# 2021-2022 Annual Waterfowl Quota Report to DPI Hunting, NSW Department Primary Industries

www.dpi.nsw.gov.au

**Published by the NSW Department of Primary Industries**

2021-2022 Annual Waterfowl Quota Report to DPI Hunting, NSW Department Primary Industries

ISBN: 978-1-76058-469-6

**More information**

Molly C Vardanega, Shannon J Dundas and Steven R McLeod / Vertebrate Pest Research Unit, Invasive Species Biosecurity / Orange Agricultural Institute

**www.dpi.nsw.gov.au**

**Acknowledgments**

We thank Patrick O'Brien for assistance with the surveys and for providing comments on a draft of this report. We would also like to thank John Martin for assistance with duck trapping, tagging and leg banding and Jon Coleman for helping with obtaining research banding licences. Thank you also to pilot Jim Ryan from TrueNorth Helicopters for his expert flying that allowed us to carry out surveys safely and efficiently. All work with animals has been approved by the DPI Orange Animal Ethics committee Animal Research Authorities ORA 18/21/008 and ORA 19/22/007 and OEH Fauna licence SL102055.

*Cover image: Patrick O'Brien*

INT21/121828

# Contents

## Figures



## Tables

# Introduction

In NSW, ten native duck species can legally be harvested for the purpose of damage mitigation to promote sustainable agricultural management primarily in the rice growing region of the Riverina. Under the Game and Feral Animal Control Act 2012 (GFAC Act), DPI Hunting (formerly known as the Game Licensing Unit (GLU)) is required to set annual quotas "on the basis of the best scientific information available of the estimated regional population of native game birds 32D(2)(a)." The role of the Vertebrate Pest Research Unit within the NSW Department of Primary Industries is to estimate population sizes of waterfowl in NSW, using the best available methods, and to recommend an annual quota to DPI Hunting. In addition, the Vertebrate Pest Research Unit will provide DPI Hunting with a framework for ongoing estimation of waterfowl populations, which can be used to derive a sustainable harvest quota.

No harvest can be guaranteed as being sustainable, but the risk of over-harvest can be minimised with appropriate monitoring and careful consideration of population dynamics. Harvesting strategies that support sustainable practices should include sources of uncertainty in decision making processes. Sources of uncertainty include monitoring bias, lack of precision in estimating total numbers of waterfowl seen, density dependent and independent factors likely to influence population dynamics and the effect harvesting has on population viability. Additionally, the dynamics of waterfowl populations are influenced by fecundity, mortality (both natural and harvest related), and rates of immigration and emigration and these factors affect the capacity of waterfowl to sustain harvesting. The influence of these factors on population viability are the subject of ongoing study.

For the 2021-2022 quotas, we conducted surveys of waterfowl within the Riverina region of NSW. Unmanned Aerial Vehicles (UAVs) and on-ground observers were used to survey larger irrigation dams, wastewater treatment ponds and wetlands (lakes) in April/May 2021 and a helicopter was used to survey small farm dams (<5ha in size) and a portion of the irrigation channel network in June 2021. The numbers of waterfowl observed from the sample of waterbodies was extrapolated to the Riverina region (Figure 1) to establish an estimate of abundance for each species for the region.

The purpose of the second portion of the waterfowl project is to observe duck movements so we can better inform population models by accounting for spatial movements of species in and out of the survey region. In this report, we present abundance estimates and a suggested quota for nine waterfowl species (Grey Teal, Pacific Black Duck, Hardhead, Pink-eared Duck, Australian Wood Duck, Australian Shelduck, Blue-winged Shoveler, Chestnut Teal and Plumed Whistling-Duck), for NSW for 2021. We also report on the radiotracking of a small sample of pacific black ducks, grey teal and wood ducks.

# Population Survey Methods

For the 2021-2022 quota, we refined our methods based on previous surveys. Small farm dams have the greatest likelihood of occupancy by the three most common species (Australian Wood Duck, Grey Teal and Pacific Black Duck), consequently we concentrated most of our survey effort on small farm dams. In addition, we assessed the presence of water in larger dams, wastewater treatment ponds and wetlands (lakes) across the Riverina region and sub-sampled a proportion of these (those holding water) using UAVs and on-ground observers. The observed numbers of waterfowl collected from this stratified sub-sample of waterbodies has been extrapolated to the Riverina region to establish an estimate of abundance for each species.

## Survey region

In NSW, most waterfowl are harvested from the Riverina region (Figure 1), so estimating abundance within this region is important for calculating quotas. There are three separate irrigation districts within the Riverina region, and the large irrigation dams generally fall within these regions (Figure 2).

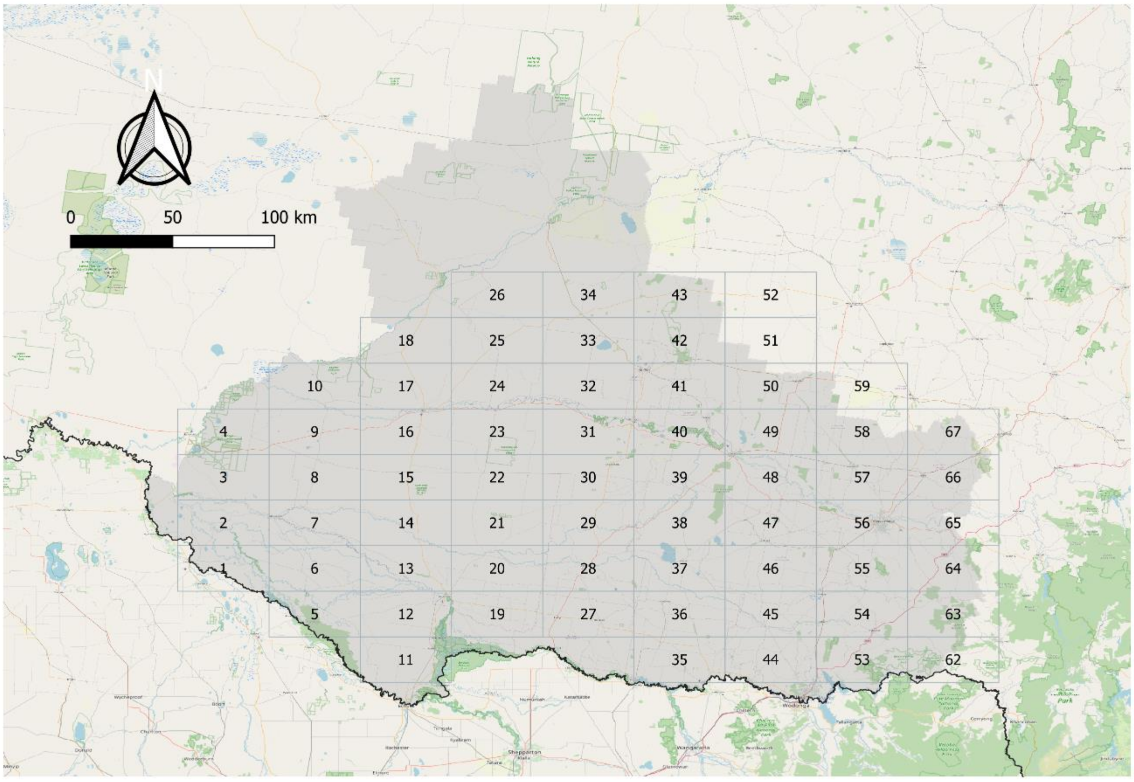



**Figure 1: The Riverina region of NSW as defined by the Bureau of Meteorology forecast areas (Source: [Bureau of Meteorology](#)) and the 62 sampling blocks in stage one. Grid blocks (0.5° longitude x 0.25° latitude) were projected across the sampling area and a simple random sample of fifteen blocks was selected. A subset of dams within each sampled block was chosen at random to be surveyed.**

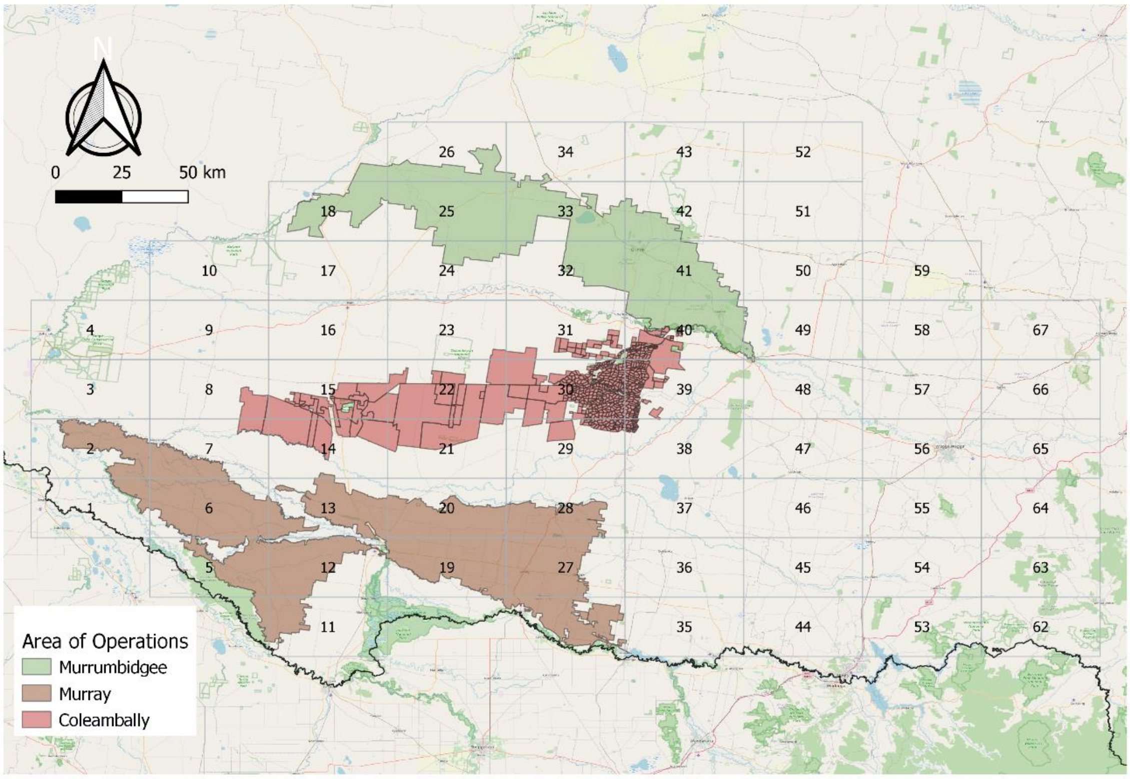



**Figure 2: The designated areas of operation for the three irrigation companies located in the Riverina; Murrumbidgee Irrigation (top, green), Coleambally Irrigation (centre, red), Murray Irrigation (bottom, brown).**

## Sampling Strategy

### Dams

A stratified random sample of dams ≤ 4.9 ha in size was selected. Sampling units (dams) were selected at random following a two-stage design (Lohr 2019). In stage one, the study site was divided into 62 equal sized sample blocks, with each block's dimensions 0.5° longitude × 0.25° latitude (46.1 × 27.7 km, total area 1279 $km^2$) (Figure 1), which formed the *sampling frame*. From the sampling frame, a simple random sample of 15 blocks (*H*) was selected, with each block (*h*) forming a *sample stratum* (Figure 1). Within each stratum an independent simple random sample of 75 dams was selected from all dams within the stratum, for a total sample size (*n*) over the sampling frame of 1125 dams. Each species was analysed separately. In stratum $h$ the number of waterfowl in dam $j$ will be $y_{h,j}$, and the total count $t_h$ in stratum $h$ will be

$$t_h = \sum_{n=1}^{N_h} y_{h,j}$$

where $N_h$ is the number of sample dams in stratum $h$.

