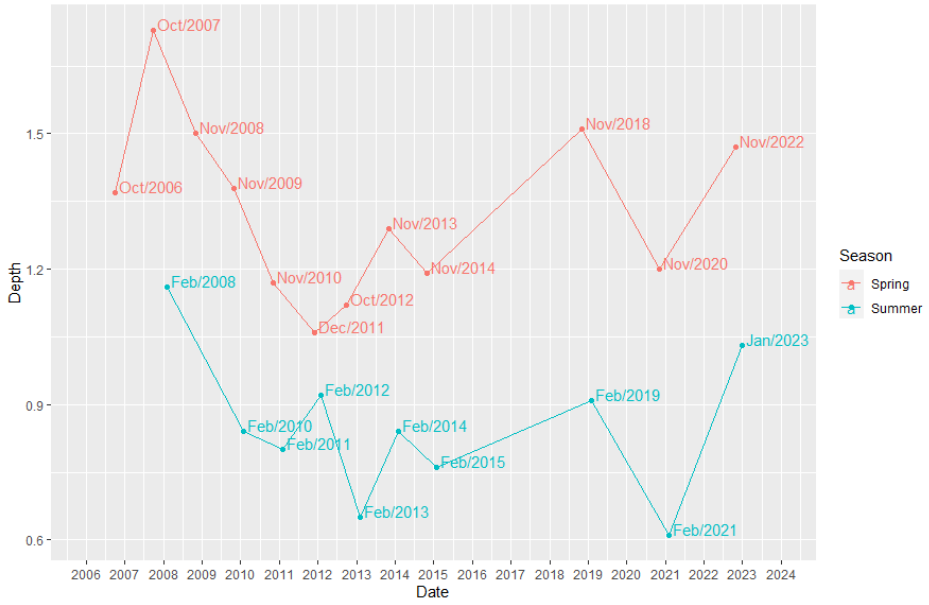

Figure 9. Average depth of gauged Warden System wetlands during each of the spring and summer waterbird surveys.

Figure 10 to Figure 12 show annual patterns in depths for three wetlands (Ewans, Wheatfield and Warden) for the period 2002 to 2023. Depths in Warden wetlands in 2019 and 2020 (orange and blue lines) were particularly low compared to most other years, during at least autumn and winter. Wetlands were deeper in 2022, at least from late winter.

Between 2003 and 2018 Ewans Lake retained water year round, other than 2014 (Figure 10). The lake dried in autumn of both 2019 and 2020 although depth was well within the usual range by the spring 2020 survey (0.94 m). Depths were not recorded between Nov 2020 and Feb 2021 but the Feb 2021 depth (0.42 m, red dot on Figure 10) was relatively low. Depths in winter and spring prior to the Nov 2022 survey (when depth was 1.1 m) were amongst the highest recorded. Depth in Feb 2023 was not especially low at 0.55 m (purple dot).

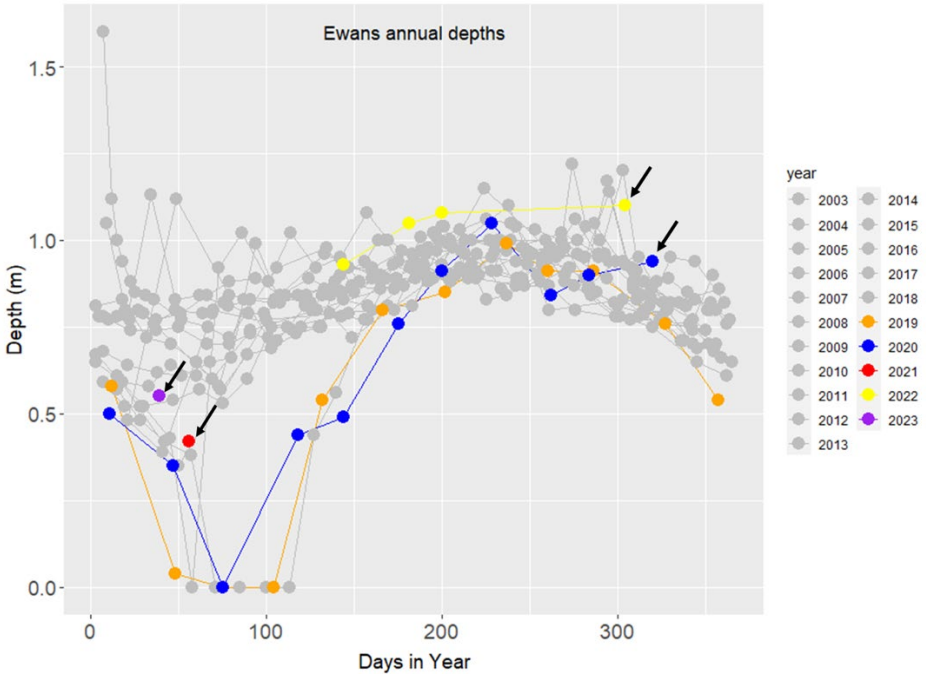

Figure 10. Annual depths of Ewans Lake between 2003 and 2023. Day 1 = 1 January. The 2020 and 2022 line ends at the spring surveys and there is no data for 2021 other than for the Feb 2021 survey. Arrows point to the four 2020-2023 survey dates.

As for Ewans Lake, autumn and early winter 2020 depths in Lake Wheatfield were the lowest since 2002 and while depth increased in late winter/spring it remained low compared to most previous years (1.42 m during the Nov 2020 survey) (Figure 11). The Feb 2021 depth of 0.85 metres (red dot on Figure 11) was similarly low compared to most years since 2002 and represented low summer depths across the central suite wetlands. Depth was also very low in mid 2022 but increased following August rains to be well within the range of previous spring depths (1.8 m in Nov 2022). Depth declined over the 2022-23 summer but only to 1.33 m for the Feb 2023 survey which is about in the middle of the range for late summer.

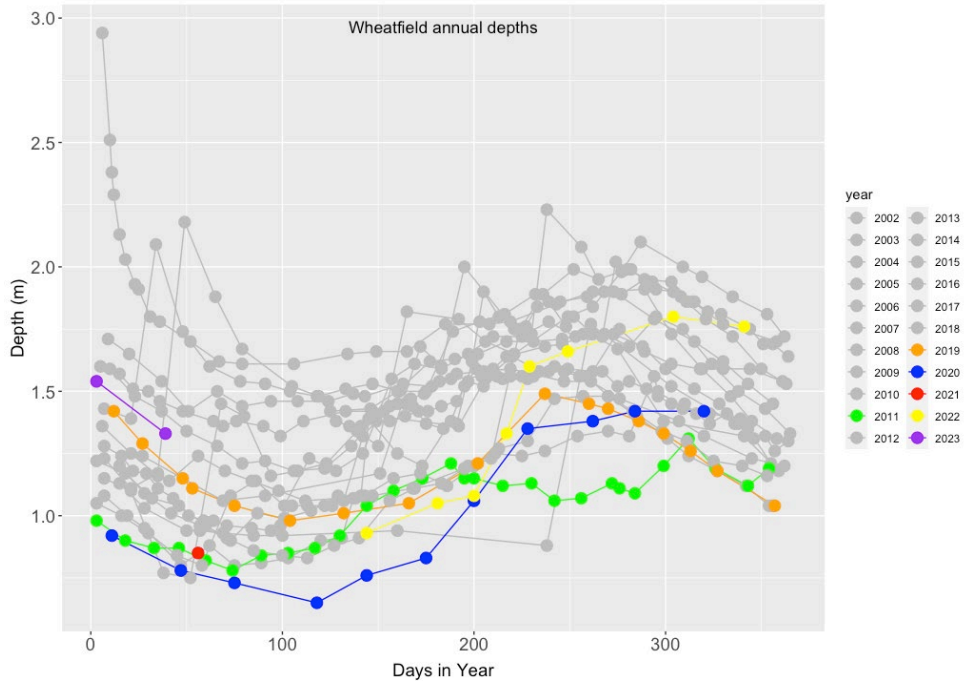

Figure 11. Annual depths of Lake Wheatfield between 2002 and Feb 2023. The 2020 line ends at the Nov survey. The red dot is depth in Feb 2021. Arrows point to the four 2020-2023 survey dates.

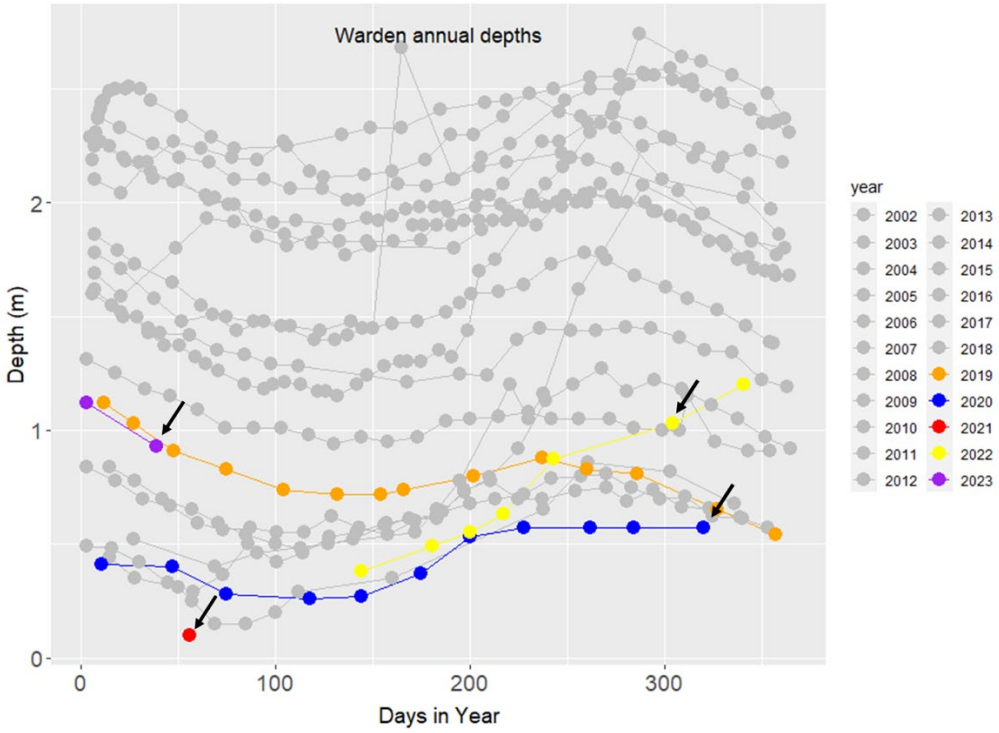

Figure 12. Annual depths of Lake Warden between 2002 and 2023. The 2020 line (blue) ends at the Nov survey. There was no data for 2021 other than during the Feb 2021 survey (red dot). Arrows point to the four 2020-2023 survey dates.

In Lake Warden (Figure 12), depths were very low throughout 2020, comparable only to 2015 and spring depths were the lowest on record since 2002 (0.57 for the Nov 2020 survey). The Wheatfield pipeline was closed in late November 2019 and has not opened since to maximise flows into Lake Warden. In Feb 2021, depth at Lake Warden was so shallow that the water line was beyond the inner-most depth gauge and depth was estimated to about 10cm. As for Ewans and Wheatfield, August rains resulted in spring depths rising from a very low base of 0.38 m to 1.03 m by the Nov 2022 survey. Depth rose further during December 2022 but had fallen back to 0.93 m by the Feb 2023 survey.

Warden waterbirds

Richness Nov 2020 to Feb 2023

Figure 13 and Figure 14 show richness of waterbird communities during spring and summer surveys from 2006. Comparisons below are made only for the same season.

Nov 2020. Richness in Nov 2020 (38) was lower than for all previous surveys except for the partial survey conducted in Oct 2006 (Figure 13) and below the average (42) for previous surveys. Most absences are species that have also been absent during many previous surveys, but there was a larger number of such species than has normally been the case. The absence of Darters was notable, perhaps associated with relatively shallow depths. These are normally present in at least Lake Wheatfield, Windabout Lake and/or Lake Warden. Great Crested Grebe, another diving species, was absent for the first time for the 2006+ surveys. While never present in large numbers, there have always been present in the system, with greatest numbers in some of the earlier surveys, with greatest numbers on Mullet Lake, Lake Wheatfield and Lake Warden. Another notable absence was Whiskered Terns which have been present during most previous surveys, especially on Windabout Lake and Lake Warden. The presence of 12 shorebird species is not unusually low for the Warden system. The two Black-tailed Godwits on Ewans Lake are the first records of this species for the current survey series.

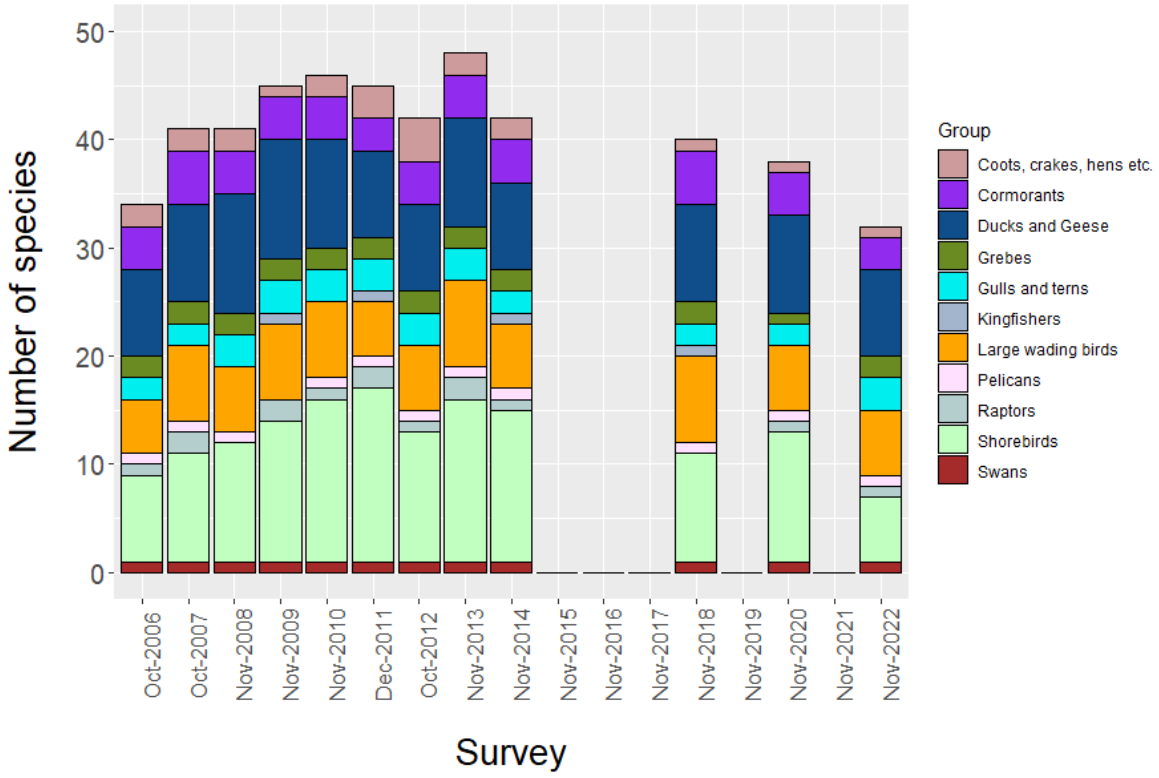

Figure 13. Number of species recorded during spring surveys of the Warden wetland system between 2006 and 2023.

Feb 2021. Only 35 species were present in Feb 2021 (Figure 14). This was the second lowest richness for the 2008+ summer surveys; the lowest being 32 species in Feb 2015. Otherwise, 40 to 46 species have been present in summer. Notable absences are the three larger non-migratory shorebirds (Black-winged Stilt, Red-necked Avocet and Banded Stilt) plus Pink-eared Duck. Some rare occurrences are a Wood Sandpiper on one of the Neridup wetlands and six Black-tailed Godwits on Wheatfield Lake. The only previous 2006+ records of Wood Sandpipers are from Feb and Nov 2008 and Feb 2012. Previous records of Black-tailed Godwit are 2 individuals on Ewans Lake in Nov 2020. Small numbers of Great Crested Grebe (3) and Darter (1) returned to the Warden wetlands after their absence in the previous spring.

Nov 2022. Only 32 species were recorded in November 2022: the lowest richness for the 2006 to 2023 surveys (Figure 13). Species absent in Nov 2022, but normally present, were mostly shorebirds (Common Sandpiper, Hooded Plover, Red-necked Avocet, Sharp-tailed Sandpiper) but also Straw-necked Ibis and Great Cormorant. Other absent species have frequently been absent in the past but in Nov 2022 the absence of several of these, such as Blue-billed Duck and Eastern Curlew coincided. Species diversity would be expected to be lower when total abundance is lower, as some species that are normally present but in low numbers drop out entirely.

