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Waterbird movements and breeding success in the Macquarie Marshes, NSW 2016 -2017

Final Report May 2017

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Report submitted to the Commonwealth Environmental Water Office (CEWO), Department of Environment and Energy.

This project is funded as a short-term intervention monitoring project by the CEWO. It is also funded by the CEWO's Murray-Darling Basin Environmental Knowledge and Research (MDB EWKR) project Waterbird Theme (satellite transmitters), and by CSIRO Land and Water, with in-kind support from NSW OEH, UNSW, and UC.

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Acknowledgments

This project is funded by the Commonwealth Environmental Water Office (CEWO) and by CSIRO Land and Water, with in-kind support from the Royal Botanic Gardens Sydney, NSW OEH, UNSW, and UC. It was supported in order to add data for the Macquarie Marshes to a larger research program being undertaken by CSIRO, UNSW and University of Canberra, through the five-year Murray-Darling Basin Environmental Water Knowledge and Research (MDB EWKR) Project being managed by the Murray Darling Freshwater Research Centre and funded by the Commonwealth Environmental Water Office (DoEE). Specifically, funding was provided for: a) analysis of monitoring camera images focused on straw-necked ibis nests; b) fieldwork necessary for deployment of MDB EWKR satellite transmitters on five adult straw-necked ibis; and c) reporting of initial findings as of May 2017.

Satellite transmitters were fitted in the field by John Martin (RBGSyd), Heather McGinness, Micah Davies and Freya Robinson (CSIRO). Monitoring cameras were installed and maintained by Paul Keyte, Stephanie Suter and Jennifer Spencer (NSW OEH) with assistance from James Rees and Emily Webster (UNSW). Ray Jones kindly showed us his snaring method and lent us three of his snares and his camo net. We thank James Rees, Emily Webster and Bill Johnson for being flexible about timing of site access. Image data extraction was conducted by Melissa Piper and Heather McGinness (CSIRO). Mapping was designed and executed by Art Langston and Heather McGinness (CSIRO). Data analyses and report preparation were completed by Heather McGinness.

The Murray-Darling Basin Environmental Water Knowledge and Research (MDB EWKR) Project is funded by the Australian Government Commonwealth Environmental Water Office and managed by the Murray-Darling Freshwater Research Centre. The Waterbird Theme of MDB EWKR is a collaboration between the CSIRO, University of NSW, and University of Canberra. The Waterbird Theme is filling knowledge gaps with new data that will assist environmental water managers. It is co-ordinated by Heather McGinness (CSIRO) with a leadership group comprising Richard Kingsford and Kate Brandis (UNSW), Veronica Doerr (CSIRO) and Ralph Mac Nally (UC) providing research direction and design advice.

Executive summary

Environmental watering events in the Murray-Darling Basin target a range of environmental outcomes including supporting waterbird habitat and waterbird breeding events when they occur. Whilst knowledge exists regarding key breeding locations in the Basin and the flows required to trigger and complete nesting events, there is limited knowledge about nest success, bird movements, and associated drivers – particularly in terms of the relative influence of flow variables, habitat variables, pressures and threats. Flow regimes, water management and threats such as habitat change and habitat loss affect the availability (quantity and distribution) and quality of both breeding and foraging sites at multiple scales. These in turn will affect the survival of young birds and consequently population sizes and species diversity. However data describing waterbird demographics, foraging preferences, locations and movements are scarce, limiting our ability to predict the effects of changes in water management and threats to habitat.

This small project was funded separately but is complementary to a larger research program being undertaken by CSIRO, UNSW and University of Canberra, through the five-year Murray-Darling Basin Environmental Water Knowledge and Research (MDB EWKR) Project being managed by the Murray Darling Freshwater Research Centre and funded by the Commonwealth Environmental Water Office (DoEE). Specifically, funding was provided for: a) analysis of monitoring camera images focused on straw-necked ibis nests in the Macquarie Marshes; b) fieldwork necessary for deployment of MDB EWKR satellite transmitters on five adult straw-necked ibis in the Macquarie Marshes; and c) reporting of initial findings as of May 2017.

The wet conditions across the Murray-Darling Basin in late 2016 triggered multiple waterbird breeding events and provided a rare opportunity to measure and compare habitats and bird responses in both the Macquarie Marshes and Barmah-Millewa at the same time. Hence this project was designed to add value to the MDB EWKR project's research by collecting novel data for the Macquarie Marshes describing aspects of:

1. Where are waterbirds foraging during breeding, and/or where do they forage between breeding events? Such data would assist managers to identify critical foraging sites during and/or between breeding events, which may then be managed with environmental water.
2. How do the timing and rates of egg laying, chick hatching, development, survival and mortality vary, and what affects them? How do they differ between Barmah-Millewa and the Macquarie Marshes?
3. What impacts do predators have on nest success and how might we manage predators and other influencing factors (e.g. vegetation structure and water depth) to reduce impacts? How does this differ between Barmah-Millewa and the Macquarie Marshes?

The project focused on straw-necked ibis as a representative species of importance to managers. It was designed to provide Marshes-specific information about which locations were being used for foraging by straw-necked ibis and what influences nest abandonment and chick survival - and therefore which locations and processes may be managed more effectively in the future.

Two primary methods were used:

1. Motion-sensing and time-lapse camera nest monitoring
2. Deployment of satellite GPS transmitters to track bird movements

It is increasingly being recognised that fine details of motion-sensing and time-lapse camera settings, positions, and timing of deployment have significant consequences for the data that can be collected. In this case, cameras were set up in the Macquarie Marshes for multiple purposes, not just to provide data on detailed nest-level reproductive parameters for this project. Unfortunately, the consequence was that camera data were only of limited utility for addressing the questions of the MDB EWKR project and the potential for cross-site comparisons was limited. Despite these limitations, the dataset did yield results of interest describing aspects of chick development stages by date, clutch sizes and egg and young chick survival. In general, hatching rates were high at monitored nests (86%), as were chick survival rates, at least at the earlier chick stages for which camera data were more reliable (97% of young chicks were still alive when monitoring ended). True chick survival is almost certainly lower than these estimates due to the short duration of monitoring by some cameras. At the time that monitoring ended, an average of two chicks had survived per straw-necked ibis nest, and an average of three chicks had survived per royal spoonbill nest. Given the limited utility of the camera data for the purposes of addressing the questions of the MDB EWKR project, it was not possible to explore details of how the timing and rates of egg laying, chick hatching, development, survival and mortality vary, and what affects them. However some aspects of the dataset will be useful for future comparisons between Barmah-Millewa and the Macquarie Marshes as part of the MDB EWKR project.

Very few mortalities were observed directly and none were due to predation. Most mortalities occurred during the egg stage. The majority were attributable to abandonment, with some also resulting from trampling, starvation or neighbouring ibis. This should not be taken to mean that predation did not occur in the colony. The camera limitations discussed previously are likely to have reduced the chance of detecting predation; the number of cameras and the areas monitored by cameras were very limited; and the timing of monitoring did not cover the full breeding season. Foxes, pigs, cats and raptors were all observed in or adjacent to the Monkeygar colony. Other Macquarie Marshes colonies were reportedly subject to predation at much higher rates, with observations indicating that falling water levels provided easier access to certain parts of those colonies for pigs in particular (Brandis et al. in prep. 2017). However it can be difficult to distinguish between the damage done by various predators after the fact and it is likely that foxes, cats and raptors were also taking eggs and/or chicks. Analyses to be conducted as part of the broader MDB EWKR project will also explore other variables potentially influencing nest success rates, including nest exposure to weather and predation, parental behaviour and disturbance.

Satellite GPS tracking of straw-necked ibis from the northern and southern basin (Macquarie Marshes and Barmah-Millewa Forest) in 2016-2017 has already advanced our knowledge of previously unknown or poorly understood ibis movement and population patterns and trends. This includes documenting long-distance movements, with northern and southern birds mixing and using some of the same sites and routes. This indicates that straw-necked ibis in the MDB may be one integrated population. However this year may be unusual with the extent and duration of flooding that occurred. This will need to be investigated with tracking in subsequent years and with more birds. Another novel outcome has been identification of potential common ‘flyways’ or movement corridors for separate birds/groups. Six of the 10 Geotrak adults and three of the juveniles have travelled along a NE-SW route (at least partly), in different directions. This route corresponds to zones / boundary lines in maps of average climatic conditions, rainfall, topography, etc. Key foraging and stopover points and regions such as the Lachlan River near Condobolin have been identified, including re-use of some sites by different birds at different times in both VIC and NSW. ‘Pairing’ of habitats for roosting and foraging has also been observed, with ideal foraging habitats (agricultural or native) being near remnant vegetation with large trees for roosting. There are also apparent movement associations with weather, with similarities in departure times and departure dates for longer trips that are probably associated with thermals, as indicated by distances travelled per hour by time of day. Weather changes may also trigger long-distance movements.

In the Macquarie Marshes, satellite tracking indicates that foraging may occur up to 50 km from the nest site. Foraging is likely to occur closer to the nest site early in chick development, progressing to locations further from the nest site as chicks develop and as adults prepare to leave the area. Foraging sites in the Marshes area are generally private grazing land or wetlands.

As tracking of these birds continues through the MDB EWKR project, data will continue to be collected and analysed in order to identify and describe:

- Critical foraging, roosting and stopover sites
- Critical habitat characteristics (nesting, foraging, roosting, stopover)
- Foraging trip distances
- Critical routes/movement corridors
- Land and water management actions/policies required to support the above

The results of these analyses will then be used to provide recommendations to water and land managers in the Macquarie Marshes and other sites and at basin scale. Given time, these data will also help to fill basic biological and ecological knowledge gaps.

Regular project updates will continue to be funded and provided as part of the MDB EWKR project via email to CEWO, NSW OEH, MDBA and other interested parties at least fortnightly, including highlights, maps of bird tracks and locations and an updated table of bird locations, movements and fates. A website has been created and made publicly available containing detailed project information, FAQs, photographs and satellite tracking maps. This website is regularly updated with new information and maps. A facebook page and twitter account have also been created and made publicly available in order to more broadly and generally disseminate information and photographs and highlight waterbird-relevant information and studies in Australia.

1 Introduction

Environmental watering events in the Murray-Darling Basin target a range of environmental outcomes including supporting waterbird habitat and waterbird breeding events when they occur. Whilst knowledge exists regarding key breeding locations in the Basin and the flows required to trigger and complete nesting events, there is limited knowledge about nest success, bird movements, and associated drivers – particularly in terms of the relative influence of flow variables, habitat variables, pressures and threats. Flow regimes, water management and threats such as habitat change and habitat loss affect the availability (quantity and distribution) and quality of both breeding and foraging sites at multiple scales. These in turn will affect the survival of young birds and consequently population sizes and species diversity. However data describing drivers and responses are scarce, limiting our ability to predict the effects of changes in water management and threats to habitat.

A recent literature review (McGinness 2016) confirmed that the largest of these gaps in knowledge are:

1. Demographics

- Survival and mortality rates, especially of fledglings and juveniles (and therefore recruitment)
- Population age structures and sex ratios
- Population and sub-population boundaries

2. Movements

- Immediately following and between breeding events – timing, distances travelled, differences between juveniles and adults, site fidelity, key foraging habitat locations and characteristics, effects of habitat availability, quality and productivity on bird condition and survival
- During breeding events – distances travelled, habitat characteristics, effects of habitat availability, quality and productivity on breeding site choice, site fidelity, event size and success
- Mechanisms, cues or drivers behind bird movements and choices and how these interact

3. Effects of interactions between flow-related drivers of waterbird responses and other stressors, pressures or threats, especially:

- Habitat loss, fragmentation and change
- Predation - rates, species, and timing
- Climate change and adverse or extreme weather

These knowledge gaps exist even for common and conspicuous taxa such as colonially-nesting waterbirds that are often thought to be relatively well-understood.

Filling these knowledge gaps will assist managers to:

- Identify, maintain, and/or restore key waterbird habitats – especially critical foraging habitats
- Better understand the spatial and temporal scales at which key habitat characteristics are required
- Better target water, vegetation and threat management actions to ensure 'event readiness' at nesting sites between flooding events and maximise waterbird recruitment
- Better predict the effects of water management and threats

Objectives

This project is complementary to a larger research program being undertaken by CSIRO, UNSW and University of Canberra, through the five-year Murray-Darling Basin Environmental Water Knowledge and Research (MDB EWKR) Project being managed by the Murray Darling Freshwater Research Centre and funded by the Commonwealth Environmental Water Office (DoEE). Specifically, funding was provided for: a) analysis of monitoring camera images focused on straw-necked ibis nests in the Macquarie Marshes; b) fieldwork necessary for deployment of MDB EWKR satellite transmitters on five adult straw-necked ibis in the Macquarie Marshes; and c) reporting of initial findings as of May 2017.

The wet conditions across the Murray-Darling Basin in late 2016 triggered multiple waterbird breeding events and provided a rare opportunity to measure and compare habitats and bird responses in both the Macquarie Marshes (northern basin) and Barmah-Millewa Forest (southern basin) at the same time. Hence this project was designed to add value to the MDB EWKR Project's research by collecting novel data for the Macquarie Marshes describing aspects of:

1. Where are waterbirds foraging during breeding, and/or where do they forage between breeding events? Such data would assist managers to identify critical foraging sites during and/or between breeding events, which may then be managed with environmental water.
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The project focused on straw-necked ibis as a representative species of importance to managers. It was designed to provide Marshes-specific information about which locations were being used for foraging by straw-necked ibis and what influences nest abandonment and chick survival - and therefore which sites and processes may be managed more effectively in the future.

Study area context and conditions

The Macquarie catchment experienced hot and dry conditions between spring 2012 and autumn 2016, with very much below average rainfall over the period and above average to very much above average maximum temperatures across the region. A combination of NSW and Commonwealth environmental water was delivered to the Macquarie River and Macquarie Marshes (Figure 1) during these dry years to help support native fish in the river channel and the inundation of core wetland areas in the Marshes.

Conditions began to change in May 2016, with above average to highest on record rainfall over winter and spring, with particularly high rainfall in June and September 2016. Maximum temperatures were also average to below average over winter. Burrendong Dam filled to 100 per cent of capacity on 4 September 2016 (up from 11 per cent of capacity in early May). Good rainfall, tributary flows and releases under airspace operations of the Flood Mitigation Zone in Burrendong Dam in late 2016 and early 2017 contributed to widespread inundation in the Macquarie Marshes. All areas of river red gum woodland in the Marshes were inundated, improving the condition of wetland vegetation. Flooding triggered large-scale colonial and general waterfowl breeding, with at least 21 colonies recorded in the Marshes. Colonies included two large straw-necked ibis colonies, two large egret colonies, a large royal spoonbill colony, plus various smaller colonies of herons, Australian white ibis, glossy ibis, and cormorants. Releases made from the Flood Mitigation Zone (FMZ) in Burrendong Dam along with local rainfall were sufficient to support two large breeding colonies of straw necked ibis and other than a small volume of Commonwealth supplementary environmental water delivered in December, no additional environmental water was delivered during those releases. Managed environmental water (a mix of NSW and Commonwealth water sources) was delivered immediately following the cessation of Flood Mitigation Zone flows (late January to mid-February) to maintain water levels in key colonial waterbird colonies and foraging areas. In particular, water was used to support those later nesting birds that had not fully completed breeding, for example egrets, night heron, cormorants and some spoonbills.

Conditions began to dry again over summer 2016-17, with average to very much below average rainfall, and very much above average to highest on record maximum temperatures. However, rainfall in March 2017 was average to above average across the catchment. A combination of NSW and Commonwealth environmental water was delivered in April and May 2017 as part of two separate actions to support native fish in response to natural tributary flows resulting from increased rainfall. Environmental water was used to: support the post spawning dispersal of native fish in the mid-Macquarie River and Marshes; and a few weeks afterwards, to provide connectivity between the lower Macquarie and Barwon rivers to support opportunities for the movement of native fish between the catchments.

This report details results from on-ground remote camera monitoring conducted from October to December 2016, and satellite tracking data collected from October 2016 – May 2017.

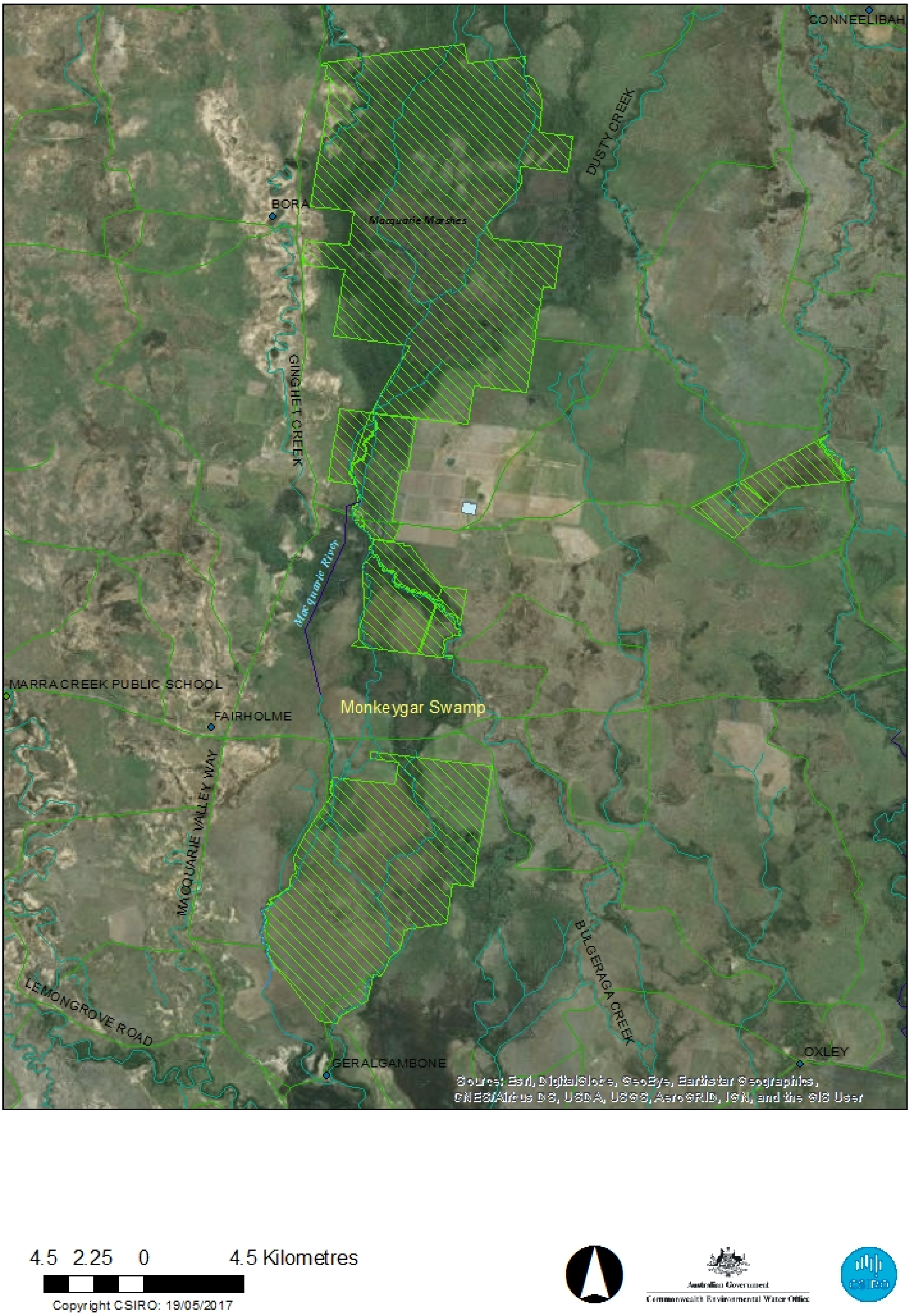


Figure 1 The Macquarie Marshes nature reserves NSW, highlighted in green hatch

2 Methods

Motion-sensing and time-lapse camera nest monitoring

The primary steps for this component were:

a. Site selection, camera deployment and maintenance – NSW OEH
b. Image sharing for communications purposes – NSW OEH
c. Image processing and data extraction – CSIRO
d. Data analysis - CSIRO
e. Reporting – CSIRO with NSW OEH

The CEWO funded data extraction from monitoring cameras deployed by NSW OEH in the Macquarie Marshes in 2016 as well as analyses that could be performed from the resulting images. CSIRO has established protocols and datasheets for monitoring camera deployment as part of the MDB EWKR project as these details have a significant influence on the data that can subsequently be obtained from the images. These protocols and datasheets were supplied to NSW OEH (Appendix 2). It was intended that deployment of cameras in the Macquarie Marshes by NSW OEH and in Barmah-Millewa by the MDW EWKR project in the same year would provide an opportunity to compare site differences in parameters such as chick development rates, mortality and survival, feeding rates, disturbance, nest attendance, water level changes, nesting habitat choices, predation rates and predator species. Camera deployment also acted to augment more extensive on-ground nest success surveys conducted by UNSW in other parts of the Macquarie Marshes (Brandis et al. in prep. 2017). On-ground nest surveys were not conducted in the same locations as the monitoring cameras; therefore survival rates calculated from the monitoring cameras are likely to differ from those calculated from on-ground visits.

Fifteen Reconyx monitoring cameras were deployed in Monkeygar swamp on the 7th and 10th of October (Figures 2-3), with ten set as time-lapse and five set as motion-sensing. Professional Camera Settings Software available from the Reconyx website was used to apply the recommended settings prior to the commencement of fieldwork. Due to the need to balance multiple purposes of the cameras, the final settings and placement differed from those used in the MDB EWKR project. Specifically, it was difficult to find areas suitable for positioning of cameras to focus on limited numbers of nests, and consequently cameras were set at different angles and facing a larger number of nests than those used in Barmah-Millewa. As a result, the motion sensing function triggered more frequently, the SD memory cards filled up more frequently, and the batteries flattened after shorter periods of deployment. The time-lapse cameras also had problems with settings and battery life in the field. The team attempted to rectify this problem where possible in subsequent weeks, but this resulted in a gap in data coverage between early and late October when many eggs hatched in the surveyed portion of the Monkeygar colony. The result was that the time over which nests were monitored was more limited, fewer details could be discerned on a per-nest basis, and the utility of the images for addressing MDB EWKR questions and comparing with Barmah-Millewa was limited.

SD cards were collected from the cameras in December 2016, and the images supplied to CSIRO in February 2017. Processing of the images was completed at the end of March 2017.