The population total count in the sampled dams and strata will be

$$t = \sum_{h=1}^{H} t_h$$

with an overall mean number of waterfowl ($\bar{y}_U = \lambda$) per dam of

$$\bar{y_U} = \frac{t}{N} = \frac{\sum_{h=1}^{H} \sum_{j=1}^{N_h} y_{h,j}}{N}$$

where $N$ is the total number of dams selected from the sampling frame. The variance ($S_h^2$) in stratum $h$ is

$$S_h^2 = \sum_{j=1}^{N_h} \frac{(y_{h,j} - \bar{y}_{hU})^2}{N_h - 1}$$

Because sampling units were selected independently of other sampling units in different strata, the variance of the stratified estimator is the sum of the individual stratum variances,

$$S_H^2 = \sum_{h=1}^{H} S_h^2$$

The confidence interval for the overall mean number of waterfowl was calculated as

$$\bar{y}_U \pm z\sqrt{S_H^2}$$

where $z$ = 1.96 (the approximate value of the 97.5 percentile point of the standard normal distribution).

### Channels

A stratified random sample of channel sections was also selected. Sampling units (sections of channel) were selected at random following a two-stage sampling strategy. In stage one, 6 sampling blocks (strata) were selected from the sampling frame of 62 blocks. Between 10 and 20 channels within each strata were selected at random. The average length of transects was 3.30 km, and a total of 105 transects were selected. Data were analysed using the N-mixture model approach used for estimating the mean number of ducks per dam.

## Selection of dams and waterbodies to survey

All waterbodies and dams within the Riverina region were mapped and categorised by size (small 0-4.9 ha, medium 5-9.9 ha, large 10-49.9 ha and extra-large ≥ 50 ha) and combined with mapping layers for wastewater treatment ponds, natural lakes and wetlands (Kay, Carter et al. 2012, Bureau of Meteorology 2013).

The process for selecting small dams to be surveyed involved stratifying small dams (<4.9 ha in size) into 0.5° longitude x 0.25° latitude grid blocks across the Riverina region. Within randomly selected blocks we chose a random sample of dams and irrigation channels to survey with consideration of proximity to airports for helicopter refuelling stops. For the 2021 helicopter survey, we surveyed 856 dams from the 46,026 small farm dams mapped across the Riverina region. We revised the mapped shapefiles used for previous surveys for all dam sizes in 2021 to confirm dams were allocated to the correct size class, to remove dams that had been filled in and to add newly created dams.

To determine which larger irrigation dams in the Riverina region we could survey using UAVs, (with complementary ground surveys), the presence of water within dams (as well as the proportion of dry dams for each size class) was determined using Sentinel WMS imagery (https://www.sentinel-hub.com/develop/api/ogc/standard-parameters/wms/) taken within the preceding month of the survey. From those holding water, we selected a random sample of large irrigation dams from three size classes (Medium, Large and Extra-large).

We selected a range of different sized wastewater treatment ponds across the Riverina region. Following the 2017 survey, we established that there was a high correlation (r = 0.89) between the number ducks present on wastewater treatment and surface area of water in ponds. Due to CASA (Civil Aviation Safety Authority) restrictions on flying zones, we excluded wastewater treatment ponds near airports from the drone surveys.

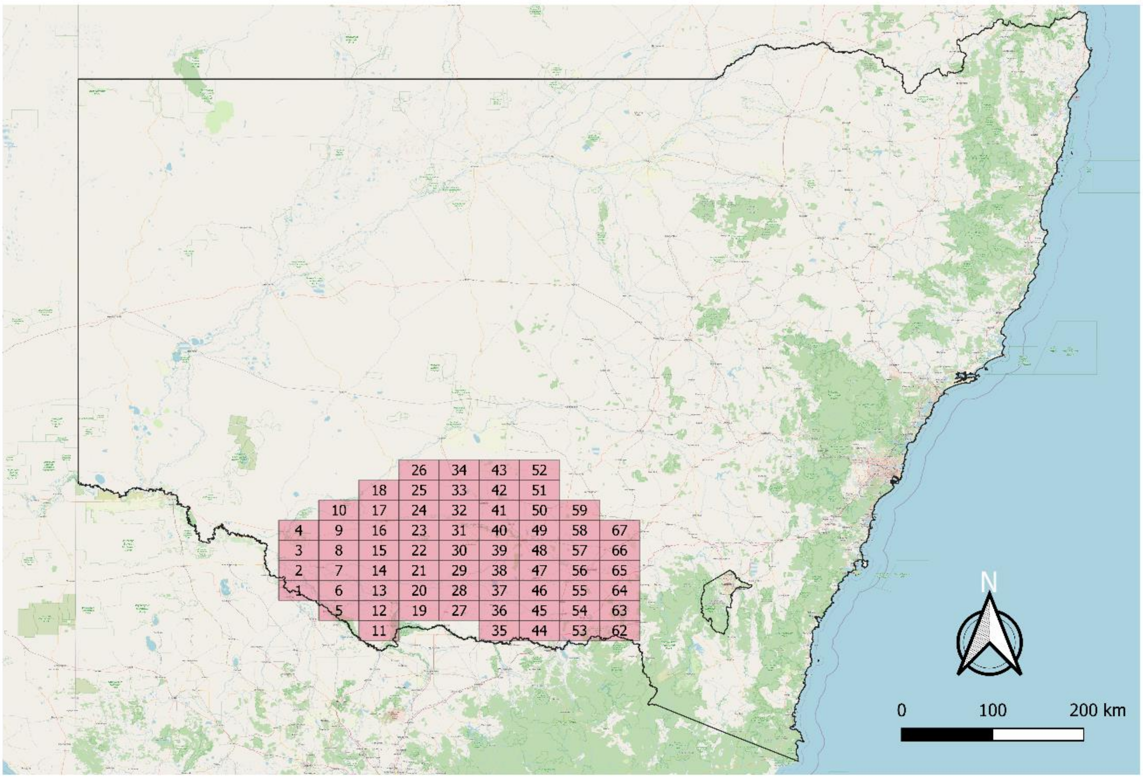



**Figure 3: Grid blocks (0.5° longitude x 0.25° latitude) projected across the sampling area. A simple random sample of fifteen blocks was selected, and a subset of dams within each sampled block was chosen at random to be surveyed.**

We selected two natural lakes within the Riverina region to survey for the 2021 survey. Many of the lakes within the survey region were either dry or unable to be accessed at the time of the survey (Lake Brewster, Lake Urana, Lake Cullivel and Lake Coolah). We were able to access Barrenbox Swamp for the survey in 2021, and aerial imagery indicated the water levels were very high (Figure 11). Tombullen water storage was holding less water than in previous years (Figure 12) but was still suitable for survey. Lake Brewster, which is often dry, was holding water again this year and Lake Cowal also had a reasonable amount of shallow water again this year however these lakes were unable to be accessed.

We carried out UAV surveys at Barrenbox and Tombullen water storages.

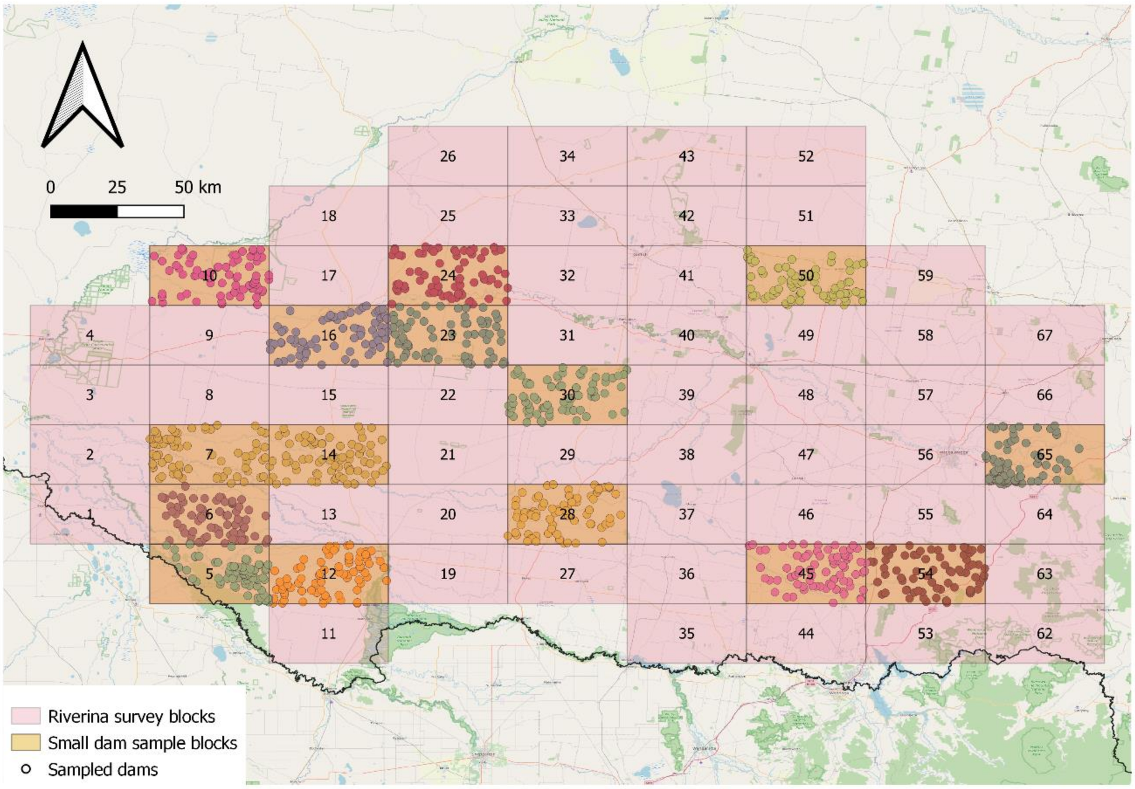
## Helicopter surveys

Within each survey block, we randomly selected 75 dams (Figure 4). The final number of dams per survey block depended on keeping the total transect length to less than 320km or a flight time of <2 hours (limited by the fuel capacity of the helicopter and fatigue of observers). Channels were also surveyed this year to expand monitoring to include other water sources occupied by waterfowl. Six blocks that included channels were surveyed (Figure 5). Dams holding no water and those with water but not occupied by waterfowl were noted. For dams with waterfowl, we flew a low and slow circuit around the dam (no lower than 18m) and the observers would identify and count waterfowl. We used a Bell 206 helicopter which allows for three observers to observe ducks on the same side of the helicopter. Aerial operations were conducted with the front and rear doors which allows for better visibility of ducks for all observers.

