Department of Primary Industries
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2024-2025 Annual Waterfowl Quota Report to NSW DPIRD Hunting, NSW Department of Primary Industries and Regional Development

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Introduction

In New South Wales (NSW), ten native duck species may be legally harvested to minimise damage and promote sustainable agricultural management. The *Game and Feral Animal Control Act 2002* (GFAC Act) requires the Regulatory Authority (DPIRD Hunting) to set annual quotas for native game birds that may be killed under the authority conferred by a native game bird management licence. The annual quotas are "to be set on the basis of the best scientific knowledge available on the estimated regional population of native game birds." (Part 3A Native game bird management licences, 32D(a)).

Sustainable use means the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations (Convention on Biological Diversity 1992). Sustainable harvesting is a specific type of use that aims to remove resources from a population or ecosystem while ensuring that the resource is preserved for the foreseeable future. To harvest sustainably, a portion of the population or ecosystem is harvested, and this portion is small enough to allow long-term replacement by birth and growth processes of the population. We aim to minimise the risk of over-harvest with appropriate monitoring and careful consideration of population dynamics. Harvesting strategies that support sustainable practices should include sources of uncertainty in decision making processes.

To derive annual quotas for waterfowl that can be harvested in NSW, the Vertebrate Pest Research Unit (NSW DPIRD) estimates waterfowl populations on artificial waterbodies within the NSW Riverina region and calculates annual quotas based on the estimated population sizes, and the productive capacity of the waterfowl populations to recover from the harvest in the long-term.

In this report, we describe the results of population size surveys of waterfowl in the Riverina region of NSW. Surveys were conducted in June-July 2024. Abundance estimates and prescribed quotas for 2024-25 are presented for nine waterfowl species:

Grey Teal (Anas gracilis)

Pacific Black Duck *(Anas superciliosa)*

Hardhead (Aythya australis)

Pink-eared Duck (Malacorhynchus membranaceus)

Australian Wood Duck *(Chenonetta jubata)*

Australian Shelduck (Tadorna tadornoides)

Blue-winged Shoveler *(Anas rhynchotis)*

Chestnut Teal (Anas castanea)

Plumed Whistling-Duck *(Dendrocygna eytoni)*

Methods

For the 2024- 2025 quota, we our methods were based on previous years surveys. Small farm dams and channels were surveyed using a helicopter. Medium, large and extra-large dams, wetlands and wastewater treatment ponds were surveyed using either a drone (UAV) or by ground counts.
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.

