Waterbird Monitoring at the Western Treatment Plant, 2000–12: The effects of climate and sewage treatment processes on waterbird populations

R.H. Loyn, D.I. Rogers, R.J. Swindley, K. Stamation, P. Macak and P. Menkhorst

April 2014

Arthur Rylah Institute for Environmental Research

Technical Report Series No. 256

Arthur Rylah Institute for environmental research

Department of Environment and Primary Industries

State Government Victoria

Waterbird monitoring at the Western Treatment Plant, 2000–12: The effects of climate and sewage treatment processes on waterbird populations

Richard H. Loyn, Danny I. Rogers, Robert J. Swindley,
Kasey Stamation, Phoebe Macak and Peter Menkhorst

Arthur Rylah Institute for Environmental Research
123 Brown Street, Heidelberg, Victoria 3084

April 2014

In partnership with:

Melbourne Water

Arthur Rylah Institute for Environmental Research
Department of Environment and Primary Industries
Heidelberg, Victoria

Report produced by: Arthur Rylah Institute for Environmental Research
Department of Environment and Primary Industries
PO Box 137
Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.depi.vic.gov.au/ari

© State of Victoria, Department of Environment and Primary Industries 2014

This publication is copyright. Apart from fair dealing for the purposes of private study, research, criticism or review as permitted under the *Copyright Act 1968*, no part may be reproduced, copied, transmitted in any form or by any means (electronic, mechanical or graphic) without the prior written permission of the State of Victoria, Department of Environment and Primary Industries. All requests and enquiries should be directed to the Customer Service Centre, 136 186 or email customer.service@depi.vic.gov.au

Citation: Loyn, R. H., Rogers, D. I., Swindley, R. J., Stamation, K., Macak, P. and Menkhorst, P. (2014) Waterbird monitoring at the Western Treatment Plant, 2000–12: The effects of climate and sewage treatment processes on waterbird populations. Arthur Rylah Institute for Environmental Research Technical Report Series No. 256. Department of Environment and Primary Industries , Heidelberg, Victoria

ISSN 1835-3827 (print)

ISSN 1835-3835 (online)

ISBN 978-1-74326-895-7 (print)

ISBN 978-1-74326-897-1 (pdf)

Disclaimer: This publication may be of assistance to you but the State of Victoria and its employees do not guarantee that the publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss or other consequence which may arise from you relying on any information in this publication.

Accessibility:
If you would like to receive this publication in an accessible format, such as large print or audio, please telephone 136 186, or through the National Relay Service (NRS) using a modem or textphone/teletypewriter (TTY) by dialling 1800 555 677, or email customer.service@depi.vic.gov.au

This document is also available in PDF format on the internet at www.depi.vic.gov.au

Front cover photo: Shorebirds roosting at high tide at the Western Treatment Plant in a redundant sewage treatment pond which is now managed as waterbird habitat, November 2008. The three species pictured are the three most abundant migratory shorebirds at the WTP, Red-necked Stint, Sharp-tailed Sandpiper and Curlew Sandpiper. Photographer Peter Menkhorst.

Authorised by: Victorian Government, Melbourne

Contents

Acknowledgements

This study was initiated and funded by Melbourne Water, and we are very grateful for the strong support we have received throughout the study, both for the monitoring work and the application of our results to habitat enhancement initiatives.

We would like to thank the many Melbourne Water staff who have assisted at different times, including senior managers and operations staff at the Western Treatment Plant. In particular Dr Will Steele has guided and supported the study from the beginning. We also thank Suelin Haynes, Peter Gall, Warren Blyth, Aaron Zanatta, Kevin Gillett and Ben Pratt for support in various ways. Members of the Western Treatment Plant Biodiversity Conservation Advisory Committee have also provided support and encouragement.

Many colleagues from ARI and the Victorian Wader Study Group (VWSG) have helped at different times, particularly Maarten Hulzebosch (shorebirds, waterfowl and ibis roost counts). Volunteers from the VWSG have made a crucial contribution to many of the shorebird counts. We thank the Shorebirds 2020 project (Birdlife Australia) for access to their shorebird count data from other Victorian shorebird sites.

The SARIMA modelling was designed and conducted by Drs David Duncan and Paul Maloney of ARI and we are very grateful for their critical contribution to data analysis.

Helpful comments on a draft were provided by Dr Josephine MacHunter, Dr Jenny Nelson, Graham Rooney and Dr William Steele.

Summary

Numbers of waterfowl, shorebirds, ibis and cormorants were monitored at the Western Treatment Plant (WTP) from 2000 to 2012 as part of a continuing program to help Melbourne Water manage this large facility (10,500 ha) near Werribee to meet multiple objectives. The WTP is used to treat about half of the sewage from Melbourne (a city of over 4 million people), discharging into Port Phillip. It also forms an important part of a Ramsar-listed wetland of international importance as a habitat for waterbirds.

Waterfowl (all ducks, geese, swans, coot and grebes) and selected other waterbirds (gulls, terns, swamphens and large wading birds) were counted across the whole WTP six times per year (73 counts). The counts in late February or early March contributed to Victorian Summer Waterbird Counts coordinated by the Arthur Rylah Institute for Environmental Research (ARI) for the Victorian Government. Waterfowl were counted by species on each treatment pond, wetland or stretch of coast over 3–6 days, focusing on a selected group of species on each day (e.g. dabbling ducks or diving ducks).

Shorebirds were counted across the whole WTP at least four times per year (three from spring to autumn and one in winter). Each year, one summer count (between late January and mid-February) and one winter count (between mid-June and mid-July) were scheduled to contribute to national summer and winter shorebird counts coordinated by the Australasian Wader Study Group (AWSG) and the Shorebirds 2020 Project at Birdlife Australia. Shorebirds were counted by species on tidal and non-tidal habitats at all potential shorebird sites within the WTP at high tide and low tide, usually on a single day. Similar counts were made for comparison at the Avalon Saltworks near Lara and at Point Wilson. The counts covered trans-equatorial migratory species that breed in the Northern Hemisphere and spend the austral summer in Australia, as well as species that breed in Australia or New Zealand.

Ibis and other waterbirds feeding in paddocks were counted six times per year, mostly between January and June, when numbers were generally highest. Ibis flying to roost at three communal roosts (Lake Borrie, 25W Lagoon and the Werribee River) were counted three times per year between January and June. Cormorants were counted at least six times each year while they were nesting at the 25W Lagoon: data were collected on the number of active nests of each species in each of the three ponds used.

This report describes the main changes in waterbird populations observed over this period and discusses the extent to which they may be attributed to management actions. Melbourne Water implemented an Environment Improvement Program (EIP) from 2003–05, to reduce nutrient discharge to Port Phillip and meet requirements of Victoria's Environment Protection Authority (EPA). The EIP was declared a controlled action under the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act), because of its potential to affect waterbird values of the Ramsar site. Continued monitoring of waterbird numbers was required as part of the Commonwealth's approval for the EIP.

The period from 1997–2009 coincided with a long drought over much of eastern Australia. The drought broke at different times in different parts of Australia. Parts of northern and inland Australia experienced heavy rain or floods in late 2008, whereas most of the south-east including Victoria remained dry until late 2009. The following three years were generally wet in eastern Australia, with extensive flooding at times. Such continent-scale phenomena are known to have profound effects on waterbird numbers and distributions at individual sites such as the WTP.

Analysis considered the hypotheses that waterbird numbers could be influenced by climatic events, effects of the EIP on habitat, disturbance from construction during the EIP, or a combination of these factors. Numbers of waterfowl and shorebirds were analysed using SARIMA time-series models to detect trend lines and break points of inflection in those trend lines. Mean numbers of each species and guild were also calculated for four time-periods (2000–02, pre EIP; 2003–05, during EIP implementation; 2006–08, post EIP; and 2009–12, post-drought). Distributional changes were described for waterfowl and shorebirds for those four time-periods, considering their use of treatment ponds, conservation ponds, other wetlands and stretches of coast.

Waterfowl

Numbers of waterfowl showed strong seasonal patterns, generally with peaks in summer-autumn and troughs in late winter or spring, which is the main breeding season. A modest declining trend was evident over the 12 years, but there were no break points of inflection associated with implementation of the EIP. Marked break points were evident from the time-series models in 2009 (declines coinciding with the breaking of the drought when birds relocated to newly flooded wetlands) and subsequent years (increases presumably following successful breeding in other parts of eastern and inland Australia). These changes are all consistent with the hypothesis that climatic patterns are a dominant driver of waterfowl numbers at the WTP. Filter-feeding ducks, diving ducks and coot showed larger declines post drought than other guilds, accounting for most of the observed decline in total waterfowl.

Some changes in waterfowl distribution at the WTP were observed, with more use being made of the old lagoons (now supporting 40% of the waterfowl at the WTP vs 25% pre EIP) and less use being made of the decommissioned lagoons and the nearby Spit Lagoon. These distributional changes are consistent with predictions about the likely effects of the EIP. They suggest an impact of the EIP on local distribution more than on total numbers present.

The upgraded new lagoons supported slightly higher proportions of the total waterfowl at the WTP during the EIP (when Activated Sludge Plants were being constructed) than in other periods (26% vs 18%). This suggests that effects of that industrial disturbance were not a dominant negative driver of waterfowl numbers at the WTP.

Overall, the WTP continues to provide habitat for very large numbers of waterfowl when rainfall or flooding events have not attracted them elsewhere. More than half the waterfowl continue to use sewage treatment ponds as their main habitat at the WTP. Hence continuing sympathetic management of these treatment ponds is needed to maintain the value of the WTP for waterfowl.

Shorebirds

Shorebirds also showed strong seasonal patterns. Trans-equatorial migrants were most numerous in summer with few remaining over winter (as expected). Australasian-breeding shorebirds were present all year, some species peaking in winter, others in late summer and others showing no clear seasonal trend. Migratory shorebirds far outnumbered Australasian-breeding shorebirds, so overall shorebird numbers peaked in summer. Time-series models identified break points at different times for the ten species analysed. Black-winged Stilt (an Australian breeding species) declined in 2010 when the drought broke, and increased in late 2011, as for waterfowl. Sharp-tailed Sandpiper (a trans-equatorial migrant) was extremely rare at the WTP in 2010–11 when there was plenty of water available in inland Australia. Other shorebirds showed more variable patterns, with time-series models indicating break points in different years. These break points did not coincide closely with EIP implementation, but they coincided with changes in shorebird numbers in other Victorian sites, suggesting that they were driven by factors elsewhere in the East Asian-Australasian Flyway.

Ibis

Numbers of ibis feeding and roosting at the WTP varied greatly. Australian White Ibis were found mainly in the north-east of the WTP and became scarce in the south-west during the EIP when the cessation of grass filtration reduced feeding opportunities there. Straw-necked Ibis were the most numerous species, especially in the first half of each year. The largest counts of feeding Straw-necked Ibis were made before full implementation of the EIP, however, the species has continued to make consistent use of the WTP for feeding and roosting. There was a substantial decline after the drought broke with what may be the beginnings of a recovery in recent years.

Cormorants

Numbers of nesting Pied Cormorant increased from 400–500 active nests in 2002–03 to ~1000 in 2010–12, with no decrease associated with EIP construction activities in 2005. Three other species of cormorants (Little Pied, Little Black and Great Cormorant) and the Australasian Darter also nested in the colony in small numbers, and a few Black-faced Cormorants roosted there.

Freshwater terns

The Whiskered Tern became most numerous post EIP towards the end of the drought, and the maximum count (5400) was made in November 2008. This species showed an unusual seasonal pattern, arriving in spring but declining in January. These terns failed to arrive in 2010–11 after the drought broke, but became numerous again in subsequent years, as for inland-breeding waterfowl. White-winged Black Terns were most numerous in late summer or autumn before departing to breed in central Asia. Both species used sewage treatment ponds and conservation ponds for feeding and roosting, and Whiskered Terns were also seen feeding over grassland (<4% of records).

General Conclusions

Season and climate, rather than the EIP, were the dominant drivers of waterbird numbers at the WTP during the period 2000-12. In particular, there was a mass exodus of many species in 2010–11 after the drought broke, followed by a return in subsequent years. The pattern of exodus in ~2009 and subsequent recovery was particularly marked for inland-breeding waterfowl, some shorebirds that breed in inland Australia (notably Red-necked Avocet and Black-winged Stilt) or have a preference for inland ephemeral swamps as non-breeding habitat (Sharp-tailed Sandpiper), and other species that also breed at ephemeral inland sites (e.g. Straw-necked Ibis and Whiskered Tern).

Changes in distribution of waterfowl accorded with predictions about likely effects of the EIP, with the old lagoons becoming the most important habitat and the decommissioned lagoons such as Lake Borrie becoming less important than previously.

Changes in numbers of trans-equatorial migratory shorebirds paralleled those observed elsewhere in Victoria and more widely in the East Asian-Australasian flyway, suggesting a common cause unrelated to management of the WTP. No evidence was found that breeding cormorants were disturbed by construction activities at the 25W Lagoon.

1 Introduction

This report presents the results of a program of waterbird monitoring at the Western Treatment Plant (WTP), Victoria, from 2000 to 2012. The program was commissioned by Melbourne Water to help manage the WTP for multiple purposes, including treatment of sewage and conservation of waterbirds. Both these main objectives are important to meet policy and legislative commitments, and may be either complementary or conflicting in different circumstances. The WTP treats sewage for almost half of Melbourne's population (>4 million people), discharging into Port Phillip under a licence issued by the Victorian Environment Protection Authority (EPA). The WTP is also renowned for its value as a habitat for waterbirds, and it forms a key part of a wetland system listed under the Ramsar Convention in 1982 as a wetland of international importance. This Ramsar-listed wetland system is known as the Port Phillip Bay (western shoreline) and the Bellarine Peninsula Ramsar site. Its Ramsar values have been documented (Lane and Peake 1990; Hale 2010) and need to be maintained under Commonwealth legislation including the *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act).

Melbourne Water undertook a major upgrade of the sewage treatment system between 2003 and 2005, to reduce nutrient discharge to Port Phillip and comply with its EPA licence. This was known as the Environment Improvement Program (EIP). Recognising that this could have consequences for waterbirds, the EIP was declared a controlled action under the EPBC Act. The Commonwealth Government allowed the EIP to proceed but stipulated some conditions, including maintenance of monitoring, modelling and research programs and implementation of adaptive management. The EIP involved a shift from three treatment processes to one, and a substantial modernisation of processes in two of the lagoon systems. There was a rapid phase-out of grass filtration which involved irrigating winter pastures of Italian Rye Grass with partly-treated sewage, mostly in the west of the WTP. The EIP also involved a more gradual phase-out of land filtration on grazed pasture grasslands, which are now irrigated entirely with treated effluent and no longer form part of the sewage treatment process. The sewage treatment process now relies entirely on the more efficient ponding process, in which sewage is treated in a succession of ponds within a lagoon. Most of the primary sewage treatment became concentrated in two large lagoons in the east of the WTP (55E and 25W) that had been constructed in the 1990s (and are known as 'new lagoons', along with 115E). Activated Sludge Plants were built in the middle ponds of these lagoons to enhance the treatment, as part of the EIP. Old lagoons east of Little River (85W A, B & C; 145W & Walsh's Lagoon), began receiving partly treated effluent from 55E and 25W, instead of untreated sewage. The easternmost 'new lagoon' at the WTP (115E) continued to operate as before until July 2010, when it also began to receive partly treated effluent instead of untreated sewage. Lagoons west of the Little River (Lake Borrie North, Lake Borrie South, T-section and Western Lagoon) were decommissioned from the sewage treatment process as part of the EIP, but now receive fully treated effluent for environmental purposes.

Some of these changes were expected to benefit waterbirds while others were expected to be negative. Early modelling showed that some waterfowl species and guilds (notably filter-feeding ducks and diving ducks) were likely to be adversely affected by reduced nutrient levels in some sewage treatment ponds, while many species and guilds might benefit from the cleaner and more aerobic water in old lagoons that were previously used for primary sewage treatment (Loyn et al. 2002a). There was concern that prey abundance for shorebirds on the tidal flats adjacent to the WTP might decline as a result of reduced levels of nutrient enrichment (Loyn et al. 2002b). However, it was also expected that potential benefits could be achieved by deliberate management of non-tidal 'conservation ponds' to provide feeding and roosting habitat that could be especially useful at or near high tide (Loyn et al. 2002b; Rogers et al. 2007). Ibis were expected to be affected by changes in irrigation (Macak et al. 2002; Loyn et al. 2002c), especially in the western part of the WTP where grass filtration was used widely until it was phased out as part of the EIP. These changes could relate to both the nutrient levels in irrigation water and the area irrigated, both of which were expected to decline. The important breeding colony of cormorants in 25W Lagoon was considered potentially vulnerable to disturbance during construction of the Activated Sludge Plant on this lagoon in 2005 (Lane et al. 2002). Longer-term negative effects on cormorants were considered unlikely because these birds feed mainly at sea in Port Phillip, where effects of the EIP were expected to be small and positive.

Melbourne Water has undertaken several measures to enhance waterbird habitat at the WTP, as part of its custodianship of the area. It has increased its efforts in this respect as part of an adaptive management program to offset or mitigate any negative effects of the EIP. Many of these measures have been targeted at waterbirds, and especially shorebirds, which were expected to be adversely affected by reduced nutrient levels on intertidal mudflats. These initiatives have included managing water levels and vegetation in selected wetlands (‘conservation ponds’) to provide habitat for the target species. New wetlands have been constructed in some cases, in ‘borrow pits’ where soil had been extracted for use elsewhere on the WTP. Measures have also been implemented to enhance habitat for a critically endangered land bird, the Orange-bellied Parrot *Neophema chrysogaster,* which winters in saltmarsh and wetland fringes at the WTP after breeding in south-west Tasmania, and for a threatened species of frog, the Growling Grass Frog *Litoria raniformis*, which breeds in well vegetated wetlands and channels at the WTP.

This report uses descriptive and statistical approaches to indicate how waterbird numbers have changed over the period from 2000 to 2012, and suggest possible causes for the patterns observed. In interpreting observed changes, it is important to recognise that waterbirds respond to seasonal and climatic events on vast spatial scales. Migratory shorebirds are affected by climatic and anthropomorphic events at their breeding sites (mainly in far northern Asia and Alaska) and on their migration routes through the East Asian–Australasian flyway. Waterfowl are affected by climatic and anthropomorphic events across the Australian continent: when it rains in inland Australia, large numbers of waterbirds move to newly formed habitats inland to breed (Frith 1987; Marchant and Higgins 1990; Kingsford et al. 1999, 2002; Chambers and Loyn 2006). Some shorebird species may be affected in similar ways (Marchant and Higgins 1993; Higgins and Davies 1996). The WTP serves as a valuable source of reliable water during times of drought, and most waterfowl species use it as a non-breeding refuge rather than breeding habitat. The period under review included a succession of very dry years throughout much of eastern Australia (1997–2009). The drought broke in northern and inland Australia in 2008–09, and locally later in 2009. The next three years were abnormally wet, with much flooding on the eastern seaboard and in the Murray-Darling Basin.

1.1 The WTP (geographical and historical information)

The WTP occupies 10,800 ha near Werribee on the western coast of Port Phillip, in an area of low rainfall between Melbourne and Geelong. As one of two main sewage treatment plants for Melbourne, it serves a population of over 2 million people. Prior to the EIP, it comprised nine systems of sewage lagoons used to treat effluent, as well as large areas of pasture used to treat sewage by land filtration in summer and grass filtration in winter. Subsequent to completion of the EIP, pastures have been irrigated with treated effluent not partially treated sewage. Some of the lagoons provided more than one treatment sequence (e.g. Lake Borrie North and South).

All the sewage lagoons are artificial, and did not exist before the WTP was built in the late 19th century. Some of them replaced natural wetlands such as Lake Borrie, but the total area of open fresh water has increased greatly as the sewage treatment plant has developed. The total area of the sewage treatment lagoons (including those that have been decommissioned or used as conservation ponds) is currently 1,824 ha (B. McLean, Melbourne Water, pers. comm.).

Since Ramsar listing in 1982, three new lagoon systems have been built in the north-eastern part of the WTP, some of which partly replaced older lagoons. The total sewage treatment lagoon area increased from 1,309 to 1,409 ha in 1986 (with construction of 115E lagoon), to 1,552 ha in 1991 (55E lagoon), to its present level of 1,824 ha in 1993 (25W lagoon) (B. McLean, Melbourne Water, pers. comm.). This represents a substantial addition (39%) to the area of lagoon habitat since 1982. Ponds in the new lagoons (115E, 55E and 25W) are generally regular in size and shape, and deeper than the old lagoons (~2 m compared with 1 m in old lagoons) where layers of organic material (such as dead algae) have accumulated over many years.

Natural, modified and artificial wetland habitats are available within and adjacent to the WTP. Artificial or modified wetlands include the sewage ponds, channels, flooded borrow pits and filtration paddocks, and a small ornamental pond at the main WTP office (which stopped being filled in 2004 during the drought). Natural wetlands include ephemeral freshwater swamps (e.g. Ryan's Swamp, filled intermittently from local rainwater runoff), Little River and its estuary, saltmarsh, tidal mudflats and lagoons (e.g. the adjacent Spit Nature Conservation Reserve), and the inshore waters of Port Phillip. The Werribee River and its estuary adjoin the north-eastern boundary of the WTP. The WTP and the adjacent Spit Nature Conservation Reserve have a combined coastline of about 21 km. The WTP also includes extensive areas of dryland habitat, mostly grazing paddocks and a variety of agricultural crops.