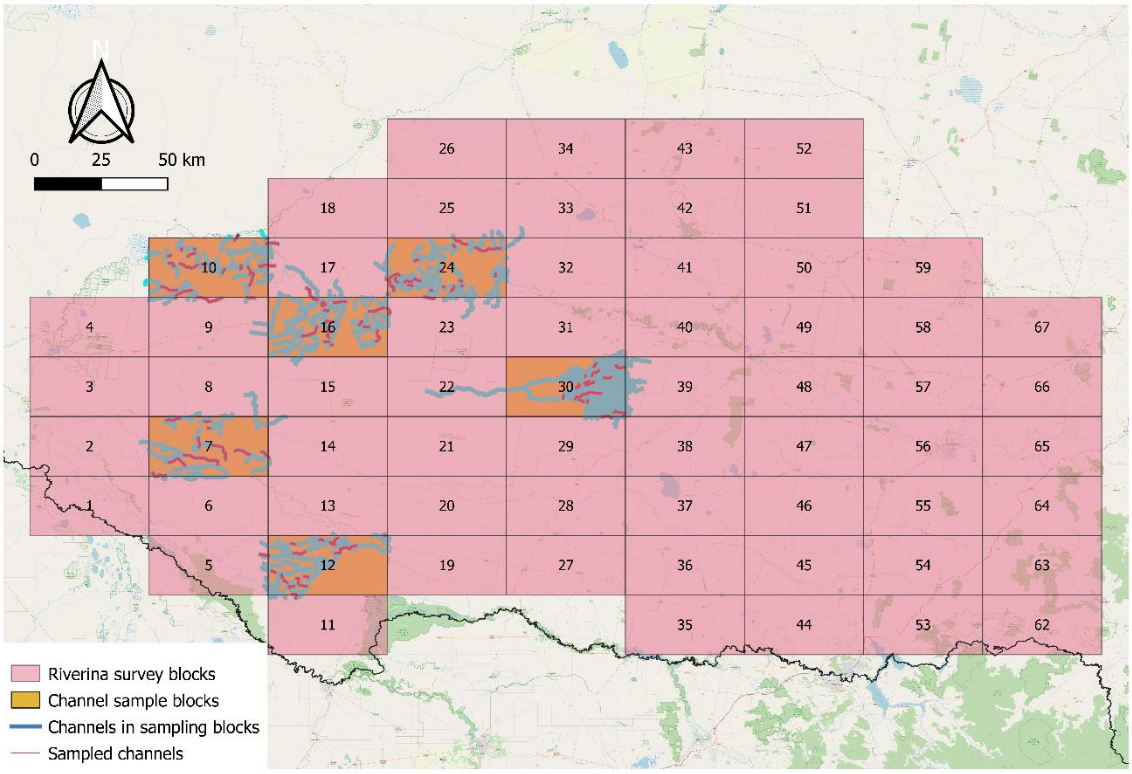
Data collected during the helicopter surveys represents a multiple observer count (with two observers, front and back, making simultaneous observations and logging species counts on GPS enabled tablets) and a third observer, seated adjacent to the rear observer, recording covariates that may have influenced detection probability and the presence of waterfowl (e.g. habitat around dams, presence of livestock). Survey data were analysed using the package `unmarked` (Fiske and Chandler 2011) in the statistical programming language R (R Core Team 2021).

The function `pcount` from the R package `unmarked` was used to estimate abundance of waterfowl using an N-mixture model (Royle 2004). N-mixture models can be used for estimating abundance in closed populations of unmarked individuals and where there is uncertainty in the state process (true abundance) and the detection process. The N-mixture model approach assumed that waterfowl counts represented replicated point-count estimates and that the counting process was a function of covariates that affected detection and could change from one survey to the next (e.g. observer, the presence of glare on the water surface etc) and covariates that were site dependent and were fixed (e.g. the presence of grass, crops or trees etc).

The function `pcount` calculates the probability of detection given that a species is present at a waterbody and an estimate of the mean number of individuals per dam. In addition, the total population size and confidence intervals around the estimate, for the dams surveyed, were calculated using empirical Bayes methods (Fiske and Chandler 2011). Detection probability and mean abundance per dam were estimated from the highest ranked model based on AIC.




## Figure 4: Map of sampled small dams (points), June 2021.




## Figure 5 Map of channels sampled, June 2021.

## N-mixture models

N-mixture models were developed to analyse replicated count data and account for imperfect detectability while deriving relationships between populations of animals and their environment (Royle 2004). The basic idea is that $r$ sites are surveyed, and each site contains an expected number of animals $\lambda$, such that the number of individuals at the $i$th site can be described by the equation

$$N_i \backsim Poisson(\lambda)$$

which describes the state process (or true abundance—a latent state) at site $i$. Each site is surveyed $j$ times (for the waterfowl survey $j = 2$ and counts are conducted simultaneously), and each individual has a probability $p$ of being detected, giving

$$y_{i,j}|N_i \backsim Binomial(N_i, p)$$

which described the observation process (or observed count, $y_{i,j}$) as a function of the true abundance, $N_i$.

The variation in true abundance at sample site $i$, is modelled as a Poisson distribution with mean $\lambda$. The observed counts $y_{i,j}$ (given $N_i$) at site $i$ and replicate survey $j$ are described by a binomial distribution with sample size $N_i$ and detection probability $p$. Distributions other than the Poisson were tested, including the zero-inflated Poisson and the negative binomial.

Covariates may affect both the state process (likelihood that waterfowl occupy a dam) or the observation process (the likelihood that waterfowl, if present, are detected). A range of potential covariates were assessed and included in a range of alternative models that were fitted to the data. Models with high levels of support ($\triangle AIC < 2$) were identified using multimodel inference (Burnham and Anderson 2002) and used to estimate mean abundance per dam, $\lambda$, and detection probability, $p$. Covariates tested that potentially influenced detection included: observer (SD, POB, MV); observer position (front, rear); and the presence of glare. Covariates that potentially affected occupancy included: presence of livestock (sheep, cattle); presence of vegetation (grass, crops, trees, unspecified vegetation); presence of vegetation in the water; and the presence of bare ground.

### Assumptions of the N-mixture model

There are a number of assumptions of N-mixture models and inference can be sensitive to the assumptions. The assumptions are,

1. Poisson and binomial distributions are true descriptions of state/observation processes
2. Abundance at each site is random and independent of abundance at all other sites
3. Population is closed between surveys
4. Observers do not double count individuals
5. All $N$ individuals have the same detection probability $p$

Of these five, the last assumption—that there is no unmodeled variation in detection probability—is probably the most likely to influence our counts, and we were confident that deviations from the other assumptions were minor. Violations of assumption 5 may lead to under- or overestimation of average abundance, and consequently, over- or underestimates of total population size, respectively. Unfortunately, it is difficult to identify model mis-specification due to unmodelled heterogeneity in detection probability (Link *et al.* 2018).

Alternatives to N-mixture models, likely to involve capture-recapture methods will be examined for future surveys.

To estimate population size, we assumed that violations of any assumptions were minor and did not greatly influence estimated abundances.

## Drone surveys

Unmanned aerial vehicles are particularly suited to sampling medium and large waterbodies (> 4.9 ha surface area). However, there are restrictions on using UAVs, specifically the requirement to have landholder permissions to fly UAVs on private property and the restrictions related to flying UAVs in restricted airspace, especially around airports.

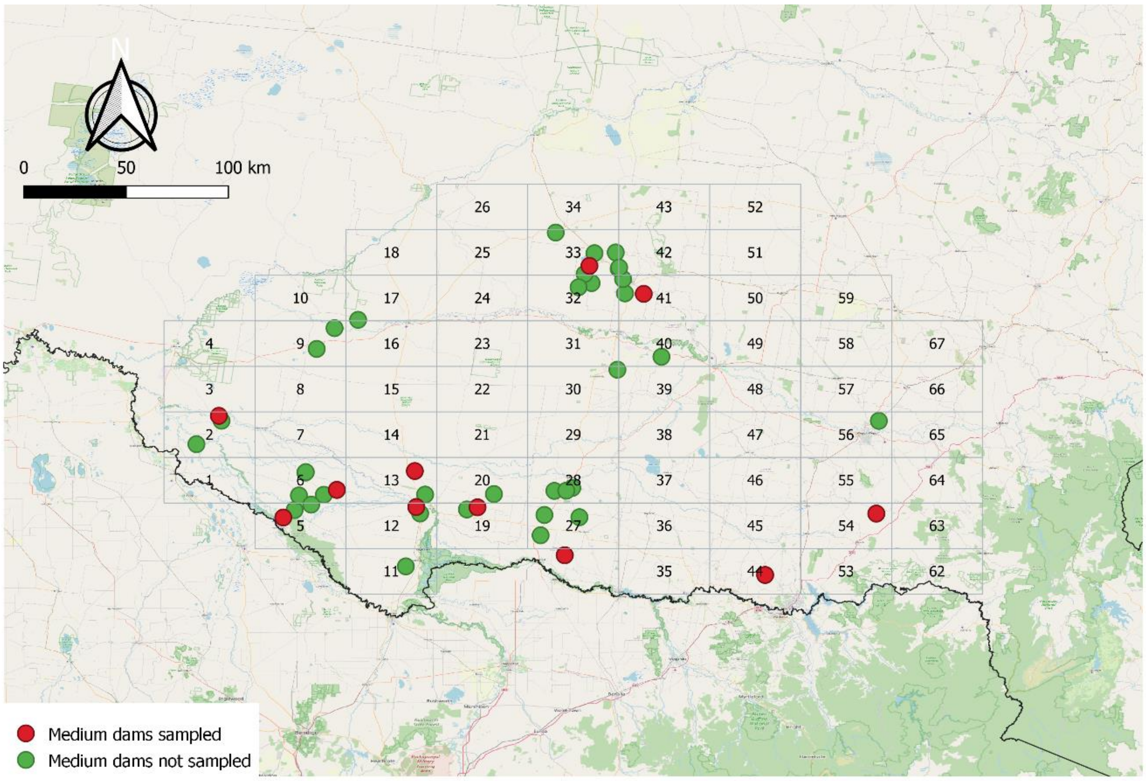
For this year's survey, we used a DJI Matrice 210 UAV with an X5S camera. The UAV had a 20MP camera and recorded high resolution video (4K) at 60fps which provided the resolution to identify ducks to species (Figure 7).