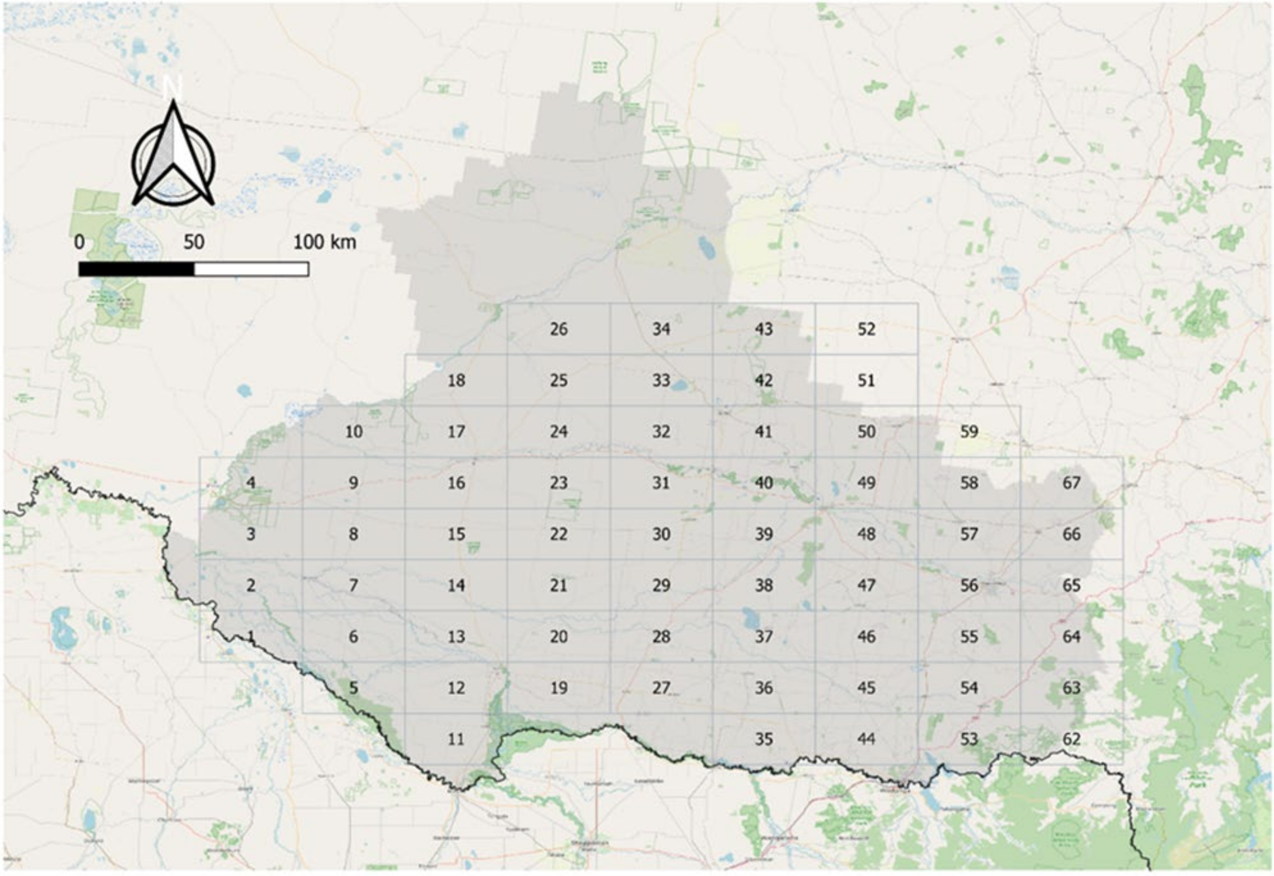

Figure 1: The area defined as the Riverina region as indicated by the Bureau of Meteorology forecast areas (http://www.bom.gov.au/nsw/forecasts/map.shtml).

Sampling Strategy

The sampling strategy for small dams and channels was different from other larger water bodies. The sampling for small dams and channels followed a two-stage stratified random sample strategy, whereas all other water bodies used a one-stage sampling strategy. The reason for the different strategies was based on the total sample size of the survey units, with small dams and channels being two orders of magnitude larger than other waterbody types.

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 a random sample of dams and irrigation channels was chosen to survey with consideration of proximity to airports for helicopter refuelling stops. Mapped shapefiles used for previous surveys were revised for all dam sizes in 2023 to confirm dams were allocated to the correct size class, to remove dams that had been filled in and to add any newly created dams.

To determine which larger irrigation dams in the Riverina region we could survey using UAVs, along 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 within the QGIS program (https://www.sentinel-hub.com/develop/api/ogc/standard-parameters/wms/) was taken within the preceding month of the survey. A random sample of large irrigation dams from three size classes (medium, large, and extra-large) was chosen from those holding water (Figure 2).

A range of different-sized wastewater treatment ponds was selected from across the Riverina region. Following the 2017 survey, we established a high correlation (r = 0.89) between the number of ducks present on wastewater treatment and the 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.

