Maintaining Straw-necked Ibis habitat at the Western Treatment Plant as pasture is converted to crops

P.V. Macak, D.I. Rogers and P.W. Menkhorst

December 2017

Arthur Rylah Institute for Environmental Research Technical Report Series No. 285

Arthur Rylah Institute for environmental research

VICTORIA State Government | Environment, Land, Water and Planning

Photo credit

Straw-necked Ibis at the Western Treatment Plant (Danny Rogers)

ISSN 1835-3827 (print)

ISSN 1835-3835 (pdf)

ISBN 978-1-76077-018-1 (print)

ISBN 978-1-76077-019-8 (pdf/online)

Accessibility

If you would like to receive this publication in an alternative format, please telephone the DELWP Customer Service Centre on 136186, email customer.service@delwp.vic.gov.au, or via the National Relay Service on 133 677 www.relayservice.com.au. This document is also available on the internet at www.delwp.vic.gov.au.

Maintaining Straw-necked Ibis habitat at the Western Treatment Plant as pasture is converted to crops

Phoebe V. Macak, Danny I. Rogers and Peter W. Menkhorst

Arthur Rylah Institute for Environmental Research

Department of Environment, Land, Water and Planning

Heidelberg, Victoria

December 2017

Arthur Rylah Institute for Environmental Research Technical Report Series No. 285

Acknowledgements

This study was commissioned and funded by Melbourne Water, and we are grateful for the support of Dr Will Steele, who initiated the study, and Heather Graham who understood its significance and allowed it to continue. Dan Mooney facilitated communication with MPH Agriculture Pty Ltd, and Kevin Gillett, Aaron Zanatta, Warren Blyth and Mathew Drysdale provided operational and OH&S support.

We thank MPH Agriculture Pty Ltd, particularly Julie Vanzyl, Laurie Fitzsimmons and Mark Earles, for supplying paddock irrigation, crop rotation and cattle quarantine information. The following people facilitated access to cattle quarantine areas during ibis surveys: Andrew Armstrong, Nick Binder, Phil McKenzie, Spencer Millear. Shayne Moor and Ted Diwell provided information and advice at various times.

Dr Paul Moloney (Arthur Rylah Institute for Environmental Research [ARI]) conducted data analyses and provided study design advice, Dr Dave Ramsey (ARI) provided study design advice in the initial stages of the project, and Dr Josephine MacHunter, Dr Jenny Nelson (ARI), and Dr Will Steele and Heather Graham (Melbourne Water) commented helpfully on an earlier draft.

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

Citation

Macak, P.V., Rogers, D.I. and Menkhorst, P.W. (2017) Maintaining Straw-necked Ibis habitat at the Western Treatment Plant as pasture is converted to crops. Arthur Rylah Institute for Environmental Research Technical Report Series No. 285, Department of Environment, Land, Water and Planning, Heidelberg, Victoria

Contents

Summary

Background

The Western Treatment Plant (WTP), managed by Melbourne Water, is Melbourne's major processor of wastewater. Its 10,500 ha of lagoons, paddocks and other environments, attract tens of thousands of birds, contributing to its recognition under the Ramsar convention of wetlands of international significance. Consequently, and in line with the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*, any changes in management must be carried out in the context of mitigating potentially adverse environmental impacts. The extensive paddock system (~4,550 ha) of the WTP has been utilised by Straw-necked Ibis *Threskiornis spinicollis* as foraging habitat for many years. Straw-necked Ibis are listed as one of the key values of the Ramsar site that includes the WTP. Consequently, an important management aim for Melbourne Water is to maintain the numbers of ibis using the site. Many WTP paddocks have now been converted from pasture (previously utilised for sewage treatment) to various agricultural crops. Ibis also use cropped areas for foraging, and although observations indicated that tall (> 45 cm) dense crops were unlikely to be utilised, this had not been investigated rigorously. Most paddocks are now leased by MPH Agriculture Pty Ltd (MPH), with 9% (~400 ha) of the total paddock area reserved for conservation purposes within what is called the Terrestrial Margin.

Long-term monitoring indicated a decline in ibis numbers, and there was concern that changes in land use could affect the amount of suitable habitat for ibis. This study was initiated to further understand ibis foraging preferences and to aid Melbourne Water in maintaining ibis habitat while improving the efficiency of water use at the property. Determining the value of the Terrestrial Margin as ibis habitat not subject to cropping was central to the study.

Methods

The study included subjecting the Terrestrial Margin to targeted irrigation during autumn and winter from 2014 to 2017 and exploring how ibis responded to different watering treatments. This information was combined with data from long-term ibis monitoring at the WTP to investigate patterns of habitat use by Straw-necked Ibis.

Ibis foraging data were collected during 46 surveys of the paddock system from March 2013 to June 2017. These were analysed with crop rotation, vegetation height and irrigation records to investigate the impact of land use on the presence, distribution and number of ibis.

Key findings

- The variety of land uses applied to the WTP paddocks is an important feature of the foraging habitat for Straw-necked Ibis that utilise the site
- Paddocks within the Terrestrial Margin are a major contributor to ibis foraging habitat, particularly when being irrigated
- Irrigation increased the odds of ibis being present by a factor of 9.4, and the average number of ibis by a factor of three
- Paddocks with vegetation heights that were medium (~20-35 cm) or short (<15 cm) were more likely to contain ibis than those with tall (~35-45 cm) or very tall (> 45 cm) vegetation

Key recommendations

To maximise habitat suitability at times when agricultural priorities limit ibis foraging habitat at the WTP:

- Continue the current regime of flood irrigation of Terrestrial Margin paddocks from December until the end of June, but particularly April to June to coincide with the peak ibis period.
- In pasture and within the Terrestrial Margin keep, as far as possible, vegetation density low and vegetation height below that of ibis (i.e. below 45 cm).

1. Introduction

The Western Treatment Plant (WTP) near Werribee, managed by Melbourne Water, is Melbourne's major processor of wastewater. It is recognised internationally for its waterbird values, with tens of thousands of waterbirds from approximately 100 species inhabiting the 10,500 ha of lagoons, paddocks and other habitats. The WTP is a component of the Port Phillip Bay (western shoreline) and Bellarine Peninsula Ramsar site (DSE 2003), and as such is required to be managed within the context of mitigating potentially adverse environmental impacts. Straw-necked Ibis use the WTP for foraging and roosting, and the high numbers at this location are listed as one of the key values of the Ramsar site (DSE 2003). Consequently, an important management aim for Melbourne Water is to maintain the numbers of ibis using the site. The Arthur Rylah Institute for Environmental Research (ARI) has been monitoring ibis at the WTP since 2001 to track yearly numbers and assess the impact of changes to land management (Loyn et. al 2014).

1.1 Changes in land use

During 2004-2007 Melbourne Water completed a major upgrade of the treatment system at the WTP, to reduce nutrient discharge to Port Phillip Bay and comply with a revised and more stringent licence issued by the Victorian Environment Protection Agency. This upgrade was known as the Environment Improvement Project (EIP). Recognising that it could have consequences for waterbirds, the EIP was approved with conditions when referred to the Commonwealth under the *Environmental Protection and Biodiversity Conservation Act 1999*. The conditions included a requirement for monitoring, modelling and research into potential impacts of the EIP on waterbird numbers, and implementation of adaptive management with the aim of retaining waterbird habitat values. Prior to the EIP, the ~4,550 ha of irrigable paddocks, which also supported large numbers of cattle and sheep, were sown mainly with Italian Ryegrass and subject to irrigation with raw or partially-treated sewage as part of the sewage treatment process. This was phased out during the EIP when the processing of sewage was confined to lagoon systems. Paddock irrigation continued using recycled water (i.e. treated effluent) to maintain pasture for stock grazing. Since the EIP, the paddocks have increasingly been converted from pasture to various agricultural crops, undergoing cycles of planting and harvesting. Most WTP paddocks are now leased to MPH Agriculture Pty Ltd (MPH) who manage irrigation schedules and use the paddocks for cropping and livestock grazing. In recent years the area used for crops (lucerne, canola, maize and wheat varieties) has greatly increased at the expense of grazing.

1.2 Straw-necked Ibis at the Western Treatment Plant

Large numbers of Straw-necked Ibis have used the WTP paddocks as foraging habitat for many years (Hamilton et al. 2004, Loyn et al. 2014, ARI unpublished data), although they have reduced over the last 10 years (Loyn et al 2014, ARI unpublished data). Australian White Ibis *T. molucca* also use the paddocks, but to a much lesser extent, with other habitats more important for this species within the WTP. Straw-necked Ibis are the focus of this research, the term 'ibis' in this report refers to this species.

Ibis forage in a variety of shallow wetlands and dry habitats, feeding on a wide range of small animals, particularly invertebrates (Carrick 1959, Marchant and Higgins 1990). It has long been observed that ibis are attracted to pasture to forage, especially when it is being irrigated (McKilligan 1979, Marchant and Higgins 1990). Observations from long-term monitoring and incidental sightings at the WTP have shown that the largest congregations of ibis foraging on paddocks occur most often on pasture during irrigation (Macak et al. 2002, Loyn et al. 2009). This suggests that although paddocks can provide foraging habitat when wet or dry, preferred foraging conditions include the presence of irrigation water. Land use changes have meant the application and timing of irrigation across most of the WTP is now more closely linked to the needs of crops, which may be affecting availability of preferred ibis habitat.

Most observations of ibis using crops have been made in crops that are at a stage when they are much shorter than adult ibis. Irrigation of crops may increase their attractiveness to ibis too, however, when crop plants are taller than ibis it is thought that habitat suitability for foraging ibis declines, because ibis tend to avoid tall, dense vegetation (McKilligan 1979, Marchant and Higgins 1990, P. Macak pers. obs.).

Many factors could influence the number of ibis that use the WTP as a feeding site (Macak et al. 2002, Loyn et al. 2008), including the area under irrigation, the volume of water applied and the nutrient content of the irrigation water. The observed decline in overall numbers and yearly peaks (Loyn et al. 2014; ARI unpublished data), may be due to a decline in habitat quality and availability, however, off-site factors, such as the availability of suitable foraging habitat outside the WTP and the widespread drought conditions between 1997 and 2010, are also likely to have influenced numbers of ibis using the paddocks. Irrigation volumes required to maintain ibis numbers through maintenance of suitable paddock habitat, were estimated in an internal Melbourne Water report and reviewed by ARI (Loyn et al. 2008). These volumes have been delivered where possible, with ~60 ML/week currently applied. However, it is unclear how effective these volumes have been in maintaining suitable foraging habitat for ibis, particularly as the area of pasture at the WTP has been substantially reduced over recent years. In addition, the actual volume applied in any given irrigation event is difficult to estimate due to loses (e.g. via evaporation and seepage) as water flows through the site.