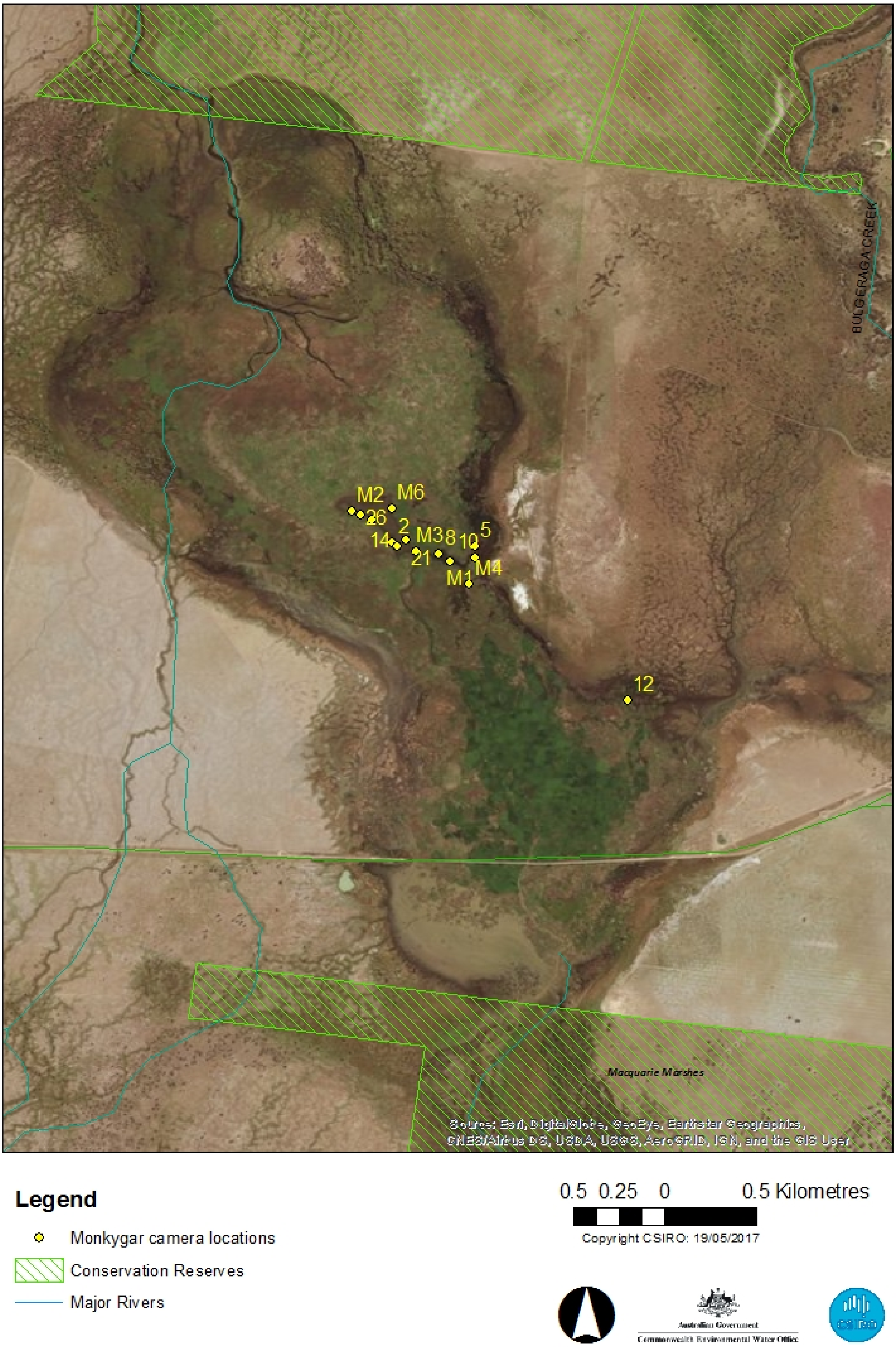


Figure 2 Camera locations, Monkeygar swamp, Macquarie Marshes NSW

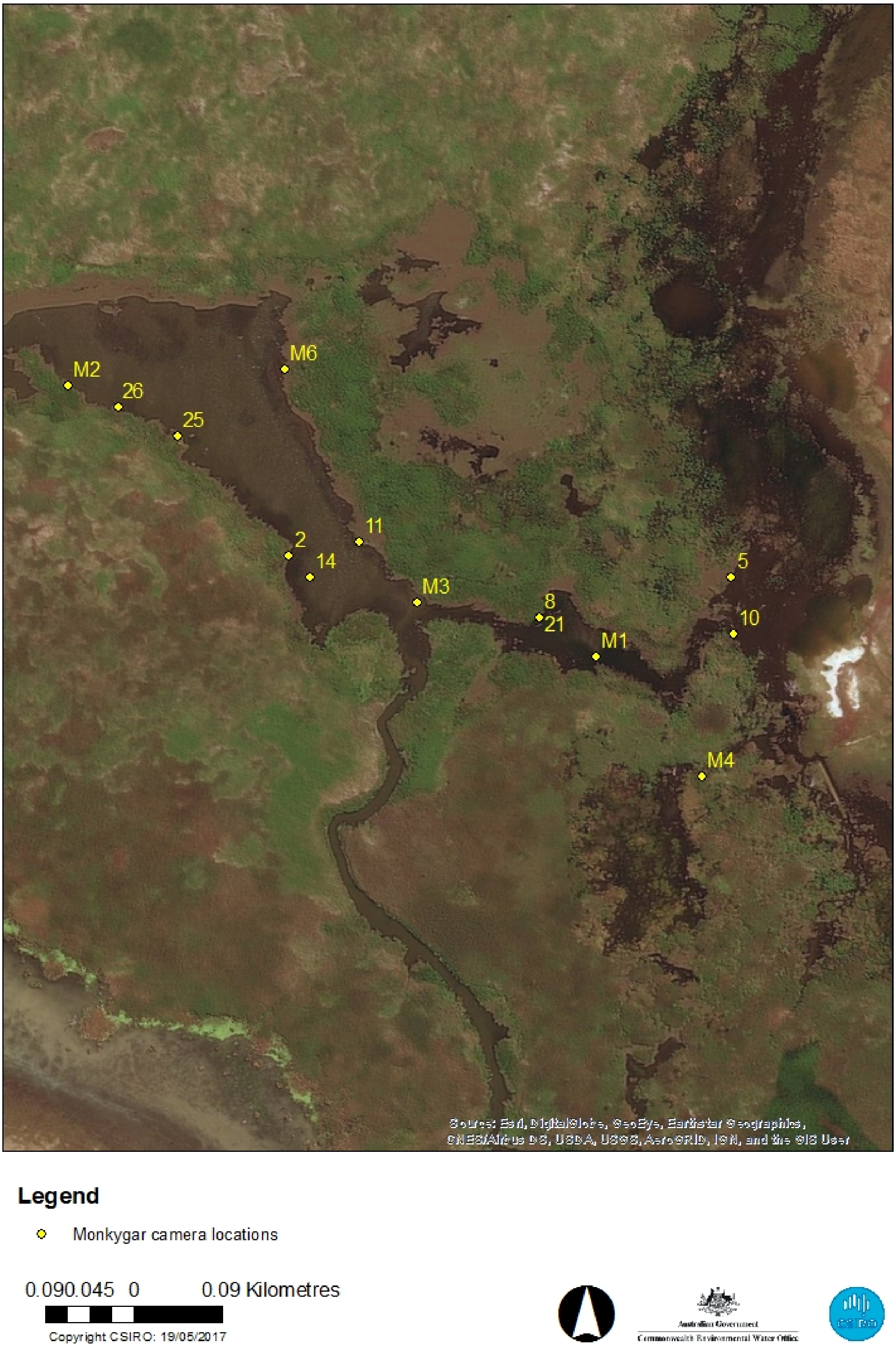


Figure 3 Close-up of camera locations, Monkeygar swamp, Macquarie Marshes NSW

Deployment of satellite GPS transmitters to track bird movements

The MDB EWKR project funded purchase and maintenance of 20 GeoTrak ARGOS GPS tracking transmitters in the 2016-17 breeding season – 10 for adults, and 10 for juveniles, with hourly location fixes and at least two years longevity.

While the plan was to deploy all MDB EWKR transmitters in Barmah-Millewa forest this year, the EWKR Waterbird Theme leadership decided that with the large breeding event occurring in the Macquarie Marshes, it would be worthwhile to deploy 5 GeoTrak ARGOS transmitters on adult ibis in the Macquarie Marshes (and the remainder in Barmah-Millewa). These provide managers with information on individual bird movements in and around the Marshes, dispersal routes and stopovers, and potential site philopatry. The 2016 breeding event was an opportunity to gain some information about where ibis from the Marshes go vs where ibis from the Barmah-Millewa go in the same year. Data are collected for as long as the transmitters stay with the birds and continue to function. Detailed analyses are being conducted as part of the MDB EWKR project during 2018 and 2019, with a final report due in June 2019.

The CEWO funded the additional fieldwork necessary for deployment of transmitters in the Macquarie Marshes in 2016. The primary steps for this component were:

a. Bird capture and transmitter attachment – CSIRO with John Martin (RBGSyd)
b. ARGOS data downloads and mapping – CSIRO
c. Data analysis – CSIRO with collaborators in the MDB EWKR Waterbird Theme
d. Reporting – CSIRO with collaborators in the MDB EWKR Waterbird Theme

Colonially-breeding waterbird species are the primary targets for recruitment data collection, because:

- they are one of the main waterbird target groups for environmental flows management and policy
- recruitment response variables are more easily measured for these than for other species, because breeding events and nests for these species are easier to locate and survey. Locations of major colonies are known, as are some of the breeding thresholds related to flows and inundation. Consequently the project is more likely to be able to improve the knowledge base for management within a reasonable budget and timeframe
- surveys of recruitment for these species are likely to cover a greater proportion of each population than for other species (e.g. ducks) where breeding is widely distributed, making interpretation more reliable
- the effects of predation and other threats on these species are likely to be more easily measured because their nests, eggs and fledglings are more visible
- there is good evidence that this group of waterbirds provides a reasonable model for understanding relationships between environmental flows and waterbird recruitment.

Straw-necked ibis (*Threskiornis spinicollis*) were chosen for satellite-tracking because they are good representatives of the above list, are known to nest in large numbers in nearly all major MDB wetlands managed with environmental flows, and are a species of particular interest to managers. Straw-necked ibis have spectacular rainbow-hued iridescent dark feathers on their wings and back, and distinctive straw-like feathers on their necks. They forage for prey in a range of habitats including wetlands, rivers, grazing lands, crops (fallow and growing), dairies, piggeries, sports grounds and rubbish dumps. They are known as the 'Farmer's friend' because when on agricultural land they eat large quantities of pest insects such as locusts. When in wetlands they eat frogs, aquatic insects, spiders, fish, molluscs and small reptiles. They are generally thought to be less adaptable and opportunistic than Australian white ibis (*Threskiornis molucca*), don't scavenge as much and tend to avoid saltwater areas. They are highly mobile and nomadic, and appear to have closer ties with inland floodplains and wetlands than white ibis.

The transmitters record hourly GPS location fixes between 7am and 7pm, plus a midnight fix to record roosting/nesting locations. They have an accuracy of approximately 10 metres. They are solar-charged, and are expected to transmit for at least two years. Location fixes are recorded and stored for 36 hours, and then transmitted during an 8-hour window via the ARGOS satellite system.

Five satellite GPS transmitters were deployed on adult straw-necked ibis in the Macquarie Marshes – two females and three males (Table 1). They were observed post fitting of transmitters and flew strongly with no physical issues. All five birds were caught on nests with eggs only. Each bird was sexed, weighed, measured for bill and head+bill length and photographed.

Each bird was also leg-banded (Figure 4). Every bird has an orange band over a stainless steel numbered band on its right tibia (above the knee) – the orange indicates that it is a bird from our study. Every bird also has two colour bands on the left tibia – light green to indicate that it is from this first group banded in the Macquarie Marshes, and another colour (green, white, black, yellow, or light blue) to identify the individual. Bird names were chosen by the field team and are loosely based on the first letters of the colours of each bird's unique leg-bands. For example, 'Gracy' has leg bands that are Green over Yellow, and 'Bridget' is Blue over Red. Birds were given names as memory-aids and also for communications and community engagement purposes.

Regular satellite tracking updates have been provided via email to CEWO, NSW OEH, MDBA and other interested parties at least fortnightly, including highlights, maps of bird tracks and locations and an updated table of bird locations, movements and fates. A website has been created and made publicly available containing detailed project information, FAQs, photographs and satellite tracking maps. This website is regularly updated with new information and maps. A facebook page and twitter account have also been created and made publicly available in order to more broadly and generally disseminate information and photographs and highlight waterbird-relevant information and studies in Australia.

Website: https://research.csiro.au/ewkrwaterbirds/

Facebook: https://www.facebook.com/ColonialWaterbirdScience/

Twitter: @AusWaterbirds

Please report any sightings of banded birds or birds with transmitters to **Heather McGinness: 0428124689 or the Australian Bird and Bat Banding Scheme (ABBBS) (02) 6274 2407** abbbs@environment.gov.au**.**

a) b)

Figure 4 a) An example of the banding system; b) A 55g adult transmitter with neoprene feather pad and harness

Table 1 Birds fitted with satellite transmitters and leg bands in the Macquarie Marshes, October 2016.

Birds were named for ease of internal project communication, with names based on the colours of their unique individual leg bands on the left tibia, e.g. Green and White = Gough Whitlam

Date	25-Oct	26-Oct	26-Oct	27-Oct	28-Oct
Name	Gracy	Gill	Gough Whitlam	Galaxy	Gigi
Sp. (SNI, RSB)	SNI	SNI	SNI	SNI	SNI
Sex M/F	F	M	M	F	M
Age	>3	>3	>3	>3	>3
Bird wet/dry (W/D)	W	W	W	W	D
Bird in bag (g)	1910	2000	1780	1620	1610
Bander	JM	JM/HM	JM/FR	JM/MD	MD/HM
Band #	121-60751	121-60753	121-60752	121-60754	121-60755
Right tibia band colours	OM	OM	OM	OM	OM
Left tibia band colours	GY	GL	GW	GX	GG
Feather samples (Y/N)	Y	Y	Y	Y	Y
Transmitter brand	GEOTRAK	GEOTRAK	GEOTRAK	GEOTRAK	GEOTRAK
Transmitter #	165117	165119	165116	165118	165111
Bill (mm)	129	173	171	141	160
Head+bill (mm)	175	228	219	190	207
Bag wgt (g)	140	150	160	125	140
Bird wgt (g)	1770	1850	1620	1495	1470
PTT wgt (g)	55	55	55	55	55
PTT % Bird	3	3	3	4	4

3 Results

Motion-sensing and time-lapse camera nest monitoring

Fifteen Reconyx monitoring cameras were deployed in Monkeygar swamp on the 7th and 10th of October 2016 (Table 2). A total of 65 nests were monitored, for varying periods. The majority (62) were straw-necked ibis nests; two were royal spoonbill nests; and one was an Australian white ibis nest that was monitored for four days. All monitored nests were built in and with common reed (*Phragmites australis*). The number of nests in view ranged from 15 to 100. The number of days of useful images ranged from 0 to 68 per camera. The total number of images taken per camera ranged from 319 to 57,201 (Table 2).

The duration of camera monitoring at each nest ranged from one to 68 days, but was often short (Table 3) and the dataset was complex because of variation in camera setup, camera settings, and memory and battery limitations. For some cameras there was a gap in data collection at the time when eggs were hatching, and by the time monitoring commenced chicks were creching and moving about between nests, making it difficult to tell to which nest they belonged. Consequently most cameras did not provide a continuous record of activities at each nest throughout the breeding period and the dataset was limited for the purpose of quantifying nest fates. Data extraction was ceased once it became impossible to tell which chicks came from which nest. Despite these limitations, the dataset did yield results of interest describing aspects of chick development stages by date, clutch sizes and egg and chick survival.

Table 2 Camera deployments and characteristics

Name	Dep. No.	Deployment date	Mean water depth (cm)	Estimated no. nests in view	No. days of useful images	No. photos
2	1	10/10/2016	79	50	1.85	17752
2	2	26/10/2016	79	50	20	574
5	1	7/10/2016	32	40	68	841
8*	1	7/10/2016	77	25	7	49846
10	1	7/10/2016	47	22	19	28190
10	2	25/10/2016	47	22	28	40721
11	1	10/10/2016	53	19	1	34126
11	2	26/10/2016	53	19	18	575
12	1	10/10/2016	43	30	1	11063
14	1	7/10/2016	58	19	6	26096
14	2	25/10/2016	58	19	9	57201
21*	1	6/10/2016	83	NA	NA	1917
25	1	27/10/2016	73	32	12	575
26	1	10/10/2016	61	15	1	7513
26	2	25/10/2016	61	15	2	12476
M3	1	7/10/2016	92	100	18	744
M1	1	7/10/2016	32	24	23	36872
M2	1	10/10/2016	72	30	66	774
M4	1	10/10/2016	20	48	66	713
M6	1	10/10/2016	19	40	65	733
M6	2	14/12/2016	19	40	29	319

*Cameras 21 and 8 were located together. It was not possible to use the images from Camera 21 because it wasn't taking photos from deployment 6/10/2016 until 24/10/2016. From the second deployment chicks were creching and moving around making it impossible to tell numbers for each nest.

Table 3 The number of straw-necked ibis and royal spoonbill nests monitored for 1 to 68 day durations

	Number of nests	
Number of days monitored	**Royal spoonbill**	**Straw-necked ibis**
1		10
4		3
5		4
7		4
12		4
13		5
18		5
22		4
34		5
45		4
60	2	
65		5
68		4

As part of the image processing, the nests closest to each camera are each assigned an individual ID, e.g. 'MM003'. The nests closest to the camera are used for data extraction and analysis because bird and predator movements at these are more likely to trigger image captures via motion-sensing within similar levels of sensitivity, thereby increasing data comparability and consistency across nests. The images below show examples of the view of each camera and the nests for which unique IDs were assigned.

Camera '2', first deployment

Camera '2', second deployment

Camera '10', first deployment

Camera '10', second deployment

Camera '11', first deployment

Camera '11', second deployment

Camera ‘14’, first deployment	Camera ‘14’, second deployment

Camera ‘26’, first deployment	Camera ‘26’, second deployment

Camera ‘Monkey 1’	Camera ‘5’

Camera ‘8’

Camera ‘12’

Camera ‘25’

Camera ‘M3’

Camera ‘M4’

Camera ‘M6’

Camera ‘M6’ prior to construction of nest ‘60’

Camera ‘M6’ after construction of nest ‘60’

Camera ‘M2’

Development stages by date

The straw-necked ibis colony in Monkeygar was well advanced when cameras were deployed in early October, with many nests containing chicks of various ages. However eggs were present and chicks continued to hatch throughout October and early November (Figure 5). Older chicks ('flappers') were present at monitored nests from the 25th October. By mid-November, chicks in monitored nests were generally too mobile to distinguish from each other or which chicks came from which nest.

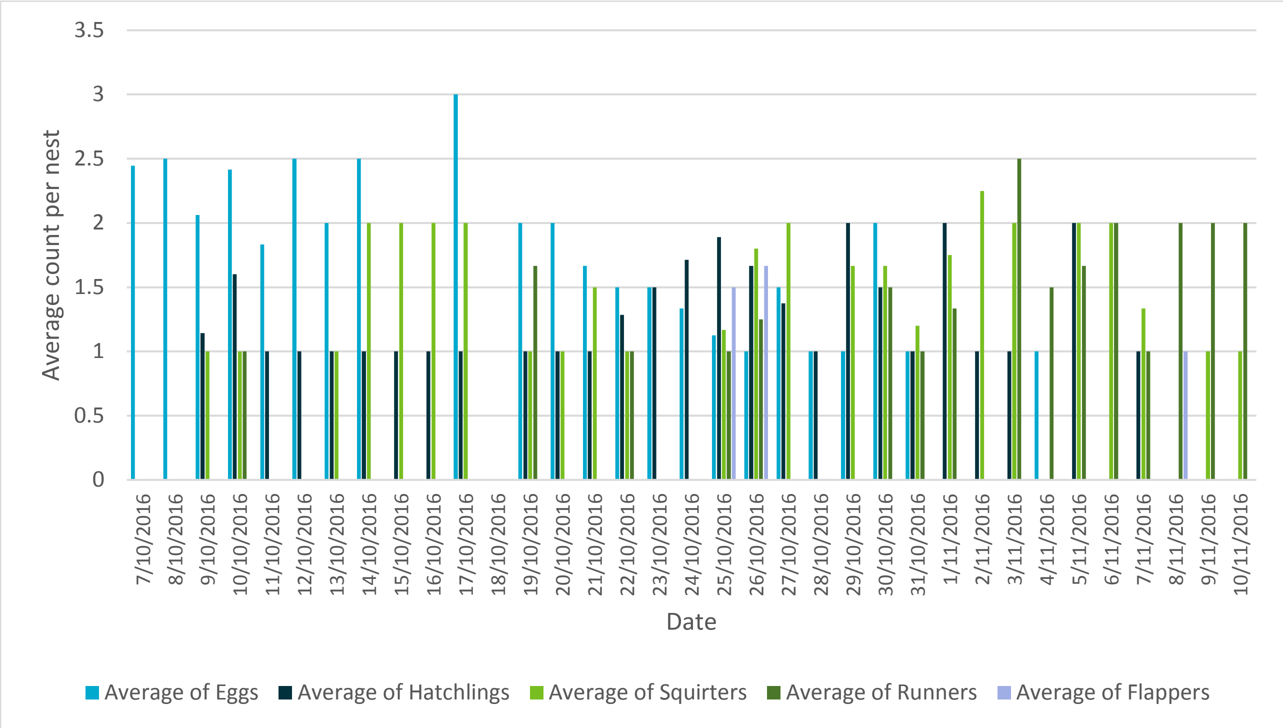


Figure 5 Average number of straw-necked ibis eggs and chicks of each stage per nest, over time

Chick ages have traditionally been visually estimated as categories (Table 4 and Figure 6) via general physical and behavioural features described by Brandis (2010) and other authors (Marchant and Higgins 1990). Using camera images from nests monitored in Barmah-Millewa forest and the Macquarie Marshes, CSIRO is currently developing detailed objective descriptions of egg and chick development stages, including a photographic guide that will assist with more accurately aging the chicks of straw-necked ibis, Australian white ibis, and royal spoonbills. This guide uses traits including eye state, bare part characteristics (colour, shape, area/length), plumage characteristics, body part length ratios and behaviour. In future, this will:

- assist with comparing development rates in different wetlands and at different times
- create a transferable method for other scientists and monitoring programs
- increase clarity and accuracy of aging, whether on-ground or for data extraction from images
- increase knowledge and understanding of species development, demographics and ecology

Table 4 General chick age categories as described by Brandis (2010) and other authors (Marchant and Higgins 1990)

Age category	General characteristics	Approximate period
Hatchlings	Downy, eyes not fully open, immobile	<1 week old
Squirters	Early sheathed feathers starting on wings, still in nest, immobile	1-2 weeks old
Runners	Mix of down and feathers, walking awkwardly, can leave nest on foot	2-3 weeks old
Flappers	Mostly feathers, can't fly but flapping and moving between nests	3-4 weeks old
Flyers	Fully feathered, can fly, but still attend nest to be fed	4+ weeks old

Royal spoonbill hatchling

Straw-necked ibis hatchling

Royal spoonbill ‘squirters’

Straw-necked ibis ‘squirters’

Royal spoonbill ‘runners’

Straw-necked ibis ‘runners’

Figure 6 Example images showing the first three age categories used for aging chicks. These images are from Barmah-Millewa Forest nest monitoring.

Clutch sizes and early chick survival rates

Over all 65 nests monitored, 155 eggs were observed, with 38 eggs and 95 chicks of various ages present when monitoring ended. Mean clutch size for straw-necked ibis was 2.7. The royal spoonbill clutches contained three and four eggs respectively. Only one white ibis nest was monitored (3 eggs; Table 5). Over all monitored nests (including those not monitored for the full period of egg to fledged chick), 9% failed to hatch, were destroyed or rejected and 46% of eggs hatched. The remaining eggs were still being incubated.

There were 33 nests monitored from egg stage onward.

- Of the 91 eggs monitored in these 33 nests, 13 (14%) were still being incubated when monitoring ended. Sixty-seven chicks (86%) had hatched. Three eggs failed to hatch.
- **Of hatched chicks, 65 (97%) were still alive when monitoring ended** – a high chick survival rate. However this number may be an overestimate, because of the short duration of monitoring by some cameras, and the fact that a third of the monitored nests were still only at hatchling stage. These numbers remain estimates and should be viewed in relation to the nest state and chick ages at the end of camera monitoring (Table 6). More extensive on-ground monitoring conducted in the areas surrounding the camera deployment sites will be more representative of final chick survival rates for the colony overall (Brandis et al. 2017 in prep).
- **At the time that monitoring ended, an average of two chicks had survived per straw-necked ibis nest, and an average of three chicks had survived per royal spoonbill nest.**

Very few mortalities were observed directly and none were due to predation. Most mortalities occurred during the egg stage. The majority were attributable to abandonment (Table 7), with some also resulting from trampling, starvation or from neighbouring ibis deliberately destroying or removing eggs with their beaks.

Analyses to be conducted as part of the broader MDB EWKR project will also explore other variables potentially influencing nest success rates, including nest exposure to weather and predation, parental behaviour and disturbance.