Feb 2023. The 42 species present in Feb 2023 was as high as several previous summer surveys and only exceeded twice since 2006 (Figure 14). Richness within taxonomic groups were within previous ranges. Notable records are a Bar-tailed Godwit on Ewans Lake and a Black-

tailed Native Hen on the Woody Lake entrance to the Woody-Windabout channel. The only notable absence is Common Sandpiper (normally up to 14 present).

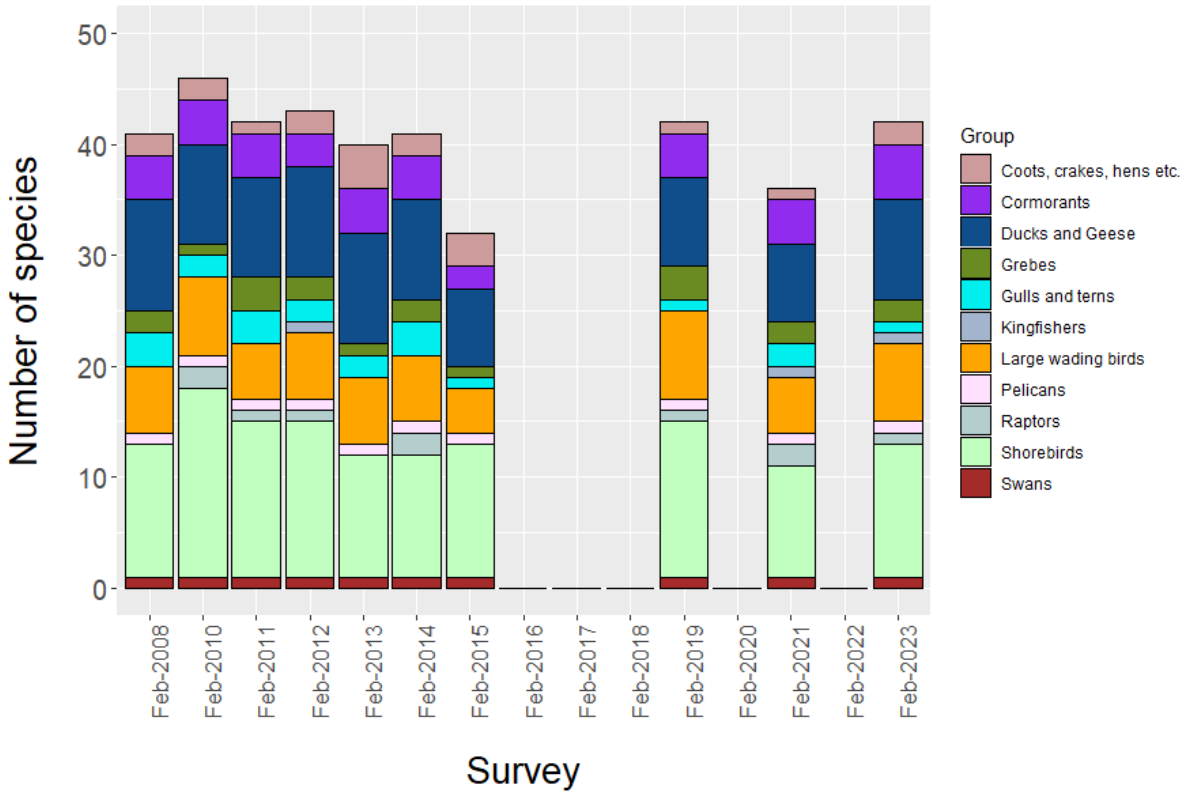

Figure 14. Number of species recorded during summer surveys of the Warden wetland system between 2008 and 2023. No summer surveys were undertaken between 2016 and 2018, nor in 2022.

Abundance Nov 2020 to Feb 2023

Figure 15 and Figure 17 show the cumulative deviation from monthly mean rainfall for the period Jan 2004 to Jan 2023, for three rainfall stations near Esperance, plus total waterbird abundance for spring and summer surveys respectively since 2006. Total abundance is also shown by waterbird group in Figure 16 and Figure 18.

Nov 2020. The 3807 waterbirds using Warden wetlands during the Nov 2020 survey was the second lowest count for the 2006 to 2023 period (Figure 16), with the lowest count being two years later in Nov 2022 (see below). Figure 15 shows that Nov 2020 survey occurred after the largest and longest rainfall deficit for the duration of the 2006+ surveys (a net deficit in rainfall for the period February 2017 to July 2020 of between 274 mm and 392 mm for the three stations). This deficit was steepest for the more coastal stations (Esperance and Myrup) and was especially steep for autumn and early winter 2020 (e.g. 82 mm for the Esperance rainfall station Mar-Jul). Rainfall had been below average for the south-west in the previous year and below to very below average over the winter other than good rains in August.

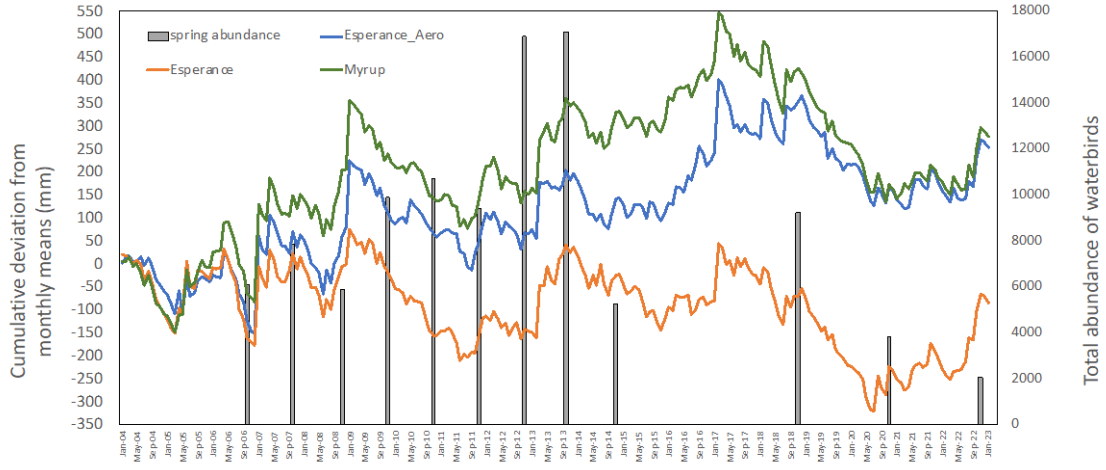

Figure 15. Cumulative deviation from monthly mean rainfall for the period Jan 2004 to Feb 2023 at three Esperance area weather stations, with columns representing total numbers of waterbirds counted for spring surveys since 2006.

Numbers of several species of duck were particularly low. The 370 Australian Shelduck was a very low count compared to counts of >1000 for 2006 to 2013 surveys, although counts in recent years have also been under 1000 (998 in 2014, 800 in 2018 and 384 in Nov 2022). The count of 452 Black Swan is also second only to the Nov 2022 count of 284. The 2006 to 2018 average for this species is 1153. Numbers of Chestnut Teal (65) were only about half the next previous low count (121) in 2008, much lower than the 2006 to 2018 average of 333, but about the same as the Nov 2022 count (71). Grey Teal numbers (749) were also much lower than the 2006 to 2018 average (1610) but higher than the Nov 2022 count of 92. Only 14 Hardhead were observed, compared to the 2006 to 2018 average of 413. Only one Straw-necked Ibis was recorded, compared to a 2006 to 2018 average of 154.

Banded Stilt vary greatly in number in the Warden system and, when abundant (sometimes several thousand), mostly congregate on Lake Warden. In 2020, Lake Warden was particularly shallow which meant that salinity was likely too high for shorebird invertebrate food and only a single Banded Stilt was observed across the Warden system. Red-necked Avocet were low in number (17) for the same reason. Several weeks prior to the Nov 2020 survey large numbers of Banded Stilt were present on Pink Lake (R. Cail pers. comm) but were not seen during the partial survey of this lake in Nov 2020. Numbers of most migratory shorebirds were not unusual, except for relatively low numbers of Common Greenshank (5 compared to an average of 71 for 2006 to 2018) and the presence of two Black-tailed Godwit.

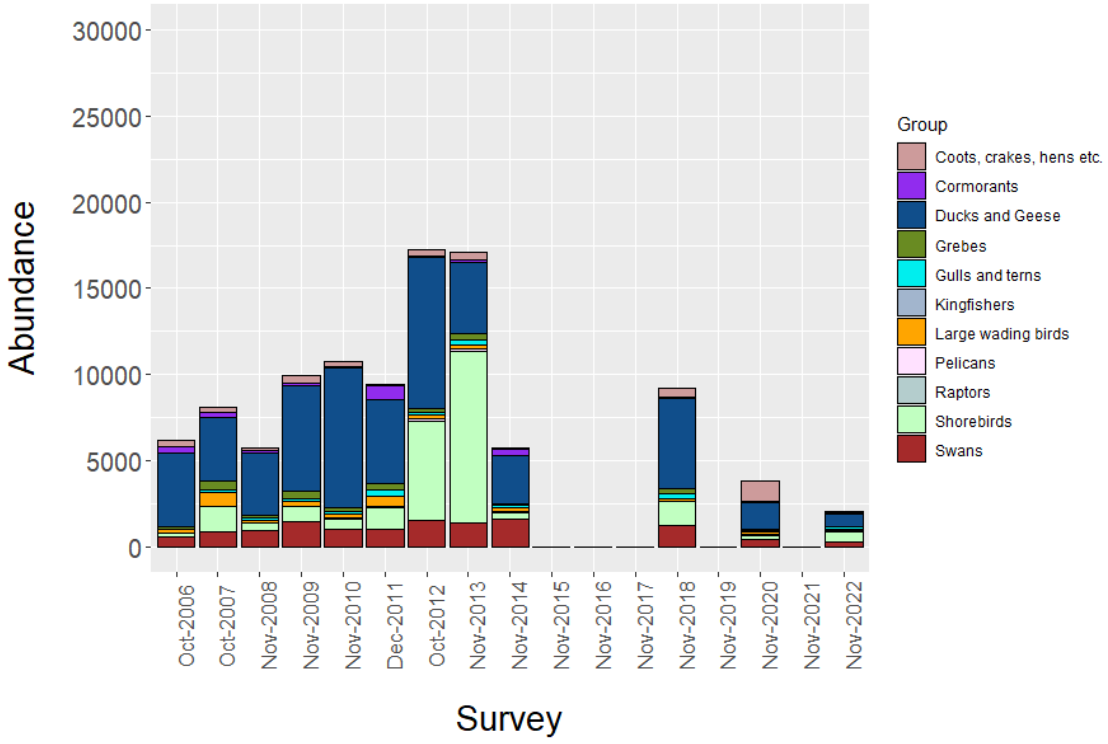

Figure 16. Abundances of waterbirds using the Warden system during spring surveys conducted between 2006 and 2020. Note that no surveys were undertaken in 2015 to 2017 and 2019.

The only species that was notably abundant was Eurasian Coot (1151 compared to a 2006 to 2018 average of 304), mostly on the central suite wetlands and possibly taking advantage of the shallower water for feeding.

The low abundance of waterbirds on the Warden system in Nov 2020 suggests that the 'missing' birds were elsewhere, and this may be related to the low depths in the Warden wetlands earlier in the year (Figure 10 to Figure 12) and/or to better habitat elsewhere, plus the low depth and high salinity at Lake Warden. However, rainfall was consistently low across most of the south-west during 2020 (Figure 3 to Figure 5) so it would not be expected that waterbirds were using significantly better wetland areas elsewhere in the south-west. Cyclone Blake brought heavy rains to central WA in January 2020, resulting in some central desert wetlands filling, including Lake Carnegie. A survey of that lake in June 2020 recorded an estimated 275000 waterbirds, including >100000 Grey Teal and >13000 Banded Stilt. Interestingly, the numbers of Grey Teal (2571) using the Warden and Gore system combined was not significantly below the average (3295 for the 2009 to 2018 ground counts) so the inland rains may not have had much impact on that species in the Warden system.

Feb 2021. Total abundance had increased over the 2020/21 summer so that 11370 were counted in Feb 2021, which is well within the range recorded in those summer surveys without large numbers of Banded Stilt (all years except for 2015 and 2019). This is despite summer rainfall being below to very below average across the south-west over the 2020-21 summer, and may reflect even less water elsewhere in the south-west (Figure 17).

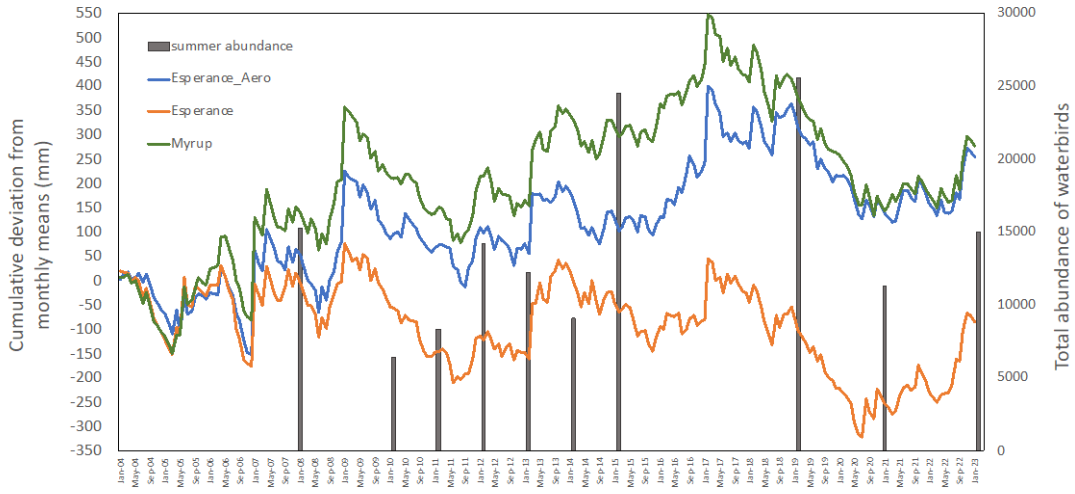

Figure 17. Cumulative deviation from monthly mean rainfall for the period Jan 2004 to Feb 2023 at three Esperance area weather stations, with columns representing total numbers of waterbirds counted for summer surveys since 2006.

This was only the second time since 2006 that Banded Stilt, Red-necked Avocet and Black-winged Stilt have been absent. A large part of the explanation for the absence of the first two of these species is that Lake Warden was nearly dry. However, the count of 621 smaller shorebirds was also low compared to recent years (1003 to 1995 between 2012 and 2019) but only slightly lower than the 637 to 783 present in some earlier years (2006, 2008 and 2010). Number of Red-necked stints (420), Hooded Plover (24) and Sharp-tailed Sandpiper (11) were especially low compared to recent years, though higher than in Feb 2023 (see below).

The number of Pacific Black Duck (3190) is the highest count for the 2006+ surveys (previous range 188 to 2676), as is the count of Yellow-billed Spoonbills (140 compared to a previous range of 62 to 120, mostly <80). Eurasian Coot are usually low in number in the Warden System and the 1543 in Feb 2021 is the third highest count. The shallow depths in the central suite would have provided greater feeding habitat for the coot, spoonbills and Pacific Black Duck than would be the case when these wetlands are deeper, but may not have suited the diving species like grebes, especially as the dense macrophyte occupied much of the water column across the central suite.