1.3 The Terrestrial Margin and potential ibis habitat

The Terrestrial Margin is a ~400 ha conservation buffer consisting of a strip of paddocks bordering areas (mainly wetlands) of high conservation significance in the western half of the WTP (Figure 1). It is intended to provide important fauna habitat (predominantly for bird species) and act as a buffer between those areas and the adjacent agricultural zone. As crop production at the WTP increases, the Terrestrial Margin has increasing potential to play an important role in providing ibis foraging habitat. It is managed by Melbourne Water with MPH carrying out the on-ground activities. The Terrestrial Margin is currently managed to comprise portions of pasture, coastal saltmarsh and dryland (e.g. Fitzsimmons 2010, Melbourne Water 2015) and is not subject to cropping. The paddocks containing coastal saltmarsh are in a transition phase from pasture to saltmarsh and contain a mix of vegetation including grasses.

The Terrestrial Margin paddocks are arranged into management groups made up of 1-5 paddocks, which are individually irrigated on a rotational basis within each group. This means that within each group, at least one paddock should be irrigated during any given week, but the irrigation cycle was not always adhered to because of logistical constraints.

In 2014, ARI commenced a trial to investigate the response of ibis to the irrigation of Terrestrial Margin paddocks containing pasture, to explore the potential of this area to contribute towards maintaining the numbers of ibis using the WTP (Macak and Menkhorst 2014). By ARI request, irrigation was applied to six Terrestrial Margin paddocks over three weeks in early winter, because by this time usual irrigation schedules across the WTP, driven by cropping needs, had ceased until spring (since then, from July 2016, year-round irrigation of the Terrestrial Margin has commenced). Results indicated that the Terrestrial Margin was a major contributor to ibis foraging habitat at the WTP in early winter, and that some paddocks were more attractive to ibis than others. The trial was expanded and undertaken again for the next three years (Macak et al. 2015, Macak et al. 2016, this report) to allow for the times when the requested irrigation could not be applied, to build on the data already collected and to provide greater statistical power. This report brings together all four years of the study, as well as one additional year of pre-study data.

Figure 1: The Terrestrial Margin of the Western Treatment Plant

Yellow lines depict the extent of the Terrestrial Margin, and show management divisions. Labels are as adopted by MPH Agriculture Pty Ltd. and were used to match irrigation and cropping data with ibis survey observations in Melbourne Water-labelled paddocks, see Appendix A. Note that A5/6 was not included in this study, as it was not surveyed.

1.4 Project scope and objectives

This study investigates the relationship between ibis numbers, irrigation regimes and the various vegetation types of the WTP paddocks. In particular, the role of the Terrestrial Margin as a whole in providing ibis habitat is examined. This will help elucidate the impact of land use changes and contribute to management decisions aimed at providing sufficient foraging habitat for ibis, while meeting broader Melbourne Water objectives of increased water efficiency for irrigation within the WTP and MPH business targets.

This project had the following objectives:

- Analyse data on ibis collected between 2013 and 2017 from both the long-term monitoring program and the irrigation study to investigate relationships between ibis numbers, irrigation, and land management
- Use data on ibis collected between December 2015 and June 2017 from the long-term monitoring program and the irrigation study to investigate relationships between ibis numbers, irrigation, and vegetation type and height
- Assess the potential of the Terrestrial Margin to provide foraging habitat for ibis
- Discuss outcomes in the context of the ongoing management of ibis foraging habitat

2. Methods

2.1 Overview

The irrigable paddocks of the WTP were surveyed for ibis using methods developed for ARI's long-term monitoring program (Macak et al. 2002, Loyn et al. 2008). For the purpose of this study, survey data between March 2013 and June 2017 were included, combining those from long-term monitoring with surveys specifically aimed at investigating ibis response to irrigation, which began in April 2014. Long-term monitoring has shown that ibis numbers at the WTP are low from mid-winter, starting to build from early summer, before an abrupt yearly decline around June-August (Loyn et al. 2014, ARI unpublished data). This coincides with the onset of breeding of Straw-necked Ibis at Mud Islands (~35 km away), where Victoria's largest breeding colony begins nest-guarding in late July and breeds through spring to January (Menkhorst 2010). Based on this pattern, the study period effectively includes five annual 'ibis years'. Ibis survey data were combined with irrigation and cropping records for the same period and analysed to establish relationships between ibis foraging preferences and paddock conditions, with a focus on the Terrestrial Margin.

2.2 Ibis observations

Ibis surveys were conducted on a single day over a 7-10 hour period, covering all paddocks within the irrigated system of the WTP. A survey was either conducted by one observer (P. Macak, D. Rogers or P. Menkhorst), who covered the whole area, or by two observers working independently of each other and covering either the north-east or south-west half of the area with Little River as the boundary. Observers drove slowly along the tracks adjacent to paddocks, frequently stopping to alight from the vehicle and scan the area with binoculars. Two observers were required when usual access to paddocks was restricted due to construction or when cattle quarantine periods were in place, to be able to complete surveys within one day. During these periods, observers were required to make arrangements with construction or MPH staff to accompany them, which slowed access. When ibis were observed, the following information was recorded: species; specific location (i.e. individual paddock, as defined by Melbourne Water, or other habitat), and ibis number and behaviour (foraging, loafing, perched in trees, or in flight).

A similar route was used in each survey: broadly starting in the north-central portion of the WTP paddock system and then zig-zagging from the east of the WTP towards the south-west. Wetland areas were not specifically covered. The exact route varied depending on whether access restrictions required detours, or when ibis were seen away from the planned direction of travel. It was not possible to randomise the sequence in which paddocks were visited, given that considerable efficiency was required to survey all paddocks in a single day.

Surveys were conducted at different frequencies during the year according to the two current ibis programs. Surveys conducted as part of the ibis irrigation study were initiated in 2014, and occurred weekly over a six-week period in April to June, to coincide with the time of year when numbers of ibis at the WTP are usually highest (the 'peak period'). Surveys as part of the long-term monitoring program were also conducted once in November, December, February, March, April, May, June and July; some of these were included in the irrigation study period. The higher frequency of surveys from February until June, was designed to match the yearly pattern of ibis presence and increase in numbers at the WTP. Data from all surveys were combined for analysis.

Forty-six surveys were conducted during the study period: 22 as part of long-term monitoring only, 17 as part of the irrigation study only, with an additional 7 included in both programs. (Appendix B). Additional opportunistic observations of ibis behaviour were also made during the surveys; these were not included in the formal analyses but some are discussed when considered relevant.

2.3 Vegetation observations

The type of vegetation within paddocks was categorised according to whether it was a crop plant, grass/general weeds (denoted as pasture), post-harvest stubble or regrowth, or bare ground (e.g. after ploughing) (Figure 2). Observations made during surveys were cross-checked with cropping schedules as supplied by MPH. Cropping regime data included paddock names or groupings, paddock size (ha), crop type (including to species level in many cases), and dates of planting and harvesting. Planting and harvesting dates were used to identify the type of vegetation present (crop or pasture) in an individual paddock or grouping at the time of each ibis survey. Paddocks that were between the time that a crop had been harvested, and the time that the next crop emerged, were denoted as ‘harvested’. For paddocks of this category it was noted whether they contained stubble (which was sometimes upright, or had sometimes been flattened) from recently cut crops (Figure 2E), and/or regrowth from either crop plants or weeds, or whether the soil was exposed (Figure 2F) after being ploughed as part of preparation for planting a new crop.

Vegetation height was classified relative to the height of an adult ibis as: very tall (i.e. taller than a standing ibis, >45 cm); tall (just below ibis height, ~35 to 45 cm); medium (about half ibis height, ~ 20-35 cm); short (below tibio-tarsal joint, <15 cm); bare ground. This classification was necessarily rough, as vegetation heights often varied across a paddock e.g. short grass was sometimes interspersed with tall tufts (Figure 2B). In these cases the dominant height was recorded. If ibis were present in paddocks which contained multiple defined areas of different heights or vegetation type, observations of vegetation were recorded for that part of the paddock where ibis were located. For example, ibis were sometimes observed foraging in small sections of bare ground or short vegetation within paddocks with tall crops. In this situation, the vegetation was classified as bare or short.

From December 2015, the type and height of the vegetation (or absence thereof) was recorded in every individual WTP paddock during each ibis survey. Prior to this, these details were only recorded via direct observation for paddocks in which ibis were present; for those without ibis, crop type was assigned using MPH cropping schedule data.

Figure 2: Examples of vegetation heights and types of paddocks surveyed for Straw-necked Ibis at the Western Treatment Plant between March 2013 and June 2017. A: short pasture, undergoing irrigation; B: short pasture with tall tufts; C: medium-height crop; D: very tall crop; E: medium-height stubble; F: bare ground; where short is <15 cm tall, medium-height is 20-35 cm, very tall is >45 cm. (Photos: Phoebe Macak)

2.4 Irrigation information

Records of paddock irrigation were supplied by MPH. Irrigation of WTP paddocks is usually applied on a weekly basis (Monday-Friday) and upcoming schedules were usually provided ahead of surveys. Planned irrigation sometimes changed without notice and special note was made during surveys to confirm that irrigation was actually occurring in specified paddocks. Irrigation records were combined with survey observations to form a record of irrigation against all individual paddocks on each day of ibis surveys. Irrigation data from MPH comprised individual paddock names or groupings, and the date when irrigation was to begin.

The volumes of water applied during current irrigation regimes are such that the whole area of paddock is flooded. It can take a day or two to apply the total volume of water of an irrigation event to an individual paddock, and for most of the water to drain away. When an ibis survey date fell within two days of an irrigation start date for a particular paddock, and there was no corresponding confirmation via observation, it was assumed that the effects of irrigation would still be present, and it was recorded as irrigation occurring. This was based on separate observations of water being present in paddocks after irrigation had ceased, e.g. as extensive puddles, in the absence of rain.

2.5 Paddock names, groupings and identification

Individual paddocks were identified according to Melbourne Water naming conventions. However, MPH has a different system of allocating names, and also grouped some paddocks. These needed to be reconciled to allow records of ibis numbers, irrigation and cropping to be accurately collated for analysis. In addition, MPH naming conventions were sometimes inconsistent between irrigation and cropping data due to differences in how water delivery and crop rotations are managed. Individual paddocks defined by Melbourne Water, were matched to those defined by MPH based on information supplied by both organisations, including on labelled maps and in databases.

Data were collated for analysis according to MPH crop groupings as this represented the lowest number of names and was considered the most accurate way to present data (and avoided splitting some groupings). MPH crop groupings included several of the Terrestrial Margin paddocks; these were split into individual paddocks to enable closer examination of this area in terms of ibis foraging preferences. The combined ibis, irrigation and cropping data used for analyses was based on 171 paddock units which represented 272 individual Melbourne Water defined paddocks. During the study period, infrastructure construction commenced on one of the paddocks, effectively decommissioning it. This meant that nine surveys did not include counts for this paddock. Data obtained from MPH included the area of each paddock. However, the given area for individual paddocks used for cropping sometimes differed slightly from year to year as it is based on how much of a paddock is used for a particular crop. For analysis purposes paddock areas were based on 2016-2017 data, and indicated that the total area of paddocks was 4,515.6 ha, with the Terrestrial Margin comprising 408.5 ha and the remainder 4,107.1 ha.

