Biodiversity and Conservation Science

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

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June 2019

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Mar 2019

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The recommended reference for this publication is:

Pinder AM, Clarke A, Winchcombe Y and Cale D. 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.

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Acknowledgments

The November 2018 and February 2019 surveys were co-funded by South Coast NRM. David Thornburg (DBCA) and Robyn Cail (SCNRM) assisted in the field in November 2018. Thanks to Stephen Butler (DBCA Esperance) for logistical support. John Lizamore measured depth and took salinity measurements at the larger Warden wetlands within a few days of each survey. Funding for the field work was provided by South Coast Natural Resource Management through the Regional Land Partnership project ''Protecting Ramsar values through rehabilitation, restoration and reducing threats to the ecological character of the Lake Warden and Lake Gore Ramsar wetlands'.

Summary

- Waterbird usage of the Warden and Gore wetland systems was surveyed in Oct/Nov 2018 and Feb 2019.

- For the Warden wetlands, waterbird richness in spring 2018 was the second lowest for the present survey program, with just 40 species, compared to between 41 and 48 for the 2007 to 2014 period. In particular there were no crakes or hens, no raptors and shorebird diversity was quite low compared to most previous surveys (most notably an absence of sharp-tailed sandpipers and red-kneed dotterels). However, this is only 1 or 2 species less then several other spring counts on the system since 2007 and is more than observed in 2006.

- In Nov 2018, total waterbird abundance across all groups was about average on the Warden system and abundances of individual waterbird groups was mostly within the range of previous spring surveys. The number of chestnut teal (914) was the highest recorded for spring. These were mostly on Lake Warden. The number of Eurasian coot was also high at 542, with most on the Wheatfield and Woodie lakes including the channel. The next highest spring count was 494 in 2013. The number of hardhead (651) was the second highest spring count, whereas counts of Australian shelduck (800), Pacific black duck (194) musk duck (49) and yellow-billed spoonbill were the lowest or 2nd lowest for spring surveys.

- Waterbird richness on Warden wetlands in Feb 2019 was within the range of most other summer surveys and much higher than in Feb 2015. The number of large wading birds was high (8 species compared to 5 to 7 for previous summer surveys), with the first records of white-necked heron for the 2008-2019 summer surveys (all previous records in spring and only since 2013). The number of shorebird species was about average at 14.

- The Feb 2019 survey recorded the highest total abundance for any of the summer surveys for the Warden system. The higher abundance was primarily a result of the high number of shorebirds, especially banded stilt (5001), red-necked avocets (1139), sharp-tailed sandpipers (414) and red-necked stints (1221), all of which are record counts for the Warden system since summer surveys started in 2008. The number of Eurasian coot (3222) was 50% higher than the previous maximum count of 2123 in Feb 2014. The number of silver gulls (770) was also nearly double the previous high count of 401 (in Feb 2013). Numbers of grey teal (6500) was the second highest count (below the 8539 in Feb 2015). Hardhead were also much more abundant (788) than previously recorded in summer (exceeded only by the count of 1588 in Oct 2007). The number of little-black cormorants (123) was lower than for most recent summer surveys.

- Richness and total abundance of shorebirds using Lake Warden since 2011 has been within (or exceeded) values recorded in the 1980s for the same depth during the spring/summer period. This includes a similar (or greater) number of

hooded plovers and sporadic occurrences of large numbers of banded stilt and red-necked avocets.

- There is no obvious trend in abundance of the two waterbird species for which the Warden wetlands are particularly important: Chestnut teal and hooded plover. The Warden wetlands continue to support >1% of the Western Australian populations of these species. Chestnut teal increase in abundance over the summer period, presumably as wetlands elsewhere become less suitable. They particularly favour Lake Warden (when depths are higher) and Windabout Lake. Hooded plovers vary in numbers depending on available shore habitat and tend to be most common on Station Lake and Lake Warden.

- About a third of inter-annual variation in the composition of waterbird communities using the Warden wetlands is associated with variation in rainfall and depths of the gauged wetlands. Operation of the pipeline is also associated with changes waterbird community composition. Further analyses of the influence of the pipeline, plus rainfall and wetland inundation are planned.

- The number of waterbird species using the Gore system during the spring surveys has been remarkably stable; normally 28 to 33 species, with the exception of November 2013 when 38 species were present. The Nov 2018 survey had second highest richness with 33 species but was the only spring survey in which raptors (swamp harrier and/or white-bellied sea-eagle) were not seen.

- The Nov 2018 count of 18241 on the Gore-Quallilup system was the highest since the current survey series commenced in 2006, with the next highest counts being 15094 in Oct 2012 and the 14455 and 14622 for aerial surveys in Oct 2007 and Feb 2008 respectively. The Gore-Quallilup system has always been dominated by ducks, with their numbers in spring quite stable over time (generally 5000 to 8000 between 2009 and 2014), except that their numbers increased to 10542 in Nov 2018. This jump in numbers is almost entirely due to larger than usual numbers of grey teal (2886) and hardhead (499, normally absent from this system). The 4739 black swan counted in Nov 2018 was exceptional (normally $\leq$ 1000). The number of coot were also exceptional in Nov 2018, with 1644 present, mostly on Kubitch and Gidong lakes. Shorebird numbers in Nov 2018 were generally low, with average to below average numbers of all species, including an absence of banded stilt, no doubt associated with the very high water levels. Great crested grebe was also relatively numerous in Nov 2018, with 17 across the system, whereas there has mostly otherwise been 0 or 1.

- Richness of waterbirds on the Gore-Quallilup system during summer surveys has been more variable, with 27 to 37 species present. Highest richness was in Feb 2012, partly reflecting the presence of 14 shorebird species. Second highest richness was Feb 2019 with 36 species, including the only records of Eurasian coot during recent (2010-2019) ground surveys and the only summer record of little egret for the current survey series.

- The summer survey results for the Gore-Quallilup system were dramatically different to previous years (Figure 32), with high abundance of ducks, swans, cormorants and coot but low numbers of shorebirds. The very high numbers of ducks is partly a result of 4337 shelduck remaining on the system over summer, whereas in previous years shelduck have moulted (especially on Lake Gore) during spring and summer but largely departed by the February surveys. There was also an exceptional number of grey teal (5551) whereas there is normally under 800 in February. Eurasian coot have not previously been recorded on the Gore-Quallilup system during summer ground surveys but 762 were present in Feb 2019, all on Kubitch Lake. The 6093 swans on the Gore system was almost four times the previous summer maximum count of 1567 in Feb 2014 and greater than any count in the current survey series. The low numbers of shorebirds was due to there being very few banded stilt (136) and avocet (9) present, as in Feb 2014. Other shorebirds were not unusually low in numbers and some had relatively high abundances. Sharp-tailed sandpipers were relatively abundant (163), lower only than in Feb 2015 (263). Red-kneed dotterels were also more numerous (22) than has been the case for previous summer surveys.

1 Background

Waterbirds using the Lake Warden and Lake Gore Ramsar wetland systems near Esperance have been monitored annually to biannually since 2006 (with a gap between late summer 2015 and spring 2018). A survey was planned for Feb 2017 but an extreme rainfall event flooded the entire Warden system preventing access. This report provides data and analyses for two additional surveys: Oct/Nov 2018 and feb 2019. This survey program is designed to provide information about waterbird diversity and abundance to:

1 Describe the 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 wetland suites.

2 Provide data on waterbird populations for Ramsar Convention reporting.

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

The first four surveys (October 2006 to November 2008) were carried out by Stuart Halse (either while with the Department of Environment and Conservation (now DBCA) or Bennelongia Pty Ltd. Surveys since Nov 2009 have been carried out by DBCA staff (Adrian Pinder, David Cale and colleagues). Previous reports are Halse (2007), Bennelongia (2008a b, 2009), Pinder *et al.* (2010) and Pinder et al. (2012; 2015).

This report presents results of the 2018/19 waterbird surveys of the Warden and Gore-Quallilup wetland systems, in context with previous surveys carried out since 2006. Included are some exploratory analyses of changes in waterbird fauna composition through time and in relation to environmental variables. The latter are not meant to be complete but provide some exploratory and preliminary understanding of the major temporal and spatial patterns at the wetland system level. Further analysis and interpretation of this dataset is planned, with greater emphasis on spatial and temporal patterns within the two systems, within individual species and using data on wetland inundation extent and depth across the south-west.

1.1 Warden wetland system

The Warden wetland system consists of about 50 wetlands occurring in an arc north of the town of Esperance (Figure 1). Formally named wetlands are (from east to west) Ewans Lake, Mullet Lake, Station Lake, Lake Wheatfield, Woody Lake, Windabout Lake, Lake Warden and Pink Lake, but there are many smaller un-named wetlands. Almost all of these wetlands have been surveyed for waterbirds during the current monitoring program. The above-named wetlands, plus one other (“Racecourse Lake” = “North Windabout”) were also surveyed on numerous occasions during the 1980s (Jaensch et al. 1986). For summarising waterbird data the wetlands have been divided into 15 suites, with numbers corresponding to the wetland codes in Table 1. These are also shown in Figure 1 below.

Neridup Creek (Suite 1) and Bandy Creek (Suite 2). Ten small wetlands south of Merivale Road and fed by flows from Bandy Creek and Neridup Creek. The two suites are divided by the dirt track almost opposite Hicks Road rather than by a Neridup/Bandy Creek drainage divide, which doesn't exist. Site 1A is clearly fed directly by Neridup Creek and site 2B is on the main channel of Bandy Creek. Some of the other wetlands would receive water from either or both sources. These have all had water during at least some of the spring surveys but most dry in summer. Sites 1A and 2B (which are part of the main Neridup and Bandy Creek drainage lines respectively) have usually had water in February. All of these wetlands are surveyed on foot.

Ewans Lake (Suite 3). This suite consists of Ewans Lake (both the larger southern basin and the smaller northern basin), the wetland areas where Bandy Creek enters the lake from the east, and the small pans north-east of the lake. All wetlands are surveyed on foot.

Mullet Lake (Suite 4). Main body of Mullet Lake. For surveys between November 2009 and February 2011, data for the Merivale Road wetlands (Suite 5B) were included with counts for Mullet Lake. Surveyed on foot, usually by walking the entire western and eastern shores and using a spotting scope for the southern shore.

Station Lake (Suite 5). This suite includes the main body of Station Lake and all peripheral areas with water. Usually the latter is just the flats to the south-east, partially separated from the main lake by a spit and the wetland to the south associated with where Bandy Creek starts again. These areas are always surveyed on foot.

Merivale Road wetlands (Suite 5B). Consisting of the chain of wetlands north and north-west of Mullet Lake, most of which form part of Bandy Creek. All surveyed on foot.

Gun Club wetlands (Suite 6). A small open water wetland within the Esperance Gun Club and a larger *Melaleuca* fringed wetland immediately north of it. Both surveyed on foot from the western shores, or more extensively for the northern wetland as required.

Lake Wheatfield (Suite7). Lake Wheatfield, including the Coramup Creek channel between Lakes Road and the lake and the two circular wetlands that form part of the Coramup system north-west of the lake. The main lake and Wheatfield to Woody channel are surveyed by boat, walking up Coramup channel. The two wetlands associated with Coramup Creek are surveyed by walking in from Lakes Road. From October 2006 to February 2008, only the main wetland was surveyed from the ground.

North Wheatfield wetlands (Suite 8). Two wetlands (A and C) north of Lakes Road and north of Lake Wheatfield. Both wetlands surveyed on foot. The third wetland (B) between these two were surveyed

Woody Lake (Suite 9). Woody Lake, plus the hour-glass-shaped wetland to its north, the channel through to Windabout Lake, the elongate wetland south of the channel, the small wetland near boat launching site and the wetland north of the intersection of

Windabout Way and Tranquil Drive. From October 2006 to February 2008, only the main wetland was surveyed from the ground.

Windabout Lake (Suite 10)**.** All basins of Windabout Lake, plus the triangular lake near the end of Windabout Way, the large basin east of the north-east bay of Windabout Lake, the small wetland just west of the Windabout Way boat launch site and the wetlands between the south-west and north-west bays. From October 2006 to February 2008, only the main wetland was surveyed from the ground.

North Windabout (Suite 11). A series of basins partially separated by parabolic dunes north of Windabout Lake. These are surveyed on foot.

Six Mile Hill wetlands (Suite 12). Five wetlands north of Lakes Road just above North Windabout Suite. All surveyed on foot.

Lake Warden (Suite 13)*.* Lake Warden, plus the wetland associated with Bukenerup Creek between Warden and the railway line, three wetlands just west of the boat launching site and another small wetland over the dune on the south-west shore.

Burkenup wetlands (Suite 14). Bukenerup Creek forms a series of shallow wetlands as it approaches Lake Warden from the west. The area surveyed is the area east of the rail-line including the eastern part of the hour-glass shaped wetland to the south of the main basin.

Pink Lake (Suite 15). Usually surveyed from the look out on the south-west corner of the lake, several vantage points on the southern shore and by walking around the eastern end of the lake from the salt works to point on the north-east shore. Pink Lake is not included in analyses because it is too large to survey effectively in the time available and has been very inconsistently surveyed.

Table 1. List of wetlands and dates surveyed since 2009. Red text = wetlands dry when visited.

Wetland Suite Name	Wetland Suite Code	Wetland	Location	Nov-09	Feb-10	Nov-10	Feb-11	Dec-11	Feb-12	Oct-12	Feb-13	Nov-13	Feb-14	Nov-14	Feb-15	Nov-18	Feb-19
Neridup Suite	WRP001	A	large southern lake with two basins	19/11/09	DRY 24/02/2010	15/11/10	14/2/11	12/12/11	13/2/12	22/10/12	11-Feb-13	25/11/13	DRY 3/02/2014	10/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		B	medium sized central eastern lake	19/11/09	DRY 24/02/2010	15/11/10	DRY 14/02/2011	12/12/11	DRY 13/02/2012	22/10/12	DRY 11/02/2013	25/11/13	DRY 3/02/2014	10/11/2014	09/02/2015	30/10/18	5/2/19
		C	medium sized central western lake	19/11/09	DRY 24/02/2010	15/11/10	DRY 14/02/2011	12/12/11	DRY 13/02/2012	22/10/12	DRY 11/02/2013	25/11/13	DRY 3/02/2014	10/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		D	small lake just above WRP001C	19/11/09	DRY 24/02/2010	15/11/10	DRY 14/02/2011	DRY 12/12/2011	DRY 13/02/2012	22/10/12	DRY 11/02/2013	DRY 25/11/2013	DRY 3/02/2014	10/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		E	small northern-most lake	19/11/09	DRY 24/02/2010	DRY 15/11/2010	DRY 14/02/2011	DRY 12/12/2011	DRY 13/02/2012	22/10/12	DRY 11/02/2013	25/11/13	DRY 3/02/2014	10/11/2014	DRY 9/02/2015	30/10/18	5/2/19
Bandy Creek Suite	WRP002	A	south-eastern lake	19/11/09	DRY 24/02/2010	15/11/10	DRY 14/02/2011	12/12/11	13/2/12	22/10/12	11-Feb-13	25/11/13	DRY 3/02/2014	10/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		B	south-western lakes and adjacent areas	19/11/09	22/2/10	15/11/10	14/2/11	12/12/11	13/2/12	22/10/12	11-Feb-13	25/11/13	03/02/2014	10/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		C	eastern lake closest to track	19/11/09	DRY 24/02/2010	DRY 15/11/2010	DRY 14/02/2011	12/12/11	DRY 13/02/2012	22/10/12	DRY 11/02/2013	25/11/13	DRY 3/02/2014	10/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		D	lake between C and D	19/11/09	DRY 24/02/2010	DRY 15/11/2010	DRY 14/02/2011	DRY 12/12/2011	DRY 13/02/2012	22/10/12	DRY 11/02/2013	25/11/13	DRY 3/02/2014	10/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		E	north-western most lake close to Merivale Road	19/11/09	DRY 24/02/2010	DRY 15/11/2010	DRY 14/02/2011	DRY 12/12/2011	DRY 13/02/2012	22/10/12	DRY 11/02/2013	25/11/13	DRY 3/02/2014	11/11/2014	DRY 9/02/2015	30/10/18	5/2/19
Ewans Lake	WRP003	A	includes large wetland areas to north and north-west of Ewans that are connected to Ewans, but didn't get into the southern-most eye-shaped section in 2009	19/11/09	22/02/2010 and 23/02/2010	15/11/10	14/2/11	12/12/11	15/2/12	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
Mullet Lake	WRP004	A	includes pans to north of main lake	19/11/09	23/2/10	15/11/10	14/2/11	12/12/11	15/2/12	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
Station Lake	WRP005	A	flats to south of main lake	20/22/2009	DRY 23/02/2010	15/11/10	DRY 14/02/2011	12/12/11	15/2/12	23/10/12	Dry 12/02/2013	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
		B	main lake	20/22/2009	DRY 23/02/2010	15/11/10	14/2/11	12/12/11	15/2/12	23/10/12	Dry 12/02/2013	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
		C	overflow areas to east of main lake	20/22/2009	DRY 23/02/2010	15/11/10	14/2/11	12/12/11	15/2/12	23/10/12	Dry 12/02/2013	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
Merivale Suite	WRP021 (ex 58)	A	Wetlands around north of Mullet Lake	not surveyed	not surveyed	not surveyed	not surveyed	12/12/11	15/2/12	23/10/12	Dry 12/02/2013	26/11/13	DRY 4/02/2014	11/11/2014	DRY 11/02/2015	31/10/18	8/2/19
Gun Club wetlands	WRP006	A	main lake opposite Lake Road (north of Gun Club)		DRY 23/02/2010	16/11/10	DRY 14/02/2011	12/12/11	DRY 15/02/2012	24/10/12	Dry 12/02/2013	26/11/13	03/02/2014	10/11/2014	09/02/2015	30/10/18	5/2/19
		B	hour-glass shaped on eastern edge of Gun Club	19/11/09	DRY 23/02/2010	16/11/10	DRY 14/02/2011	12/12/11	DRY 15/02/2012	23/10/12	Dry 12/02/2013	26/11/13	03/02/2014	10/11/2014	DRY 9/02/2015	30/10/18	5/2/19
Wheatfield Suite	WRP007	A	Wheatfield Lake plus channel to Woodie Lake	20/11/09	23/2/10	17/11/10	15/2/11	13/12/11	15/2/12	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
		B/C	areas between the larger eastern section of the Wheatfield to Woodie channel and the Coramup inflow channel (including the channel)	20/11/09	DRY 23/02/2010	17/11/10	DRY (except for channel) 15/02/2011	13/12/11	DRY 15/02/2012	23/10/12	Dry 12/02/2013	26/11/13	DRY 4/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
		D	satellite wetland north-west of main channel	20/11/09	23/2/10	17/11/10	DRY 15/02/2011	13/12/11	15/2/12	24/10/12	Dry 12/02/2013	26/11/13	04/02/2014	11/11/2014	not surveyed	31/10/18	8/2/19
		E	satellite wetland north-west of 007D near Lake Road	20/11/09	DRY 23/02/2010	17/11/10	DRY 15/02/2011	13/12/11	15/2/12	23/10/12		26/11/13	DRY 4/02/2014	12/11/2014	not surveyed	31/10/18	8/2/19
North Wheatfield Suite	WRP008	A	western	20/11/09	DRY 24/02/2010	16/11/10	14/2/11	13/12/11	14/2/12	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	9/02/2015 and 11/02/2015	31/10/18	8/2/19
		B	central	20/11/09	DRY 24/02/2010	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	31/10/18	8/2/19
		C	eastern	20/11/09	DRY 24/02/2010	16/11/10	14/2/11	13/12/11	14/2/12	23/10/12	12/2/13	26/11/13	05/02/2014	11/11/2014	9/02/2015 and 11/02/2015	31/10/18	8/2/19
Woodie Suite	WRP009	A	main lake	20/11/09	23/2/10	17/11/10	15/2/11	13/12/11	15/2/12	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
		B	very small wetland just near western edge of main lake	20/11/09	DRY 23/02/2010	17/11/10	DRY 15/02/2011	13/12/11	DRY 15/02/2012	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	DRY 11/02/2015	31/10/18	8/2/19
		C	'spectacle' lake north of Woodie	20/11/09	DRY 23/02/2010	17/11/10	DRY 15/02/2011	13/12/11	15/2/12	23/10/12	Dry 12/02/2013	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
		D	Woodie to Windabout channel	20/11/09	23/2/10	17/11/10	15/2/11	13/12/11	15/2/12	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
		E	small wetland opposite boat lauch area	20/11/09	23/2/10	17/11/10	DRY 15/02/2011	13/12/11	DRY 15/02/2012	23/10/12	Dry 12/02/2013	26/11/13	04/02/2014	11/11/2014	DRY not surveyed	31/10/18	8/2/19
		F	long wetland between Woodie and Windabout	20/11/09	23/2/10	17/11/10	15/2/11	13/12/11	DRY 15/02/2012	23/10/12	Dry 12/02/2013	26/11/13	04/02/2014	11/11/2014	DRY 11/02/2015	31/10/18	8/2/19
		G	wetland at end of Windabout Way	20/11/09	23/2/10	17/11/10	DRY 15/02/2011	13/12/11	DRY 15/02/2012	23/10/12	Dry 12/02/2013	26/11/13	DRY 4/02/2014	11/11/2014	DRY not surveyed	31/10/18	8/2/19
Windabout Suite	WRP010	A	main lake	20/11/09	23/2/10	17/11/10	15/2/11	13/12/11	15/2/12	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
		B	triangular lake south-east of main body	20/11/09	23/2/10	17/11/10	15/2/11	13/12/11	15/2/12	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
		C	small wetland south of south-east bay	20/11/09	23/2/10	17/11/10	15/2/11	13/12/11	15/2/12	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	DRY 11/02/2015	31/10/18	8/2/19
		D	small wetland north of south-west bay	20/11/09	DRY 23/02/2010	17/11/10	15/2/11	13/12/11	DRY 15/02/2012	23/10/12	Dry 12/02/2013	26/11/13	04/02/2014	11/11/2014	DRY 11/02/2015	31/10/18	8/2/19
		E	large wetland south of north-west bay	20/11/09	23/2/10	17/11/10	15/2/11	13/12/11	15/2/12	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
		F	large wetland east of north-east bay	20/11/09	23/2/10	17/11/10	15/2/11	13/12/11	15/2/12	23/10/12	12/2/13	26/11/13	04/02/2014	11/11/2014	11/02/2015	31/10/18	8/2/19
North Windabout Suite	WRP011	A	series of interconnected wetlands between Lake Road and Windabout	20/11/09	24/2/10	17/11/10	DRY 15/02/2011	13/12/11	DRY 14/02/2012	24/10/12	Dry 12/02/2013	27/11/13	05/02/2014	11/11/2014	DRY 9/02/2015	30/10/18	5/2/19
Six Mile Hill Suite	WRP012	A	south-east	21/11/09	DRY Aerial only	18/11/10	DRY 15/02/2011	13/12/11	DRY 14/02/2012	24/10/12	Dry 12/02/2013	26/11/13	DRY 4/02/2014	12/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		B	south-west	21/11/09	DRY Aerial only	18/11/10	DRY 15/02/2011	13/12/11	DRY 14/02/2012	24/10/12	Dry 12/02/2013	26/11/13	DRY 4/02/2014	DRY 12/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		C	south-central	21/11/09	DRY Aerial only	18/11/10	DRY 15/02/2011	13/12/11	DRY 14/02/2012	24/10/12	Dry 12/02/2013	26/11/13	04/02/2014	12/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		D	southern wetland of central pair	21/11/09	DRY Aerial only	18/11/10	DRY 15/02/2011	13/12/11	DRY 14/02/2012	24/10/12	Dry 12/02/2013	26/11/13	04/02/2014	12/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		E	northern wetland of central pair	21/11/09	DRY Aerial only	18/11/10	DRY 15/02/2011	13/12/11	DRY 14/02/2012	24/10/12	Dry 12/02/2013	26/11/13	04/02/2014	DRY 12/11/2014	DRY 9/02/2015	30/10/18	5/2/19
		F	northern wetland	not surveyed	DRY Aerial only	not surveyed	not surveyed	not surveyed	not surveyed	24/10/12	Dry 12/02/2013	26/11/13	04/02/2014	not surveyed	not surveyed	not surveyed	not surveyed
Lake Warden Suite	WRP013	A	main lake	21/11/09	24/2/10	18/11/10	16/2/11	14/12/11	14/2/12	24/10/12	13/2/13	27/11/13	05/02/2014	12/11/2014	10/02/2015	2/11/18	8/2/19
		B	middle of three satellite wetlands on south-eastern edge	21/11/09	24/2/10	18/11/10	16/2/11	not surveyed	not surveyed	not surveyed	Dry 13/02/2013	27/11/13	05/02/2014	not surveyed	not surveyed	not surveyed	8/2/19
		C	long wetland immediately west of boat ramp track	21/11/09	24/2/10	18/11/10	15/2/11	14/12/11	14/2/12	24/10/12	Dry 13/02/2013	27/11/13	05/02/2014	12/11/2014	DRY 10/02/2015	not surveyed	not surveyed
		D	western-most of three stallite wetlands on south-eastern edge	21/11/09	24/2/10	18/11/10	not surveyed	14/12/11	14/2/12	not surveyed	Dry 13/02/2013	27/11/13	05/02/2014	not surveyed	not surveyed	not surveyed	not surveyed
		E	small satellite wetland on south-western edge of lake	not surveyed	24/2/10	18/11/10	16/2/11	not surveyed	not surveyed	DRY 24/10/2012	13/2/13	27/11/13	not surveyed	DRY 12/11/2014	DRY 10/02/2015	2/11/18	8/2/19
Burkenup Suite	WRP014	A	west of rail-line only, including satellite wetlands to south of main area	21/11/09	24/2/10	18/11/10	16/2/11	14/12/11	14/2/12	24/10/13	Dry 13/02/2013	27/11/13	DRY 5/02/2014	12/11/2014	DRY 10/02/2015	2/11/18	8/2/19
Pink Lake	WRP015	A	main lake	21/11/09	DRY Aerial only	18/11/10	16/2/11	14/12/11	15/2/12	24/10/13	13/2/13	27/11/13	05/02/2014	12/11/2014	10/02/2015	30/10/18	5/2/19
Lake Gore Suite including eastern parabolic wetlands and small wetlands to north-west and west	WRP016	A	Main Lake	22/11/09	25/2/10	19/11/10	17/2/11	15/12/11	16/2/12	25/10/12	14/2/13	28/11/13	06/02/2014	13/11/2014	12/02/2015	1/11/18	7/2/19
		B	Eastern peripherals behind dunes	22/11/09	25/2/10	19/11/10	17/2/11	15/12/11	16/2/12	25/10/12	14/2/13	28/11/13	06/02/2014	13/11/2014	DRY 12/02/2015	1/11/18	7/2/19
		C	North Western satellite lake 1 (northern lake east of Carbul Lake)	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	14/02/2013	27/11/13	not surveyed	13/11/2014	DRY 10/02/2015	2/11/18	7/2/19
		D	North Western satellite lake 2 (middle lake east of Carbul Lake)	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	14/02/2013	27/11/13	not surveyed	13/11/2014	10/02/2015	2/11/18	7/2/19
		E	North Western satellite lake 3 (southern lake east of Carbul Lake)	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	27/11/13	not surveyed	13/11/2014	DRY 10/02/2015	2/11/18	7/2/19
		F	North Western satellite lake 4 (lake between Lake Gore, Carbul Lake and Kubitch Lake)	22/11/09	25/2/10	19/11/10	17/2/11	15/12/11	16/2/12	25/10/12	14/2/13	28/11/13	06/02/2014	13/11/2014	DRY 10/02/2015	1/11/18	7/2/19
Carbul Lakes (Carbul, Gidon and Kubich)	WRP017	A	Carbul Lake	22/11/09	DRY 25/02/2010	19/11/10	16/2/11	15/12/11	DRY 16/02/2012	25/10/12	Dry 14/02/2013	28/11/13	06/02/2014	13/11/2014	DRY 10/02/2015	1/11/18	7/2/19
		B	Kubitch Lake	22/11/09	DRY 25/02/2010	19/11/10	16/2/11	15/12/11	16/2/12	25/10/12	Dry 14/02/2013	28/11/13	06/02/2014	13/11/2014	10/02/2015	1/11/18	7/2/19
		C	Gidong Lake	Aerial only	DRY Aerial only	Aerial only	16/2/11	15/12/11	16/2/12	25/10/12	14/2/13	28/11/13	06/02/2014	13/11/2014	10/02/2015	2/11/18	7/2/19
Dalyup Channel and associated wetlands	WRP018	A	Dalyup Channel	22/11/09	25/2/10	19/11/10	16/2/11	15/12/11	16/2/12	25/10/12	14/2/13	28/11/13	06/02/2014	13/11/2014	12/02/2015	1/11/18	7/2/19
		B	Wetland connected to south of Dalyup Channel	22/11/09	25/2/10	19/11/10	16/2/11	15/12/11	16/2/12	25/10/12	14/2/13	28/11/13	06/02/2014	13/11/2014	DRY 12/02/2015	1/11/18	7/2/19
		C	Large L-shaped wetland south-east of WRP018B	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	28/11/13	not surveyed	not surveyed	not surveyed	2/11/18	7/2/19
Qualilup Lake	WRP019	A	main lake	22/11/09	25/2/10	19/11/10	17/2/11	15/12/11	16/2/12	25/10/12	14/2/13	28/11/13	06/02/2014	13/11/2014	12/02/2015	1/11/18	7/2/19
		B	satellite wetland on north-eastern edge	not surveyed	25/2/10	19/11/10	17/2/11	15/12/11	16/2/12	25/10/12	14/2/13	28/11/13	06/02/2014	13/11/2014	12/02/2015	1/11/18	7/2/19
Kubitch to Qualilup flow-through	WRP020	A	From Qualilup north through wetland complex as far as water depth allows boat access	22/11/09	25/2/10	19/11/10	17/2/11	15/12/11	16/2/12	25/10/12	14/2/13	28/11/13	06/02/2014	13/11/2014	12/02/2015	1/11/18	7/2/19