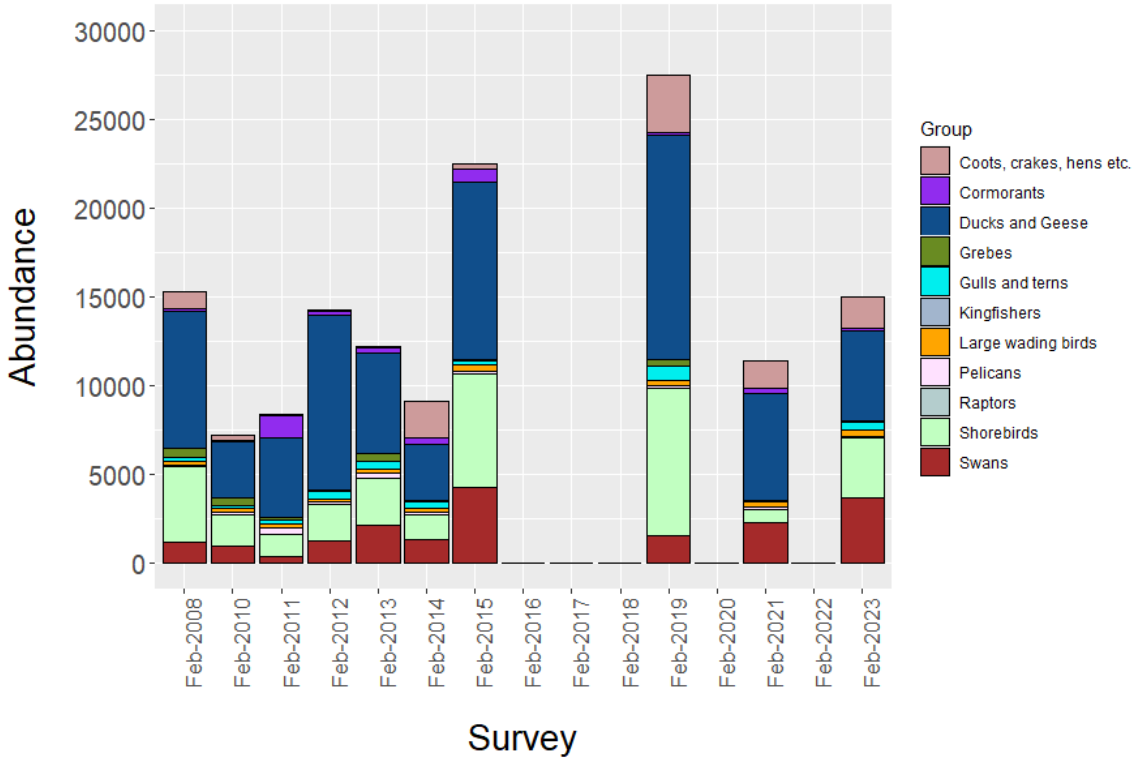

Figure 18. Abundances of waterbirds using the Warden system during summer surveys conducted between 2006 and 2023. Note that no summer surveys were undertaken between 2016 and 2019, nor in 2020 and 2022.

Most non-shorebird species were present in numbers within ranges observed since 2006. Exceptions were Chestnut Teal (46) and Hoary-headed Grebe (3). Chestnut Teal normally have highest abundance on Lake Warden and Windabout Lake and Hoary-headed Grebe are also normally in highest abundance on Lake Warden. That Lake Warden was nearly dry largely explains the low numbers of these two species.

Nov 2022. The 2068 individuals recorded in Nov 2022 was the lowest of the 2006-2023 counts (Figure 16). This was particularly the case for ducks and geese, with just 711 compared to a previous range of 2813 to 8793 (average 5172), but almost all species had below average abundance. This is despite 2021-2022 having average to above average rainfall along the south coast, particularly in late winter and spring of 2022, prior to the November survey (Figure 15), which reduced the rainfall deficit for the Esperance Station by 110 mm (less for the other two stations). Rainfall elsewhere in Western Australia during 2022 does not clearly explain the low numbers of waterbirds on this system during this survey. Much of arid Western Australia had 'very much above average' rains in early to mid-spring, but not amounts that would create extensive waterbird habitat. It is possible that some waterfowl moved east in response to extraordinary rains in 2021-2022. Very little is known about movements of waterbirds between the south-west and other parts of Australia, especially eastern Australia, though some certainly make large movements across the continent in response to episodic wetland filling events (Halse *et al.*, 2005; Pedler, Ribot & Bennett, 2014). There is evidence, albeit limited, of west-east waterbird movements (Downes, 1955; Kingsford & Norman, 2002). Grey Teal is a candidate here since only 92 were found on this system that has supported >1000 in most years and these are known to be continentally nomadic at times (Roshier, Asmus & Klaassen, 2008). Many of the other species that were

also low in abundance, such as cormorants, are probably not moving such distances and must have found suitable habitat elsewhere in south-western Australia.

Feb 2023. Rainfall across the south-west was below to very below average over the 2022-23 summer (fewer than 25 mm) except for the eastern coast (Figure 8). Large numbers of waterbirds returned to the Warden system over this period, resulting in the 4th highest count (14968) since 2006 (Figure 17 and Figure 18). Counts of most groups were within previous ranges, including Grey Teal with 1908 present. Pelicans were not as abundant as they have been, with just 55 recorded (previous range 114 to 323). Only one common Greenshank was present whereas there are normally more than 50 and often more than 100. There were fewer Little Black Cormorant (46) than has been present for all other 2006+ surveys but these move between the Gore and Warden system and there were 700 on the Gore system in Feb 2023. Red-necked Stint were absent whereas there have been 420 to 1221 during previous surveys. A few species had the highest counts (2005 Red-necked Avocets, 199 White-faced Heron) or second highest counts (3654 Black Swan, 149 Red-capped Plover, 508 Silver Gulls).

General patterns in waterbird communities of the Warden wetland system

Spring surveys. Discounting the partial Oct 2006 survey, species richness in spring from 2007 to 2013 was consistently over 40 species. Richness declined over the next few surveys, from a high of 48 in 2013 to 32 in 2022. Shorebirds showed the greatest decline, with 15 species present in 2013, 14 in 2014, 12 in 2020 and only 6 in 2022. The last two spring surveys have also been characterised by particularly low abundance, especially amongst ducks, grebes and swans, but also larger wading birds (herons etc.) and shorebirds (especially the non-migratory Red-necked Avocet and Banded stilt) associated with lower depths in Lake Warden in recent years).

Figure 19 is an ordination that portrays similarity of composition of waterbird communities using Warden wetlands during spring, with each survey represented by a circle coloured and scaled by average depths in the gauged wetlands (larger and darker = deeper). Greater between circles indicates greater differences in composition. The Nov 2020 and Nov 2022 surveys are positioned outside of the range of previous spring surveys, suggesting waterbird composition during these surveys was atypical. For the Nov 2020 survey this may reflect the unusually low depths during autumn and early winter prior to the survey (Figure 10, Figure 11 and Figure 12). Not surprisingly, given the low richness and the low abundance of most species, the overall composition of the Nov 2022 waterbird community was notably different to all previous surveys, even to those with similar high wetland depths such as 2008 and 2018 (Figure 19). Despite the separation of both the Nov 2020 and Nov 2022 from previous surveys, there is still a pattern of waterbird composition being associated with wetland depth, with deeper periods to bottom and right of the plot (paler larger symbols) and shallower conditions to towards the top and left (smaller, darker symbols). The ordination also suggests a temporal transition in composition from the earlier surveys (2006 to 2009 towards the right), middle surveys (2010 to 2018 nearer the centre) and the two later surveys (2020 and 2022, to the bottom and left). However, few individual species showed temporal trends in abundance (Figure 20). Australian Shelduck were less common during the last four spring surveys, with all 2014 to 2022 counts being <1000, Hoary-headed Grebes were less abundant during the last two surveys (2020 and 2022) and Yellow-billed Spoonbills less common in most surveys since 2012. Australian Pelicans were more abundant in most years from 2012. Several species

were more abundant for various spans in the middle years, such as Grey Teal (2010-2018), Red-necked Avocet (2009-2013), Australian White Ibis (2009-2014), Black Swan (2009-2018) and several species of shorebirds (including Hooded Plover, Red-necked stint and Sharp-tailed Sandpiper) showed similar patterns, the latter partly related to more suitable depths in Lake Warden for several years after 2009. Banded Stilt were particularly abundant in 2012 and 2013.

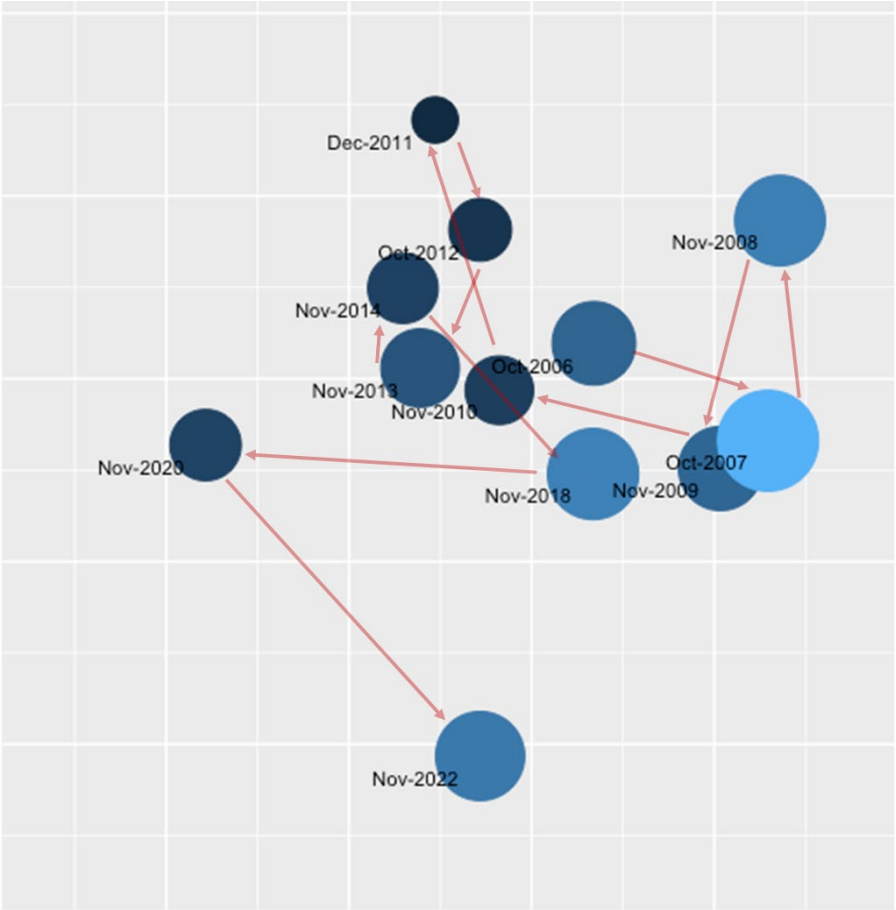

Figure 19. An nMDS ordination of waterbird communities using Warden wetlands during spring from 2006 to 2022. Axes 1 v 2 of a 3D ordination. Stress = 0.08. Arrows are year transitions.

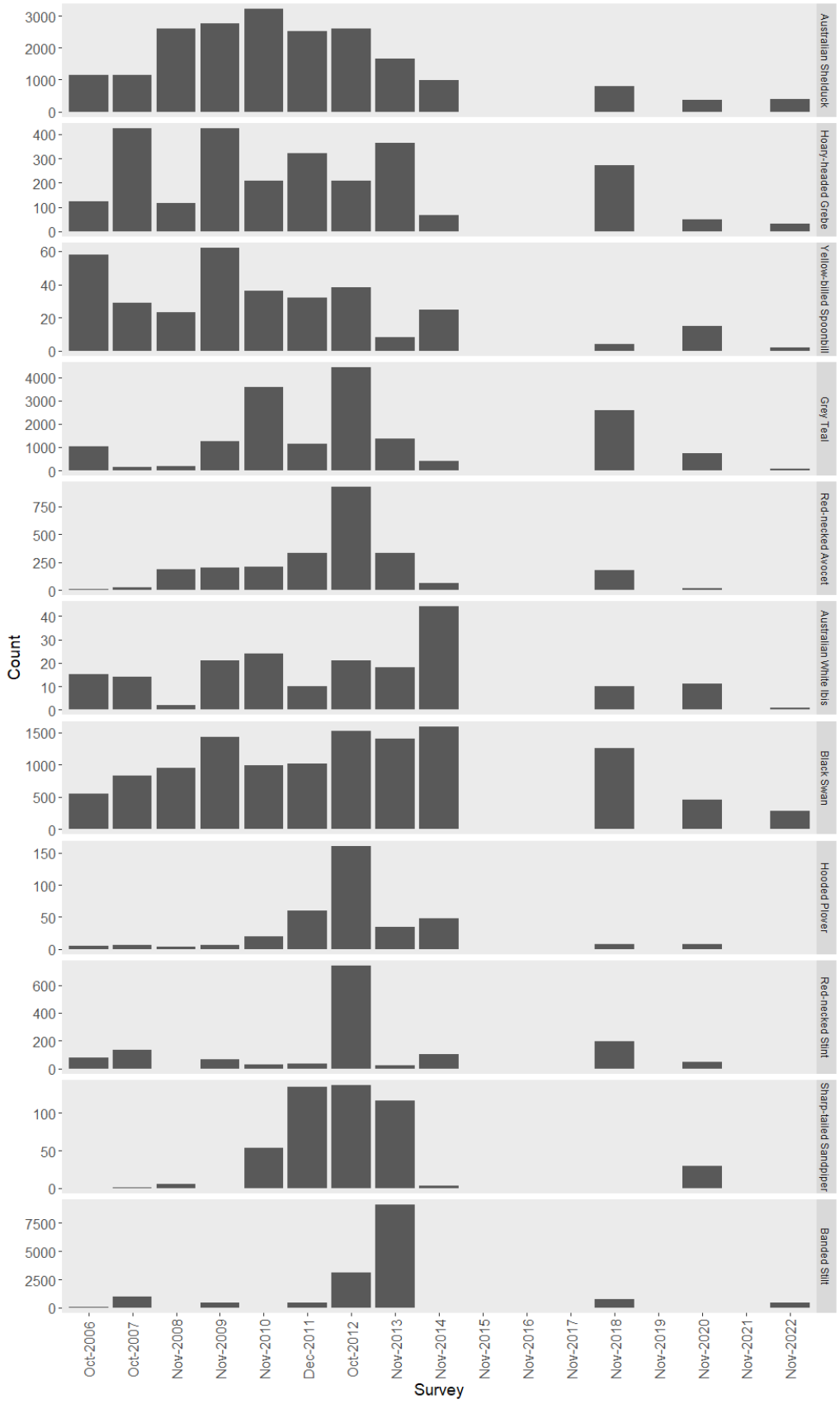

Figure 20. Changes in abundance of selected species over the course of the 2006 to 2022 spring surveys. Note that no surveys were undertaken in 2015 to 2017, 2019 and 2021.

Summer surveys. There have been no distinct patterns in richness and total abundance amongst the summer surveys. There have been a couple of years of lower than usual richness (2015 and 2021) but adjacent years (2019 and 2023) had similar richness to the 2006 to 2014 period. Total abundance has been variable in summer but without a discernible trend.

Figure 21 is an ordination of waterbird communities using Warden wetlands during summer between 2008 and 2023, with colour and size of the survey symbols scaled by average depths in the gauged Warden wetlands. As was the case up to 2019 (Pinder *et al.*, 2019), there is little relationship between average wetland depth and waterbird community composition in summer compared to spring. The Feb 2021 and Feb 2023 surveys were on the edge of the spread of previous surveys but not so separated from them as was the case for the associated spring surveys. Looking at the arrangement of surveys in this plot there may be a transition in composition from the earlier surveys in the bottom left to the latest surveys in the top right (following the arrows). However, ordination plots have no meaningful scale so even if this is a real transition it may be of little significance and would not necessarily indicate a negative change. Also, the 2008 survey is no more different to the 2023 survey than it is to the 2012 survey.

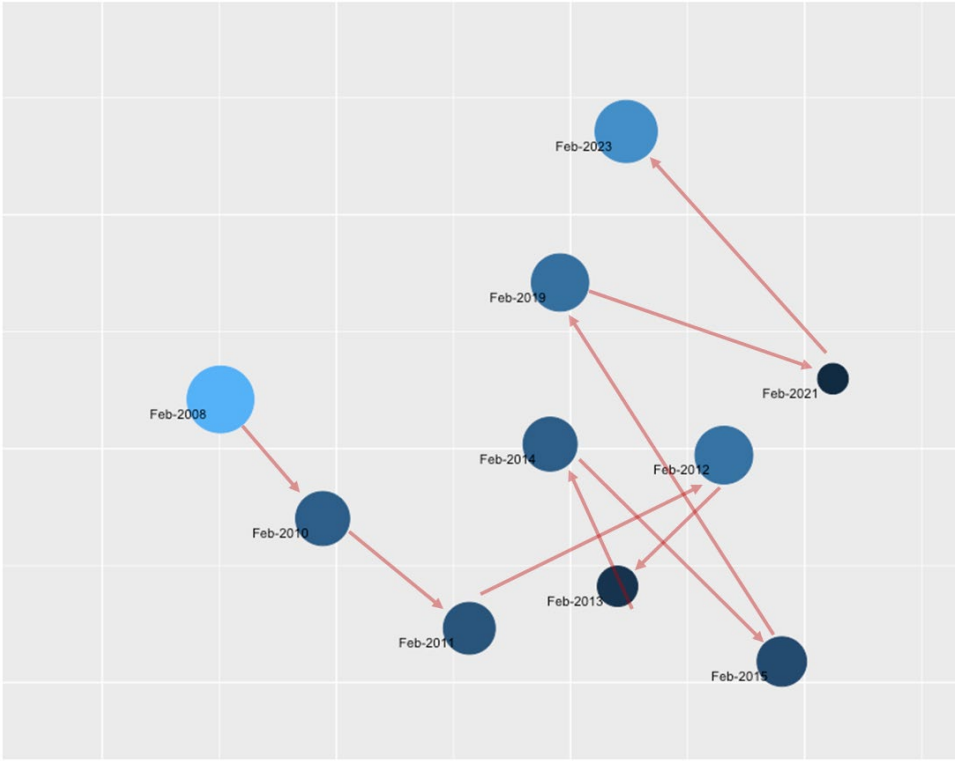

Figure 21. An nMDS ordination of waterbird communities using Warden wetlands during summer from 2008 to 2023. Stress = 0.10. Arrows are year transitions.