2.6 Data analysis

The following attributes and conditions were tabulated for each survey date against paddock names: number of ibis, presence or absence of irrigation and ploughing, paddock type, and observed height of vegetation. For paddock type, paddocks within the Terrestrial Margin were identified separately, with other WTP paddocks categorised as crop, harvested or pasture according to their land use at the time of each survey. Twenty-one individual Terrestrial Margin paddocks (Figure 1) were included in the ‘Terrestrial’ category for analysis purposes, including those that are not managed as pasture (Appendix A). The Terrestrial Margin paddock identified as A 5/6 was omitted as it had not been routinely included in ibis surveys. Vegetation height categories were used as defined in Section 2.3.

To control for the effect of ibis annual breeding patterns data were divided into two periods: July to March (non-peak) and April to June (peak).

The data were divided into two overlapping ranges due to the level of detail able to be accurately obtained for the stage of vegetation within cropping cycles, and vegetation height (Table 1). Data from March 2013 to June 2017 were used to compare all cropping paddocks, regardless of state, with Terrestrial Margin paddocks and those outside of the Terrestrial Margin that contained pasture. Data from December 2015 to June 2017 were used to compare cropping paddocks containing crops, cropping paddocks in various states of post-harvest management, Terrestrial Margin paddocks, and those outside of the Terrestrial Margin that contained pasture. Vegetation height was also investigated.

Table 1: Data used for each of two analyses to assess ibis response to irrigation and cropping at the Western Treatment Plant between March 2013 and June 2017

Data used	2013-2017	2015*-2017
Ibis numbers	Y	Y
Irrigation	Y	Y
Paddock type	crop/Terrestrial Margin/pasture	crop/harvested/Terrestrial Margin/pasture
Vegetation height	N	Y
Ploughing	Y	Y

* from December 2015

To determine how the recorded paddock attributes and conditions influence habitat preferences of ibis, a hurdle model (Zuur et al. 2009) was used. A hurdle model is appropriate for count data that contain many zeros. Hurdle models are split into two sections. For this study, the first section describes the relationship between the attributes (vegetation type and height) and conditions (ibis period, presence of irrigation or ploughing) and the probability that ibis will be detected (if present) in a paddock. The second section describes how paddock conditions (peak or non-peak ibis period, presence of irrigation or ploughing) influence the number of ibis, given that ibis are present. The model was constructed using a Bayesian framework.

See Appendix C for a more technical description of the models (which express the above relationships via mathematical equations).

3. Results

3.1 Ibis numbers at the WTP 2013-2017

During the study period, 171 individual paddock units were surveyed on 46 separate days (apart from one paddock that was surveyed 37 times), equalling a collective 7857 individual paddock counts. Ibis were sighted in a paddock on 439 individual paddock counts (5.6%) and a combined total of 54,207 ibis was counted on 129 (75%) of the paddocks.

Ibis numbers and patterns of occurrence varied from year to year, with lowest overall numbers in 2014, and highest in 2015 (Figure 3). Three of the five years showed a clear peak in numbers, with 2015 experiencing the highest number of ibis (4,871 in June) followed by 2016 (2,832 in March). Apart from 2015, and the peak in 2016, numbers stayed below 2000.

The total number of observations of ibis over the 46 surveys in the Terrestrial Margin (17,421) was smaller than the other paddocks (36,786). However, on an area basis, there was a higher proportion of ibis on Terrestrial Margin paddocks than on the other paddocks – mean ibis density (ibis per 25 ha) was 23 in the Terrestrial Margin, and 4.9 outside it.

When ibis were seen, the number per paddock ranged from one to several hundred. The largest flock seen was 1,965 birds, on the 5th June 2015, and was on a paddock in the north-east of the WTP (5W 120-140) which consisted of stubble left after harvesting, and was not undergoing irrigation at the time. Two other flocks above 1,000 birds were observed: 1,380 in irrigated medium-height maize (115E 100-120) in December 2014, and 1,350 in irrigated medium-height pasture of a Terrestrial Margin paddock (J8) in March 2013.

Non-paddock habitats along the survey route were also used by ibis, sometimes making up a substantial proportion of the overall count for the day. These habitats included grasslands, tracks and track-side vegetation. In particular, grasslands near Ryan’s Swamp contained large numbers (up to 450) of ibis on several occasions.

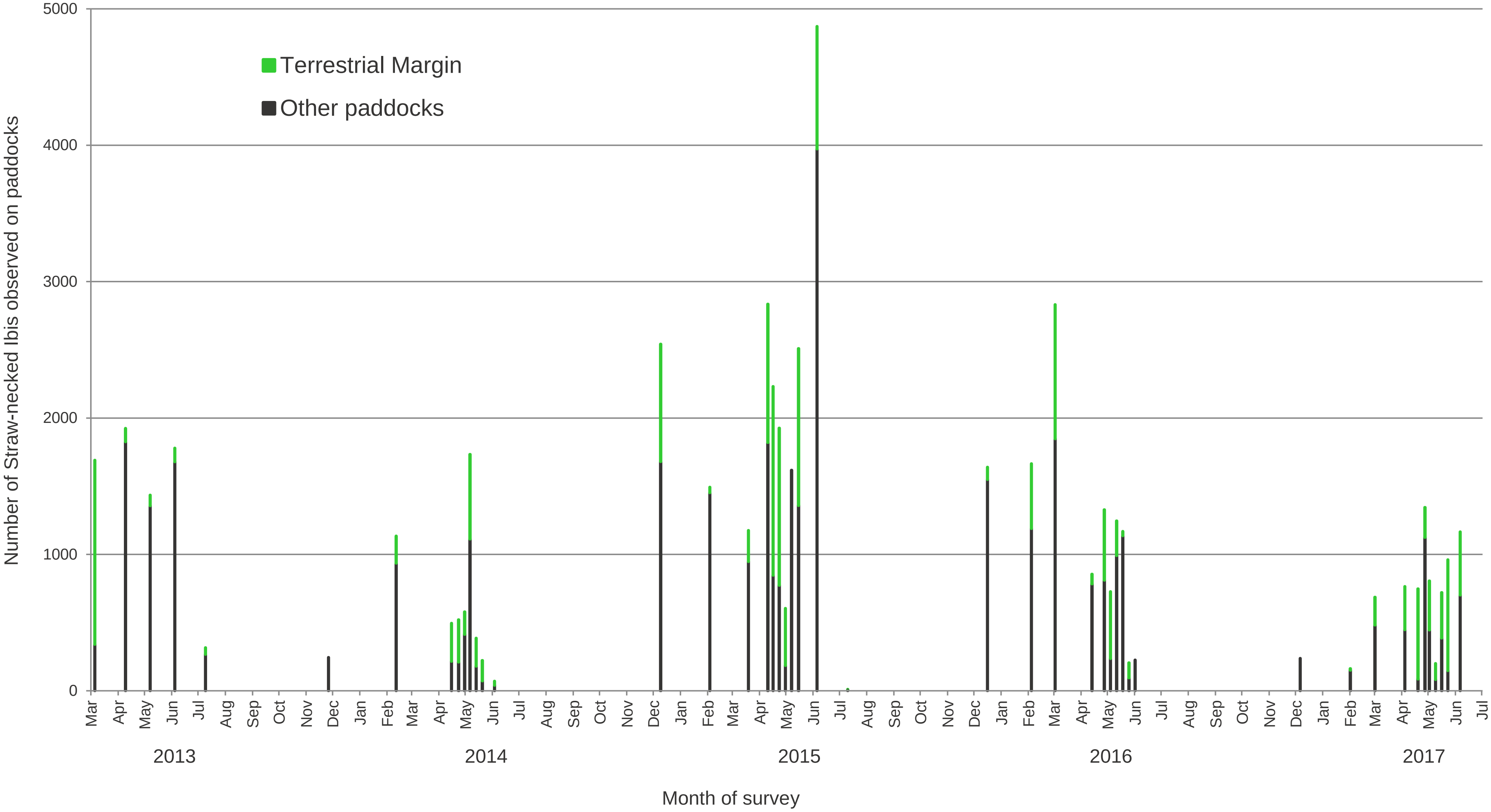

Figure 3: Numbers of Straw-necked Ibis observed during 46 surveys between March 2013 and June 2017 showing the proportion recorded on the Terrestrial Margin (green) and other Western Treatment Plant paddocks (black). Months without data are months when no surveys were conducted. Note that the ibis number for July 2015 (11) is barely visible.

Forty-two (25%) individual paddocks had no ibis observed on them during the study period, and a further 44 (26%) paddocks were used by ibis only once (Figure 4). Tyquins/145W/Moubrays, an area made up of several paddocks (totalling 146 ha) that are not subject to cropping or irrigation, was used 21 times; the next most commonly used paddock was H1(17 times), which is within the Terrestrial Margin. Irrigation was being actively applied to WTP paddocks during 31 of the 46 surveys, with three other dates where irrigation was not occurring but a number of paddocks were inundated from heavy rain or recent irrigation (Table 3).

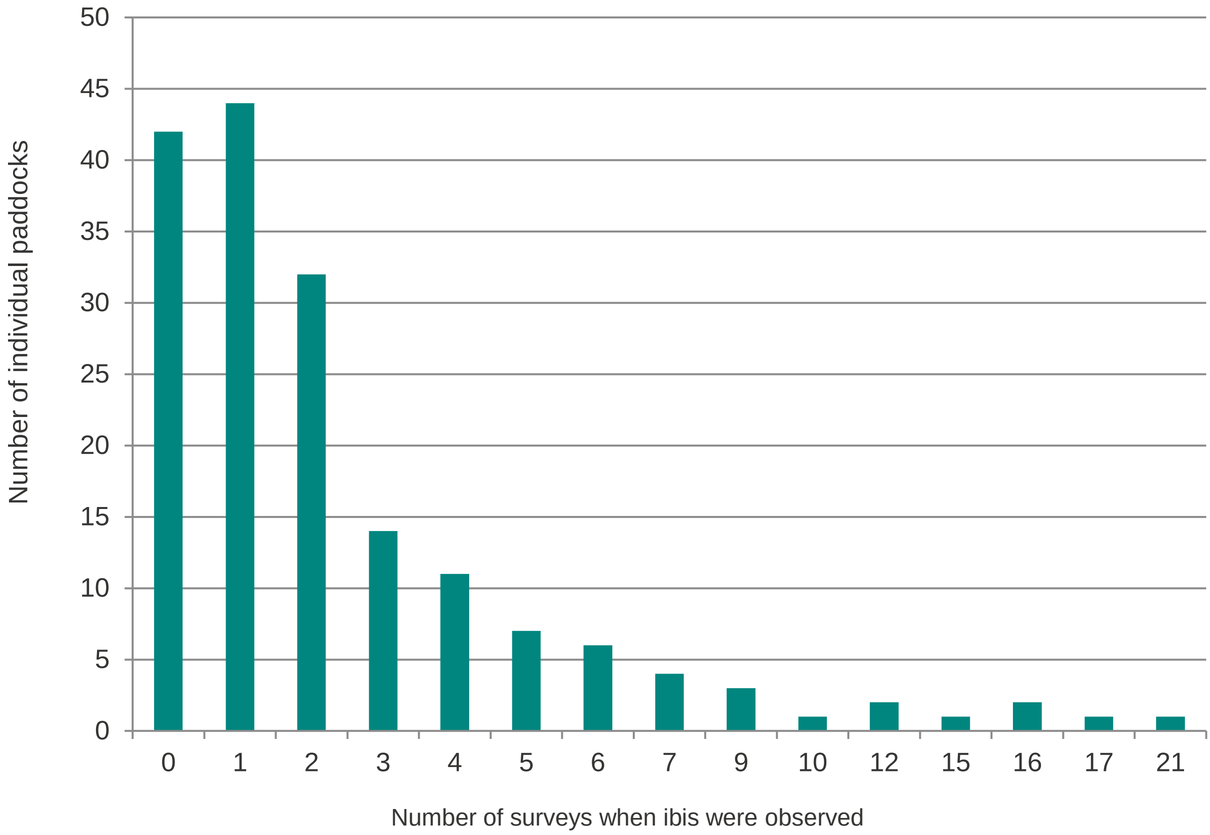

Figure 4: Number of times Straw-necked Ibis were observed in individual paddocks (n=171) during surveys (n=46) at the Western Treatment Plant, March 2013 – June 2017.