1.2 Purpose of this report

This report gives an overview of the monitoring program, its main results and the implications for management. The primary question we address is:

> Did trends in waterbird numbers change in association with implementation of the EIP?

To address this question we considered three hypothetical scenarios, which could apply separately or together:

1. The EIP could be a dominant driver of waterbird numbers at the WTP. This would lead to strong inflection points in trend graphs as the EIP was implemented in 2003–05.
2. Climatic patterns could be a dominant driver of waterbird numbers at the WTP, with strong inflection points at or near the breaking of the drought in ~2009. Numbers of Australian breeding species would be expected to be high at the start of the long drought and decrease gradually in line with poor breeding and declining national populations. Waterbird numbers would be expected to decline markedly after the drought broke (2008–10) as many waterbirds moved inland to breed in recently refilled ephemeral wetlands. Large influxes to the WTP would then occur in subsequent years after successful breeding and as the ephemeral inland wetlands dried out.
3. Disturbance during construction of Activated Sludge Plants could be a dominant driver of waterbird numbers and dispersion at the WTP. Numbers of waterbirds would be expected to decline markedly on 55E Lagoon in 2003 and on 25W Lagoon in 2005, for relatively short periods during construction. Breeding cormorants at the 25W Lagoon might be reduced in number while construction was under way.

Map 1. The Western Treatment Plant showing major lagoon systems and other features mentioned in the text.

2 Methods

2.1 Waterfowl

Waterfowl were counted across the whole WTP six times per year from October 2000 to November 2012, as part of an ongoing monitoring program. The second count of each year (in late February or early March) was designed to form part of the annual state-wide Summer Waterfowl Count, conducted by the Victorian Government through the Arthur Rylah Institute since 1987.

All ducks, geese, swans, coot and grebes were counted on each of these occasions (73 counts), these being the species that habitually gather on large bodies of water to feed and rest. These were classed as ‘standard species’ (Table 1), and the term ‘total waterfowl’ refers to the sum of those species. Other waterbirds including gulls, terns, crakes, swamphens and wading birds were counted opportunistically, but no attempt was made to visit every habitat used by this miscellaneous group (for example, crakes usually hide in dense aquatic vegetation and it is not practical to estimate their numbers during surveys of this sort). Data on gulls, terns and ‘waterhens’ (Purple Swamphen, Dusky Moorhen and Black-tailed Native-hen) are considered to be reasonably indicative of those using the WTP, and are shown in selected tables where appropriate. The waterfowl counts covered all treatment ponds, wetlands and flooded areas likely to attract waterfowl at the WTP, along with adjacent stretches of coast. Waterfowl were counted by species on each treatment pond, wetland or stretch of coast. Each count (session) was conducted over 3–6 days, focusing on a selected group of species on each day (e.g. dabbling ducks or diving ducks, etc.). This was necessary so that each group could be counted over the whole WTP in a single day, minimising the risks of missing birds or double-counting when flocks moved between sites overnight.

One complication arose from this process, when noteworthy observations were made on a species (generally an uncommon species such as Freckled Duck), on days other than the days when they were being counted comprehensively. This could result in two counts of that species from a single site on different days within a session. On the few occasions when this happened, mean values were taken for the two counts at that site. Adjustments were then made manually if it was thought that the same individual birds were counted twice during a session, at different sites (e.g. with rare hybrids or vagrants such as Northern Shoveler, which were believed to be represented by single birds).

One experienced observer (Robert Swindley) conducted all these counts, with occasional assistance from other experienced observers. Observer variation was assessed during early counts and showed that different observers counted different numbers of birds, but they detected similar species composition across geographical and temporal gradients (Loyn et al. 2001). Data were entered into a database and used to generate tables, graphs and data for statistical analysis.

2.1.1 Species groupings for analysis

Waterfowl were considered by species and also by grouping duck or grebe species with similar feeding behaviours into guilds (Table 1). The guilds were dabbling ducks (which upend for food in near-surface waters), diving ducks (which dive to access deeper food), filter-feeding ducks (which filter surface waters to retain abundant small organisms), grazing ducks (which sometimes feed on terrestrial vegetation) and grebes (which dive for animal food such as fish or crustaceans). Swans and coot were also treated as guilds (respectively upending or diving for vegetable matter in water of medium depth) although each was represented by a single species (Black Swan and

Eurasian Coot). Total waterfowl was also considered as a guild, consisting of all the standard species (Table 1).

2.1.2 Analysis

Waterbird count data were considered in three main ways as follows:

1. Graphical and statistical analysis of trends over time for selected waterfowl guilds and species across the whole WTP, investigating whether there may have been an inflection when the EIP was implemented during 2003–05, and whether that affected particular species as predicted;
2. Examination of mean counts of all species across the whole WTP for four time-periods: 2000–02 (pre-EIP); 2003–05 (during EIP); 2006–08 (post-EIP with continuing drought); and 2009–12 (post-EIP, post-drought); and
3. Examination of bird distributions and mean counts of selected important species for various combinations of sites at the WTP for the four time-periods used in approach 2, to assess whether the habitat values of those site combinations have increased or decreased over time. The combinations of sites are listed for waterfowl in Table 2.

Time-series models were used to inform the first approach (see section 2.6) while descriptive methods were applied to approaches 2 and 3. For approaches 2 and 3, count data were excluded where necessary to achieve an equal representation of counts from each of five seasons (late February or early March; April to June; July; August to September; and October to November). January counts were unfortunately missed in two years (2001 and 2003) and counts from that season (January) were excluded from this analysis, along with a single December count (2001). A count from June 2002 was excluded from this analysis as it followed one in late April/early May, which was the more usual timing for that season (the only exception being June 2006). Similarly, a count in November 2010 was excluded from this analysis because it followed one in October 2010. A count from October 2000 was included to balance a missed count for October 2002. This produced a balanced set of 60 counts (12 years x 5 seasons). Further statistical analysis was planned to apply quantitative methods to approaches 2 and 3 but did not prove necessary in view of results from the time-series models.

Table 1. Waterfowl species recorded in 73 waterfowl counts at the Western Treatment Plant, with guilds to which they were assigned and mean and maximum counts (2000–12, n=73). A few extra species (marked *) are also shown where the counts provided useful data, but are not 'standard species' and are not included in 'total waterfowl'.

Species	Scientific name	Guild	Mean	Max
Magpie Goose	*Anseranas semipalmata*	Goose	0.2	11
Musk Duck	*Biziura lobata*	Diving duck	1005	2103
Freckled Duck	*Stictonetta naevosa*	Filter-feeding duck	65.2	554
Cape Barren Goose	*Cereopsis novaehollandiae*	Goose	13.7	65
Domestic Goose	*Anser sp.*	Goose	0.5	2
Black Swan	*Cygnus atratus*	Swan	2977	6244
Australian Shelduck	*Tadorna tadornoides*	Grazing duck	5623	34922

Species	Scientific name	Guild	Mean	Max
Australian Wood Duck	*Chenonetta jubata*	Grazing duck	8.4	109
Pink-eared Duck	*Malacorhynchus membranaceus*	Filter-feeding duck	12419	50991
Australasian Shoveler	*Anas rhynchotis*	Filter-feeding duck	3759	17433
Northern Shoveler	*Anas clypeata*	Filter-feeding duck	0.1	1
Grey Teal	*Anas gracilis*	Dabbling duck	3651	12466
Chestnut Teal	*Anas castanea*	Dabbling duck	3578	10914
Mallard	*Anas platyrhynchos*	Dabbling duck	0.1	1
Mallard-Black Duck hybrid	*Anas sp.*	Dabbling duck	0.2	1
Domestic Duck	*Anas sp.*	Dabbling duck	0.1	1
Pacific Black Duck	*Anas superciliosa*	Dabbling duck	1001	3148
Hardhead	*Aythya australis*	Diving duck	3429	15518
Blue-billed Duck	*Oxyura australis*	Diving duck	4078	11897
Australasian Grebe	*Tachybaptus novaehollandiae*	Grebe	80.8	684
Hoary-headed Grebe	*Poliocephalus poliocephalus*	Grebe	8959	24881
Great Crested Grebe	*Podiceps cristatus*	Grebe	44.4	760
Eurasian Coot	*Fulica atra*	Coot	2712	17527
Australian Pelican*	*Pelecanus conspicillatus*	Pelican	166	509
Brolga*	*Grus rubicunda*	Crane	1.3	6
Purple Swamphen*	*Porphyrio porphyria*	Waterhen	147	1055
Black-tailed Native-hen*	*Tribonyx ventralis*	Waterhen	20.1	211
Dusky Moorhen*	*Gallinula tenebrosa*	Waterhen	1.5	25
Silver Gull*	*Chroicocephalus novaehollandiae*	Gull	1527	13462

Table 2. Combinations of sites considered in relation to distribution of waterfowl at the Western Treatment Plant, 2000–12, with notes on effects of the Environment Improvement Program (EIP) including construction of Activated Sludge Plants. Mean counts of waterfowl (standard species) are shown to indicate the relative importance of each group of sites over this period (n = 73).

Site combinations	Mean waterfowl count	Notes
New lagoons (115E)	4300	Stable management to July 2010 when received treated effluent not raw sewage
New lagoons (55E & 25W)	9685	Now main site of primary sewage treatment: Activated Sludge Plants built in 2003 (55E) and 2005 (25W)
Old lagoons	16104	Primary sewage treatment discontinued under EIP; continue to provide secondary treatment
Decommissioned lagoons (Lake Borrie North & South)	10812	Removed from treatment process under EIP; receive treated effluent for environmental purposes; some ponds drawn down for conservation purposes
Decommissioned lagoons (Western & T-section Lagoons)	1462	Removed from treatment process under EIP; receive treated effluent for environmental purposes; many ponds drawn down for conservation purposes (shorebirds, frogs and saltmarsh for Orange-bellied Parrot)
Conservation ponds	2651	Managed to provide habitat for waterbirds and frogs, involving drawdown cycles for shorebirds in some cases; includes borrow pits and new flooded paddocks (Q-section)
Utility ponds, paddocks and channels	409	Paddocks removed from treatment process under EIP, now receive treated effluent for agricultural purposes
Natural swamps or creeks	155	Four disparate sites: an ephemeral swamp (Ryan Swamp, important when flooded), periodically flooded saltmarsh near Point Wilson and two creeks (Cherry-tree Creek and Little River)
Spit Lagoon	742	Intertidal area sheltered by North and South Spits; received treated effluent from Murtcaim Drain until 2003 when grass filtration discontinued under EIP
Coast and outlets	2110	Coast from South Spit in west to Werribee River in east, including intertidal mudflats (other than those in Spit Lagoon), outlets and Little River estuary

2.2 Shorebirds

Shorebirds were counted across the whole WTP at least three times each summer and once in winter each year from 2000 to 2012, as part of a continuing program. One of the summer counts and the winter count were designed to coincide with other counts in southern Australia, and contribute to a national program of shorebird counts coordinated by the Royal Australasian Ornithologists Union (now Birdlife Australia) and the Australasian Wader Study Group (AWSG). These biannual counts provide a run of data from the WTP since 1981, when they began as a voluntary initiative of the Victorian Wader Study Group. The counts are carried out at high tide when shorebirds are concentrated in roosts. Observers visit all known shorebird sites in the WTP, explore for new ones, and count individuals of each shorebird species present.

For the current program, component counts were organised in ten separate districts of the WTP, and counts were usually conducted at low tide as well as high tide to give a better picture of foraging sites as well as roosting sites. Counts of shorebirds at high and low tides at the WTP were found to correspond closely, with no tendency for one to be higher than the other (Rogers et. al 2013). In the analyses, when both high and low tide counts were done on the same day, we used the higher of the two counts for each species. Since 2004 the exact time and location of each component shorebird count has been recorded, along with the proportion of birds foraging during each count. This allows shorebird totals seen at any one site to be compared with tide conditions, and an assessment of whether sites are used for foraging, roosting or both. Standard field surveys are carried out by three observers, now typically Danny Rogers (counting shorebirds at the Western Lagoon and The Spit Nature Conservation Reserve), Robert Swindley (sites east of Little River) and Maarten Hulzebosch (remaining sites). The observers co-ordinate closely by mobile phone during the surveys to ensure no birds are double-counted or overlooked.

In some years, additional counts were carried out in spring and autumn to improve understanding of seasonal fluctuations in numbers. Similar data were collected from a nearby site (Avalon Saltworks), with the intention of using this as a reference site. However, there have been major changes in the management of the saltworks, complicating any use of the data for this purpose. Hence the data from Avalon are not presented or considered specifically in this report.

2.2.1 Species groupings for analysis

Of the 37 shorebird species recorded during counts at the WTP between 2000 and 2012 (Table 3), 12 were species that nest in Australia or New Zealand (henceforth referred to as 'Australasian shorebirds') and the remaining 25 were 'trans-equatorial migrants' from breeding grounds in the Northern Hemisphere. Some 27 shorebird species occurred quite regularly at the WTP, but only four species (Australian Pied Oystercatcher, Black-winged Stilt, Masked Lapwing and Red-necked Stint) were recorded in every shorebird survey. About ten of the species were vagrants, recorded in three or fewer years during the study period, and they are not considered further in this report.

We also classified the habitat preference of each species (Table 4). Species were treated as 'coastal' if they foraged predominantly on tidal flats when the tide was low enough to do so; as 'wetland' if they foraged predominantly on non-tidal ponds even when the tide was low; and as 'both' if they foraged regularly in both non-tidal ponds and on tidal flats. Demarcations between these categories were not always clear cut. For example, reasonable numbers of Red-necked Avocets were recorded foraging on tidal flats, but they only did so occasionally, in very still, hot conditions, for short periods when the tide was very low. In contrast, Red-necked Avocets were recorded foraging on non-tidal ponds whenever they were present at the WTP, so we treated them as a 'wetland' species.

Table 3. Mean and maximum counts of shorebird species at the Western Treatment Plant, 2000–12.

Species	Scientific name	Guild#	Mean	Max
Australian Pied Oystercatcher	*Haematopus longiristris*	Aus	39.6	77
Sooty Oystercatcher	*Haematopus fuliginosus*	Aus	0.4	6
Black-winged Stilt	*Himantopus himantopus*	Aus	236	453
Red-necked Avocet	*Recurvirostra novaehollandiae*	Aus	448	1876
Banded Stilt	*Cladorhynchus leucocephalus*	Aus	132	623
Pacific Golden Plover	*Pluvialis fulva*	NH	7.9	45
Grey Plover	*Pluvialis squatarola*	NH	0.7	7
Red-capped Plover	*Charadrius ruficapillus*	Aus	61.1	282
Double-banded Plover	*Charadrius bicinctus*	Aus	41.7	296
Black-fronted Dotterel	*Elseyornis melanops*	Aus	21.3	151
Red-kneed Dotterel	*Erythrogonys cinctus*	Aus	18.8	146
Banded Lapwing	*Vanellus tricolor*	Aus	1.6	40
Masked Lapwing	*Vanellus miles*	Aus	119	248
Australian Painted Snipe	*Rostratula australis*	Aus	0.0	2
Latham's Snipe	*Gallinago hardwickii*	NH	0.3	8
Black-tailed Godwit	*Limosa limosa*	NH	5.0	23
Hudsonian Godwit	*Limosa haemastica*	NH	0.0	1
Bar-tailed Godwit	*Limosa lapponica*	NH	6.3	56
Little Curlew	*Numenius minutus*	NH	0.1	2
Eastern Curlew	*Numenius madagascariensis*	NH	0.8	14
Terek Sandpiper	*Xenus cinereus*	NH	0.0	1
Common Sandpiper	*Actitis hypoleucos*	NH	0.4	3
Common Greenshank	*Tringa nebularia*	NH	24.0	84
Marsh Sandpiper	*Tringa stagnatilis*	NH	19.4	238
Wood Sandpiper	*Tringa glareola*	NH	0.5	2
Ruddy Turnstone	*Arenaria interpres*	NH	1.2	13
Great Knot	*Caldiris tenuirostris*	NH	0.1	2
Red Knot	*Calidris canutus*	NH	4.8	77

Species	Scientific name	Guild#	Mean	Max
Red-necked Stint	*Calidris ruficollis*	NH	5286	12850
Long-toed Stint	*Calidris subminuta*	NH	0.1	3
Pectoral Sandpiper	*Calidris melanotus*	NH	0.9	7
Sharp-tailed Sandpiper	*Calidris acuminata*	NH	1452	6536
Curlew Sandpiper	*Calidris ferruginea*	NH	742	2732
Broad-billed Sandpiper	*Limicola falcinellus*	NH	0.1	2
Ruff	*Philomachus pugnax*	NH	0.2	3
Red-necked Phalarope	*Phalaropus lobatus*	NH	0.1	1
Oriental Pratincole	*Glareola maldivarum*	NH	0.1	2

Aus = Australasian breeding species (Double-banded Plover breeds in New Zealand, others in Australia), NH = Northern Hemisphere breeding species (trans-equatorial migrant).

Table 4. Number of records of foraging shorebirds at the Western Treatment Plant 2004–12, on coastal tidal flats and non-tidal wetlands or ponds and assigned habitat guild. Species sorted by proportion observed feeding on tidal flats.

Species	Records of foraging birds	Coast (tidal)	Ponds/ wetland	% feeding on coast	Habitat guild
Australian Painted Snipe	3	0	3	0.0%	Wetland
Common Sandpiper	3	0	3	0.0%	Wetland
Little Curlew	2	0	2	0.0%	Wetland
Long-toed Stint	25	0	25	0.0%	Wetland
Pectoral Sandpiper	33	0	33	0.0%	Wetland
Red-necked Phalarope	3	0	3	0.0%	Wetland
Terek Sandpiper	1	0	1	0.0%	Both #
Wood Sandpiper	33	0	33	0.0%	Wetland
Banded Stilt	4672	20	4652	0.4%	Wetland
Black-fronted Dotterel	260	2	258	0.8%	Wetland
Red-kneed Dotterel	369	3	366	0.8%	Wetland
Marsh Sandpiper	827	53	774	6.4%	Wetland
Black-winged Stilt	11458	747	10711	6.5%	Wetland
Black-tailed Godwit	196	23	173	11.7%	Wetland

Species	Records of foraging birds	Coast (tidal)	Ponds/ wetland	% feeding on coast	Habitat guild
Red-necked Avocet	14193	1901	12291	13.4%	Wetland
Ruff	14	2	12	14.3%	Wetland
Masked Lapwing	1327	219	1108	16.5%	Both
Broad-billed Sandpiper	4	1	3	25.0%	Both #
Curlew Sandpiper	55071	27650	27421	50.2%	Both
Sharp-tailed Sandpiper	135763	74532	61231	54.9%	Both
Common Greenshank	1499	951	548	63.4%	Both
Red-capped Plover	2407	1626	781	67.6%	Both
Double-banded Plover	1538	1050	488	68.3%	Both
Red-necked Stint	444159	352667	91492	79.4%	Both
Red Knot	83	76	7	91.6%	Coastal
Pacific Golden Plover	119	117	2	98.3%	Coastal
Pied Oystercatcher	1802	1778	24	98.7%	Coastal
Bar-tailed Godwit	493	492	1	99.8%	Coastal
Eastern Curlew	19	19	0	100%	Coastal
Great Knot	2	2	0	100%	Coastal
Grey Plover	24	24	0	100%	Coastal
Ruddy Turnstone	36	36	0	100%	Coastal
Sooty Oystercatcher	19	19	0	100%	Coastal
TOTAL	684151	471510	212641	68.9%	

These two species were also observed foraging on tidal flats (as well as wetlands) outside formal counts. Both species are rare at the WTP. Elsewhere in Australia they forage mainly on tidal flats.

2.3 Ibis (feeding and roosting)

Ibis were counted in two ways. Firstly, numbers of ibis in irrigated paddocks were counted six or seven times, mostly between January and July (the period when ibis numbers are highest at the WTP)each year from 2001-2012. This was done by driving a set route around the WTP and scanning paddocks with binoculars. Numbers of ibis and other waterbirds were recorded by species along with locations of all flocks observed. These counts were mostly undertaken by a single observer, Phoebe Macak. The pastures were used as part of the sewage treatment process before the EIP (land filtration in summer, and grass filtration in winter in the western part of the WTP). Subsequently, they were irrigated with treated effluent not raw sewage.

Secondly, numbers of ibis were counted three or four times per year between January and June from 2002–12, as they flew to roost at two communal roosts at the WTP (in dead trees at Lake Borrie and 25W Lagoon). A third roost was found in living trees beside the Werribee River east of the WTP, and roost counts were also conducted there on the same days where possible. The roost counts were conducted mainly by Richard Loyn or Peter Menkhorst (Lake Borrie), Bob Swindley (25W lagoon) and Maarten Hulzebosch (Werribee River). These counts were restricted to the January-June period because that is when most ibis visit the WTP: many leave the area in June, presumably to breed at wetlands near Geelong or on Mud Islands. Data collected by roost counts and paddock counts are not directly comparable because ibis that roost at the WTP may feed elsewhere, therefore the two data sets are treated independently. Several other waterbird and land bird species were found to use the same trees for communal roosting, and their numbers were recorded during the ibis roost counts but are not analysed in this report.

2.4 Cormorants (breeding)

Numbers of nesting cormorants were counted by species at the 25W lagoon at least six times each year during the breeding period (in dead trees along submerged, disused road alignments at Ponds 3, 5 and 8). The number of active nests of each species was recorded on each visit, and data were obtained on the stage of nesting (building, eggs or young in nest). Numbers of eggs or young visible in individual nests were recorded where possible without disturbing the birds. However, a full record of nest contents could not be obtained without causing undue levels of disturbance. Cormorant monitoring was undertaken by Robert Swindley.