Despite the apparent shift in composition, few individual species showed strong temporal trends in abundance. Darter and Common Greenshank each had a moderate decline in abundance after 2011 and 2012 respectively. Hoary-headed Grebe were less abundant in the

two most recent surveys. Eurasian Coot have tended to be occur more consistently in numbers >1000 since 2014 and Silver Gulls and Red-capped Plovers have been more abundant since 2012. Sharp-tailed Sandpipers had greater abundance over the 2012-2019 period and Little Black Cormorants and Hooded Plovers showed a similar pattern over the 2011-2015 period. Abundances of these species are shown in Figure 22.

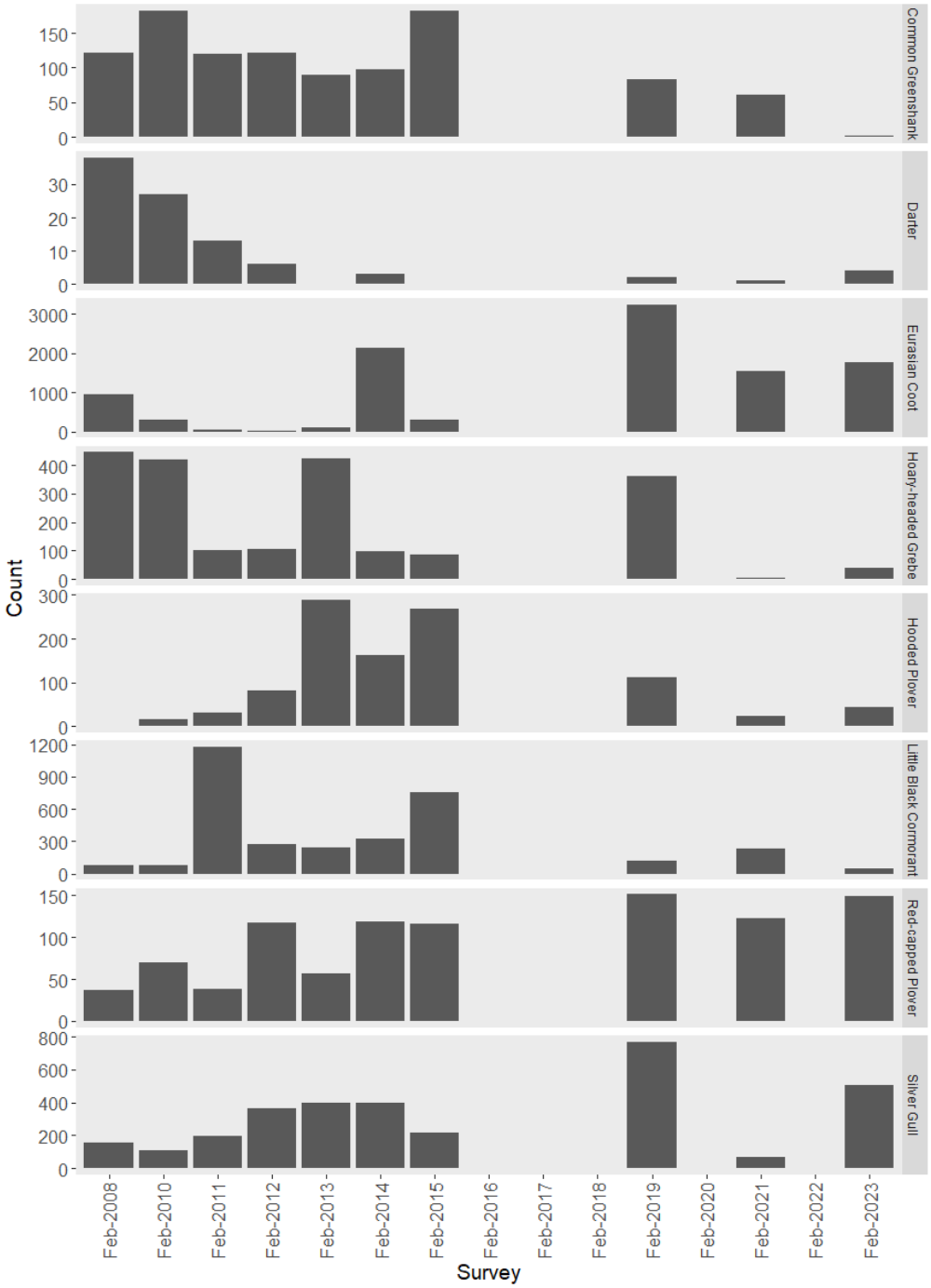

Figure 22. Changes in abundance of selected species over the course of the 2008 to 2022 summer surveys. Note that no surveys were undertaken in 2016 to 2018, 2020 and 2022.

Influence of rainfall and depth on Warden system waterbird assemblages

Pinder et al. (2019) investigated the influence of antecedent rainfall and depth at the time of the survey on waterbird assemblages. Antecedent rainfall explained about a third of variation in assemblage composition in 2006 to 2018 surveys conducted in spring. Addition of the 2020 and 2022 data extended the gradients of both antecedent rainfall and assemblage composition, and a new model including 6 month CDM for the Esperance Station and 12 month CDM for the Myrup station increased the explanatory power to about R = 0.47 ($p<0.01$). Adding in the number of days in which the Wheatfield to Bandy Creek pipeline was open in the three months prior to the surveys increased explanatory power to R = 0.57 ($p<0.01$), using the number of days the pipeline was open plus the same CDM variables. On its own, the number of days the pipeline was open prior to the survey was also correlated with assemblage composition (R = 0.33, $p<0.01$). Variation in timing of the spring surveys was not correlated with assemblage composition.

The best model the 2008 to 2019 summer surveys (with or without pipeline days available for selection) consisted of just the 6 month CDMs for the Esperance Aerodrome and Myrup weather stations, with a correlation (R) of 0.30 (Pinder *et al.*, 2019). Addition of the 2021 and 2023 data resulted in a model with an increased correlation of R = 0.37 ($p<0.05$) and 6 month CDMs from the Esperance and Esperance Aerodrome weather stations selected as best correlates. The summer waterbird communities thus seem to be more influenced by CDMs over shorter terms compared to spring communities. This may reflect the importance of rates of drying of the wetlands between the spring and summer surveys. Neither timing of the summer surveys, nor the number of days that the pipeline was open prior to the survey were correlated with assemblage composition.

These analyses suggest that antecedent rainfall, perhaps indicating antecedent depths, or habitat availability at a regional scale, have a greater influence on waterbird communities than depths at the time of the survey. This would reflect decision-making by waterbirds about whether the Warden wetlands provide suitable (or more suitable than elsewhere) habitats over periods of months. Nonetheless, they also show that climate (most likely as an indicator of hydrological conditions) are a significant driver of waterbird communities in the Warden system.

Species for which the Warden wetlands support >1% of the global population

Chestnut Teal

Numbers of Chestnut Teal are highly variable from year to year (Figure 23) making comment about trends difficult. Between 2007/8 and 2012/13 the number of this species using the system increased over summer. This has mostly not been the case post 2013, although the pattern was again observed in 2022/23. Counts between Feb 2019 and Nov 2022 were much lower than previous spring or summer counts, although this series of surveys followed very high numbers present in Nov 2018, and the Feb 2023 count was back in the range of 2006-2015 summer counts. Chestnut Teal are usually in greatest numbers on Windabout Lake and Lake Warden. The low depths (and presumed associated high salinity) at Lake Warden in 2020/21 may have contributed to the low abundance in those surveys, although Windabout should have provided adequate habitat. The 306 Chestnut Teal present in Feb 2023 were spread across several wetlands including one of the Bandy Creek wetlands, the two North

Wheatfield wetlands, Mullet Lake, Lake Wheatfield and Lake Warden. One percent of the estimated global Chestnut Teal population is 50 and this has been exceeded in all counts except for Feb 2021 (46 individuals). Ongoing surveys will allow an assessment of whether the recent low numbers of this species is a concern.

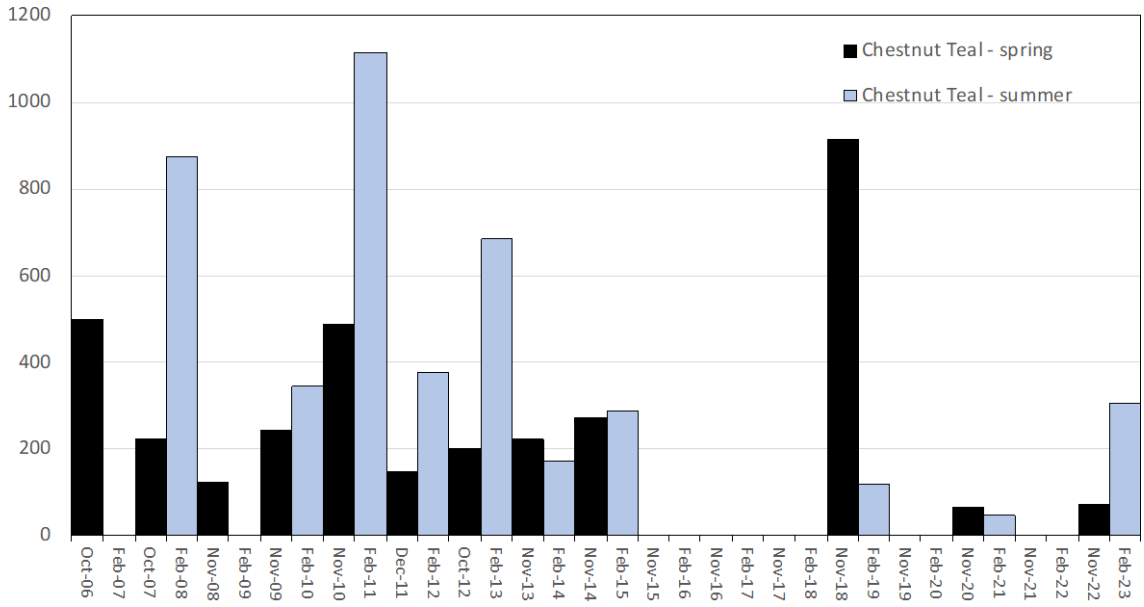

Figure 23. Abundance of Chestnut Teal across the Warden wetlands during surveys undertaken between Oct 2006 and Feb 2023. Blank columns = no survey.

Hooded Plover

Hooded Plover have been present during all but two of the 2006-2023 surveys (Figure 27). The large increase in numbers after 2009 is an effect of increased area of shorebird habitat in Lake Warden, in large part due to operation of the Wheatfield to Bandy Creek pipeline. The low 2020/21 counts coincide with particularly low depths across the system with Lake Warden almost dry. The species was absent from the system in Nov 2022 when depths were much higher in Lake Warden, but not so high as to have eliminated shore habitat for this species, so its absence is surprising. Station Lake also provides good habitat for Hooded Plovers, but only in the summer surveys when depth is <30cm.

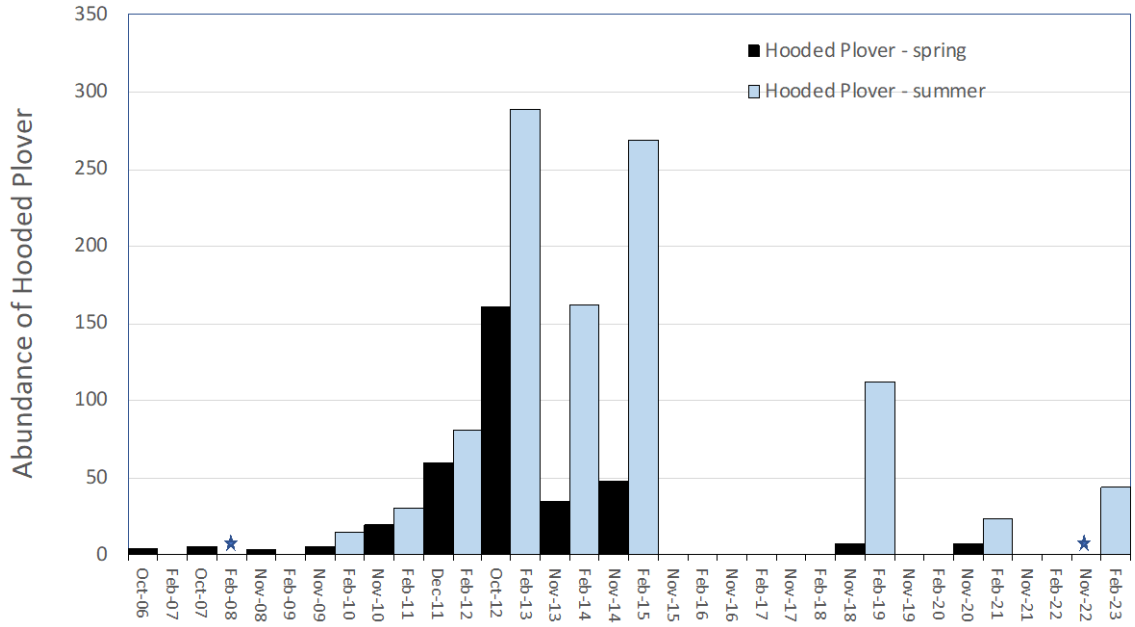

Figure 24. Abundance of Hooded Plover across the Lake Warden system during surveys undertaken between Oct 2006 and Feb 2023. Asterisks = survey carried out but no Hooded Plovers present. Other blank columns = no survey.

Shorebirds using Lake Warden

Figure 25 shows the abundance of shorebirds on Lake Warden versus depth for the 1980s (Jaensch *et al*., 1988), 2006 to 2008 (current survey program before installation of the pipeline), 2009 to 2019 (prior to the current four surveys) and 2020 to 2023. For the 1980s data only counts from Oct-Feb are shown for consistency with the 2006+ data. Shorebird abundance varied during the 1980s (when depth was always < 1.5 m) including one survey (Nov 1982) with large numbers of Banded Stilt and a total shorebird abundance of 7841. The four surveys over the 2006 to 2008 period were all undertaken when depths were over 2 m and shorebirds were only present during one of those (44 Red-necked Avocet in Feb 2008). Depth was still high in Nov 2009 (2.2. m) and no shorebirds were recorded. The next two surveys (Feb 2010 and Nov 2010) were undertaken when depths had declined to 1.65 and 1.68 m and shorebird abundance had increased to 243 and 195 respectively. Depths for 2011 to 2019 were below 1.5 m and shorebird abundances were generally back within the range for the 1980s counts, including two surveys with over 7000 shorebirds (Nov 2013 and Feb 2019) comprising primarily Banded Stilt (in Nov 2013) or Banded Stilt and Red-necked Avocet (in Feb 2019).

Depth in Nov 2020 was 0.57 m and there were only 37 shorebirds. Depth declined to 0.1 m by Feb 2021 and no shorebirds present. With the lake being deeper in Nov 2022 (1.03 m) and Feb 2022 (0.93 m) shorebirds returned, with the Feb 2023 count of 3183 being the fourth highest on record.

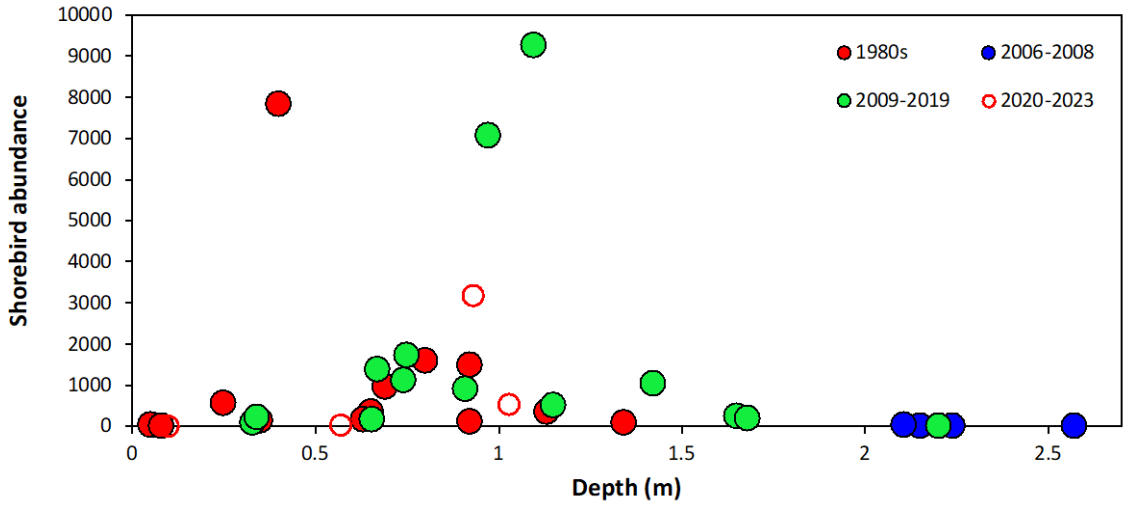

Figure 25. Abundance of shorebirds at Lake Warden during spring and summer surveys undertaken in the 1980s and during the 2006+ surveys split into three periods.