We used the DJI Pilot app to define a survey grid for each surveyed waterbody. For each selected dam or wastewater treatment pond, the UAV was flown in a grid pattern with the aim of surveying all waterfowl present on the dam or pond. For the wastewater treatment ponds, we calculated an average number of each species per ha of surface area surveyed (60ha) and extrapolated this to the total surface area of all wastewater treatment ponds in the Riverina (total of 153ha of surface water). For natural lakes, we surveyed a sub-sample of the lake with the UAV and calculated the area of the lake covered during the survey (~18%). We then extrapolated the counts from the sub-sample to the entire lake, considering the current water level (as determined from recent Landsat images).

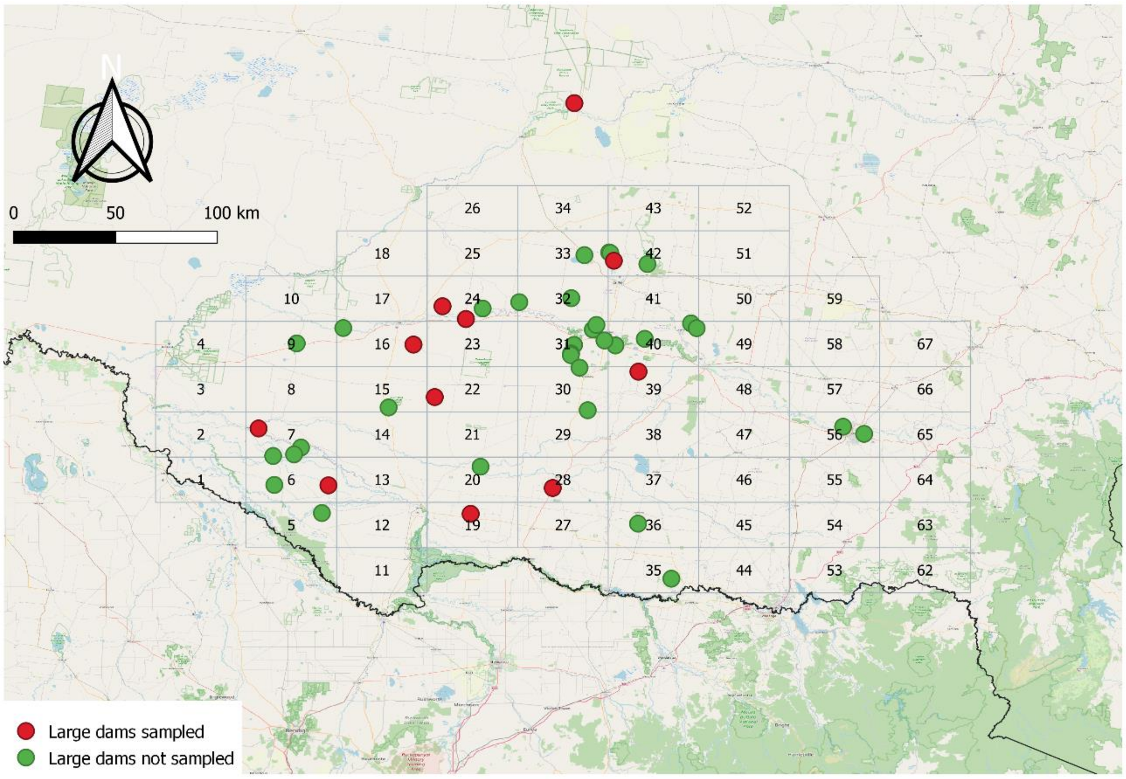
We aimed to collect video footage of waterfowl across each dam while they were on the water by flying the UAV as close as possible without causing them to fly away. Depending on the reaction of waterfowl to the drone, the survey height of the drone was varied (30m-35m). Flying at a faster speed (20-25kph) also reduced the amount of disturbance to waterfowl sitting along banks or on water.

We analysed the video using a custom program (Birdtags, Mathworks) written for MATLAB (https://au.mathworks.com/products/matlab.html). For each video, one observer went through all videos manually and identified and tagged all waterfowl seen. The footprint of the drone was calculated using maps provided by Airdata (linked to each UAV and displays individual flights), using this footprint a buffer was created around the flight line, this mapping information was then used in conjunction with Google Earth to map the exact area surveyed on each waterbody. We then used the area of water present with the area covered by the UAV to calculate total area covered (%). The counts were adjusted to represent 100% coverage for each dam. The program then automatically outputs the resulting data into an Excel spreadsheet. In some cases, very few ducks were present on the dams, and these were surveyed by ground counts only, where two observers carried out independent counts using a spotting scope.

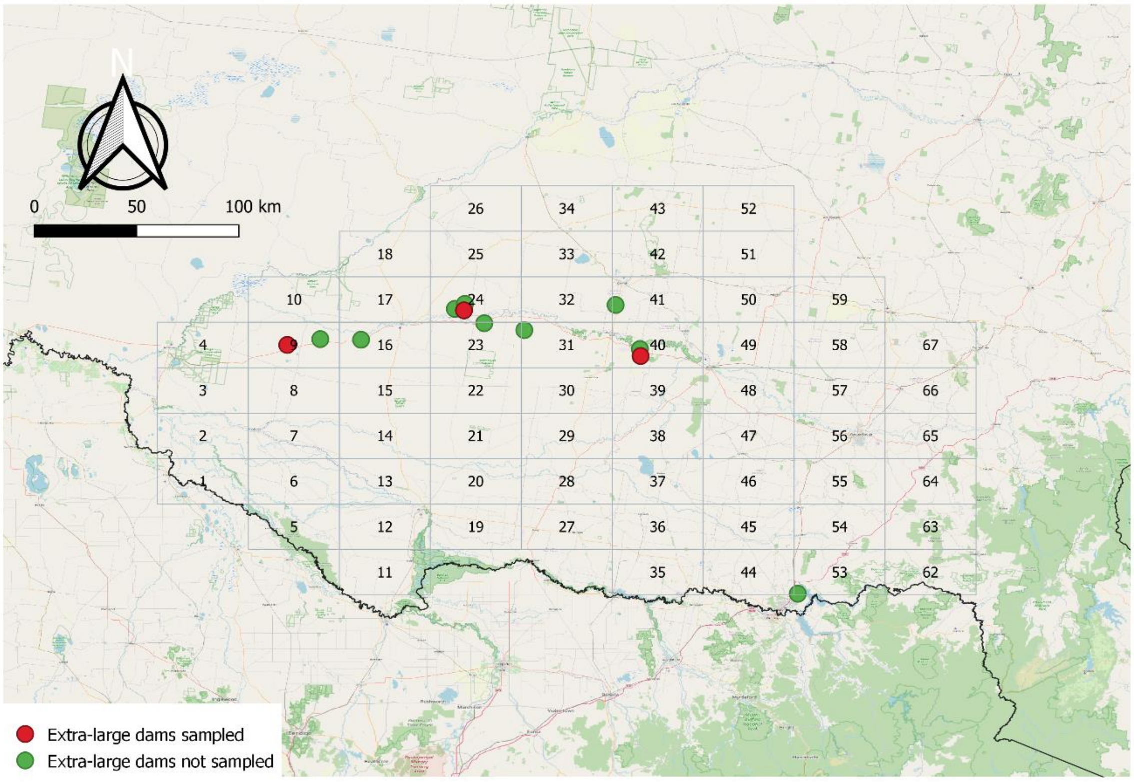
6 a)


N
0
50
100 km
Medium dams sampled
Medium dams not sampled

6 b)


N
0
50
100 km
Large dams sampled
Large dams not sampled

6 c)




6 d)

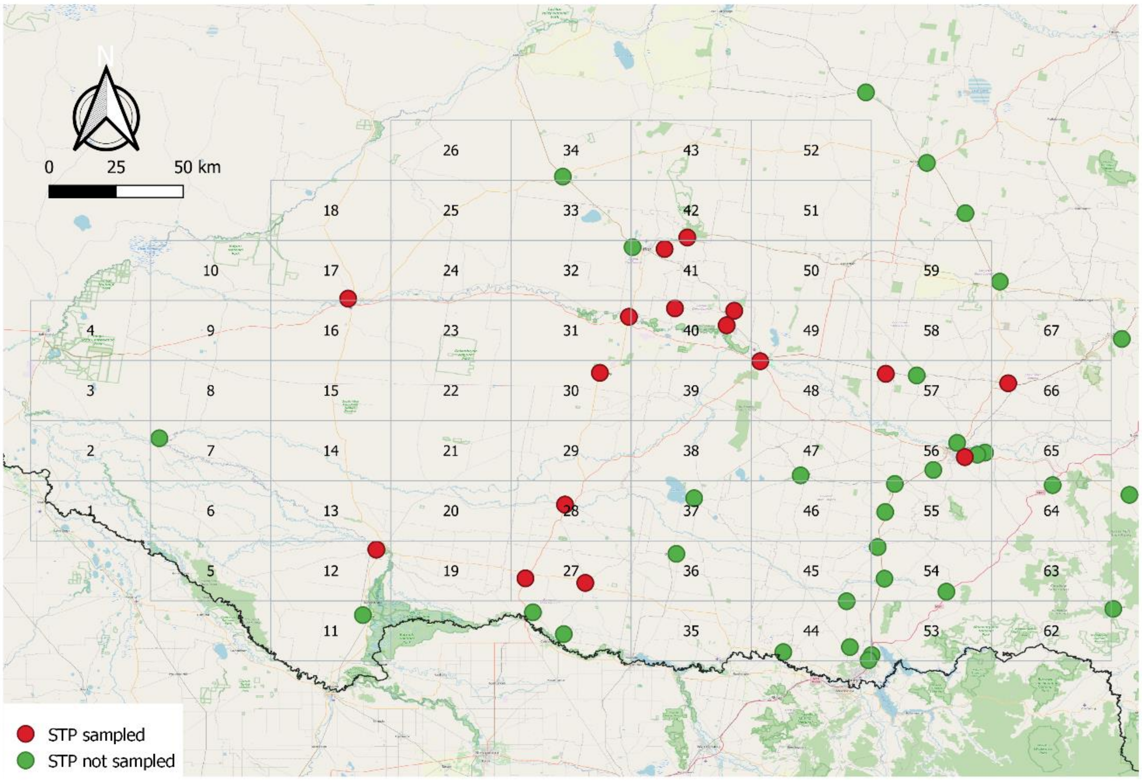



**Figure 6 a) Medium dams 5-9.9ha, b) large dams 10-49.9ha, c) extra-large dams 50+ha, natural lakes (green dots) and d) wastewater treatment ponds surveyed using the drone during the June 2021 survey.**