Cormorants were found to begin nesting at each pond at slightly different times, so the maximum number of active nests was not synchronous between ponds. Hence the maximum simultaneous total of active nests was always less than the annual sum of maximum totals for each pond, and the latter was chosen as the best estimate of the number of pairs that actually nested in a given year. Numbers of young fledged could not be calculated because birds fledged at different times and some soon left the colony to feed elsewhere. The length of the breeding season was also recorded, as it was found to vary from a few months when there were few nesting pairs to >8 months when there were many pairs breeding.

2.5 Freshwater Terns

Numbers of freshwater terns (Whiskered Tern and White-winged Black Tern) were counted during waterfowl counts when they were feeding over treatment ponds and other wetlands, or roosting in those habitats. They were also counted during counts of feeding ibis when they were feeding over paddocks: this happened on some occasions when areas with long grass had been irrigated. However, the vast majority of records involved birds at wetlands.

2.6 Statistical analyses

Descriptive and quantitative approaches were used to address the main question: did trends in waterbird numbers change in association with the implementation of the EIP? Firstly, total counts were graphed and mean values were calculated for the numbers of each waterbird species or guild in four time-periods: 2000–02 (pre-EIP); 2003–05 (during EIP); 2006–08 (post-EIP with continuing drought); and 2009–12 (post-EIP, post-drought). These means were based on balanced sets of data with respect to season, to minimise effects of seasonal variation. For the shorebird graphs LOWESS smoothers (locally weighted scatterplot smoothers) were plotted to guide the eye, using Systat 13.

Bird distributions and mean counts of 'standard waterfowl' species (Table 1) were also examined for various combinations of sites at the WTP (Table 2) for the four time-periods. This allowed an assessment of whether the habitat values of those site combinations have increased or decreased over time at groups of sites where management varied in particular ways associated with implementing the EIP. Simple t-tests were used to determine the significance of any differences between mean counts before and after implementation of the EIP.

To determine whether the changes in sewage management at the WTP are likely to have affected the use of the site by waterbirds, time-series analyses of transformed count data from 2000–12 were combined with tests for structural change or breakpoints in the time trend.

To characterise the time-series a family of time-series models known as SARIMA models was used. These are autoregressive (AR), integrated (I) moving average (MA) models with a seasonal (S) component to the variation (Chatfield 2001). These models were developed for describing trends and forecasting in economics but now are widely used in various contexts where seasonality is expected, for example, fisheries (Prista et al. 2011), tourism (Brida and Garrido 2009), epidemiology (Martinez et al. 2011), macroeconomics (Saz 2011) and resource consumption (Maamar 2013; Sigauke and Chikobvu 2011). ARIMA models are said to be agnostic or atheoretic in nature, ignoring explanatory variables, and interested only in the predictive power of past values of the response variable (Saz 2011). The value of this atheoretic approach for the present study is that it enabled focus on one simple question; whether the EIP is associated with a disturbance in the time-series, once seasonal variation is accounted for.

The SARIMA time-series models were implemented as dynamic linear models in R (R Development Core Team 2012), using the package 'dynlm' (Zeileis 2013). These models compartmentalise the variation in the time-series into its various seasonal components. In addition, structural changes in the linear trend associated with the implementation of the EIP were tested for using the 'breakpoint' routine in the package 'strucchange' (Zeileis et al. 2002). 'Breakpoint' determines and reports the best supported location of breakpoints in linear trend data, if breaks are indeed suggested. This type of approach has also been referred to as broken-stick regression. In our context, breakpoints identified around the time of the EIP might indicate its influence on waterbird use of the WTP site.

Firstly, the raw count data were log-transformed (ln) and 'differenced' (represented as difference from a previous value in the time series) according to the expected seasonal factor, or factors. In our case, log-transformed count data were differenced by season, recognising that a winter count in one year is most likely similar to winter the previous year, rather than to the previous survey in autumn. Differencing aims to neutralise the variation attributable to known seasonal structure. For waterfowl three seasons were considered (January to March, April to July and August to December) and for shorebirds two seasons (summer and winter), taking mean values from multiple counts in each case. In some migratory shorebird species, there were repeated zero counts during the austral winter (when adults migrate to the breeding grounds), so log-tranformation of data was impossible. For such species only analysed summer counts were analysed (ARIMA rather than SARIMA time-series models), but model selection procedures were identical to those described below for the SARIMA models.

A suite of candidate models including potential break points was then examined, and the best models selected after inspecting the outputs for Residual Sum of Squares (RSS) and Deviance Information Criteria (DIC) from the breakpoint analysis. If the RSS and DIC criteria did not suggest the same optimal number of break points models representing more than one of the supported break point options were included.

Aikaike Information Criteria corrected for small sample sizes (AICc) (Burnham and Anderson 2002) were used to select a single best model, or best and next best models if AICc, model weight, and r^2 were similar. Selected models were tested for residual autocorrelation and partial autocorrelation with a view to rejecting models where residuals indicated time-dependence.

This modelling procedure was applied to data on waterfowl (collectively) and all waterfowl guilds at the WTP, along with their main constituent species. It was also applied to the two main shorebird groups (trans-equatorial migrants that breed in north Asia or Alaska, and Australasian breeding species that breed in Australia or New Zealand), along with some of the main species in each group. For shorebirds, the models were applied both to shorebirds at the WTP and to shorebirds across all main sites in Victoria which have been monitored annually through the study period (Corner Inlet, Western Port Bay, Bellarine Peninsula from Swan Bay to Avalon, the WTP, Pt Cook Coastal Park and Cheetham Wetlands). Data from these additional sites was collected in annual summer and winter counts co-ordinated by the Australasian Wader Studies Group (AWSG), and the data were provided through the Shorebirds 2020 project of Birdlife Australia. SARIMA models were not applied to data on freshwater terns, ibis or breeding Pied Cormorants, because the sampling regimes were different.

3 Results

3.1 Waterfowl

3.1.1 Trends over time across the whole WTP

Changes in numbers of key waterfowl species and guilds across all 73 counts are shown in Figure 1 (species of dabbling duck and diving duck), Figure 2 (species of filter-feeding duck, grazing duck, grebe, swan and coot) and Figure 3 (waterfowl guilds). Marked seasonal variation is evident in all cases, with remarkable consistency between most years despite variation in climatic conditions. The most obvious discrepancy was in 2010–11, when the usual seasonal peaks failed to materialise, especially for inland-breeding species such as Pink-eared Duck, Hardhead and Hoary-headed Grebe. All these species declined temporarily to extremely low numbers at the WTP in summer-autumn 2010–11 (the season when numbers are usually high), before further influxes in subsequent years (Figures 1 and 2).

The graphs (Figures 1–3) showed little change in total waterfowl numbers over the first ten years, other than seasonal patterns as described below. Time-series models showed no evidence of break points in waterfowl numbers associated with implementation of the EIP in 2003–05, and little evidence of significant trends over time (Table 5). The one clear exception was grazing ducks and their main constituent species, Australian Shelduck, both of which increased significantly ($P<0.05$) (Table 6) with no convincing evidence of break points in the trend (Table 5).

Major fluctuations occurred for most guilds and species the last four years of the study (Figures 1–3), as the drought broke at different times in different parts of Australia. A mass exodus of waterfowl was observed in 2010–11 (or earlier for some species), presumably leaving to breed on ephemeral inland swamps that had filled with rain or floodwaters after many years of drought. Declines were most pronounced for species known to breed inland (e.g. Hoary-headed Grebe, Grey Teal, Pink-eared Duck and Hardhead) and guilds dominated by those species (grebes, filter-feeding ducks and diving ducks) but affected all species to varying degrees. The time-series models identified break points for all guilds and species (except grazing ducks and Australian Shelduck) in ~2009 (followed by steep declines) and again in ~2011 (followed by rapid increases) as birds of these species began to return, presumably after successful breeding in those replenished habitats (and perhaps as those habitats began to dry out and become unsuitable again). These rapid decreases and subsequent increases were significant for most guilds and species ($P<0.05$) (Table 4). Massive declines in Hoary-headed Grebe (from >10,000 in 2009 to <10 in early 2010–11) and Eurasian Coot (from 2832 in summer 2010 to 16 in spring 2011) did not register as statistically significant because they happened at seasons when these species were increasing in other years. Most of the species that declined returned in high numbers in the next two years (2011–12). One species that did not return in this period (Blue-billed Duck) was found in high numbers in 2013 (>10,000, R.Swindley unpubl.).

Examination of data for the whole 12 years of the study revealed some details that are of interest even though they did not manifest as significant trends or break points in the time-series models. Figures 1-3 suggest modest declining trends for some waterfowl species (mainly diving ducks and filter-feeding ducks) over the first ten years of the monitoring program, before the fluctuations associated with the breaking of the drought. Locally breeding species such as Pacific Black Duck, Chestnut Teal and Black Swan did not show these initial declining trends, and some (e.g. Australasian Grebe and Eurasian Coot) reached their highest levels in the post-drought period (2009–12) (Table 5).

Table 5. Main features of SARIMA time-series models for waterfowl at the Western Treatment Plant, showing the number of inflection points (according to the best supported model), the years when the trend lines changed (mean values), the gradients of trend lines for each segment of the graph (expected annual % change) and whether they differed significantly from zero (flat lines)(indicated by *).

Species or guild	Number of inflection points	Mean years of inflection	Expected annual % change for segment 1	Expected annual % change for segment 2	Expected annual % change for segment 3
Total waterfowl	2	2009, 2011	–5.8%	–69.9% *	146.0% *
Dabbling ducks	2	2009, 2011	0.0%	–54.2% *	141.1% *
Diving ducks	2	2009, 2011	9.4%	–79.6% *	339.3% *
Filter-feeding ducks	2	2009, 2011	–19.7%	–95.3% *	242.1% *
Grazing ducks #	2	2003, 2005	–82.8% *	203.4% *	7.3%
Grazing ducks #	0	no breaks	25.9% *		
Black Swan	2	2009, 2011	11.6%	–13.9%	16.2%
Australian Shelduck #	2	2003, 2005	–91.8% *	281.9% *	11.6%
Australian Shelduck#	0	no breaks	26.4%*		
Grey Teal	2	2009, 2011	–5.8%	–86.7% *	385.5% *
Chestnut Teal	2	2009, 2011	6.2%	–40.0% *	95.4% *
Pacific Black Duck	2	2009, 2011	2.0%	– 23.7%	75.1% *
Australasian Shoveler	2	2009, 2011	–13.9%	–11.3%	69.9%
Pink-eared Duck	2	2009, 2011	–17.3%	–96.7% *	784.6% *
Blue-billed Duck	2	2009, 2011	–9.3%	–76.5% *	10.5% *
Hardhead	2	2009, 2011	–12.2%	–92.9% *	917.6% *
Musk Duck	2	2009, 2011	7.3%	0.0%	–1.0%
Musk Duck	0	no breaks	-0.8%		
Hoary-headed Grebe	2	2009, 2011	3.0%	–58.9%	263.3% *
Eurasian Coot	2	2009, 2011	–11.3%	–80.2%	646.3% *

Models with two or no inflection points had similar levels of support, but the models with no inflection points provide a better fit

3.1.2 Seasonal patterns

Numbers of all species showed simple seasonal patterns, with single peaks and troughs during the year when mean data were examined over the 12-year period (Figures 1 and 2). Mean numbers of most species reached their highest levels in summer or autumn (January to June) and their lowest levels in late winter or spring. The low levels coincide with the main breeding seasons for those species, and also the time of the year when water is most likely to be available elsewhere in Australia. Counts in January and February-March were quite similar for most species, but Australian Shelduck were most numerous in January when many thousands gathered each year at the WTP to moult (becoming flightless for short periods). Hardhead also tended to be most numerous earlier in spring-summer (October-January) than other species (Figure 1). Australasian Grebe and Great Crested Grebe appeared to be least numerous in January and most numerous in winter or spring, but the pattern varied between years.

3.1.3 Mean counts for four time-periods (pre EIP 2000–02; during EIP 2003–05; post EIP 2006–09; post drought 2010–12)

Mean counts for the four time-periods are shown in Table 6 for standard species, guilds and selected other species. Waterfowl were collectively ~25% less numerous in the two post-EIP periods (2006–09 and 2010–12) than before or during the EIP (2000–02 and 2003–05). However, the pattern varied considerably between species and guilds (Table 6). All species continued to use the WTP in large numbers.

One guild (grazing ducks) and its main constituent species (Australian Shelduck) were markedly more numerous in the two post-EIP periods (2006–09 and 2010–12) than before or during the EIP (2000–02 and 2003–05). The time-series models showed that this increase was significant ($P<0.05$). A much less common grazing bird, the Cape Barren Goose, showed the same pattern, whereas Australian Wood Duck, a freshwater species, has never been common at the WTP and remained scarce throughout the study.

Two guilds appeared to be less numerous in the two post-EIP periods than before or during the EIP, and the time-series models also showed significant declines. Filter-feeding ducks were collectively 67% less numerous, and this was evident for all constituent species (Pink-eared Duck, Australasian Shoveler and Freckled Duck) (Table 6). Diving ducks were 32% less numerous (Table 6), but the timing of the decline differed between constituent species (Figure 1), with Hardhead showing an earlier decline (becoming scarce in 2006-07). Musk Duck, Blue-billed Duck and Hardhead declined markedly in 2010–11 after the drought broke, and returned at various times subsequently (Blue-billed Duck in 2013, R.Swindley unpubl. data). Two waterfowl species that dive for food and are not ducks (Eurasian Coot, which feeds mainly on aquatic vegetation, and Australasian Grebe, which catches fish and other small animals) became far more numerous post drought than previously (Table 6).

Grebes as a guild were dominated by one very numerous inland-breeding species, the Hoary-headed Grebe (Table 6). This species and the guild as a whole showed rather little variation between the four time-periods (Table 6, Figures 2 and 3). However, there was huge variation between individual counts (Figure 2), and a mass exodus of Hoary-headed Grebes in 2010–11 after the drought broke, as well as at occasional times in earlier years.

The Black Swan appeared to be ~30% less numerous pre-EIP than in any of the three subsequent periods, suggesting a modest increase. Dabbling ducks showed little variation between the four time-periods. One of the dabbling duck species, Grey Teal, showed substantial variation between individual counts (Figure 1), but numbers of all other constituent species were relatively stable between counts, apart from seasonal changes. Two of the dabbling ducks (Pacific Black Duck and Chestnut Teal) showed their highest mean count in the last of the four time-periods.

Among the non-standard species, several showed higher mean values after the EIP than before: these included Australian Pelican, Purple Swamphen, Dusky Moorhen (very low numbers), Whiskered Tern, White-winged Black Tern and Silver Gull (Table 6). No species showed the reverse trend.

Figure 1. Numbers of waterfowl at the Western Treatment Plant 2000–12: three species of dabbling duck (Chestnut Teal, Grey Teal and Pacific Black Duck) (left side) and three species of diving duck (Hardhead, Blue-billed Duck and Musk Duck) (right side). Grey Teal, Hardhead and Blue-billed Duck are inland breeders, leaving the WTP when wetlands fill elsewhere. X-axis: 1 = Jan; 2 = Feb–Mar; 3 = Apr–Jun; 4 = Jul; 5 = Aug–Sep; 6 = Oct–Nov

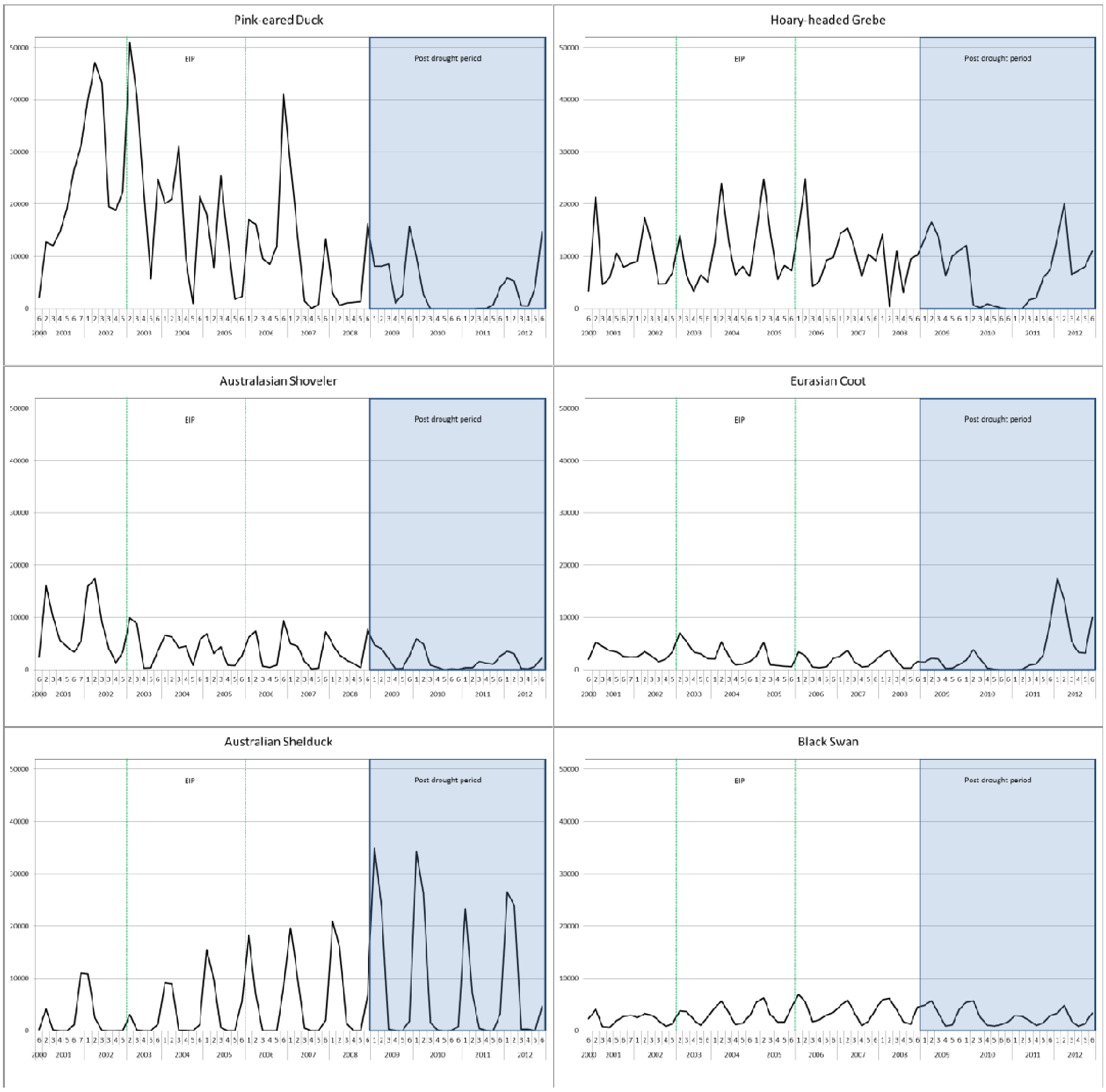


Figure 2. Numbers of waterfowl at the Western Treatment Plant 2000-2012: two species of filter-feeding duck (Pink-eared Duck and Australasian Shoveler) and one species of grazing duck (Australian Shelduck) (left side) and three other common waterfowl species (Hoary-headed Grebe, Eurasian Coot and Black Swan) (right side). Pink-eared Duck and Hoary-headed Grebe are inland breeders, leaving the WTP when wetlands fill in inland Australia. X-axis: 1 = Jan; 2 = Feb – Mar; 3 = Apr–Jun; 4 = Jul; 5 = Aug–Sep; 6 = Oct–Nov; 7 = Dec

Figure 3. Numbers of waterfowl at the Western Treatment Plant 2000–12: six waterfowl guilds (dabbling ducks, diving ducks, filter-feeding ducks, grazing ducks, grebes and total waterfowl). X-axis: 1 = Jan; 2 = Feb–Mar; 3 = Apr–Jun; 4 = Jul; 5 = Aug–Sep; 6 = Oct–Nov

Table 6. Mean counts of standard waterfowl species and guilds and selected other waterbirds (marked *) at the Western Treatment Plant in four time-periods (2000–02 pre-EIP; 2003–05 during EIP; 2006–08 post-EIP and 2009–12 post-drought). Means are based on five counts in each year (Feb-Mar, Apr-Jun, July, Aug-Sep and Oct-Nov). Counts in January (and one in December) were excluded as they were missed in some years.