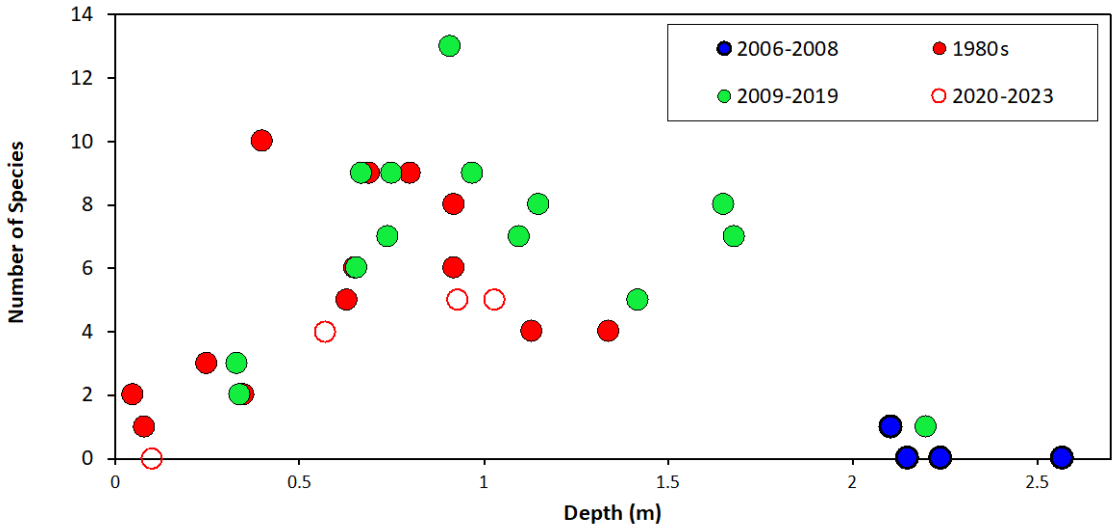

Figure 26. Richness of shorebirds at Lake Warden during spring and summer surveys undertaken in the 1980s and during the 2006+ surveys split into three periods.

Richness of shorebirds using Lake Warden follows a similar pattern (Figure 26), with richness above 4 species only when depth is between 0.4 and 1.7 m. Depth was within this range for three of the most recent surveys but the richness (4-5 species) was near the bottom of the range previously recorded for the same depths (4 to 13 species, average 7).

Figure 27 shows abundance of Hooded Plovers on Lake Warden over the same four date ranges. During the early 1980s, Hooded Plovers were most abundant when depths were 0.6 to 0.8 m. Between 2006 and 2009 the lake was much deeper, greatly reducing shorebird habitats and Hooded Plovers were absent. Depths were lower after 2009, creating more shore

habitat and Hooded Plovers returned, with two high abundances recorded at 0.33 and 0.34 m. Lake Warden was shallow during the Nov 2020 and Feb 2021 surveys (0.57 and 0.1 m respectively) and Hooded Plovers were low in number (2 in Nov) or absent (Feb), as they frequently were during the 1980s at such depths. Hooded Plovers do not require much water, feeding mostly on the drying shore and they are frequently found on completely dry lakes. The high salinity may have reduced the amount of invertebrates stranded on the shores and/or there was insufficient discharge of freshwater from the seepages around the north-east corner of the lake where this species is usually most abundant. None were seen in Nov 2022 despite there being more water (depth 1.03 m), while 37 were present in Feb 2023 at a depth of 0.93 m.

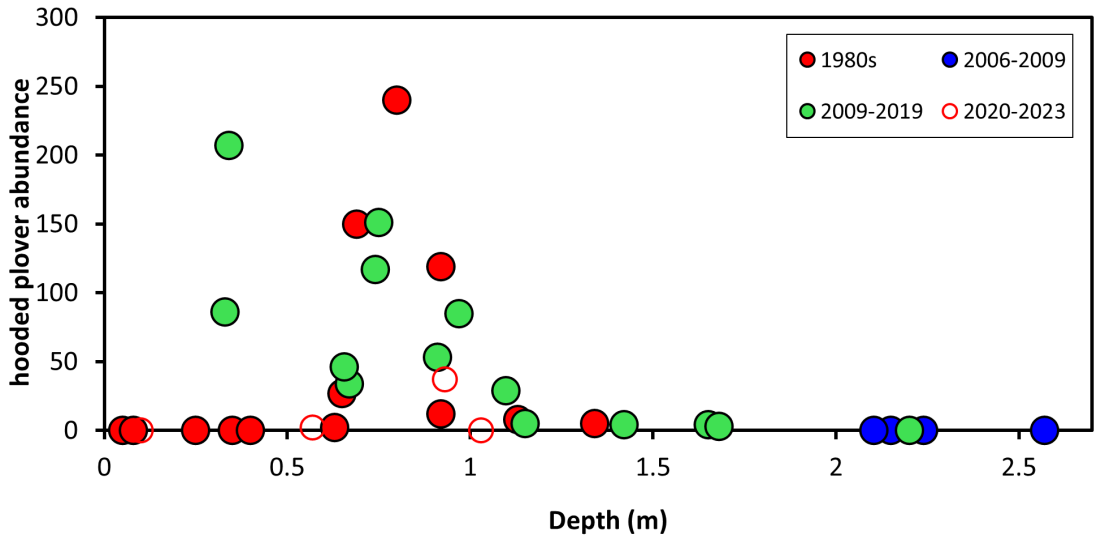

Figure 27. Abundance of Hooded Plovers at Lake Warden during spring and summer surveys undertaken in the 1980s and during the 2006+ surveys split into three periods.

Gore Depths

Lake Gore and the associated wetlands were relatively deep (1.28 m at Lake Gore) during the Nov 2020 survey compared to many other surveys since 2006, although we do not have good depth time series for Gore system wetlands. Depth during the Feb 2021 survey was 0.65 m so a significant reduction in depth over summer. The depth of Lake Gore was not measured in Nov 2022 but in Feb 2023 it was 1.43 m so much higher than at the same time in 2021. Depths measured in spring between 1979 and 2016 were mostly 1 to 2 metres but more consistently in the upper half of this range after 1997 (Lane, Clarke & Winchcombe, 2017).

Gore waterbirds

Richness Nov 2020 to Feb 2023

Figure 28 and Figure 29 depict richness of waterbirds using the Gore System between 2009 (when ground surveys commenced) and 2023. The number of species present during the four

most recent surveys has been similar to other post 2009 surveys, with no trend in total number of species present or richness within the major waterbird groups.

Nov 2020. Unlike the Warden system, the 32 species using the Gore system was not lower than average in Nov 2020. This was the first survey in which five cormorant species were recorded and only the third time since 2009 that Eurasian Coot have been present during ground surveys.

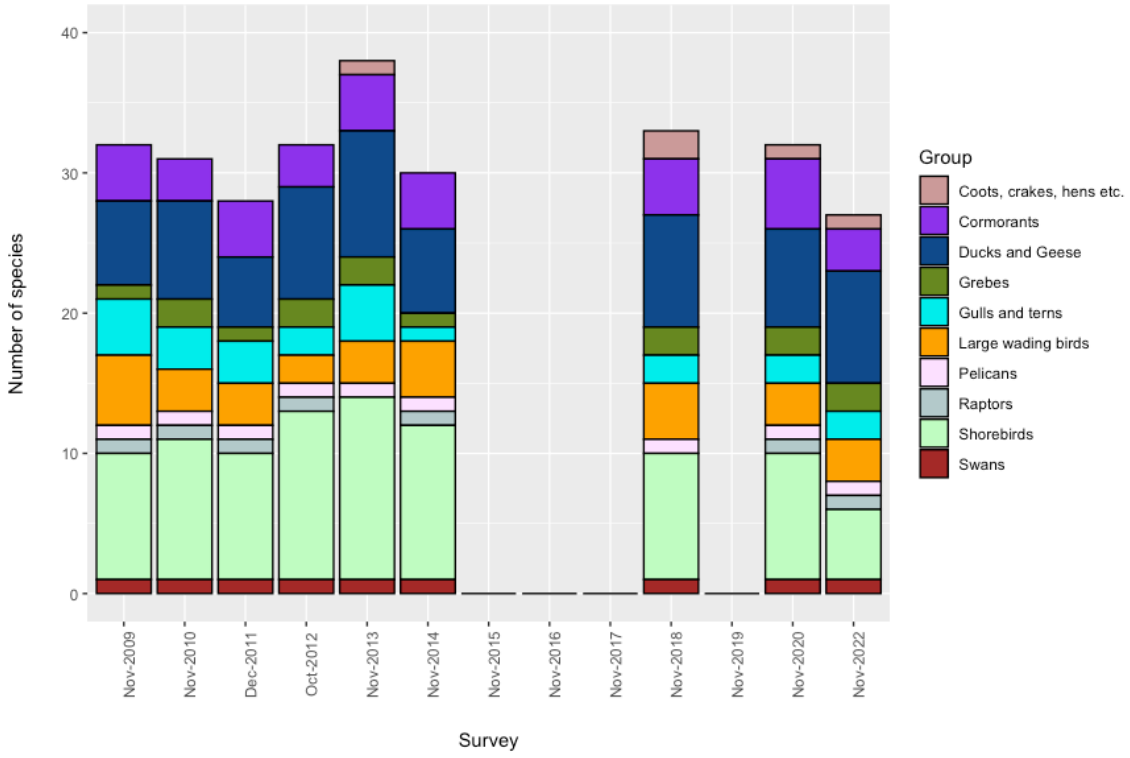

Figure 28. Number of species recorded during spring surveys of the Gore wetland system between 2009 and 2022.

Feb 2021. Thirty-three species were recorded in Feb 2021 which is about in the middle of the range for the 2010-2023 summer surveys (Figure 29). Richness within each of the major groups was also not unusual. Bar-tailed Godwit were recorded for the first time (in the Gore-Quallilup Flow-through). Notable absences are Hooded Plover and Great Crested Grebe. The former is normally most abundant on the Carbul Lakes (especially Carbul and Kubich), even when Carbul is dry. Absence of Great Crested Grebes may be due to the low depth of Lake Gore.

Nov 2022. The 27 species present in Nov 2022 was the lowest for the current series of surveys. This largely reflected the absence of a number of shorebirds (Common Sandpiper, Red-necked Avocet, Red-necked Stint, Sharp-tailed Sandpiper) in a season where depths were high across the system leaving little shore habitat. A Gull-billed Tern was tentatively identified from one of the Dalyup River wetlands east of lake Gore and if correct would be a first for the system in the 2009+ surveys.

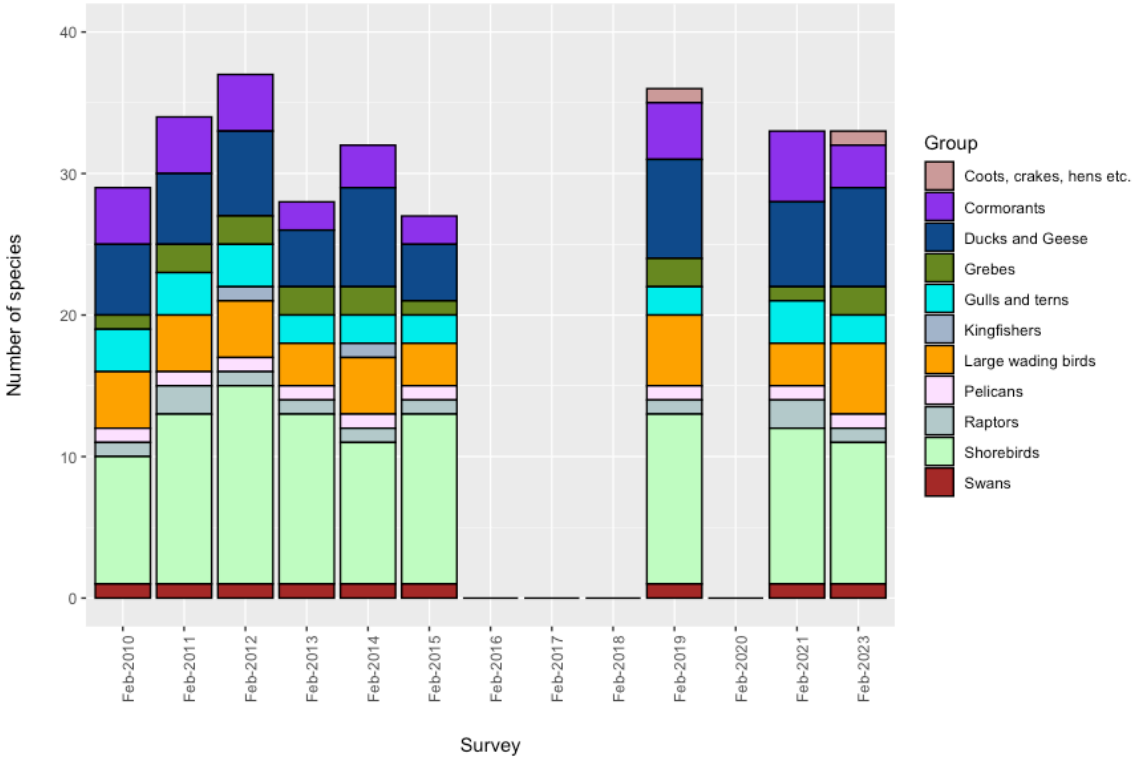

Figure 29. Number of species recorded during summer surveys of the Gore wetland system between 2010 and 2023. Note that no summer surveys were undertaken between 2016 and 2018, and in 2020.

Feb 2023. Total richness in Feb 2023 was the same as for Feb 2021. The presence of Eurasian Coot in summer is unusual for this system, at least for the 2010+ ground surveys, although it was present in Feb 2019 and has been present in spring for most of the 2013+ spring surveys. Coot were also recorded during the 2006-2008 aerial surveys. The presence of Pink-eared Ducks was a first for the summer surveys on Lake Gore. Notable absences were Red-necked Stint (present in all other 2010+ summer surveys) but the other shorebirds absent in the previous spring had returned.

Abundance Nov 2020 to Feb 2023

Abundance of waterbirds present in the Gore system in spring and summer for 2009+ surveys is shown in Figure 30 and Figure 31. While abundance was particularly low for some of the most recent four surveys there is no directional change in overall abundance or abundance of within taxonomic groups.

Nov 2020. The count of 9987 was below the average of 11642 but well within the range of previous spring surveys (Figure 30). Lake Gore is known as an important site for moulting Australian Shelduck. The 4461 counted in the Gore system, including 2157 on Lake Gore and 1552 on the Carbul Lakes, is only slightly less than is normally present in this system in spring (4649 to 7346, average 6221). The 715 Little Black Cormorant is the highest count for the 2009+ surveys. This species was abundant on Lake Gore and the Gore-Quallilup flow-through in 2009 (492) and 2010 (524) when water levels were high, and this species was breeding in

the flow-through. Some of the later surveys (from 2011 to 2018) were undertaken when depths in the flow-through were lower and breeding declined or ceased. Depths in the flow-through were once again quite high in 2020 and this was associated with a return to larger numbers of Little Black Cormorant, albeit not nesting. Counts for most shorebirds were within previous ranges, despite the greater depths and consequently narrower shore zones (at least for the Lake Gore and Carbul suites). Numbers of Sharp-tailed Sandpipers were in record numbers at 243; the previous high being 170 in 2014. These were all on the flow-through which had substantial areas of shallow feeding habitat. There are normally at least a few hundred Banded Stilt in the Gore system (maximum 3113 in Oct 2012), especially on the Carbul Lakes, but none were present in 2020.