**Figure 7 Still image example from the UAV survey of ducks. These are primarily Plumed Whistling ducks with some Pacific Black Duck. Videos collected from the UAV are processed using the custom Matlab Birdtags program.**

### Water availability in the Riverina

Much of the Riverina region experienced average or above average rainfall in the past year (Figure 9). The start of 2021 brought rain to the Riverina region with above average and very much above average rainfall deciles (Figure 8). Despite this, many of the extra-large irrigation dams weren't holding water at the time of the survey. Off allocation water may have been provided to farmers before the helicopter survey but many irrigation dams were dry in April/May 2021 when we carried out the drone surveys. Most of the extra-large irrigation dams act as a storage for water and are periodically filled (on a needs basis, generally in summer) with water from the irrigation network.  Additional rain was experienced in the Riverina region in June 2021 (Figure 10).

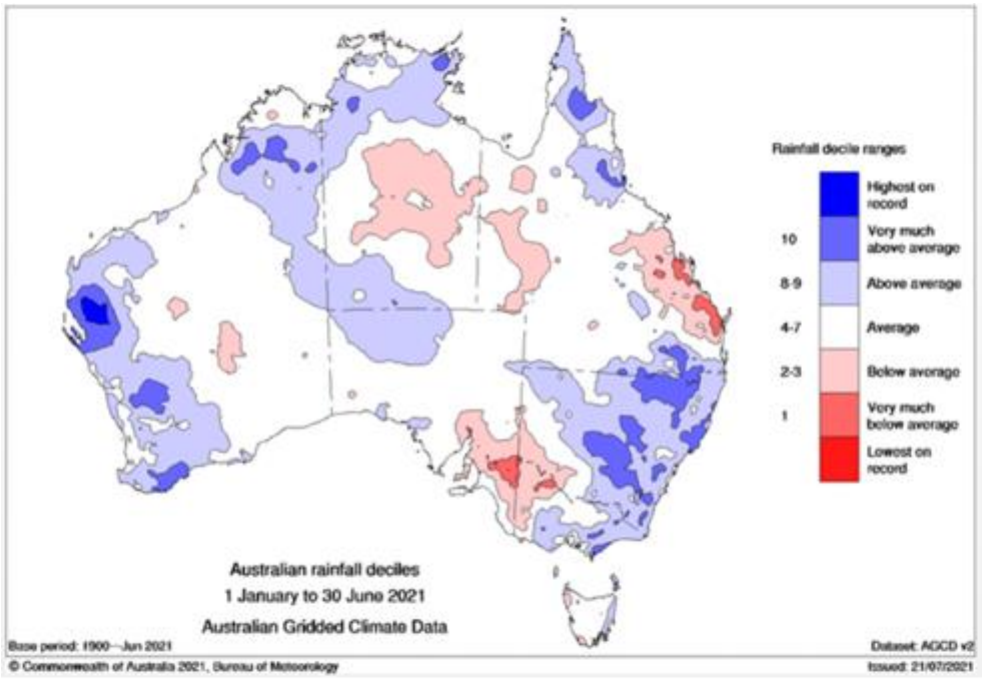



**Figure 8 Australian rainfall deciles for last 6 months January 2021 to June 2021.  Source: Bureau of Meteorology**

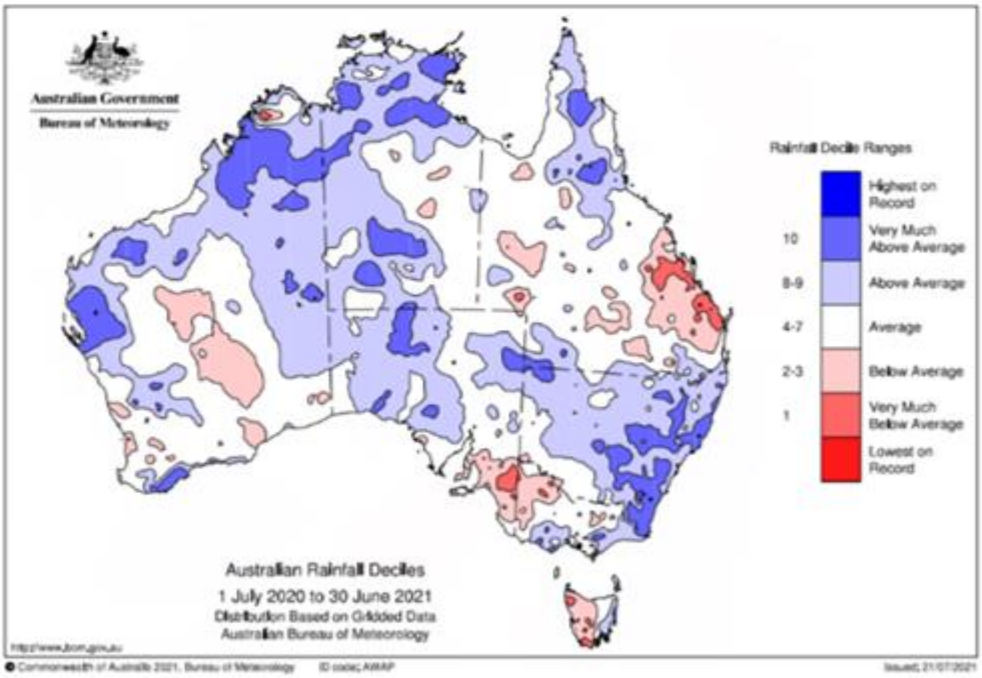



**Figure 9 Australian rainfall deciles for 1st July 2020-30th June 2021**
**Source: [Bureau of Meteorology]**

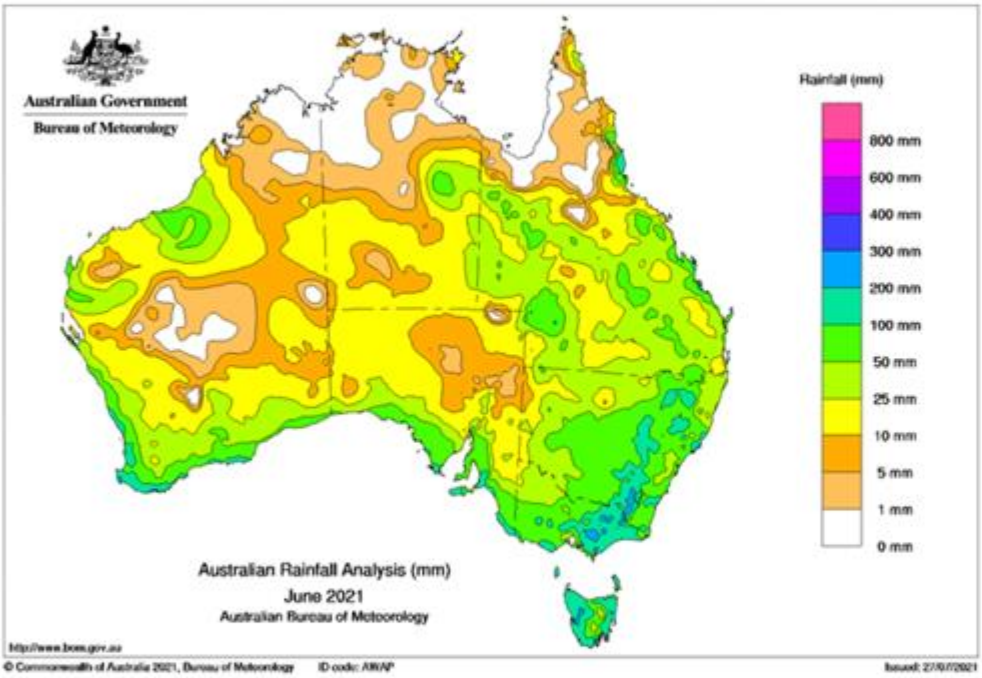



**Figure 10 Australian rainfall totals for June 2021  Source: [Bureau of Meteorology]**

Even with greater rainfall during 2020 and 2021 compared to past years many of the large waterbodies in the Riverina were dry or had very little water during the 2021 survey including Lake Cullivel, Lake Uranagong, Lake Urana and Lake Coolah. Lake Brewster and Lake Cowal has some water but access was not possible for this year's survey. We were able to survey Barrenbox Swamp (Figure 11) and Tombullen water storage (Figure 12) for the 2021 survey, both lakes had a reasonable amount of water.