3.2 Vegetation type and ibis numbers

Thirty-eight percent of total ibis observations were on harvested paddocks, 32% were on the Terrestrial Margin (9% of the total paddock area), and 15% each were in crops and pasture (Table 2). In paddocks where ibis were present, 55% of all ibis observations were in short (<15 cm) vegetation, which was the most common height for all paddock types except for the Terrestrial Margin, where 51% of ibis observations were in medium height (~20-35 cm) vegetation. Very few of the paddocks where ibis were observed had tall (~35-45 cm) vegetation, and only one had very tall (>45 cm) vegetation. There were a few occasions where ibis were seen in paddocks containing tall crops, but were foraging within open areas of the paddock, where vegetation was much shorter. For example, in December 2014 ibis in a flooded paddock with tall maize were observed foraging within a strip of dead vegetation. Some ibis were seen to forage along the edge of the maize, and occasionally ventured in a little way, but emerged after only a few moments. In this case the vegetation was categorised as short.

Over the course of the study, land use changes saw the area of pasture external to the Terrestrial Margin reduce from approximately 1,424 ha at the start of 2013, to 402 ha by June 2017 (Figure 4). This reduction was mainly due to pasture being converted to crops, with one paddock now a site of treatment infrastructure. This also includes a small number of paddocks that were converted from pasture, to crop, then back to pasture by the end of the study period.

Table 2: The number and proportion of Straw-necked Ibis observations (in an individual paddock) recorded in four paddock categories and five vegetation heights during 46 surveys of 171 paddocks (n=7857) at the Western Treatment Plant 2013-2017.

Paddock type	Number of observations (% of total ibis)	Vegetation Height* (% of paddock type)				
		Bare	Short	Medium	Tall	Very tall
Terrestrial Margin	140 (32%)	3 (2%)	56 (40%)	72 (51%)	9 (6%)	0
Pasture	65 (15%)	8 (12%)	32 (49%)	23 (35%)	2 (3%)	0
Crop	68 (15%)	0	46 (68%)	18 (26%)	3 (4%)	1 (100%)
Harvested	166 (38%)	25 (15%)	107 (64%)	29 (17%)	5 (3%)	0
Total	**439**	**36 (8%)**	**241 (55%)**	**142 (32%)**	**19 (4%)**	**1 (0.2%)**

* Bare = exposed soil. Heights are relative to an adult ibis (45 cm); Short = <15 cm, Medium = ~20-35 cm, Tall = ~35-45 cm, Very tall = >45 cm.

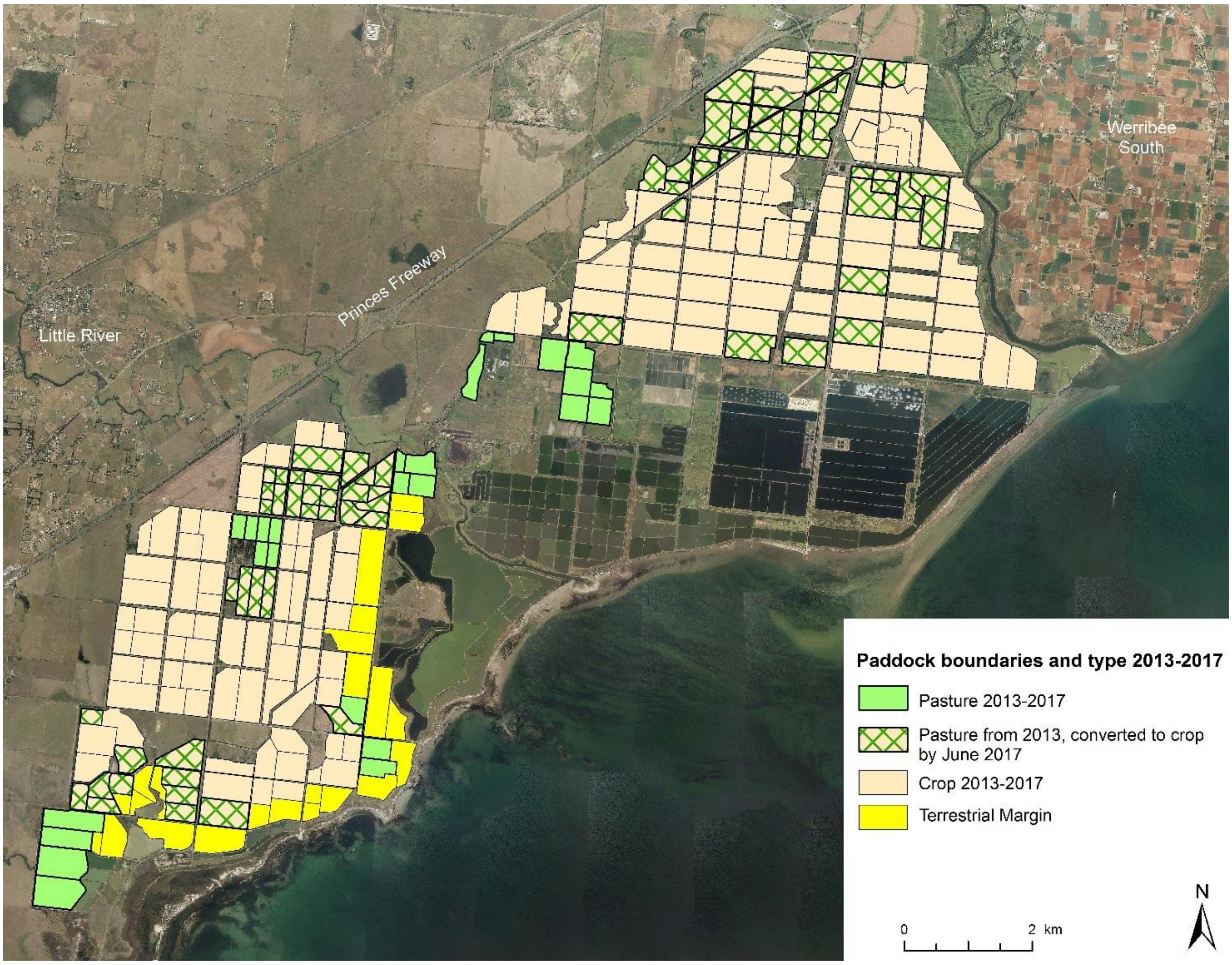

Figure 5: Paddocks at the Western Treatment Plant surveyed for Straw-necked Ibis March 2013 – June 2017, showing land use during this time, including paddocks that were pasture at the start of the study, and those that had been converted to crops by the end of the study. Note that Terrestrial Margin paddock A5/6 is not included here – see Figure 1.

3.3 Terrestrial Margin observations

Of the 966 overall observations of the 21 Terrestrial Margin paddocks, ibis were present on 140 occasions (14.5%). Fifty-eight percent of Terrestrial Margin paddocks held ibis when irrigated, but only 8% of paddocks held ibis when they were not irrigated. Fifty-nine percent of paddocks in their first week of irrigation held ibis (Table 3), indicating that ibis adapted quickly to rotation of irrigated paddocks.

The proportion of ibis at the WTP that were seen in the Terrestrial Margin paddocks differed between surveys, ranging from 0 to 88% (mean 34%) (Figure 3, Table 3). Overall, 18 of the 21 Terrestrial Margin paddocks were observed to have ibis in them at least once. The three individual Terrestrial Margin paddocks that were seen to have ibis on them on the highest number of occasions were H1 (17 times), E9 (16 times) and E4 (15 times). Ibis were not recorded on three of the Terrestrial Margin paddocks at any time during the study period (H2, R5, and S4).

Surveys at weekly intervals showed that week to week use of individual paddocks was highly dynamic, with some paddocks used on consecutive weeks, while most were not. The number of ibis that were present fluctuated widely among paddocks. There were no ibis on Terrestrial Margin paddocks during four surveys.

The largest number of ibis seen on an individual Terrestrial Margin paddock was 1,350 on J8, in March 2013. The next largest number was 940 on E9 in April 2015. Irrigation was occurring on both these occasions.

Irrigation was occurring, or paddocks were inundated from very heavy rain, within the Terrestrial Margin on 33 of the 46 survey days. Individual, paddocks were undergoing irrigation on 2-11 surveys (including those flooded from rain). Five paddocks were never observed to be receiving irrigation water: H2, Q4, R5, S2 and S4. Water was recorded on one paddock (E4) on 11 May 2016, which was thought to be residual from the previous weeks' irrigation or from heavy rain in the preceding several days. In late April 2017, a particularly heavy rain event meant that the WTP was inundated to the degree that many paddocks were observed to still have surface water during a survey a few days (27 April) and a week later (2 May). The amount of water was considered similar to that which would be a result of irrigation, and was scored so for analysis purposes.