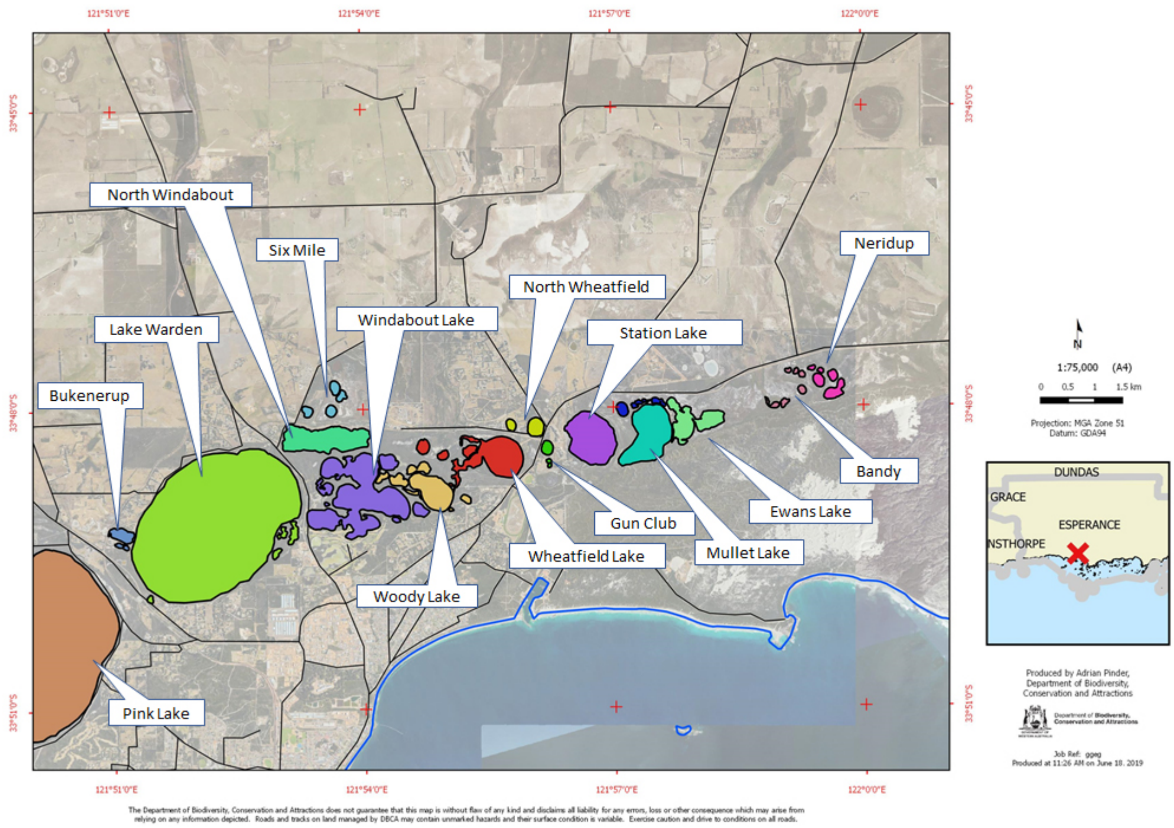

Figure 1. Wetlands surveyed for waterbirds in the Warden system. Suites indicated by colour.

1.2 Gore wetlands

Wetlands surveyed in the Gore-Quallilup system have also been divided into suites. From 2006 to 2008 only aerial surveys were undertaken. Between 2009 and 2012 these wetlands were surveyed from the air and from the ground, but only ground counts have been undertaken since 2013. For summarising waterbird data the wetlands have been divided into 5 suites, with numbers corresponding to the wetland codes in Table 1. These are also shown in Figure 2 below.

Dalyup wetlands (Suite 16). The Dalyup River upstream from Lake Gore to a basin connected to it on the south side of the channel. Usually surveyed on foot but if water deep enough then boat taken up the channel from Lake Gore. From 2009 to Feb 2012 this suite and Lake Gore (Suite 18) were scored together.

Carbul wetlands (Suite 17). This suite consists of Lake Carbul, Lake Kubitch and Lake Gidong. Lake Carbul is surveyed on foot to the extent that it is required to count and identify shorebirds with a spotting scope. Lake Kubitch has normally only been surveyed from the southern shore (either from the fringing *Melaleuca* or from the high ground adjacent to the lake). Lake Gidong has only been surveyed on the ground since November 2010 but was surveyed from the air since 2006. From 2010 to 2015 it was surveyed from the southern shore by spotting scope but new fencing has prevented access from that side. For the last two surveys Lake Gidong has been accessed via a paddock to its north and spotted from the northern shore.

Lake Gore (Suite 18). Main body of Lake Gore plus the peripheral wetlands that fringe its eastern side. Surveyed from a boat if deep enough, with surveys of the peripheral wetlands done on foot. If Lake Gore too shallow, then the suite is surveyed using a spotting scope from the northern shore (including the elevated premonitory), the Dalyup River entrance, walking and spotting from the river to the southern shore west of the end of the south-east peripheral wetland and from the western shore near Kubitch Lake. This allows fairly good coverage of the whole lake.

Quallilup Lake (Suite 19). Consisting of Lake Quallilup and a satellite wetland to its north-east associated with the Kubitch-Quallilup flow-through.

Kubitch to Quallilup flowthrough (Suite 20). A series of interconnected basins and channels that carries water overflowing from Lake Gore to Lake Quallilup and, when extensively flooded, west to Barker Inlet. When depth is sufficiently high it is possible to navigate the entire system by boat, otherwise the surveys have been done by boat as far as possible from Lake Quallilup, then surveying the rest of the system by walking through to the Lake Gore overflow.

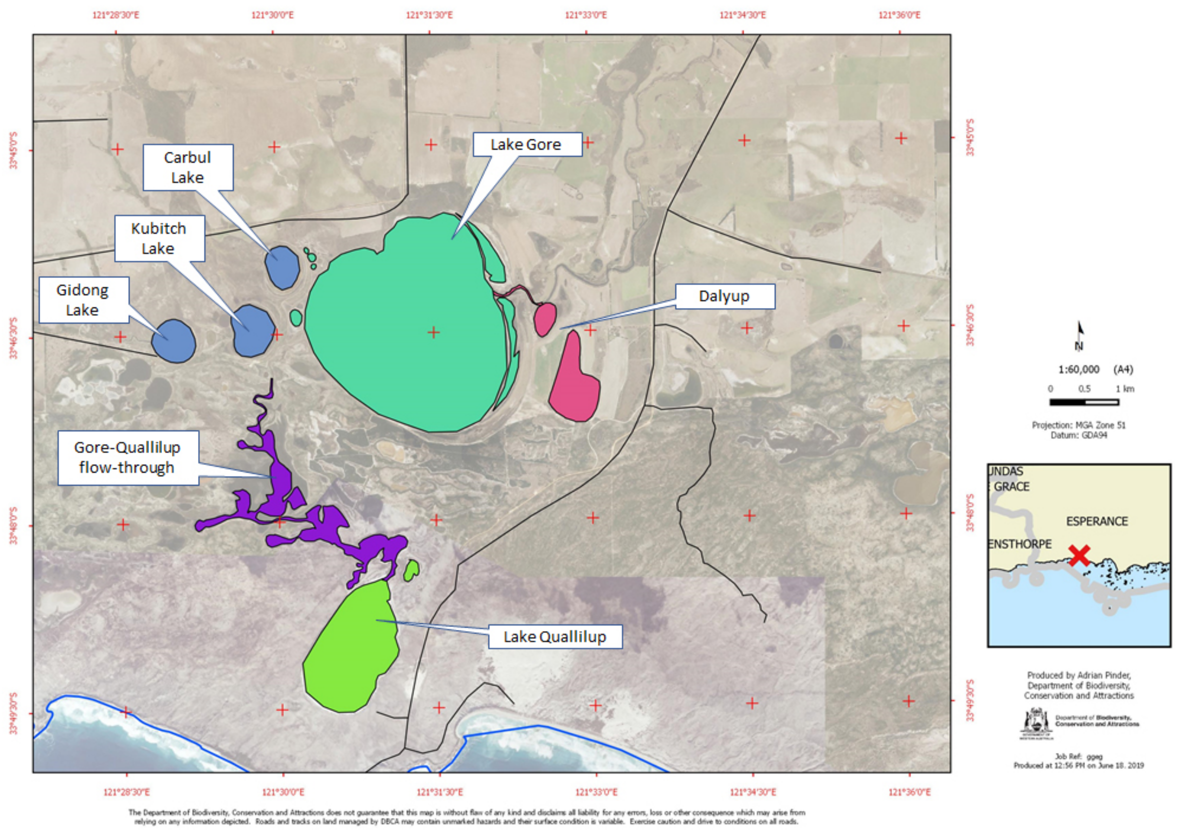

Figure 2. Wetlands surveyed for waterbirds in the Gore-Quallilup system. Wetland suites indicated by colour.

2 2018-19 survey methods

2.1.1 Spring 2018

Ground surveys of all wetlands were undertaken between 30 Oct and 2 Nov 2018 (in Figures this survey is denoted ‘Nov-2018’). These were undertaken by David Cale, Alan Clarke, Adrian Pinder and Yvonne Winchcombe, assisted by David Thornburg (DBCA, Stokes Inlet) and Robyn Cail (South Coast NRM) at selected wetlands. Lakes Wheatfield, Woody, Windabout, Warden, Gore, Quallilup and the Kubitch-Quallilup flow-through were surveyed by two observers by boat. Remaining wetlands were surveyed by 2 to 4 observers on foot. Wetland specific survey methods are described above with each wetland suite.

2.1.2 Late summer 2019

Ground surveys of all wetlands were undertaken between 5 and 8 Feb 2019 (in Figures this survey is denoted ‘Feb-2018’). These were undertaken by Alan Clarke, Michael Coote, Adrian Pinder and Yvonne Winchcombe. Lakes Wheatfield, Woody, Windabout, Warden, Quallilup and much of the Kubitch-Quallilup flow-through were surveyed by two observers by boat. Remaining wetlands were surveyed by 2 to 4 observers on foot, as described above.

For all surveys, the number of chestnut teal have been estimated by doubling the number counted (because only males can reliably be distinguished from grey teal in large numbers) by subtracting an equivalent number from the grey teal count on the assumption of a 50/50 sex ratio.

3 Data management and analysis

Counts were recorded in notebooks and then entered onto a MS Access database. This will be transferred to NatureMap. Previous data from 2006 had mostly been held as an excel spreadsheet. While transferring this spreadsheet data onto the Access database a number of minor errors were detected and resolved by referring to the original notebooks and reports. The spreadsheet will no longer be maintained, and the Access database will be the point of reference for this data. All waterbird count data is provided here as Appendices.

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:

1. Neridup, Bandy Creek and North Wheatfield wetlands in 2006, 2007 and 2008.
2. 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 in Pinder et al. (2015) and previous reports.

Furthermore, 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 of the satellite wetlands around Wheatfield, Woody, Windabout Lakes and Lake Warden. This means richness and abundance may have been underestimated compared to later surveys.

Analyses of Gore system waterbirds in this report are based on the ground counts undertaken since 2009.

For this report, the 2006 to 2019 data were exported from the database and analysed using R (R Development Core Team, 2018). R markdown code and the raw data for these analyses can be viewed at https://github.com/AdrianMP62/Warden-2019.git. Packages used include 'zoo' (Zeilis *et al.*, 2019), 'plyr (Wickham, 2016), 'ggrepel' (Slowikoswski et al, 2018), 'vegan' (Oksanen et al. 2019), 'scales' (Wickham 2018), 'stringr' (Wickham, 2019), 'reshape2 (Wickham, 2007) and 'car' (Fox and Weisberg (2011).

Non-metric multidimensional ordinations were performed using the metaMDS function in vegan (Oksanen *et al.*, 2018) with or without square root transformation of waterbird count data (as indicated in the text). Simper analysis was used to find waterbird species that best discriminated between subsets of waterbird data (e.g. that best distinguish Warden and Gore waterbird communities), using the simper function of vegan. To find subsets of species that best represented patterns in the entire datasets, a stepwise selection method (bv.step[1]) was used that maximises spearman rank correlations between similarity matrices calculated from the full and reduced datasets, penalised by number of species. The pearson correlation between the dissimilarity matrix from the subset of species and the dissimilarity matrix from all species was calculated using the 'mantel' function of R with a permutational test (999 randomisations) used to test significance.

Two types of analysis have been undertaken to investigate the relationships between environmental variables and waterbird community composition. These are 'bio-env' and distance-based redundancy analysis (db-RDA), as follows:

Bio-env. This uses the bio-env function in the vegan package is equivalent to the bv.step procedure used above to detect subsets of species. Bio-env identifies subsets of environmental variables that create (Euclidean) survey x survey similarity matrices best correlated with the waterbird (Bray-Curtis) dissimilarity matrices. That is, environmental variables that change between surveys in ways that are most similar to ways that waterbird communities change.

db-RDA is an ordination technique that finds species ordination axes that are best explained by a linear combination of explanatory variables[2]. We used the ordistep

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[1] http://menugget.blogspot.com/2011/06/clarke-and-ainsworths-bioenv-and-bvstep.html

[2] http://ubio.bioinfo.cnio.es/Cursos/CEU_MDA07_practicals/Further%20reading/Multivariate%20analysis%20Borcard%202006/

function in the vegan R package to implement this analysis and tested significance of resulting models with significance of the model assessed with a permutation test.

Rainfall data was downloaded from the Bureau of Meteorology in March 2019, from three weather stations: Esperance (station 9789), Esperance Aero (9542) and Myrup (9584). 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 the average value for the month.

4 Results

4.1 Rainfall and depths

4.1.1 2018/19 rainfall

The Esperance coast had average to below average rainfall in the months prior to the November 2018 survey (Figure 3, Figure 4) and prior to the Feb 2019 Survey.

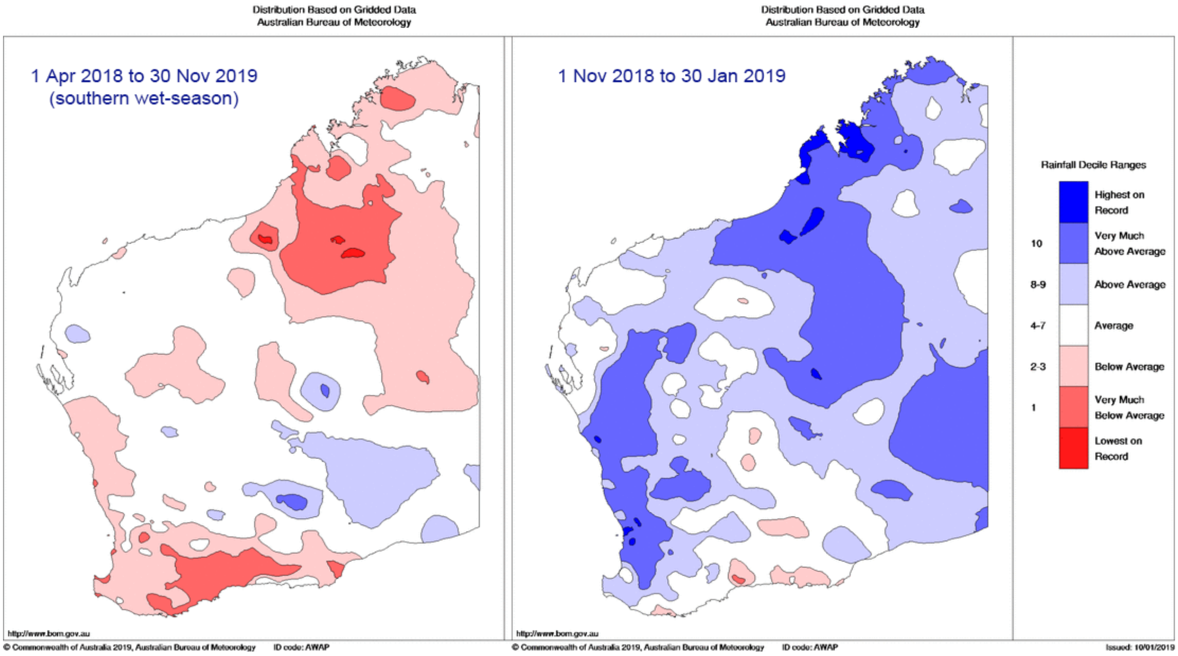

Figure 3. Rainfall deciles for the southern wet season (April to Nov) in 2018 (left) and the three month period 1 Nov 2018 to 30 Jan 2019 (Source, Bureau of Meteorology 27 Mar 2019).