Species	Pre-EIP Mean	During-EIP Mean	Post-EIP Mean	Post-drought Mean	Grand Mean	SE of Grand Mean
N (number of counts):	10	15	15	20		
Musk Duck	1010	1058	1353	694	1003	77.3
Freckled Duck	51.6	176.5	30.0	19.4	66.7	16.9
Cape Barren Goose	0.6	7.5	19.1	20.4	13.5	2.6
Black Swan	2086	3143	3144	2945	2901	221.8
Australian Shelduck	814	2662	4103	9766	5082	1212.4
Australian Wood Duck	8.3	14.5	6.3	6.8	8.8	2.3
Pink-eared Duck	21928	18487	7357	5032	11793	1671.8
Australasian Shoveler	7321	4169	2425	2370	3659	492.8
Grey Teal	4839	3479	2874	3881	3688	313.6
Chestnut Teal	3271	3132	3221	4114	3504	348.7
Pacific Black Duck	954	974	950	1048	989	94.1
Hardhead	3718	4088	1423	4856	3616	462.9
Blue-billed Duck	5557	5501	4789	1276	3924	443.0
Australasian Grebe	21.6	5.9	40.3	199.7	81.7	22.3
Hoary-headed Grebe	9568	10841	9994	7961	9457	799.8
Great Crested Grebe	4.1	74.7	81.7	25.7	48.3	15.3
Australian Pelican*	33	100	240	227	166	16.8
Brolga*	0.2	0.9	1.6	1.3	1.1	0.2
Purple Swamphen*	87	77	146	269	160	30.0
Black-tailed Native-hen*	46.8	19.8	5.7	15.9	19.5	4.8
Dusky Moorhen*	0.1	0.2	0.0	5.0	1.7	0.7
Eurasian Coot	3278	2614	1366	3703	2776	427.4
Whiskered Tern*	511	578	552	1164	756	183.2
White-winged Black Tern*	41.5	35.5	59.5	57.3	49.8	14.9
Pacific Gull*	0.7	0.6	0.5	1.5	0.9	0.2

Species	Pre-EIP Mean	During-EIP Mean	Post-EIP Mean	Post-drought Mean	Grand Mean	SE of Grand Mean
Silver Gull*	473	739	1177	2438	1371	301.0
Coots	3278	2614	1366	3703	2776	427.4
Dabbling Ducks	9064	7585	7046	9043	8183	648.3
Diving Ducks	10285	10647	7565	6827	8543	620.0
Filter-feeding Ducks	29301	22833	9811	7421	15518	2052.1
Grazing Ducks	822	2676	4110	9773	5091	1213.0
Grebes	9594	10922	10116	8187	9587	795.8
Swans	2086	3143	3144	2945	2901	221.8
Waterfowl (all standard species)	64432	60428	43177	47918	52612	4181.4

3.1.4 Distributional changes at the Western Treatment Plant

Mean counts of waterfowl (all standard species) are shown for ten combinations of sites in Appendix 1, for each of the four time-periods considered in Table 5 (pre-EIP 2000–02, during EIP 2003–05, post-EIP 2006–09 and post-drought 2010–12). The combinations of sites include treatment ponds, other wetlands and coastal habitats as shown in Table 2. The data are summarised for waterfowl collectively in Table 7. A chi-squared test for homogeneity showed the distribution between these groups of sites differed significantly between the two crucial time periods (pre-EIP vs post-EIP before the breaking of the drought) ($p<0.001$).

The upgraded new lagoons supported slightly higher proportions of the total waterfowl at the WTP during the EIP (when Activated Sludge Plants were being constructed) than in other periods (26% vs 18%, from Table 7). This suggests that industrial disturbance was not a major factor reducing use of those lagoons.

After the EIP, waterfowl as a group decreased by ~50% on the two new lagoons where Activated Sludge Plants were installed during the EIP, but increased by a similar amount on the old lagoons which then received treated effluent rather than raw sewage (Table 7). They also decreased by >50% on the decommissioned lagoons west of the Little River, including Lake Borrie. Waterfowl numbers on the tidal Spit Lagoon decreased at an earlier stage (from 2003), as grass filtration was reduced, resulting in lower effluent discharge through Murtcaim Drain close to the Spit Lagoon. Mean numbers on the unmodified new lagoon (115E) and along the coast and outlets remained stable during this time. Mean numbers at most sites declined after the drought broke in 2009–10 (Table 7), apparently holding up best on the unmodified new lagoon (115E).

The net result of these distributional changes was that mean waterfowl numbers remained high across the whole WTP (~25% less than before the EIP, before the drought broke) but waterfowl became more concentrated on the old lagoons, and less concentrated on the two upgraded new lagoons and on the decommissioned lagoons. After the EIP, the new lagoons supported 27% of the waterfowl (vs 30% before or during the EIP), the old lagoons supported 43% (vs 25%), and

Lake Borrie supported 15% (vs 30%), with 15% elsewhere as before (Table 7). These distributional percentages barely changed when the drought broke (Table 7).

Table 7. Mean counts of waterfowl (collectively) at combinations of sites within the Western Treatment Plant (see Table 2). Counts are divided into four time-periods (2000–02 pre-EIP; 2003–05 during EIP; 2006–08 post-EIP and 2009–12 post-drought). Means are based on five counts in each year (Feb–Mar, Apr–Jun, July, Aug–Sep and Oct–Nov). Counts in January (and one in December) were excluded as they were missed in some years. Further details by species and guild are given in Appendix 1.

Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Post-EIP as % of mean pre and during		
New lagoons (115E)	3408	4437	4223	4701	107.7	NS	
New lagoons (55E & 25W)	13545	15291	7325	5321	50.8	<0.01	decline
Old lagoons	15562	14423	19557	15045	130.4	<0.01	increase
Decommissioned lagoons (all)	24141	17372	7575	5975	36.5	<0.01	decline
Other (conservation ponds, natural and tidal)	7774	6712	7034	4005	97.1	NS	

Most of the individual species and guilds showed similar patterns, though the magnitude of the changes varied considerably between them (Appendix 1). Increased numbers on the old lagoons were a consistent feature across all species and guilds. Decreases on the upgraded new lagoons were observed for some species (e.g. Pink-eared Duck, Freckled Duck, Hardhead, Grey Teal and Chestnut Teal) but not others (e.g. Australasian Shoveler and Hoary-headed Grebe), and Australian Shelduck increased at both the old and new lagoons. Three species (Musk Duck, Grey Teal and Chestnut Teal) increased post-EIP on the unmodified new lagoon (115E), as well as on the old lagoons. Hardhead and Hoary-headed Grebe increased markedly on 115E post drought, after a short absence. Decreases on the decommissioned Lake Borrie were observed for filter-feeding ducks, diving ducks and swans, but not for dabbling ducks, grazing ducks or coot.

Some species increased greatly in the later part of the post-drought period (e.g. Hardhead, Australasian Grebe and Eurasian Coot), and they generally appeared to favour the old lagoons and the unmodified new lagoon (115E).

3.2 Shorebirds

3.2.1 Seasonal patterns

Shorebird abundance at the WTP varied seasonally (Figure 4). Seasonal trends were particularly obvious in trans-equatorial migrants, in which all species peak in numbers during the austral summer (Table 8); their numbers are lowest in the austral winter, when adults have migrated to their northern hemisphere breeding grounds, and only some immatures remain in Australia. The build-up of numbers was gradual in spring, with numbers peaking in late summer (coinciding well with the timing of the annual summer counts that have been maintained since 1981). The rate of decline in autumn was clearly greater, with numbers dropping from high levels in February to low levels in May; counts in April would be needed to quantify this more precisely.

There were also seasonal fluctuations in numbers of Australasian shorebirds, with total numbers showing peaks between late summer and mid-winter, and varying between species (Table 8). For example, Double-banded Plovers (migrants from breeding grounds in New Zealand) were winter visitors, the first birds arriving in late February and nearly all departing in August. Black-fronted Dotterel was another species that regularly peaked in numbers in winter. Several species showed a late summer peak when their numbers were augmented by the young of the year (e.g. Black-winged Stilt, Masked Lapwing), while others showed dramatic periodic variations that were not clearly seasonal (e.g. Banded Stilt and Red-necked Avocet).

Migratory shorebirds outnumber resident Australasian shorebirds at the WTP, so the seasonal trends for total numbers of shorebirds were similar to those for migrants only: numbers were lowest in late autumn and winter, and then gradually built up to a peak in late summer.

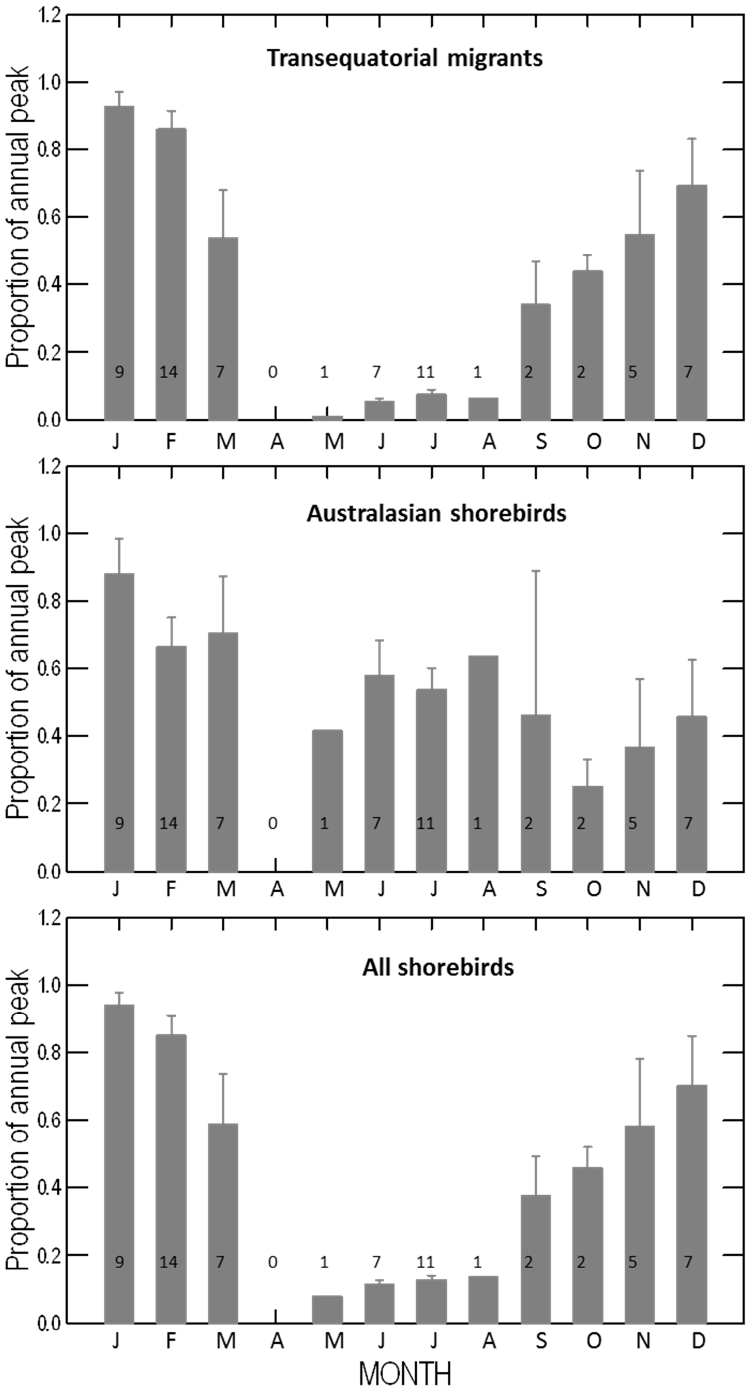


Figure 4. Monthly abundance of shorebirds at the Western Treatment Plant as a proportion of peak annual numbers, 2000–12. Bars are means, error bars depict standard errors, and the digits indicate the number of counts carried out each month.

Table 8. Mean numbers of shorebird species counted at the Western Treatment Plant in each of four seasons 2000–12 (summer = Dec–Feb, autumn = Mar–May, winter = June–Aug, spring = Sep– Nov). Species that occur infrequently at the WTP (recorded in fewer than three years of the study period) are not included. * indicates trans-equatorial migrants.

Species	summer	autumn	winter	spring
Australian Pied Oystercatcher	43	29	26	30
Black-winged Stilt	225	164	168	129
Red-necked Avocet	471	134	210	216
Banded Stilt	194	10	47	77
Pacific Golden Plover*	16	1	0	4
Grey Plover*	1	0	2	2
Red-capped Plover	34	78	87	32
Double-banded Plover	3	49	125	0
Black-fronted Dotterel	10	21	56	10
Red-kneed Dotterel	22	23	65	16
Banded Lapwing	3	4	1	7
Masked Lapwing	168	138	90	68
Latham's Snipe*	3	0	0	4
Black-tailed Godwit*	8	3	1	4
Bar-tailed Godwit*	6	3	2	7
Eastern Curlew*	3	0	1	1
Common Sandpiper*	1	0	0	1
Common Greenshank*	42	11	6	13
Marsh Sandpiper*	31	0	1	3
Wood Sandpiper*	1	1	0	0
Ruddy Turnstone*	4	1	1	4
Red Knot*	8	19	8	15
Red-necked Stint*	6162	1454	674	3976
Pectoral Sandpiper*	2	1	0	1
Sharp-tailed Sandpiper*	2295	122	2	1128
Curlew Sandpiper*	2098	248	225	873

3.2.2 Changes over the 12-year period

Counts of total shorebirds and trans-equatorial migrant shorebirds were both dominated by one migratory species, the Red-necked Stint. Summer counts of total shorebirds, migrant shorebirds and Red-necked Stint were at their highest from 2003–05, during the construction period of the EIP, and declined subsequently (Figure 5). Winter counts also declined from ~2007 (Figure 5).

Trends in numbers of Australasian shorebirds in summer (Figure 5) appeared broadly similar to those of most waterfowl (Figures 1–3): they peaked in the early years, declined when the drought broke and then increased again. In contrast, Australian shorebird numbers during winter remained reasonably stable.

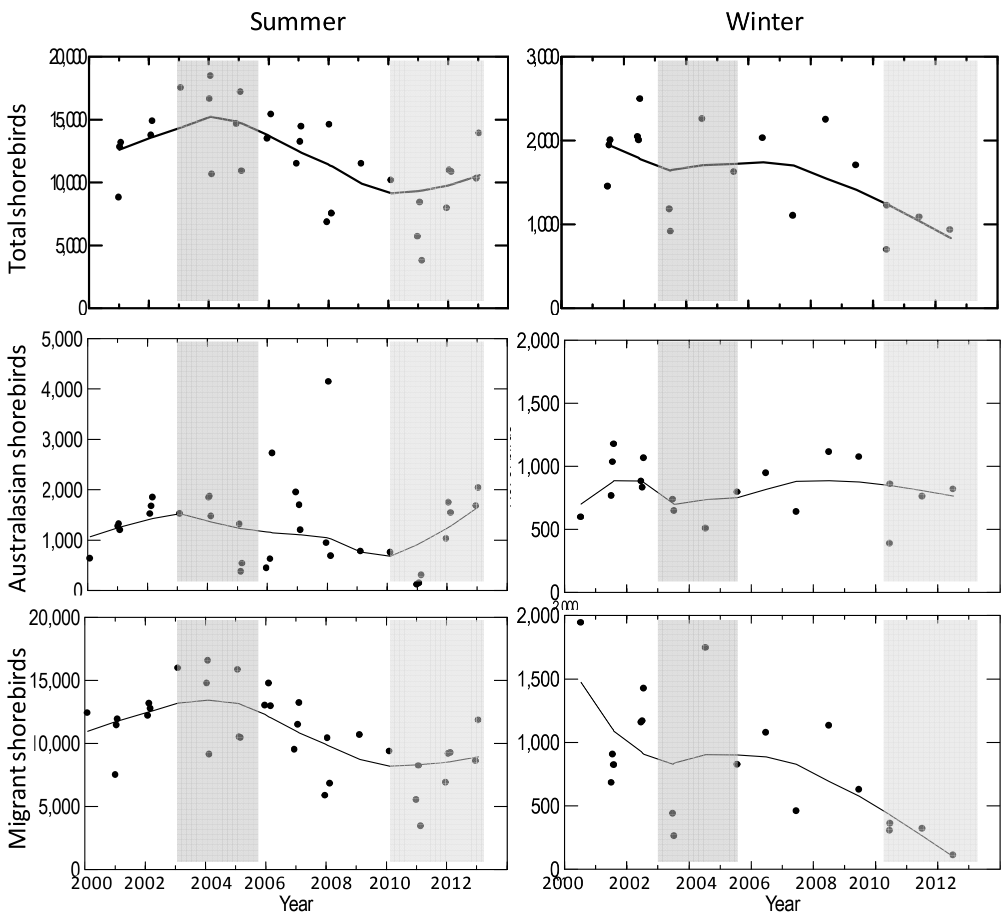


Figure 5. Summer counts (left panel) and winter counts (right panel) of all shorebirds (top), Australasian shorebirds (centre) and migrant shorebirds (bottom). The shaded grey areas depict the period of the EIP (left) and the post-drought period (right). The lines are LOWESS smoothers with a tension of 0.5.

Plots of counts against date for shorebirds that forage in both non-tidal and tidal habitats suggested similar trends to those of migrants and total shorebirds, again reflecting the proportionate abundance of the Red-necked Stint (Figure 6). Numbers of shorebirds that forage in non-tidal wetlands (referred to as inland species in Figure 6) during summer showed a decline in the post-drought period and a subsequent increase (Figure 6), as for Australasian breeding shorebirds (most of which are wetland species) and waterfowl. During winter, numbers of wetland shorebirds were high in the first two years and lower for most of the monitoring period (Figure 6). A very different pattern was shown by strictly coastal shorebirds (dominated by Pied Oystercatcher), which appeared to increase steadily in numbers during the study period, both in summer and in winter (Figure 6).

When examined at species level (Appendix 2), plots of bird numbers versus counts indicated there were interspecific differences in trends over time, though many species declined in numbers immediately post-drought and then recovered. Notable exceptions included the resident Australian Pied Oystercatcher, which has steadily increased in numbers through the entire study period; Red-kneed Dotterel and Red-capped Plover, which seem to have increased in numbers since the EIP, and Masked Lapwing, which may have declined during the construction phase of the EIP.

Results from time-series modelling are summarised in Table 9 (WTP) and 10 (Vic). SARIMA modelling was impossible for several species because there were repeated winter counts of zero. For these species we instead present results from ARIMA modelling of summer counts only (without a seasonal component). In several species, these time series analyses revealed identifiable breakpoints corresponding roughly with the breaking of the drought in 2009; most of these species (Black-winged Stilt, Red-capped Plover, Red-necked Avocet and Sharp-tailed Sandpiper) are known to occur periodically in large numbers on wetlands of inland Australia. In most other species, breakpoints could not be identified with confidence. Identified breakpoints did not correspond closely with the implementation of the EIP at the WTP.

Similar results were found when data were modelled from all main Victorian shorebird sites. In both the WTP and Victoria overall, counts of most species of migratory shorebirds seemed to be in decline during the study period (Tables 9 and 10). These declines were statistically significant at the 0.05% level for several species, while in others the apparent declines were not significant at this level, but the most strongly supported models were nevertheless those estimating negative gradients (Tables 9 and 10). Sustained increases in numbers were only found in one shorebird species, the non-migratory Australian Pied Oystercatcher.

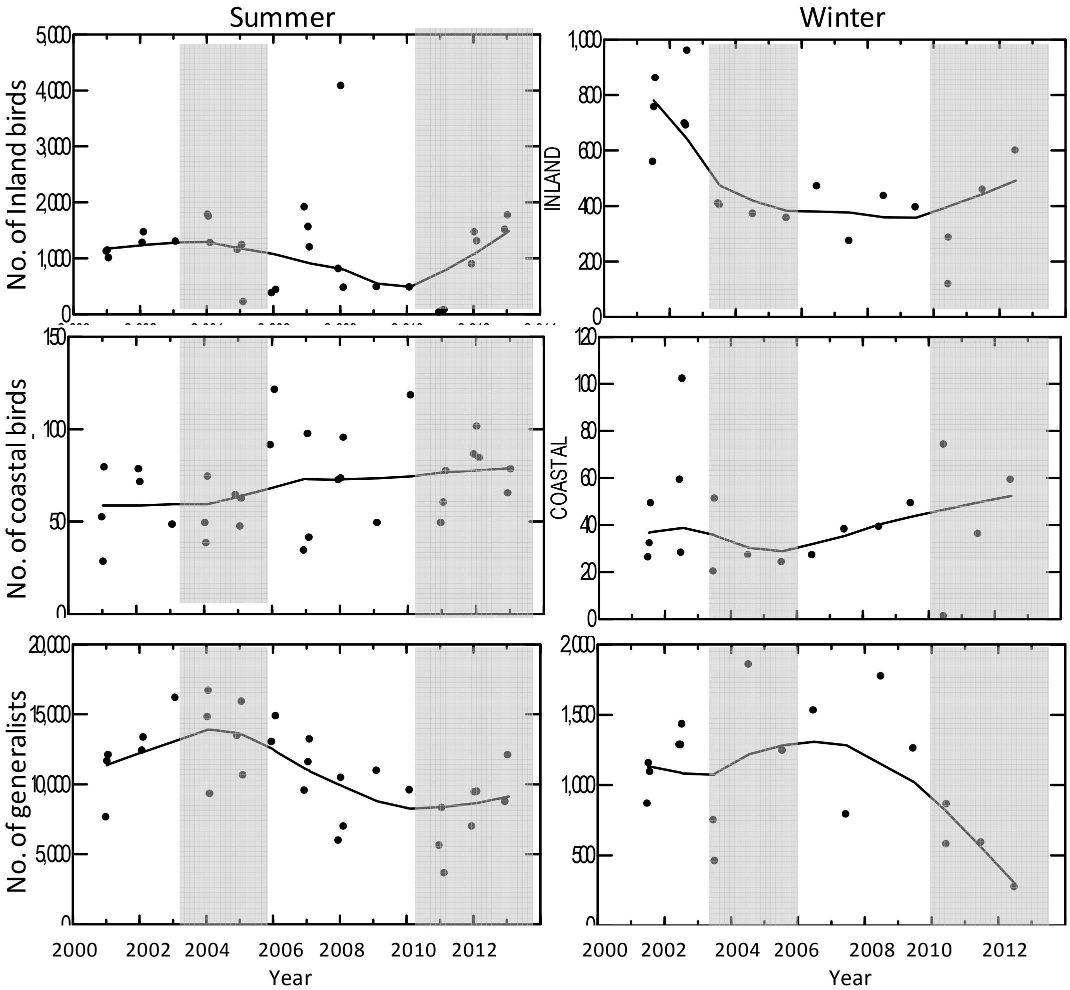


Figure 6. Summer counts (left panel) and winter counts (right panel) of inland (=wetland) shorebird species (top), coastal shorebird species (centre) and generalists (bottom). The shaded grey areas depict the period of the EIP (left) and the post-drought period (right). The lines are LOWESS smoothers with a tension of 0.5.