Table 5 Clutch sizes and egg and chick mortality in nests monitored by cameras

	Australian white ibis	Royal spoonbill	Straw-necked ibis (means)
Clutch size	3	3 and 4	2.7
No. eggs failed to hatch		0 and 3	1.2
No. chicks hatched		3 and 1	2.0
No. chicks died in nest		0 and 1	1.2
No. chicks that left the nest		Unknown and 0	1.7
No. of surviving chicks		3 and 0	1.9
No. chicks in last useful image		3 and 0	2.0
No. eggs in last useful image	3	0 and 0	1.8

Table 6 Nest state in last useful image (number of nests)

Nest state	Australian white ibis	Royal spoonbill	Straw-necked ibis	Grand Total
Eggs	1	1	5	7
Hatchlings			11	11
Squirters			3	3
Runners			32	32
Flappers			9	9
Abandoned at egg stage			2	2
Abandoned at chick stage		1		1
Grand Total	**1**	**2**	**62**	**65**

Table 7 Causes of egg and chick mortality, where known

Species and cause of mortality	Total eggs failed to hatch, destroyed or rejected	Total chicks died in nest
Royal spoonbill	**3**	**1**
Abandonment	3	1
Straw-necked ibis	**7**	**5**
Abandonment	3	2
Neighbouring ibis	3	
Starvation		2
Trampling	1	1
Grand Total	**10**	**6**

Satellite tracking of bird movements

Highlights and trends – all tracked birds from the Macquarie Marshes and Barmah-Millewa Forest

Tracking of straw-necked ibis from the northern and southern basin has already advanced our knowledge of previously unknown or poorly understood ibis movement and population patterns and trends, including:

Long-distance movements

- Northern and southern birds are mixing and using some of the same sites and routes
- Straw-necked ibis in the MDB may (or may not) be one integrated population. However this year may be unusual with the extent and duration of flooding that occurred. This will need to be investigated with tracking in subsequent years and with more birds.

Common 'flyways' or movement corridors for separate birds/groups

- Six of the 10 Geotrak adults and three of the juveniles have travelled along a NE-SW route (at least partly), in different directions (Figure 7)
- This route corresponds to zones / boundary lines in maps of average climatic conditions, rainfall, topography, etc. For examples of climate zones, see: http://www.bom.gov.au/climate/averages/maps.shtml

Key foraging and stopover points and regions

- E.g. The Lachlan River near Condobolin (Figure 8)
- Re-use of some sites by different birds at different times in both VIC and NSW

'Paired' habitats for roosting and foraging - adults

- Ideal foraging habitats seem to have remnant vegetation with large trees for roosting adjacent to foraging habitats, which may be agricultural or native (Figure 9)

'Paired' night vs day habitats - juveniles at nesting sites

- Juveniles showing a pattern of roosting in one part of the nesting colony, but spending the day creching in another part of the colony up to 100m away (Figure 10)

Associations with weather

- Similarities in departure times and departure dates for longer trips
- Probably associated with thermals, as indicated by distances travelled per hour by time of day (Figure 11 and Figure 12)
- Weather changes may trigger long-distance movements
    - E.g. Four adult birds that were resident in the Gwydir, Namoi, and near Scone for several weeks all decided to fly north around the 5/6/7th March.
    - Perhaps coincidentally, around these dates the temperature dropped, rain fell, and winds shifted to come from the south.

Data analyses to be conducted as part of the broader MDB EWKR project will explore these patterns and trends in more detail.

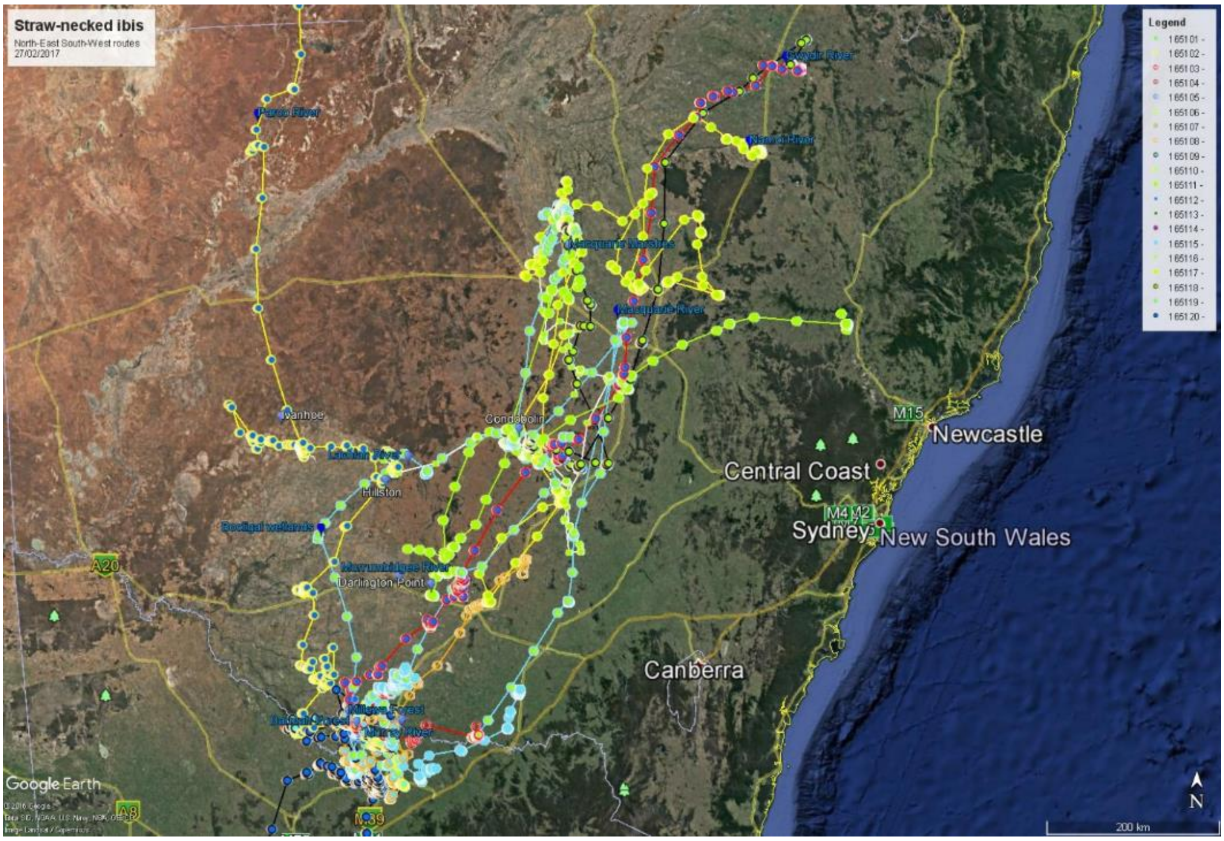


Figure 7 Common 'flyways' or movement corridors have been identified through tracking straw-necked ibis, October 2016 – May 2017

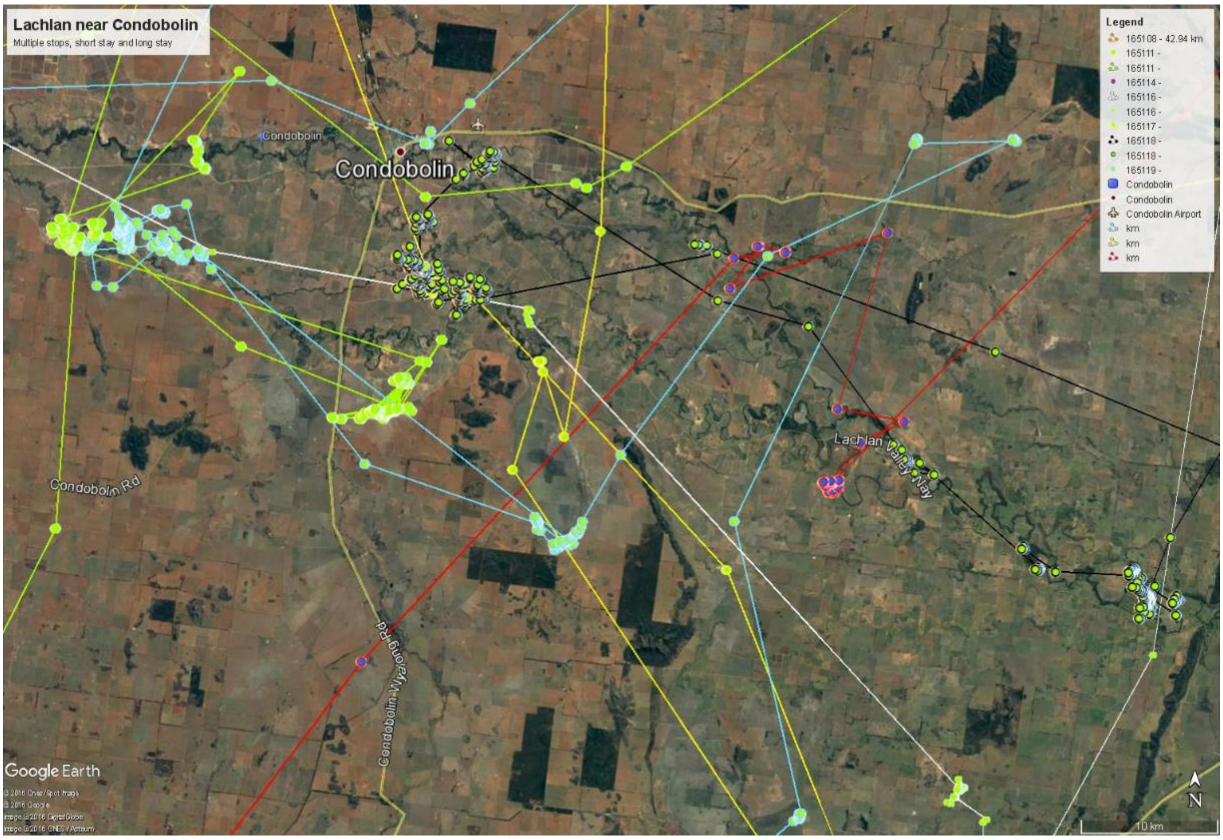
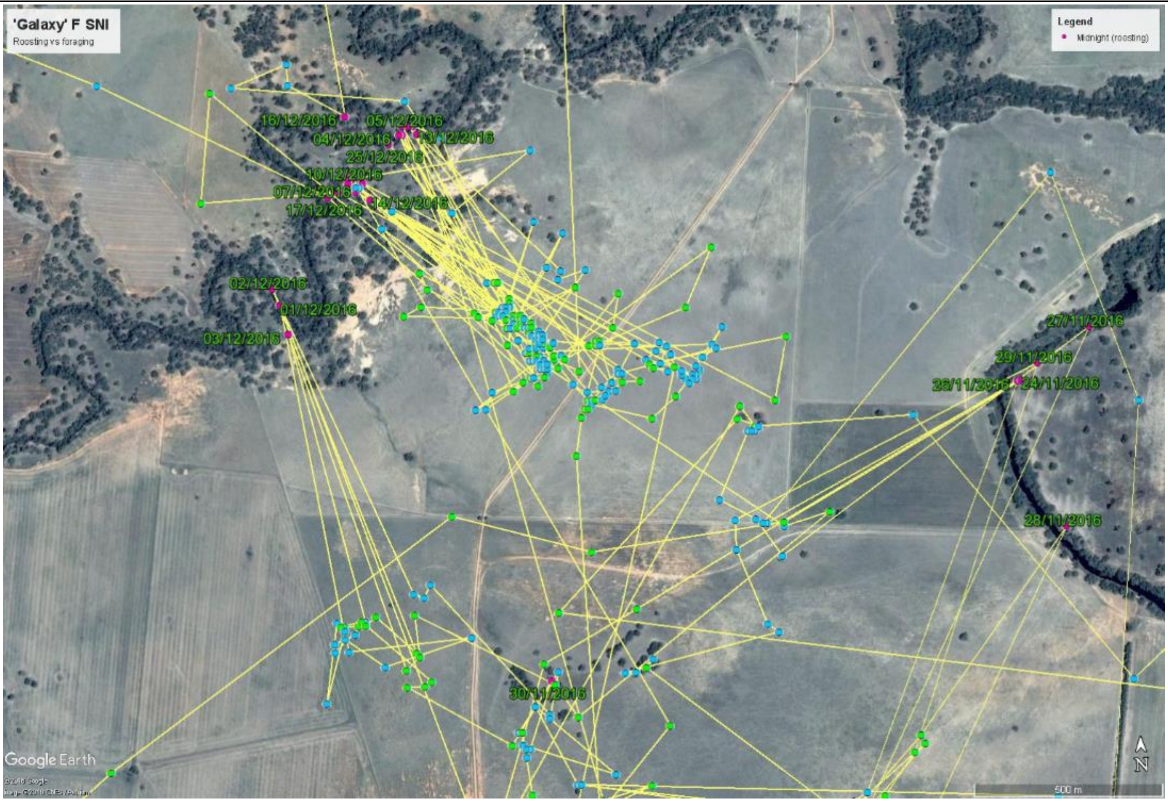
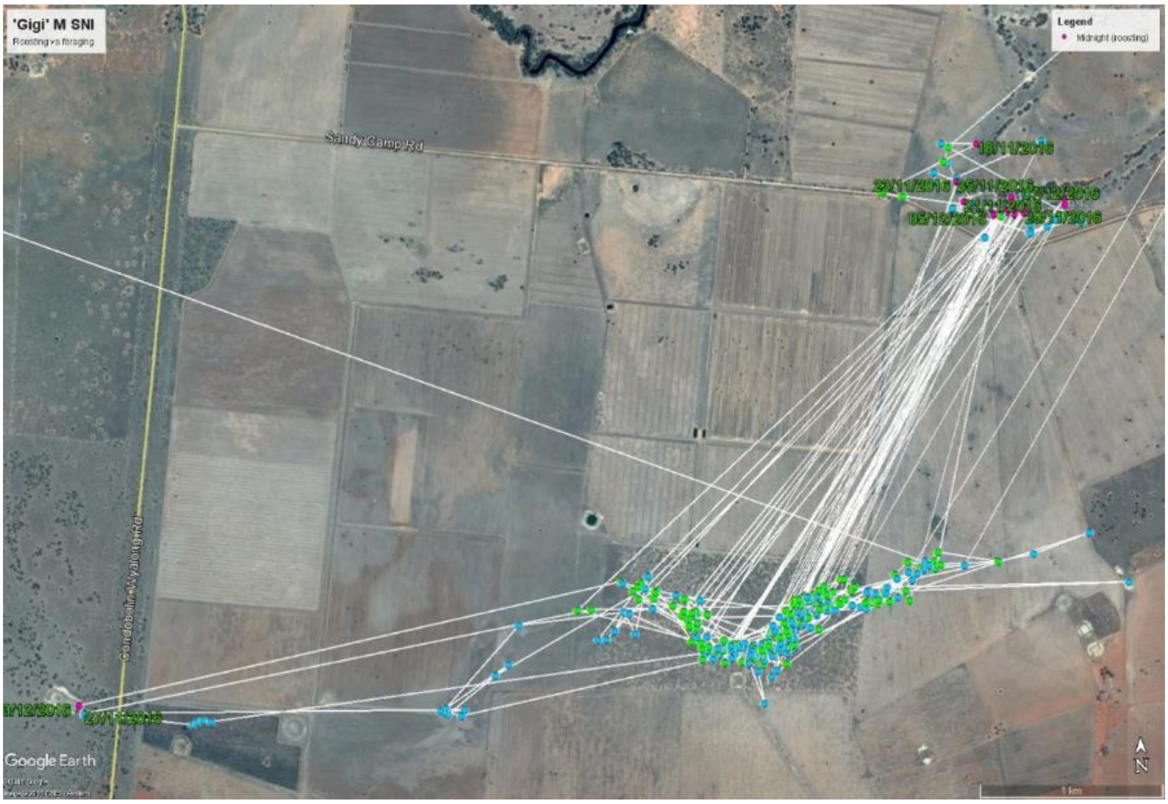


Figure 8 The Lachlan River at Condobolin: A key foraging and stopover region for straw-necked ibis, summer 2016



a)



b)

Figure 9 'Paired' habitats for roosting (pink dots) and foraging (blue and green dots) by straw-necked ibis adults. Ideal foraging habitats seem to have remnant vegetation with large trees for roosting adjacent to foraging habitats, which may be agricultural (a) or native (b).

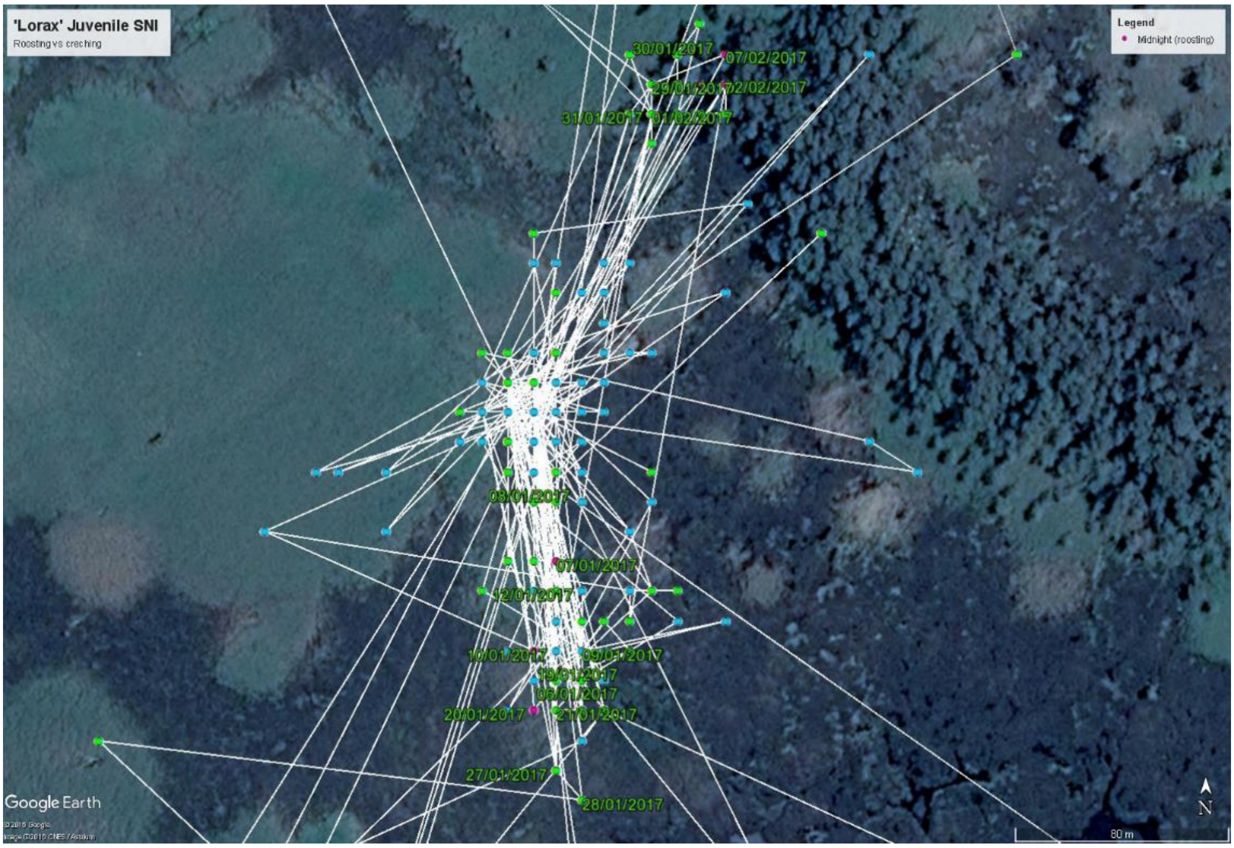


Figure 10 An example of 'Paired' night vs day habitats for straw-necked ibis juveniles at nesting sites. Juvenile tracking showed a pattern of roosting (pink dots) in one part of the nesting colony, but spending the day creching in another part of the colony up to 100m away (blue and green dots).

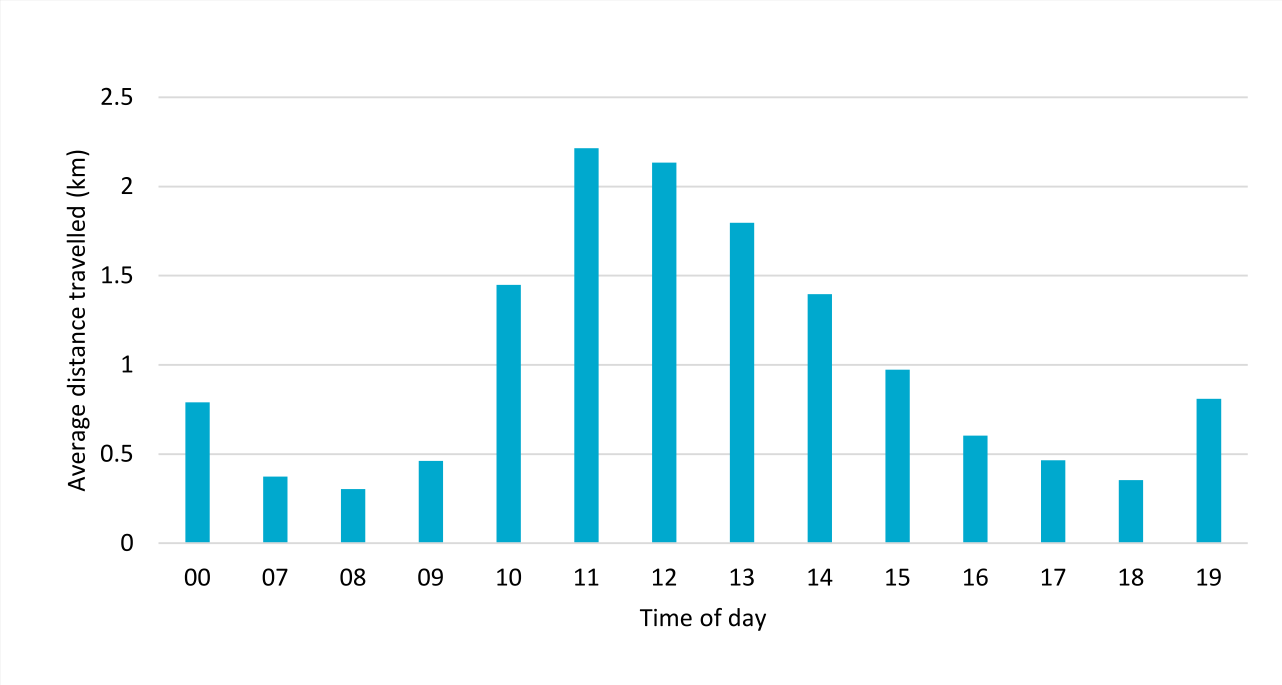


Figure 11 Average distance travelled per hour by time of day (all tracked straw-necked ibis)

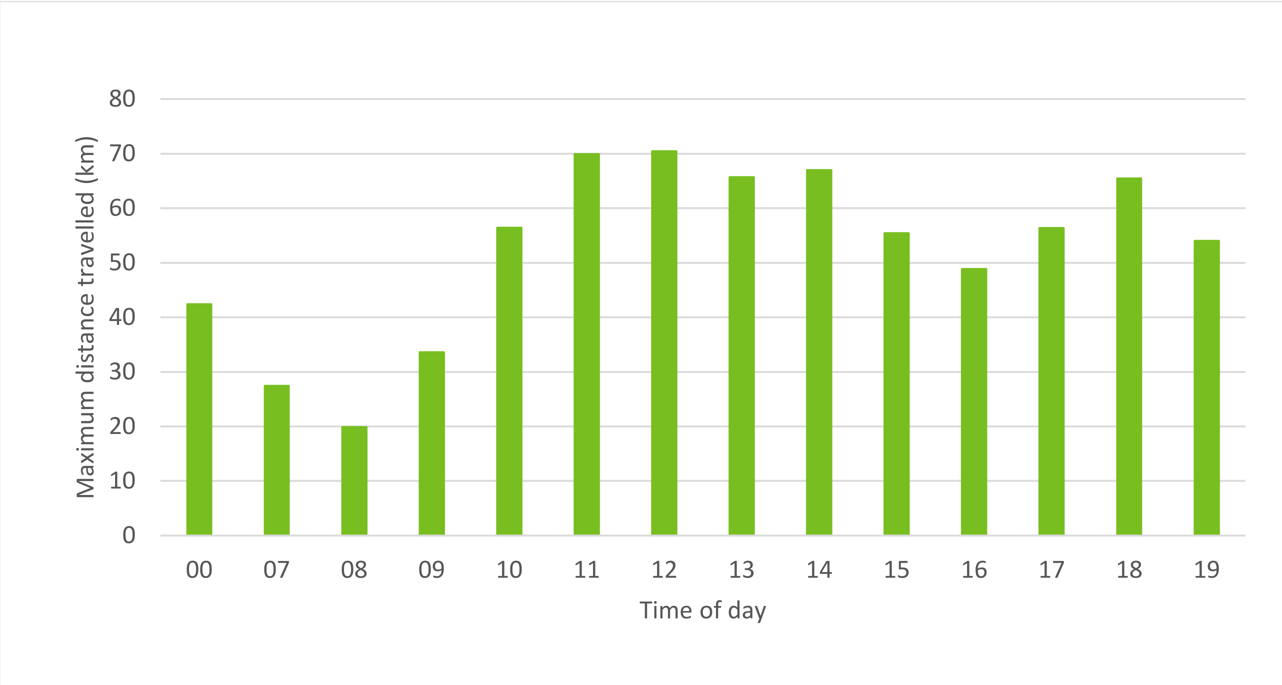


Figure 12 Maximum distance travelled per hour by time of day (all tracked straw-necked ibis)

Individual birds tracked from the Macquarie Marshes

Movements within the Macquarie Marshes

The data indicated that post-tagging all five birds were healthy and highly mobile, continuing to forage and travel without issue. Bird movements following fitting of the transmitters varied, with a range of foraging sites used by each bird in the Macquarie Marshes (Table 8; Figure 13 - Figure 18).