Table 3: Numbers of Straw-necked Ibis observed in individual Terrestrial Margin paddocks, and totals for all paddocks at the Western Treatment Plant 2013-2017

Dates are days that surveys occurred, with those conducted during the designated TM irrigation study period shaded in the darker green. Shading in body of table indicates that irrigation (or inundation from heavy rain) was occurring in that paddock at the time of the survey. TM = Terrestrial Margin, WTP = Western Treatment Plant

Paddock	5/03/2013	9/04/2013	7/05/2013	4/06/2013	9/07/2013	26/11/2013	11/02/2014	15/04/2014	23/04/2014	30/04/2014	6/05/2014	13/05/2014	20/05/2014	3/06/2014	9/12/2014	3/02/2015	19/03/2015	10/04/2015	16/04/2015	23/04/2015	30/04/2015	7/05/2015	15/05/2015	5/06/2015	10/07/2015
A 8/9	0	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E 4	0	0	3	0	0	0	0	0	0	0	550	0	0	0	350	0	0	0	0	0	113	0	640	0	0
E 8	0	0	0	0	0	0	0	0	60	0	0	120	0	0	0	0	0	0	327	282	0	0	0	0	0
E 9	0	5	0	0	0	0	0	100	180	5	0	0	150	0	0	0	0	238	940	282	0	0	0	0	1
H 1	0	8	36	0	0	0	0	0	0	0	0	0	0	0	0	3	0	255	0	0	0	0	0	88	0
H 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J 8	1350	15	40	0	40	0	0	160	0	0	0	0	0	0	0	0	19	0	0	0	0	0	56	0	0
O 6	0	0	0	0	0	0	200	0	70	0	0	0	0	0	250	0	0	0	0	0	9	0	450	0	0
O 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	146	0	0	0	0	0	4	0	3
P 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0	0	0	280	0	0	0	0
P 7	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	110	0	0	0	0	0
P 10	0	0	0	0	0	0	0	20	0	0	70	0	0	0	0	38	0	0	0	0	0	0	0	381	0
P 12	0	0	0	0	0	0	0	0	0	0	0	22	0	0	250	0	14	0	83	10	1	0	0	429	0
Q 4	0	0	0	0	0	0	0	0	0	0	0	65	0	0	12	0	0	13	0	0	0	0	0	0	0
R 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0
R 7	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	38	0	468	0	0	0	0	0
R 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 1	0	0	0	0	10	0	0	0	0	0	0	0	0	30	0	0	0	470	35	0	8	0	0	0	0
S 2	0	0	0	0	0	0	0	0	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total in TM	1350	98	79	100	50	0	200	280	310	165	620	207	150	30	862	41	228	1014	1385	1152	420	0	1150	898	4
total in non-TM	340	1826^	1356	1679^	266	244	935^	216^	210	414	1113	179	72	40	1680^	1452	948	1821	846	774	185	1618	1359	3973	7
total in all WTP paddocks	1690	1924	1435	1779	316	244	1135	496	520	579	1733	386	222	70	2542	1493	1176	2835	2231	1926	605	1618	2509	4871	11
% ibis in TM	80%	5%	6%	6%	16%	0%	18%	56%	60%	28%	36%	54%	68%	43%	34%	3%	19%	36%	62%	60%	69%	0%	46%	18%	36%

Paddock	16/12/2015	4/02/2016	2/03/2016	13/04/2016	27/04/2016	4/05/2016	11/05/2016	18/05/2016	25/05/2016	1/06/2016	6/12/2016	1/02/2017	1/03/2017	4/04/2017	19/04/2017	27/04/2017*	2/05/2017*	9/05/2017	16/05/2017	23/05/2017	6/06/2017
A 8/9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120	0	0	0	0	0	0
E 4	0	0	70	0	220	180	115*	0	0	0	0	0	170	177	180	0	80	0	30	8	0
E 8	0	0	0	0	0	0	0	0	0	0	0	0	5	25	5	0	0	0	100	154	0
E 9	0	16	5	0	170	0	0	0	0	0	0	0	0	20	3	0	0	117	0	0	350
H 1	0	294	0	0	6	0	28	33	0	0	0	12	31	55	350	80	0	0	181	650	80
H 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J 8	0	0	80	0	0	0	112	0	0	0	0	0	0	0	0	130	120	0	23	0	0
O 6	0	0	500	0	0	0	0	0	0	0	0	0	0	20	3	0	100	0	0	0	0
O 7	0	0	70	0	0	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P 3	0	0	110	0	80	0	0	0	0	0	0	0	0	21	0	0	0	0	1	0	34
P 7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
P 10	88	63	0	22	0	240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P 12	0	69	30	0	0	0	0	0	0	0	0	0	0	0	0	4	40	0	0	0	0
Q 4	0	34	0	0	0	0	0	0	110	0	0	0	0	0	0	0	0	0	0	0	0
R 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R 6	0	0	80	0	16	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0
R 7	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R 9	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 1	0	0	0	50~	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 2	0	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total in TM	89	530	985	72	517	491	255	33	110	0	0	12	206	318	661	219	360	117	335	812	464
total in non-TM	1150^	1190	1847^	783	810^	236^	991	1136	95	225	237	150	481	447	86	1125^	445^	83	386	148	702
total in all WTP paddocks	1239	1720	2832	855	1327	727	1246	1169	205	225	237	162	687	765	747	1344	805	200	721	960	1166
% ibis in TM	7%	31%	35%	8%	39%	68%	20%	3%	54%	0%	0%	7%	30%	42%	88%	16%	45%	59%	46%	85%	40%

* water was present, either from previous irrigation or recent heavy rain

~ ibis were foraging in ploughed bare earth

irrigation (or in some cases inundation from heavy rain) was occurring on at least one paddock, with ^ ibis observed on at least one of the irrigated paddocks

* recent heavy rain resulted in many paddocks being inundated at levels similar to irrigation

3.4 Influence of irrigation, vegetation type, time of year and Terrestrial Margin

Over 2013-2017, ibis responded to period (peak or non-peak), paddock condition (application of irrigation or ploughing) and vegetation type.

During the peak period (April-June) ibis were distributed among fewer paddocks than during the non-peak period (July-March), but were present in higher numbers per paddock. Most of the ibis present were in paddocks containing crops of various stages, however this type of paddock by far makes up the largest area compared to pasture and Terrestrial Margin paddocks.

The overall model showed that on average, paddocks that were being irrigated or ploughed had higher ibis densities than those that weren't (Figure 6, Appendix D).

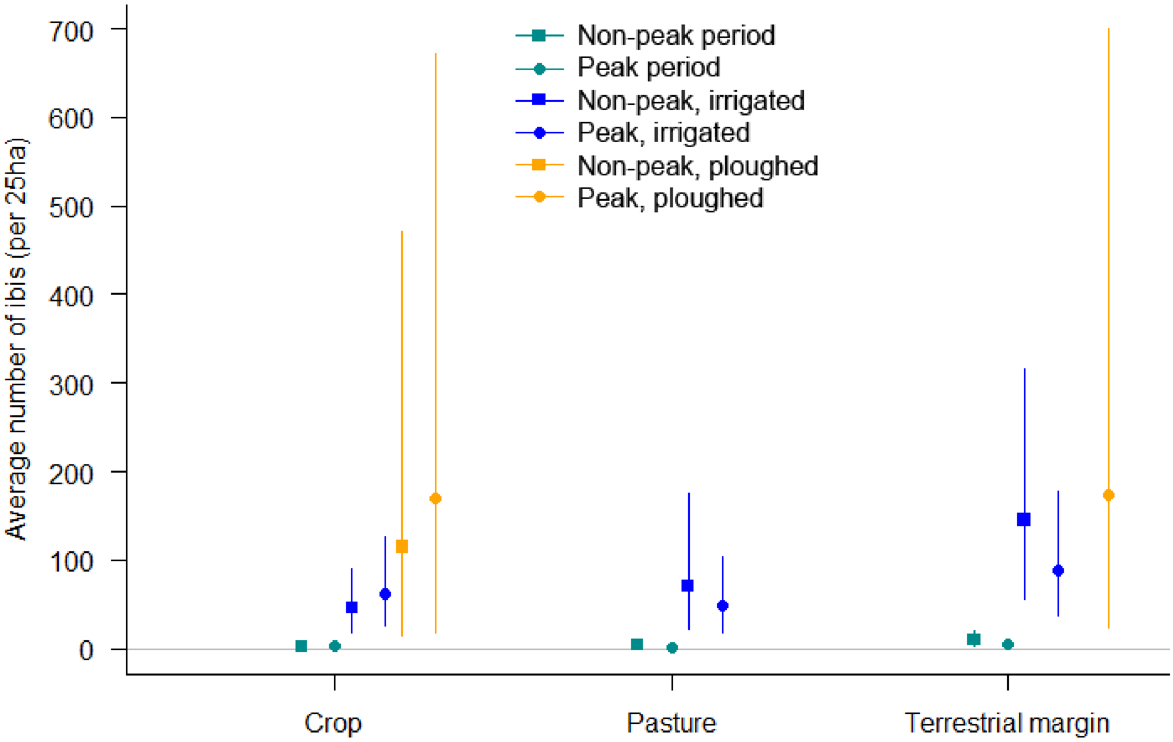

Figure 6: The modelled average number of ibis using paddocks of different types at the Western Treatment Plant under various conditions of season and management activities. Non-peak period = July-March, Peak period = April-June, Bars are 95% credible intervals.

The likelihood of ibis being present (detected) on a paddock was much higher if irrigation or ploughing was occurring (Figure 7), increasing the odds by factors of 9.4 (95% CI from 6.9 to 12.8) and 29 (95% CI from 7 to 122) respectively (Appendix D). Otherwise, paddocks were unlikely to have any ibis in them most of the time, and during the non-peak period, ibis were most likely to be in the Terrestrial Margin or pasture than crop paddocks.

For paddocks where ibis were detected, the number of ibis was influenced by the time of year, and whether irrigation was occurring (Figure 8). During the peak period, the number of ibis in an occupied paddock was 1.7 (95% CI from 1.2 to 2.6) times larger than during the non-peak period. Irrigation increased the abundance of ibis by a factor of 3 (95% CI from 2.1 to 4.4) compared to when no irrigation was being applied. The effect of ploughing was less clear due to the few times this activity was observed during surveys. Note that ploughing does not usually occur in the Terrestrial Margin – in this case it was part of paddock improvement works.

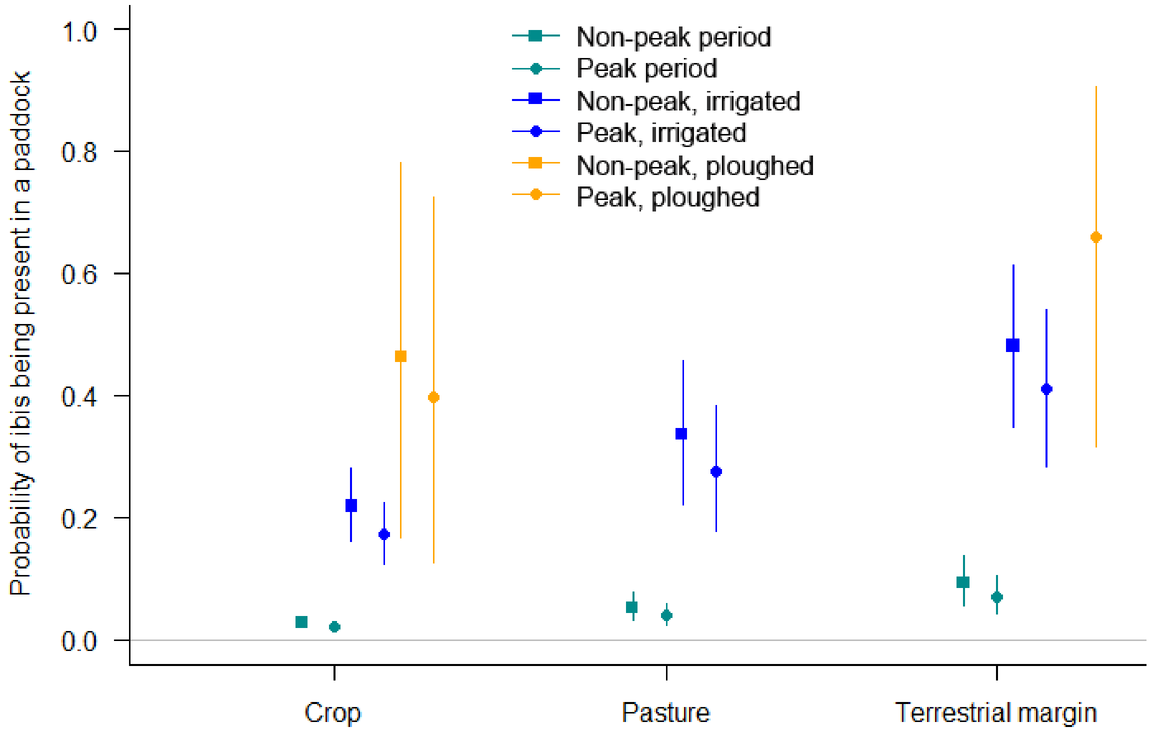

Figure 7: Probability of ibis being present on any of the paddock types of the Western Treatment Plant under various conditions of season and management activities. Crop = paddocks used for agricultural crops, Pasture = grassed paddocks managed for stock grazing, Terrestrial Margin = mixed vegetation managed for conservation; Non-peak period = July-March, Peak period = April-June. Bars are 95% credible intervals.