Table 9. Main features of time-series models for shorebirds at the Western Treatment Plant, showing the number of inflection points (according to the best supported model), the years when the trend lines changed (mean values), the gradients of trend lines for each segment of the graph (presented as % change per year) and whether they differed significantly from zero (* if p<0.05).

Species or guild	Model type	No. of inflection points	Mean years of inflection	Gradient for segment 1	Gradient for segment 2	Gradient for segment 3
Migratory shorebirds						
All migrants	SARIMA	0		–6.8%		
Common Greenshank	ARIMA	1	2011	–30.3%	107%	
Curlew Sandpiper	ARIMA	0		–17.6%		
Red-necked Stint	SARIMA	0		–12.3%		
Sharp-tailed Sandpiper	ARIMA	2	2011	–35.7%	691% *	
Australasian shorebirds						
All Australasian	SARIMA	2	2008, 2011	11.4%	–44.7% *	95.7% *
Aust. Pied Oystercatcher	ARIMA	1		6.1%		
Black-winged Stilt	SARIMA	2	2008, 2011	1.0%	–44.6% *	101.4%
Masked Lapwing	ARIMA	0		3.8%		
Red-capped Plover	SARIMA	2	2003, 2009	–21.3%	37.7% *	–23.7%
Red-necked Avocet	SARIMA	2	2006, 2008	55.3%	–97.3% *	395.3%

Table 10. Main features of time series models for shorebirds in Victorian sites overall, showing the number of inflection points (according to the best supported model), the years when the trend lines changed (mean values), the gradients of trend lines for each segment of the graph (presented as % change per year) and whether they differed significantly from zero (* if p<0.05).

Species or guild	Model type	No. of inflection points	Mean years of inflection	Gradient for segment 1	Gradient for segment 2	Gradient for segment 3
Migratory shorebirds						
All migrants	SARIMA	0		–6.8%		
Common Greenshank	SARIMA	0		–3.0% *		
Curlew Sandpiper	ARIMA	0		–18.7%		
Red-necked Stint	SARIMA	2	2004, 2006	–1.2%	–33.6% (*)	3.6%
Sharp-tailed Sandpiper	SARIMA	0		–47.1%		
Australasian shorebirds						
All Australasian	SARIMA	0		2.5%		
Aust. Pied Oystercatcher	ARIMA	0		2.8%		
Black-winged Stilt	SARIMA	2	2006, 2007	–16.3%	79% *	–17.4%
Masked Lapwing	SARIMA	0		–0.6%		
Red-capped Plover	SARIMA	2	2007, 2010	–8.9%	44.3% **	–16.5%
Red-necked Avocet	SARIMA	0		–35.6%		

3.2.3 Distributional changes at the Western Treatment Plant

Mean counts of shorebirds (all species combined) are shown for ten site combinations (regions) within the WTP (Table 11) for each of the four time-periods (pre-EIP 2000–02, during EIP 2003–05, post-EIP 2006–09 and post-drought 2010–12) in Tables 11 (high tide) and 12 (low tide).

The site combinations could be categorised as tidal habitats, as conservation ponds or other ponds (used for treatment, or with varying patterns of usage during the study period). A chi-squared test for homogeneity showed the distribution between these groups of sites differed significantly between the two crucial time periods (pre-EIP vs post-EIP before the breaking of the drought), at both high tide ($chi^2 = 1120$, d.f. = 2, $p<0.001$) and at low tide ($chi^{2 = 715}$, d.f. = 2, $p<0.001$).

In tidal habitats, the proportion of birds foraging at low tide remained reasonably consistent through most of the study period, perhaps with a recent increase (Table 12). The proportion of birds roosting at coastal sites at high tide increased during the middle of the study period (Table 11). Most noticeably, numbers of birds roosting on rocky spits north of Beach Road have increased in recent years. This increase has coincided with the establishment of nearby conservation ponds at Lake Borrie Ponds 28 and 29, and when disturbed (e.g. by birds of prey), shorebirds often move between these new sites and the adjacent coast.

Shorebirds were adept at finding new conservation ponds when they were constructed. During our study period, numbers of shorebirds increased dramatically at a number of previously unused ponds once they were converted to conservation ponds and their water levels were drawn down: these included Lake Borrie Ponds 28 and 29, 85WC Lagoon Pond 9, the Q-Section Lagoon and Western Lagoon Ponds 4 and 5.

The proportion of birds roosting and foraging at long-established conservation ponds of the WTP (the 35E conservation ponds, Austin Rd summer ponds and the T-Section Lagoon) seemingly declined after an initial peak before the EIP. Several factors were probably involved, including: (1) movement of some shorebirds to ‘new’ conservation ponds in the Lake Borrie system (Ponds 28 and 29) and at 85WC Lagoon Pond 9, and (2) low water flows at the height of the drought, resulting in shallow water and exposed wet mud in some active treatment ponds, which were used by large numbers of shorebirds at times.

Table 11: Average numbers of shorebirds in different regions of the Western Treatment Plant at high tide.

Region	Main Habitat	Pre-EIP	During EIP	Post EIP	Post-drought
Summer, high tide		n = 10	n = 12	n = 6	n = 6
Austin Rd / T- Section	conservation	2810	2583	1373	908
35 E Conservation Lagoons	conservation	2041	1207	2004	1605
Paradise Road	conservation	156	100	92	106
Lake Borrie lagoons	other ponds	126	165	276	325
Treatment ponds NE of Little R.	other ponds	181	1077	1175	388
145W to Kirk Pt	tidal	81	382	50	255
15E drain outlet to Werribee R.	tidal	43	23	5	13
Between 145W and 15E	tidal	0	17	0	9
Kirk Point	tidal	44	308	68	5
The Spits	tidal	768	1333	1180	327
Total conservation ponds	**conservation**	**5007**	**3890**	**3469**	**2619**
Total other ponds	**other ponds**	**307**	**1242**	**1451**	**713**
Total tidal	**tidal**	**812**	**1658**	**1248**	**341**
Total	**total**	**6126**	**6790**	**6168**	**3673**
Total conservation ponds as %	**conservation**	**81.7**	**57.3**	**56.2**	**71.3**
Total other ponds as %	**other ponds**	**5.0**	**18.3**	**23.5**	**19.4**
Total tidal as %	**tidal**	**13.3**	**24.4**	**20.2**	**9.3**
Total as %	**total**	**100**	**100**	**100**	**100**

Table 12: Average numbers of shorebirds in different regions of the Western Treatment Plant at low tide.

Region	Habitat	Pre-EIP	During EIP	Post EIP	Post-drought
Summer, high tide		**n = 6**	**n = 12**	**n = 6**	**n = 14**
Austin Rd / T- Section	conservation	1223	615	851	177
35 E Conservation Lagoons	conservation	514	366	931	160
Paradise Road	conservation	13	66	76	136
Lake Borrie lagoons	other ponds	16	363	61	30
Treatment ponds NE of Little R	other ponds	11	373	936	95
145W to Kirk Pt	tidal	3729	3594	1831	2001
15E drain outlet to Werribee R.	tidal	201	136	33	58
Between 145W and 15E	tidal	0	544	1062	1289
Kirk Point	tidal	2	149	159	87
The Spits	tidal	1676	1211	1007	245
Total conservation ponds	**conservation**	**1750**	**1047**	**1858**	**473**
Total other ponds	**other ponds**	**27**	**736**	**997**	**125**
Total tidal	**tidal**	**1678**	**1904**	**2228**	**1621**
Total	**total**	**3455**	**3687**	**5083**	**2219**
Total conservation ponds as %	**conservation**	**50.7**	**28.4**	**36.6**	**21.3**
Total other ponds as %	**other ponds**	**0.8**	**20.0**	**19.6**	**5.6**
Total tidal as %	**tidal**	**48.6**	**51.6**	**43.8**	**73.1**
Total as %	**total**	**100**	**100**	**100**	**100**

3.3 Ibis

Numbers of ibis feeding in paddocks at the WTP varied greatly over time with a tendency for highest numbers of Straw-necked Ibis in autumn and early winter, and of Australian White Ibis in spring-summer (Figure 7). Mean numbers of ibis recorded in paddock counts during the first and second halves of the year are shown in Table 13 for each of the time periods.

Straw-necked Ibis were generally about ten times more numerous in paddocks than Australian White Ibis, and counts exceeded 7,000 on two occasions (May 2002 and May 2005). There was a strong seasonal effect for this species, with the largest flocks in the first six months of each year ($P<0.001$) before they dispersed, presumably to local breeding sites near Geelong and on Mud Islands. From 2006 to 2009 the peak counts were lower but intermediate numbers were more consistently present (Figure 7), and differences between the four designated annual periods (Table 13) proved to be not significant ($P=0.080$). No overall interaction was found between the designated time periods and binary season ($P=0.076$), but particularly high counts were found pre EIP in the first six months of the year ($P=0.012$).

Australian White Ibis showed a much weaker (non-significant) seasonal effect ($P=0.118$), but a stronger effect of designated annual periods ($P<0.001$) and a significant interaction between these periods and binary season ($p=0.023$). These effects involved a decline over time, which was most pronounced in the first six months of the year in the second designated period (during the EIP). Most Australian White Ibis were found feeding in the north-east part of the WTP and the species became very scarce in the south-west. Supplementary observations showed that small additional numbers of Australian White Ibis were feeding at wetlands and tidal mudflats at the WTP, and larger numbers were feeding at nearby sites including the Werribee Zoo (at wetlands) and the Werribee rubbish tip where they were scavenging for waste food (M. Hulzebosch pers. comm.).

Numbers of ibis roosting at the two main roosts at the WTP (Lake Borrie Pond 9 and 25W Ponds 3, 5 and 8) also varied greatly over time (Figure 8). They were generally higher than the counts of feeding ibis (by ~25% for each species), indicating that the roosts attracted birds that had been feeding elsewhere in the region, outside the WTP.

Between 3,000 and 6,000 Straw-necked Ibis were recorded at the two roosts in 2002 and every year from 2007 to 2009 (Figure 8). Fewer Straw-necked Ibis were found at these roosts in 2010–11 but over 2,000 had returned in 2012. This pattern resembles that of many waterfowl species and certain shorebird species that declined at the WTP when the drought broke and returned subsequently.

Australian White Ibis showed a different pattern. Up to ~200 were found entering roosts from 2002–07 but numbers then dropped to <50 over the next two years. Only small numbers of Australian White Ibis roosted at Lake Borrie, with most being found at 25W Lagoon. Even larger numbers (up to ~1200) regularly used the roost at the Werribee River. Numbers increased after the drought broke (in contrast to Straw-necked Ibis) and the highest count was of 1868 birds at 25W in January 2012.

A third species, Glossy Ibis, was found mainly in wetland habitats, in very small numbers (<20). Favoured habitats included the 270S borrow pits, the Paradise Road ponds, and flooded pasture in or near the west of the WTP. They usually roosted near where they were feeding but were sometimes seen joining other roosting ibis in dead trees at Lake Borrie or 25W.

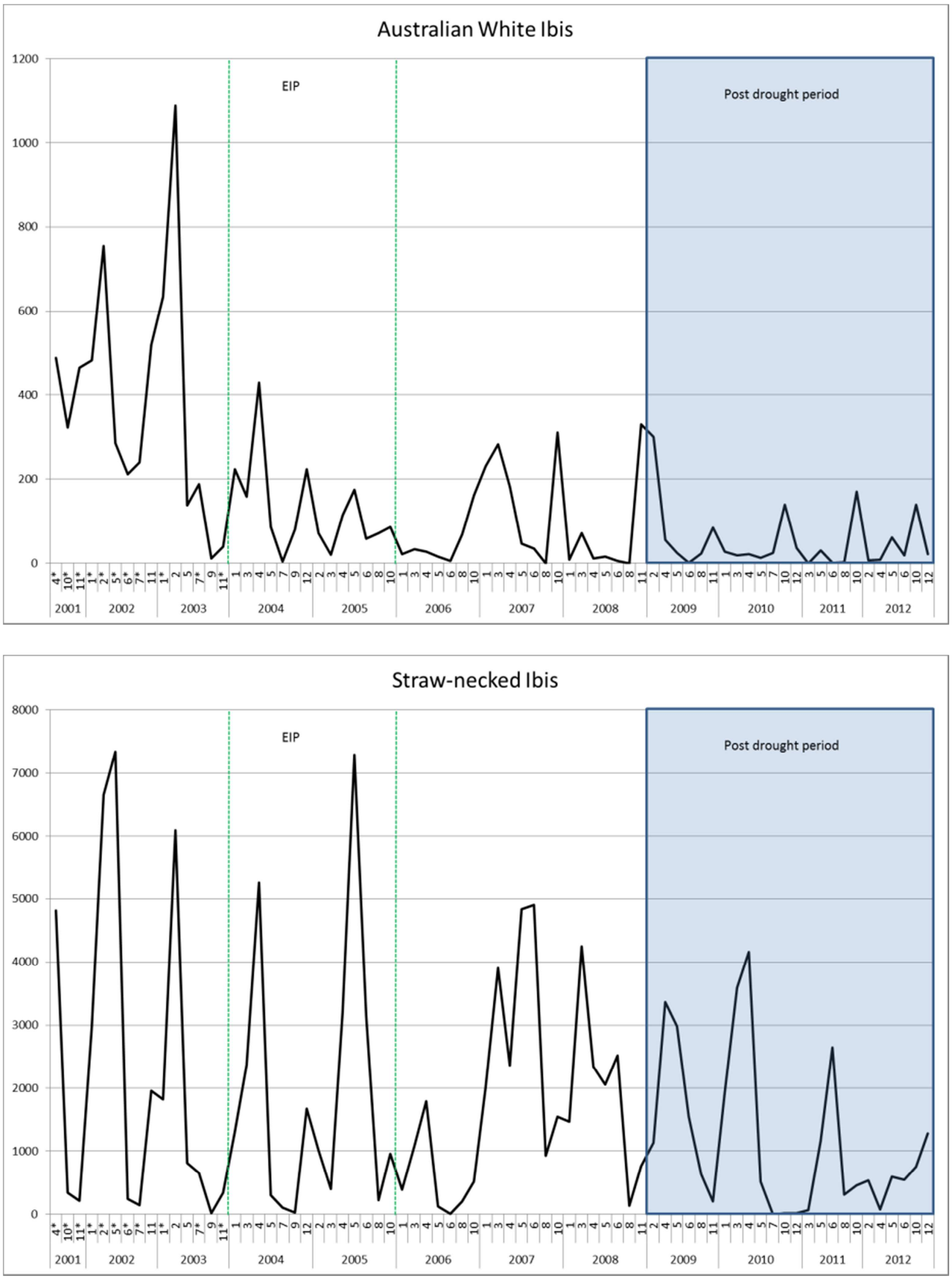


Figure 7. Total numbers of Australian White Ibis and Straw-necked Ibis recorded feeding in paddocks at the Western Treatment Plant, 2001 to 2012. Numbers on x-axis are month, * - counts were over 2 days.

Table 13. Mean counts of ibis (Australian White Ibis and Straw-necked Ibis) in paddocks at the Western Treatment Plant, 2001–12, for two seasons (Jan–June and July–Dec) and the four time periods (pre EIP 2001–02, during EIP 2003–05, post EIP 2006–08 and post-drought 2009–12).

	Yearly period:	2000-02	2003-05	2006-08	2009-12
Species	**Season**	**Pre EIP**	**During EIP**	**Post EIP**	**Post drought**
Australian White Ibis	Jan–June	440	264	65	43
Australian White Ibis	July–Dec	286	75	142	71
Straw-necked Ibis	Jan–June	4406	2753	2266	1653
Straw-necked Ibis	July–Dec	449	500	682	419

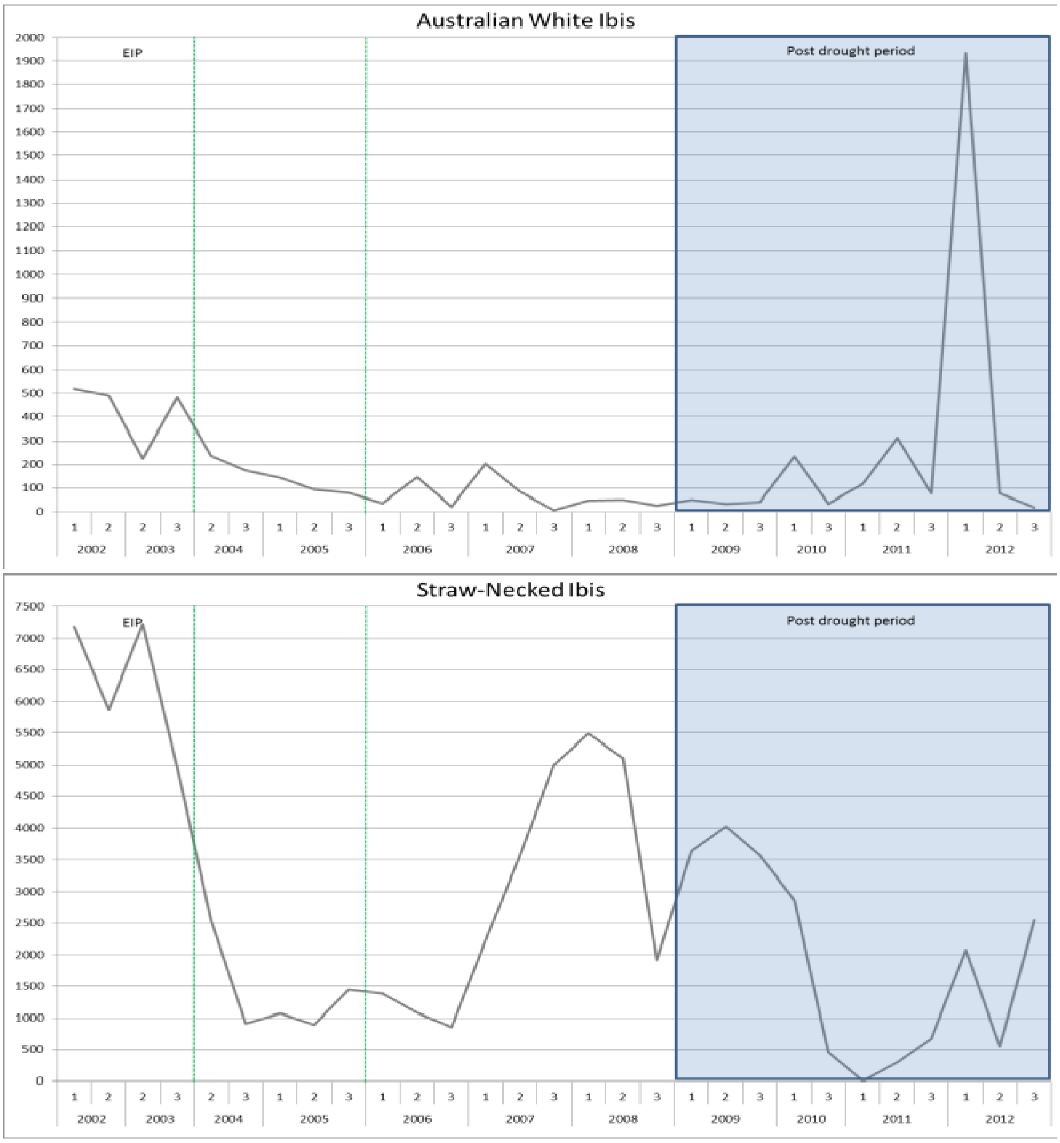


Figure 8. Total numbers of Australian White Ibis and Straw-necked Ibis roosting at the Western Treatment Plant (Lake Borrie & 25W lagoon), 2001-2012. X-axis 1 = Jan–Feb; 2 = Mar-Apr and 3 = May–Jun.

3.4 Cormorants

Four species of cormorant and one similar fish-eating bird (Australasian Darter) were found to nest regularly in dead trees at the 25W Lagoon (Table 14). A fifth species of cormorant (Black-faced Cormorant) was found to roost consistently in the same trees in small numbers (<20) from 2008, although there was no sign of nesting (and nesting would not be expected for this species at the WTP, as it generally favours exposed rocky coasts).

Pied Cormorants were by far the most numerous species (Table 14). Nesting began in January in most years, or sometimes as early as late December of the previous calendar year (2010, ahead of the 2011 season). In 2002 all nests were in trees at Pond 8 (Brett Lane and associates 2002) but increasing use was made of trees in Pond 5 in subsequent years. Trees at Pond 3 were also used from 2005 to 2010. In recent years, the first nests were usually built in trees at Pond 5, but new nests continued to be built over several weeks, typically starting in February in trees at Ponds 3 and 8. The trees at Pond 5 usually supported the most nests, and trees at Pond 8 supported the second most nests.

The number of active Pied Cormorant nests increased from 400–500 in 2002–03 to ~800 in 2004–06 before dropping to ~600 over the next three years and then increasing to ~1000 in 2010–12 (Figure 9). No decline was observed in 2005 when the Activated Sludge Plant was built on the 25W Lagoon. The colonisation of trees at Pond 3 in that year was associated with a small decrease at Pond 3 (from 400 to 312 active nests) but little change at Pond 5 where 360 active nests were found (compared with 370 the previous year).