**Figure 11 Barrenbox Swamp from a UAV (27th April 2021) and on a satellite image from 30th April 2021 (blue indicates water present).**

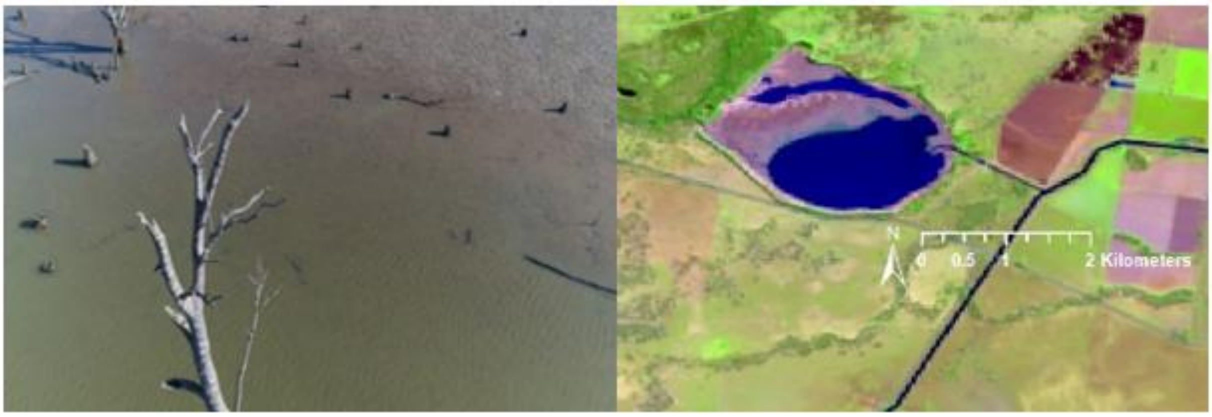



**Figure 12 Tombullen water storage from a UAV (surveyed 2nd May 2021) and satellite image from 30th April 2021 (blue indicates water present).**

# Results

## Estimating waterfowl abundance

The helicopter and drone surveys represent a sub-sample of the available waterbodies that waterfowl occupy. To estimate total abundance for all waterfowl species, the observed numbers of waterfowl collected during both the aerial, drone and ground survey are extrapolated to a known number of dams (separated into waterbody type and size classes) in the Riverina region (minus the estimated proportions of dry dams).

**Small (<4.9 ha) dams** - We mapped 46,026 small dams in the Riverina region. During the June survey, we surveyed 856 from the helicopter (Figure 4). A total of 29.9% of small dams were dry at the time of the survey (n = 256 of dams surveyed). For the small dams with water, 62.5% were occupied by at least one duck, while 225 dams that contained water were not observed to have any ducks.

**Medium dams** (**5-9.9 ha**) - We mapped 165 medium dams in the Riverina region. During the survey, we surveyed 3 of these using the UAV and a further 7 using ground counts (Figure 6a). A total of 54% of medium dams were dry at the time of the survey and 80% of surveyed dams with water were occupied by at least one duck.

**Large dams** (**10-49.9 ha**) - We mapped 150 large irrigation dams in the Riverina region. During the survey, we surveyed 2 of these using the UAV and a further 9 using ground counts (Figure 6b). A total of 43% of large dams were dry, while 91% of surveyed dams that had water and were occupied by at least one duck.

**Extra-large dams** (**50+ ha**) - We mapped 20 extra-large irrigation dams in the Riverina region. During the survey, we surveyed 2 of these using the UAV (Figure 6c). Fifty percent of extra-large dams were dry, while 50% of surveyed dams with water and were occupied by at least one duck.

**Wastewater treatment ponds** – We mapped 38 wastewater treatment ponds in the Riverina and surveyed 10 of these using a UAV and a further 6 using ground counts. 100% had water and all were occupied by at least one duck (Figure 6d).

**Channels** – We surveyed 346.6 km of channel systems in the Riverina region. The mean length of the transects was 3.6 km (n = 105). Approximately 57% of the surveyed channels held water. The estimated total length of channels that held water during the time of the survey was 8448 km (from a total of 14,873 km) (Figure 5).

Helicopter survey (Table 1 and Table 2) and UAV data analyses indicated that common species such as Pacific Black Duck, Grey Teal and Australian Wood Duck were most likely to be found on small dams. These three species make up 99% of the total number of waterfowl that were surveyed in the Riverina (13.6%, 30.8% and 54.7%, respectively). Chestnut Teal were observed on wastewater treatment ponds in addition to smaller numbers on small, medium, and large dams. Hardhead were found in small numbers on small, medium, and large dams as well as STPs and wetlands. A small number of Blue-winged Shovelers were observed on small and large dams. Australian Shelduck were commonly observed on small dams. Pink-eared Ducks were only seen in low numbers. This species often travels long distances to opportunistically take advantage of macroinvertebrates in stagnant flood waters (Frith 1959, Martin, Jarrett et al. 2007).

Only the three most common species (Pacific Black Duck, Grey Teal and Australian Wood Duck) were observed on channels. These species made up 55.7%, 31.4% and 12.9%, respectively, of observed ducks. The detection probabilities of Pacific Black Duck and Australian Wood Duck were higher on channels, whereas the detection probability of Grey Teal was lower (Table 2). Overall, channels had approximately a quarter of all Pacific Black Duck observed on small dams and channels, whereas channels had only about 7% and 1.7% of all Grey Teal and Australian Wood Duck, respectively. These two species showed a much higher preference for small dams.

**Table 1 Average abundance per small dam for nine species of waterfowl in NSW Riverina region, July 2021. $\lambda$ = mean abundance per dam, lcl = 95% lower confidence level, ucl = 95% upper confidence level, $p$ = detection probability and SE(p) = standard error of detection probability (p). Too few Plumed-whistling Duck were seen on small dams to estimate mean abundance ($\lambda$) or detection probability ($p$).**

| Species | $\lambda$ | lcl | ucl | $p$ | SE(p) |
|---|---|---|---|---|---|
| Pacific Black Duck | 4.16 | 3.17 | 5.16 | 0.251 | 0.0177 |
| Grey Teal | 9.40 | 6.58 | 12.2 | 0.452 | 0.0107 |
| Australian Wood Duck | 16.7 | 14.5 | 18.9 | 0.199 | 0.0097 |
| Chestnut Teal | 0.0038 | 0.00 | 0.0084 | 0.666 | 0.315 |
| Australian Shelduck | 0.137 | 0.0674 | 0.207 | 0.492 | 0.192 |
| Pink-eared Duck | 0.00167 | 0.00 | 0.0049 | 1 | NA |
| Hardhead Duck | 0.0184 | 0.0027 | 0.034 | 0.949 | 0.0523 |
| Plumed-whistling Duck | — | — | — | — | — |
| Blue-winged Shoveler | 0.131 | 0.00 | 0.295 | 0.0381 | 0.0428 |

**Table 2 Average abundance per surveyed section of channel for nine species of waterfowl in NSW Riverina region, July 2021. $\lambda$ = mean abundance per dam, lcl = 95% lower confidence level, ucl = 95% upper confidence level, $p$ = detection probability and SE($p$) = standard error of detection probability (p). Waterfowl that have "—" were not observed during the survey of channels. Too few Chestnut Teal, Australian Shelduck, Pink-eared Duck, Hardhead Duck, Plumed-whistling Duck or Blue-winged Shoveler were seen on channels to estimate mean abundance ($\lambda$) or detection probability ($p$).**

| Species | $\lambda$ | lcl | ucl | $p$ | SE($p$) |
|---|---|---|---|---|---|
| Pacific Black Duck | 18.1 | 14.7 | 22.9 | 0.415 | 0.0319 |
| Grey Teal | 10.2 | 7.22 | 14.6 | 0.202 | 0.032 |
| Australian Wood Duck | 4.18 | 3.43 | 5.59 | 0.543 | 0.168 |
| Chestnut Teal | — | — | — | — | — |
| Australian Shelduck | — | — | — | — | — |
| Pink-eared Duck | — | — | — | — | — |
| Hardhead Duck | — | — | — | — | — |
| Plumed-whistling Duck | — | — | — | — | — |
| Blue-winged Shoveler | — | — | — | — | — |

# Recommended quotas for waterfowl in NSW

Quotas are set using the best scientific information available and separate quotas are set for each species. The quotas set the upper limits to the number of waterfowl of a particular species that can be sustainably harvested in a year. Given some of the uncertainties in the drivers of the population dynamics of ducks and the impacts that harvesting has on duck population viability, we recommend that low risk, conservative quotas are set for all duck species hunted in NSW. If new information becomes available, quotas may be revised.

For species whose population dynamics respond predictably to changes in climate (as determined from previous analyses using the Eastern Australian Aerial Waterbird Survey data and occur in high abundance e.g. Pacific Black Duck, Grey Teal and Australian Wood Duck), we recommend that a management quota is set at 10% of the estimated population size (Table 3).The population dynamics of the other species (i.e. Pink-eared Ducks, Plumed Whistling-Ducks, Blue-winged Shoveler, Chestnut Teal and Australian Shelduck) did not respond predictably to changes in climate or only occur in low abundance, and consequently we recommend that reactive quotas only are set for these species.

**Table 3 Summary of the number of waterfowl estimated per waterbody type and size class. Estimates for small dams and channels were estimated using an N-mixture model. Estimates for medium dams, large dams, extra-large dams and sewage treatment ponds were based on uncorrected drone counts and corrected ground counts. STP = sewage treatment ponds. Small dams (<4.9ha) Medium dams (5-9.9ha) Large dams (10-49.9ha) Extra-large dams (>50ha).**

| | Pacific Black Duck | Grey Teal | Australian Wood Duck | Pink-eared Duck ǂ | Chestnut Teal ǂ | Hardhead ǂ | Australian Shelduck ǂ | Plumed-Whistling Duck ǂ | Blue-Winged Shoveler ǂ |
|---|---|---|---|---|---|---|---|---|---|
| Small dams | 134,000 (lcl: 102,100 ucl: 166,200) | 302,800 (lcl: 212,000 ucl: 393,100) | 538,000 (lcl: 467,200 ucl: 608,900) | 54 (lcl: 0 ucl: 158) | 122 (lcl: 0 ucl: 271) | 595 (lcl: 87, ucl: 1,095) | 4,414 (lcl: 2171 ucl: 6,669) | — | 4,221 (lcl: 0 ucl: 9,504) |
| Medium dams | 3,725 | 8,861 | 1,474 | — | 175 | 217 | 175 | — | — |
| Large dams | 7,658 | 11,050 | 12,060 | 1,677 | 216 | 599 | — | — | 592 |
| Extra-large | 110 | 85 | 195 | — | — | — | — | — | — |
| STP | 2,202 | 2,500 | 948 | 886 | 821 | 427 | 57 | 19,390 | 258 |
| Wetlands | 4,490 | 7,140 | 11 | 233 | — | 989 | 22 | — | 44 |
| Channels | 42,298 (lcl: 34,352 ucl: 53,515) | 23,836 (lcl: 16,872 ucl: 34,119) | 9,768 (lcl: 8,016 ucl: 13,063) | — | — | — | — | — | — |
| Total | 194,483 | 356,272 | 562,456 | 2,850 | 1,334 | 2,827 | 4,668 | 19,390 | 5,115 |
| Quota | 19,450 | 35,630 | 56,250 | 285 | 133 | 283 | 467 | 1,940 | 512 |

ǂ Reactive quota recommended for these species

Management quotas are set for species with lower risk of overharvest. The population dynamics of these species react predictably to changes in the environment and—except for Hardhead—they have relatively high population size. Reactive quotas are set for species with a higher risk of overharvest, due to low population size and/or dynamics that are less predictable. We recommend that allocations from reactive quotas should only be provided if a property is both; 1) prone to damage from those species; and 2) can demonstrate that damage is occurring or very likely to occur.