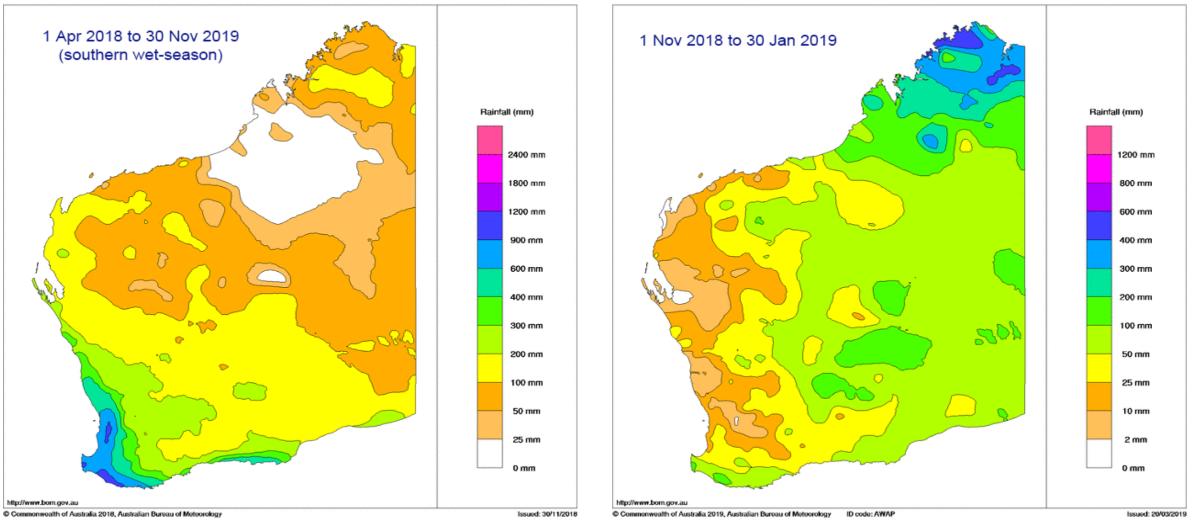

Figure 4. Rainfall amounts for the southern wet season (April to Nov) in 2018 (left) and the three month period 1 Nov 2018 to 30 Jan 2019 (Source, Bureau of Meteorology 27 Mar 2019).

4.1.2 Depths of Warden wetlands during surveys

Figure 5 shows depths of the seven depth gauged Warden wetlands for the ten surveys conducted in spring between 2006 and 2018. These depths are interpolated from depths measured before and after the surveys (normally within a week either side of the survey). Spring depth in Lake Warden declined after the Wheatfield pipeline was installed in 2009 leading to less water overflowing from Lake Windabout, although lower rainfall probably also played a part in this. Depths in Lake Warden in Nov 2018 were higher than for most other post 2009 spring periods in which surveys have been undertaken (with the exception of Nov 2010). Depths in Wheatfield, Woody and Windabout declined from 2007 to 2011 and have been variable since. These wetlands were relatively deep in November 2018 (similar to depths recorded in 2007). Depths in Ewans, Mullet and Station lakes have been relatively more stable and were not much different in Nov 2018 than for other surveys undertaken since 2006.

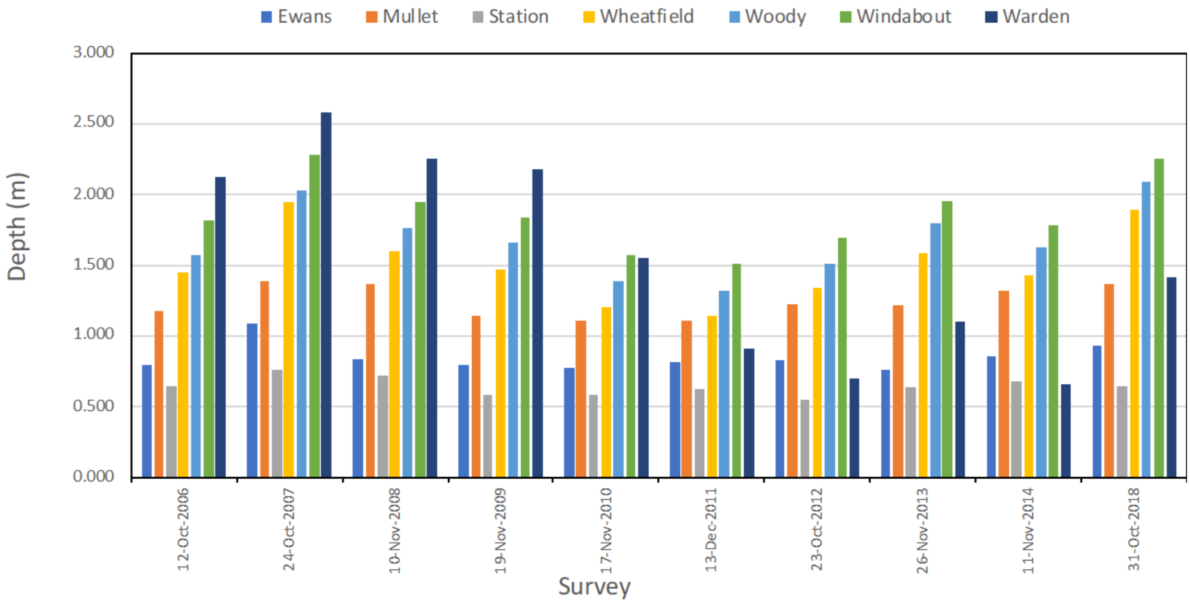

Figure 5. Depths of depth gauged wetlands for the surveys undertaken in the Warden system during spring 2006 to 2018. If not measured within a couple of days of the survey depths are interpolated between the nearest two dates (up to 2 weeks either side of the actual survey date).

Figure 6 shows interpolated depths of the seven depth gauged Warden wetlands for the eight surveys conducted in late summer (February) between 2008 and 2019. The largest change over this time was decline in depth of Lake Warden between 2008 (2.05 m) and 2013 (0.34 m) and its depth remaining under 1.0 m for subsequent surveys. February depths in Wheatfield, Woody and Windabout have not changed as significantly over time as depths in the same wetlands in spring. February depths in Ewans, Mullet and Station lakes have varied over the years but not in a directional way. This is most noticeable in Station Lake which has almost completely dried in some years but has been as deep as 0.49 m. Ewans Lake was noticeably shallow in Feb 2019 with an estimated depth of just 0.20 m on 6 Feb (measured 0.05 m on 17 Feb).

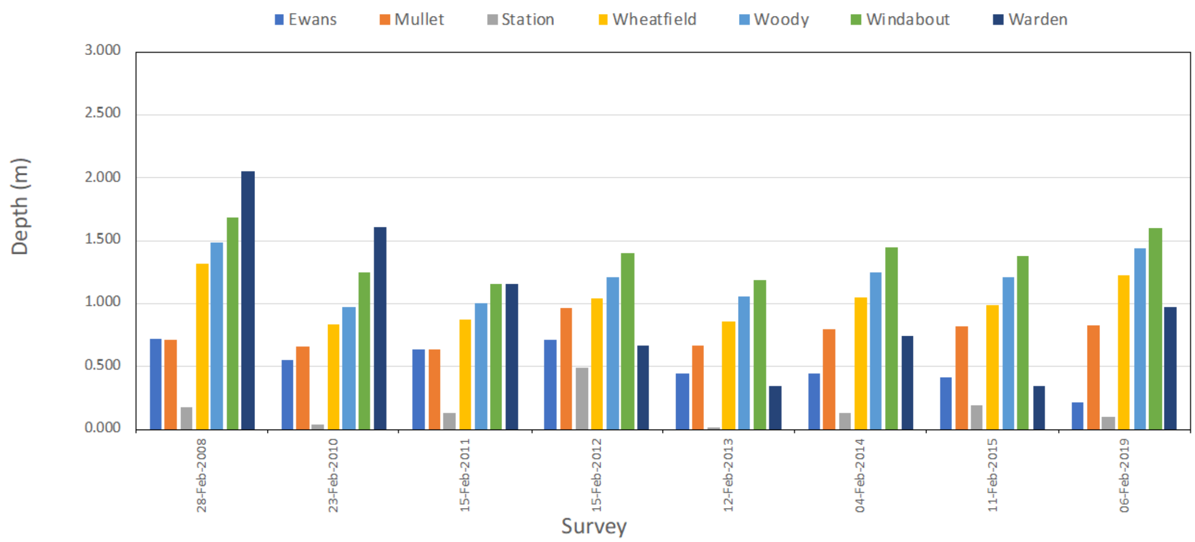

Figure 6. Depths of depth gauged wetlands for the surveys undertaken in the Warden system during summer 2008 to 2019. If not measured on the day Lake Wheatfield was surveyed, then depths are interpolated between the nearest two dates (up to 2 weeks either side of the actual survey date).

4.1.3 Timing of surveys in relation to rainfall for the Warden system

The cumulative deviation from mean monthly rainfall (CDM) at three Bureau of Meteorology weather stations (orange blue and green lines) is shown for the period Jan 2004 to Jan 2019 in Figure 7 and Figure 8, together with the total abundance of waterbirds for spring and summer surveys (grey columns). In these graphs, increasing cumulative deviation from mean (using Jan 2004 as the zero point) is indicated by ascending (above average rainfall) or descending (below average) lines. Periods where rainfall is not significantly different from average have more horizontal lines. Interestingly, the three rainfall gauges were largely in sync until Jan 2013, when the Myrup and Esperance Aerodrome started to register higher rainfalls than the Esperance town gauge, especially from late 2013.

Spring surveys in Oct 2006, Oct 2009 and Oct 2012 were undertaken after periods of consistently and significantly below average rainfall. The October 2013 survey was undertaken after a substantial period of well above average rainfall. Other surveys were preceded by periods of variably below or above average rainfall. For example, the Oct 2008 survey was undertaken during an above average rainfall late winter/spring following a below average rainfall summer and autumn.

Summer surveys in Feb 2010 and Feb 2011 occurred during a particularly dry period, with a rain deficit of about 250 mm between Jan 2009 and Aug 2011. The only spring survey undertaken following a lengthy above average rainfall period was in Feb 2012 after a 4 to 6 month period (depending on the gauge) with 86 to 135 mm rainfall in excess of the average.

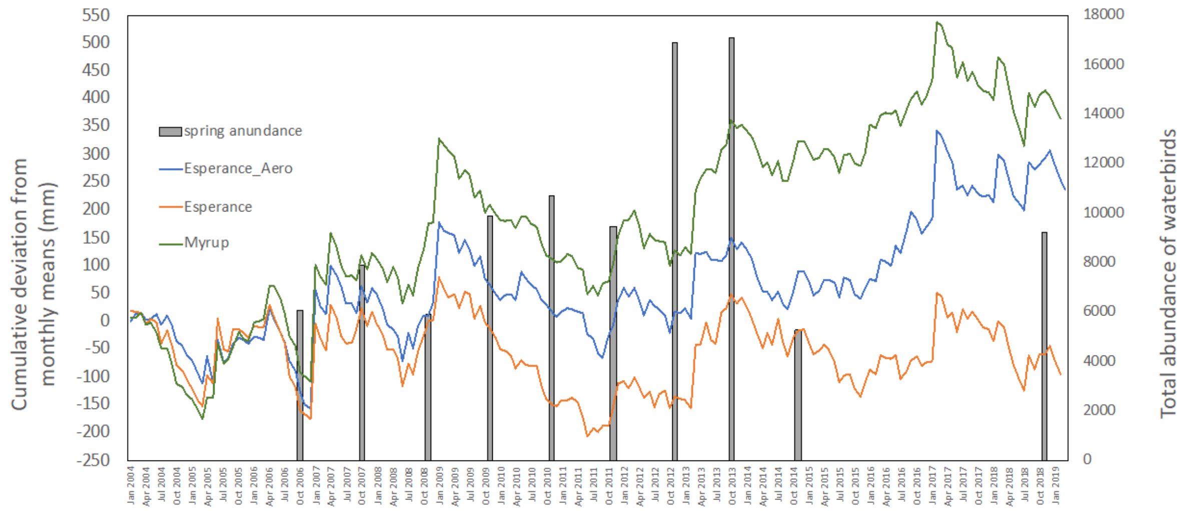

Figure 7. Cumulative deviation from mean monthly rainfall since Jan 2004, for three Esperance area rainfall stations, with total waterbird abundances for each of the spring surveys. Rainfall data from Bureau of Meteorology downloaded March 2019.

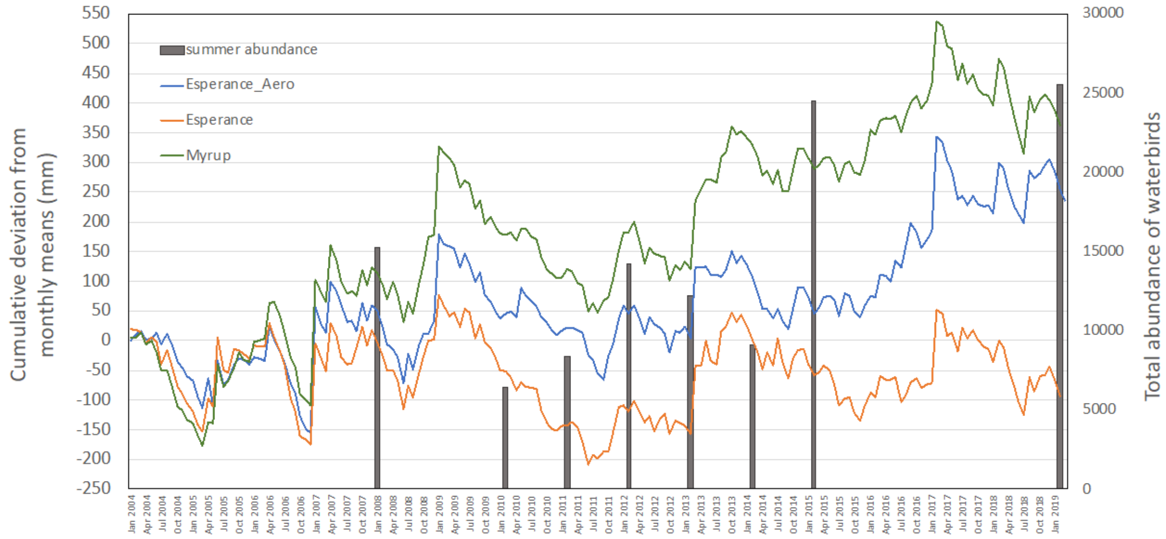

Figure 8. Cumulative deviation from mean monthly rainfall since Jan 2004, for three Esperance area rainfall stations, with total waterbird abundances for each of the summer surveys. Rainfall data from Bureau of Meteorology downloaded March 2019.

4.1.4 Lake Warden depth and operation of the Wheatfield pipeline

Several wetlands in the Warden system have undergone significant changes in depth between the 1980s and the present day (Figure 9). Here we focus on Lake Warden due to the effects on shorebirds. During most of the 1980s spring depths in Lake Warden were mostly below 1 m (Lane, Clarke & Winchcombe, 2017) and the lake occasionally dried. Shallow depths during this period provided large areas of shore and shallow water and Lake Warden supported significant numbers and diversity of shorebirds (Jaensch, Vervest & Hewish, 1988). Depths rose erratically during the late 1980s and 1990s as a result of increased discharge from the catchment and the period 2000 to 2008 saw spring depths consistently above 1.5 m and from 2003 consistently at or above 2 m (Lane *et al.*, 2017). This dramatically reduced shorebird habitat (Robertson & Massenbauer, 2005) and diversity of the shorebird communities using this lake and led to the death of much of the fringing vegetation.

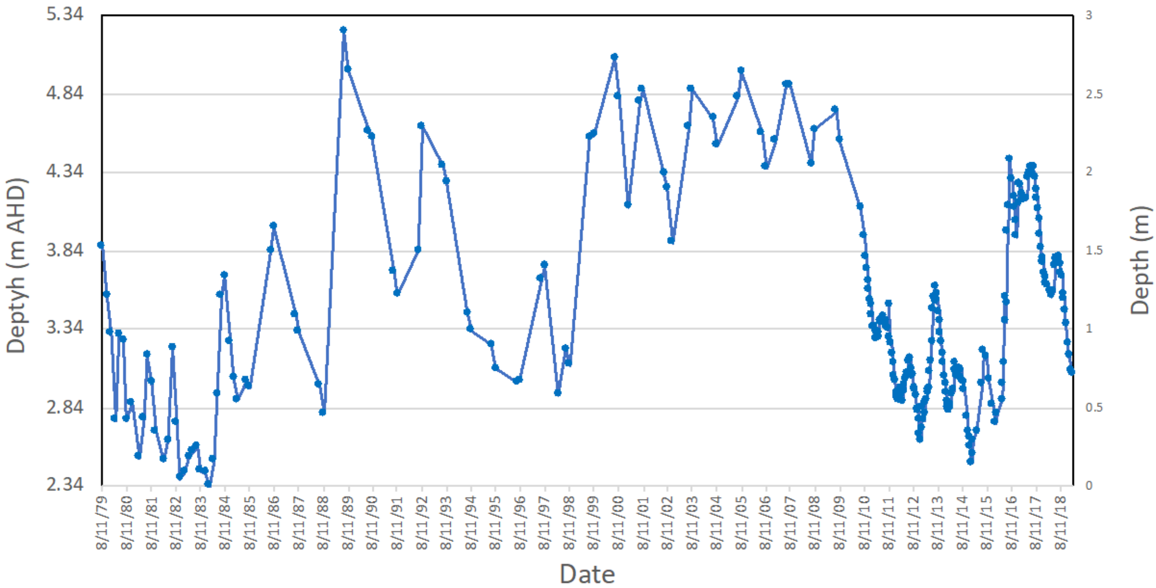

Figure 9. Depth of Lake Warden Nov 1979 to May 2019. Data from Lane et al. (2017) and monitoring undertaken by the DBCA Esperance District. Left axis = metres as Australian Height datum, Right axis = depth of lake.

Reducing depth in Lake Warden was a major management priority of the Warden Natural Diversity Recovery Catchment Program, with canvassed solutions including a gravity-fed pipeline from Lake Wheatfield to Bandy Creek. This pipeline was installed and has been operated since 2009 with the aim of maintaining depth in Lake Wheatfield within a target range that also reduces water flowing through the system to Lake Warden (Figure 10). Depths in Lake Warden consequently fell back to be within about the same range as the early 1980s thereafter (Figure 9 and Figure 10), other than a period between 2016 and 2018 when depths were again high following periods of very high rainfall. The pipeline was open for most of this high depth period and undoubtedly prevented depths being even in higher in Lake Warden.

Patterns in shorebird usage of Lake Warden in relation to these changes in depth are analysed in Section 4.4.4.

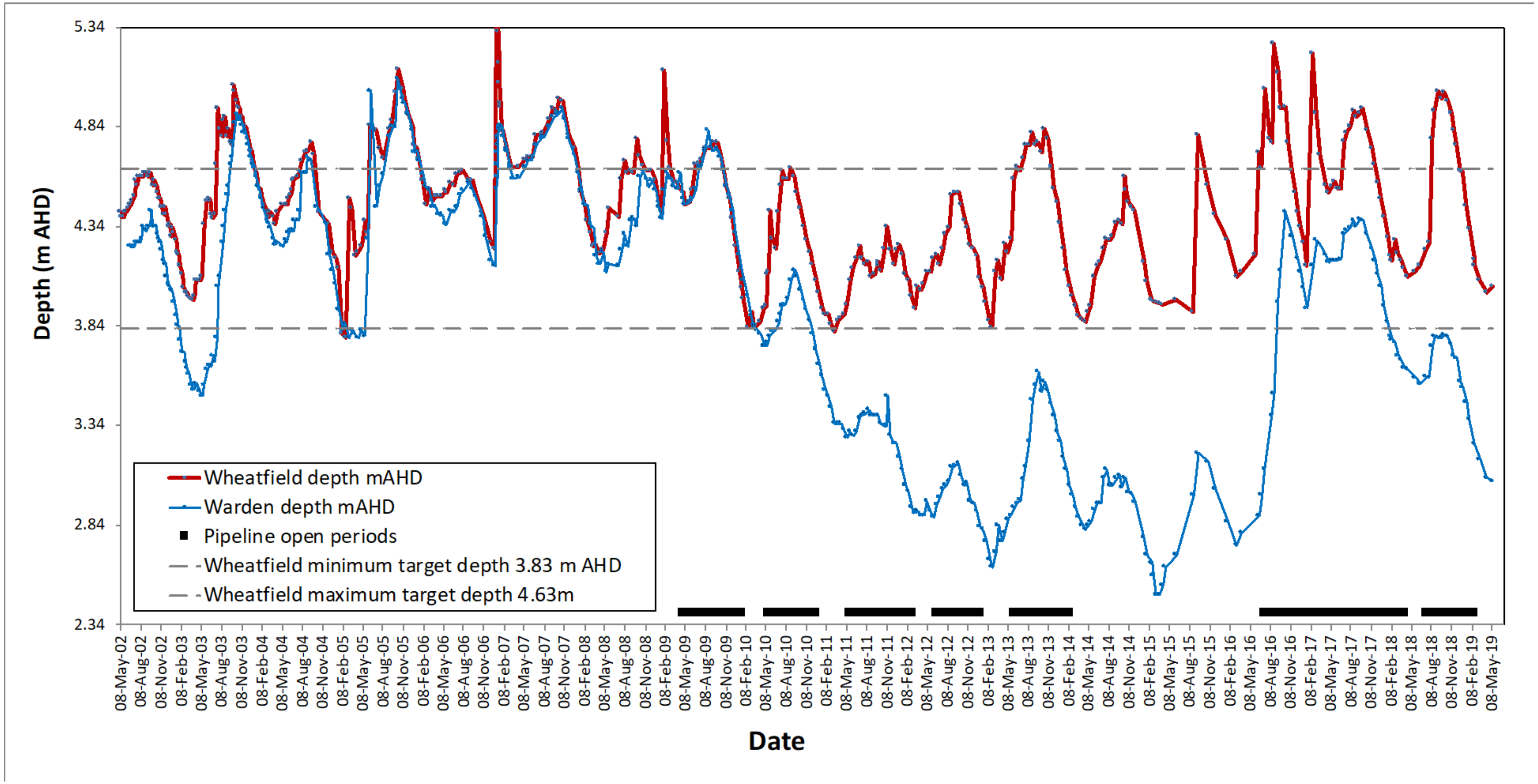

Figure 10. Depths (mAHD) of Lake Warden (blue line) and Lake Wheatfield (red line) since 2002, with Wheatfield pipeline open periods indicated by the black bars along the bottom of the plot. The target range of depths for Lake Warden are shown as grey dashed lines.