Table 14. Mean numbers of active nests and adult cormorants observed in the breeding colony of cormorants at 25W Lagoon in the Western Treatment Plant in four time periods, 2002–12.

	pre EIP#	during EIP	post EIP	post drought	SE	Max	Year of max
Years:	**2002#**	**2003–05**	**2006–08**	**2009–12**			
Active nests							
Pied Cormorant	462	604	698	866	62.2	1033	2010
Little Pied Cormorant	0	56	31	28	5.7	97	2004
Great Cormorant	0	3	10	4	1.2	12	2006
Little Black Cormorant	0	68	55	14	22.3	237	2005
Australasian Darter	0	11	21	9	2.2	23	2006
Max counts (eg at roost)							
Pied Cormorant	906	979	1093	1060	99.8	1300	2011
Little Pied Cormorant	52	122	74	55	10.7	220	2004
Black-faced Cormorant	0	0	4	12	1.9	15	2012
Great Cormorant	10	17	28	41	7.4	94	2012
Little Black Cormorant	222	508	306	589	100.3	1160	2012
Australasian Darter *	1	12	15	14	2.2	24	2012

data for 2002 are from Brett Lane and Associates 2002.
* Australasian Darters often arrived late at roosts, flying singly and low in the dusk, and numbers may have been under-estimated.

Peak numbers of active nests were found in February or March each year at Ponds 5 and 3, and a little later at Pond 8 (mainly late March or April, occasionally as late as early July). Most nests had finished by June or July but very small numbers continued to be active in subsequent months in some years. Nesting at Pond 5 had finished in May in 2005, but continued into July at Pond 8. The other cormorant species showed different seasonal patterns, e.g. Little Pied Cormorants began breeding in spring. No clear trends were evident for other species. Large numbers of Little Black Cormorants were found nesting in 2005 (237 nests) and 2006 (131 nests), with many fewer in other years (Table 14).

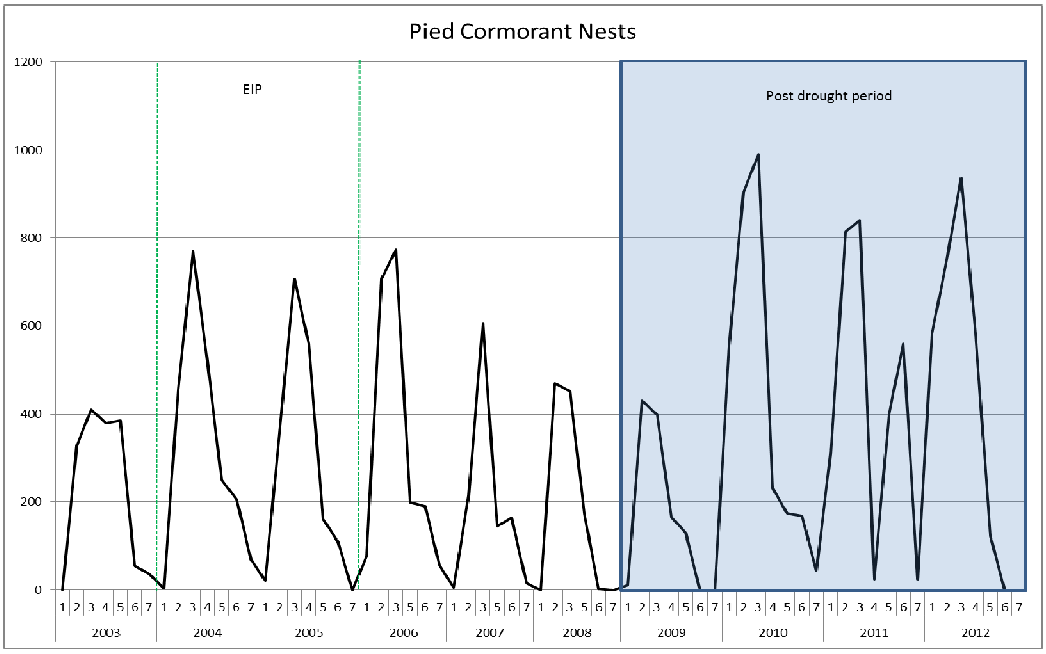


Figure 9. Numbers of active Pied Cormorant nests at the 25W Lagoon (Pond 3, 5 & 8) of the Western Treatment Plant, 2000-2012. X-axis: 1 = Jan; 2 = Feb; 3 = Mar; 4 = Apr; 5 = May-Jun; 6 = Jul-Aug; and 7 = Dec.

3.5 Freshwater Terns

Both Australian species of freshwater tern occurred regularly at the WTP: the Whiskered Tern (which breeds in inland Australia) and the less common White-winged Black Tern (a trans-equatorial migrant that breeds in central Asia). Both were found feeding mainly over wetlands where they took insects such as midges and mayflies from the water surface (Figure 10) and from tall vegetation on the banks. Flocks often gathered to rest in vegetated wetlands, especially the 35E conservation ponds and the 270S borrow pits, the 85WC Lagoon Pond 9 (after it was converted to a conservation pond), among dead trees at Lake Borrie Pond 9 and among rocks at the Austin Road summer ponds. Flocks occasionally fed over coasts and estuaries and sometimes rested on tidal mudflats. Flocks of Whiskered Terns sometimes foraged over grasslands, usually where there was tall vegetation or irrigation water. Birds feeding in grassland constituted only 3.8% of records (on nine dates) and all were found at times when the species was also numerous over treatment ponds (Table 15). Birds in treatment ponds and other wetland habitats were all counted as part of the waterfowl counts, albeit with less precision than for waterfowl because flocks were highly mobile, feeding on the wing and moving readily between wetlands.

Whiskered Terns were numerous from October to January in most years and scarce at other times (Figure 11). Few juveniles were observed and there was no evidence of local breeding. The species failed to appear in 2010–11 after the drought had broken but returned in large numbers in subsequent years (as for inland-breeding waterfowl and some shorebirds). The highest counts over treatment ponds and other wetlands were of 5400 in November 2008, 4400 in January 2009 and 4000 in November 2007. The highest counts over grasslands were of 416 in October 2001 and 430 in November 2008 (P. Macak unpubl. data). Mean numbers were higher post EIP (towards the end of the drought) than at other times.

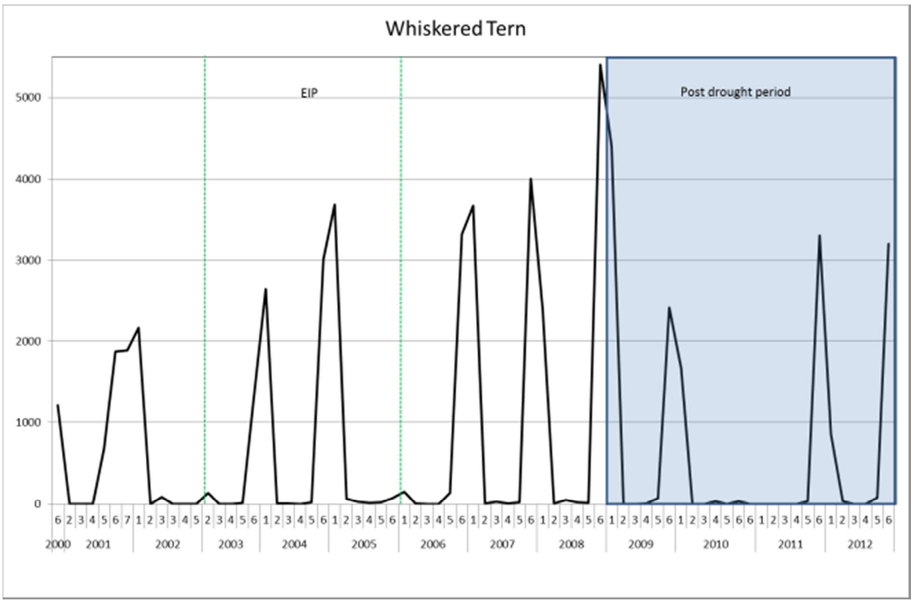
White-winged Black Terns were less numerous and showed a different seasonal pattern, with few seen in spring and the main arrival occurring in late December or early January (Figure 11). Numbers then remained high into April or May (Table 14); these birds often attained breeding plumage and a few sometimes stayed as late as June. They were not seen foraging over grasslands except in close association with adjacent wetlands.

Neither species showed strong changes in numbers associated with implementation of the EIP.

Table 15. Mean numbers of freshwater terns counted in or near wetlands at the Western Treatment Plant during waterfowl counts, in four time periods 2000–12.

Species		Pre EIP	During EIP	Post EIP	Post drought	Grand
	Years:	2000–02	2003–05	2006–08	2009–12	
	Season					
Whiskered Tern	Mean	609	651	1069	647	745
Whiskered Tern	SE	239.0	298.5	423.3	256.3	157.2
White-winged Black Tern	Mean	23.5	18.5	17.3	12.7	17.1
White-winged Black Tern	SE	11.8	7.3	8.4	3.4	3.5

Figure 10. Whiskered Tern, WTP November 2008. Leg flag applied by the Victorian Wader Study Group to investigate movement patterns, Photographer Peter Menkhorst



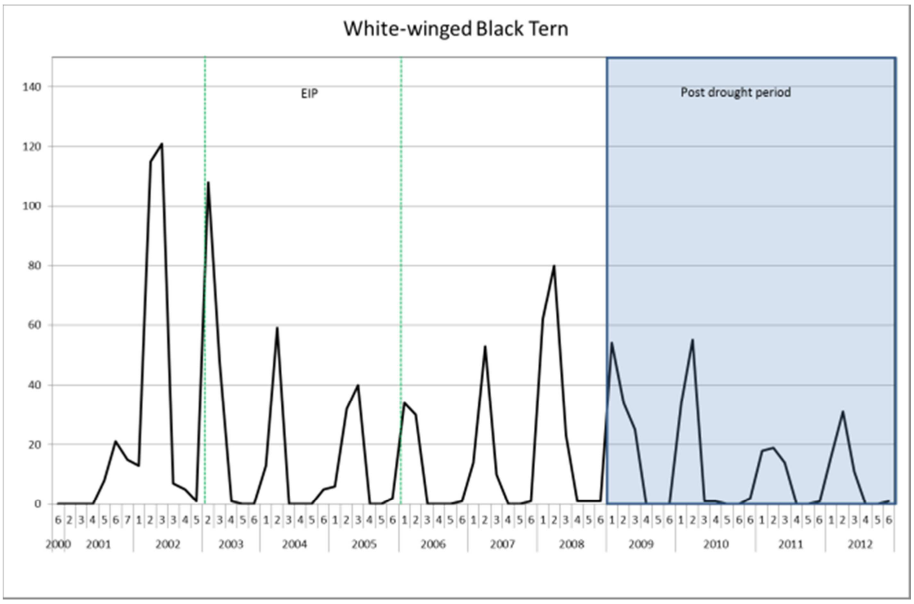


Figure 11. Numbers of Whiskered Tern and White-winged Black Tern at the Western Treatment Plant. 2000-2012. X-axis: 1 = Jan; 2 = Feb–Mar; 3 = Apr–Jun; 4 = Jul; 5 = Aug–Sep; 6 = Oct–Nov; 7 = Dec.

4 Discussion

4.1 Waterfowl

The results show a dominant effect of climatic conditions on waterfowl numbers – the lack of inflection points in the SARIMA models that coincided with the EIP provides strong evidence that the EIP did not have a dominant impact on waterfowl numbers using the WTP. The observed redistribution of waterfowl at the WTP was probably a consequence of the EIP, but the positive effects (on the old lagoons) helped counteract the negative effects (on the decommissioned lagoons and the new lagoons where Activated Sludge Plants were installed).

The impact of climate became most evident when the drought broke in ~2009. It is rarely possible to give exact dates for the start and finish of a complex environmental condition such a drought, as dry periods are punctuated by rainfall events of varying intensity. This is especially difficult when considering a vast area such as eastern Australia, where rainfall patterns vary greatly between regions. There may be long time lags (several months) between water falling in one place and arriving at another where it provides useful habitat for waterbirds. Much of eastern Australia became progressively drier from about 1997, and the usual amount of winter–spring rain did not return to the south-east until 2009–10. However, heavy rains fell in parts of northern and inland Australia from 2008, and some of the water flowed inland to fill ephemeral wetlands in subsequent years. By the end of 2009 significant rain had fallen over much of eastern Australia, and wet conditions prevailed over the following three years. By 2010 it was obvious that the drought had broken.

Following the breaking of the drought numbers of many waterfowl species plummeted to record low levels in 2010–11. The usual summer–autumn seasonal peaks failed to materialise, especially for inland-breeding species such as Hoary-headed Grebe, Grey Teal, Pink-eared Duck and Hardhead. It is highly likely that they left to breed at ephemeral wetlands in inland Australia, where habitat had just become available after the long drought. Lesser short-term declines were observed in some locally breeding species, suggesting that some of these birds may also have moved to breed in newly filled, ephemeral wetlands in south-eastern Australia or beyond. Numbers of all these species increased again in subsequent years, presumably in response to successful breeding and perhaps also to summer drying of some of the unknown wetlands where they bred. Variations between species in the extent and timing of these fluctuations may reflect their favoured destinations. Hardhead are known to move further north in Australia than many species (Marchant and Higgins 1990), and their scarcity in the late 2000s may have reflected availability of habitat in northern Australia after tropical rains before the drought broke in the south. The record influxes of Eurasian Coot and Australasian Grebe to the WTP in 2011–12 may have been a product of successful breeding in wetlands within Victoria, and subsequent dispersal to local sites including the WTP.

Data from the annual Victorian Summer Waterfowl Count did not show such a clear pattern when the drought ended (Purdey and Loyn 2010, 2011). Many wetlands in northern and western Victoria had been dry for several years, and attracted large numbers of waterfowl when they refilled; clearly they were part of the magnet that attracted waterfowl away from the WTP. During the drought the WTP came to support increasingly high proportions of waterfowl observed on the Summer Waterfowl Counts, reaching a maximum of 70% in 2008. On aerial surveys in late 2008 ~70% of the waterfowl counted in Victoria were at the WTP (R. Kingsford pers. comm.). We suspect that many birds are missed from both the Summer Waterfowl Count and the aerial surveys, when wetlands are not counted or not easily visible from the air. However, the data suggest that the WTP maintained its value as waterfowl habitat to a much greater extent than natural wetlands during the drought, and this is entirely credible as the WTP receives a reliable supply of water from Melbourne's sewage system.

The consistency of seasonal patterns during the drought at the WTP deserves some comment, as it suggests that waterfowl were able to find alternative habitat somewhere in Australia in the seasons when they are in lowest numbers at the WTP. This was usually in spring, the main breeding season for most of these birds. Some ephemeral wetlands fill with spring rains and snow-melt during spring, but during the drought there would be much less natural habitat than at other times. It would be of interest to know where the birds went when they left the WTP during drought, and whether they attempted to breed there. Of course, it would also be of interest to know where they went when the drought broke. Previous studies elsewhere (e.g. Frith 1987; Marchant and Higgins 1990; Kingsford et al. 2002) suggest that breeding would have been far more successful in the latter case than the former, and this is reflected in the longer periods of absence from the WTP.

The species that appeared to decline in the first ten years of the study are inland-breeding birds, and it would be expected that their populations could decline nationally during a long period of drought when few breeding opportunities became available to them. Two of the guilds (diving ducks and filter-feeding ducks) had been predicted to be adversely affected by the EIP (Loyn et al. 2002a). However, their numbers varied greatly between years, and time-series models showed that the declining trends were not significant and did not coincide with implementation of the EIP. The most parsimonious explanation for the patterns observed for these species is that they were responding mainly to effects of drought and rainfall at a continental scale.

Conservation ponds have been managed mainly for shorebirds and frogs: some other waterbirds have benefited (e.g. Purple Swamphen, Whiskered Tern) but the conservation ponds only support a small proportion of the total waterfowl at WTP: treatment lagoons are the main habitat used by waterfowl, and management of the treatment ponds remains the main factor that makes the WTP attractive and important for large numbers of waterfowl when climatic conditions are suitable (i.e. when there is not abundant water elsewhere in Australia).

4.2 Shorebirds

The results show strong seasonal patterns for migratory species (as expected) and also for many Australasian breeding species. The picture was given further complexity by a strong response to continental rainfall patterns. This involved numbers of some species declining markedly when the drought broke in about 2009, and recovering in subsequent years, in much the same way as inland-breeding waterfowl (see above). This pattern was observed most strongly in two Australasian breeding species (Red-necked Avocet and Black-winged Silt) and presumably involved similar mechanisms, with birds leaving the WTP to breed in ephemeral inland wetlands when they filled with fresh water (Higgins and Davies 1996). The pattern was also observed in at least one trans-equatorial migratory species, the Sharp-tailed Sandpiper, which was extremely rare at the WTP in 2010–11 when there was plenty of water in inland Australia. This case does not involve breeding because the species breeds exclusively in Arctic tundras of Siberia (Higgins and Davies 1996), but it seems to indicate a preference for inland wetlands during the non-breeding season when the species visits Australia. In general, species known to make extensive use of inland wetlands, both migratory (e.g. Marsh Sandpiper) and non-migratory (e.g. Banded Stilt), showed extensive year-to-year variation in numbers at the WTP. As a result the count data were not conducive to modelling, and long-term population trends in these species remain poorly understood.

SARIMA modelling identified changes in trend for a few other migratory species but none coincided clearly with the implementation of the EIP. Rather, they coincided well with changes in trend line apparent from analysis of shorebird data for the whole of Victoria. The other Victorian sites are effectively independent of the WTP – and banding studies have confirmed that birds from

Western Port, Corner Inlet and sites around Swan Bay are highly site-faithful (VWSG, unpublished data). If, as seems likely, there is a common cause for the correspondence of WTP and other Victorian counts, then it is likely to occur on the breeding grounds or staging sites in East Asia which are used by all Victoria's migratory shorebirds. Over the whole 12 years, most species showed a declining trend at the WTP and a similar trend for the whole of Victoria (D. Rogers unpubl. Data). Similar declines have been reported for Western Port (Hansen et al. 2011, in press), Corner Inlet (Minton et al. 2012) and for broader areas in Australia (Wilson et al. 2011) and the flyway (Amano et al. 2010).

In general, Australasian breeding species did not show such marked declines at the WTP. The Australian Pied Oystercatcher showed an increasing trend at the WTP, and similar increases have been observed in Western Port which is a known stronghold for the species (Dann et al. 1994; Hansen et al. 2011, in press). Apparent increases in Red-kneed Dotterel and Red-capped Plover at the WTP since the EIP may have been related to the development of new conservation ponds. Masked Lapwing may have declined during the construction phase of the EIP (perhaps in association with phasing out of grass filtration).

Within the WTP, shorebird numbers at specific feeding and roosting sites were dynamic, changing rapidly in response to local conditions. Local shorebird distribution on the tidal flats adjacent to the WTP has been the focus of detailed studies (Rogers et al. 2007, 2013) and is largely driven by prey abundance and tide conditions. Local shorebird distribution on the non-tidal ponds has not been studied in such detail, however, our monitoring has demonstrated that shorebirds have readily located and used 'new' conservation ponds constructed by Melbourne Water, highlighting the important role that pond management has played in increasing the conservation value of the WTP to shorebirds.

4.3 Ibis

Numbers of Straw-necked Ibis fluctuated with no obvious pattern except for a decline with the breaking of the drought in a similar manner to inland-breeding waterfowl, despite the fact that a large breeding colony exists nearby at Mud Islands (Menkhorst 2010). Similar responses have been observed in other coastal locations such as Western Port (Loyn et al. 1994; Hansen et al. 2011). Australian White Ibis showed a declining trend early in the monitoring period, coinciding with implementation of the EIP when grass filtration was discontinued in the south-west part of the WTP. The species became scarce in that area, and it is plausible that the two events were causally related. However, the species does much of its feeding round wetlands rather than in grasslands, and also scavenges at local rubbish tips. Numbers increased post-drought, presumably reflecting the improved local conditions.

Ibis are recognised as an important contributor to the ecological character of the Ramsar site (Hale 2010). They have declined at the WTP since 50,000 were recorded there in the 1970s (Macak et al. 2002) and maximum counts in recent years have been 4000-5000. However, both Australian White and Straw-necked Ibis are common in eastern Australia, and have increased in historical times because they make use of cleared farmland, artificial wetlands and rubbish tips (Marchant and Higgins 1990). They may play an important and positive ecological role at the WTP and more broadly in the region. But, with current numbers, the WTP cannot be said to be of major importance for the conservation of these ibis. From a conservation viewpoint, meeting the needs of ibis at the WTP is a worthwhile aim but does not deserve as high a priority as the conservation of other groups such as waterfowl, shorebirds, breeding cormorants and the Orange-bellied Parrot.

4.4 Cormorants (breeding)

The nesting colony of cormorants at the 25W Lagoon is probably the most diverse nesting colony of cormorants in the world, as few others, if any, support more than two or three species on a regular basis (del Hoyo et al. 1992). The gradual increase over time, and lack of a decline in 2005, suggest that construction activities associated with the EIP had no adverse effects on the nesting colony. No conclusions can be made about breeding success because this proved impractical to measure. However, any impacts were clearly temporary (if they happened at all) as the colony continues to thrive. Variation between years may be related to fish stocks in Port Phillip where these cormorants feed.