# Satellite tracking of waterfowl in the Riverina

## Methods

In November 2019, we fitted solar powered GPS transmitters, attached to a harness, to ducks from three common species; Australian Wood Duck, Pacific Black Duck and Grey Teal. Some individuals are recognised as being more sedentary and will remain within a smaller home range area, irrespective of water availability elsewhere. Conversely, the movements of other individuals is driven by water availability in the broader region. Details of trapping, tagging and tracking ducks was provided in the 2020-2021 report. Here we provide an update of the ducks that continued to be tracked since the last report (Table 4).

## Results and Discussion

The use of satellite transmitters has continued to be an effective method to establish longer-term movement patterns for waterfowl (Table 4, Figure 13 and Figure 14). We are still tracking one duck (Australian Wood Duck female 180353 = +602 days tracked). It is interesting to see ducks are regularly using a range of waterbody types such as farm dams and the irrigation channel network which we cover during the helicopter and drone surveys.

### Grey Teal Male 184216

This duck was initially captured in November 2019 and moved from the site of capture in Leeton in January 2020 to take advantage of flood waters across the Paroo-Darling National Park (Figure 14). He made use of the water storage dams across the southern Riverina region as well as smaller farm dams like those we survey during the helicopter surveys. He also visited some of the natural lakes we often survey with the drone (Lake Cowal, Lake Urana) and the sewerage treatment ponds, Junee STP and Leeton STP (where he was captured). Grey Teal are well known for travelling long distances and this duck has demonstrated the wide ranging and opportunistic nature of this species for using a range of water sources across the Riverina. The last location for this duck was east of Lake Cowal where the low-lying paddocks had flooded. Overall, this duck moved 4721.07km over 590 days.

### Grey Teal Female 184217

This duck initially remained close to her site of capture at Leeton STP and we regularly sighted her during on-ground visits to Leeton STP (Figure 14). She started moving from Leeton STP early August 2020 and did a loop from Leeton to Narrandera and then north to Lake Cowal visiting small farm dams along the way. She stayed at Lake Cowal from 30$^{th}$ December 2020 until 29$^{th}$ January 2021 before making her way south again. She visited farm dams south west of Whitton and this was where her last point was recorded at the start of March 2020, after travelling a total of 1294.84km over 484 days.

### Grey Teal Male 184218

This duck remained at the capture site at Leeton STP and started moving west in early April 2020, probably in response to higher than average rainfall during this month. He headed to Lake Cowal in April 2020, when low levels of water were present. After travelling further north near Nyngan, he headed south again to Lake Cowal. He then headed south from Lake Cowal back to Leeton STP. He then made smaller exploratory visits to a location near Gunbar on the river and Lake Wyangan towards the end of 2020 before returning to Lake Cowal in December 2020 and stayed there until the end of January 2021. Between these forays, he always returns back to the Leeton STP. He visited Barrenbox at the start of February 2021 to the end of March 2021 before returning to Leeton STP where his transmitter stopped transmitting at the end of May 2021. Known water sources appear to provide a safe and reliable source of resources. Ducks can then use these locations as a return point as they explore new locations with unknown resources.

### Australian Wood Duck Male 180349

This duck showed strong site fidelity and stayed within 10km of the Yanco STP where he was captured (Figure 13). He regularly used the channels, a few small farm dams and a larger lake/wetland about 40ha in size. He did make a few longer forays out to Lake Coolah near Narrandera in February 2020. He returned to a previously used small farm dam before heading north at the start of April 2020 to a location east of Ardlethan where there are several small farm dams. He moved between these dams as well as part of the river. His last transmission was between dams at the end of April.

### Australian Wood Duck Female 180352

This duck initially remained close to the point of capture at Yanco STP. She regularly visited channels, small dams and creeklines between November 2019 to August 2020. She then made a longer distance move east on the 8$^{th}$ August 2020 and travelled 138km over 12 hours. She used a few small farm dams for the next 16 hours before flying another 25 km south east to a group of small farm dams and a creekline that she moved between. Her transmitter stopped transmitting on 14$^{th}$ September 2020 along a creekline.

### Australian Wood Duck Female 180353

This duck is still transmitting as of 16$^{th}$ July 2021. She was captured along with male 180349 and female 108352 at Yanco STP in November 2019. She initially stayed within 20km of the point of capture and used small dams and channels. She also visited Leeton STP and Fivebough swamp. On the 15$^{th}$ August 2020, she flew 64km within a 4 hour period (during the day) to a few small farm dams near Ganmain. Over the next 3 days, she travelled 76km between small farm dams. She then remained near Combaning and Temora using the same small farm dams and this is where she is currently located. She has also been using dams within the Temora golf course and a dam next to a grain store in Temora. To date she has travelled 2642km over 602 days.

## Table 4 Ducks fitted with solar powered GPS transmitters in the Riverina region in November 2019. Updates current as of 16th July 2021

| Species | Sex | ID | Capture site | Tag type | Days tracked | Distance moved between points (km) | Average movement (km) per day | Movement type | Home range (100% minimum convex polygon in sqkm$^{-2}$) |
|---|---|---|---|---|---|---|---|---|---|
| Pacific Black Duck | F | 180354 | Yanco STP | Microwave Telemetry 17g | 49^ | 236.36 | 4.82 | Sedentary <12km | 47.43 |
| Pacific Black Duck | F | 180355 | Leeton STP | Microwave Telemetry 17g | 68^ | 217.37 | 3.20 | Sedentary <15km | 62.94 |
| Pacific Black Duck | M | 180356 | Deniliquin STP | Microwave Telemetry 17g | 50^ | 186.44 | 3.73 | Sedentary <20km | 113.67 |
| Pacific Black Duck | M | 180357 | Deniliquin STP | Microwave Telemetry 17g | 32^ | 9.92 | 0.31 | Sedentary <2km | 0.40 |
| Pacific Black Duck | F | 180358 | Leeton STP | Microwave Telemetry 17g | 8* | 1.30 | 0.16 | Sedentary <0.5km | 0.02 |
| Pacific Black Duck | F | 180359 | Leeton STP | Microwave Telemetry 17g | 32^ | 98.88 | 3.09 | Sedentary <25km | 22.59 |
| Pacific Black Duck | F | 180360 | Leeton STP | Microwave Telemetry 17g | 137^ | 253.37 | 1.85 | Sedentary <20km | 89.49 |
| Pacific Black Duck | F | 180361 | Leeton STP | Microwave Telemetry 17g | 55^ | 249.52 | 4.54 | Sedentary <15km | 34.95 |
| Australian Wood Duck | M | 180347 | Yanco STP | Microwave Telemetry 17g | 197^ | 738.14 | 3.75 | Sedentary <25km | 164.26 |
| Australian Wood Duck | F | 180348 | Yanco STP | Microwave Telemetry 17g | 84^ | 103.55 | 1.23 | Sedentary <10km | 8.20 |
| Australian Wood Duck | M | 180349 | Yanco STP | Microwave Telemetry 17g | 415^ | 767.59 | 1.85 | Sedentary <45km | 583 |
| Australian Wood Duck | M | 180350 | Yanco STP | Microwave Telemetry 17g | 203^ | 978.77 | 4.82 | Nomadic >350km | 13,760 |
| Australian Wood Duck | F | 180351 | Yanco STP | Microwave Telemetry 17g | 91^ | 211.01 | 2.32 | Sedentary <15km | 26.98 |
| Australian Wood Duck | F | 180352 | Yanco STP | Microwave Telemetry 17g | 305^ | 646.77 | 2.12 | Sedentary <10km | 2,505 |
| Australian Wood Duck | F | 180353 | Yanco STP | Microwave Telemetry 17g | 602+ | 2642.03 | 4.39 | Sedentary <20km | 4,118 |
| Grey Teal | F | 184215 | Leeton STP | GeoTrak 12g | 90^ | 23.45 | 0.26 | Sedentary <5km | 0.08 |
| Grey Teal | M | 184216 | Leeton STP | GeoTrak 12g | 590^ | 4721.07 | 8.00 | Nomadic >400km | 18,734 |
| Grey Teal | F | 184217 | Leeton STP | GeoTrak 12g | 484^ | 1294.84 | 2.68 | Nomadic <200km | 10,693 |
| Grey Teal | M | 184218 | Leeton STP | GeoTrak 12g | 575^ | 2997.84 | 5.21 | Nomadic <400km | 42,559 |