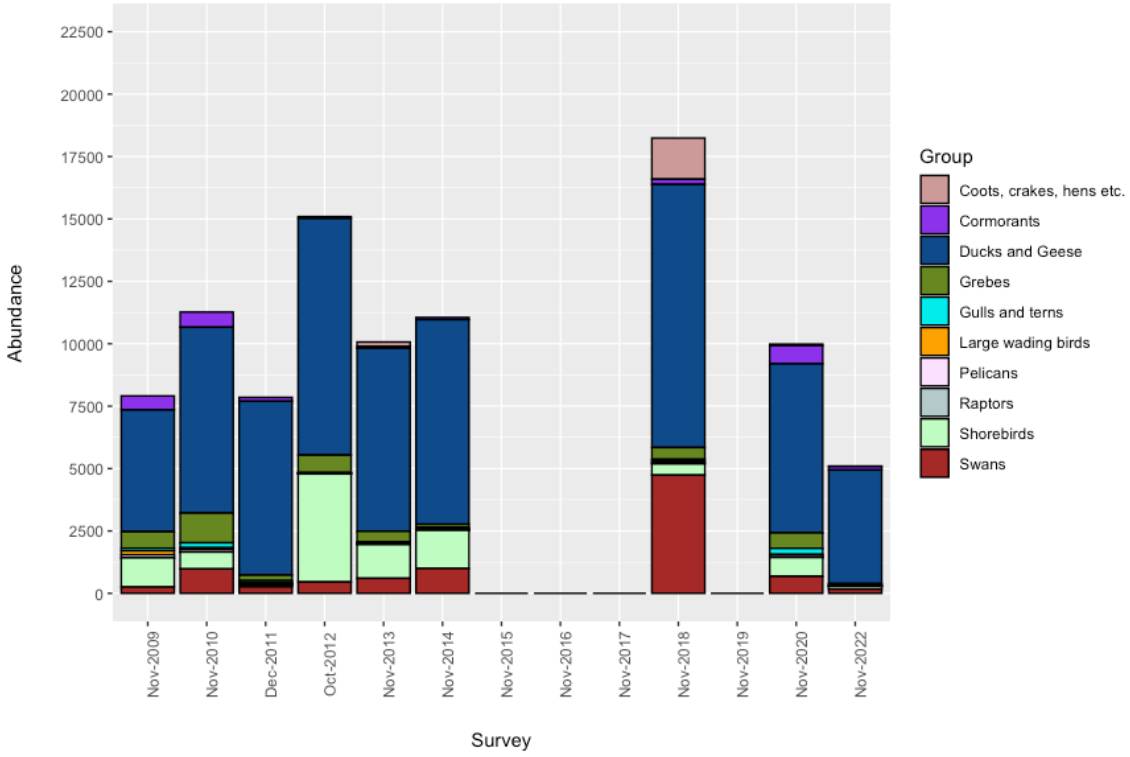

Figure 30. Abundances of waterbirds using the Gore system during spring ground-based surveys conducted between 2010 and 2022. Note that no surveys were undertaken in 2015 to 2017 and in 2019.

Feb 2021. Only 2800 birds were counted across the Gore-Quallilup system in Feb 2021. This is the lowest count of the 2010+ summer surveys and 24% lower than the next lowest count (in 2012). Numbers were low in most taxonomic groups other than Black Swan, larger wading birds (herons etc.) and seabirds. The number of Grey Teal was exceptionally low, with only six present compared to a previous range of 161 to 5551 (average of 1208 for other 2010+ summer surveys). Other species with counts lower than for all previous summer surveys are Banded Stilt (8, previous average 668), Black-winged Stilt (23, 87) and Musk Duck (1, 283). The three duck species are normally in greatest numbers on Lake Gore, but this was very shallow and probably too saline to support large numbers. Numbers of other individual species were not exceptionally low, but the combination of many species towards the lower end of their range of abundances combined to give an overall low count. For example, there

were only 385 Australian Shelduck compared to a previous count range of 256 to 4337 (average 1669) and only 43 Sharp-tailed Sandpipers compared to a previous range of 29 to 226 (average 97).

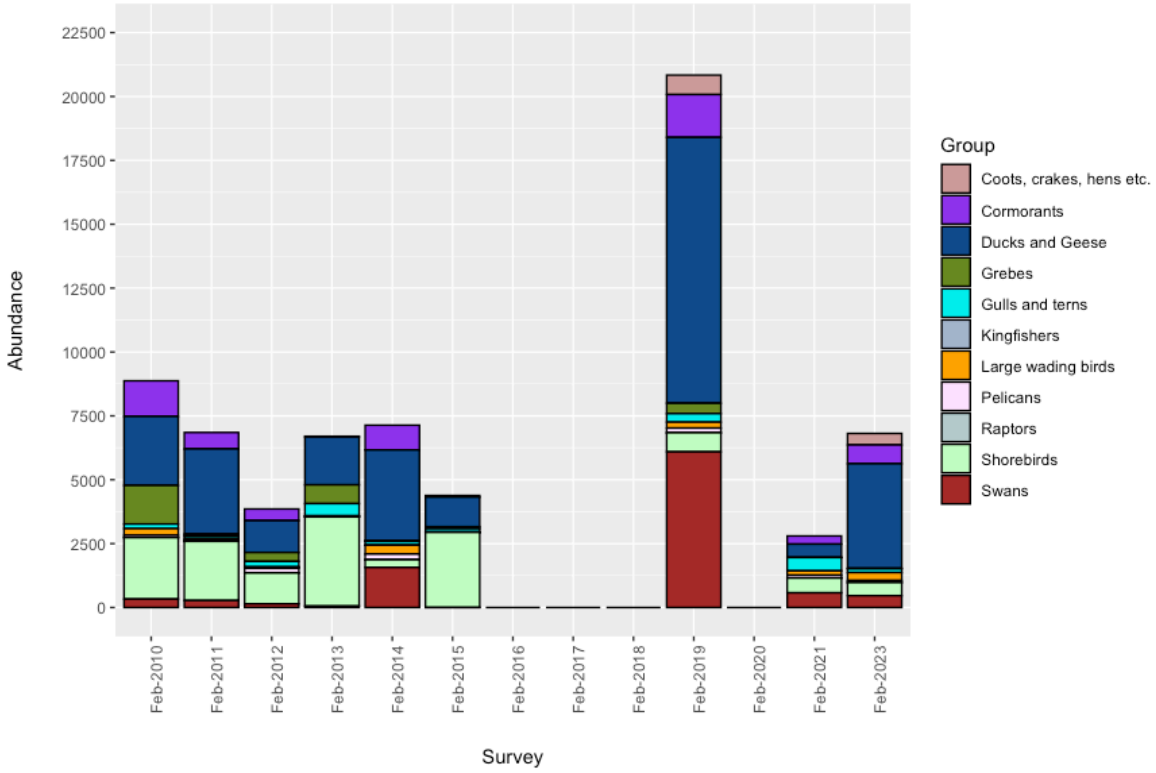

Figure 31. Abundances of waterbirds using the Gore system during summer ground-based surveys conducted between 2010 and 2023. Note that no surveys were undertaken in 2016 to 2018 and in 2020.

Nov 2022. The 5100 birds present in Nov 2022 was substantially lower than the next low count of 7854 in Nov 2011. For most taxonomic groups total abundance was not lower than has been recorded during some other spring surveys but counts of ducks (4551), grebes (40) and swans (170) were the lowest recorded since 2009 and the number of shorebirds (97) only exceeded that of Dec 2011 and was much lower than the 2009-2020 average (1291). Ducks have normally constituted 58 to 75% of waterbirds present in any one survey, but in Nov 2022 this was 89%, similar only to Dec 2011 (also 89%).

Feb 2023. In comparison to the very low count of Feb 2021, the Feb 2023 survey saw a return to a total abundance well within the range of past surveys, with the 6813 birds not far below the average of 7672. This was an increase over the Nov 2022 survey with additional Black Swan, Eurasian Coot, Grey Teal, Little Black Cormorant and Hooded Plover. Grey Teal numbers increased from 132 to 2697 over the summer. Conversely, and as is normal in this system, most of the 4216 Shelduck present in Nov 2022 left the system, leaving only 809 in Feb 2023. With depth being so high in the Gore System in Nov 2022 there was little habitat for shorebirds, but depths declined over summer and the 267 Hooded Plover were all on the still relatively narrow western shore of Lake Gidon.

General patterns in waterbird communities of the Gore wetland system

Spring surveys. There is no trend in the number of species using the Gore system wetlands in spring, with richness varying between 28 and 38 species, except for Nov 2022 (27 species). While total abundance was very low in Nov 2022 there is no general trend to reduced total abundance. An exception may be that shorebird abundance has been lower in the 2018 to 2022 period than in most prior years. Few species have shown distinct trends in spring abundance. Banded Stilt have been absent for the three most recent surveys and Darters have been less abundant over the last four surveys. Grey Teal and Chestnut Teal have been more abundant since 2012, except that Grey Teal were again lower in number in 2022. Eurasian Coot were not seen during ground counts prior to 2013 but were seen during aerial surveys in 2007 and 2008. Little Black Cormorant were not as numerous in 2012-2014 surveys but have otherwise numbered >100.

Figure 36 portrays composition of the Gore-Quallilup communities by synthesising all species abundances in a survey. Composition in Nov 2020 was similar to some other spring surveys and closest to that of 2013. The Nov 2022 community was not especially similar to any of the other spring surveys, reflecting low richness and abundance. A notable pattern in this ordination is that year to year differences in community composition were relatively smaller in the 2009 to 2014 period (shorter blue arrows) compared to differences in composition from 2014 onwards (longer red arrows). This suggests Gore-Quallilup communities have become much more variable in recent years. This pattern is not just that there is a greater time interval between more recent surveys, as pairs of earlier surveys with >1 year intervals still have the closer spacing (e.g. the distance between the 2010 and 2012 surveys).

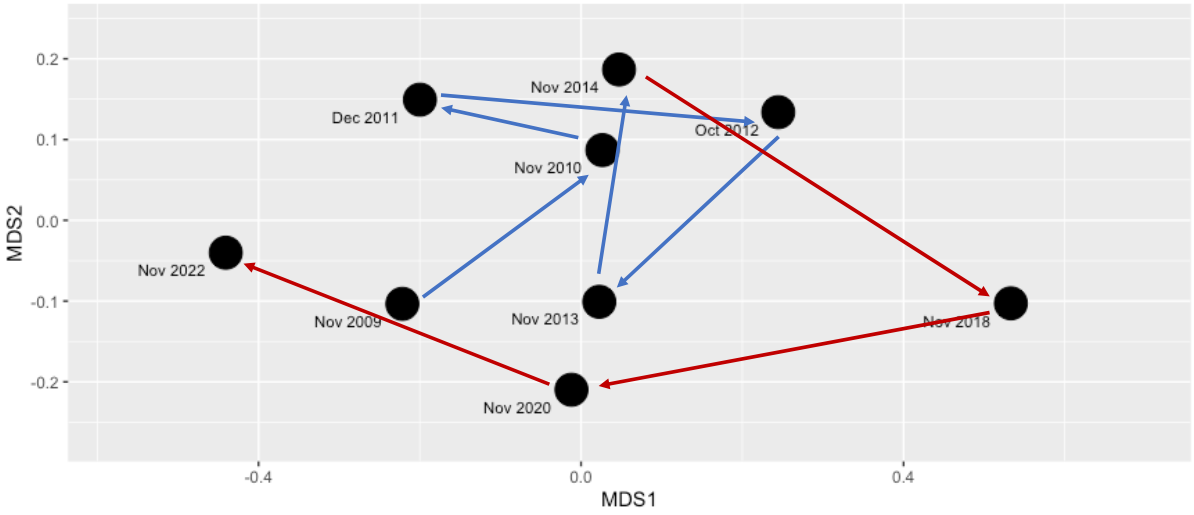

Figure 32. nMDS ordination of waterbird communities present during spring surveys of Gore-Quallilup wetlands conducted between 2009 and 2022 (ground counts). Stress = 0.07.

Summer surveys. There is no trend in the number of species using the Gore system wetlands in summer, with richness varying between 27 to 37 species. While total abundance was very low in Feb 2021 there is no temporal trend in total abundance. Most species have varied greatly in abundance but very few show any distinct temporal patterns. Red-necked Avocets were more abundant between 2010 and 2013 and Yellow-billed Spoonbills were more

abundant between 2010 and 2012 than either they have been subsequently. Conversely, Great Teal were significantly more abundant in 2019 and 2023 than in other years. Eurasian Coot numbered in their hundreds in the same two years but have otherwise been absent from ground counts (310 counted from the air in 2008).

In an ordination of the summer surveys, the most recent three surveys appear in the left of the ordination plot, away from the earlier surveys, with the annual transitions for 2015-2023 tending to be greater than for the 2010-2015 surveys. As for the spring surveys this indicates increased variability in composition in the more recent surveys.

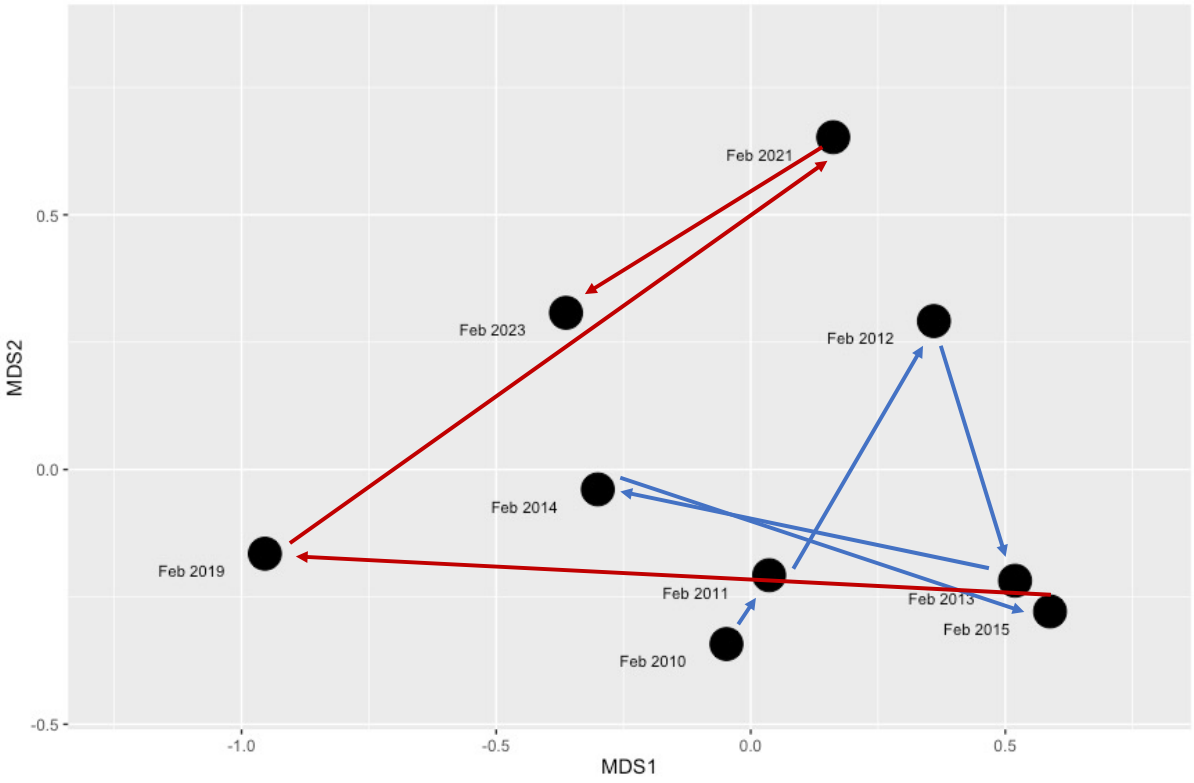

Figure 33. nMDS ordination of waterbird communities present during summer surveys of Gore-Quallilup wetlands conducted between 2010 and 2023 (ground counts). Stress = 0.08.

Warden and Gore combined waterbirds

Abundance

Nov 2020. Combining ground count data across both systems (Figure 34), the Nov 2020 count was the lowest for spring surveys to date, even excluding the large numbers of Banded Stilt in 2012 and 2013 (because they are nomadic and highly variable in numbers). The number of shorebirds was especially low at 935, of which only one was a Banded Stilt. By contrast, the number of Eurasian Coot across the systems was the second highest count at 1210.