Only one bird continued to attend to its original nest – a male (165119; Figure 19 and Figure 36; Appendix 3). This bird foraged in and around the Macquarie Marshes, initially travelling approximately 10-20 kilometres at a time, and later travelling up to 50 kilometres. He attended his nest for approximately 3 weeks after he was fitted with the transmitter. During this time he foraged in several different sites in and around the Macquarie Marshes (Figure 19; Table 8). These sites were mostly private grazing land. Foraging initially occurred closer to the nest site, progressing to locations further from the nest site as time passed and as the adult prepared to leave the area. He then travelled south to the Lachlan catchment (Wallaroi Creek south-west of Condobolin), with one overnight stop near Nyngan on the way.

Draft classifications of midnight roosting points, daytime movement activity types and overall daily translocation types have been developed and are shown for the above male and his movements in the Macquarie Marshes area in Figure 19. These classifications aim to distinguish and prioritise various sites in terms of the way that birds use them. The metrics used include the distance between consecutive midnight positions, the distance travelled each day, distance travelled between each position fix, and the furthest distance from the starting midnight fix obtained each day. In some instances midnight positions fixes are missing from the data. These have been interpolated from the previous known location closest in time to midnight. For the purposes of display two distance metrics have been categorised: translocation (distance between consecutive midnight position) and activity (distance travelled between each position fix). Translocation was classified as: stay (distance <= 0.1km), shift (0.1km < distance <=2.5km), move (2.5lm < distance <= 25km) and travel (distance >25km). Activity was classified using the same thresholds. These classifications will be further refined and used for analyses and site prioritisation as part of the ongoing MDB EWKR project.

The four remaining adults did not remain in the nesting colony in which they were caught. It is possible that these birds were not actually attending to a particular nest, but were investigating the area. Ibis are known to spend time visiting existing nesting colony sites prior to and during constructing nests and breeding. If they were adults with eggs, we do not consider the lack of nest attendance by these individuals to be an adverse event for the population, considering breeding colony and population sizes, but we took the precaution of notifying the UNSW animal ethics committee. The total size of the Macquarie Marshes breeding colony was approximately 30,000 birds, and other large breeding colonies were active in other catchments in the Murray-Darling Basin. The movement of ibis away from the colony and the rejection or desertion of eggs due to environmental factors is not uncommon in large colonial waterbird colonies. It is also common for these species to re-nest in a single season – though it is unlikely that any of the tracked birds did so. We checked the colony (10th Nov 2016) and while there were falls in water level, the colony as whole was doing well. However, predators were observed in the colony (foxes, pigs and raptors), and pig hunting was occurring nearby, with shots heard and vehicles observed.

The four birds that did not return to their nests moved to other locations both in the Macquarie Marshes area and outside of it and continued to forage. Most of the important foraging and roosting locations were south of Monkeygar (Figure 18; Table 8). These included ephemerally wetted areas on Willie Station (Reed Paddock) and the Southern Reserve. These areas were regularly wet and in good condition in the 1940's, but are no longer regularly watered. Other sites included effluent creeks and minor wetlands. None of the areas visited were known recent breeding colony sites.

In-depth data analyses to be conducted as part of the broader MDB EWKR project will explore foraging habitat locations and characteristics as well as movement patterns and trends in more detail.

Table 8 GPS latitude and longitude locations (decimal degrees) of the primary sites used by tracked straw-necked ibis the Macquarie Marshes region, October-November 2016. Map figures are presented in Appendix 3 for sites at which significant periods of time were spent, repeat visits made or more than one individual was tracked.

Transmitter	Sex	Name	Map figure(s)	Latitude	Longitude
165111	M	Gigi	Figure 22, Figure 32	-31.1034	147.6721
				-30.8907	147.5587
				-31.0829	147.675
				-31.0934	147.6745
				-31.1086	147.6695
				-31.68	147.4243
165116	M	Gough	Figure 23, Figure 33	-30.8739	147.5548
				-31.8934	147.3726
				-32.1102	147.3309
				-32.1551	147.3267
				-32.1724	147.3326
				-32.0562	147.7126
165117	F	Gracy	Figure 22, Figure 25, Figure 26, Figure 27, Figure 28, Figure 29, Figure 34	-30.8394	147.5652
				-30.839	147.5591
				-30.9321	147.4955
				-30.9485	147.5047
				-31.0608	147.5459
				-31.0721	147.5419
165118	F	Galaxy	Figure 24, Figure 35	-31.0671	147.5715
				-31.0727	147.5823
				-31.077	147.5769
				-31.1119	147.6078
				-30.9102	147.5438
				-31.1141	147.6067
165119	M	Gill	Figure 19, Figure 25, Figure 26, Figure 30, Figure 31, Figure 36	-30.9526	147.5015
				-30.9488	147.4929
				-30.9644	147.5897
				-30.9555	147.333
				-30.9478	147.3571
				-30.9054	147.5429
				-30.8763	147.5171
				-31.0018	147.5964
				-30.9111	147.5908
				-31.3031	147.2844
				-31.1343	147.6983
				-31.5707	147.455

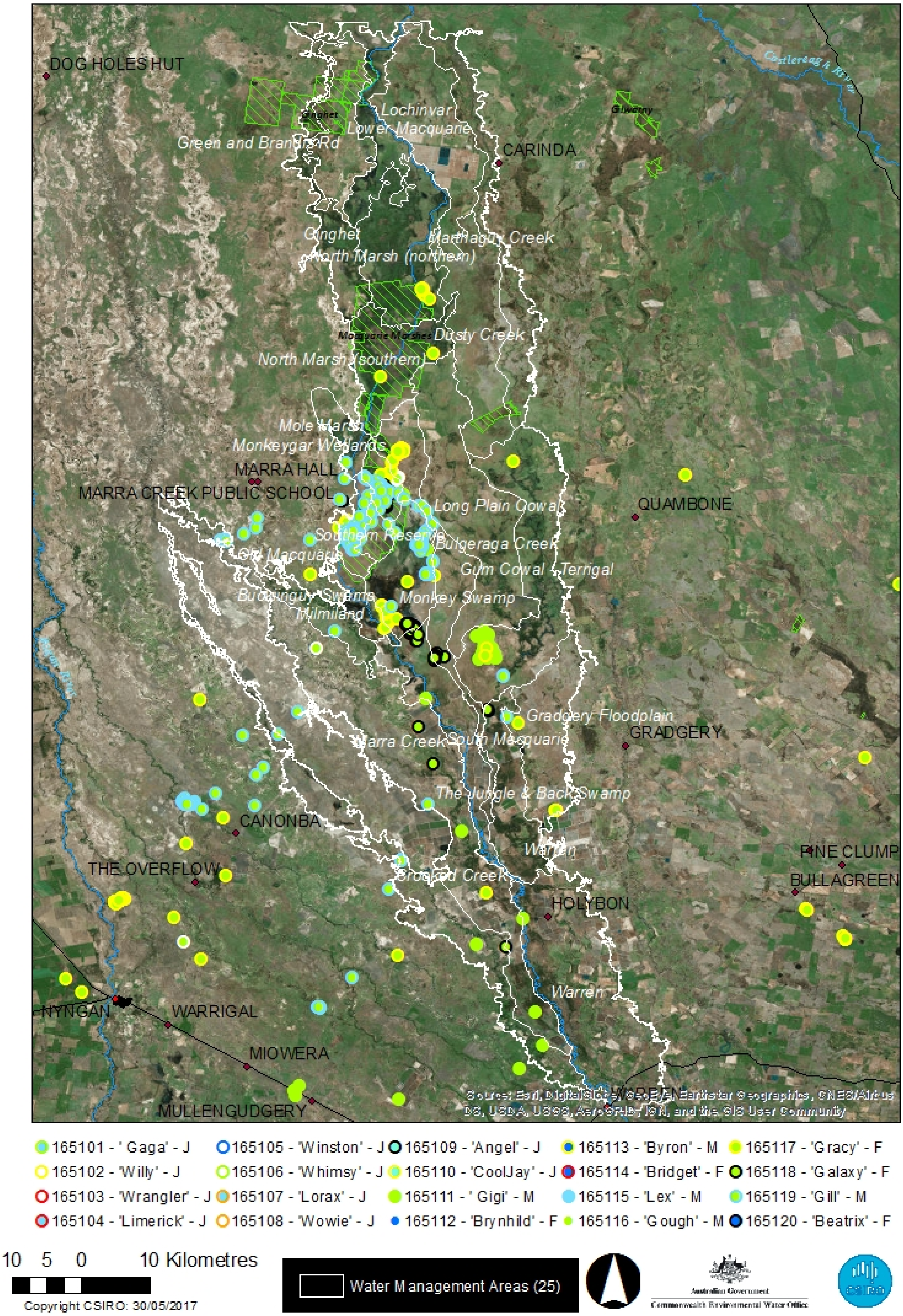


Figure 13 Locations used by five adult straw-necked ibis within the Macquarie Marshes region, Oct-Nov 2016

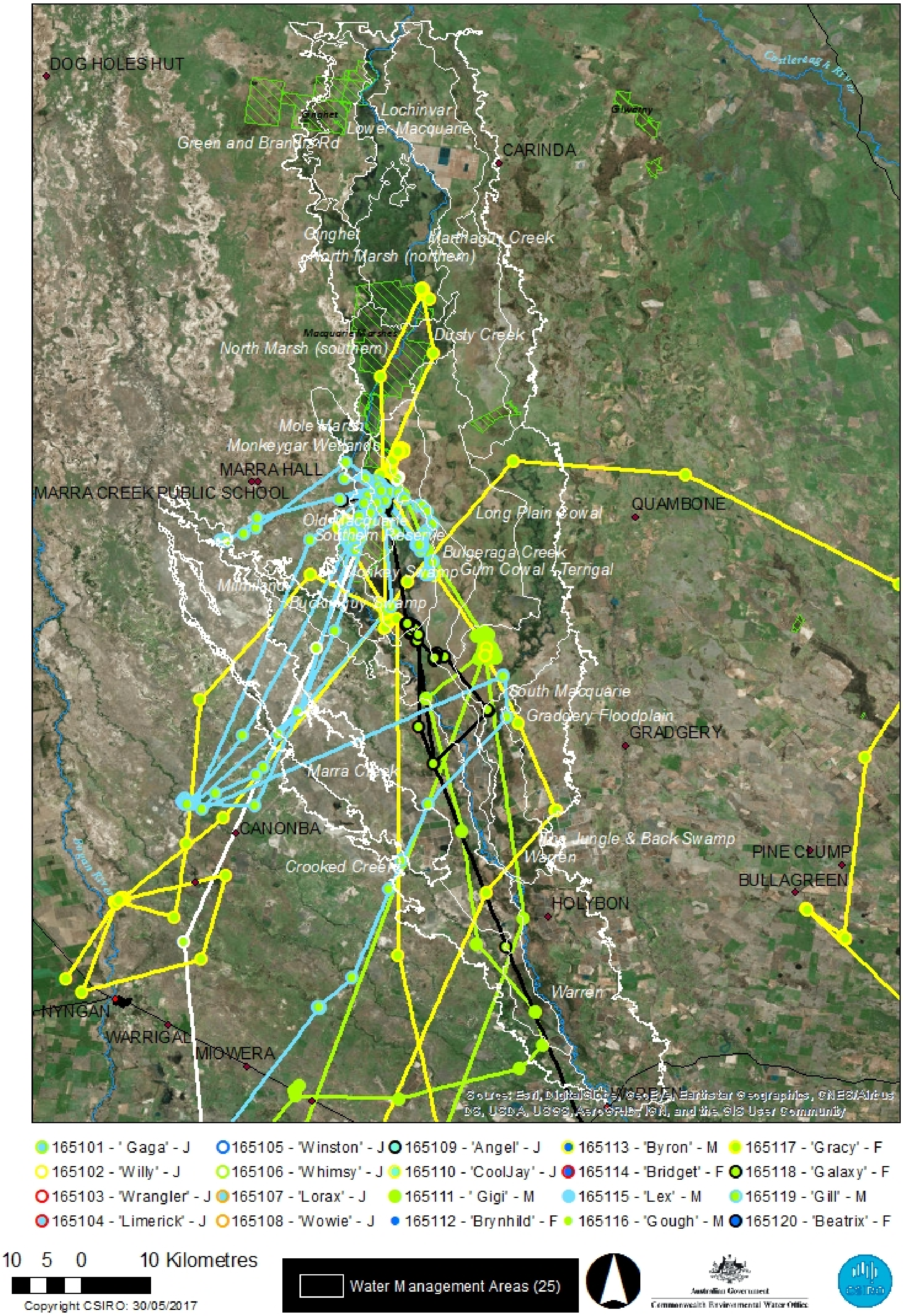


Figure 14 Locations used by five adult straw-necked ibis within the Macquarie Marshes region, with lines indicating movements, Oct-Nov 2016

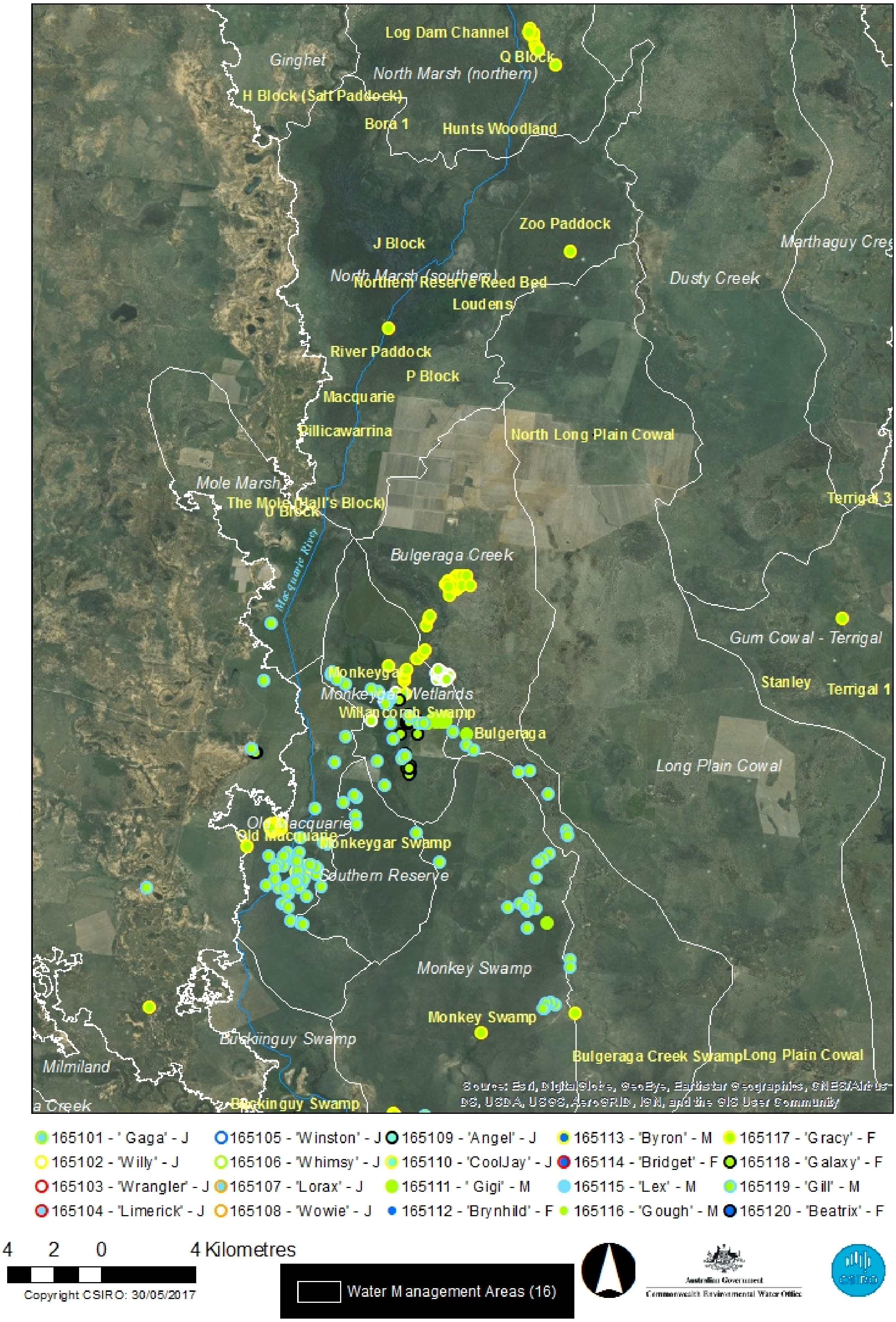


Figure 15 Locations used by five adult straw-necked ibis within the Macquarie Marshes reserve areas, Oct-Nov 2016

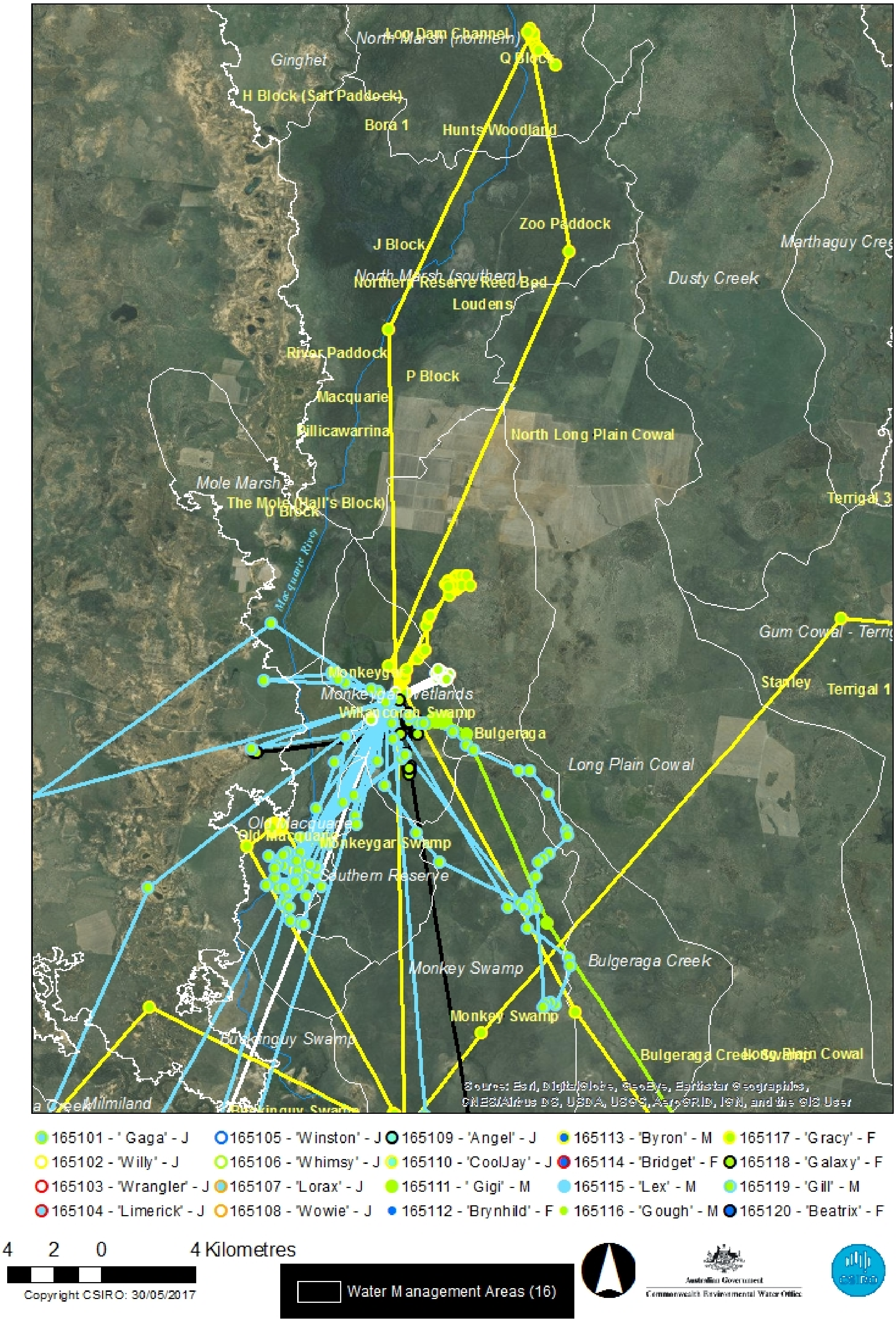


Figure 16 Locations used by five adult straw-necked ibis in the Macquarie Marshes reserve areas, within lines showing movements, Oct-Nov 2016

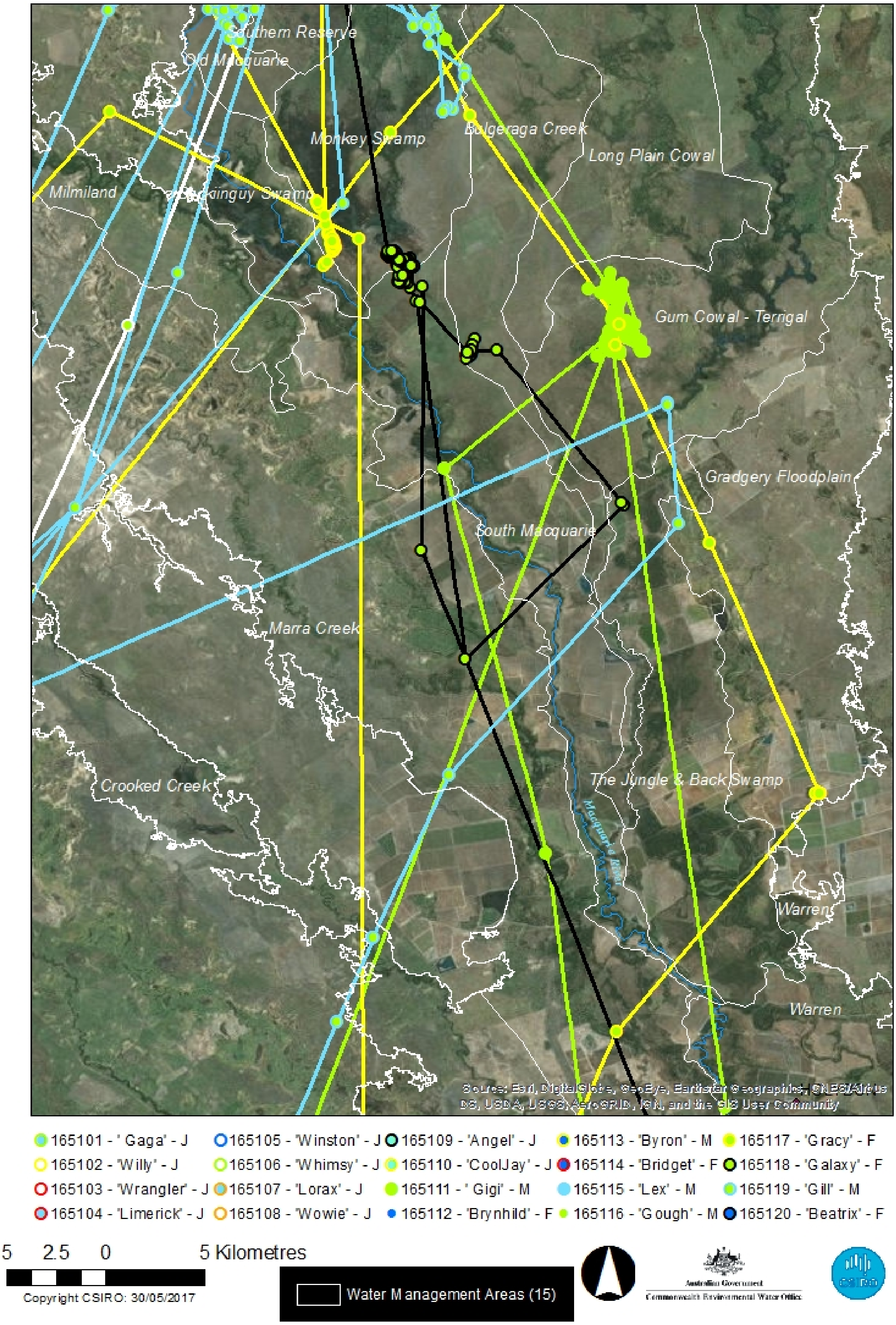


Figure 17 Locations used by tracked straw-necked ibis in the southern Macquarie Marshes area, Oct-Nov 2016