4.2 Spring versus summer waterbird communities across the Warden and Gore systems

With data combined across both systems, there is a distinct difference between waterbird communities present in spring and late summer (Figure 11). The November 2018 and February 2019 communities were not especially different from other surveys in the respective seasons, although the Feb 2019 survey was the most spring-like community surveyed. The ordination suggests that there is greater variation in communities present in spring than those present in summer, with the exception of Feb 2008 which had a different composition from other summer surveys. This ordination shows the need to survey in at least two seasons to document waterbird usage of these wetland systems.

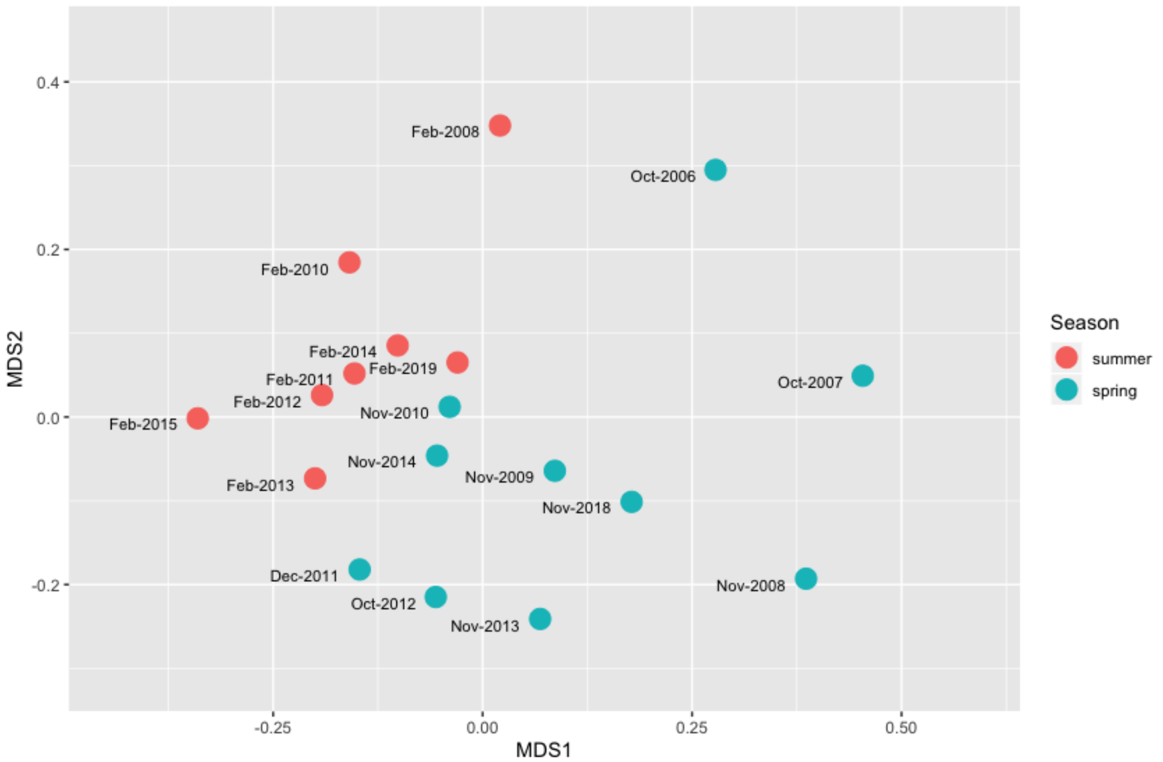

Figure 11. Axes 1 and 2 of a three-dimensional ordination of waterbird surveys by season. Each point represents all waterbird data combined across both systems for one survey.

4.3 Gore versus Warden wetland systems

When waterbird abundance data is separated by both season (spring versus summer) and system (Warden versus Gore) there is still clear separation of communities present in summer (filled symbols) and those present in spring (open symbols) in an ordination plot (Figure 12).

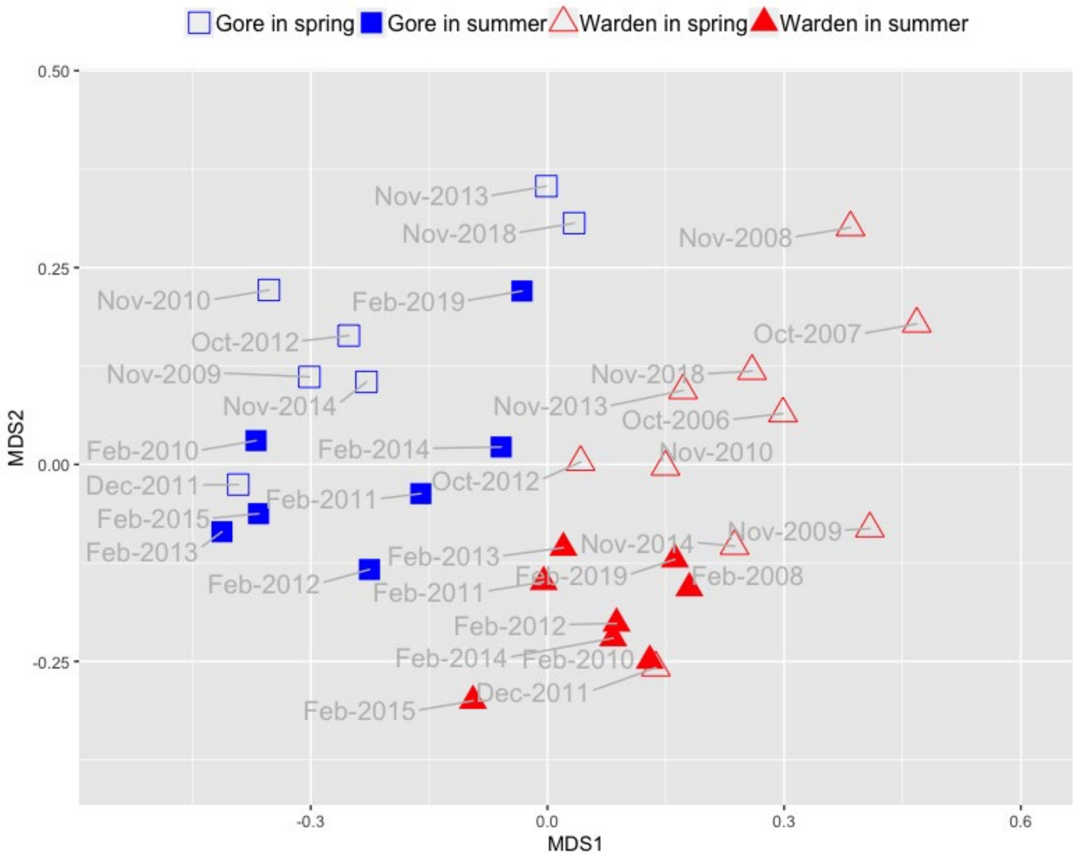

Figure 12. Axes 1 v 2 of three-dimensional ordination showing waterbird communities present during each survey, with different symbols representing system (Warden v Gore) and season.

It is also very clear from Figure 12 that the Warden and Gore wetland systems support very different communities. Most species occur in both systems, but some species tended to be more or less abundant on or other system. A 'simper' analysis identified a subset of ten species whose abundances across all surveys (spring and summer) best distinguished the Warden and Gore communities. Box-plots of the abundance of these species are shown in Figure 13. These species accounted for 82% of the difference in community composition between the Warden and Gore wetlands. Of these species Australian shelduck, hoary-headed grebe, Eurasian coot and little black cormorant tended to be more abundant on the Gore system whereas black swan, grey teal, Pacific black duck, banded stilt, hardhead and red-necked stint tended to be more abundant on the Warden system. However, the difference in abundance between the systems was statistically significant in Mann-Whitney pairwise comparisons ($p<0.05$)

only for Pacific black duck, red-necked stint, black swan, grey teal and Australian shelduck.

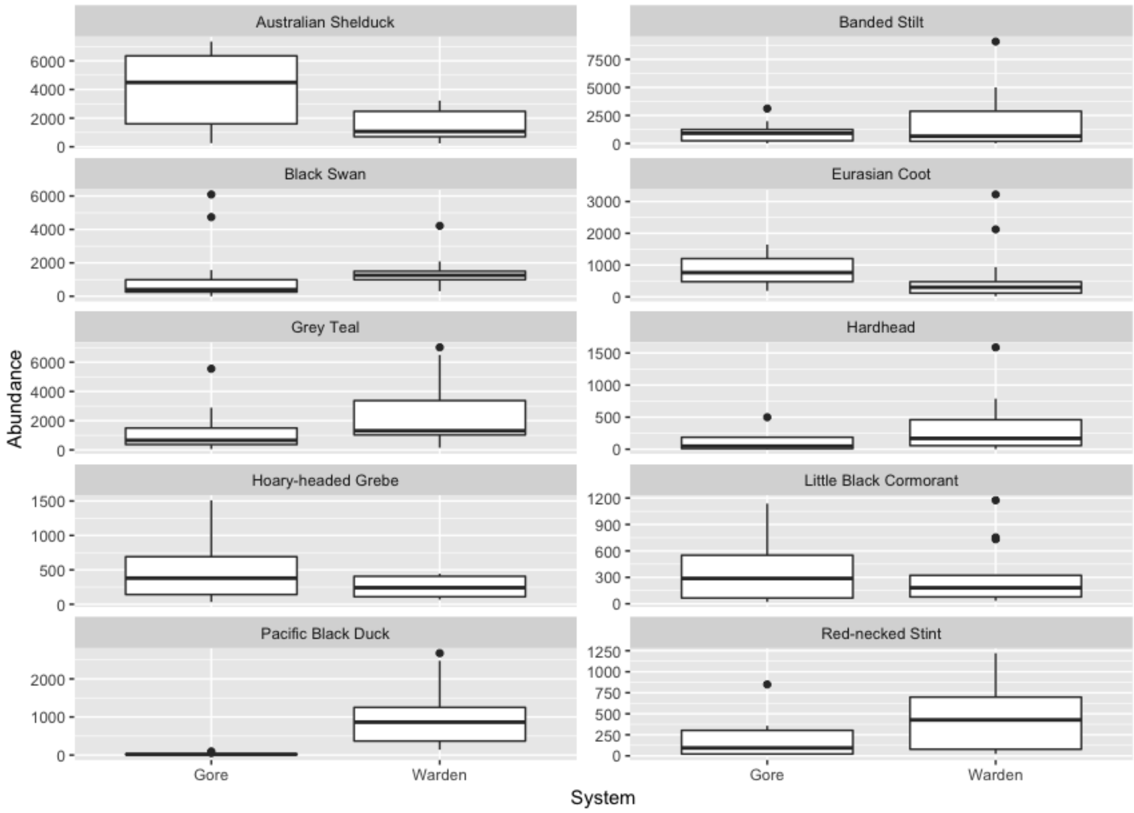

Figure 13. Box plots of abundance of the eight species most contributing to differences between waterbird communities in the Gore and Warden wetland systems, as identified by a Simper analysis.

4.4 Warden wetlands

4.4.1 Warden system species richness

Waterbird richness in spring (Figure 14) was the second lowest for the present survey program, with just 40 species, compared to between 41 and 48 for the 2007 to 2014 period. In particular there were no crakes or hens and no raptors and shorebird diversity was quite low compared to most previous surveys (most notably an absence of sharp-tailed sandpipers and red-kneed dotterels). However, this is only 1 or 2 species less then several other spring counts on the system since 2007 and is more than observed in 2006.

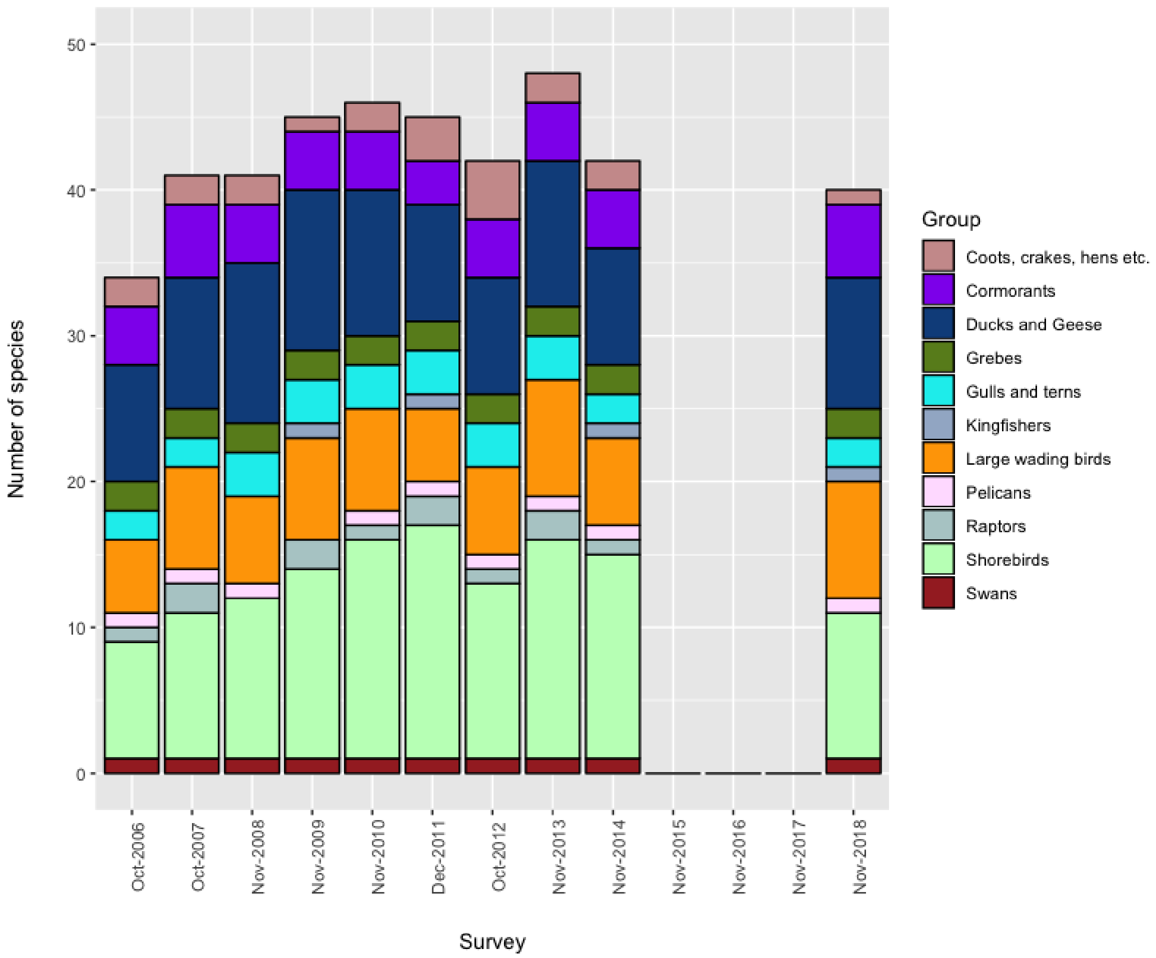

Figure 14. Species richness by major waterbird group for surveys of the Warden wetland system undertaken in spring.

Waterbird richness in Feb 2019 was within the range of most other summer surveys and much higher than in Feb 2015 (Figure 15). The number of large wading birds was high (8 species) compared to 5 to 7 for previous summer surveys, with the first records of white-necked heron for the 2008-2019 summer surveys (all previous records in spring and only since 2013). The number of shorebird species was about average at 14. As in 2015, Caspian terns were absent whereas they had been present during previous summer surveys from 2008 to 2014.

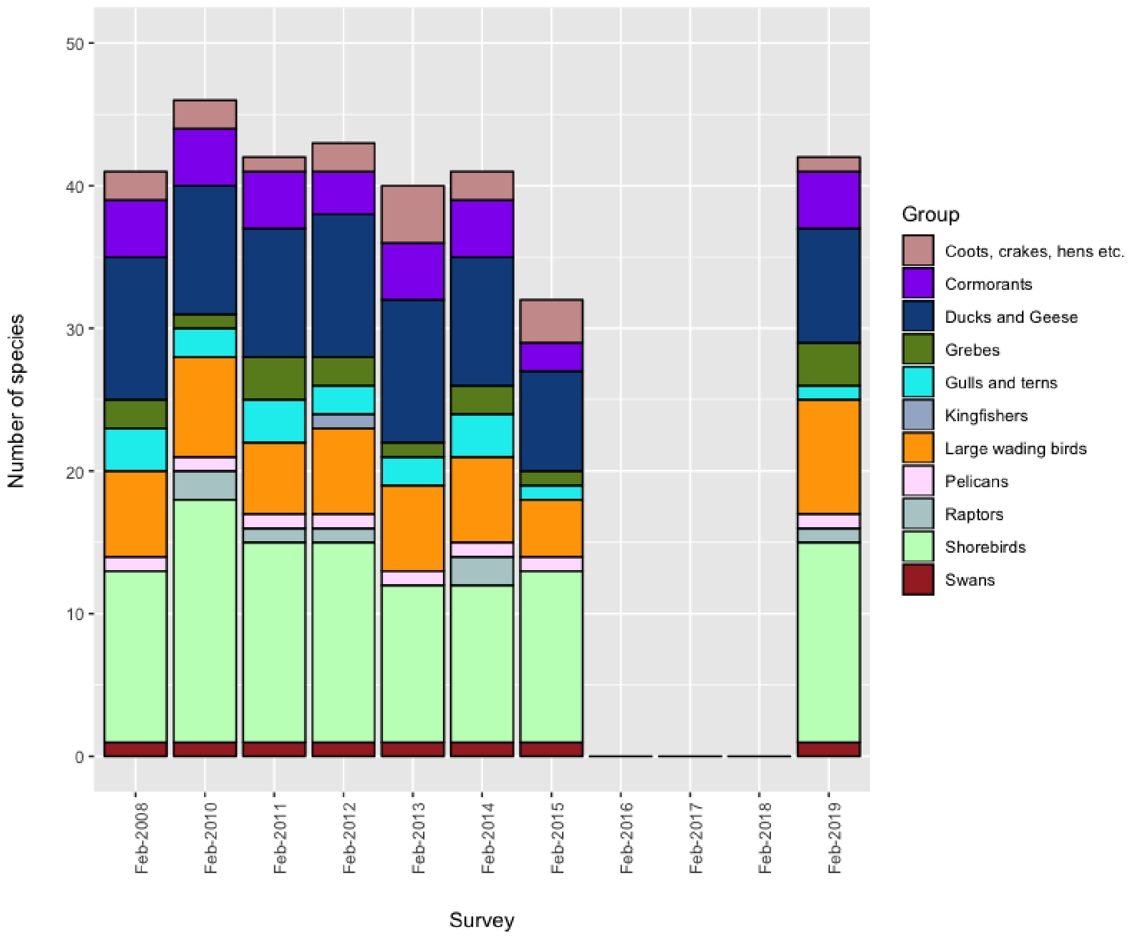

Figure 15. Species richness by major waterbird group for surveys of the Warden wetland system undertaken in summer.

4.4.2 Warden system abundance

Figure 16 and Figure 17 show abundances by major waterbird group for the spring and summer surveys respectively.

In Nov 2018, total waterbird abundance across all groups was about average and abundances of individual waterbird groups was mostly within the range of previous spring surveys. The number of chestnut teal (914) was the highest recorded for spring, exceeded only by the Feb 2011 survey count (1114). These were mostly on Lake Warden. The number of Eurasian coot was also high at 542, with most on the Wheatfield and Woodie lakes including the channel. The next highest spring count was 494 in 2013. The number of hardhead (651) was the second highest spring count, with almost all on Station Lake, Lake Wheatfield and the western North Wheatfield wetland. By contrast, the counts of Australian shelduck (800), Pacific black duck (194) musk duck (49) and yellow-billed spoonbill were the lowest or 2nd lowest for spring surveys.

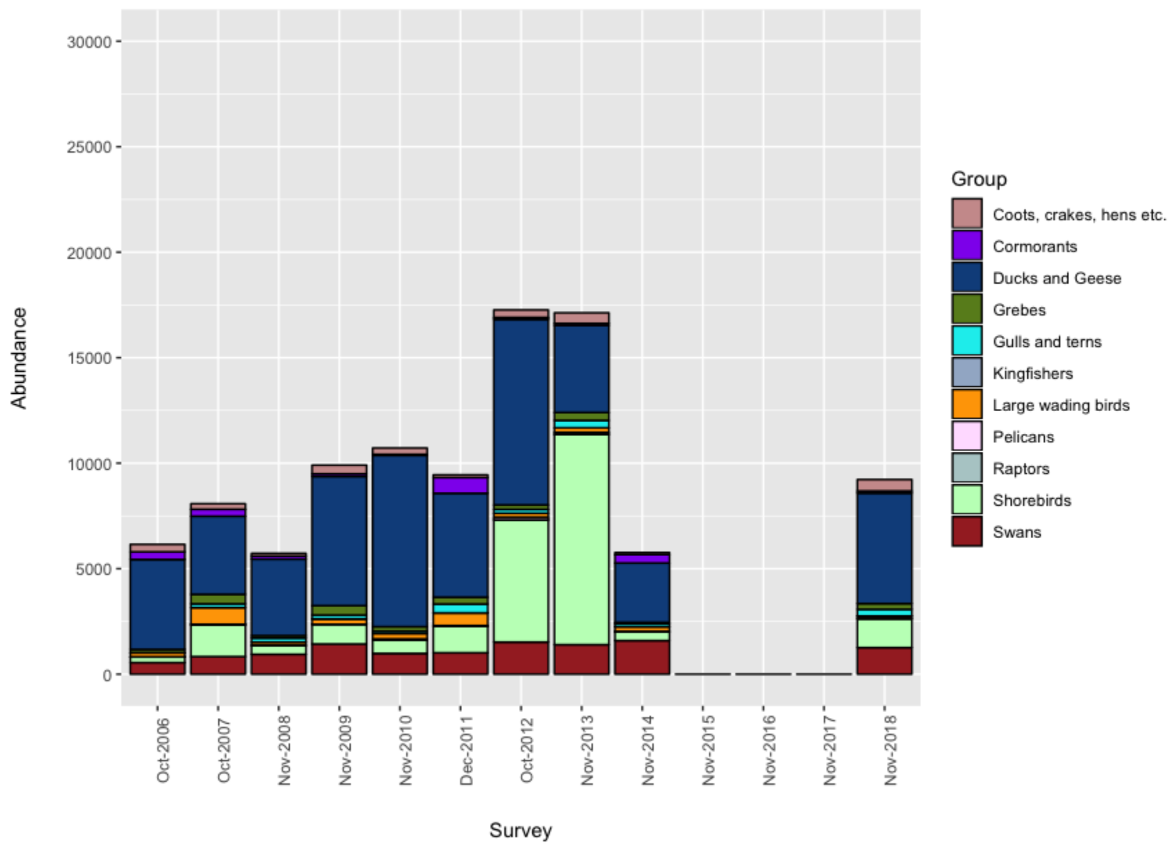

Figure 16. Abundance of waterbirds by taxonomic group for surveys conducted on the Warden wetlands during spring since 2006.