* Likely transmitter malfunction

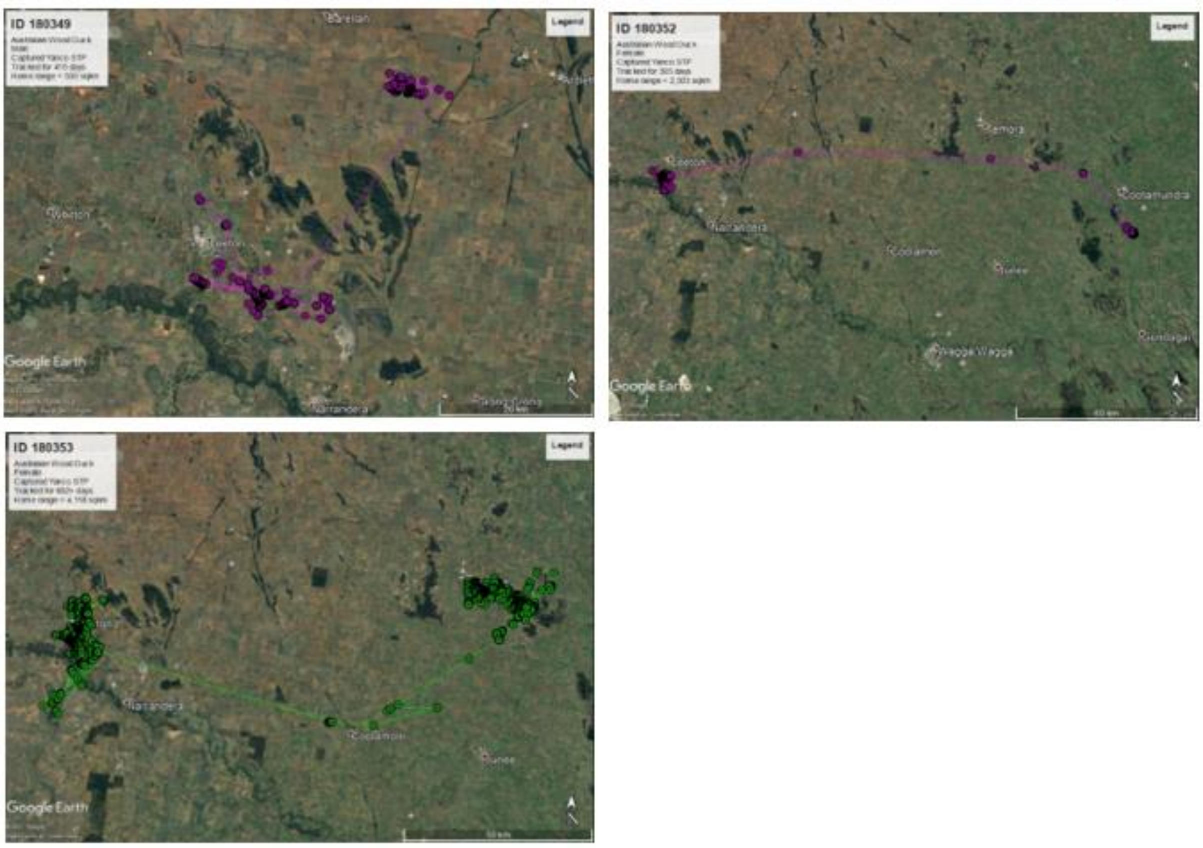
+ Still being tracked

^ Most likely deceased

Greyed lines represent updated data from the previous report

## Challenges

We were unsure why the tags on Pacific Black Ducks were losing signal sooner than the tags on the other two species. We had some insight when one of our tagged (satellite transmitter and unique leg band) female Pacific Black Ducks was shot legally in Victoria missing her harness and transmitter. We recaptured a few ducks a few days after they were fitted with transmitters and found the ends of the Teflon ribbon had frayed despite the application of superglue to seal the ribbon ends. Given we had secured the tag with 3-4 tight knots at the back of the transmitter, we weren't concerned the ribbon would fray any further. Unfortunately, this seems to have been the problem for the tags on the Pacific Black Ducks. We have since found a superglue that can set underwater and this may be more suitable to secure and seal the Teflon ribbon in future.




#### Figure 13 Updated GPS tracks for Australian Wood Duck as of 16th July 2021

We have also had three of the Pacific Black Duck tags start transmitting signals again after many months of being offline. We hypothesise that these may have been tags that have fallen off and have since been disturbed, resulting in the solar panel getting enough charge to transmit its location (locations are the same as the last location before they went offline). One of these tags was in a channel in Leeton and we were unable to locate it with a metal detector. The second 'zombie tag' was in a cattle saleyard in Deniliquin but we were unable to locate this tag even though we managed to get within a metre of the final transmitted location. There is a lag with the locations transmitted (4hrs between satellite locations transmitted weekly) and it is likely the last transmitted location wasn't necessarily the last location of the duck. It is also very likely duck carcasses would have been readily scavenged before we could find any evidence of them. For a number of tags, the final location was in the middle of a dam, pond or channel where we had no chance of recovering it.

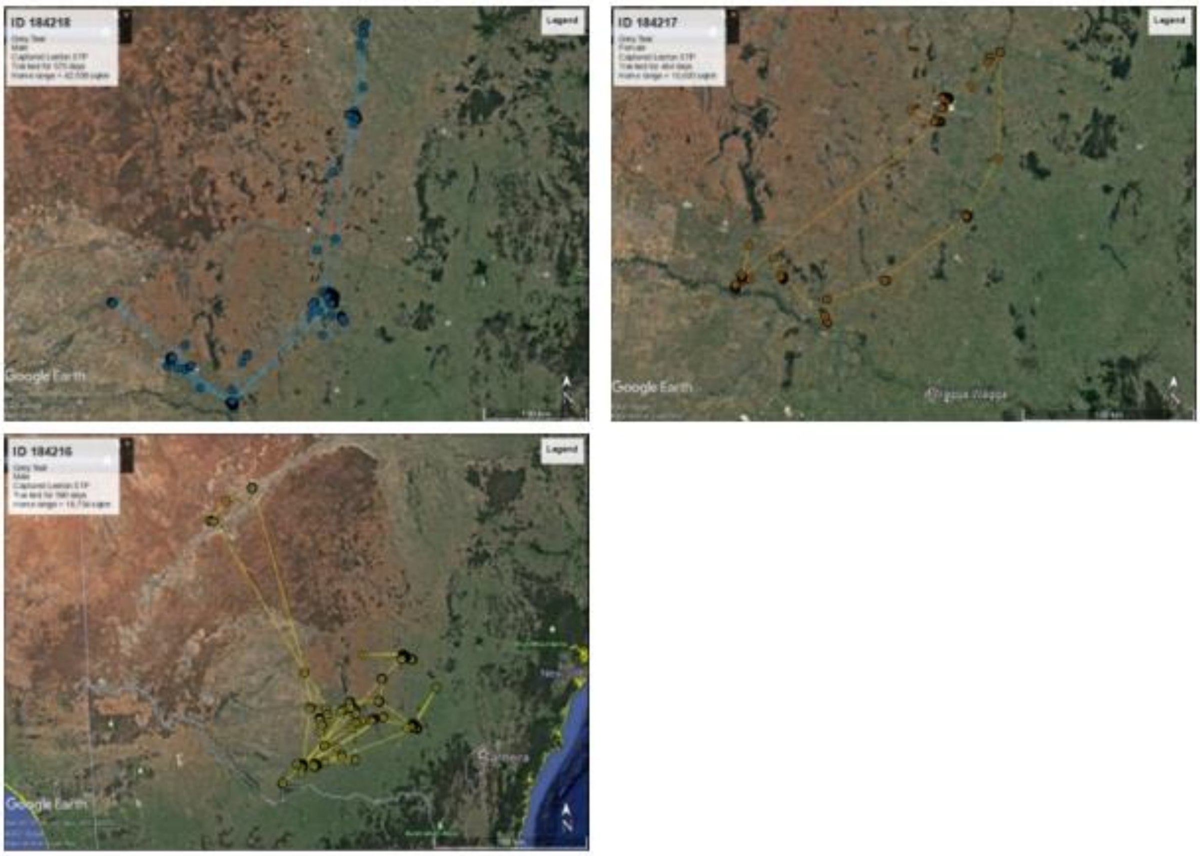



**Figure 14 Updated GPS tracks for Grey Teal as of 16th July 2021**

## Conclusions

The long-distance movements for Grey Teal and Australian Wood Duck in particular are important findings and represent data we would not have been able to collect any other way. The sedentary nature of some individuals is also a finding that is important for the population models we are building. We found there was a lot of individual variation between tagged animals. Ideally, we need to include more tagged individuals from different types of waterbodies when conducting tracking studies, although this is very much limited by the cost of the equipment. We were also able to demonstrate that some ducks are highly sedentary and won't move far beyond the capture site, even though more standing water was available after good rainfall early in 2020.

In terms of the possible fate of tracked ducks, previous surveys of tracked Australian Wood Ducks found 4 of 8 tagged ducks were predated by a fox or cat and one duck was hit by a car (McEvoy, Hall et al. 2019). Ducks were tracked for 32-162 days and the remaining 3 were tracked to the end of the battery life (226-308 days tracked) (McEvoy, Hall et al. 2019). Predation or misadventure are very likely causes of death for out tracked ducks. There is also the possibility of the tags causing an issue for ducks causing premature death. Based on our observations of both re-trapped ducks fitted with harnesses and transmitters and on-ground observations of tagged ducks, we are confident this was not a significant issue. The only way to test this is to compare survival of individually identified ducks with and without the transmitters (all ducks fitted with metal leg bands). This would require a large sample size of ducks to obtain representative data and would require ducks with metal leg bands to be re-trapped on numerous occasions to establish survival.

In terms of improvements for future work, we would recommend the smaller 12g satellite tags for all birds because they represent a lighter payload and therefore require less energy for birds to carry. We only purchased a few of these tags for this project because they were a brand new product and we wanted to be sure they worked. The larger 17g tags have been used extensively worldwide for several years so we knew they worked.

# References

Bureau of Meteorology (2013). Australian Hydrological Geospatial Fabric (Geofabric) Product Suite, © Commonwealth of Australia (Bureau of Meteorology).

Burnham, K. P., and Anderson, D. R. (2002). 'Model Selection and Inference: A Practical Information-Theoretic Approach.' 2nd edition. (Springer: New York.)

Fiske, I. and R. Chandler (2011). "unmarked: An R Package for Fitting Hierarchical Models of Wildlife Occurrence and Abundance." 2011 **43**(10): 23.

Frith, H. J. (1959). "The ecology of wild ducks in inland New South Wales. IV. Breeding." Wildlife Research **4**(2): 156-181.

Kay, R., et al. (2012). National Wastewater Treatment Plants Database, Geoscience Australia.

Link, W. A., Schofield, M. R., Barker, R. J., and Sauer, J. R. (2018). On the robustness of N-mixture models. *Ecology* **99**, 1547–1551. doi:10.1002/ecy.2362

Lohr, S. (2019). 'Sampling: Design and analysis.' Second Edition. (CRC Press: Boca Raton, Florida.)

Martin, G. R., et al. (2007). "Visual fields in Blue Ducks *Hymenolaimus malacorhynchos* and Pink-eared Ducks *Malacorhynchus membranaceus*: visual and tactile foraging." Ibis **149**(1): 112-120.

McEvoy, J. F., et al. (2019). "Movements of Australian Wood Ducks (*Chenonetta jubata*) in an agricultural landscape." Emu - Austral Ornithology **119**(2): 147-156.

R Core Team (2021). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing: Vienna, Austria. Available at: https://www.R-project.org/.

Royle, J. A. (2004). "N-mixture models for estimating population size from spatially replicated counts." Biometrics **60**(1): 108-115.

## Reference datasets and layers

Geoscience Australia National Wastewater Treatment Plants Database

http://www.ga.gov.au/metadata-gateway/metadata/record/74625/