The extent of the colony has expanded during the study. In 2002 Pied Cormorants only nested in trees at 25W Pond 8, though other species were known to nest in trees at Pond 5 (Brett Lane and associates 2002; R.Swindley pers.obs.). In recent years trees have been used at all three Ponds (Ponds 3, 5 and 8).These changes may be due to a range of factors including the suitability of the dead trees as they shed branches, competition from the dominant large cormorant species (especially Pied Cormorant), and proximity to marine waters where the birds feed (Pond 8 is closest and Pond 3 is furthest). It is always a challenge for land managers to maintain a habitat resource such as dead trees, where deterioration over time is inevitable and replacement problematic at any given site.

4.5 Freshwater Terns

Both species of freshwater tern continued to use wetlands at the WTP in substantial numbers through the monitoring period, and showed no clear response to the EIP. The highest counts of Whiskered Tern were made post EIP towards the end of the drought. Variations in seasonal or annual pattern were probably related to availability of water at inland swamps, as for inland-breeding waterfowl and some shorebirds. The failure of Whiskered Terns to arrive in 2010–11 was a close parallel to a shorebird species (Sharp-tailed Sandpiper) that has a similar preference for vegetated ephemeral wetlands (Higgins and Davies 1996), despite the different use that each species makes of those wetlands (breeding habitat for the tern and non-breeding for the sandpiper).

The mid-summer (January) departures of Whiskered Terns are unique among waterbirds visiting the WTP, and could imply a later breeding season than for other waterbird species (which usually show their minimum seasonal numbers in spring). This is plausible as the terns typically breed among aquatic vegetation (Higgins and Davies 1996), and may need water levels to subside to reveal suitable sites at ephemeral inland wetlands. White-winged Black Terns do not breed in Australia and hence would not be affected by these variables, hence their markedly different seasonal response. It is remarkable that they often remain at the WTP into May or June, as that is the time of year when they would be expected to begin nesting in central Asia, where eggs are generally laid in early June after two weeks of nest site selection (Cramp 1985). This suggests a very rapid northward migration by some of these birds.

Whiskered Terns were found making substantial use of conservation ponds and have undoubtedly benefited from construction and management of these wetlands, as well as from the food supplies provided by the sewage treatment ponds. Whiskered Terns were also found feeding over grasslands on an occasional basis, but these records constituted a small proportion (<4%) of all observations at the WTP.

5 General conclusions

The EIP did not appear to be a major driver of waterbird numbers at the WTP. Two common species that feed in grasslands (Australian White Ibis and Masked Lapwing) declined early in the period, especially in the south-west of the WTP, and may have been affected adversely by termination of the grass filtration process. Some marked changes in distribution of waterfowl accorded with predictions about likely effects of the EIP, with the old lagoons becoming the most important habitat and the decommissioned lagoons such as Lake Borrie becoming less important than previously. Some waterfowl and shorebirds declined gradually during the drought but these changes did not coincide clearly with implementation of the EIP. Changes in numbers of trans-equatorial migratory shorebirds paralleled those observed elsewhere in Victoria and more widely in the East Asian-Australasian flyway, suggesting a common cause unrelated to management of the WTP. No evidence was found that breeding cormorants were disturbed by construction activities at the 25W Lagoon.

The results show that seasonal and climatic events were dominant drivers of waterbird numbers at the WTP. In particular, there was a mass exodus of many species in 2010–11 after the drought broke, followed by a return in subsequent years. Different species left at different times: this may reflect variations in timing of rainfall events in different parts of Australia (some of which experienced high rainfall as early as 2007–08). Different species returned at different times and in varying numbers: many species reached their highest levels in the last two years of the period under review. The pattern of exodus in ~2009 and subsequent recovery was particularly marked for inland-breeding waterfowl, some shorebirds that breed in inland Australia (notably Red-necked Avocet and Black-winged Stilt) or have a preference for inland ephemeral swamps as non-breeding habitat (Sharp-tailed Sandpiper), and other species that also breed at ephemeral inland sites (e.g. Straw-necked Ibis and Whiskered Tern).

In terms of the three hypothetical scenarios, the role of climatic events (scenario 2) was the only one to be strongly supported by this study. The breaking of the drought had much greater impact than any effects of the EIP (scenario 1) or disturbance during construction (scenario 3).

References

Amano, T., Székely, T., Koyama, K., Amano, H. and Sutherland, W. J. (2010) A framework for monitoring the status of populations: an example from wader populations in the East Asian–Australasian flyway. *Biological Conservation* **143**, 2238-2247

Brida, J. G. and Garrido, N. (2009) Tourism Forecasting using SARIMA Models in Chilenean Regions. Retrieved from http://papers.ssrn.com/abstract=1457984

Brett Lane and associates (2002) Investigation of cormorant breeding and roosting ctivities at the Western Treatment Plant. Report for Melbourne Water Corporation

Burnham, K. P. and Anderson, D. R. (2002) *Model selection and multimodel inference: A practical information-theoretic approach* (2nd ed.) New York: Springer-Verlag

Chatfield, C. (2001) *Time-Series Forecasting*. Chapman and Hall, Boca Raton

Chambers, L. and Loyn, R.H. (2006) The influence of climate on numbers of three waterbird species in Western Port, Victoria, 1973–2002. *Journal of International Biometeorology* **50**, 292-304

Cramp, S. (ed.) (1985) *Handbook of the Birds of Europe, the Middle East and North Africa. Vol. 4. Terns to Woodpeckers.* Oxford University Press, Oxford

Dann, P., Loyn, R.H. and Bingham, P. (1994) Ten years of waterbird counts in Western Port, Victoria, 1973–83: II. Waders, Gulls and Terns. *Aust. Bird Watcher* **15**, 351–365

del Hoyo, J., Elliott, A. and Sargatal, J. (eds.) (1992) *Handbook of the Birds of the World. Vol. 1.* Lynx Edicons, Barcelona

Frith, H.J. (1987) *Waterfowl in Australia. 3rd edition*. Angus & Robertson, Sydney

Hale, J. (2010) Ecological Character Description of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site. A Report to the Department of Environment, Water, Heritage and the Arts, Canberra

Hansen, B., Menkhorst, P. and Loyn, R. (2011) Western Port Welcomes Waterbirds: waterbird usage of Western Port. Arthur Rylah Institute for Environmental Research Technical Report Series No. 222. Department of Sustainability and Environment, Heidelberg, Victoria

Hansen, B.D., Menkhorst, P., Moloney, P. and Loyn, R.H. (in press) Long-term waterbird monitoring in Western Port, Victoria, reveals significant declines in multiple species. *Austral Ecology*.

Higgins, P.J. and Davies, S.J.J.F. (eds.) (1996) *Handbook of Australian, New Zealand and Antarctic birds. Vol. 3. Snipe to pigeons*. Oxford University Press, Melbourne

Kingsford, R.T., Wong, P.S., Braithwaite, L.W. and Maher, M.T. (1999) Waterbird abundance in eastern Australia. *Wildlife Research* **26**, 351–366

Kingsford, R.T. and Norman, F.I. (2002) Australian waterbirds–products of the continent's ecology. *Emu* **102**, 47 –69. doi:10.1071/MU01030

Lane and Associates Pty Ltd. (2002). Investigation of Cormorant Breeding and Roosting Activities at the Western Treatment Plant. Report to Melbourne Water Corporation. Report No. 2001.46C(2.2)

Lane, B.A. and Peake, P. (1990) Nature Conservation at the Werribee Treatment Complex. Environment Series. No. 91/008 (Board of Works, Melbourne)

Loyn, R.H., Dann, P. and Bingham, P. (1994) Ten years of waterbird counts in Western Port, Victoria. 1. Waterfowl and large wading birds. *Australian Bird Watcher* **15**, 333–350

Loyn, R.H., Norman, F.I., Swindley, R.J. and Saunders, K. (2001) Observer variation in counts of waterfowl at the Western Treatment Plant. Unpublished report to Melbourne Water Corporation. Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria

Loyn, R.H., Schreiber, E.S.G., Swindley, R.J., Saunders, K. and Lane, B.A. (2002a) Use of sewage treatment lagoons by waterfowl at the Western Treatment Plant –an overview. Report for Melbourne Water Corporation. Arthur Rylah Institute in association with Brett Lane and Associates Pty Ltd and Water ECOscience

Loyn, R.H., Lane, B.A., Tonkinson, D., Berry, L., Hulzebosch, M. and Swindley, R.J. (2002b) Shorebird use of managed habitats at the Western Treatment Plant. Report for Melbourne Water Corporation. Arthur Rylah Institute in association with Brett Lane and Associates Pty Ltd.

Loyn, R.H., Swindley, R.J., Hulzebosch, M. and Lane, B.A. (2002c) Study of ibis roosting at the Western Treatment Plant, Werribee. Report for Melbourne Water Corporation. Arthur Rylah Institute in association with Brett Lane and Associates Pty Ltd.

Loyn, R.H., Macak, P., Gormley, A. and McCormick, P. (2008) Requirements for land and water by ibis at the Western Treatment Plant. Unpublished report to Melbourne Water Corporation. Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria

Macak, P., Loyn, R.H. and Lane, B.A. (2002) Investigation into use of filtration paddocks by ibis and other waterbirds at the Western Treatment Plant. Report for Melbourne Water Corporation. Arthur Rylah Institute in association with Brett Lane and Associates Pty Ltd.

Maamar, S. (2013). ANN versus SARIMA models in forecasting residential water consumption in Tunisia. *Journal of Water, Sanitation and Hygiene for Development*. doi:doi:10.2166/washdev.2013.031

Marchant, S. and Higgins, P.J. (eds.) (1990) *Handbook of Australian, New Zealand and Antarctic birds. Vol. 1. Ratites to ducks*. Oxford University Press, Melbourne

Marchant, S. and Higgins, P.J. (eds.) (1993) *Handbook of Australian, New Zealand and Antarctic birds. Vol. 2. Raptors to lapwings*. Oxford University Press, Melbourne

Martinez, E.Z., da Silva, E.A.S., and Fabbro, A.L.D. (2011) A SARIMA forecasting model to predict the number of cases of dengue in Campinas, State of São Paulo, Brazil. *Revista da Sociedade Brasileira de Medicina Tropical*, **44**, 436–440. doi:10.1590/S0037-86822011000400007

Menkhorst, P. (2010) A survey of colonially-breeding birds on Mud Islands, Port Phillip, Victoria; with an annotated list of all terrestrial vertebrates. Arthur Rylah Institute for Environmental Research Technical Report Series No. 206

Minton, C., Dann, P., Ewing, A., Taylor, S., Jessop, R., Anton, P. and Clemens, R. (2012) Trends of shorebirds in Corner Inlet, Victoria, 1982–2011. *Stilt* **61**, 3–18

Prista, N., Diawara, N., Costa, M. J. and Jones, C. (2011) Use of SARIMA models to assess data-poor fisheries: a case study with a sciaenid fishery off Portugal. *Fishery Bulletin*. Retrieved from http://aquaticcommons.org/8715/1/prista_Fish_Bull_2011.pdf

Purdey, D. and Loyn, R.H. (2010) The 2010 summer waterbird count in Victoria. Unpublished report to Department of Sustainability and Environment. Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria

Purdey, D. and Loyn, R.H. (2011) The 2011 summer waterbird count in Victoria. Arthur Rylah Institute for Environmental Research Technical Report Series No. 231

R Development Core Team. (2012) R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.r-project.org

Rogers, D.I., Loyn, R., McKay S., Bryant D., Swindley, R. and Papas, P. (2007) Relationships between Shorebird and Benthos Distribution at the Western Treatment Plant. Arthur Rylah Institute for Environmental Research Technical Report Series No. 169

Rogers, D.I., Loyn, R.H. and Greer, D. (2013) Factors influencing shorebird use of tidal flats adjacent to the Western Treatment Plant. Arthur Rylah Institute for Environmental Research Technical Report Series No. 250

Saz, G. (2011) The Efficacy of SARIMA Models for Forecasting Inflation Rates in Developing Countries: The Case for Turkey. *International Research Journal of Finance and Economics* **62**, 111–142. Retrieved from http://papers.ssrn.com/abstract=1845643

Sigauke, C., and Chikobvu, D. (2011) Prediction of daily peak electricity demand in South Africa using volatility forecasting models. *Energy Economics* **33**, 882–888. Retrieved from http://ideas.repec.org/a/eee/eneeco/v33y2011i5p882-888.html

Wilson, H.B., Kendall, B.E., Fuller, R.A., Milton, D.A. and Possingham, H.P. (2011) Analyzing variability and the rate of decline of migratory shorebirds in Moreton Bay, Australia. *Conservation Biology* **25**, 758-766. doi: 10.1111/j.1523-1739.2011.01670.x

Zeileis, A. (2013) dynlm: Dynamic Linear Regression. Retrieved from http://cran.r-project.org/package=dynlm

Zeileis, A., Leisch, F., Hornik, K. and Kleiber, C. (2002) strucchange: An R Package for Testing for Structural Change in Linear Regression Models. *Journal of Statistical Software* **7**. Retrieved from http://www.jstatsoft.org/v07/i02/

Appendix 1. Mean counts of waterfowl species (and selected other waterbirds) and waterfowl guilds at the combinations of sites within the Western Treatment Plant used in the analyses

Counts are divided into four time-periods (2000–02 pre-EIP; 2003–05 during EIP; 2006–08 post-EIP and 2009–12 post-drought). Means are based on five counts in each year (Feb–Mar, Apr–Jun, July, Aug–Sep and Oct–Nov). Counts in January (and one in December) were excluded as they were missed in some years.

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
Musk Duck						
New lagoons (115E)	165	346	429	281	315	31
New lagoons (55E & 25W)	303	379	276	180	274	29
Old lagoons	315	219	571	182	311	35
Decommissioned lagoons (Borrie N & S)	176	106	31	25	72	11
Decommissioned lagoons (Western & T-section)	4	4	7	2	4	1
Conservation ponds	2	0	0	0	0	0
Utility ponds, paddocks and channels	2	1	0	0	1	0
Natural swamp or creek	9	16	17	3	11	2
Spit Lagoon	0	0	0	0	0	0
Coast and outlets	33	37	95	26	47	6
Freckled Duck						
New lagoons (115E)	0	0	0	0	0	0
New lagoons (55E & 25W)	16	86	7	2	26	9
Old lagoons	3	3	13	10	8	2
Decommissioned lagoons (Borrie N & S)	29	91	6	7	31	10
Decommissioned lagoons (Western & T-section)	0	0	0	0	0	0
Conservation ponds	3	8	0	0	3	2
Utility ponds, paddocks and channels	0	0	0	0	0	0
Natural swamp or creek	0	0	0	0	0	0
Spit Lagoon	0	0	0	0	0	0
Coast and outlets	0	0	0	0	0	0
Cape Barren Goose						

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
New lagoons (115E)	0	0	0	0	0	0
New lagoons (55E & 25W)	0	0	0	0	0	0
Old lagoons	0	1	0	0	0	0
Decommissioned lagoons (Borrie N & S)	0	1	1	1	1	0
Decommissioned lagoons (Western & T-section)	0	1	5	4	2	1
Conservation ponds	1	5	15	4	6	1
Utility ponds, paddocks and channels	0	0	1	1	1	0
Natural swamp or creek	0	0	0	0	0	0
Spit Lagoon	0	0	0	2	1	0
Coast and outlets	0	0	0	0	0	0
Black Swan						
New lagoons (115E)	13	42	30	48	36	5
New lagoons (55E & 25W)	25	42	27	46	37	4
Old lagoons	718	990	1571	1341	1207	169
Decommissioned lagoons (Borrie N & S)	538	681	171	277	395	62
Decommissioned lagoons (Western & T-section)	80	134	129	109	117	10
Conservation ponds	89	227	154	157	162	13
Utility ponds, paddocks and channels	26	240	246	46	141	37
Natural swamp or creek	31	38	19	20	26	4
Spit Lagoon	88	71	122	125	105	17
Coast and outlets	477	526	839	272	512	56
Australian Shelduck						
New lagoons (115E)	8	10	13	35	19	6
New lagoons (55E & 25W)	48	97	152	855	355	137
Old lagoons	228	779	1594	2472	1455	411
Decommissioned lagoons (Borrie N & S)	121	318	180	511	315	87
Decommissioned lagoons (Western & T-section)	50	209	91	160	136	38
Conservation ponds	310	589	940	626	643	149

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
Utility ponds, paddocks and channels	16	26	451	16	127	77
Natural swamp or creek	0	0	0	9	3	2
Spit Lagoon	23	14	47	11	23	13
Coast and outlets	10	9	24	12	14	4
Australian Wood Duck						
New lagoons (115E)	0	0	0	0	0	0
New lagoons (55E & 25W)	0	0	0	0	0	0
Old lagoons	1	0	0	1	0	0
Decommissioned lagoons (Borrie N & S)	0	0	0	0	0	0
Decommissioned lagoons (Western & T-section)	2	0	1	0	1	0
Conservation ponds	6	11	5	3	6	2
Utility ponds, paddocks and channels	0	2	0	1	1	0
Natural swamp or creek	0	0	0	0	0	0
Spit Lagoon	0	0	0	0	0	0
Coast and outlets	0	0	0	0	0	0
Pink-eared Duck						
New lagoons (115E)	923	1011	1064	203	740	175
New lagoons (55E & 25W)	5118	7230	2319	1062	3594	664
Old lagoons	2473	1609	2029	1148	1704	414
Decommissioned lagoons (Borrie N & S)	12229	7298	3158	1010	4989	738
Decommissioned lagoons (Western & T-section)	180	242	23	0	98	42
Conservation ponds	991	1230	587	37	632	150
Utility ponds, paddocks and channels	11	1	1	0	2	1
Natural swamp or creek	3	0	0	13	5	4
Spit Lagoon	0	0	0	0	0	0
Coast and outlets	0	15	0	0	4	4
Australasian Shoveler						
New lagoons (115E)	369	160	249	112	201	39

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
New lagoons (55E & 25W)	1443	987	1118	310	870	203
Old lagoons	2723	1354	1400	837	1421	258
Decommissioned lagoons (Borrie N & S)	2209	986	224	129	714	156
Decommissioned lagoons (Western & T-section)	166	84	23	4	57	14
Conservation ponds	294	136	62	26	107	19
Utility ponds, paddocks and channels	5	4	1	0	2	1
Natural swamp or creek	29	0	0	16	10	6
Spit Lagoon	59	8	4	1	13	6
Coast and outlets	24	30	5	5	15	8
Grey Teal						
New lagoons (115E)	410	479	580	530	510	71
New lagoons (55E & 25W)	541	350	252	241	321	39
Old lagoons	1051	704	775	950	862	127
Decommissioned lagoons (Borrie N & S)	179	224	151	243	204	32
Decommissioned lagoons (Western & T-section)	375	218	85	55	159	42
Conservation ponds	887	705	506	400	584	55
Utility ponds, paddocks and channels	133	80	34	12	55	11
Natural swamp or creek	40	0	1	42	21	7
Spit Lagoon	450	128	52	122	161	31
Coast and outlets	773	466	705	376	547	79
Chestnut Teal						
New lagoons (115E)	96	266	403	874	474	96
New lagoons (55E & 25W)	160	131	63	52	92	12
Old lagoons	463	614	859	1208	848	152
Decommissioned lagoons (Borrie N & S)	693	878	721	721	755	85
Decommissioned lagoons (Western & T-section)	36	109	64	82	80	17
Conservation ponds	92	131	52	269	151	28
Utility ponds, paddocks and channels	10	9	3	6	7	1

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
Natural swamp or creek	20	1	5	44	19	7
Spit Lagoon	1098	306	223	313	420	88
Coast and outlets	603	536	1099	350	626	84
Pacific Black Duck						
New lagoons (115E)	98	138	157	177	149	16
New lagoons (55E & 25W)	92	117	132	138	123	11
Old lagoons	251	254	342	374	315	47
Decommissioned lagoons (Borrie N & S)	224	157	134	182	171	20
Decommissioned lagoons (Western & T-section)	60	73	81	50	66	10
Conservation ponds	64	104	50	89	79	11
Utility ponds, paddocks and channels	40	51	16	51	41	14
Natural swamp or creek	7	1	0	48	17	8
Spit Lagoon	50	22	15	7	20	4
Coast and outlets	69	36	76	16	45	10
Hardhead						
New lagoons (115E)	151	394	166	809	435	106
New lagoons (55E & 25W)	841	909	310	549	628	106
Old lagoons	1420	1628	1251	1952	1607	246
Decommissioned lagoons (Borrie N & S)	932	321	69	188	315	63
Decommissioned lagoons (Western & T-section)	255	173	6	65	109	20
Conservation ponds	102	28	14	11	31	7
Utility ponds, paddocks and channels	8	2	1	3	3	1
Natural swamp or creek	7	0	0	4	3	1
Spit Lagoon	0	0	0	0	0	0
Coast and outlets	3	0	0	1	1	1
Blue-billed Duck						
New lagoons (115E)	322	608	665	109	408	61
New lagoons (55E & 25W)	3329	3166	1069	286	1709	244