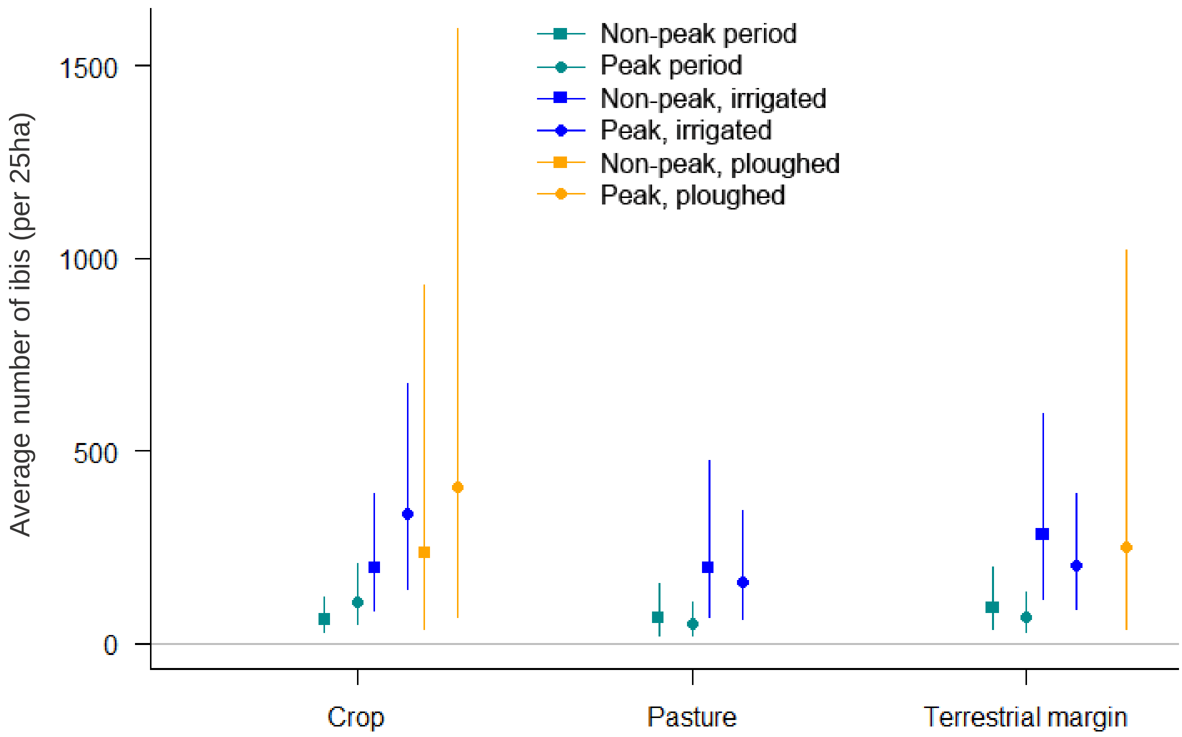

Figure 8: The modelled average number of ibis per 25 ha of paddock where ibis were detected at the Western Treatment Plant under various conditions. Crop = paddocks used for agricultural crops, Pasture = grassed paddocks managed for stock grazing, Terrestrial Margin = mixed vegetation managed for conservation; Non-peak period = July-March, Peak period = April-June.Bars are 95% credible intervals.

3.5 Influence of vegetation height

Modelling of vegetation height was shown to affect the likelihood of ibis being present in a paddock (Figure 9, Appendix D). Paddocks containing medium height vegetation were more likely to attract ibis than those with bare soil, or tall or very tall vegetation. Ibis were more likely to be in paddocks of short vegetation compared to those with tall or very tall vegetation. Paddocks with very tall vegetation were much less likely to contain ibis than all other categories. There was no difference in the probability of ibis being present between bare paddocks, those with short vegetation and those with medium vegetation. Any relationships between vegetation height, paddock type and ibis were not strong enough to be described by the model.

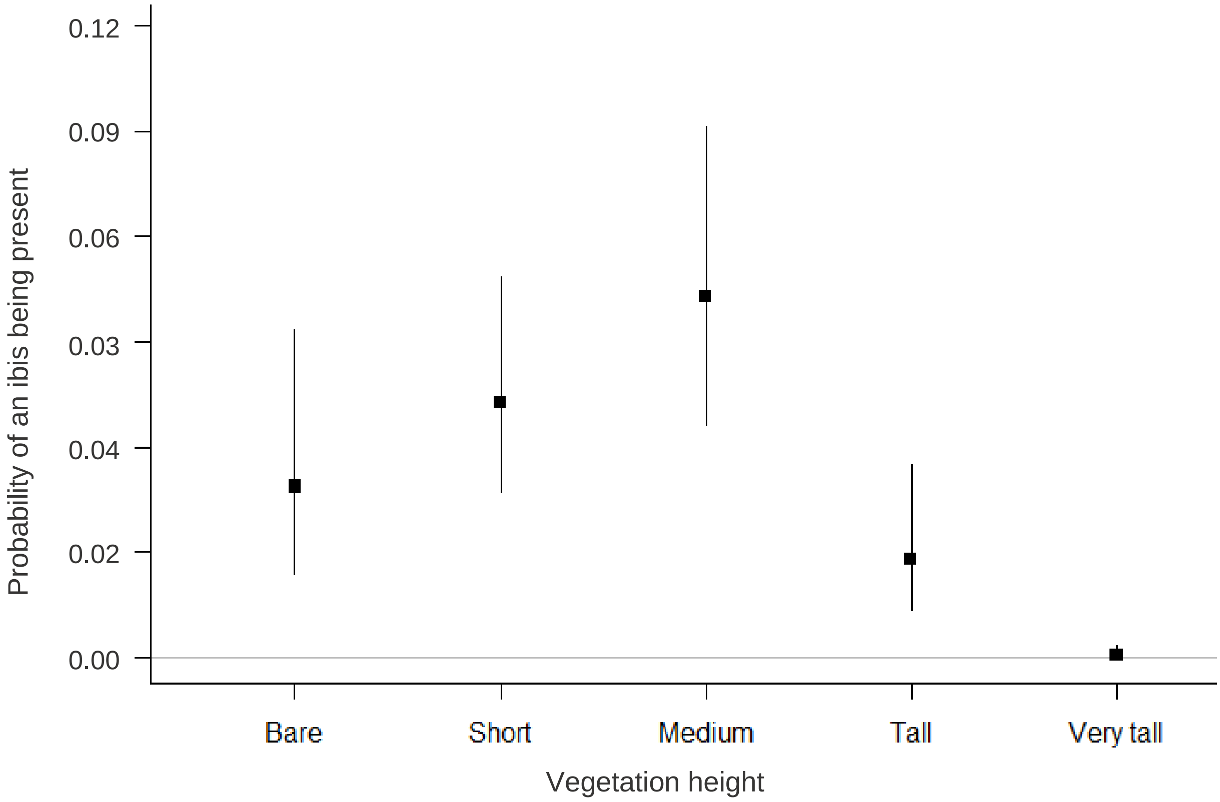

Figure 9: Modelled probability of ibis being present on a paddock at the Western Treatment Plant according to the height of the vegetation. Bare = exposed soil. Heights are relative to an adult ibis; Short = <15 cm, Medium = ~20-35 cm, Tall = ~35-45 cm, Very tall = >45 cm. Bars are 95% credible intervals.

3.6 Behavioural observations

Ibis adopted differing foraging behaviour in irrigated paddocks compared to those not being irrigated. In irrigated paddocks prey were nearly always picked from the ground surface and there were no observations of ibis probing deeply into the soil for prey. Individuals appeared to swallow several prey items per minute. Ibis picked some prey from the surface or vegetation in paddocks that were not being irrigated, but they also took some prey by probing deeply into the soil; in some pasture paddocks the only prey captures observed were achieved by deep probing. Prey intake rates appeared to be lower in paddocks that were not irrigated, but survey time was too limited to make quantitative assessments of foraging success.

Paddocks that were being ploughed at the time of surveys also appeared to be attractive to ibis, with birds foraging in the turned bare earth, picking up prey items such as worms (Figure 10). Incidental observations of ibis movements included seeing flocks moving between paddocks and areas outside the WTP, e.g. to crops beyond the eastern boundary. Flock movements were sometimes able to be attributed to disturbance by birds of prey.

Figure 10: Straw-necked Ibis foraging in the wake of a tractor ploughing a harvested paddock at the Western Treatment Plant. An earthworm can be seen in the beak of the ibis at the centre. (Photo: Danny Rogers)

4. Discussion

4.1 Influence of habitat variables on ibis foraging

It has long been observed that Straw-necked ibis are attracted to pasture to forage, especially when it is being irrigated (McKilligan 1979, ARI unpublished data). During this study, the application of flood irrigation water to a paddock clearly resulted in higher ibis use of that paddock. This was true for all paddock types, but particularly the Terrestrial Margin paddocks as ibis were more likely to be found on paddocks within this area than elsewhere on the WTP.

Vegetation height analysis from data collected in 2016 indicated that ibis were more likely to be found in short and medium height Terrestrial Margin paddocks and tall harvested paddocks (Macak et al. 2016). However, an extra years' data in 2017 indicates that the effect of vegetation height combined with paddock type may not be as strong as previously thought, highlighting the importance of conducting studies over several years to allow for differences between years. Although vegetation height data could not be analysed against ibis abundance, the effect of this attribute on ibis presence have implications for how some paddocks may be managed. The height of pasture in a paddock can be controlled via grazing; keeping grass to medium or short heights will increase the likelihood that ibis will forage there.