The Feb 2019 survey recorded the highest total abundance for any of the summer surveys. The higher abundance was primarily a result of the high number of shorebirds, especially banded stilt (5001), red-necked avocets (1139), sharp-tailed sandpipers (414) and red-necked stints (1221), all of which are record counts for the Warden system since summer surveys started in 2008. The banded stilt, red-necked avocets and red-necked stints were mostly on the eastern and north-eastern shores of Lake Warden whereas 344 of the sharp-tailed sandpipers were on the northern 'gun club' wetland (site WRP006A) opposite Lake Wheatfield.

The number of Eurasian coot (3222) was 50% higher than the previous maximum count of 2123 in Feb 2014. These were mostly (2352) on Lake Wheatfield. The number of silver gulls (770) was also nearly double the previous high count of 401 (in Feb 2013) and these were almost all on Mullet Lake, Lake Warden and Windabout Lake. Numbers of grey teal (6500) was the second highest count (below the 8539 in Feb 2015), with most on the eastern-most North Wheatfield wetland and on Windabout Lake. Hardhead were also much more abundant (788) than previously recorded in summer (exceeded only by the count of 1588 in Oct 2007). The number of little-black cormorants (123) was lower than for most recent summer surveys. White-necked herons (18) had not previously been recorded during summer surveys and these were all on one of the Woodie Lake satellite wetlands.

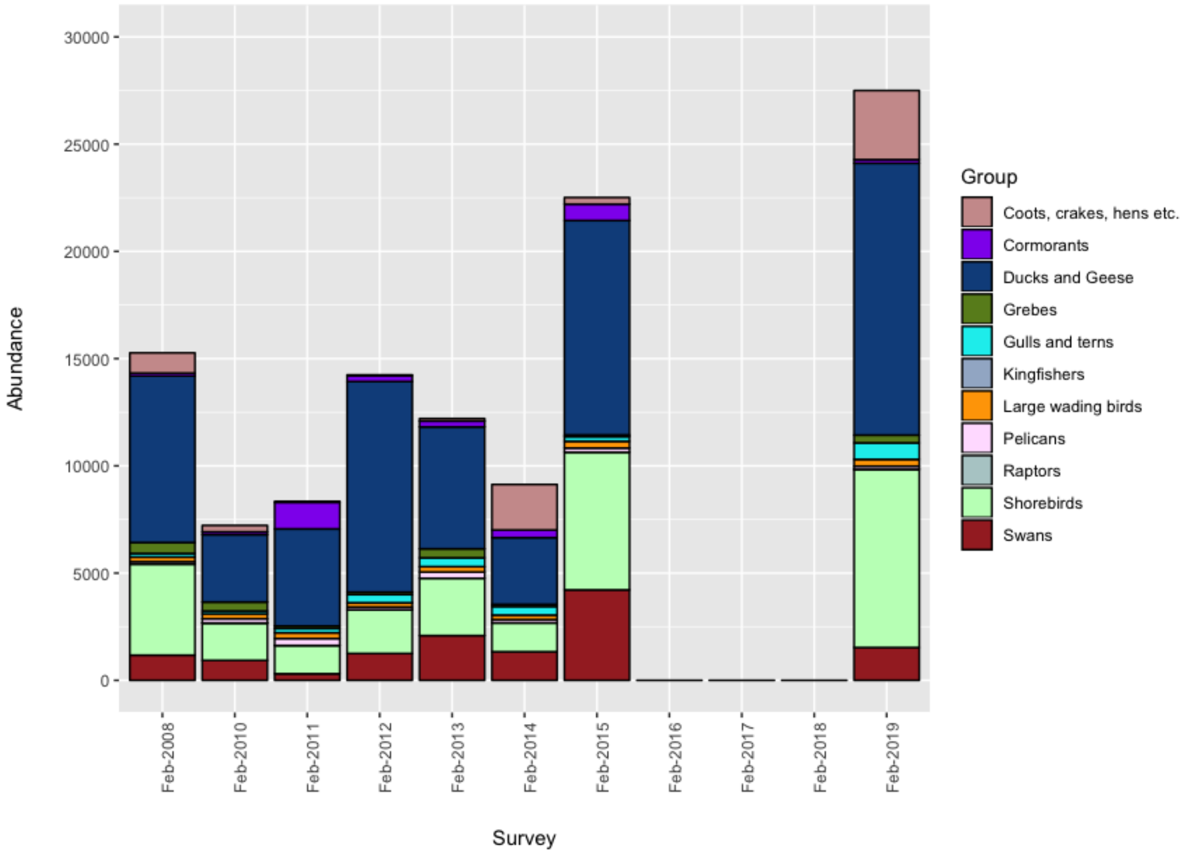

Figure 17. Abundance of waterbirds by taxonomic group for surveys conducted on the Warden wetlands during summer since 2006.

4.4.3 Multivariate analyses of waterbirds occurring in the Warden system

4.4.3.1 Patterns in species composition over time

Figure 18 is an ordination plot of waterbird communities using the Warden wetland system during spring (ten surveys between 2006 and 2018). The points representing each survey are scaled and coloured (but not linearly) by the average depth of the depth gauged wetlands for each survey. In this plot surveys undertaken when depths were greater (>1.3 m) are to the left of the plot and surveys undertaken when depths were lower are to the right of the plot, with the Dec 2011 survey located to the far right of the plot when average depth was 1.06 m.

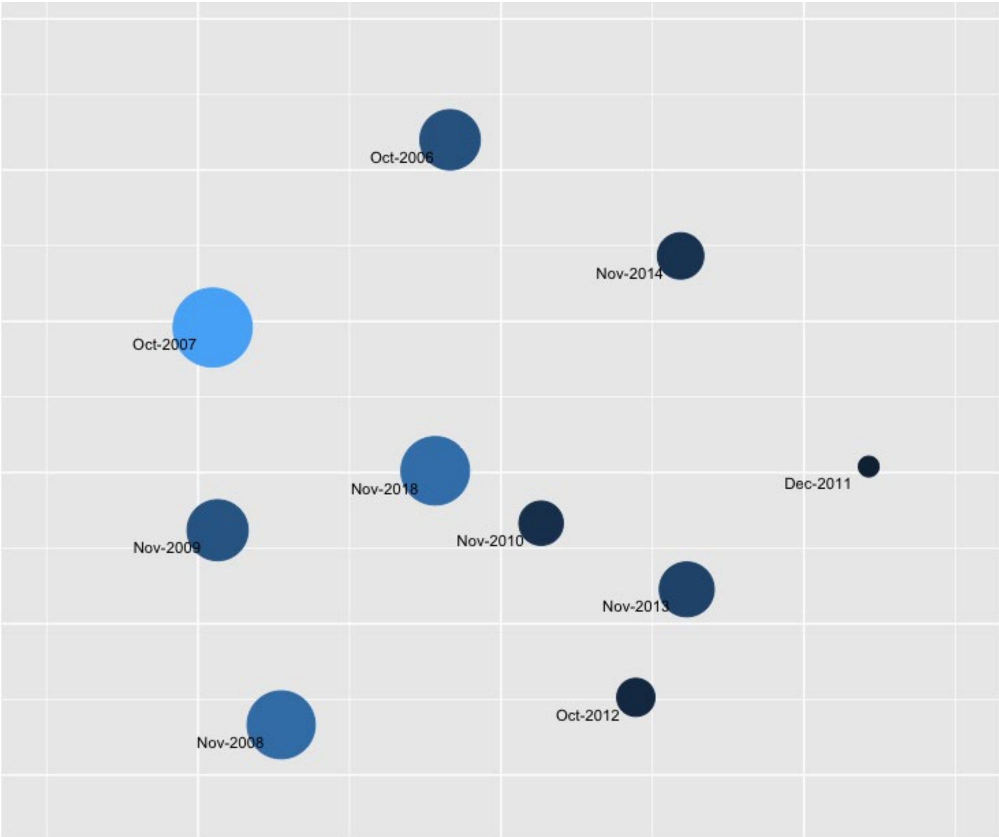

Figure 18. Two-dimensional ordination of waterbird communities surveyed over ten spring periods between 2006 and 2018, with points representing surveys scaled by (but not directly proportional to) average depth of gauged wetlands.

For surveys conducted in late summer there is not such a clear relationship between average depth and community composition (Figure 19).

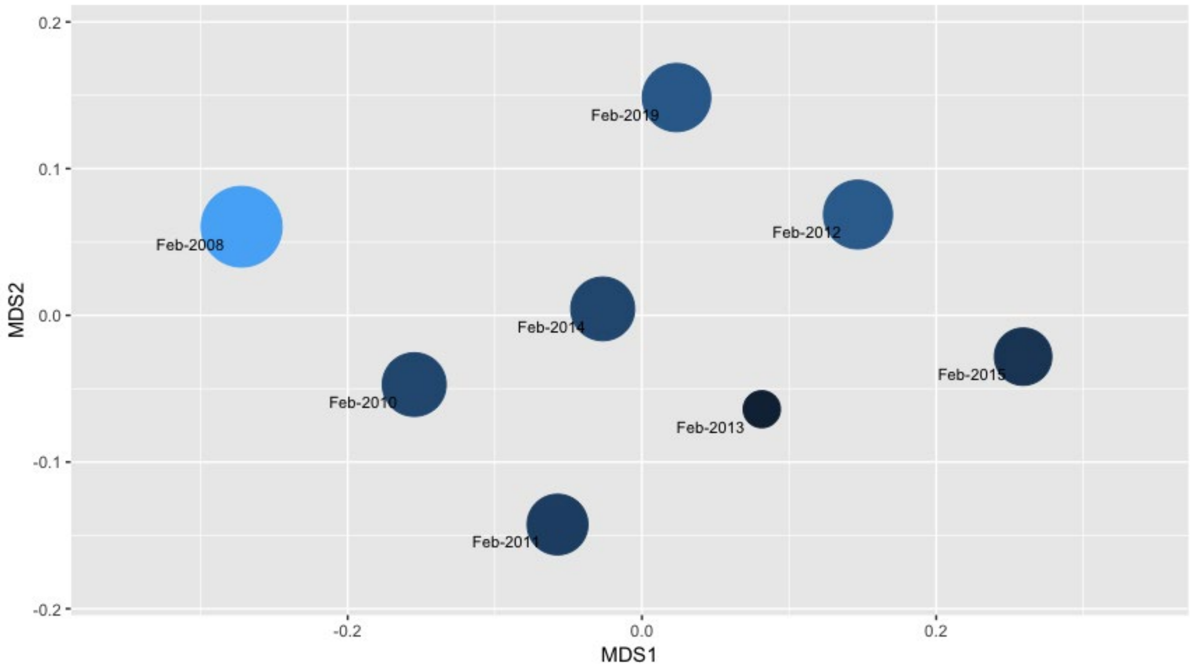

Figure 19. Two-dimensional ordination of waterbird communities surveyed over eight late summer periods between 2008 and 2019, with points representing surveys scaled by (but not directly proportional to) average depth of gauged wetlands.

4.4.3.2 Species – environment relationships

Two types of more quantitative analysis have been undertaken to investigate the relationships between environmental variables and waterbird community composition. These are 1) 'bio-env' which identifies subsets of environmental variables that produce survey x survey dissimilarity matrices correlated with the dissimilarity matrix based on waterbird species abundance and 2) 'distance-based redundancy analysis' (db-RDA) which produces linear models of relationships between environmental variables and constrained ordination axis scores based on species composition.

Environmental variables used in these analyses are shown in Table 2 and include average depths of the gauged wetlands and cumulative deviation from the monthly Mean (CDM) rainfall for periods of three, six and twelve months prior to the survey for each of the three weather stations listed above. We have also investigated the influence of the timing of the surveys and the operation of the pipeline. The timing of spring surveys has varied over the 2006 to 2019 period, with earlier surveys mostly in October, later surveys mostly in November and one in December 2011. Late summer surveys have always been held in February but there was still some variability in the time of the month surveys were conducted. This variable timing of surveys may have influenced waterbird composition, depth and the range of rainfall values used to calculate CDM. To investigate the effect of survey timing a variable (‘Days’) was created by calculating the number of days between the survey and either the start of spring (1 Sep) or start of the year (1 Jan) for spring and summer surveys respectively (Table 2), with the day of the survey deemed to be the day Lake Wheatfield was surveyed.

The Wheatfield pipeline was installed in 2009 and depths in Lake Warden and the main central suite wetlands (Wheatfield, Woody and Windabout) were frequently lower in following years as a result. The influence of this factor on waterbird communities was investigated by calculating the number of days (‘Pipeline_days’) that the pipeline was open in the three months prior to each survey (Table 2). For spring surveys this is almost a binary variable (either zero days or 92 days other than for the Dec 2011 survey). For the summer surveys the pipeline was more variably open in the 3 months prior to the surveys.

Few of the variables in Table 2 were sufficiently correlated with one another to require removal from the analyses. The three month CDM for the Esperance and Esperance Aerodrome weather stations for summer surveys were the only two variables with Pearson correlations >0.9.

Table 2. Variables used in analyses of relationships between environment and waterbird communities (bio-env and db-RDA). Depth is average depth of the seven depth gauged wetlands. CDM is cumulative deviation from the monthly mean for periods of 3, 6 or 12 months for 3 rainfall stations. Pipeline _days is the number of days the Wheatfield pipeline was open in the 3 months prior to the survey. Days is the number of days between either the first of September (for spring surveys) and the survey date or between the 1st January and the summer survey date.

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-08	Summer	1.16	0	59	-15	16.6	-8.1	-27.7	36.6	1.3	-6.3	33.8	11
Feb-10	Summer	0.84	55	54	-39.8	-92	-140.5	-48.9	-98.6	-127.9	-14.6	-82.3	-146.1
Feb-11	Summer	0.80	35	46	-12	-48.6	-20.3	-2.9	-62.6	-92.3	-10.3	-67.3	-73.1
Feb-12	Summer	0.92	92	45	84.8	90.8	42.1	79.1	84.4	33.9	109.4	118.6	74.8
Feb-13	Summer	0.65	52	43	43.2	-4.6	-36.5	14.7	11.2	-33.9	32.9	-12.8	-48.9
Feb-14	Summer	0.84	92	35	-23.8	15.8	104.3	-24.1	64.6	166.5	49.3	-15.4	122.9
Feb-15	Summer	0.76	0	42	19	20.2	-54.3	-9.1	-42.6	-62.9	53.8	82.8	76.9
Feb-19	Summer	0.91	92	37	0	82.8	67.3	-9.9	56.5	-33.6	93.7	47	12.8
Oct-06	Spring	1.37	0	42	-69.6	-54.1	-47.3	-100.9	-109.9	-104.7	-86	-47.2	2
Oct-07	Spring	1.73	0	53	-45	2.3	103.9	15.3	38.9	106.5	-25.2	8.8	118.5
Nov-08	Spring	1.50	0	70	33.2	25.8	-52.5	51.1	24.3	-49.5	63.2	31	9.9
Nov-09	Spring	1.38	92	79	-52.2	-78	65.7	-49.7	-49.7	23.9	-67.7	-100.6	66.6
Nov-10	Spring	1.17	92	75	-36.6	-9.4	-48.1	-59.7	-55.1	-138.3	-57	-49.8	-77.4
Dec-11	Spring	1.06	61	102	50.2	-20.8	-24.3	44	16.2	-4.7	56.8	10.3	-9.2
Oct-12	Spring	1.12	92	52	-26.8	-47.7	76.7	2.7	-23.1	63.1	-15.9	-58.7	74.2
Nov-13	Spring	1.29	92	84	39.6	29	171.3	88.7	89.9	205.3	-64.7	-49.1	106.5
Nov-14	Spring	1.19	0	70	1.2	0.4	-97.1	-33.5	18.5	-77.9	29	-20	72.4
Nov-18	Spring	1.51	92	59	82.8	24.4	52.1	66.4	-13.2	-61.2	-46.7	-25.4	17.7

Analyses below investigate the relationships between the composition of waterbird communities surveyed in spring or summer with these operational, depth and rainfall variables. These analyses are a provisional examination of the relative influences of the above variables. Further analyses using remote-sensed inundation extent, and possibly on individual wetland and wetland suites, knowledge of waterbirds using the Gore system and using waterbird guilds rather than species are planned.

Bio-env analyses. Bio-env analysis indicated that there was no significant relationship between timing of the surveys and the composition of waterbird communities within a season.

For spring, there was a weak but significant relationship revealed by a bio-env analysis ($R^2 = 0.18$, $p<0.01$) between the number of days the pipeline was open and waterbird community composition. The pipeline is really an indicator of whether the pipeline was installed (post 2008) or not (2006 to 2008) since most of the spring periods in which the pipeline was operating had the same value (92) for this variable. There was no relationship between pipeline operation and waterbird communities for summer surveys.

The influence of the number of pipeline open days was removed (partialled out) prior to the analysis of spring surveys to focus on the influence of rainfall.

Once the influence of pipeline open days was removed, a bio-env analysis indicated that the set of environmental variables whose variation best matched variation in the waterbird community consisted of average depth plus three rainfall variables (the six and twelve month CDM for the Esperance weather station and the twelve month CDM for the Esperance Aerodrome station). The correlation (R^2) between these variables and the variation in waterbird communities after removing the influence of the pipeline was 0.30 ($p<0.01$). This means that local and catchment rainfall can account for about a third of the variation in spring waterbird composition remaining after accounting for pipeline operation. This result suggests that rainfall patterns over the intermediate term (six to twelve months) may be more important than more recent rainfall and more important than depth at the time of the survey. This may indicate that other habitat variables, such as food resources, are affected by rainfall earlier in the year or that the 6 to 12 month rainfall is associated with habitat availability elsewhere in the south-west or more broadly and so determines spread of waterbirds prior to the spring survey.

If the pipeline variable is allowed to be considered by the bio-env analysis (i.e. not partialled out), then the stepwise model building procedure selects the same variables as above plus pipeline_days with an R^2 value of 0.40 ($p=0.001$) which is higher than the model without the pipeline considered. This is not surprising as depths in some of the gauged wetlands is not affected by operation of the pipeline.

The best model for bio-env analysis of 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^2) of 0.30 ($p<0.05$). The summer waterbird communities thus seem to be more influenced by CDMs over shorter terms (6 rather than 12 month CDM). This may reflect the importance of rates of drying out of the wetlands between the spring and summer surveys.

Db-RDA. db-RDA analyses were undertaken for each of the environmental variables separately (Table 3) and as a stepwise model building process, for both spring and summer surveys. For the individual variables, the longer term CDM variables were more strongly related to waterbird composition than the shorter term CDM variables in spring, whereas for the summer data the 3 and/or 6 month CDM variables were more strongly related to waterbird composition than the 12 month CDM variables. However, as individual variables, few had associations with waterbird communities that were statistically significant.

The association between the number of pipeline operating days, and spring waterbird communities is significant on its own (14% of variation, $p<0.01$).

After removing the effect of the pipeline, the stepwise model building produced a spring model consisting of one variable: 12 month CDM for the Esperance Aerodrome weather station. In this model, a quarter of the variability in spring waterbird community composition is associated with this rainfall variable ($p<0.05$).

If the effect of the pipeline operation is not removed the best spring model consists of the 12 month CDM for the Esperance weather station and 'Pipeline_days', associated with 46% of spring waterbird community variation ($p=0.001$)

*Table 3. Proportion of variation (total inertia) in waterbird composition constrained in the dbRDA analyses by individual (range standardized) environmental variables. n.s. = p>0.05, * = p<0.05, ** = p<0.01.*

Environmental Variable	spring proportion	summer proportion
Depth	0.12 (n.s.)	0.11 (n.s.)
Pipeline_days	0.14 (**)	0.11 (n.s.)
Days	0.09 (n.s.)	0.17 (n.s.)
CDM 3MO Esperance Aero	0.06 (n.s.)	0.16 (n.s.)
CDM 6MO Esperance Aero	0.08 (n.s.)	0.30 (*)
CDM 12MO Esperance Aero	0.24 (*)	0.17 (n.s.)
CDM 3MO Esperance	0.13 (n.s.)	0.13 (n.s.)
CDM 6MO Esperance	0.15 (n.s.)	0.17 (n.s.)
CDM 12MO Esperance	0.22 (*)	0.11 (n.s.)
CDM 3MO Myrup	0.13 (n.s.)	0.26 (n.s.)
CDM 6MO Myrup	0.13 (n.s.)	0.31 (*)
CDM 12MO Myrup	0.16 (n.s.)	0.17 (n.s.)

The db-RDA analysis of summer data suggested that shorter term rainfall closer to Esperance is more important, with the 'best' model consisting of just the 6 month CDM at Myrup, associated with 31% of variation in waterbird community composition ($p<0.05$). The number of pipeline operating days was not significantly associated with summer waterbird communities on its own and so was not partialled out in this analysis and it was not selected by the stepwise procedure.

These bio-env and db-RDA analyses suggest that about a third of the interannual variation in waterbird communities using the Warden wetlands is associated with patterns in depth and rainfall and, in spring, even more when operation of the pipeline is considered. Further analyses are planned, including of individual wetlands and use remote sensed inundation locally and across the south-west which may lead to further understanding of the determinants of waterbird community composition in the system.

4.4.3.3 Species patterns

Species driving patterns over time. The above analyses are based on all abundances of all waterbird species. However, it is possible to identify subsets of species that account for most of the between survey differences in composition. An analysis (using the bv.step R function from http://menugget.blogspot.com/) identified seven species accounting for three-quarters of the patterns in spring composition over time (Pearson $R^2 = 0.80$, $p=0.001$). That is, these seven species produce a survey x survey dissimilarity matrix that is very similar to the matrix created from the full spring waterbird dataset. These species are Australian shelduck, banded stilt, grey teal, Pacific black duck, red-necked stint, silver gull and red-necked avocet and their abundances across the 10 spring surveys are shown in Figure 20. This shows very different patterns in the abundance of these species over time.