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
Old lagoons	989	938	2402	294	1098	188
Decommissioned lagoons (Borrie N & S)	864	997	516	85	550	75
Decommissioned lagoons (Western & T-section)	43	34	29	1	25	6
Conservation ponds	10	6	6	0	5	1
Utility ponds, paddocks and channels	0	0	1	0	0	0
Natural swamp or creek	0	0	0	0	0	0
Spit Lagoon	0	0	0	0	0	0
Coast and outlets	0	0	0	0	0	0
Australasian Grebe						
New lagoons (115E)	1	0	1	28	10	4
New lagoons (55E & 25W)	3	0	1	4	2	1
Old lagoons	1	0	24	123	47	14
Decommissioned lagoons (Borrie N & S)	0	0	6	31	12	4
Decommissioned lagoons (Western & T-section)	2	0	4	31	11	3
Conservation ponds	2	3	2	5	3	1
Utility ponds, paddocks and channels	7	1	2	5	4	1
Natural swamp or creek	1	0	0	8	3	2
Spit Lagoon	0	0	0	0	0	0
Coast and outlets	5	0	0	0	1	1
Hoary-headed Grebe						
New lagoons (115E)	620	673	391	1136	748	116
New lagoons (55E & 25W)	1006	1096	939	653	894	135
Old lagoons	3548	4522	6176	3540	4446	472
Decommissioned lagoons (Borrie N & S)	3140	2605	1113	881	1746	230
Decommissioned lagoons (Western & T-section)	703	848	403	194	501	57
Conservation ponds	170	148	46	19	83	14
Utility ponds, paddocks and channels	34	19	3	4	12	2
Natural swamp or creek	50	14	16	12	20	4

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
Spit Lagoon	1	0	0	0	0	0
Coast and outlets	299	293	316	113	240	43
Great Crested Grebe						
New lagoons (115E)	0	1	0	9	3	3
New lagoons (55E & 25W)	0	1	1	0	1	0
Old lagoons	0	0	0	0	0	0
Decommissioned lagoons (Borrie N & S)	1	1	1	2	1	0
Decommissioned lagoons (Western & T-section)	0	0	1	1	1	0
Conservation ponds	0	0	0	0	0	0
Utility ponds, paddocks and channels	0	0	0	0	0	0
Natural swamp or creek	1	2	1	1	1	0
Spit Lagoon	0	0	0	0	0	0
Coast and outlets	2	71	88	9	43	15
Australian Pelican						
New lagoons (115E)	0	5	12	0	4	3
New lagoons (55E & 25W)	0	0	0	1	0	0
Old lagoons	11	14	7	38	19	5
Decommissioned lagoons (Borrie N & S)	10	0	22	94	38	10
Decommissioned lagoons (Western & T-section)	0	0	3	5	3	1
Conservation ponds	8	48	167	43	69	10
Utility ponds, paddocks and channels	0	0	0	0	0	0
Natural swamp or creek	0	2	1	1	1	1
Spit Lagoon	0	11	13	9	9	2
Coast and outlets	5	10	22	27	18	4
Purple Swamphen						
New lagoons (115E)	0	0	0	3	1	1
New lagoons (55E & 25W)	0	0	0	2	1	1
Old lagoons	4	20	16	19	16	5

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
Decommissioned lagoons (Borrie N & S)	38	0	53	90	49	12
Decommissioned lagoons (Western & T-section)	0	0	1	14	5	2
Conservation ponds	45	57	80	116	80	9
Utility ponds, paddocks and channels	0	0	0	3	1	1
Natural swamp or creek	0	0	0	2	1	0
Spit Lagoon	0	0	0	0	0	0
Coast and outlets	0	0	0	2	1	0
Black-tailed Native-hen						
New lagoons (115E)	0	0	0	0	0	0
New lagoons (55E & 25W)	0	0	0	0	0	0
Old lagoons	0	0	0	0	0	0
Decommissioned lagoons (Borrie N & S)	0	0	0	2	1	0
Decommissioned lagoons (Western & T-section)	0	0	0	0	0	0
Conservation ponds	34	19	6	11	16	3
Utility ponds, paddocks and channels	4	0	0	0	1	0
Natural swamp or creek	7	0	0	1	2	1
Spit Lagoon	0	0	0	0	0	0
Coast and outlets	2	0	0	0	0	0
Eurasian Coot						
New lagoons (115E)	234	309	75	350	252	41
New lagoons (55E & 25W)	620	700	661	944	758	114
Old lagoons	1376	808	548	613	773	94
Decommissioned lagoons (Borrie N & S)	746	470	125	799	539	102
Decommissioned lagoons (Western & T-section)	107	112	19	126	94	23
Conservation ponds	152	282	58	137	156	38
Utility ponds, paddocks and channels	28	14	2	10	12	4
Natural swamp or creek	13	2	0	42	17	6
Spit Lagoon	0	0	0	0	0	0

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
Coast and outlets	1	4	1	44	16	14
Whiskered Tern						
New lagoons (115E)	18	15	45	30	28	14
New lagoons (55E & 25W)	85	84	0	90	65	35
Old lagoons	94	93	142	168	130	45
Decommissioned lagoons (Borrie N & S)	200	87	90	56	97	30
Decommissioned lagoons (Western & T-section)	1	5	8	9	6	2
Conservation ponds	56	74	315	169	163	58
Utility ponds, paddocks and channels	3	7	42	58	32	22
Natural swamp or creek	3	0	0	0	1	0
Spit Lagoon	4	8	1	2	4	2
Coast and outlets	48	28	6	7	19	7
White-winged Black Tern						
New lagoons (115E)	0	0	0	0	0	0
New lagoons (55E & 25W)	18	0	0	0	3	2
Old lagoons	7	14	2	16	11	3
Decommissioned lagoons (Borrie N & S)	14	15	8	10	12	4
Decommissioned lagoons (Western & T-section)	1	0	2	0	1	1
Conservation ponds	2	6	46	3	14	11
Utility ponds, paddocks and channels	0	0	0	0	0	0
Natural swamp or creek	0	0	0	0	0	0
Spit Lagoon	0	0	0	0	0	0
Coast and outlets	0	0	2	3	1	1
Silver Gull						
New lagoons (115E)	11	37	0	229	88	41
New lagoons (55E & 25W)	387	485	1058	1108	819	113
Old lagoons	52	209	308	802	405	149
Decommissioned lagoons (Borrie N & S)	0	6	20	172	64	28

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
Decommissioned lagoons (Western & T-section)	0	1	16	5	7	5
Conservation ponds	0	4	38	0	11	5
Utility ponds, paddocks and channels	22	0	0	75	29	25
Natural swamp or creek	0	0	0	0	0	0
Spit Lagoon	0	0	0	100	33	33
Coast and outlets	0	0	0	416	139	111
Coots	See Eurasian Coot above					
Dabbling Ducks						
New lagoons (115E)	604	882	1140	1580	1133	144
New lagoons (55E & 25W)	793	598	446	431	537	47
Old lagoons	1765	1572	1976	2532	2025	287
Decommissioned lagoons (Borrie N & S)	1095	1259	1006	1145	1131	112
Decommissioned lagoons (Western & T-section)	470	399	229	187	306	57
Conservation ponds	1043	940	608	758	814	71
Utility ponds, paddocks and channels	183	141	53	69	102	20
Natural swamp or creek	67	2	6	133	58	16
Spit Lagoon	1598	455	291	442	600	112
Coast and outlets	1445	1037	1881	742	1218	159
Diving Ducks						
New lagoons (115E)	637	1348	1260	1199	1158	134
New lagoons (55E & 25W)	4473	4454	1656	1014	2611	318
Old lagoons	2724	2784	4224	2428	3015	291
Decommissioned lagoons (Borrie N & S)	1972	1424	616	298	938	109
Decommissioned lagoons (Western & T-section)	303	211	42	69	139	21
Conservation ponds	114	34	21	11	36	7
Utility ponds, paddocks and channels	11	3	2	3	4	1
Natural swamp or creek	16	16	17	7	13	2
Spit Lagoon	0	0	0	0	0	0

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
Coast and outlets	36	37	96	27	48	6
Filter-feeding Ducks						
New lagoons (115E)	1292	1171	1313	315	941	204
New lagoons (55E & 25W)	6577	8303	3443	1374	4491	786
Old lagoons	5200	2966	3443	1995	3134	573
Decommissioned lagoons (Borrie N & S)	14466	8374	3388	1146	5734	828
Decommissioned lagoons (Western & T-section)	346	327	46	4	156	50
Conservation ponds	1289	1374	650	62	742	159
Utility ponds, paddocks and channels	16	5	2	0	4	2
Natural swamp or creek	32	0	0	29	15	7
Spit Lagoon	59	8	4	1	13	6
Coast and outlets	24	45	5	5	18	8
Grazing Ducks						
New lagoons (115E)	8	10	13	35	19	6
New lagoons (55E & 25W)	48	97	152	855	355	137
Old lagoons	228	779	1595	2473	1456	411
Decommissioned lagoons (Borrie N & S)	121	318	180	511	315	87
Decommissioned lagoons (Western and T-section)	52	209	92	160	136	38
Conservation ponds	316	601	945	629	649	150
Utility ponds, paddocks and channels	16	28	451	17	128	77
Natural swamp or creek	0	0	0	9	3	2
Spit Lagoon	23	14	47	11	23	13
Coast & outlets	10	9	24	12	14	4
Grebes						
New lagoons (115E)	621	675	392	1173	761	118
New lagoons (55E & 25W)	1008	1097	940	657	896	136
Old lagoons	3549	4523	6201	3664	4494	470
Decommissioned lagoons (Borrie N & S)	3141	2605	1120	914	1760	229

Species and Site group	Pre-EIP	During EIP	Post-EIP	Post-drought	Grand mean	SE (n = 60)
Decommissioned lagoons (Western and T-section)	704	848	407	225	512	56
Conservation ponds	173	151	48	24	86	14
Utility ponds, paddocks and channels	41	20	5	9	16	2
Natural swamp or creek	51	16	17	21	24	4
Spit Lagoon	1	0	0	0	0	0
Coast & outlets	306	364	404	122	284	49
Swans	See Black Swan above					
Waterfowl						
New lagoons (115E)	3408	4437	4223	4701	4300	403
New lagoons (55E & 25W)	13545	15291	7325	5321	9685	1172
Old lagoons	15562	14423	19557	15045	16104	1477
Decommissioned lagoons (Borrie N & S)	22079	15132	6606	5092	10812	1147
Decommissioned lagoons (Western and T-section)	2062	2240	969	883	1462	155
Conservation ponds	3176	3615	2498	1781	2651	243
Utility ponds, paddocks and channels	319	452	762	156	409	91
Natural swamp or creek	210	74	59	261	155	30
Spit Lagoon	1769	549	464	582	742	119
Coast and outlets	2300	2022	3251	1225	2110	223

Appendix 2. Summer and winter counts of the most numerous shorebird species at the Western Treatment Plant, 2000–12

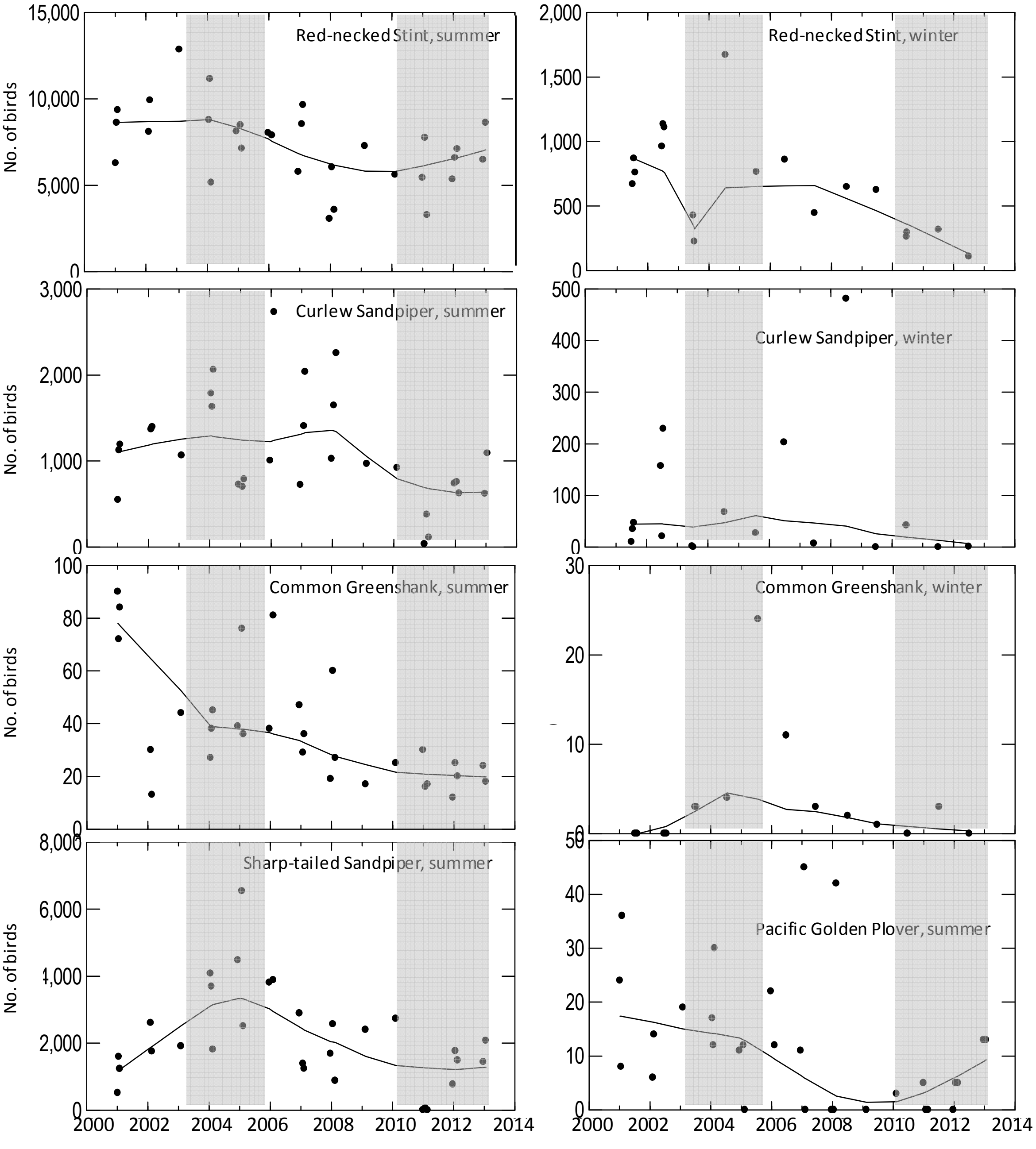


Figure 12. Counts of selected species of migratory sandpipers at the Western Treatment Plant. The shaded grey areas depict the period of the EIP (left) and the post-drought period (right). The lines are LOWESS smoothers with a tension of 0.5.

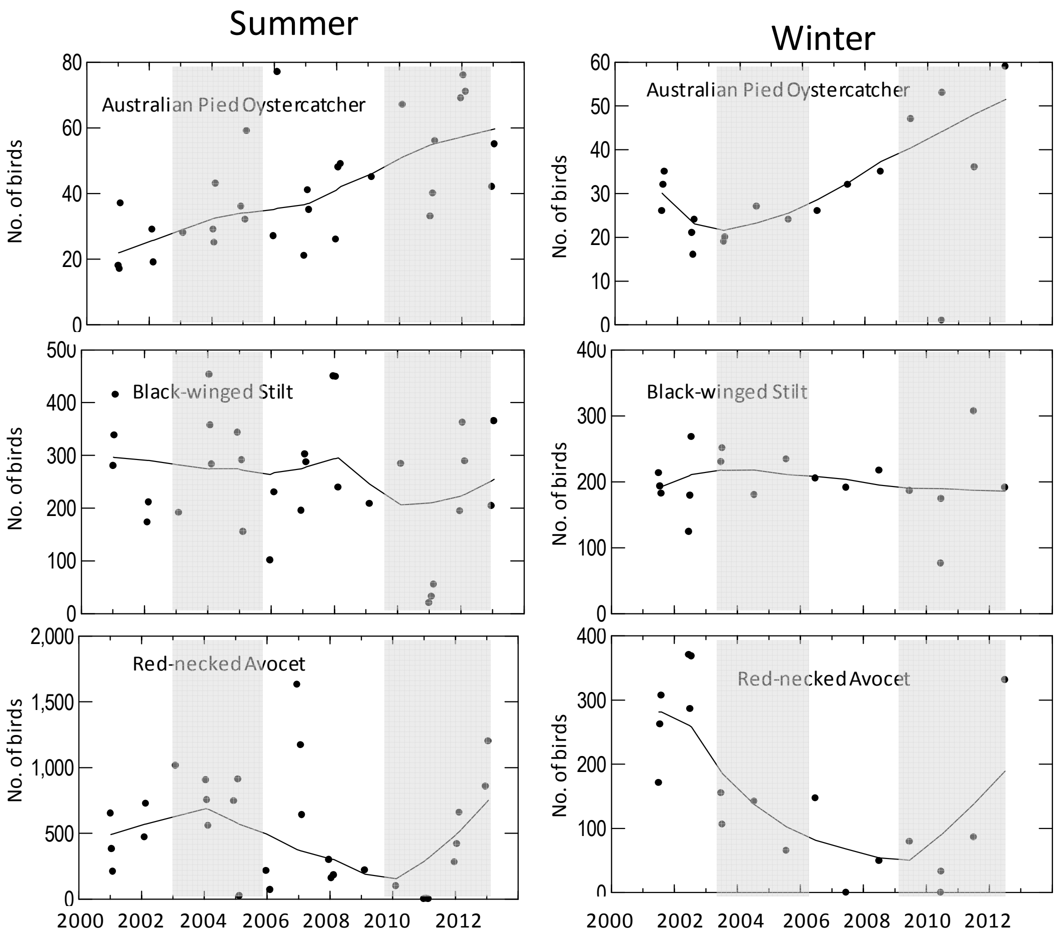


Figure 13. Counts of selected species of Australasian shorebirds (Haematopodidae and Recurvirostridae) at the Western Treatment Plant. The shaded grey areas depict the period of the EIP (left) and the post-drought period (right). The lines are LOWESS smoothers with a tension of 0.5.

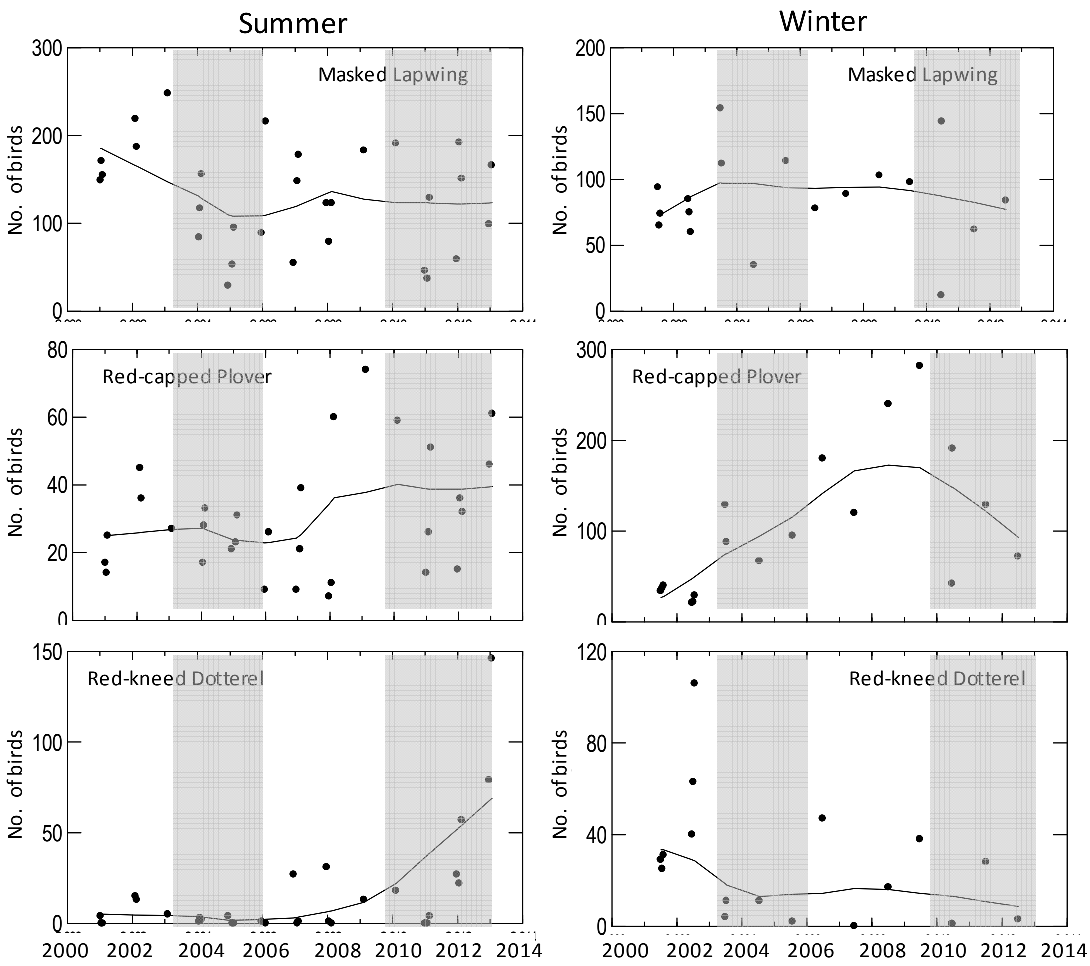


Figure 14. Counts of selected species of Australasian plovers and lapwings at the Western Treatment Plant. The shaded grey areas depict the period of the EIP (left) and the post-drought period (right). The lines are LOWESS smoothers with a tension of 0.5.

ISSN 1835-3827 (print)
ISSN 1835-3835 (online)
ISBN 978-1-74326-895-7 (print)
ISBN 978-1-74326-897-1 (pdf)