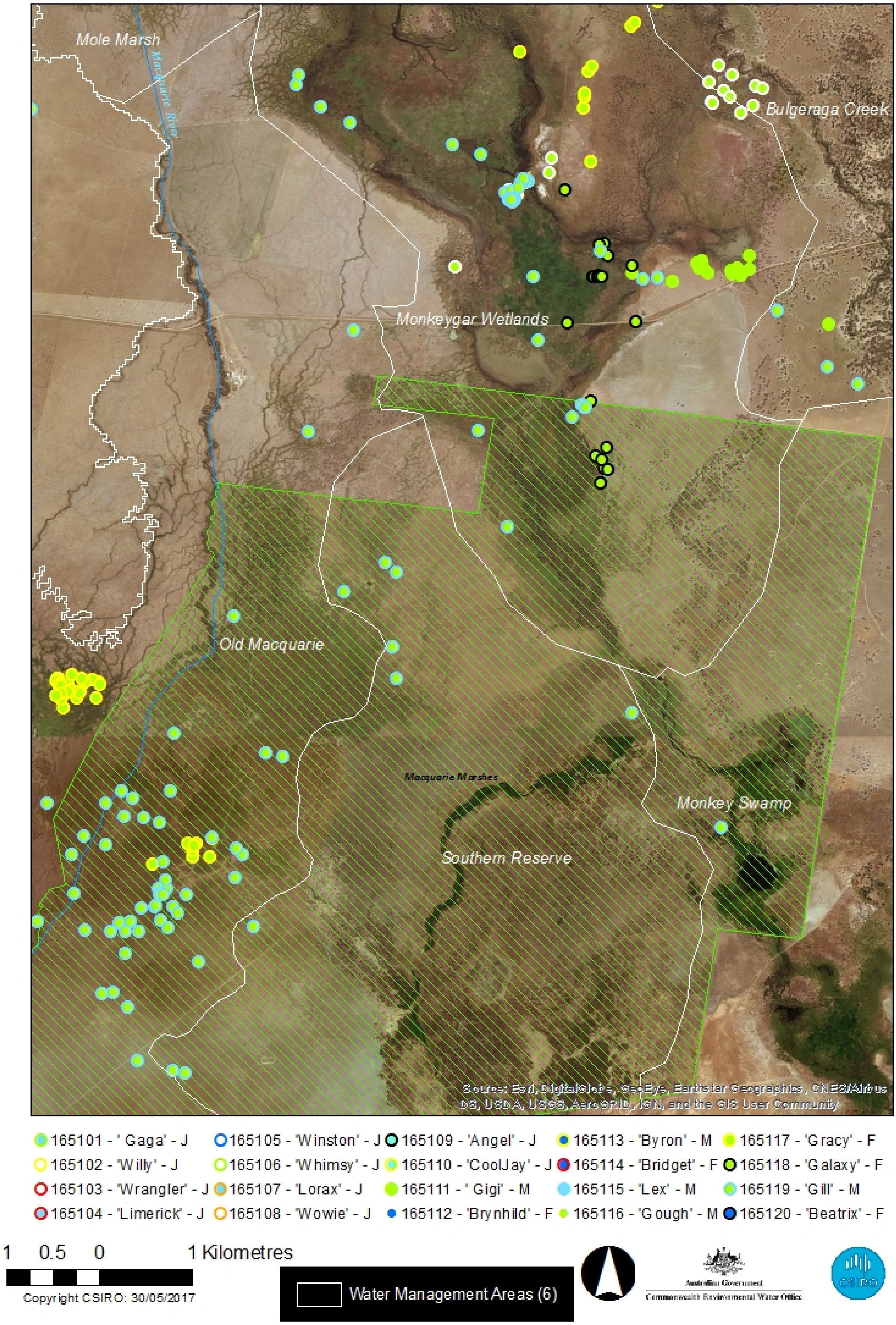


Figure 18 Locations used by tracked straw-necked ibis in the Monkeygar swamp area, Oct-Nov 2016

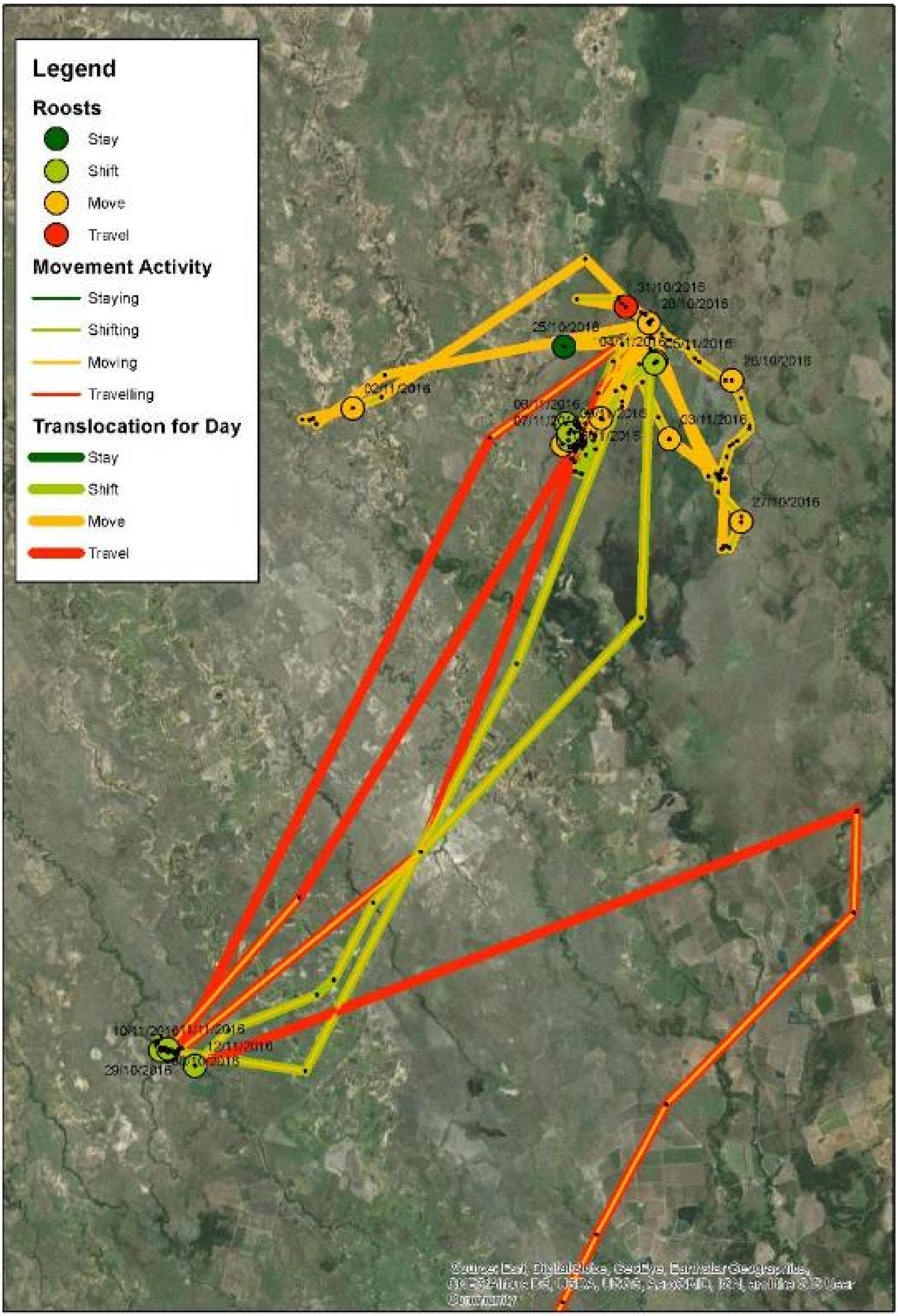


Figure 19 Movements of 'Gill', a male straw-necked ibis, over three weeks of nesting Oct-Nov 2016 in the Marshes, showing draft classifications of midnight roosting points, daytime movement activity types and overall daily translocation types.

All movements since tracker deployment

All five birds eventually left the Macquarie Marshes (Figure 20). The tracked bird movements varied temporally, with each leaving the Macquarie at different times. However there were some surprising consistencies spatially.

- All five birds tagged in the Macquarie Marshes travelled directly south past or to the Lachlan river – at least stopping over, if not staying.
- All passed within a few kilometres of the same area of the Lachlan as part of their travels, though generally at different times.
- Three (2 M, 1 F) spent time foraging and roosting in the same general area south of Condobolin, within 20km of each other.
- The two remaining birds (1 M, 1 F) spent time south of Condobolin before moving on. The male followed the Lachlan west. The female continued south to Lake Cowal, where she spent time prior to heading for the Murrumbidgee, after which she travelled all the way back to the Macquarie Marshes, with stopovers back at Lake Cowal and south of Condobolin.

After leaving the Macquarie Marshes, all five straw-necked ibis travelled significant distances per day and overall (Figure 21, Figure 32, Figure 33, Figure 34, Figure 35, Figure 36). Three are still active, one has been found dead due to botulism and one is missing (Table 9).

While a high mortality rate for juvenile birds was expected as part of normal population dynamics, the project team were still surprised at the total number of straw-necked ibis found dead or missing as part of the wider tracking program. The harnessing methods and similar trackers have been used previously without issue on similar species (Australian white ibis). Discussions with the transmitter manufacturers confirm that this mortality rate is unusual. Confirmed reasons for mortalities include disease (e.g. botulism), predation and vehicle impact. Other possible reasons include poisoning, heatstroke, hunting, parasites, or entanglement in fences or vegetation. At least two of the tracked adults are thought to have succumbed to botulism, based on evidence at the sites at which they were found, including the fact that many other waterbirds were also found deceased in the immediate area. The species affected included: Straw-necked ibis; Australian white ibis; White-faced heron; Pacific black duck; Pink-eared duck; Grey teal; Eurasian coot; Purple swamphen; Hardhead duck. Both adults and chicks/juveniles were observed deceased, often at, near or below nests (particularly ducks and coots). All birds were too decomposed for testing. Similar waterbird deaths at other wetlands and bird breeding sites in the same period have been attributed to botulism as being the most likely cause following post-mortems by veterinarians. The wet conditions in winter-spring 2016 combined with unusually warm temperatures were ideal precursors for botulism events across the Murray-Darling Basin and beyond, with reports of waterbird deaths in spring and summer 2016 in many areas in which the tracked birds were foraging, such as the Lachlan river and wetlands, Willandra creek and wetlands, the Lower Murrumbidgee wetlands and the Macquarie Marshes. Botulism and other diseases also have the effect of weakening birds and making them more prone to predation, poisoning and heatstroke – the latter being a distinct possibility considering the record-breaking temperatures recorded during the 2016-17 summer.

In-depth data analyses to be conducted as part of the broader MDB EWKR project will explore foraging habitat locations and characteristics as well as movement patterns and trends in more detail.

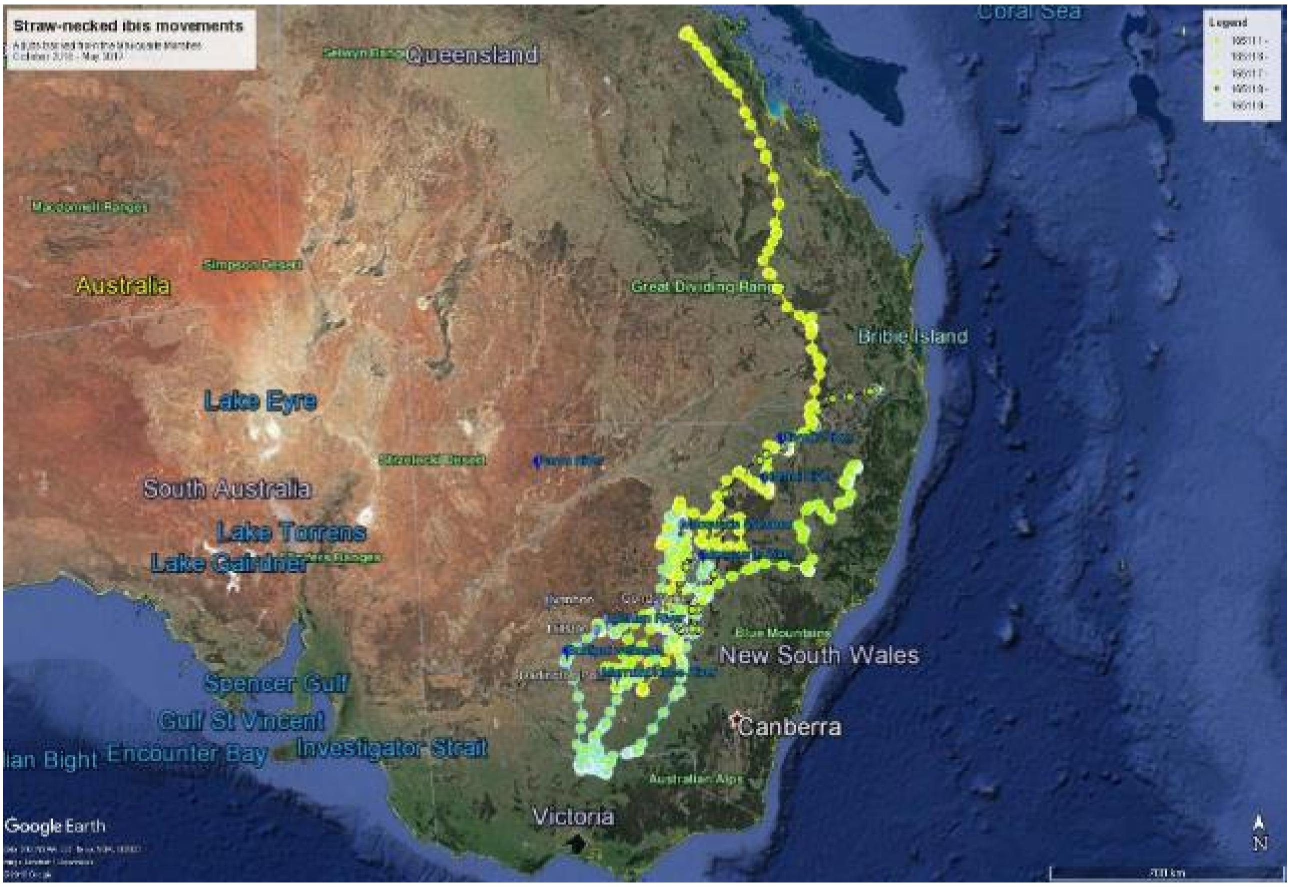


Figure 20 Movements of five straw-necked ibis captured at the Macquarie Marshes, from October 2016 - May 2017.

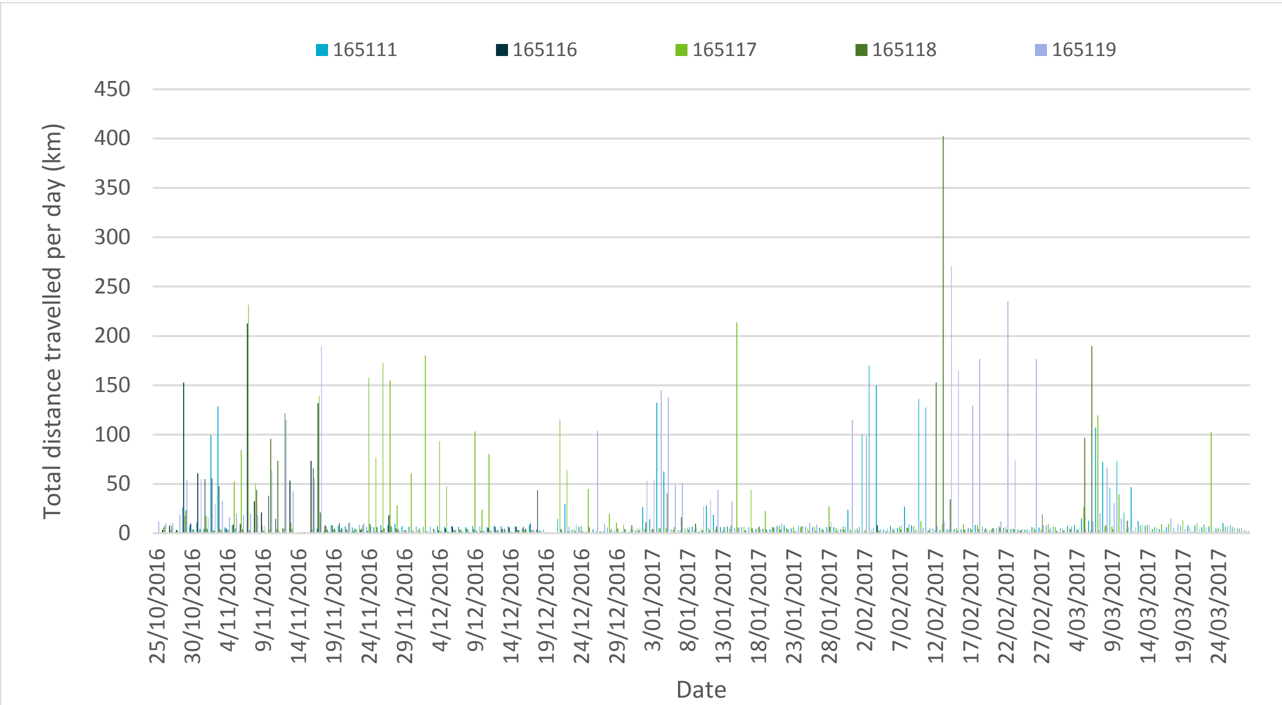


Figure 21 Total daily distances travelled by tracked straw-necked ibis captured in the Macquarie Marshes over time

Table 9 Status and locations (May 2017) of tracked straw-necked ibis captured in the Macquarie Marshes

ID	Name	Sex	Last catchment	Location	Comments
165111	Gigi	M	Border Rivers	20km SE of Glenn Innes. GPS -29.8441, 151.8985.	Mobile, generally travelling north but resident in this area for some weeks.
165116	Gough	M	Lachlan	Dead. Found in a wetland near Hillston.	Cause of death: botulism. Bird feathers, bones and leg rings and transmitter recovered by CSIRO. Transmitter moved and cached in tree by Pied Butcherbirds.
165117	Gracy	F	Burdekin	Burdekin River, near Ayr, south of Townsville Qld.	Mobile, has been travelling north.
165118	Galaxy	F	Condamine-Balonne	Missing 35km E of Warwick, Qld. GPS -28.1447, 152.3887	Missing. Last fix 11/3 5pm 12km E of farm. GPS -28.1447, 152.3887. Johanne Forbes, DNRM QLD arranged for the landholders too search, with no luck. The creekline and dam had been flooded and there were signs of wild dogs.
165119	Gill	M	Goulburn-Broken	Between Coombana and Undera, Goulburn R area. GPS -36.2982, 145.2765.	Mobile. Resident in this area for some weeks. Roosting in trees adjacent to channels and foraging at a nearby (pig?) farm

4 Discussion

How do the timing and rates of egg laying, chick hatching, development, survival and mortality vary, and what affects them?

Hatching rates and early chick survival rates were high at monitored nests. However these rates may be overestimates, because of the short duration of monitoring by some cameras, and the fact that a third of the monitored nests were still only at hatchling stage when monitoring ended. At the time that monitoring ended, an average of two chicks had survived per straw-necked ibis nest, and an average of three chicks per royal spoonbill nest. Given the limitations with the camera images, it was not possible to explore details of how the timing and rates of egg laying, chick hatching, development, survival and mortality vary, and what affects them. However some aspects of the dataset such as clutch sizes will be useful for future comparisons between Barmah-Millewa and the Macquarie Marshes as part of the MDB EWKR project. More extensive on-ground nest surveys were conducted over the same period at a range of other sites in the Monkeygar colony and the Macquarie Marshes, and these should be referred to for more representative survival rates (Brandis et al. in prep. 2017).

What impacts do predators have on nest success and how might we manage predators and other influencing factors (e.g. vegetation structure and water depth) to reduce impacts?

In the colony, very few mortalities were observed directly and none were due to predation. This should not be taken to mean that predation did not occur in the colony. The camera limitations discussed previously are likely to have reduced the chance of detecting predation; the number of cameras and the areas monitored by cameras were very limited; and the timing of monitoring did not cover the full breeding season. Foxes, pigs, cats and raptors were all observed in or adjacent to the Monkeygar colony. Other Macquarie Marshes colonies were reportedly subject to predation at much higher rates, with observations indicating that falling water levels provided easier access to certain parts of those colonies for pigs in particular (Brandis et al. in prep. 2017). However it can be difficult to distinguish between the damage done by various predators after the fact and it is likely that foxes, cats and raptors were also taking eggs and/or chicks. Analyses to be conducted as part of the broader MDB EWKR project will also explore other variables potentially influencing nest success rates, including nest exposure to weather and predation, parental behaviour and disturbance. The results with then be used provide recommendations to land and water managers in the Macquarie Marshes and other sites regarding actions that could be taken to increase hatching rates, fledging rates and juvenile survival.

Where are waterbirds foraging during breeding, and/or where do they forage between breeding events?

Tracking the male that continued to nest has provided information about the locations of foraging sites used by a bird nesting in Monkeygar Swamp. Foraging sites were mostly private grazing land. Foraging initially occurred closer to the nest site, progressing to locations further from the nest site as time passed and as the adult prepared to leave the area. The four birds that did not return to their nests moved to other locations both in the Macquarie Marshes area and outside of it and continued to forage. Consequently the data have provided useful information on the locations of foraging and roosting sites both within the Macquarie Marshes area and outside of it. Most of the important foraging and roosting locations in the Macquarie Marshes were south of Monkeygar and were outside of the reserve areas in private grazing land. None of the areas visited were known recent breeding colony sites.

After leaving the Macquarie Marshes, all five straw-necked ibis travelled significant distances per day and overall. As tracking continues through the MDB EWKR project, data will continue to be collected and analysed in order to identify and describe:

- Critical foraging, roosting and stopover sites
- Critical habitat characteristics (nesting, foraging, roosting, stopover)
- Foraging trip distances

- Critical routes/movement corridors
- Land and water management actions/policies required to support the above

The results of these analyses will then be used to provide recommendations to water and land managers in the Macquarie Marshes and other sites and at basin scale. These data will also help to fill basic biological and ecological knowledge gaps such as:

- Sub-population boundaries/connectivity/existence or not, ranges
- Philopatry and natal philopatry
- Movement cues and modifiers – e.g. thermals, weather
- Movement paths, directions and distances (foraging, dispersal etc.)
- Variation among individuals
- Differences between sexes and/or age categories
- Timing of departures and arrivals and relationships with other factors
- Physical and behavioural changes as birds age (how can we 'age' them more accurately?)

Recommendations

We recommend that the GPS locations and maps of foraging areas provided in this report form the basis for further investigation of site ownership, landuse, vegetation type, flood (water) regime and other characteristics. Each of these characteristics may vary for each site, or there may be commonalities that can be gleaned that are informative for future land and water management to promote suitable foraging habitat for target waterbird species, both during and between breeding events. The MDB EWKR Waterbird Theme will be pursuing these investigations using the data collected from all tracked birds and publicly available information including spatial GIS layers and on-ground survey data. However the unique knowledge possessed by local land and water managers would be invaluable in helping to explain the choices birds are making regarding movements, habitat and breeding initiation. In this context, we also recommend engaging with local land and water managers and other locals or visitors to visit sites in 'real time' when they are in use by tracked birds, as well as after birds have left, in order to observe bird behaviour and characterise and document habitats. It may be possible to incorporate these activities into existing bird survey activities conducted in the area.