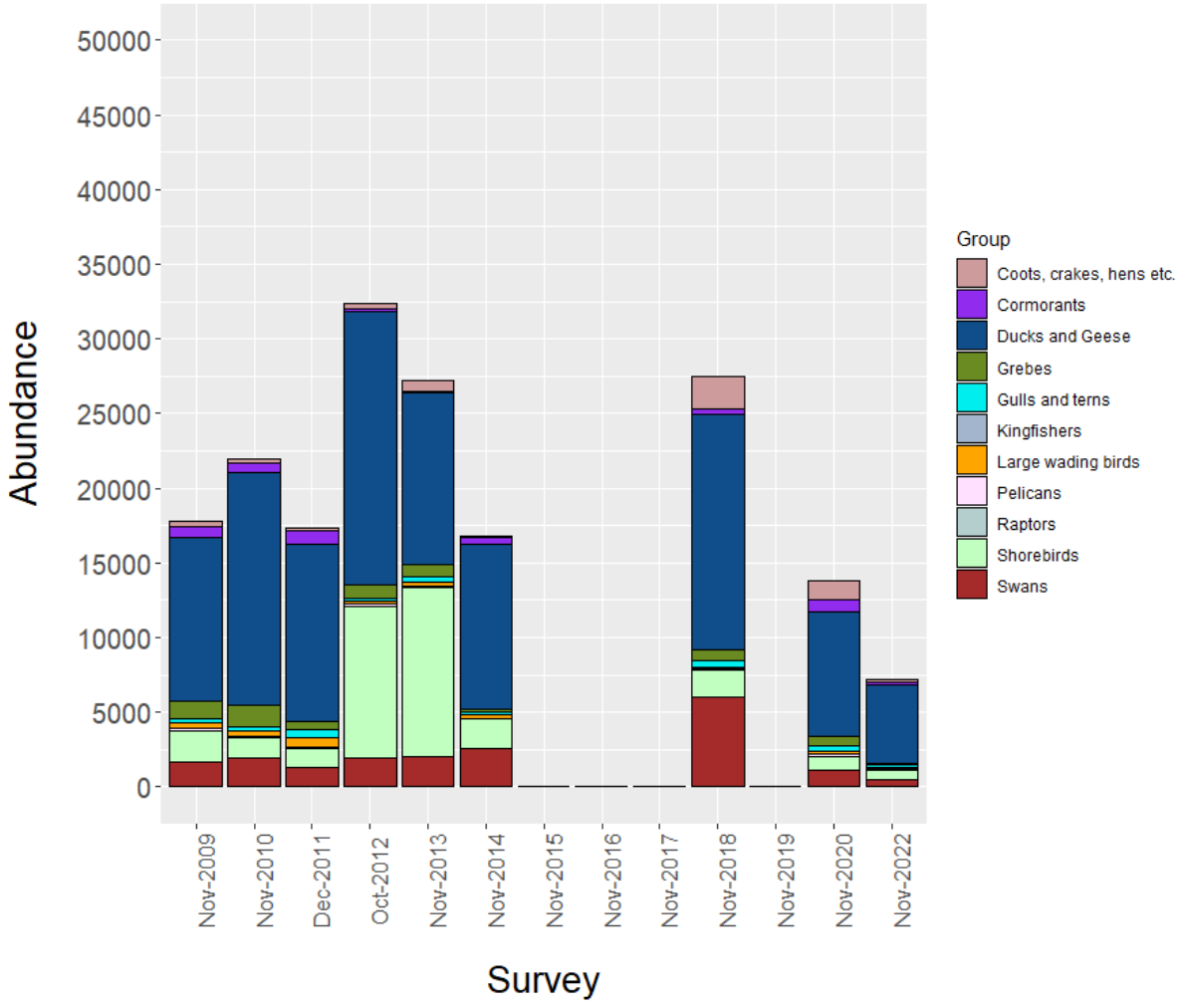

Figure 34. Abundances of waterbirds by major group across both the Warden and Gore-Quallilup systems for ground counts conducted during spring between 2009 and 2022.

Feb 2021. The 14170 waterbirds across both systems was also the lowest since 2010, but only slightly lower than some other summer counts. If counts of banded stilt are excluded, then the Feb 2021 count of 14162 is similar to counts of 14492 and 13962 in Feb 2010 and Feb 2011 respectively.

Nov 2022. The Nov 2022 survey produced the lowest count yet across both systems, with just 7140 birds present. Abundance was near or below previous low counts for all taxonomic groups and for most species, and even more dominated by ducks than has been the case prior to this survey, with Australian Shelduck one of the few species not reduced in abundance. The system seems to retain value as an Australian Shelduck moulting site even in an otherwise 'poor' year for waterbirds. The low combined total count demonstrates that the low Warden system count was not balanced by a relatively high count on the Gore system, so waterbirds were using other systems entirely.

Feb 2023. Across both systems the Feb 2023 count was the third highest of the 2010+ surveys, with a count of 21781, reflecting comparatively high counts on each system. Counts within

major taxonomic groups were within previous ranges, although grebes were very low in abundance (71), only higher than for Feb 2021 (14).

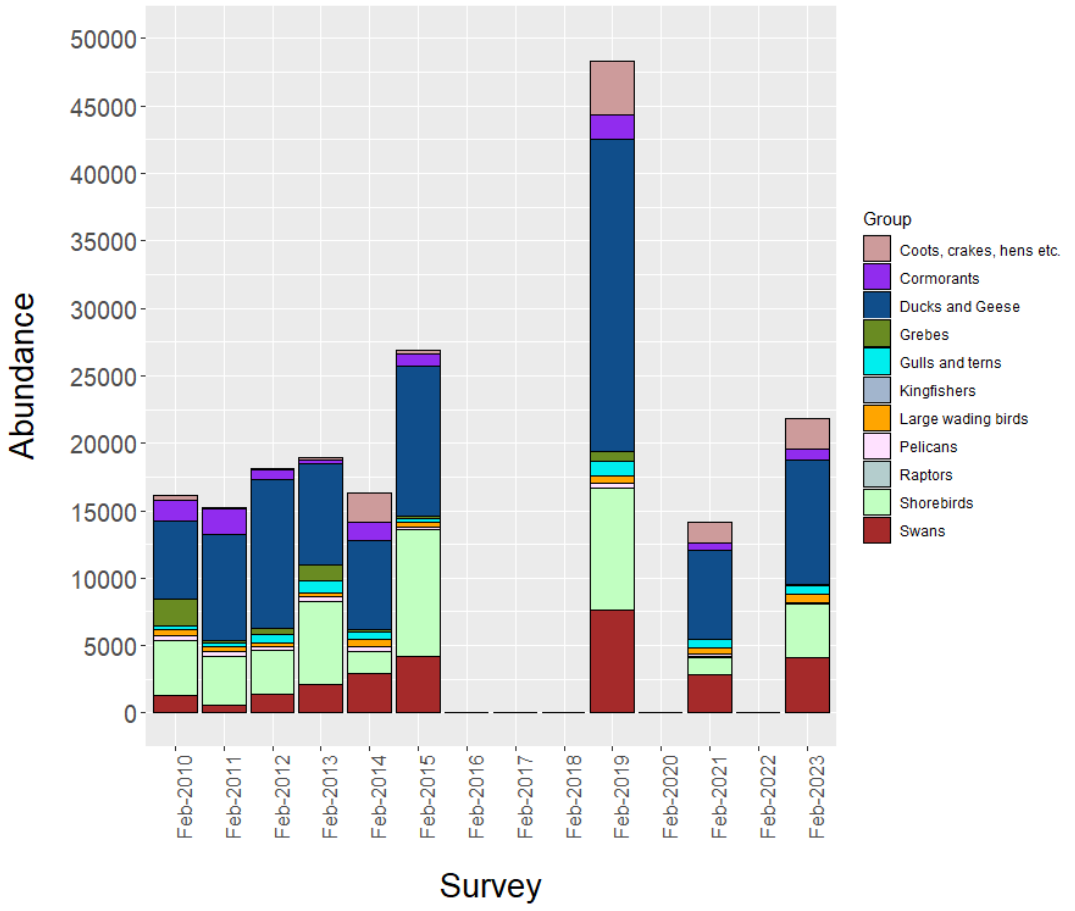

Figure 35. Abundances of waterbirds by major group across both the Warden and Gore-Quallilup systems for ground counts conducted in February between 2010 and 2023.

Assemblage composition Nov 2020

Figure 36 shows an ordination of waterbird communities for both systems combined, by season, for the 2009 to 2023 ground-based surveys. The 2006 to 2008 data are excluded because ground counts were not undertaken on the Gore system prior to Nov 2009. This shows that the combined waterbird assemblage present in Nov 2020 (represented by the lower right blue symbol) was quite different to other spring periods since 2009 and closer to some of the summer communities. The Feb 2021 survey was closest in composition to Nov 2020 suggesting that the 2020-21 year was different to previous years.

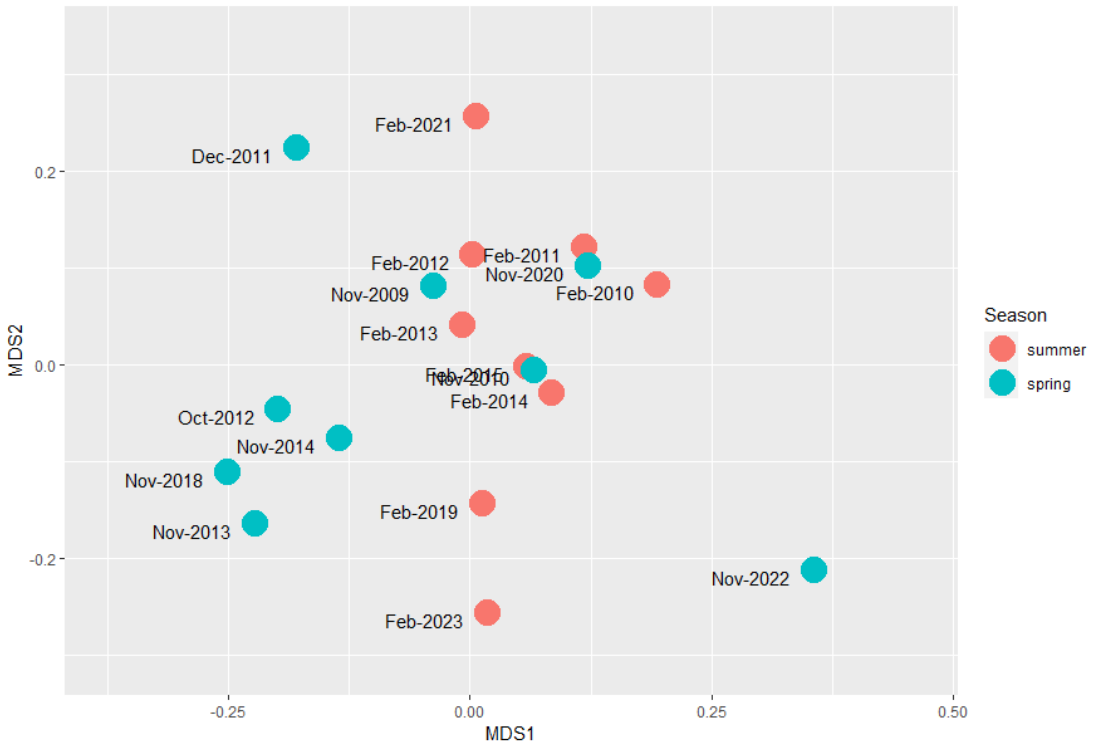

Figure 36. Axes 1 and 2 of a three-dimensional ordination (stress = 0.13) of all ground count waterbird data combined across the Warden and Gore systems, by season from Nov 2009 to Feb 2023.

Figure 37 shows the same data in an ordination with communities separated by both system (Warden and Gore) and season (spring and summer). Despite significant variation in waterbird assemblages recorded since 2009 the Warden and Gore assemblages remain largely distinct and so the two systems are supporting complementary waterbird values. The only exception to this pattern is that the Nov 2022 survey of the Warden system (arrowed) is located amongst some of the Gore surveys. This analysis also suggests the Gore system communities are more variable than those in the Warden system, perhaps because Gore wetlands are much more variable in their hydrology.

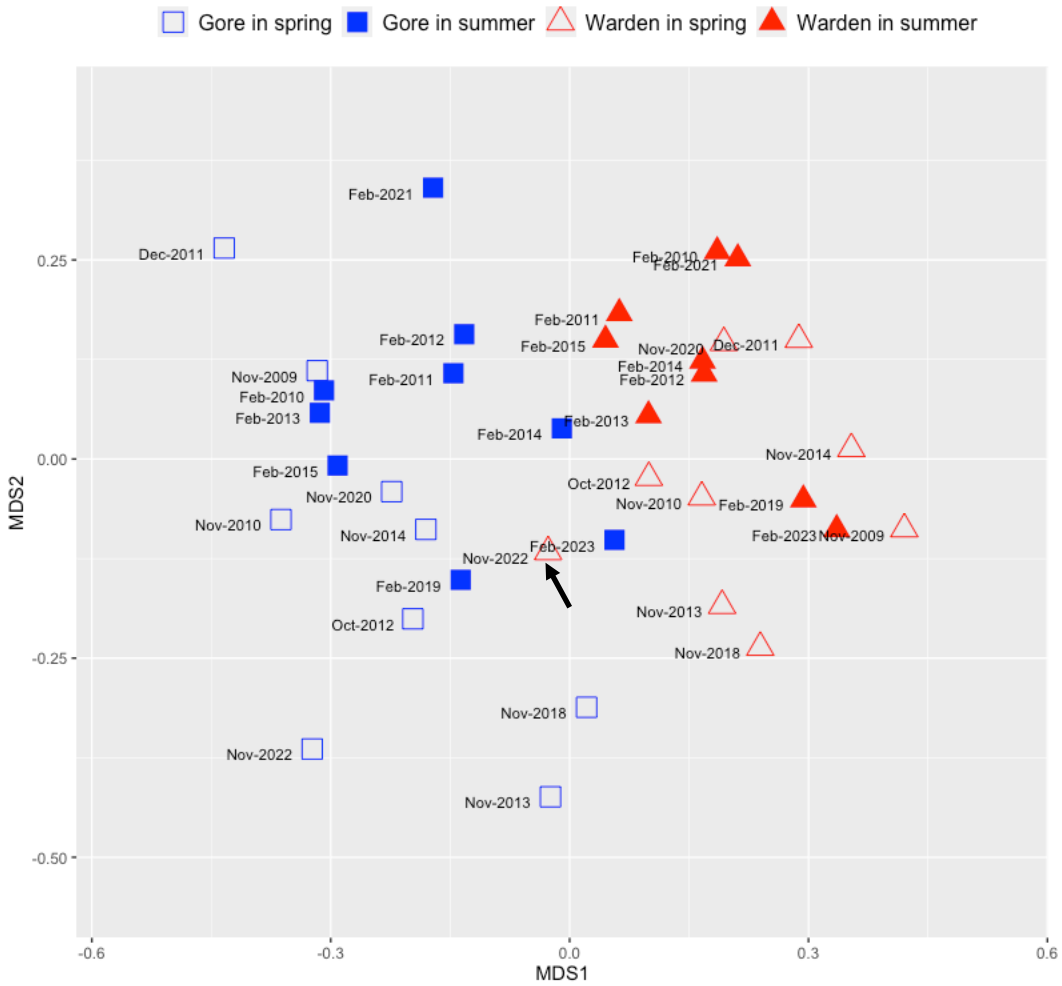

Figure 37. Axes 1 and 2 of a three-dimensional ordination (stress = 0.13) of all waterbird data separated by season and system.

References

Downes M.C. (1955). Recovery of banded ducks. *Emu* **55**, 313–314

Halse S.A., Pearson G.B., Hassell C., Collins P., Scanlon M.D. & Minton C.D.T. (2005). Mandora Marsh, north-western Australia, an arid-zone wetland maintaining continental populations of waterbirds. *Emu* **105**, 115–125

Kingsford R.T. & Norman F.I. (2002). Australian waterbirds—products of the continent's ecology. *Emu* **102**, 47–69

Lane J., Clarke A. & Winchcombe Y. (2017). *South west wetlands monitoring program report 1977 – 2016*. Department of Parks and Wildlife, Perth.

Oksanen J., Simpson G.L., Blanchet F.G., Kindt R., Legendre P., Minchin P.R., *et al.* (2022). *vegan: Community Ecology Package*.

Pedler R.D., Ribot R.F.H. & Bennett A.T.D. (2014). Extreme nomadism in desert waterbirds: flights of the banded stilt. *Biology Letters* **10**, 20140547. https://doi.org/10.1098/rsbl.2014.0547

Pinder A., Felton F., Venarsky M., Cale D. & Barratt P. (2021). *Surveys of waterbirds using the lake Warden and Lake Gore Ramsar sites in November 2020 and February 2021.* Department of Biodiversity, Conservation and Atractions, Perth, Western Australia.

Pinder A.M., Clarke A., Winchcombe Y.C., Cale D.J. & Coote M. (2019). *Surveys of waterbirds using the Lake Warden and Lake Gore Ramsar sites in November 2018 and February 2019, with exploratory analyses of the 2006 to 2019 dataset*. Department of Biodiversity, Conservation and Attractions, Perth , Western Australia.

R Development Core Team (2023). *R: A Language and Environment for Statistical Computing, V 4.1.0*. R Foundation for Statistical Computing, Vienna, Austria.