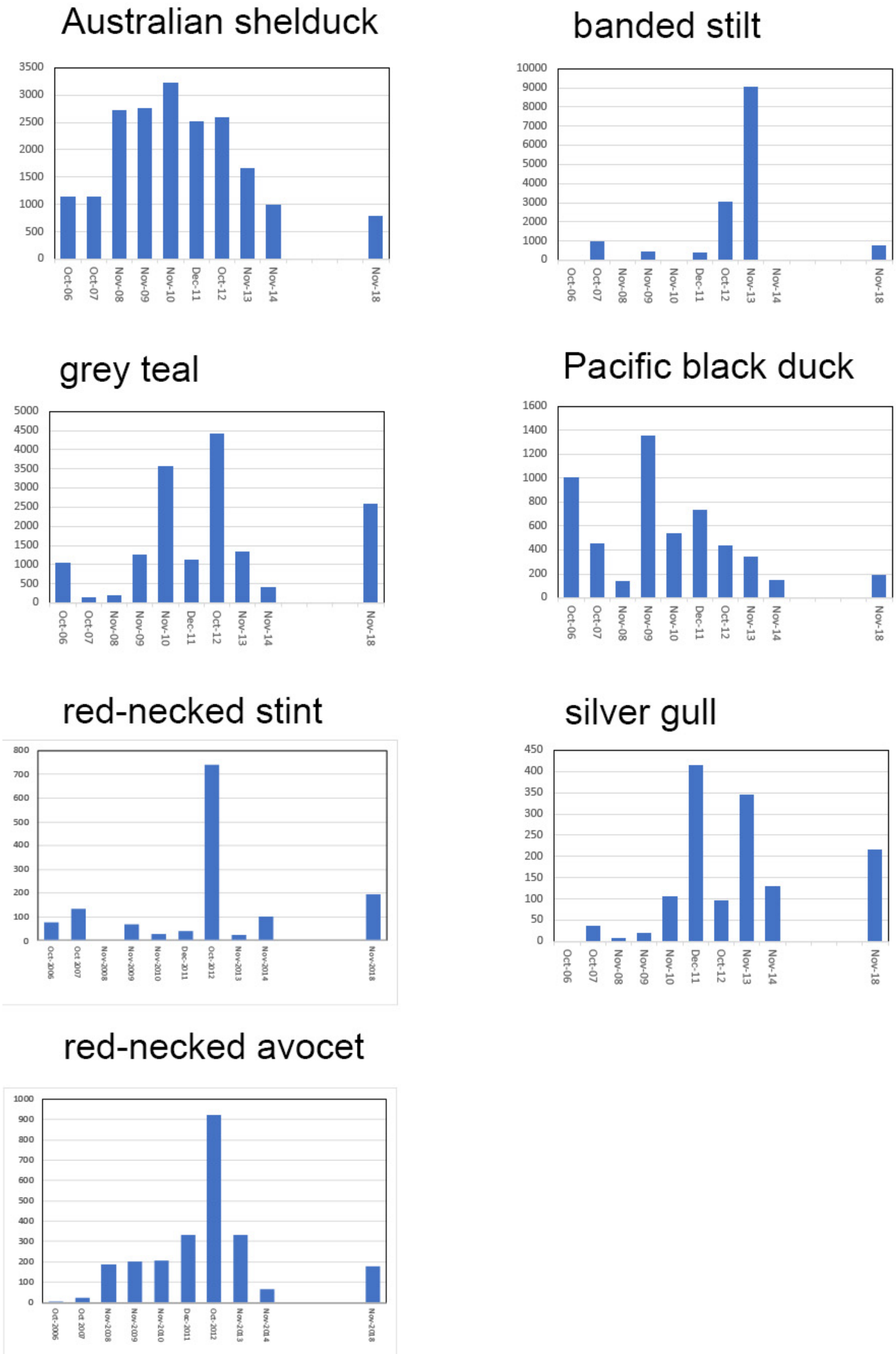

Figure 20. Abundances during spring surveys of the seven species accounting for 80% of the interannual variation in spring waterbird community composition across the Warden system.

Of these, two of the three shorebirds (banded stilt and red-capped plover) were mostly low in abundance but more abundant in 2012 and/or 2013. Banded stilt were much more abundant in 2012 and 2013 than in other years. In 2012 these were primarily on Station Lake (2300) and Lake Warden (665) and in 2013 they were almost entirely on Lake Warden (9086), when these wetlands were at or near their shallowest depths for spring surveys.

Red-necked stint occurred at abundances below 110 across the system in most springs, but 740 were present in 2012, mostly on Lake Warden (370), North Windabout (100), Lake Windabout (98), Station Lake (60) and the Bukenerup wetlands (70).

Red-necked avocet was usually present in numbers greater than 180, but, as for the other two shorebird species, was much more abundant in 2012.

Australian shelduck were more abundant (>1500) between 2008 and 2012 than in other years. Wetland usage by shelduck during these years was not consistent, however, with largest numbers on Windabout Lake in 2008, Lake Mullet in 2009, Windabout Lake, North Windabout and Ewans in 2010 and Lake Warden in 2011 and 2012. In years with few shelduck they would be using wetlands outside of the Warden system, but when abundant on the Warden system they vary their use between wetlands. There does not appear to be a strong relationship between depth and usage of these wetlands by shelduck.

Silver gull were normally present in numbers fewer than 150 across the system, but occasionally exceeded 200. These were on Lake Warden (258) and Pink Lake (107) in 2011, Ewans Lake (157) and one of the Six Mile Hill wetlands (131) in 2013 and on Lake Warden and Windabout Lake in 2018. Silver gulls primarily seem to use these wetlands for loafing rather than feeding so their inconsistent presence may depend on how they are using aquatic habitats in the broader Esperance area.

Grey teal and Pacific black duck are highly mobile species and will be using wetlands across the south-west and further afield over time and much of their variable abundance will reflect that.

Grey teal usage of the Warden system was greatest in 2010 (especially on the largest of the Neridup wetlands [WRP001A], Ewans Lake and Lake Wheatfield), 2012 (same wetlands plus Lake Windabout) and 2018 (primarily the same Neridup wetland plus Station Lake). The highest counts in 2010 and 2012 (3581 and 4422) coincided with a period of shallow depths in the central suite wetlands (Figure 5), although depths in these wetlands were not much different in 2011 when <1000 grey teal occurred across the system (and with very few of the central suite).

Pacific black duck had a different pattern of occurrence from grey teal, with highest abundance in 2006 (1005, spread across several wetlands) and 2009 (1354, half on Mullet Lake. Numbers of Pacific black duck declined between 2009 and 2014 but not out of the range observed from 2006-2008.

For the summer survey data, the subset of species resulting in a survey x survey species composition matrix best correlated with the matrix based on all species consisted of three species (Australian shelduck, grey teal and little black cormorant). Thus, patterns of abundance in these three species accounted for about half of the overall variation in waterbird communities between summer surveys (R^2 = 0.53, p=0.001).

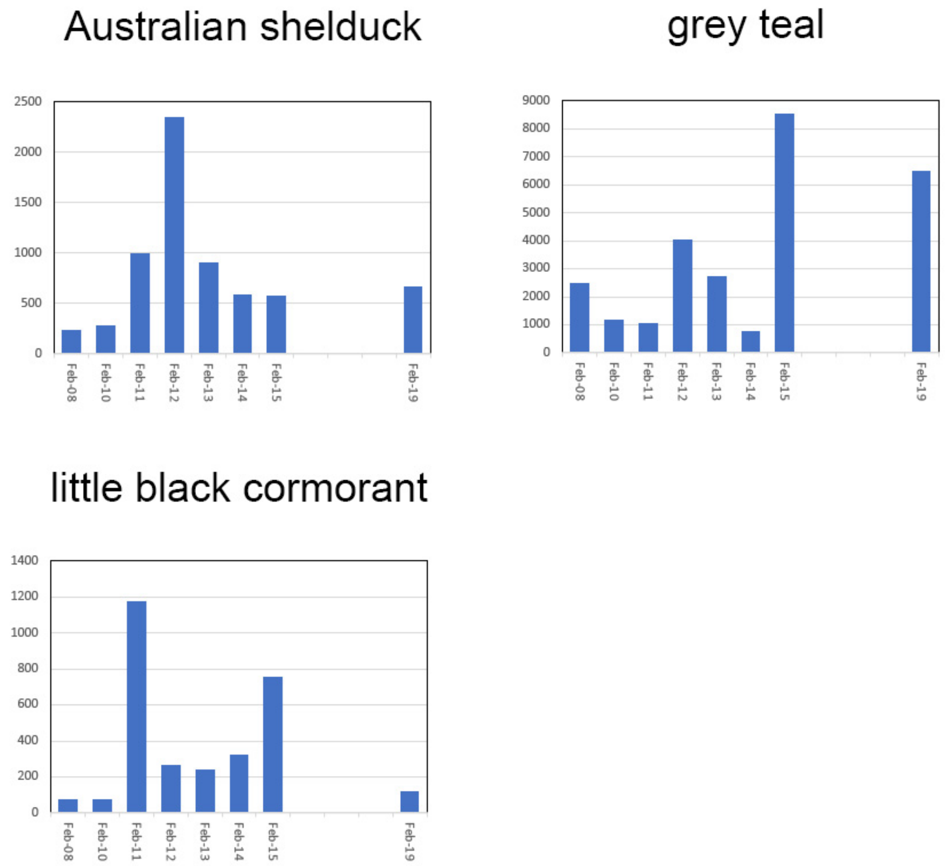

Figure 21. Abundances during summer surveys of the three species accounting for 53% of the interannual variation in summer waterbird community composition.

On average, 60% of Australian shelduck depart the Warden system between the spring and summer surveys (range 42 to 90%), so summer counts are usually under 1000. An exception was the spring and summer counts of 2011/12 where the spring count of 2515 only declined by 6.6% to 2350 in summer (Figure 21), although in summer they more evenly spread across a number of wetlands (Lake Warden, Windabout Lake, Station Lake) compared to spring (mostly Lake Warden).

In contrast to the shelduck, the number of grey teal has variably increased or decreased over summer. The high summer counts are all after significant immigration to the system since the previous spring. These counts were 4054 in Feb 2012 (mostly on Ewans Lake, Windabout Lake and Lake Wheatfield), 8539 in Feb 2015 (Windabout suite, North Wheatfield wetlands and Mullet) and 6500 in Feb 2019 (Wheatfield, Windabout and North Wheatfield).

4.4.4 Shorebird usage of Lake Warden

Figure 22 shows the abundance of shorebirds on Lake Warden versus depth for the 1980s (Jaensch *et al.*, 1988) and the periods 2006 to 2008 (current survey program before installation of the pipeline) and since 2009 (since installation of the pipeline). For the 1980s data only counts from Oct-Feb are shown for consistency with the 2006-2019 data. This shows variable shorebird abundance during the 1980s (when depth was always < 1.5 metres) including one survey (Nov 1982) with large numbers of banded stilt and a total abundance of 7841. The four surveys over the 2006 to 2008 period were all undertaken when depths were over 2 metres 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. Depth for all subsequent surveys were below 1.5 m and shorebird abundances were 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). Depths < 0.4 in both the 1980s and since 2009 have been associated with relatively low shorebird abundance, possibly associated with high salinity.

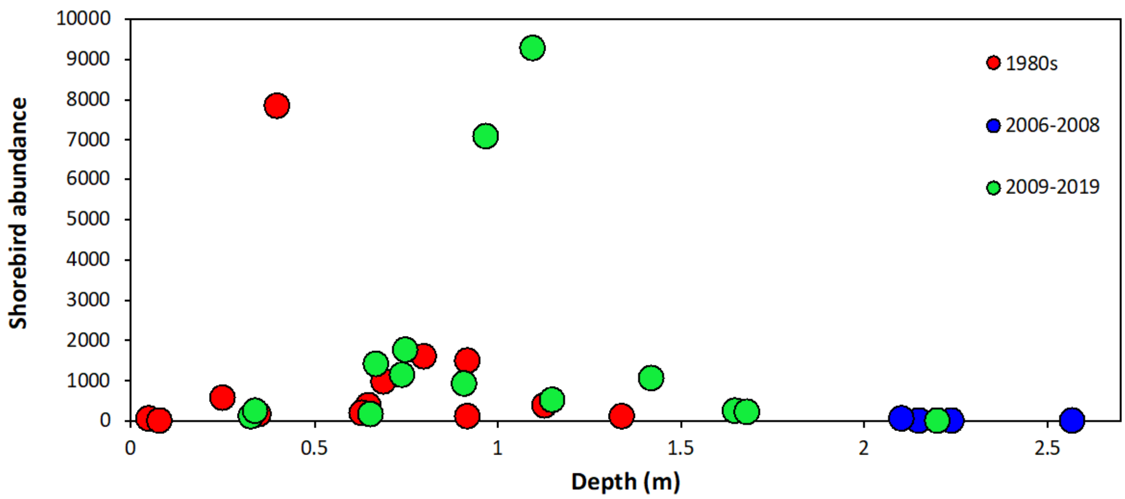

Figure 22. Shorebird abundance on Lake Warden for three periods: 1980s, 2006-2008 and 2009-2019. 1980s data for Oct-Feb period only.

The richness of shorebirds at lake Warden showed a very similar pattern, with normally six or more species in the 1980s, 0 or 1 species in the 2006-2009 period when depths were greater than 2 m, then more than five species for most of the 2010-2019 surveys when depth has been between 0.4 and 1.7 m. Depths below 0.4 m were associated with a reduced shorebird diversity (1 to 3 species), mirroring the effect of shallow depths on abundance.

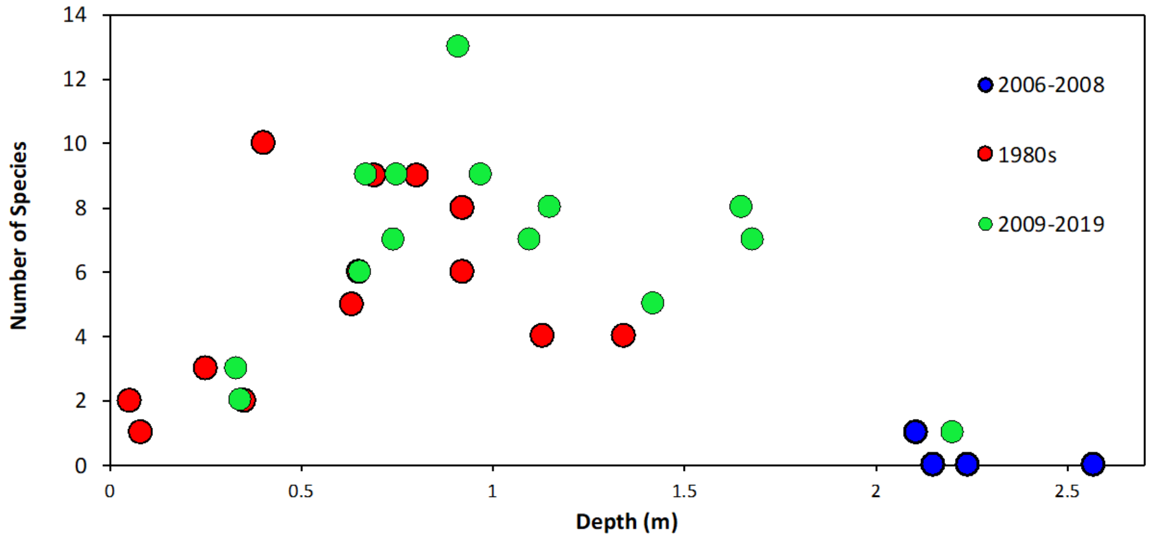

Figure 23. Shorebird richness on Lake Warden for three periods: 1980s, 2006-2008 and 2009-2019. 1980s data for Oct-Feb period only.

Figure 24 shows the number of hooded plovers on Lake Warden for the three periods as above. Hooded plovers were mostly absent during surveys conducted in the 1980s, except where depths were between 0.63 m and 1.34 m and highest abundances (>100) were recorded during a narrower range of 0.69 to 0.92 m. Hooded plover were absent for the 2006-2008 period and in 2009 when depths were greatest 2009 and then fewer than 10 were counted for the three surveys between Feb 2010 to Feb 2011. Subsequent surveys, with depths below 1.1 m, have had 29 to 207 hooded plover. The only survey after Feb 2011 with fewer individuals was Nov 2018 when depth was 1.42. Interestingly, hooded plovers were present in good numbers for two surveys when depth was <0.5 m which contrasts with the absence of this species at similar depths in the 1980s. Of course, hooded plovers do not enter the water so depth per-se means little other than availability of shore habitat. It is interesting, however, that two recent surveys at depths below 0.5 m had large numbers of hooded plover whereas surveys at similar depth in the 1980s had none.

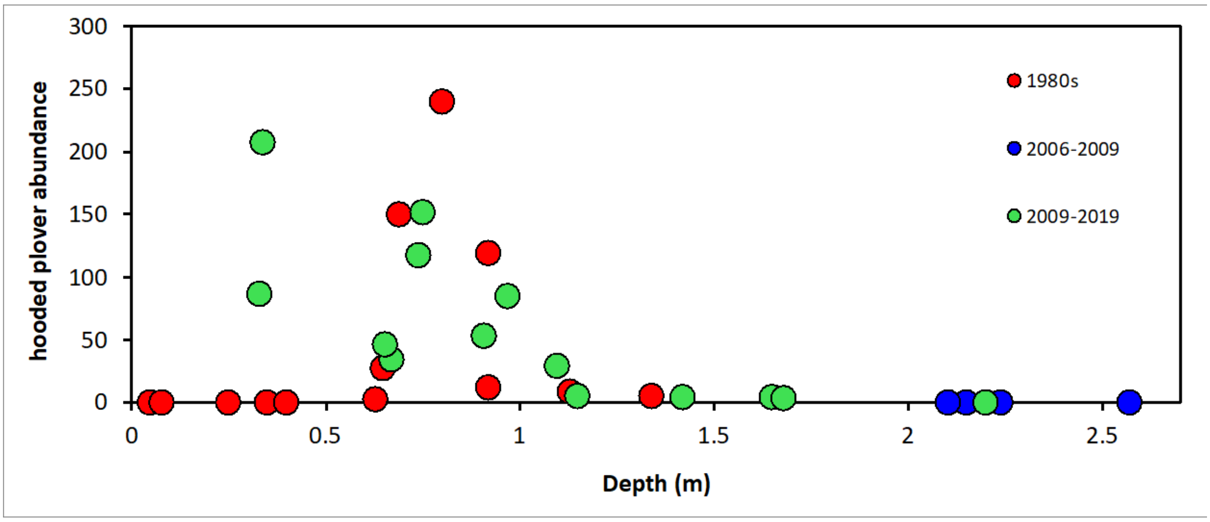

Figure 24. Hooded plover abundance on Lake Warden for three periods: 1980s, 2006-2008 and 2009-2019. 1980s data for Oct-Feb period only.

Species with notable temporal trends. For individual species, the numbers present on Warden wetlands has been highly variable over the 2006 to 2019 period but there have been few trends over time. Black swans were less abundant in 2006 to 2008 (550 to 1103) than in subsequent years (984 to 1592). The increase in numbers after 2008 was mostly at Ewans, Station and Mullet Lakes.

Silver gulls have also tended to become more common since 2009, with 1 to 38 present between 2006 and 2009 and 98 to 414 present from 2010.

Great-crested grebes declined in numbers over the same period, with 6 to 33 (average 23) present in 2006 to 2009 but only 1 to 8 present from 2010. The larger numbers in earlier years were always present on Mullet Lake.

It is notable that the above three changes all happened over the 2008-2009 period.

4.4.5 Species for which the Warden system is of particular importance

The Warden system Ramsar site is amongst the most important sites in south Western Australia for chestnut teal (*Anas castanea*) and the hooded plover (*Thinornis rubricollis*), with >1% of their Western Australian populations regularly occurring in this system (Department of Environment and Conservation, 2009).

4.4.5.1 Chestnut teal

Chestnut teal has varied in abundance over the 2006 to 2019 period, from under 200 to more than 800 (Figure 25). They have usually been more abundant in summer than in the preceding spring, with the exception of 2018/19, suggesting an influx from other wetlands over summer. There has been no trend in numbers of this species using the

Warden wetlands over time during this period. The south-west population is estimated to be 5000 birds, so the 1% threshold (50) is always exceeded in the Warden wetlands. The 1% threshold for the Australian population (which would be 1050) has been exceeded once.

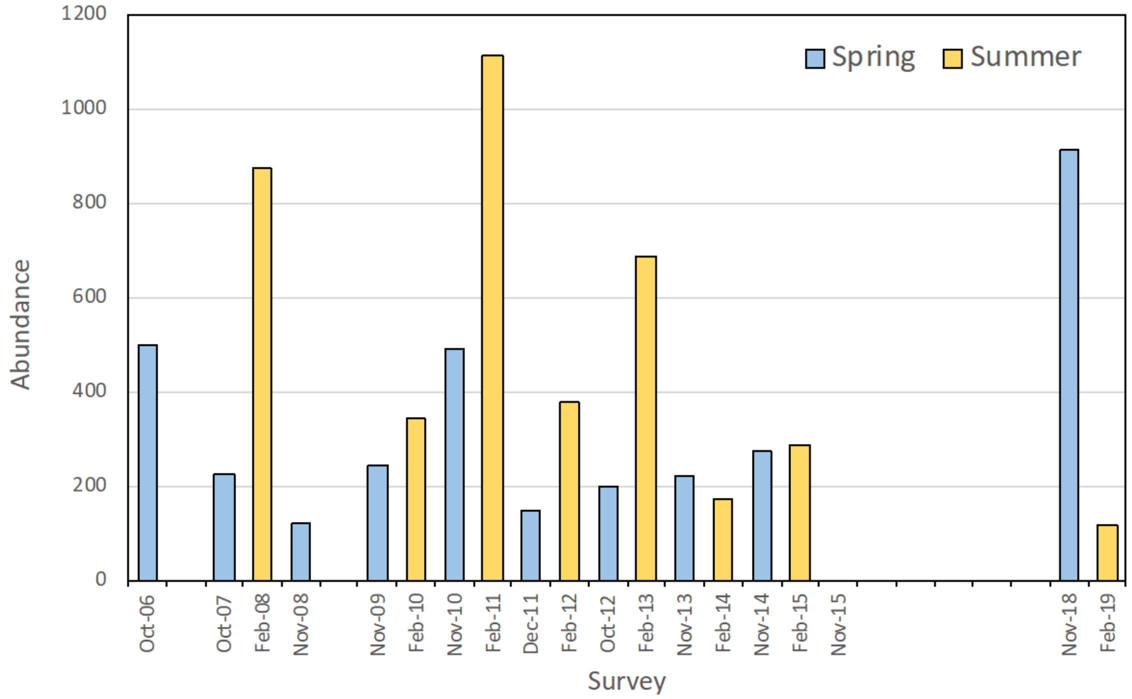

Figure 25. Abundance of chestnut teal across all Warden system wetlands 2006 to 2019 for spring and summer surveys.

Figure 26 shows usage of the Warden wetlands by chestnut teal for two spring surveys (2006 and 2010) and the average usage in spring across the 2006 to 2018 period. This shows that Windabout Lake and Lake Warden tend to support most chestnut teal in spring, with some also present on Lake Wheatfield and lesser numbers on other wetlands.