If circumstances allow (resources, flooding, breeding and accessibility), we recommend that additional waterbird species more dependent on surface water for foraging than straw-necked ibis should be tracked. Such species would provide information on waterbird requirements that are more tightly linked to surface flooding and associated resources. For example, royal spoonbills require surface water for feeding and breeding; breed in reasonable numbers at most MDB sites in most years; often breed and feed adjacent to ibis colonies (logistical and cost efficiency); are relatively easy to find; the reed or rush nesting populations would be relatively easy to catch; and they are charismatic species of public interest.

Alternative timing of bird capture for satellite tracker deployment may also need testing. Firstly, it may be possible (though more difficult) to capture adults either prior to nesting or during the early nest construction (trampling) stage, in order to test whether adults at this stage of breeding are more likely to continue nesting in the area post-capture and to reduce the risk of egg abandonment. However, other bird tagging studies and the experience of the research teams involved suggest that adults are significantly more dedicated to nests after chicks hatch compared to prior stages. Adults flushed or captured when they have young chicks will return to the nest quickly and continue to raise chicks, whereas adults flushed or captured with empty nests or eggs take longer to return or do not return at all. Adult 'investment' in or commitment to breeding differs at different stages, and basing bird capture activities on this fact may reduce nest abandonment and increase our ability to collect nesting-period foraging movement data. Finally, if collection of immediate 'during nesting' foraging data is not possible because birds will not nest post-capture regardless of stage, then adults may need to be captured toward the end of the breeding event after their chicks have fledged, or well before or after the breeding event entirely. This poses its own logistical challenges. Other changes to satellite tracking methods such as reducing the size and weight of the transmitters and their solar panels and altering harness design are also being proposed. The MDB EWKR Waterbird Theme leadership are currently working on the best way forward and all changes to methods are subject to the approval of the relevant animal ethics committee(s).

Finally, in future years, we recommend deployment of greater numbers of cameras at a range of colony sites, in order to better establish the drivers of nest success and the relative impacts of various predator species and other disturbances. Numbers of cameras will depend on the questions asked and desired datasets. Camera setup and settings should be altered and made consistent with standard methods used in other sites in order to better quantify egg and chick survival and their drivers. If reproductive success is the primary dataset sought (without documenting drivers of mortality), then cameras should only be set to time-lapse at intervals of approximately 15 minutes, at least during the first two weeks. At later stages, hourly images are sufficient. Previous experience has shown that provided the largest SD card memory size and good quality batteries are used, these settings allow continuous monitoring for the entire nesting period without the need for maintenance. If predation or behavioural datasets are sought, then cameras should be set to motion-sensing – perhaps with adjustments to sensitivity and the number of images taken per trigger. The MDB EWKR team are currently reviewing ideal motion-sensing settings for target datasets. Camera settings should be checked immediately prior to deployment in the field. Using taller poles, or two poles bolted together allows cameras to be directed facing down on 1-5 nests at better angles for motion sensing, or to gain a better view of the contents of more nests for time-lapse monitoring of reproductive success. If feasible, cameras could also be deployed at known nesting clumps used by birds in previous seasons, before birds arrive, nest or lay eggs, in order to reduce disturbance during nesting. Visits to change settings are less disturbing than visits to install posts and cameras. This will require forward planning and provision of sufficient staff and resources. Feasibility would vary depending on specific site characteristics – for example, site access in some locations can be difficult in early stages of breeding and the locations of nests can vary from year to year.

Regular satellite tracking updates will continue to be funded and provided as part of the MDB EWKR project via email to CEWO, NSW OEH, MDBA and other interested parties at least fortnightly, including highlights, maps of bird tracks and locations and an updated table of bird locations, movements and fates. A website has been created and made publicly available containing detailed project information, FAQs, photographs and satellite tracking maps. This website is regularly updated with new information and maps. A facebook page and twitter account have also been created and made publicly available in order to more broadly and generally disseminate information and photographs and highlight waterbird-relevant information and studies in Australia.

Website: https://research.csiro.au/ewkrwaterbirds/

Facebook: https://www.facebook.com/ColonialWaterbirdScience/

Twitter: @AusWaterbirds

5 Next steps for MDB EWKR Waterbird Theme research

Component 1: Foraging habitats and movements

- Continued tracking of 2016-17 straw-necked ibis for as long as the birds are mobile and the transmitters continue to function.
- Analysis of datasets in conjunction with flooding, vegetation, weather, landuse and other data
- Tracking of new individuals from 2017-18
- New proposal to track a species that is representative of a dominantly water-foraging bird guild

  E.g. Royal spoonbills

- It would be cost-efficient to do this during next season's straw-necked ibis tracker deployment(s)
- Royal spoonbills nest with ibis and (probably) respond to the same flow triggers, but have different foraging habitat requirements
- Value-adding to current research and overall outcomes

Component 2: Nesting habitat requirements

- Continued monitoring of nests and egg and chick survival and their drivers via remote cameras (2017-18)
- Analysis of data extracted from images for straw-necked ibis, Australian white ibis and royal spoonbills - in conjunction with flooding, vegetation, weather, landuse and other data
- Analysis of data from on-ground tagged nest monitoring, water depth monitoring, and drone surveys

Updates and photos

For more photos and updates, please visit CSIRO's EWKR Waterbird Theme website: https://research.csiro.au/ewkrwaterbirds/

Alternatively you can find more general interest photos and waterbird information via our Twitter account **@AusWaterbirds** which is linked to the '*Colonial-nesting Waterbirds Australia: Science for Management*' Facebook page: https://www.facebook.com/ColonialWaterbirdScience/?ref=page_internal

6 Milestones and staffing

Milestones

Milestone	Date	Complete?
Contracting	20/10/2016	Yes
Satellite transmitters deployed	30/11/2016	Yes
Monitoring camera image processing and data analysis completed	30/03/2017; rescheduled to 8/05/2017 following delays in receiving camera images	Yes
Draft final report with maps showing tracked bird movements and identifying key sites completed	30/04/2017	Yes
Final report submitted	31/05/2017	Yes

Project staff

There have been no changes in project staffing to-date.

Satellite transmitters were fitted in the field by John Martin (RBGSyd), Heather McGinness, Micah Davies and Freya Robinson (CSIRO). Monitoring cameras were installed and maintained by Paul Keyte, Stephanie Suter and Jennifer Spencer (NSW OEH) with assistance from James Rees and Emily Webster (UNSW). Ray Jones kindly showed us his snaring method and lent us three of his snares and his camo net. We thank James Rees, Emily Webster and Bill Johnson for being flexible about timing of site access. Image data extraction was conducted by Melissa Piper and Heather McGinness (CSIRO). Mapping was designed and executed by Art Langston and Heather McGinness (CSIRO). Data analyses and report preparation were completed by Heather McGinness.

References

- Brandis, K. (2017 in prep.) High resolution monitoring of waterbird colonies it the Macquarie Marshes. Draft final report to the Commonwealth Environmental Water Office 2017.
- Brandis, K. (2010) Colonial waterbird breeding in Australia: Wetlands, water requirements and environmental flows. PhD Thesis, Australian Wetlands and Rivers Centre, School of Biological, Earth and Environmental Sciences, UNSW.
- Marchant, S. & P.J. Higgins (eds) 1990. *Handbook of Australian, New Zealand and Antarctic Birds. Volume 1: Ratites to Ducks.* Oxford University Press, Melbourne. ISBN 0-19-553244-9

Appendix 1 Field observations

Below are some general observations circulated to local managers via email following fieldwork

Macquarie Marshes Monkeygar colony observations

24-28 October:

Most Straw-Necked Ibis nests have chicks, ranging from hatchlings to runners, however, some pairs on the fringes still have eggs (probably 10% of the total we saw). Most chicks are at or nearing runner stage to the north, and at young hatchling stage to the south – but it is variable.

All the nests we observed were on phragmites, except for one group of approximately 100 birds nesting on a sandbank. The nests on the sandbank were very poorly constructed and shallow and most had just eggs or one or two new hatchlings.

Other species

Glossy ibis are scouting the area and foraging in flocks of 10-50 birds. They were observed perching in the phragmites fringing Straw-Necked Ibis nests in one location in a group of about 20.

A few white ibis nests are scattered on the fringes of the Straw-Necked Ibis clumps.

Brolgas, night herons, white ibis, intermediate egrets, great egrets, magpie geese (with chicks), Eurasian coots (eggs and chicks), pink-eared ducks (chicks), musk ducks, hardheads, wood ducks, purple swamp hens, and other species were all observed foraging adjacent to the colony.

Other notes

The water level fell noticeably from 24-28 October in the fringing and foraging areas near the colony. However, water levels in the main nesting areas are still good and haven't changed dramatically.

There was very little direct evidence of predation (e.g. smashed eggs) but we did see a feral pig, cat, and fox on the edge of the colony, and a whistling kite and swamp harrier were hunting nearby in more open areas. No ravens were observed in the colony area.

Photos and updates

For more photos and updates as the season progresses, please visit our EWKR website: https://research.csiro.au/ewkrwaterbirds/

Alternatively you can find more general interest photos and waterbird information at the '*Colonial-nesting Waterbirds Australia: Science for Management*' Facebook page https://www.facebook.com/ColonialWaterbirdScience/?ref=page_internal

Appendix 2 Monitoring camera setup

Notes:

- Motion sensing cameras need to be set facing down at an angle at 1-5 nests ONLY in order to produce sufficient data.
- Facing too horizontally or at too many nests causes too many triggers of the motion sensor, filling the SD card too fast and/or flattening the battery. This reduces the effectiveness of the MS cameras, limits the amount of data we can extract, and reduces representativeness.
- Cut vegetation down from in front of cameras, otherwise it will trigger the sensor.
- Bird spikes or similar deterrents are essential.
- Spider spray prevents lens obscuration.

Camera category	EGG AND CHICK COUNTS AND GROWTH	BEHAVIOUR, FEEDING RATES	PREDATION, DISTURBANCE
TIMELAPSE/ MOTION	Timelapse	Motion	Motion
Motion sensitivity	None	High	Medium
Pics per trig. Motion sensing	N/A	3	3
Period armed for motion sensing	N/A	Diurnal 7am-7pm	24hrs
Time-lapse interval	Hourly	8AM, 6PM	8AM, 6PM
Pics per trig. Timelapse	1	1	1
Period armed for timelapse	Diurnal 7am-7pm	Diurnal 7am-7pm	Diurnal 7am-7pm
Pic rate (secs)	N/A	RAPIDFIRE	RAPIDFIRE
Quiet period	N/A	0	0
Nests in cam view	5 to 15	1 to 5 with good visibililty	1 to 5 with good visibililty

MOTION-SENSING AND TIME-LAPSE MONITORING CAMERA SETUP INSTRUCTIONS
Heather McGinness, CSIRO
Reconyx Hyperfire Professional
Note:
Keep batteries cool in transit - e.g. try not to leave them in a hot car or boot
Batteries lose their charge very quickly when subjected to high temperatures.
Each Reconyx camera takes 12 AA batteries.
Installation

At base

Purchase the largest capacity SD cards that the cameras can handle, and preferably 'eneloop' rechargable long-life NiMH batteries
Pre-drill the stakes (together, so they line up) to the diameter of the bolts purchased
Attach the bolts to one of the stakes so they're ready to go, or put them in an accessible pocket
Number the SD cards and cameras with unique IDs
Install the batteries and SD card, and record the camera and SD no.'s.
Check that the SD card is empty and that the batteries are fully charged
Set and record timelapse times (check that times are correct - am/pm, daylight saving etc.)
Set and record motion-sensing sensitivity, pics per trigger, pic rate and quiet period.
Check that temperature is set to degrees centigrade (not Fahrenheit)
Set 'Battery Type':
*Select 'NiMH' if rechargeables are being used (e.g. white Eneloop batteries)
*or select 'Lithium' if Li-ion batteries are being used (e.g. blue Energizer lithiums)

Turn camera off
Check that the screw attaching the camera to the swivel clamp is tight
Attach bird spikes to camera and post (glue to camera; drill to post)
Spray outside of camera with spider spray from behind (avoiding lens and sensor).
Attach camera to post with clamp

At nest

Drive first post into ground
Estimate camera direction and angle required and tighten screws
Turn camera on and select 'Arm Camera'
Close camera
Attach camera post to base post with bolts
Check camera angle and adjust if necessary - clear reeds or rushes that may trigger the motion sensor
Attach cable tie around post and camera to provide backup support
Mark camera GPS location using camera number as mark name
Record camera number, location, no. nests in view (incl. clump and nest tags if present), number of eggs/chicks in each nest, nest heights from water surface (cm) and water depth (cm).

On pickup

You may be able to open the cameras without detaching them, depending how they are set up and how high they are. If necessary, undo post bolt to lower camera.
To open, simply flick open the side latch.
If necessary, briefly press the menu button to wake up the display.
Record remaining battery details on the spreadsheet provided
Switch off camera, and if necessary swap the SD card for a new one
Swap batteries if necessary
Clear camera lens and sensor of spiderwebs & dirt (cloth supplied - clean shirt sleeve also works :-)
If you changed batteries, switch camera on again and scroll through camera menu to 'Battery Type':
*Select 'NiMH' if rechargeables are being used (e.g. white Eneloop batteries)
*or select 'Lithium' if Li-ion batteries are being used (e.g. blue Energizer lithiums)
Switch on camera, scroll through camera menu and select 'Arm Camera'
Close camera, get out of range, and check direction/level
Spray outside of camera with spider spray from behind (avoiding lens and sensor).

Any questions call Heather McGinness on 0428 124 689 or (02) 62 464 136. Thanks!
Please bring all used (and unused) batteries back.
Please keep used and unused batteries separate - don't mix them up.

Appendix 3 Straw-necked ibis location and movement maps

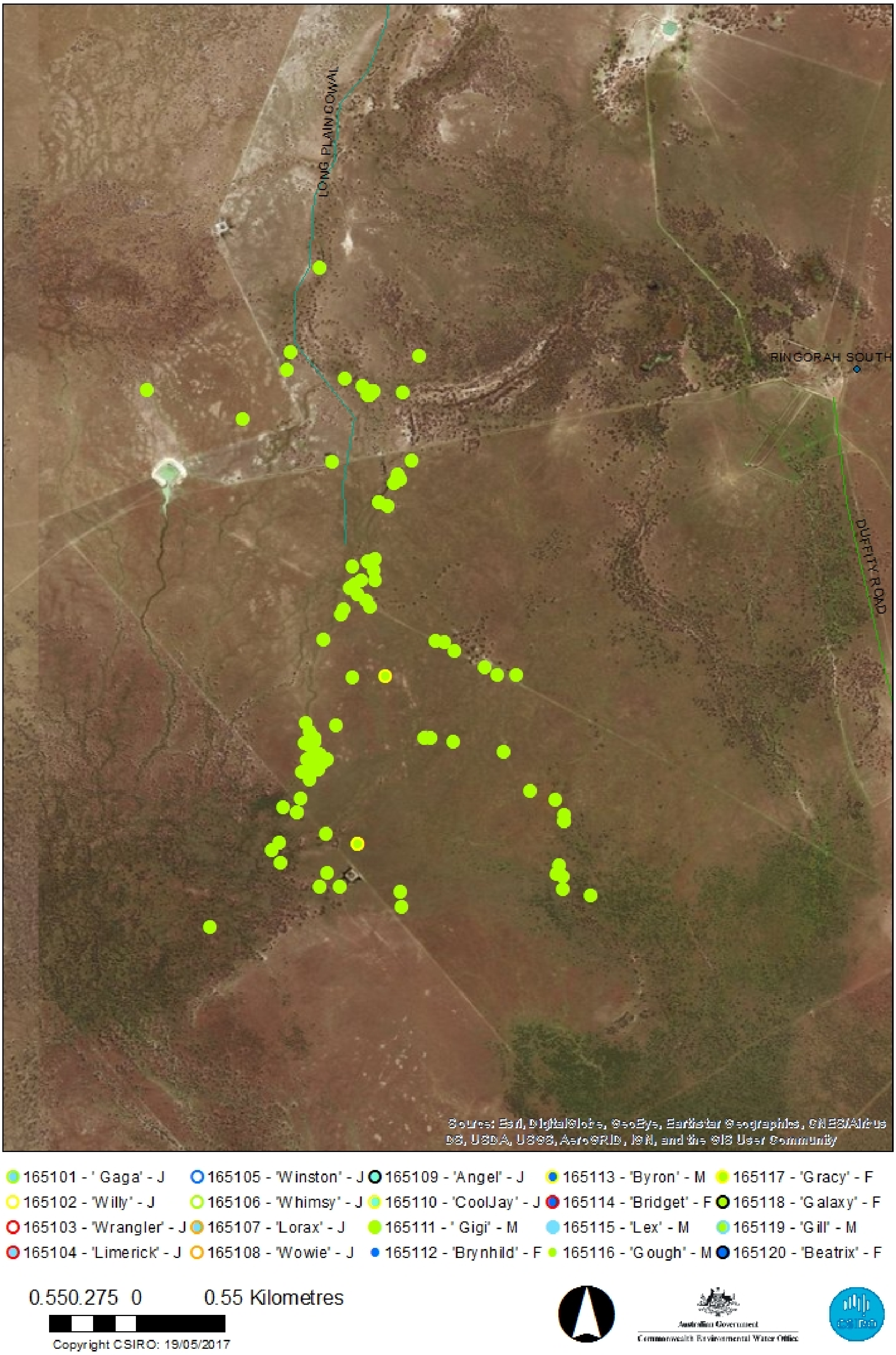


Figure 22 Locations used by tracked straw-necked ibis 'Gigi' and 'Gracy' in the south-east, Oct-Nov 2016

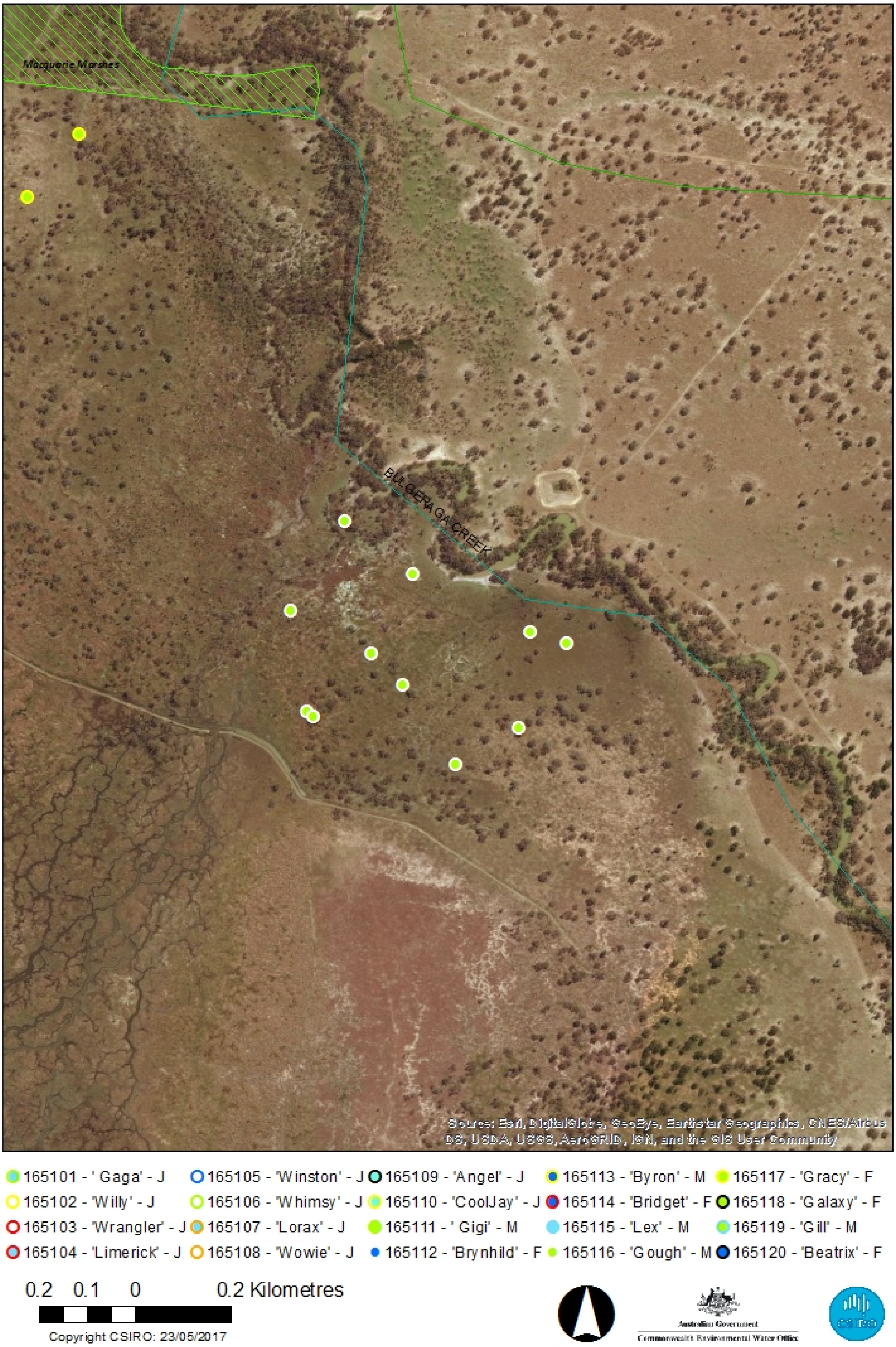


Figure 23 Primary locations used by tracked straw-necked ibis 'Gough', east of Monkeygar swamp, Oct-Nov 2016

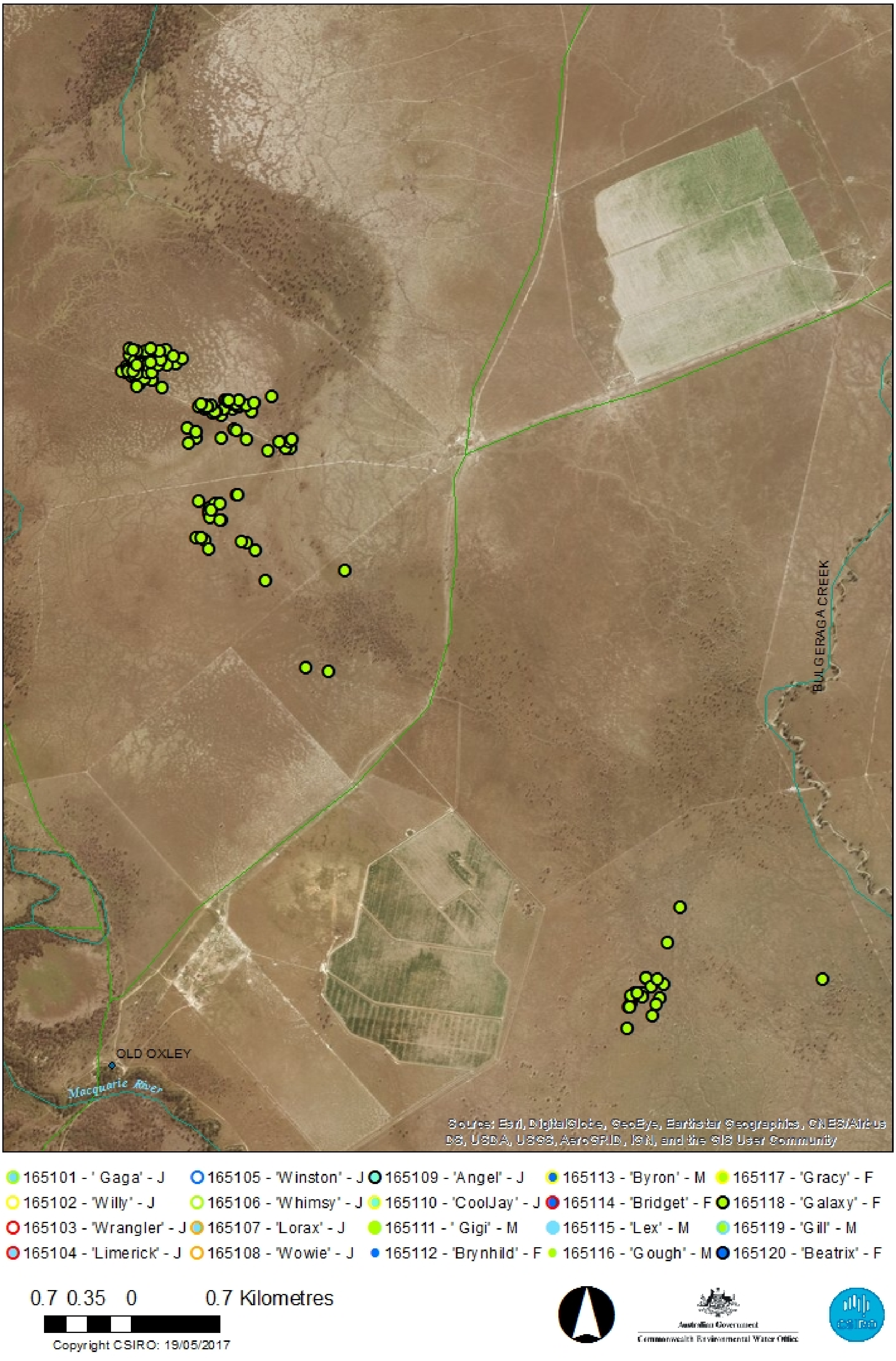


Figure 24 Primary locations used by tracked straw-necked ibis 'Galaxy', in the south, Oct-Nov 2016