Roshier D., Asmus M. & Klaassen M. (2008). What drives long-distance movements in the nomadic Grey Teal Anas gracilis in Australia? *Ibis* **150**, 474–484

RStudio Team (2022). RStudio: Integrated development environment for R (Version 2022.12.0)

Appendix 1. Variables used in the Bio-env modelling.
(see Methods)

Survey	Season	Depth	Pipeline_days	Days	CDM3MO_EAERO	CDM6MO_EAERO	CDM12MO_EAERO	CDM3MO_ESPER	CDM6MO_ESPER	CDM12MO_ESPER	CDM3MO_MYRUP	CDM6MO_MYRUP	CDM12MO_MYRUP
Feb/2008	Summer	1.16	0	59	-15.6	15.9	-5.5	-28.1	36.2	0.1	-7	33	9.8
Feb/2010	Summer	0.84	55	54	-40.4	-92.7	-137.9	-49.3	-99	-129.1	-15.3	-83.1	-147.3
Feb/2011	Summer	0.8	35	46	-12.6	-49.3	-17.7	-3.3	-63	-93.5	-11	-68.1	-74.3
Feb/2012	Summer	0.92	92	45	84.2	90.1	44.7	78.7	84	32.7	108.7	117.8	73.6
Feb/2013	Summer	0.65	52	43	42.6	-5.3	-33.9	14.3	10.8	-35.1	32.2	-13.6	-50.1
Feb/2014	Summer	0.84	92	35	-24.4	15.1	106.9	-24.5	64.2	165.3	-20.2	74.6	131.1
Feb/2015	Summer	0.76	0	42	18.4	19.5	-51.7	-9.5	-43	-64.1	17.2	-44.9	-99.4
Feb/2019	Summer	0.91	92	37	-0.6	82.1	69.9	-10.3	56.1	-34.8	-22.7	67.1	-14
Feb/2021	Summer	0.61	0	55	-8.6	-1.7	-89.3	30.7	70.2	-48.2	7.5	-13.8	-119.7
Feb 2023	Summer	1.03	0	38	-3	87.5	71.5	18.1	131.2	144.3	38.8	116.4	101.5
Oct/2006	Spring	1.37	0	42	-68.8	-51.6	-44.7	-100.9	-109.9	-105.9	-85.9	-47.2	0.8
Oct/2007	Spring	1.73	0	53	-44.2	4.8	106.5	15.3	38.9	105.3	-25.1	8.8	117.3
Nov/2008	Spring	1.5	0	70	33.1	78.3	-49.9	51.1	74.3	-50.7	63.2	31	8.7
Nov/2009	Spring	1.38	92	79	-52.3	-75.5	103.7	-49.7	-49.7	22.7	-67.7	-100.6	65.4
Nov/2010	Spring	1.17	92	75	-36.7	-6.9	-45.5	-59.7	-55.1	-139.5	-57	-49.8	-78.6
Dec/2011	Spring	1.06	61	102	51.1	-19.3	-21.7	44.1	16.3	-5.9	56.4	9.9	-10.4
Oct/2012	Spring	1.12	92	52	-26	-45.2	79.3	2.7	-23.1	61.9	-15.8	-58.7	73
Nov/2013	Spring	1.29	92	84	39.5	31.5	173.9	88.7	89.9	204.1	94.9	29.1	183.5
Nov/2014	Spring	1.19	0	70	1.1	2.9	-94.5	-33.5	18.5	-79.1	-62	-51.4	-136.8
Nov/2018	Spring	1.51	92	59	82.7	26.9	54.7	66.4	-13.2	62.4	89.9	-15.1	-18.9
Nov/2020	Spring	1.2	0	76	6.9	-58.5	-91.1	39.5	-29.7	-106.4	-21.2	-83	-137.6
Nov/2022	Spring	1.47	0	61	90.5	68.3	11.5	113.1	134.3	69.3	77.6	50.7	24.1

Appendix 2. Total species counts for the Warden wetland system 2006 to 2023. Based on ground counts except for added aerial counts for wetlands not surveyed from the ground (Neridup, Bandy Creek and North Wheatfield wetlands in 2006, 2007 and 2008, Ewans Lake in 2006 and Ewans Lake and Mullet Lake combined in 2008.

	Feb-08	Feb-10	Feb-11	Feb-12	Feb-13	Feb-14	Feb-15	Feb-19	Feb-21	Feb-23	Oct-06	Oct-07	Nov-08	Nov-09	Nov-10	Dec-11	Oct-12	Nov-13	Nov-14	Nov-18	Nov-20	Nov-22
Australasian Grebe	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Australasian Shoveler	872	57	155	55	31	180	6	57	28	27	66	66	17	72	35	33	14	79	35	10	11	3
Australian Pelican	114	200	323	123	292	148	197	147	120	55	2	21	26	0	65	32	121	91	18	43	80	95
Australian Shelduck	242	280	996	2350	913	587	584	668	1065	1364	1146	1137	2597	2754	3222	2515	2593	1667	998	800	370	384
Australian Spotted Crake	0	0	0	13	0	0	5	0	0	0	0	0	0	0	0	5	1	0	0	0	0	0
Australian White Ibis	7	13	43	23	72	49	131	98	26	62	15	14	2	21	24	10	21	18	44	10	11	1
Australian Wood Duck	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
Banded Lapwing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0
Banded Stilt	2805	524	149	511	1165	0	4754	5001	0	1096	54	970	0	440	24	418	3079	9087	20	780	1	481
Bar-tailed Godwit	0	6	2	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	4	0	0	0
Black-fronted Dotterel	32	55	38	23	22	21	8	13	26	2	0	0	1	7	16	7	10	5	4	4	4	5
Black-tailed Godwit	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	2	0
Black-tailed Native-hen	0	0	0	0	4	0	0	0	0	1	2	3	10	0	0	2	3	5	1	0	0	0
Black-winged Stilt	17	80	84	42	84	9	81	85	0	58	6	0	2	34	47	37	85	147	4	49	6	51
Black Swan	1175	932	308	1253	2088	1334	4217	1531	2273	3654	550	835	943	1430	984	1014	1522	1399	1592	1260	452	284
Blue-billed Duck	0	0	0	1	0	0	0	0	0	0	0	18	4	1	3	0	0	0	0	4	0	0
Cape Barren Goose	43	6	3	6	6	5	0	0	0	31	5	0	1	0	2	6	15	7	0	0	0	0
Caspian Tern	5	21	2	16	11	1	0	0	7	0	0	0	2	0	2	2	6	1	0	0	4	0
Cattle Egret	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Chestnut Teal	873	344	1114	377	686	172	288	118	46	306	500	224	121	243	489	148	200	223	273	914	65	71
Common Greenshank	121	182	120	121	89	98	183	83	61	1	12	63	11	103	128	115	99	77	82	21	5	10
Common Sandpiper	2	14	4	11	11	2	10	6	10	0	4	8	3	29	9	14	8	4	6	2	5	0
Crested Tern	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Curlew Sandpiper	210	27	8	0	0	0	0	23	0	11	0	0	0	0	1	31	0	0	0	0	0	0
Darter	38	27	13	6	0	3	0	2	1	4	2	23	8	20	5	0	2	5	1	9	0	6
Eastern Curlew	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Eurasian Coot	935	297	49	19	111	2123	303	3222	1543	1763	351	259	116	410	297	122	352	494	99	542	1151	94
Fairy Tern	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Freckled Duck	5	1	1	0	1	0	0	0	0	0	0	0	0	2	0	0	0	6	0	0	2	0
Glossy Ibis	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	1	0	0	0	0
Great Cormorant	6	5	15	0	12	2	0	1	15	4	5	8	39	4	5	2	1	10	5	7	6	0
Great Crested Grebe	66	0	15	11	0	4	0	2	3	8	31	28	2	24	8	3	1	8	2	3	0	14
Great Egret	23	15	11	47	49	8	74	55	59	31	33	48	20	39	43	18	44	13	30	20	42	20
Great Knot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Greater Sand Plover	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
Grey-tailed Tattler	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Grey Plover	0	0	2	0	0	0	0	0	0	0	0	0	0	9	2	1	0	1	0	0	0	0
Grey Teal	2495	1642	1042	4054	2750	766	7015	6500	1478	1908	1019	144	188	1262	3581	1136	4422	1350	400	2600	749	92
Hardhead	169	0	0	2	48	6	0	788	5	8	166	1588	282	7	64	165	546	373	294	651	14	21
Hoary-headed Grebe	445	420	101	104	422	97	86	361	3	39	125	425	115	423	208	321	210	366	68	272	49	31
Hooded Plover	0	15	31	81	289	162	269	112	24	44	5	6	4	6	20	60	161	35	48	8	8	0
Lesser Sand Plover	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Little Black Cormorant	77	74	1175	268	240	327	754	123	231	46	327	255	58	90	33	732	80	80	310	67	80	56
Little Egret	0	1	0	0	1	1	0	1	0	4	0	3	1	0	2	0	2	3	0	1	0	3
Little Pied Cormorant	12	24	32	4	1	23	11	41	26	60	28	43	40	9	11	10	8	1	80	11	1	2
Marsh Sandpiper	0	2	0	1	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Masked Lapwing (southern)	0	12	30	44	66	40	54	38	42	13	0	0	4	10	24	17	13	41	9	12	13	9
Musk Duck	921	359	48	293	174	219	508	47	242	44	117	65	144	177	132	188	211	61	144	49	87	17
Nankeen Night Heron	2	12	0	1	0	0	0	1	0	1	0	2	0	2	1	0	0	0	0	1	0	2
Pacific Black Duck	2011	188	1158	2676	1066	1135	1284	2477	3190	1343	993	455	141	1354	540	736	436	346	148	194	253	117
Pacific Gull	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Pectoral Sandpiper	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pied Cormorant	0	0	0	0	20	0	0	0	0	1	0	1	0	0	0	0	0	0	0	9	1	0
Pink-eared Duck	130	264	10	6	7	41	307	90	0	53	0	4	90	253	48	0	0	3	21	9	6	6
Purple Swamphen (southern)	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Red-capped Plover	37	70	38	117	56	118	116	151	123	149	87	92	10	19	58	47	520	56	54	110	35	14
Red-kneed Dotterel	8	5	0	0	0	1	0	15	0	7	0	0	1	2	1	0	0	20	9	0	0	0
Red-necked Avocet	516	301	268	14	129	196	31	1139	0	2005	7	24	189	200	207	334	923	333	64	177	17	0
Red-necked Stint	486	427	512	919	621	698	801	1221	420	0	78	132	0	69	28	38	740	22	101	195	47	0
Red Knot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0
Ruddy Turnstone	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Sacred Kingfisher	0	0	0	1	0	0	0	0	1	1	0	0	0	1	0	1	0	0	2	1	0	0
Sharp-tailed Sandpiper	6	15	33	152	139	0	107	414	11	24	0	1	5	0	54	135	137	116	3	0	29	0
Silver Gull	159	110	197	363	401	397	217	770	71	508	1	38	8	21	107	414	98	346	130	216	101	93
Spotless Crake	8	4	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Straw-necked Ibis	31	1	101	5	7	14	0	39	45	9	40	655	75	70	61	490	37	64	20	19	1	0
Swamp Harrier	0	1	0	1	0	2	0	4	1	1	2	1	0	4	1	1	0	2	5	0	1	1
Terek Sandpiper	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Whiskered Tern	0	0	0	0	0	0	0	0	0	0	6	141	183	160	2	0	79	5	1	98	0	1
White-bellied Sea-eagle	0	1	1	0	0	2	0	0	1	0	0	1	0	1	0	1	3	1	0	0	0	0
White-faced Heron	37	107	49	62	49	70	53	36	27	199	43	36	21	53	82	49	43	106	89	36	68	64
White-necked Heron	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	1	10	7	0	0
Wood Sandpiper	2	0	0	3	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0
Yellow-billed Spoonbill	120	80	63	62	72	69	55	67	140	22	58	29	23	62	36	32	38	8	25	4	15	2

Appendix 3. Total species counts from ground surveys for the Gore-Quallilup wetland system 2009 to 2023. Earlier aerial data are also available.

	Feb-10	Feb-11	Feb-12	Feb-13	Feb-14	Feb-15	Feb-19	Feb-21	Feb-23	Nov-09	Nov-10	Dec-11	Oct-12	Nov-13	Nov-14	Nov-18	Nov-20	Nov-22
Australasian Shoveler	0	0	1	0	212	0	1	4	68	0	17	0	42	108	6	66	10	2
Australian Pelican	88	38	180	31	219	4	180	110	80	118	103	51	25	13	18	41	86	16
Australian Shelduck	1372	2324	256	487	2289	619	4337	385	809	4649	6137	6417	7013	5186	7346	6802	4461	4216
Australian White Ibis	26	6	17	1	32	4	14	2	34	21	2	0	0	0	16	11	0	0
Australian Wood Duck	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Banded Stilt	1080	1084	16	1985	0	1706	136	8	0	550	273	13	3113	1072	749	0	0	0
Bar-tailed Godwit	0	0	0	0	0	0	0	5	0	0	1	0	0	0	0	0	0	0
Black-fronted Dotterel	27	4	22	13	0	13	7	3	1	0	0	7	10	5	2	0	5	0
Black-tailed Native-hen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
Black-winged Stilt	109	48	28	172	27	261	40	23	71	27	106	0	92	149	50	146	114	67
Black Swan	332	276	144	57	1567	4	6093	575	463	254	979	262	457	604	994	4739	681	170
Blue-billed Duck	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Caspian Tern	3	1	6	0	8	2	0	28	1	7	7	1	2	2	0	35	0	0
Chestnut Teal	424	242	110	205	272	182	282	118	377	36	71	69	331	116	110	167	130	156
Common Greenshank	44	47	51	24	42	28	31	53	11	16	19	14	7	7	41	10	23	12
Common Sandpiper	0	4	4	4	1	14	6	5	1	6	4	1	4	2	3	2	6	0
Crested Tern	0	0	0	0	0	0	60	1	0	0	0	0	0	1	0	0	0	0
Curlew Sandpiper	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Darter	60	14	8	3	25	12	33	29	3	18	74	17	10	16	9	7	7	2
Eastern Curlew	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Eurasian Coot	0	0	0	0	0	0	762	0	451	0	0	0	0	188	0	1644	59	21
Fairy Tern	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0
Freckled Duck	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0	0
Great Cormorant	5	7	3	0	0	0	7	28	0	13	0	19	0	1	3	9	7	0
Great Crested Grebe	0	25	7	1	7	0	72	0	1	0	34	0	1	1	0	17	8	1
Great Egret	109	22	6	3	156	8	105	77	30	33	41	11	7	9	20	19	21	3
Great Knot	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0
Grey Teal	753	161	466	665	527	336	5551	6	2697	164	839	54	2011	1711	647	2886	1822	132
Gull-billed Tern	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Hardhead	0	0	0	0	2	0	13	0	0	0	0	0	0	82	0	499	0	7
Hoary-headed Grebe	1511	41	341	733	33	76	337	8	24	664	1156	219	700	418	116	456	613	39
Hooded Plover	0	64	184	189	2	158	32	0	267	213	0	0	2	2	25	0	0	0
Little Black Cormorant	1129	560	438	20	893	50	1137	238	700	492	524	112	62	41	75	137	715	134
Little Egret	0	0	0	0	0	0	3	0	18	0	0	0	0	0	0	0	0	0
Little Pied Cormorant	200	60	5	0	50	0	496	2	32	39	10	8	2	0	1	56	2	1
Masked Lapwing (southern)	10	5	7	4	12	2	0	12	11	0	2	8	11	8	0	26	2	7
Musk Duck	130	592	396	520	190	25	125	1	9	8	20	408	46	43	7	74	338	21
Nankeen Night Heron	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Pacific Black Duck	22	14	20	0	52	0	97	5	97	19	5	20	12	17	33	18	6	13
Pacific Gull	3	3	2	1	0	0	0	0	0	2	3	0	0	0	0	0	2	0
Pectoral Sandpiper	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pied Cormorant	0	0	0	0	0	0	0	22	0	0	0	0	0	2	0	0	1	0
Pink-eared Duck	0	0	0	0	0	0	0	0	34	0	356	0	20	45	0	18	6	4
Red-capped Plover	0	11	124	343	23	47	20	7	10	68	4	14	169	8	12	15	18	9
Red-kneed Dotterel	0	0	6	1	4	4	22	0	1	0	0	0	23	2	18	15	0	2
Red-necked Avocet	1061	127	499	332	11	132	9	185	76	215	159	2	515	16	440	186	289	0
Red-necked Stint	23	849	123	357	135	329	272	232	0	64	22	17	313	36	22	11	56	0
Sacred Kingfisher	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Sharp-tailed Sandpiper	27	62	124	29	45	226	163	43	63	10	85	2	68	40	170	34	243	0
Silver Gull	174	96	210	475	132	118	271	488	143	93	186	83	13	20	54	42	206	38
Swamp Harrier	0	1	0	0	2	0	0	1	1	0	0	0	0	0	0	0	0	0
Whiskered Tern	0	0	0	0	0	0	0	0	0	1	0	0	0	21	0	0	0	0
White-bellied Sea-eagle	1	2	1	3	0	2	2	2	0	1	2	4	1	0	1	0	1	1
White-faced Heron	107	33	20	9	164	4	107	94	227	103	28	6	6	45	5	17	14	11
White-necked Heron	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Wood Sandpiper	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-billed Spoonbill	20	18	11	0	1	0	6	0	2	4	0	7	0	0	11	19	3	1