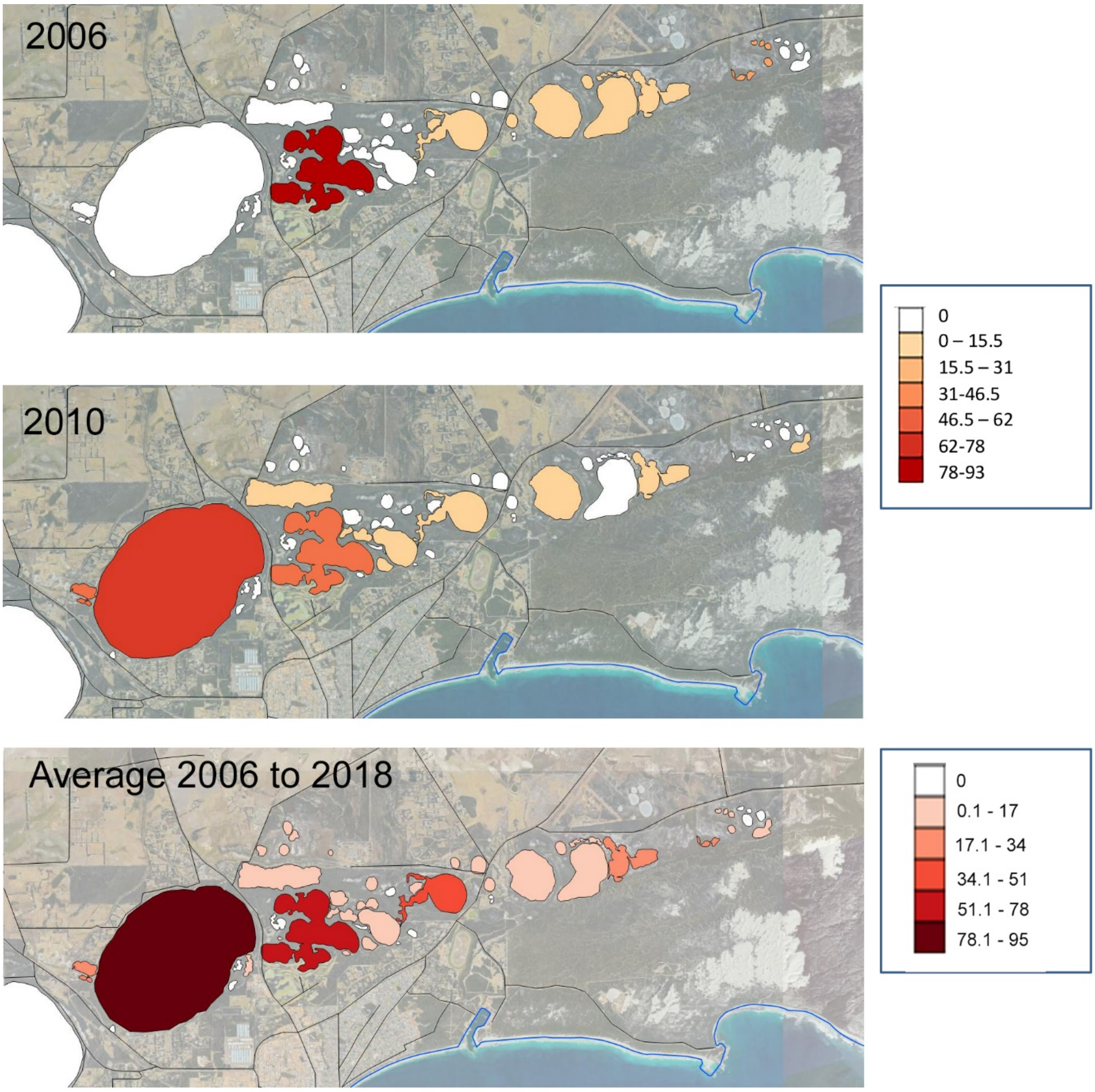

Figure 26. Maps of the Warden system, with wetlands coloured according to the abundance of chestnut teal (darker colours represents higher abundance) for spring 2006, spring 2010 and average usage in spring for the 2006 to 2019 period (10 surveys). Note different colour scale for the map of average abundance.

4.4.5.2 Hooded Plover

Hooded plovers were rare on the Warden system during the period 2006 to 2009. From Feb 2011 they have been more abundant, with greater numbers present in summer than the preceding spring, often much more so. Numbers were low in Nov 2018, probably due to high depths and little shore habitat, but were back above 100 in Feb 2019, with 85 on Lake Warden.

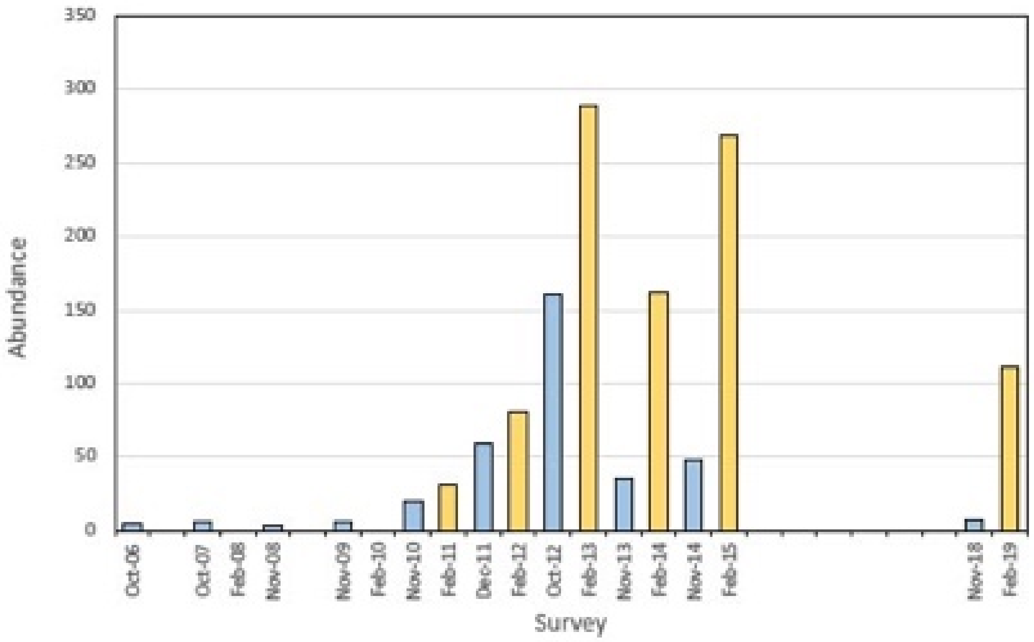

Figure 27. Abundance of hooded plover across all Warden system wetlands 2006 to 2019 for spring and summer surveys.

Figure 28 shows warden system wetlands coloured according to average abundance of hooded plover in spring and summer for the 2006-2019 period. In spring the average abundance on any one wetland was <1 except at Lake warden (average 28.6). For summer, most wetlands still had <1 hooded plover on average but Lake Warden had 77, Station Lake 40 and Mullet Lake 9.5. These three lakes also had the maximum numbers of hooded plovers in either season (i.e. maximum within each season).

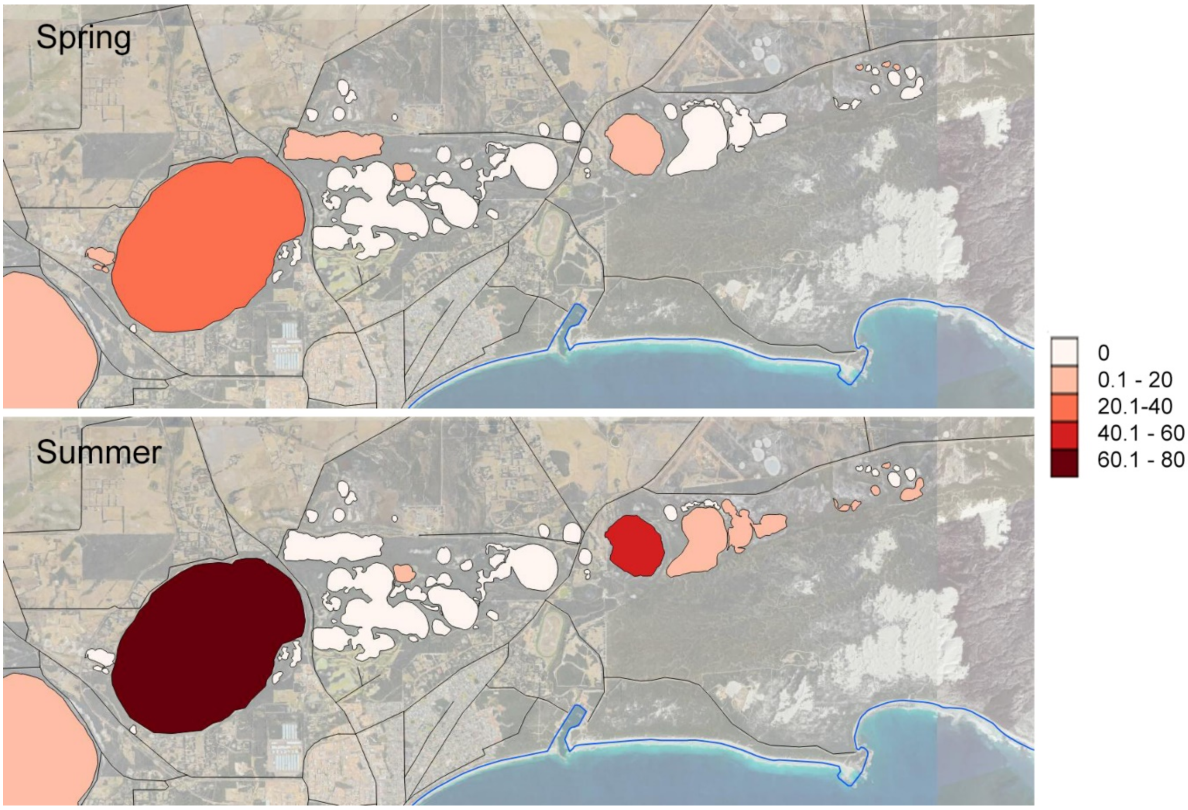

Figure 28. Maps of the Warden system, with wetlands coloured according to the average abundance of hooded plover in spring (top) and summer (bottom). Colour scale same for both maps.

4.5 Gore wetland system

4.5.1 Gore system richness

The number of waterbird species using the Gore system during the spring surveys has been remarkably stable; normally 28 to 33 species, with the exception of November 2013 when 38 species were present (Figure 29). The latter included the highest richness of ducks and shorebirds and equal high numbers of seabirds and grebes. The Nov 2018 survey had second highest richness with 33 species, but was the only spring survey in which raptors (swamp harrier and/or white-bellied sea-eagle) were not seen.

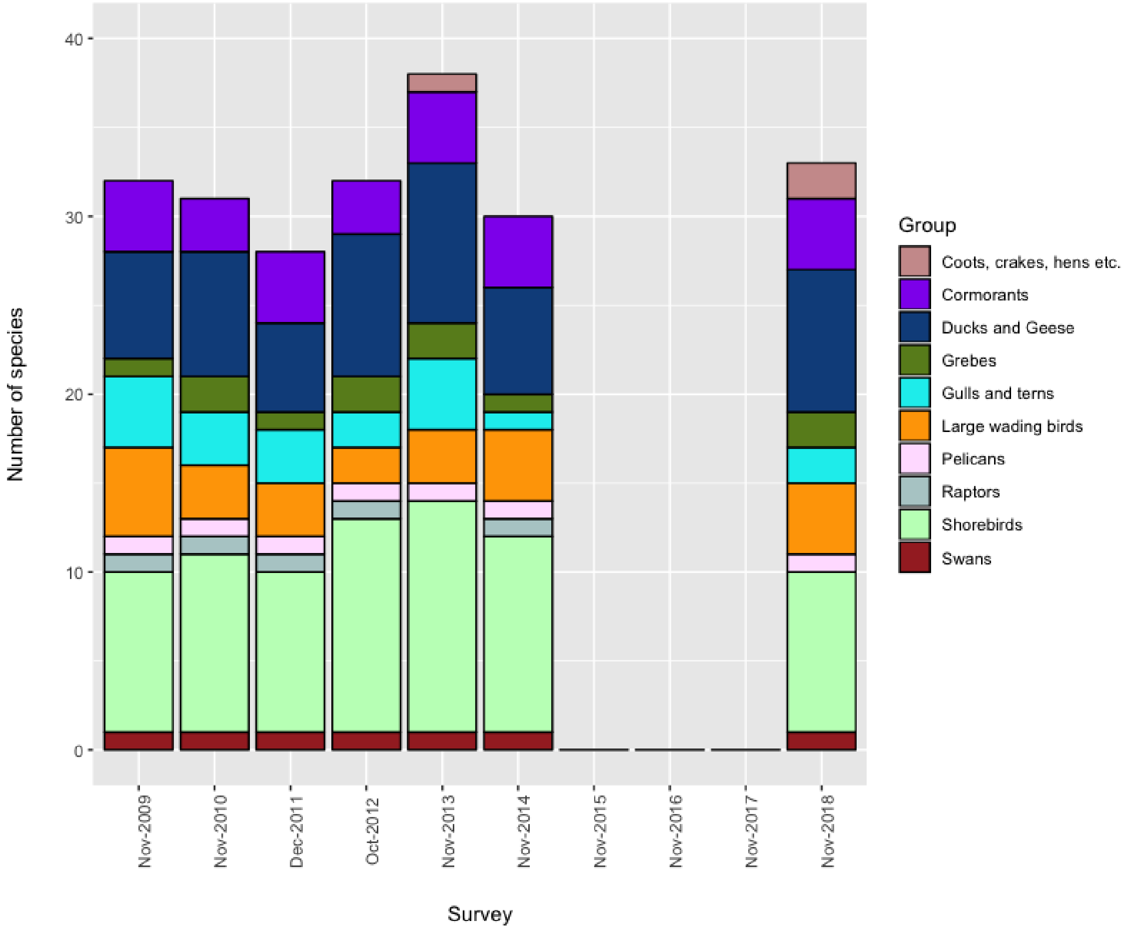

Figure 29. Species richness by major waterbird group for surveys of the Gore wetland system undertaken in spring.

Richness during summer surveys has been more variable, with 27 to 37 species present (Figure 30). Highest richness was in Feb 2012, partly reflecting the presence of 14 shorebird species. Second highest richness was Feb 2019 with 36 species, including the only records of Eurasian coot during recent ground surveys and the only summer record of little egret for the current survey series.

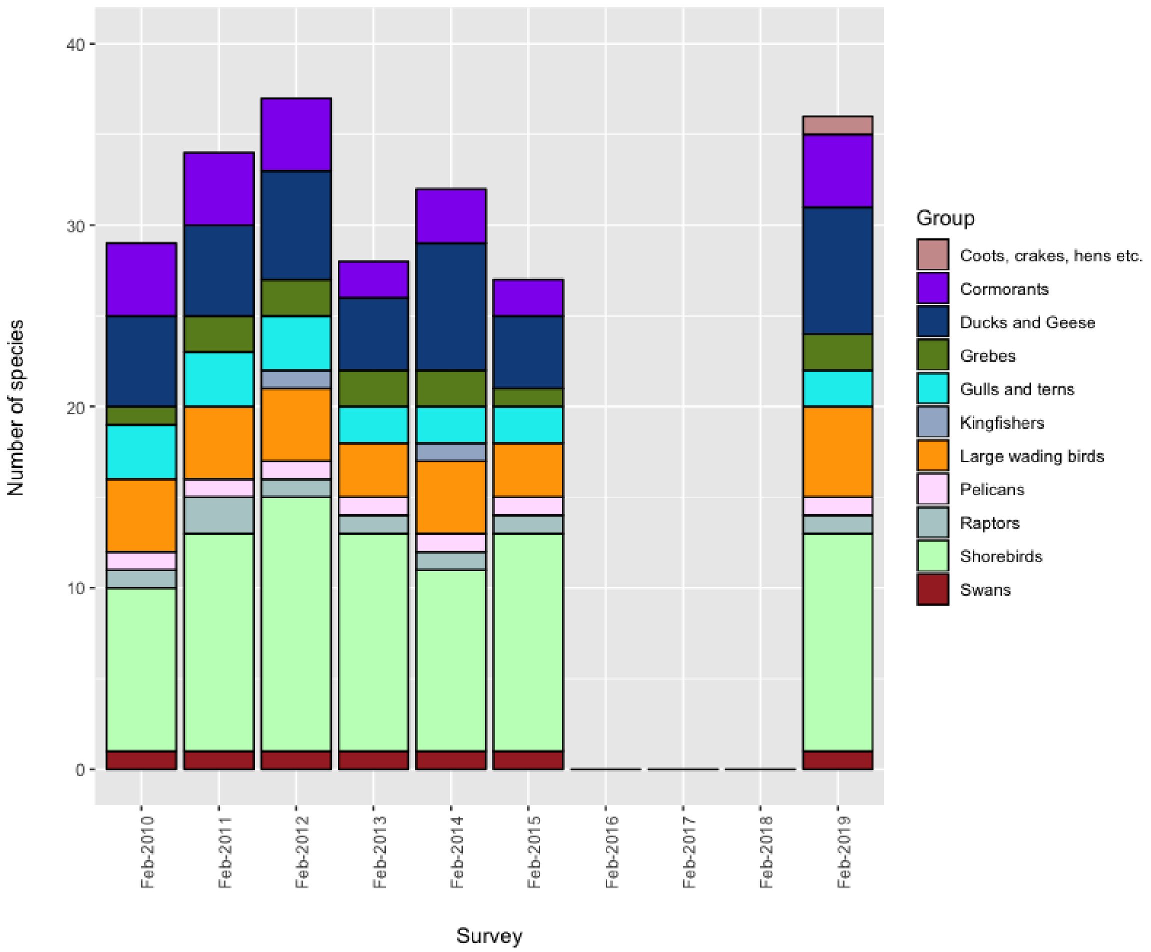

Figure 30. Species richness by major waterbird group for surveys of the Gore wetland system undertaken in summer.

4.5.2 Gore system abundance

Figure 31 and Figure 32 show abundances by major waterbird group for the spring and summer ground-based surveys respectively.

The Nov 2018 count of 18241 was the highest since the current survey series commenced in 2006, with the next highest counts being 15094 in Oct 2012 and the 14455 and 14622 for aerial surveys in Oct 2007 and Feb 2008 respectively. These aerial counts did not include lakes Carbul, Kubitch and Gidong, which between them can have thousands of waterbirds, so the counts are underestimates and totals could have been closer to the Nov 2018 count.

The Gore-Quallilup system has always been dominated by ducks, with their numbers in spring quite stable over time (generally 5000 to 8000 for ground counts between 2010 and 2014), except that their numbers increased to 10542 in Nov 2018. This jump in numbers is almost entirely due to larger than usual numbers of grey teal (2886, previous maximum 2011) and hardhead (499, normally absent from this system). The grey teal were spread over the Kubitch-Quallilup flow-through channel and several wetlands surrounding Lake Gore: the parabolic wetlands along the eastern side of

Lake Gore (16A), the Dalyup River (18A) and the associated wetland (18B) and the wetland on the property east of lake Gore (18C) the small wetlands on the north-west corner of the lake (16C and D). Hardheads are normally absent from the Gore-Quallilup system but in Nov 2018 lake Gore had 433.

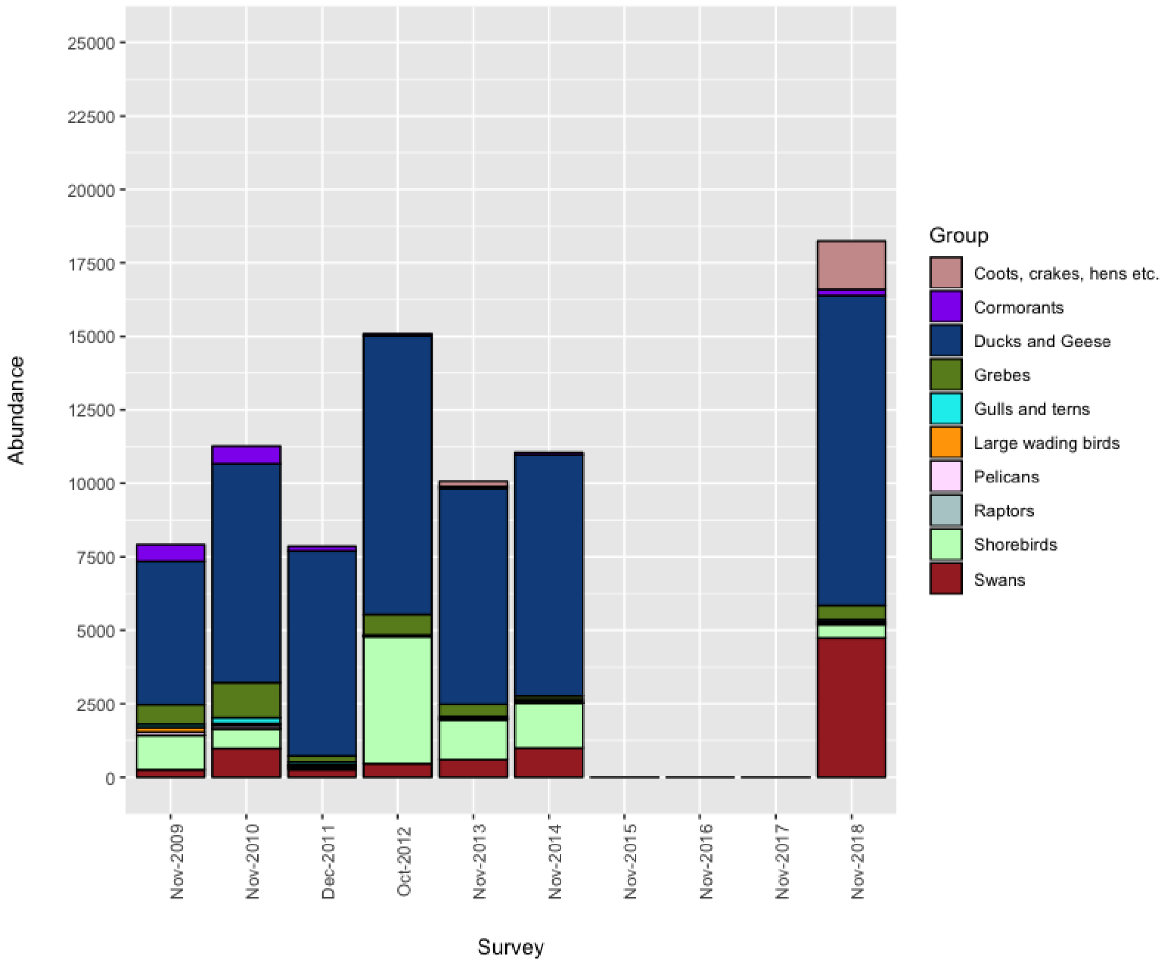

Figure 31. Abundance of waterbirds by taxonomic group for ground surveys conducted on the Gore wetlands during spring since 2009.

Other waterbird groups have been more variable in abundance. Swan numbers have mostly varied between about 250 and 1000 so the 4739 counted in Nov 2018 was exceptional (mostly on Lake Gore (3927). The number of coot were also exceptional in Nov 2018, with 1644 present, mostly on Kubitch and Gidon lakes. This species has otherwise been absent since 2009, other than 188 (mostly on Kubitch) in Nov 2013. The species was observed regularly during the aerial surveys from 2006 to 2008 but has rarely been seen during ground surveys. Shorebirds have also been highly variable in abundance, though driven in the most part by numbers of banded stilt, avocet and black-winged stilt. Shorebird numbers in Nov 2018 were generally low, with average to below average numbers of all species, including an absence of banded stilt. This is not surprising given the very high-water levels in the wetlands.