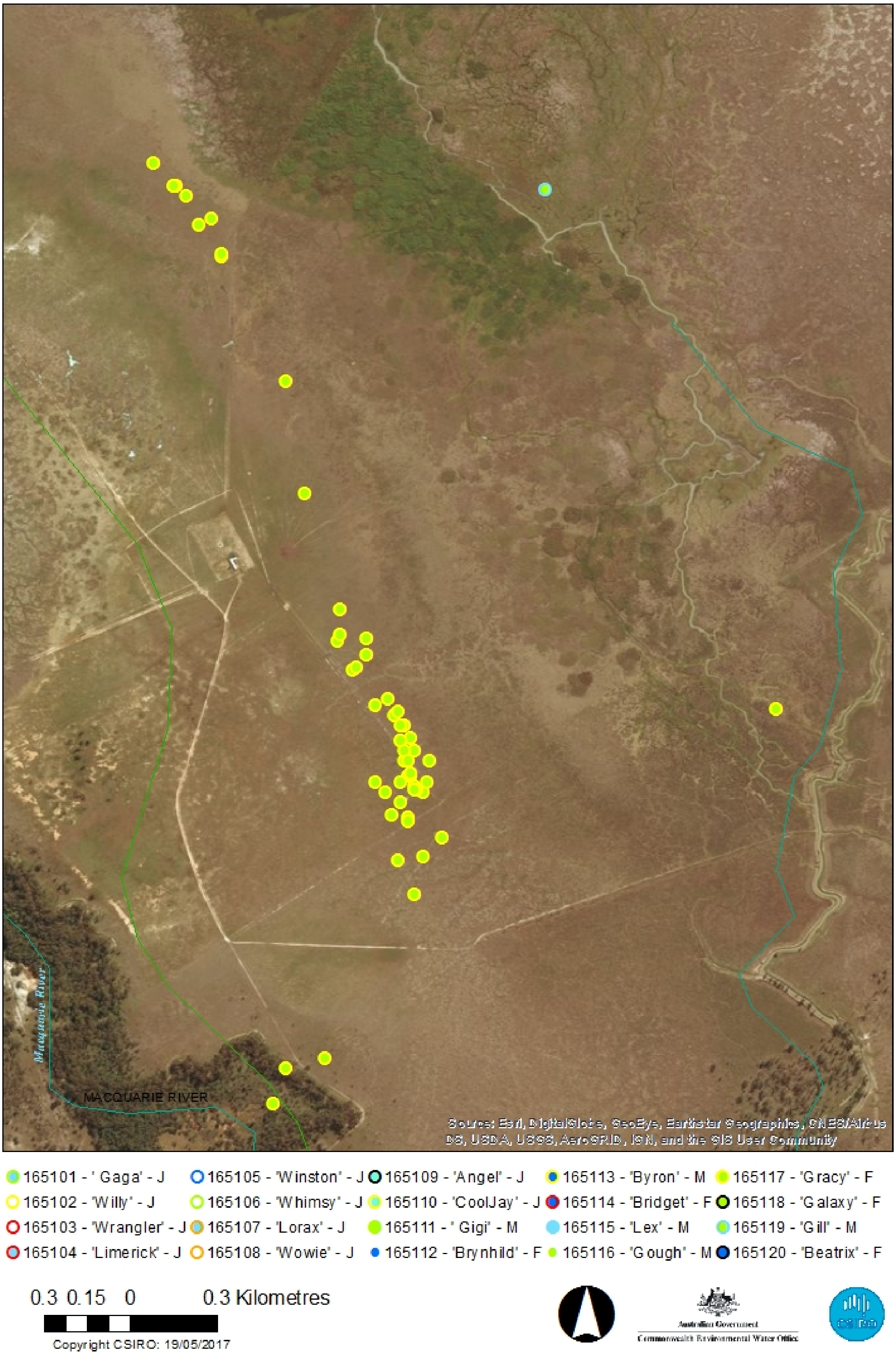


Figure 25 Primary locations used by tracked straw-necked ibis 'Gracy' and 'Gill' in the south, Oct-Nov 2016

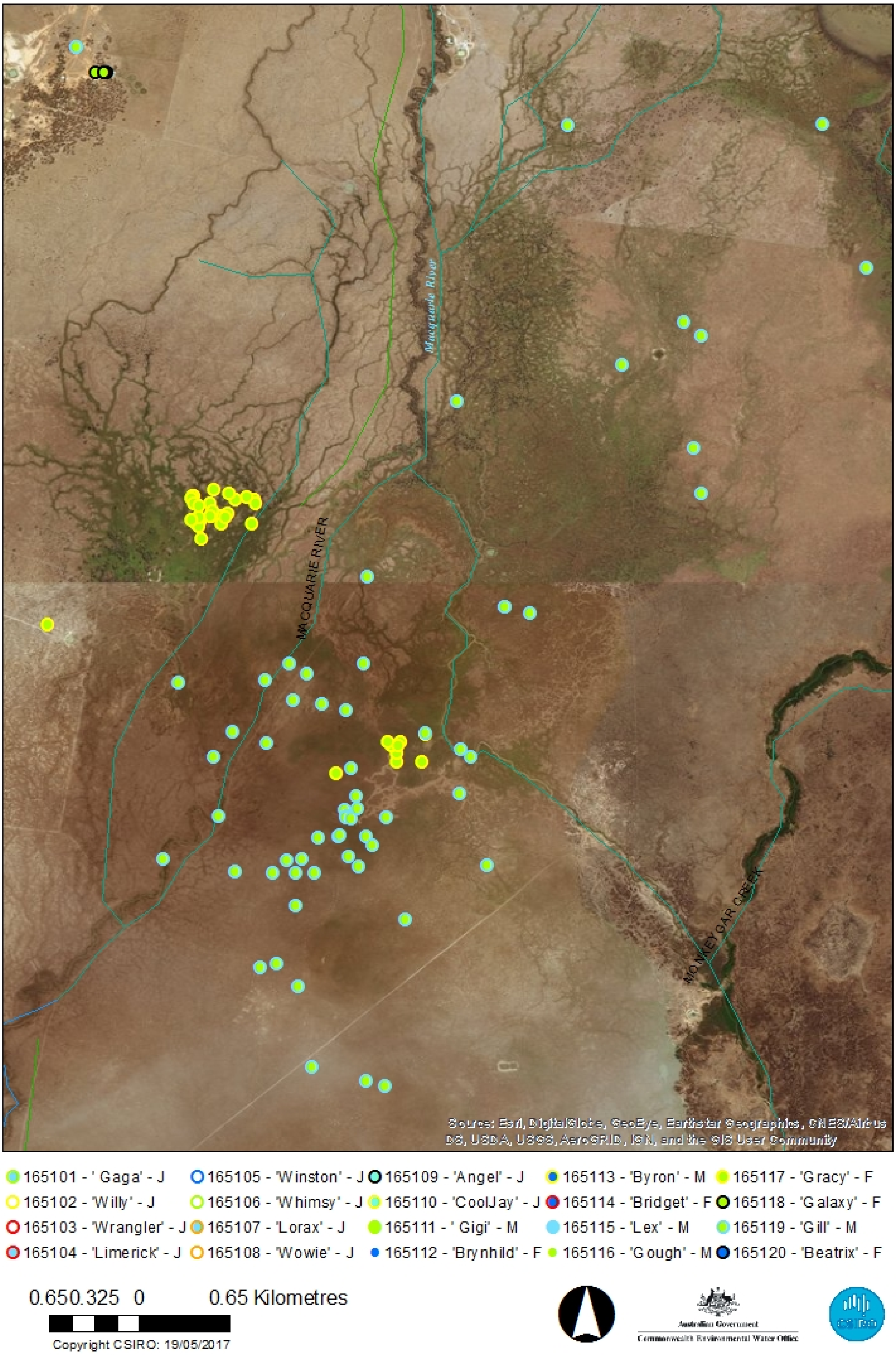


Figure 26 Primary locations used by tracked straw-necked ibis 'Gracy' and 'Gill' in the west, Oct-Nov 2016

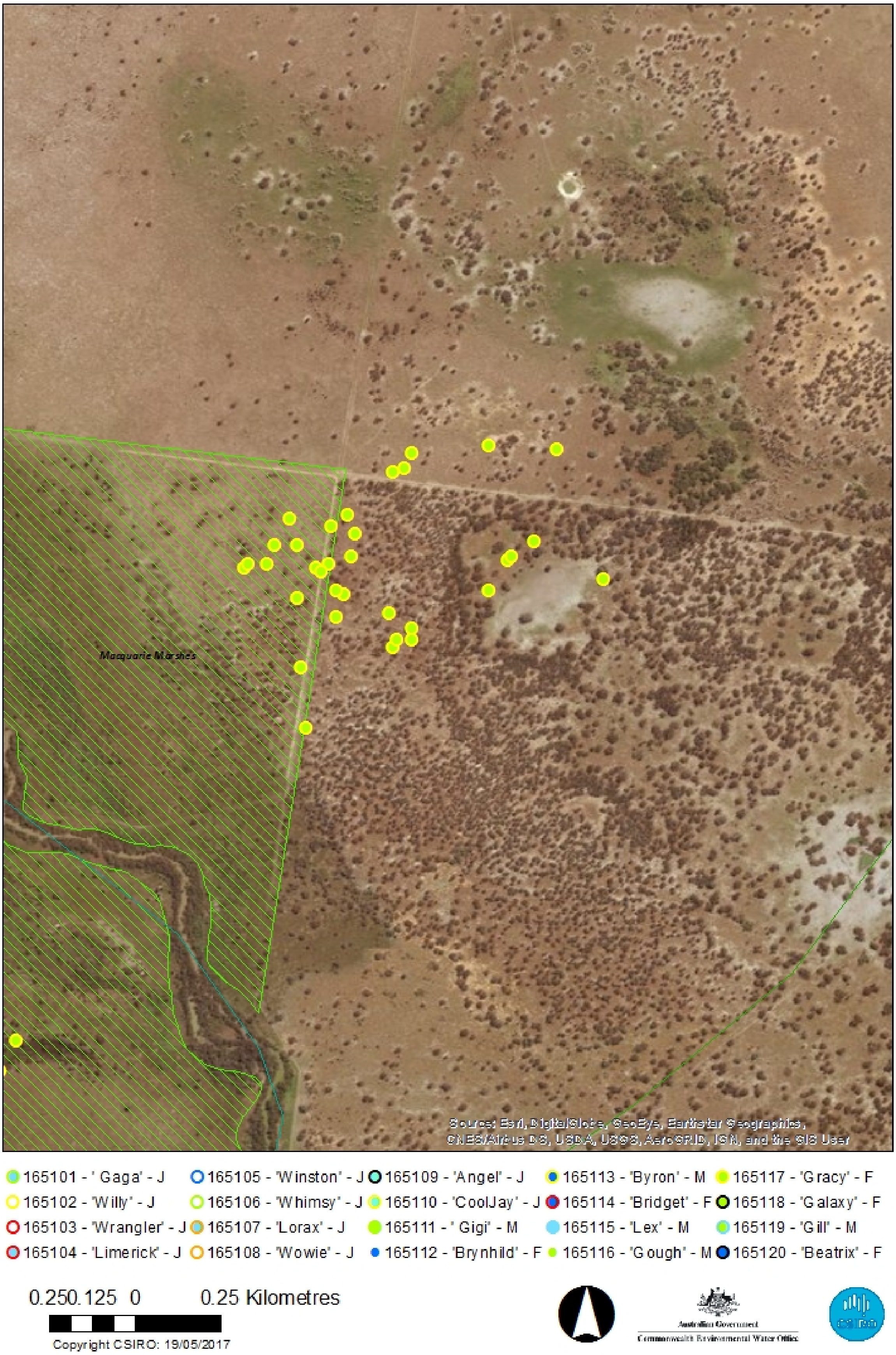


Figure 27 Primary locations used by 'Gracy' near the northern reserve post-capture, Oct-Nov 2016

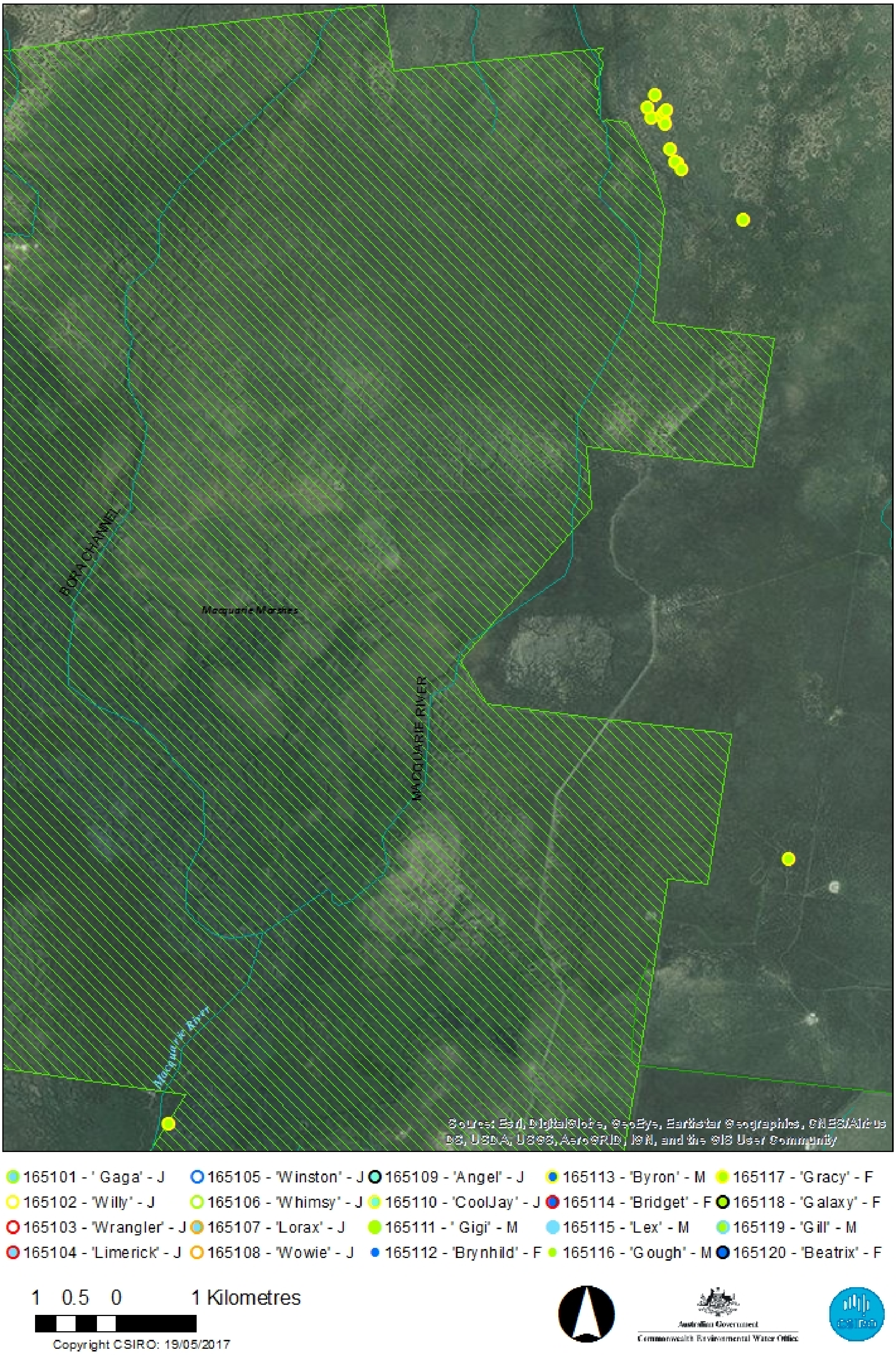


Figure 28 Primary locations used by tracked straw-necked ibis 'Gracy' near the northern reserve, Oct-Nov 2016

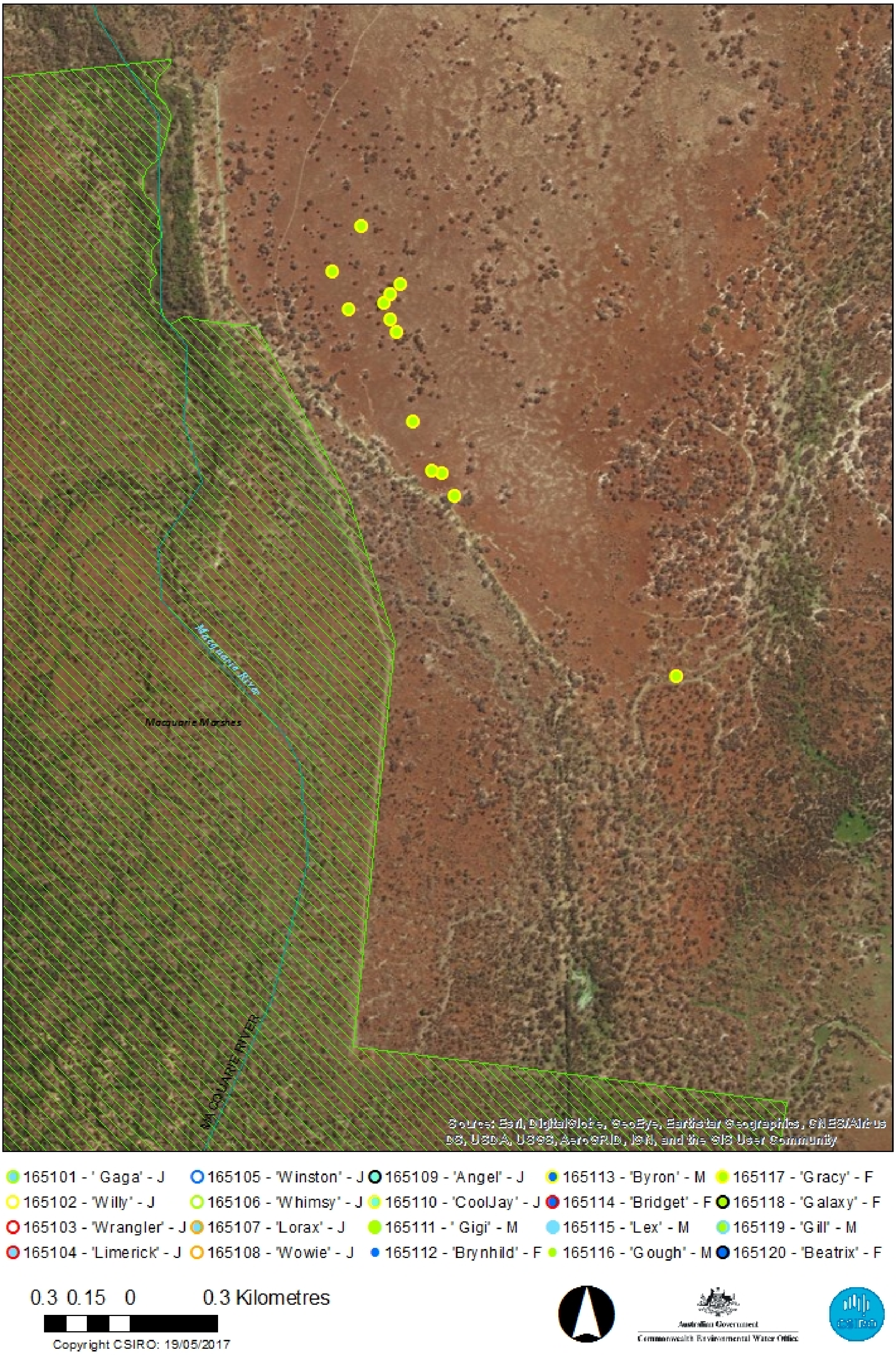


Figure 29 A closeup of the northernmost site used by 'Gracy', near Northern Reserve, Oct-Nov 2016

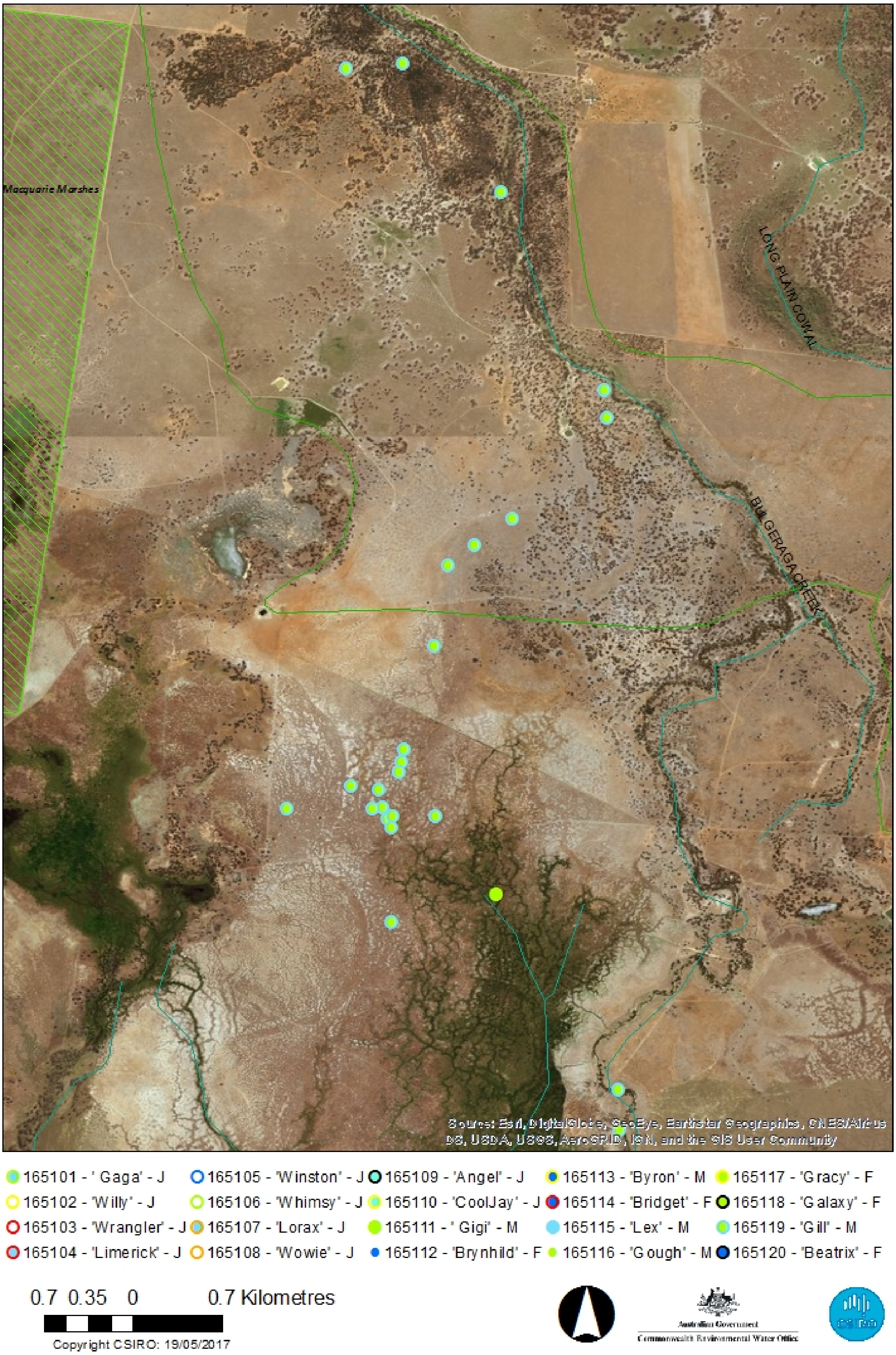


Figure 30 Sites used by tracked straw-necked ibis 'Gill' in the east, Oct-Nov 2016