In 2015-2016, a larger number of ibis was seen during the historically defined, non-peak ibis period compared to the peak ibis period. This was the reverse of the usual pattern and may be due to the lack of irrigation from mid-May onwards on the Terrestrial Margin, and throughout the WTP. In addition, there was no large spike in ibis observed on a single day, as has occurred in many previous years during the peak period (Loyn et al. 2014, Macak et al. 2015). This pattern was also observed for the overall study period when considering Terrestrial Margin and pasture paddocks on their own. External factors may have had some effect, such as high rainfall, potentially creating alternative habitats outside the WTP. During 2017, a local heavy rain event that inundated the WTP coincided with the years' highest count of ibis, and the lowest count during the ibis peak period of the same year coincided with the absence of irrigation leading up to and including the day of the survey. It is possible that factors that led to the current definition of 'peak' and 'non-peak' have changed and caused a shift in within-year abundance patterns. On average, ibis distributed differently among paddocks of the WTP during the peak compared to non-peak period: during the peak period ibis were more abundant but congregated on fewer paddocks.

Although ploughing was not occurring very often during ibis surveys, the effect of this activity was partially quantified in our study, appearing to sometimes have an immediate effect of attracting large numbers of ibis. However, as this seems to be due to prey (particularly worms) becoming more accessible as the earth is turned, this effect is likely to be short lived.

Ibis appear to be resourceful and opportunistic in their use of the WTP paddock system. They have a strong preference for irrigated paddocks, probably tracking inflows of irrigation water to exploit the peaks it causes in readily accessible prey. They forage in some paddocks of the WTP when they are not irrigated, provided vegetation structure is suitable. Ibis are able to exploit the varied land use of the paddocks in the WTP. They forage in pasture, on harvested paddocks dominated by stubble and bare earth, and in crops. There is more to be learned about the structural characteristics of vegetation that are most suitable for foraging ibis; the data suggest that ibis avoid paddocks in which vegetation is taller than ibis height (McKilligan 1979, this study), including mature maize crops which are extensive in the WTP. Nevertheless, they can use a variety of shorter vegetation structures, and the chance of there being suitable habitat at any one time increases when different paddocks are managed in different ways.

4.2 Use of the Terrestrial Margin

This study highlights the value of the Terrestrial Margin as ibis foraging habitat, especially considering the small size of this area relative to the WTP paddock system (i.e. 9%). Nevertheless, the remainder of the paddock system on average held still larger numbers of ibis in total, indicating that the use of these paddocks is also important to maintaining ibis numbers at the WTP. Indeed, of the non-Terrestrial Margin paddocks, those containing pasture were also a proportionally larger contributor to the habitat where ibis were observed foraging than crops or harvested paddocks. This was particularly true for several individual paddocks (P8, P9, J7) that are immediately adjacent to the Terrestrial Margin. Habitats outside the paddock system were also used by large numbers of ibis at times.

4.3 Ibis and land management

Although the agricultural paddocks of the WTP provide many foraging opportunities for ibis, this is not their primary purpose, and it is likely that the amount of suitable habitat for ibis varies through the year. In autumn, for example, many paddocks probably become unsuitable for ibis because the maize crops become too tall. There is more flexibility to manage the Terrestrial Margin paddocks in a way that suits Straw-necked Ibis. This study demonstrated that ibis are adept at exploiting a rolling schedule of irrigation of the Terrestrial Margin paddocks. Management of this kind could therefore be used to ensure that there is suitable foraging habitat at the WTP for ibis, even at times when the agricultural imperatives may limit the amount of habitat suitable for ibis in other parts of the WTP. Increasing the area of pasture (or increasing the Terrestrial Margin) should provide extra opportunities for ibis; previous modelling on 2005–2007 ibis data suggested that reducing the area of pasture available as irrigated foraging habitat would result in a decrease in overall ibis numbers (Loyn et al. 2008). Given that pasture (outside the Terrestrial Margin) was a major component of foraging habitat, the 70% reduction in its extent over the four years of this study is likely to have reduced the overall number of ibis using the site.

Maintaining Terrestrial Margin paddocks to avoid dense tall grass is likely to be more favourable to ibis. Only a small number of Terrestrial Margin paddocks actually contain dense tall grass e.g. H2, with most paddocks containing shorter grass much of the time. When tall grass has been observed, it has often been part of a mixture with short and/or medium grass and not very dense.

Finally, although the terrestrial margin paddocks provide excellent ibis habitat when irrigated, they comprise only 9% of the paddock system of the WTP, with 67.8% of ibis observed in our study using other paddocks of the WTP. Clearly the agricultural paddocks remain of some importance to ibis, especially pasture paddocks where many ibis were recorded. We note in particular that a small number of paddocks consistently supported ibis flocks. Of those, paddocks P8, P9 and J7 that abut the Terrestrial Margin, were used as pasture during our study, and seemed to receive some spillover irrigation water from the Terrestrial Margin. To the eyes of field observers, they appeared to effectively (if not officially) to be part of the Terrestrial Margin and it would be helpful to continue managing these paddocks as they are managed at present.

4.4 Further research

The current irrigation schedule, as applied to the Terrestrial Margin during this study, appeared to be suitable for ibis, although many questions remain relating to duration and timing, as well as volume of water. Irrigation of a paddock makes it temporarily more attractive for ibis, but it is unclear for how long it remains suitable. For example, soil moisture content and nutrient levels may help determine the biomass or density of invertebrates that ibis feed upon (Davis et al. 2006). If ibis follow irrigation solely to exploit the easy pickings provided by prey being flooded from their burrows, the beneficial effects of irrigation might be quite brief, i.e. only a few days. If this is the key prey resource in irrigated paddocks, then presumably a period of non-irrigation may be important for populations of burrowing prey to rebuild. The duration of this potential prey replenishment period is unknown. Irrigation may also have longer term effects on vegetation structure and abundance of potential ibis prey.

Agricultural priorities may impinge on irrigation schedules, for example periods when cattle grazing is concentrated in paddocks including some of those within the Terrestrial Margin, means that irrigation is not applied on those paddocks for many weeks. In contrast, other paddocks where cattle are not being grazed may receive water many weeks in succession. Delivery of water can also be influenced by other aspects of water availability, such as heavy rainfall, which may see paddocks receive water more regularly than usual.

4.5 Recommendations

Based on the clear response of ibis to irrigation, their use of the Terrestrial Margin paddocks, and the agricultural priorities of the remainder of the WTP paddocks, it is recommended that the Terrestrial Margin continue to be irrigated with the objective of providing foraging habitat for ibis:

- Schedule irrigation (under current regimes) of the Terrestrial Margin such that it continues from at least December through autumn and early winter, (until the beginning of July) to ensure irrigation is occurring during the whole of the peak ibis period
- Apply irrigation to the Terrestrial Margin unless extremely heavy rainfall floods the paddocks
- Prevent Terrestrial Margin paddocks from becoming dominated by tall dense grass
- Evenly distribute irrigation among the Terrestrial Margin paddocks avoiding watering a given paddock in successive weeks
- Consider maintaining remaining non-Terrestrial Margin pasture as pasture, especially P8, P9 and J7, and prevent these from becoming too dense with tall grass

5. References

Burkner, P.C. (in press). brms: an R package for Bayesian Multilevel Models using Stan. *Journal of Statistical Software*.

Davis, C.A., Austin, J.E. and Buhl, D.A. (2006). Factors influencing soil invertebrate communities in riparian grasslands of the central Platte River floodplain. *Wetlands* **26** (2), 438–454.

DSE (2003). *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site: strategic management plan.* Department of Sustainability and Environment, East Melbourne, Victoria.

Carrick, R. (1959). The food and feeding habits of the Straw-necked Ibis, *Threskiornis spinicollis* (Jameson), and the White Ibis *T. molucca* (Curvier), in Australia. *CSIRO Wildlife Research* **4,** 69–92.

Fitzsimmons, L. (2010). Enhancement of Terrestrial Margin works plan. Internal document, MPH Agriculture Pty Ltd, Werribee, Victoria.

Gelman, A.B., Carlin, J.S., Stern, H.S. and Rubin, D.B. (2004). *Bayesian Data Analysis* (Second edition). Chapman and Hall/CRC, Boca Raton, USA.

Hamilton, A.J., Taylor, I.R. and Rogers, P. (2004). Seasonal and diurnal patterns in abundance of waterbirds at a waste stabilisation pond, Victoria. *Corella* **28** (2), 43–54.

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

Loyn, R.H., Macak, P., Hulzebosch, M., Swindley, R.J. and Stamation, K. (2009). *Use of habitat by ibis at the Western Treatment Plant: a summary of data, 2001–09.* Unpublished client report to Melbourne Water. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria.

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.

Macak, P., Loyn, R.H. and Lane, B.A. (2002). *Investigation into the use of filtration paddocks by ibis and other waterbirds at the Western Treatment Plant.* Unpublished client report to Melbourne Water. Arthur Rylah Institute for Environmental Research, Department of Natural Resources and Environment, Heidelberg, Victoria, and Brett Lane and Associates Pty Ltd, Mansfield, Victoria.

Macak, P.V. and Menkhorst, P.W. (2014). *Ibis management at the Western Treatment Plant: Terrestrial Margin irrigation trial – preliminary results 2014.* Unpublished client report to Melbourne Water. Arthur Rylah Institute for Environmental Research, Department of Environment and Primary Industries, Heidelberg, Victoria.

Macak, P.V., Rogers, D.I. and Menkhorst, P.W. (2015). *Straw-necked ibis use of the Western Treatment Plant paddocks: irrigation, cropping and the Terrestrial Margin.* Unpublished client report to Melbourne Water. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Macak, P.V., Rogers, D.I. and Menkhorst, P.W. (2016). *Straw-necked ibis use of the Western Treatment Plant paddocks 2015-2016: cropping, vegetation height and the Terrestrial Margin.* Unpublished client report to Melbourne Water. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Marchant, S. and Higgins, P.J. (eds) (1990). *Handbook of Australian, New Zealand and Antarctic Birds, Volume 1: Ratites to Ducks*. Oxford University Press, Melbourne, Victoria.

McKilligan, N.G. (1979). The ecology of the Straw-necked Ibis in winter at Toowoomba, south-east Queensland. *Sunbird* **10** (3-4), 49–57.

Melbourne Water (2015). Western Treatment Plant Terrestrial Margins management framework. Unpublished internal planning document 13 February 2015. Melbourne Water, Docklands, Victoria.

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. Department of Sustainability and Environment, Heidelberg, Victoria.

R Core Team (2017). *R: a language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. Retrieved from http://www.R-project.org

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A. and Smith, G.M. (2009). *Mixed Effects Models and Extensions in Ecology with R.* Springer Science+Business Media, New York, USA.

Appendix A Terrestrial Margin paddocks of the Western Treatment Plant

Names applied to the Terrestrial Margin paddocks (included in current study) of the Western Treatment Plant by Melbourne Water and MPH Agriculture Pty Ltd, showing current land management*.