Little black cormorants have been in very low abundance on the Gore-Quallilup system in recent years whereas prior to 2011 large numbers used to breed in dead trees of the Kubitch-Quallilup through. It is likely that low water depths have made the flow-through unsuitable in most recent years. The abundance of little black cormorants was relatively high in Nov 2018 (137), albeit still not nesting, as was the numbers of little pied cormorant (56), with both species probably attracted by the deeper waters during spring 2018.

Great crested grebe was also relatively numerous in Nov 2018, with 17 across the system, most on Lake Gore, whereas there has mostly otherwise been 0 or 1, other than in Nov 2010 when 34 were counted.

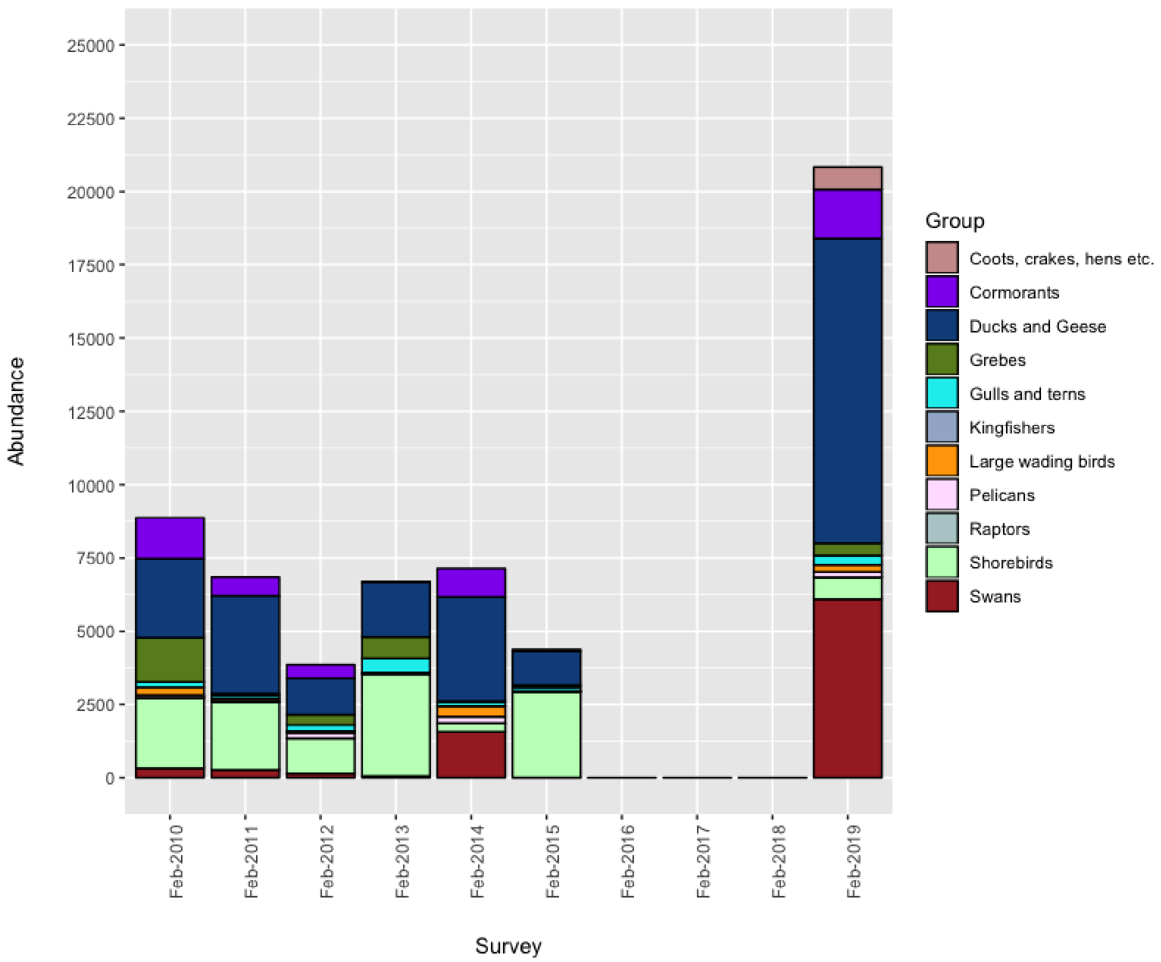

Figure 32. Abundance of waterbirds by taxonomic group for surveys conducted on the Warden wetlands during summer since 2010.

The summer survey results for the Gore system were dramatically different to previous years (Figure 32), with high abundance of ducks, swans, cormorants and coot but low numbers of shorebirds. The very high numbers of ducks is partly a result of 4337 shelduck remaining on the system over summer, whereas in previous years shelduck have moulted (especially on Lake Gore) during spring and summer but largely departed by the February surveys. In 2018/19 conditions must have been favourable for this species to remain on the system (or were unfavourable elsewhere), almost all on Lake Gore, or usual summer habitats were not as suitable. This is nearly twice the previous maximum summer count on this system. There was also an exceptional number of grey teal (5551) whereas there is normally under 800 in February. This is twice the number of this species as was present in the previous spring survey so many of these had moved into the system over summer which also suggests poorer than usual conditions elsewhere. They were almost all on Lake Gore, Lake Carbul and Lake Kubitch. There was also record numbers of Pacific black duck and hardhead but these were still low in number (97 and 13 respectively).

Eurasian coot have not previously been recorded on the Gore system during summer ground surveys but 762 were present in Feb 2019, all on Kubitch Lake. The 6093 swans on the Gore system was almost four times the previous summer count of 1567 in Feb 2014 and greater than any spring count in the current survey series (4739 in Nov 2018). These were almost all on Lake Gore (2835) and Lake Kubitch (3062).

The number of little black cormorants (1137) was the highest count for the summer ground surveys but only slightly exceeded the 1129 counted on the ground in Feb 2010 and was lower than the 1488 seen from the air in Feb 2008, but there are usually fewer than 600. In Feb 2019 they were almost all on the Kubitch-Quallilup flow-through system but the rookery was not active. The count of 496 little pied cormorants, also almost all on the flow-through system) is a record for the Gore wetlands in the current survey series.

The low numbers of shorebirds was due to there being very few banded stilt (136) and avocet (9) present, as in Feb 2014. Other shorebirds were not unusually low in numbers and some had relatively high abundances. Sharp-tailed sandpipers were relatively abundant (163), lower only than in Feb 2015 (263). Red-kneed dotterels were also more numerous (22) than has been the case for previous summer surveys.

The number of great-crested grebe was also the highest count for the summer surveys and was higher than the 17 present in the previous spring.

4.5.3 Multivariate analyses of waterbirds occurring in the Gore system

4.5.3.1 Patterns in species composition over time

Figure 33 is a two-dimensional ordination of spring surveys based on waterbird species abundances. This could be interpreted as an erratic drift in composition from 2009 (bottom left) to Nov 2018 (top right) over the seven surveys, as indicated by the lines joining consecutive surveys. However, this pattern is not particularly strong and could be just showing the range of communities supported by the Gore wetlands over a decade of years with differing rainfall and depth. Nonetheless, the Nov 2018 community was well outside of the range of compositions recorded previously (i.e. in a different part of ordination space).

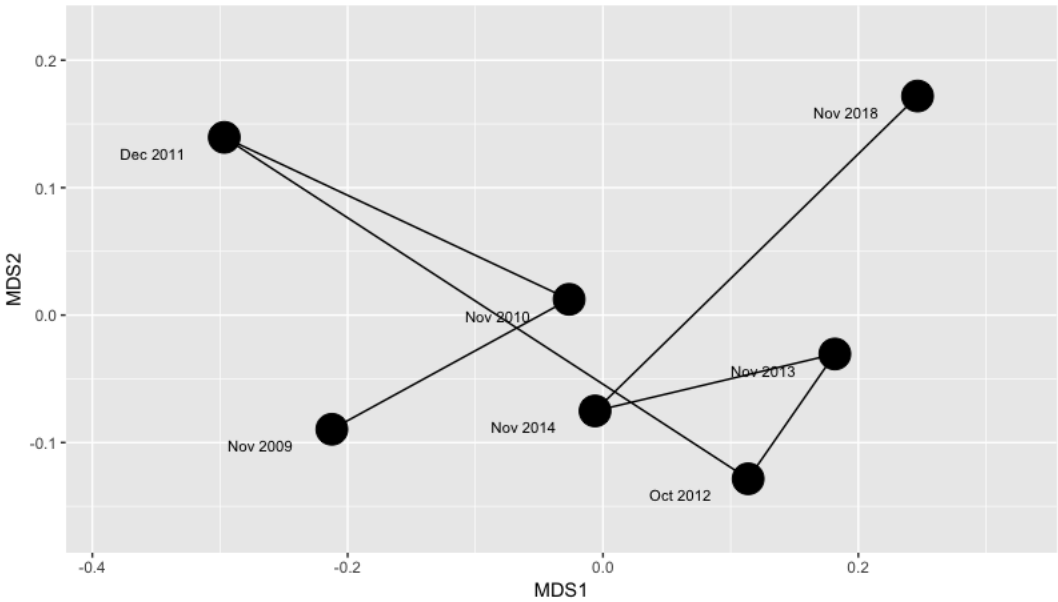

Figure 33. Two dimensional ordination of Gore system waterbird communities (abundances square-root transformed) surveyed over seven spring periods between 2010 and 2018. Stress = 0.05.

However, Figure 33 represents an ordination based on abundances that have been square-root transformed. This is often undertaken so that a small number of especially abundant species (e.g. swans and grey teal in Nov 2018 and banded stilt in Oct 2012) do not dominate the analysis. This is appropriate where the aim is to monitor the underlying capacity of the wetlands to support similar waterbird communities – i.e. outlier years with high abundances of a few species will always occur but should not detract from the long-term trends.

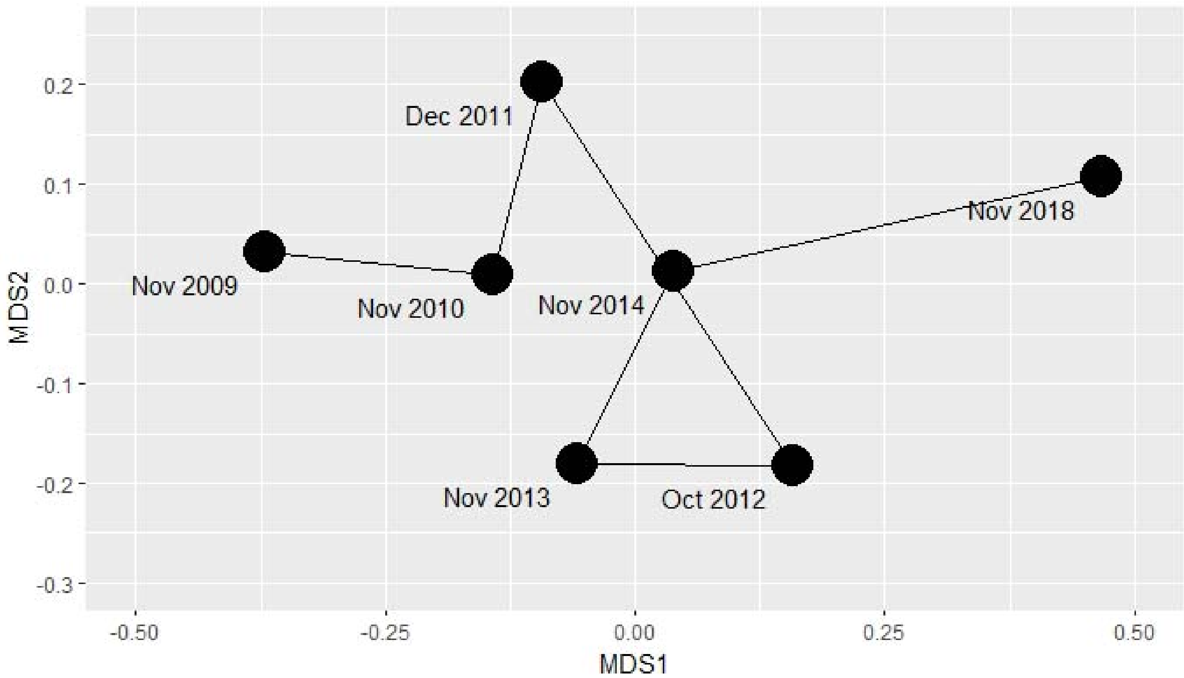

Figure 34. Two-dimensional ordination of Gore system waterbird communities (raw abundances) surveyed over seven spring periods between 2010 and 2018. Stress = 0.03.

To examine whether the high abundances of a few species in some years affect the interpretation of the data through ordination, a separate nMDS analysis was undertaken without transformation of the abundance data. This ordination (Figure 34) suggests a more pronounced but still somewhat erratic drift in composition between Nov 2009 and Nov 2019, with the difference between Nov 2014 and Nov 2019 more pronounced. This ordination changed the 'distance' between some of the surveys and the relative placement of the 2013 survey changed, but not the general pattern displayed.

A bio-env analysis identified four species (Australian shelduck, grey teal, banded stilt and black swan) whose raw spring abundances created a survey x survey similarity matrix highly correlated (r^2 = 0.97, p=0.001) with the matrix based on raw spring abundances of all species. This means that these four species are very strongly associated with the survey to survey changes portrayed in Figure 34. The changing abundances of these are shown in Figure 35 by scaling the size of the symbols representing each survey by the abundance of each survey. This highlights the large numbers of black swan in Nov 2018 and banded stilt in Oct 2012, higher abundances of grey teal in Oct 2012, Nov 2013 and (especially) Nov 2018 and lower abundance of shelduck in Nov 2013 and Nov 2009. The higher abundances of black swan and grey teal are mostly what makes the Nov 2018 counts distinct and placed away from other counts in Figure 34.

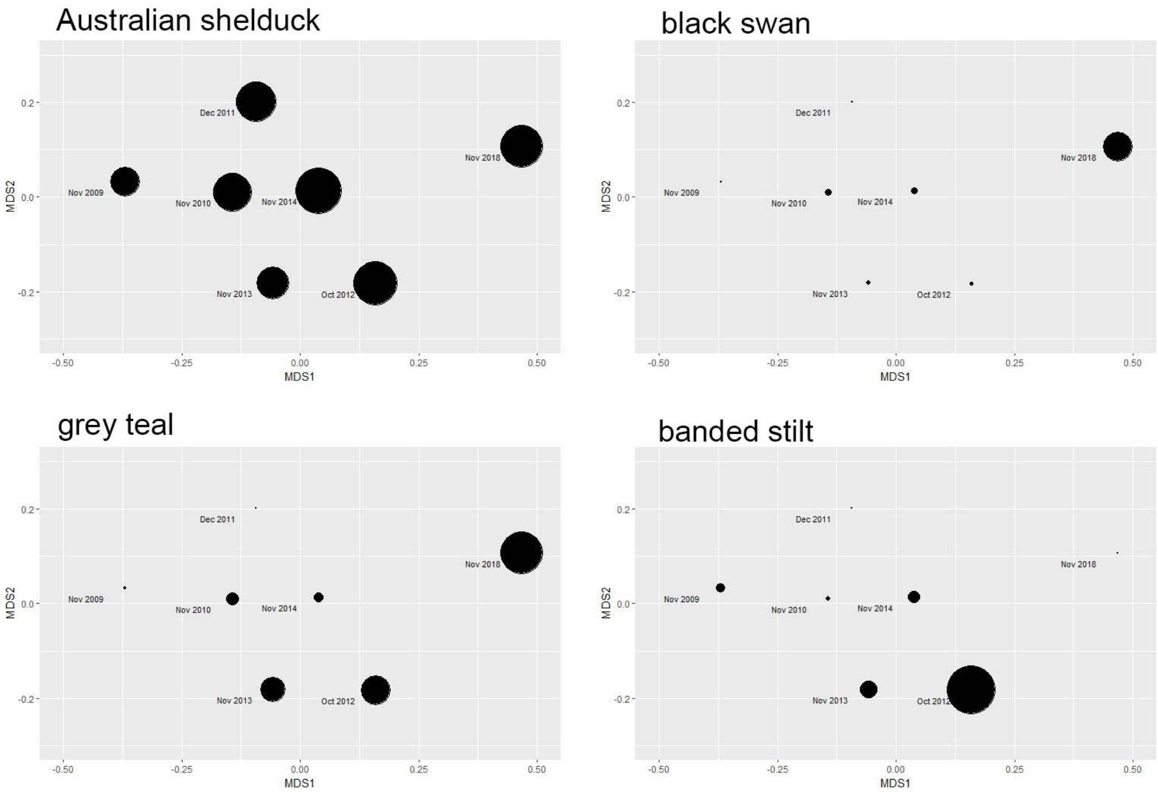

Figure 35. The same ordination plot as shown in Figure 34, with surveys scaled by abundances of the four species best correlated with the whole dataset. Scaling not comparable between species.

Figure 36 is a two-dimensional ordination of summer surveys based on square root transformed waterbird species abundances. This does not reveal any directional trend in composition over time, but, as for the previous spring survey, the Feb 2019 count is outside of the range of compositions seen previously since 2010. This is not surprising given the very high abundances of species such as grey teal, hardhead and black swan. An ordination using raw abundance data could not reach a solution.

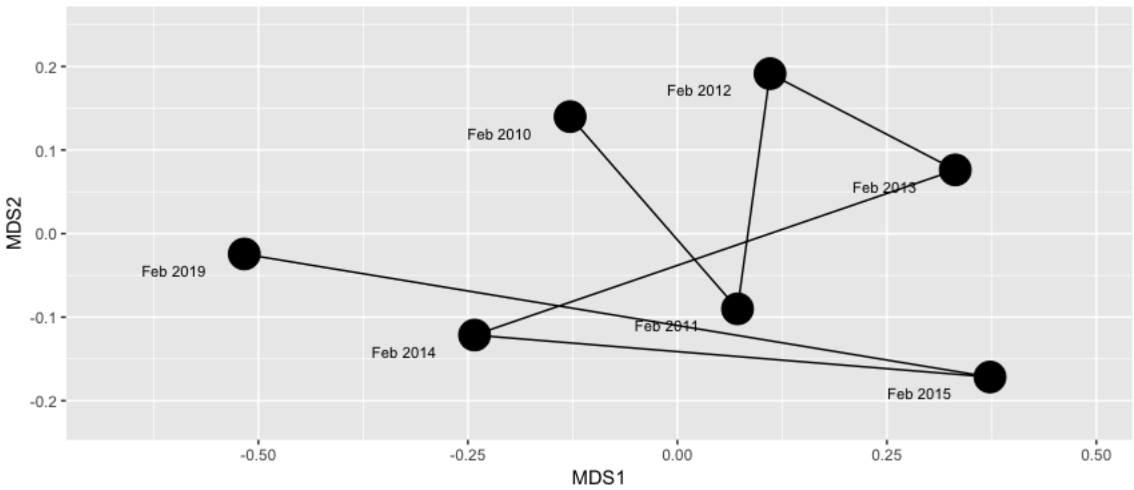

Figure 36. Two-dimensional ordination of Gore system waterbird communities (abundances square-root transformed) surveyed over seven summer periods between 2010 and 2019. Stress = 0.05.

References

Bennelongia Pty Ltd (2008a). *Waterbird Monitoring of the Lake Warden and Lake Gore Wetland Systems, February 2008*. Bennelongia Pty Ltd, Perth.

Bennelongia Pty Ltd (2009). *Waterbird Monitoring of the Lake Warden and Lake Gore Wetland Systems, November 2008*. Bennelongia Pty Ltd, Perth.

Bennelongia Pty Ltd (2008b). *Waterbird Monitoring of the Lake Warden and Lake Gore Wetland Systems, October 2007*. Bennelongia Pty Ltd, Perth.

Department of Environment and Conservation (2009). *Ecological Character Description of the Lake Warden System Ramsar Site: A Report by the Department of Environment and Conservation. Prepared by G. Watkins*. Department of Environment and Conservation, Perth, Western Australia.

Fox J. and Weisberg S (2011). An {R} Companion to Applied Regression, Second Edition. Thousand Oaks CA: Sage. URL: http://socserv.socsci.mcmaster.ca/jfox/Books/Companion. Version 3.0-2.

Halse S.A. (2007). *A waterbird census of the Lake Warden and Lake Gore Wetland Systems, October 2006*. Department of Environment and Conservation, Perth.

Jaensch R.P., Vervest R.M. & Hewish M.J. (1988). *Waterbirds in nature reserves of south-western Australia 1981-85: reserve accounts*. Royal Australasian Ornithologists Union, Melbourne.

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

Oksanen J., Blanchett F.G., Kindt R., Legendre P., Minchin P.R., O'Hara R., *et al.* (2019). *Vegan: Community Ecology Package, v2.5-4*.

Pinder A.M., Cale D.J. & Quinlan K. (2015). *2015 update on monitoring of waterbirds of the Warden and Gore Wetland systems (2006 to 2015)*. Department of Parks and Wildlife, Perth, Western Australia.

Pinder A.M., Halse S.A., Cale D.J. & Quinlan K. (2012). *Waterbird Monitoring of the Warden and Gore Wetlands in December 2011 and February 2012*. Department of Environment and Conservation, Perth.

Pinder A.M., Leung A.E., Cale D.J. & Halse S.A. (2010). *Waterbird and Invertebrate Monitoring of the Warden and Gore Wetlands in November 2009 and February 2010*. Department of Environment and Conservation, Perth.

R Development Core Team (2018). *R: A Language and Environment for Statistical Computing, V 3.5.1*. R Foundation for Statistical Computing, Vienna, Austria.

Robertson D. & Massenbauer T. (2005). Applying hydrological thresholds to wetland management for waterbirds, using bathymetric surveys and GIS. (Eds A. Zerger & R.M. Argent), pp. 2407–2413. Modelling and Simulation Society of Australia and New Zealand.

Slowikowski, K. (2018). ggrepel: Automatically Position Non-Overlapping Text Labels with 'ggplot2'. R package. Version 0.8.0. https://CRAN.R-project.org/package=ggrepel.

Wickham (2007). Reshaping Data with the reshape Package. Journal of Statistical Software, 21(12), 1-20. URL http://www.jstatsoft.org/v21/i12/. version 1.4.3.

Wickham H (2016) plyr R package. Tools for Splitting, Applying and Combining Data. Version 1.8.4.

Wickham H. (2018). scales: Scale Functions for Visualization. R package version 1.0.0. https://CRAN.R-project.org/package=scales.

Wickham, H. (2019). stringr: Simple, Consistent Wrappers for Common String Operations. R package version 1.4.0. https://CRAN.R-project.org/package=stringr.

Zeilis A, Grothendieck G, Ryan J, et al (2019) Package "zoo" for R. Infrastructure for Regular and Irregular Time Series (Z's Ordered Observations). Version 1.8-5.