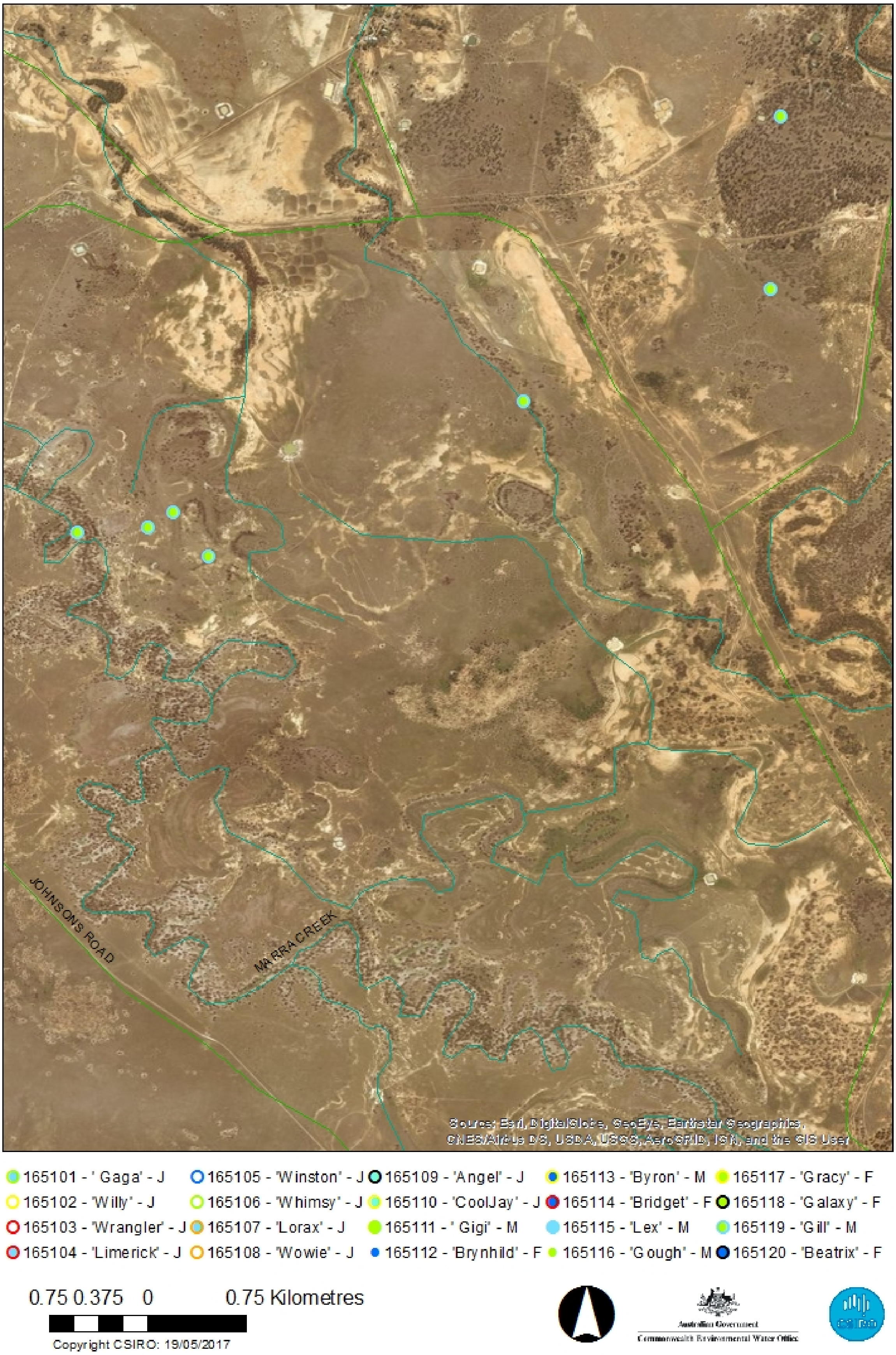


Figure 31 Sites used by tracked straw-necked ibis 'Gill' in the west, Oct-Nov 2016

Tracker 165111 - 'Gigi' - Adult male straw-necked ibis

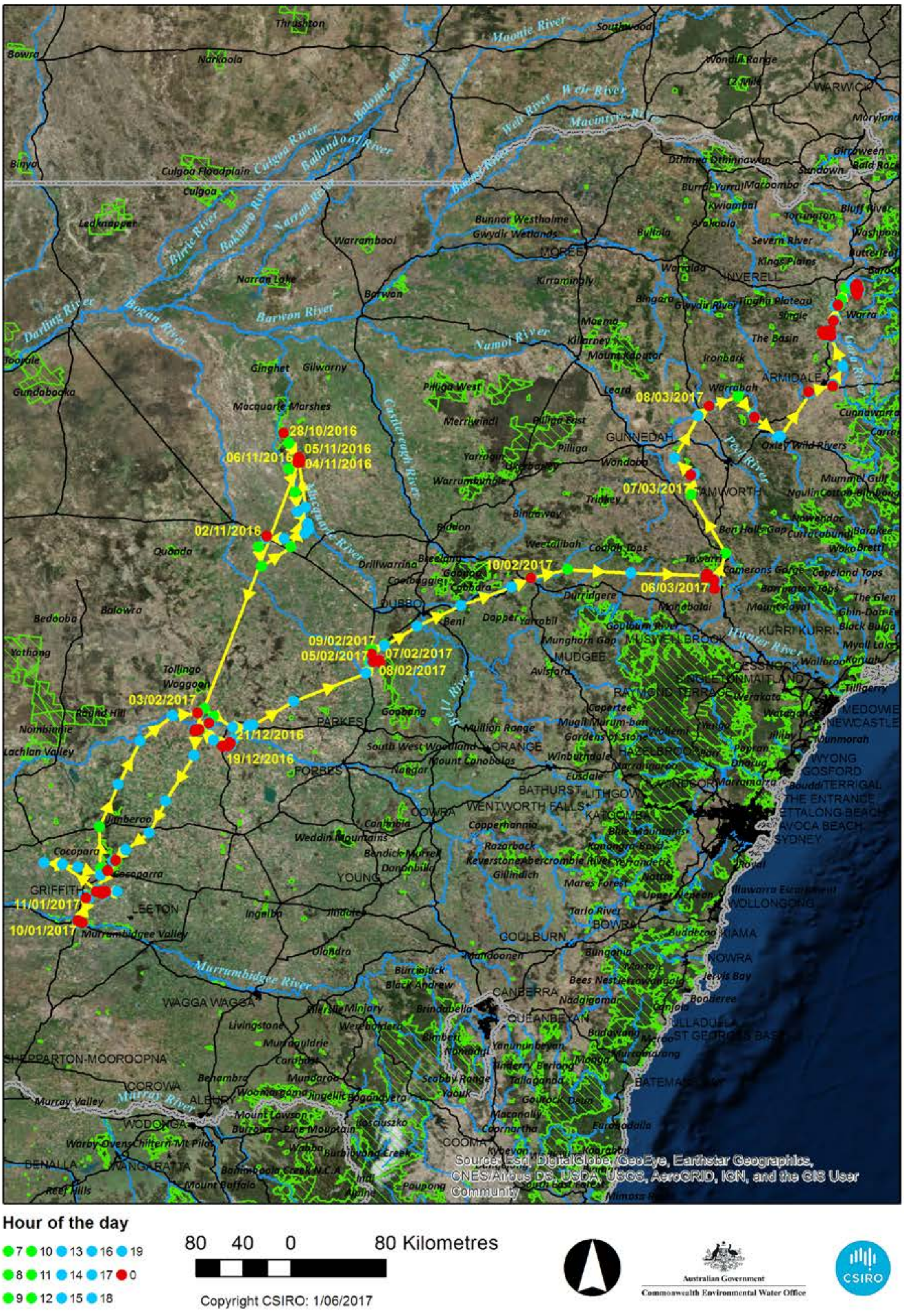


Figure 32 Movements of 'Gigi', a male straw-necked ibis, from October 2016 – May 2017

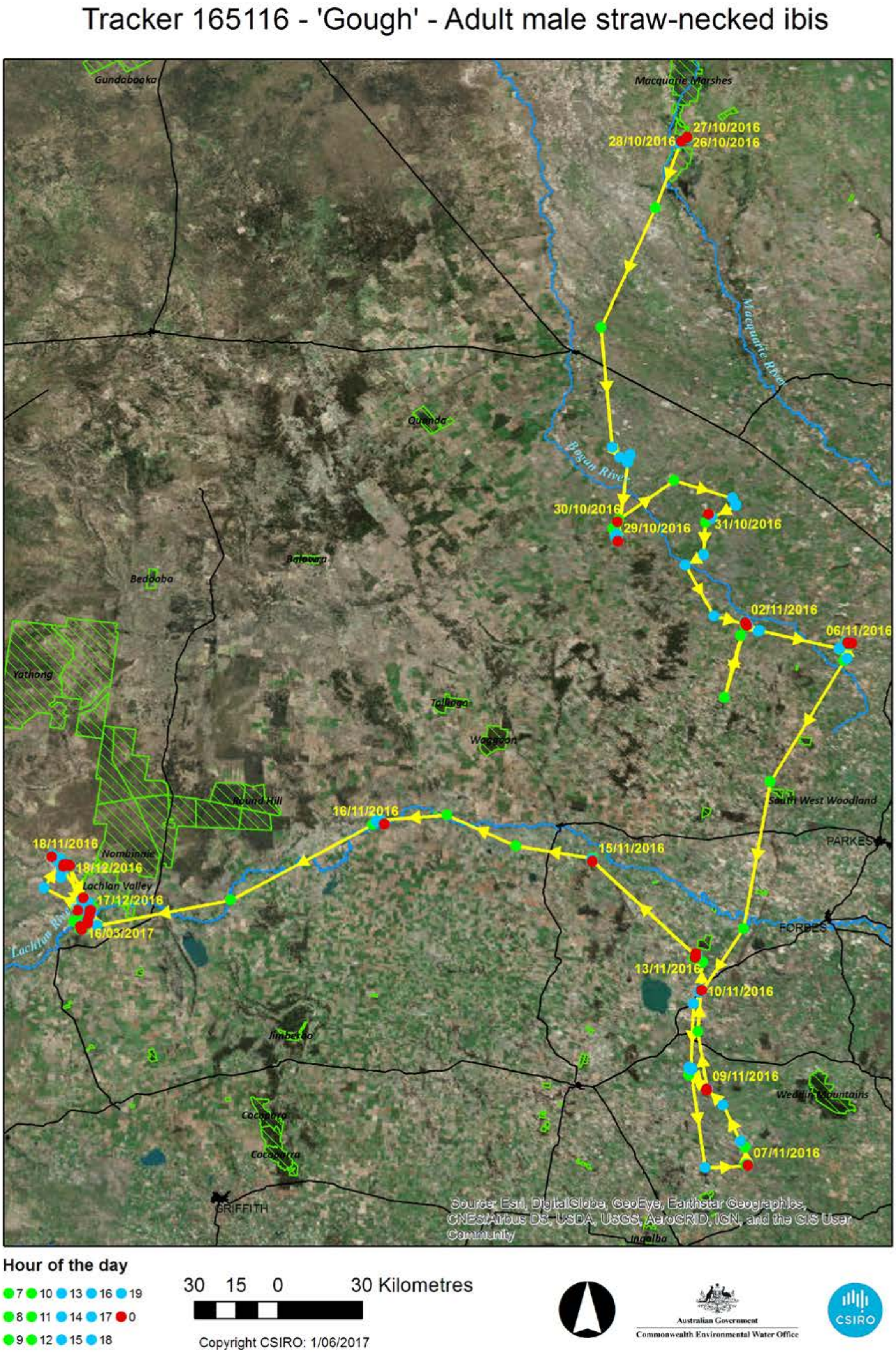


Figure 33 Movements of 'Gough Whitlam', a male straw-necked ibis, from October – December 2016.

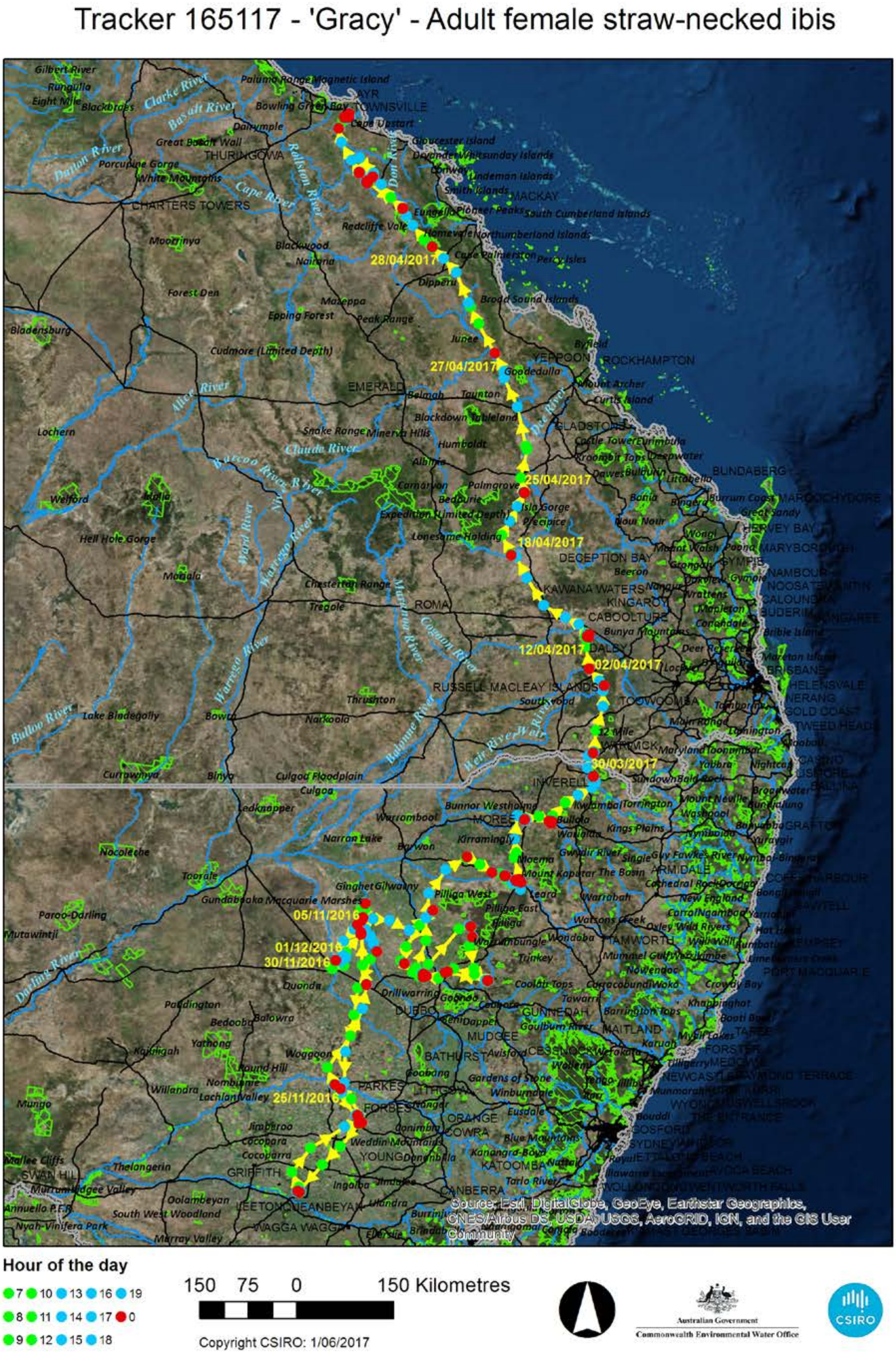


Figure 34 Movements of 'Gracy', a female straw-necked ibis, from October 2016 – May 2017.

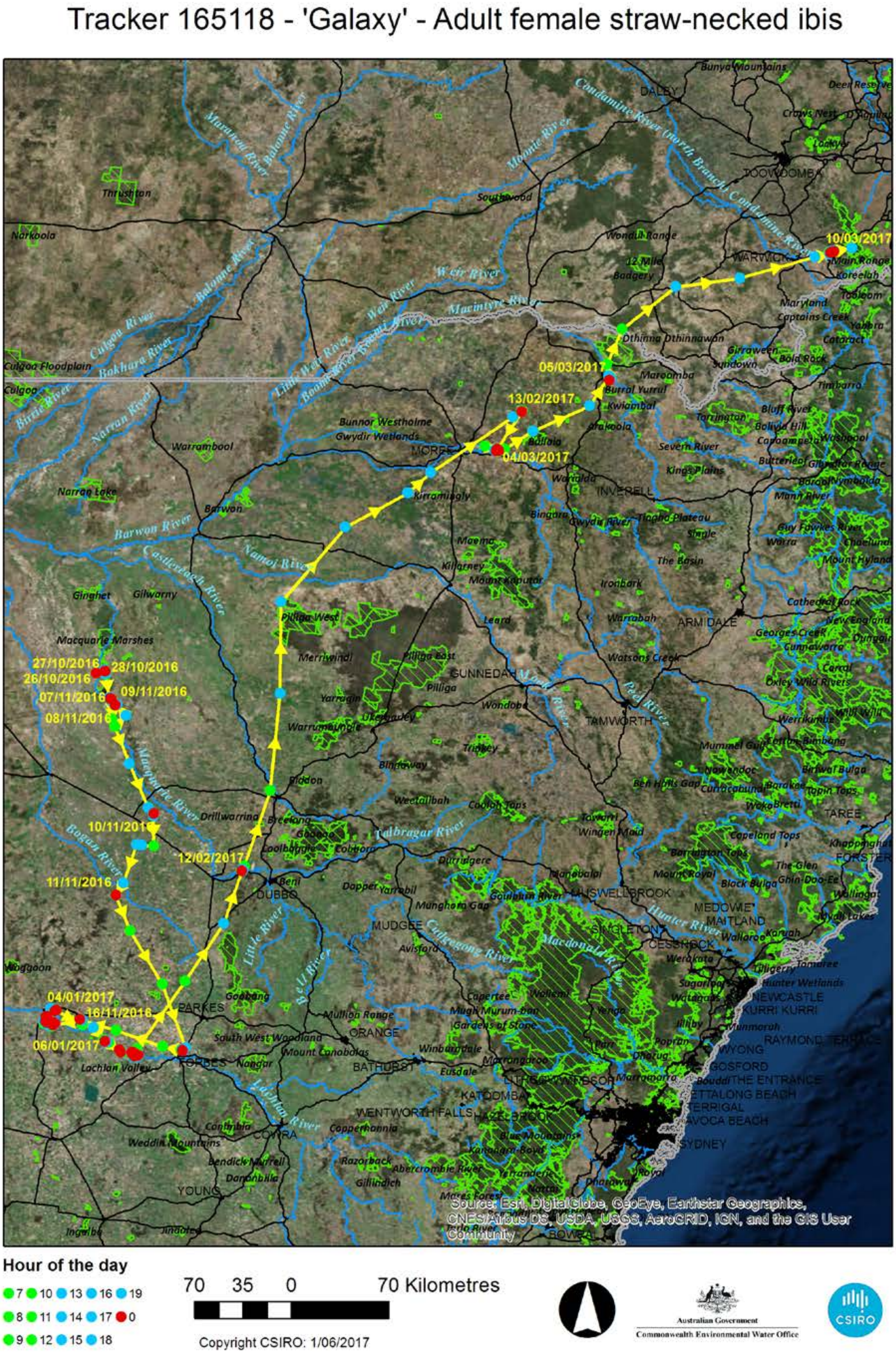


Figure 35 Movements of 'Galaxy', a female straw-necked ibis, from October 2016 – March 2017

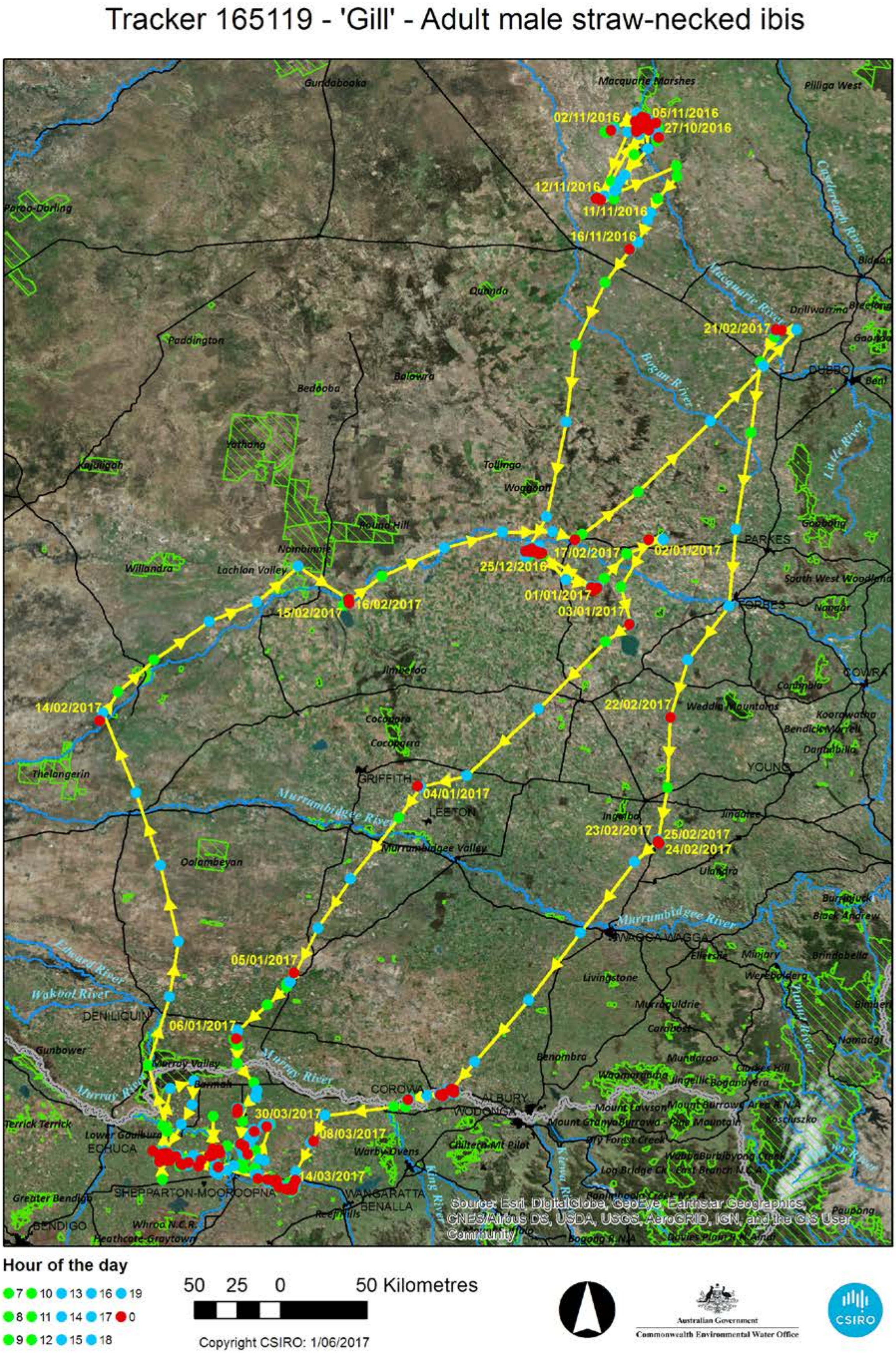


Figure 36 Movements of 'Gill', a male straw-necked ibis, from October 2016 – May 2017

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