MPH^	MPH crop grouping	Melbourne Water	Management~
A 8/9	A8/9	A-SECTION PADDOCK 8	Pasture
		A-SECTION PADDOCK 9	
E4	E4	E-SECTION PADDOCK 4	Pasture
E8	E8 & 9	E-SECTION PADDOCK 8	Pasture
E9	E8 & 9	E-SECTION PADDOCK 9	Pasture
H1	H1	H-SECTION PADDOCK 1	Pasture
H2	H2	H-SECTION PADDOCK 1	Dryland
J8	J8	J-SECTION PADDOCK 8	Pasture
O6	O6 & 7	O-SECTION PADDOCK 6	Pasture
O7	O6 & 7	O-SECTION PADDOCK 7	Pasture
P3	P3 & 7	P-SECTION PADDOCK 2	Pasture
		P-SECTION PADDOCK 3	
P7	P3 & 7	P-SECTION PADDOCK 7	Coastal saltmarsh
P10	P10 & 12	P-SECTION PADDOCK 10	Pasture
P12	P10 & 12	P-SECTION PADDOCK 11	Pasture
Q4	Q4	Q-SECTION PADDOCK 4	Pasture/wetland
R5	R5-9	R-SECTION PADDOCK 5	Coastal saltmarsh
R6	R5-9	R-SECTION PADDOCK 6	Pasture
R7	R5-9	R-SECTION PADDOCK 7	Pasture
R9	R5-9	R-SECTION PADDOCK 8	Pasture
S1	S1	S-SECTION PADDOCK 1	Pasture/Coastal saltmarsh
S2	S2	S-SECTION PADDOCK 2	Coastal saltmarsh
S4	S4	S-SECTION PADDOCK 4	Coastal saltmarsh

* according to Melbourne Water and MPH internal management documents e.g. Fitzsimmons (2010), Melbourne Water (2015)
^ used in statistical analysis
~ paddocks managed for coastal saltmarsh are in transition from pasture

Appendix B Ibis survey dates and observers

Survey dates and observers for long-term ibis monitoring, and the irrigation study at the Western Treatment Plant, March 2013 - June 2017

Survey date	Observer*	Purpose
5/03/2013	Phoebe Macak	Monitoring
9/04/2013	Phoebe Macak	Monitoring
7/05/2013	Phoebe Macak	Monitoring
4/06/2013	Phoebe Macak	Monitoring
9/07/2013	Phoebe Macak	Monitoring
26/11/2013	Phoebe Macak	Monitoring
11/02/2014	Phoebe Macak	Monitoring
15/04/2014	Phoebe Macak	Monitoring/Irrigation study
23/04/2014	Phoebe Macak	Irrigation study
30/04/2014	Phoebe Macak	Irrigation study
6/05/2014	Phoebe Macak	Monitoring/Irrigation study
13/05/2014	Phoebe Macak	Irrigation study
20/05/2014	Phoebe Macak	Irrigation study
3/06/2014	Phoebe Macak	Monitoring
9/12/2014	Phoebe Macak	Monitoring
3/02/2015	Phoebe Macak	Monitoring
19/03/2015	Peter Menkhorst	Monitoring
10/04/2015	Danny Rogers	Monitoring/Irrigation study
16/04/2015	Danny Rogers	Irrigation study
23/04/2015	Danny Rogers	Irrigation study
30/04/2015	Danny Rogers	Irrigation study
7/05/2015	Danny Rogers	Monitoring/Irrigation study
15/05/2015	Danny Rogers	Irrigation study
5/06/2015	Danny Rogers	Monitoring
10/07/2015	Danny Rogers	Monitoring
16/12/2015	Danny Rogers	Monitoring
4/02/2016	Danny Rogers	Monitoring
2/03/2016	Phoebe Macak	Monitoring
13/04/2016	Phoebe Macak	Monitoring
27/04/2016	NE = Danny Rogers; SW = Phoebe Macak	Irrigation study
4/05/2016	NE = Danny Rogers; SW = Phoebe Macak	Monitoring/Irrigation study
11/05/2016	NE = Danny Rogers; SW = Phoebe Macak	Irrigation study
18/05/2016	NE = Danny Rogers; SW = Phoebe Macak	Irrigation study
25/05/2016	NE = Danny Rogers; SW = Phoebe Macak	Irrigation study
1/06/2016	NE = Danny Rogers; SW = Phoebe Macak	Monitoring/Irrigation study
6/12/2016	Phoebe Macak	Monitoring
1/02/2017	Phoebe Macak	Monitoring
1/03/2017	Phoebe Macak	Monitoring
4/04/2017	Phoebe Macak	Monitoring
19/04/2017	Phoebe Macak	Irrigation study
27/04/2017	Phoebe Macak	Irrigation study
2/05/2017	Phoebe Macak	Monitoring/Irrigation Study
9/05/2017	Phoebe Macak	Irrigation study
16/05/2017	Phoebe Macak	Irrigation study
23/05/2017	Phoebe Macak	Irrigation study
6/06/2017	Phoebe Macak	Monitoring

* NE = north-east side; SW = south-west site of the WTP relative to Little River

Appendix C Details of statistical analyses

This appendix contains technical details of the statistical model used to determine how paddock attributes and conditions influenced the distribution of ibis across the paddock system. It is necessarily technical and some terms cannot be easily simplified. It has been included as a record of analytical methods applied during this study, and for reference for possible future studies.

We chose to use a hurdle model with a random component related to paddock. A hurdle model (Zuur et al. 2009) splits the model into two sections: the first models the probability that ibis will be detected (if present), the second models the number of ibis only at the paddocks where ibis were detected. The analysis was conducted using a Bayesian framework. The model has fixed effects of paddock type (cropping, pasture or Terrestrial Margin); ibis period (peak or non-peak ibis); and the current state of the paddock (no treatment, irrigated or being ploughed). Additionally, a model considering vegetation height (bare, short, medium, tall or very tall) where data are available (December 2015 to June 2017) was also constructed. Paddock was considered a random effect in the detection model. Year was considered a random effect in the abundance model.

The model for detection is a Bernoulli distribution with a random component for paddock, and expressed by,

$$
\begin{aligned}
X_{i,t} &\sim \mathrm{Bern}(p_{i,t}) \\
\mathrm{logit}(p_{i,t}) &= \alpha_{\text{Paddock type}} + \beta_{\text{Ibis period}} + \gamma\,\mathrm{State}_{i,t} + \varepsilon_i \\
\varepsilon_i &\sim \mathrm{N}(0, \sigma^2_{\text{Paddock}})
\end{aligned}
$$

where, $X_{i,t}$ is 0 if no ibis are detected and 1 if any ibis are detected at paddock i on visit t; $p_{i,t}$ is the probability that ibis are detected at paddock i on visit t; ε_i is the random component for paddock i.

The model for abundance is a truncated negative binomial distribution. This allows for the fact that it deals with only those paddocks where ibis are detected, so the smallest possible value is 1 (rather than 0 for the standard negative binomial model), and allows for possible over-dispersion. The model is,

$$
\begin{aligned}
Y_{i,t} &\sim \mathrm{TNB}(\nu_{i,t}, r) \\
\nu_{i,t} &= \frac{r}{r + \mu_{i,t}} \\
\log(\mu_{i,t}) &= \gamma_{\text{Paddock type,Ibis period}} + \eta\,\mathrm{State}_{i,t} + \xi_t \\
\xi_t &\sim \mathrm{N}(0, \sigma^2_{\text{Year}})
\end{aligned}
$$

where $Y_{i,t}$ is the number of ibis detected at paddock i on visit t; $\nu_{i,t}$ is the scale parameter; r is the aggregation parameter; ε_i is the random component for paddock i. The suitability of the model was confirmed by the value of the aggregation parameter (r) being very close to zero (0.426, Appendix C). A very large value for r corresponds to an absence of ibis aggregation, and would have suggested that a Poisson distribution may be more appropriate.

All models were fitted in a Bayesian framework using the *brms* package (Burkner in press) in *R* version 3.4.1 (R Core Team 2017). This uses Monte Carlo Markov Chains (MCMC), a class of algorithms for sampling from a probability based on constructing a Markov chain that has the desired distribution as its equilibrium distribution. It is a standard iterative technique for estimating posterior distributions in Bayesian models. Uninformative priors were used as prior distribution for all parameters. Four chains were used, each with 4000 iterations and a burn-in of 1000, without thinning, and convergence was checked. For detailed explanation of technical terms, see Gelman et al. (2004) and Burkner (in press). Convergence was defined as having all Gelman and Rubin's convergence diagnostic potential scale reduction factors being less than 1.05 (Gelman et al. 2004). A parameter is considered to have sufficient evidence of an impact on the model if the lower and upper 95% credible interval for a parameter excludes zero. The lower and upper 95% credible interval is constructed from the posterior distribution for that parameter.

Appendix D Hurdle model parameter statistics

Paddock type, ibis period, occurrence of irrigation or ploughing model, March 2013- June 2017

Model	Effect	Parameter	Estimate	Lower bound	Upper bound
Absence	Fixed	Intercept	3.529	3.269	3.808
Absence	Fixed	Paddock type: pasture	-0.590	-1.056	-0.114
Absence	Fixed	Paddock type: terrestrial margin	-1.211	-1.690	-0.718
Absence	Fixed	Period: peak	0.294	0.079	0.506
Absence	Fixed	State: irrigated	-2.243	-2.551	-1.935
Absence	Fixed	State: ploughed	-3.366	-4.804	-1.953
Absence	Random	sd (Paddock)	0.907	0.733	1.113
Abundance	Fixed	Intercept	0.864	0.226	1.527
Abundance	Fixed	Paddock type: pasture	-0.026	-0.752	0.792
Abundance	Fixed	Paddock type: terrestrial margin	0.362	-0.211	0.952
Abundance	Fixed	Period: peak	0.549	0.146	0.946
Abundance	Fixed	State: irrigated	1.107	0.749	1.492
Abundance	Fixed	State: ploughed	0.952	-0.315	2.623
Abundance	Fixed	Pasture and peak period	-0.722	-1.685	0.160
Abundance	Fixed	Terrestrial margin and peak period	-0.862	-1.589	-0.174
Abundance	Random	sd (Year)	0.592	0.217	1.528
Abundance	Aggregation	intercept	0.426	0.345	0.510

Absence parameters on logit scale. Abundance parameters on log scale.

Vegetation height model, December 2015 – June 2017

Model	Effect	Parameter	Estimate	Lower bound	Upper bound
Absence	Fixed	Intercept	3.398	2.711	4.134
Absence	Fixed	Vegetation: short	-0.419	-1.105	0.199
Absence	Fixed	Vegetation: medium	-0.789	-1.495	-0.102
Absence	Fixed	Vegetation: tall	0.566	-0.374	1.547
Absence	Fixed	Vegetation: very tall	4.678	2.618	7.706
Absence	Fixed	Period: peak	0.527	0.155	0.892
Absence	Fixed	State: irrigated	-2.491	-2.921	-2.047
Absence	Random	sd (Paddock)	1.031	0.774	1.329

Absence parameters on logit scale.

www.ari.vic.gov.au