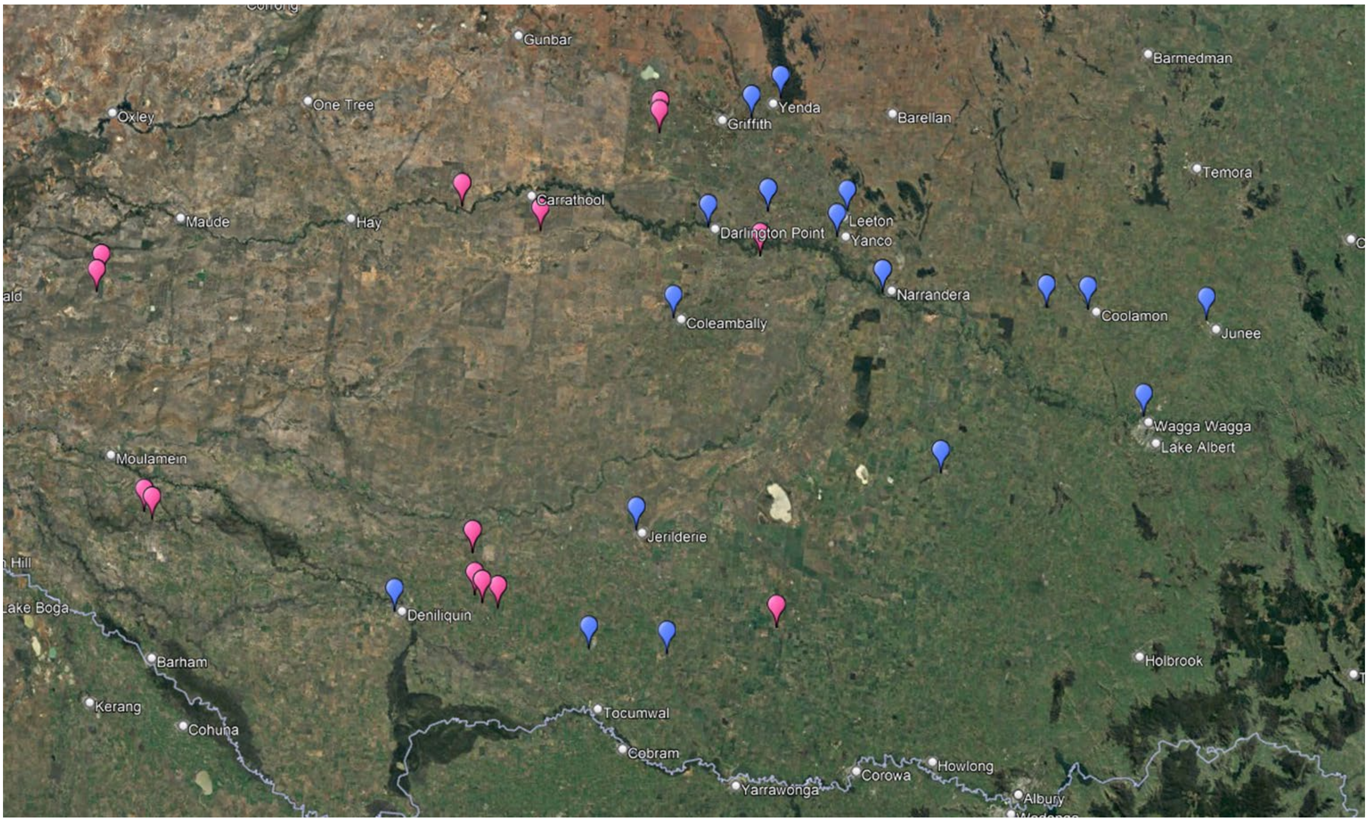

Figure 2: Medium and large dams and STPs surveyed in 2024 using UAVs/ground counts.

Small Dams

A stratified random sample of dams, ≤ 4.9 ha in size, was selected. Using a two-stage stratified sampling design, sampling units (dams) were randomly selected without replacement (Lohr 2019). In stage one, the study site was divided into 62 equal-sized sample blocks (primary sampling units, PSUs), with each PSU's dimensions 0.5° longitude × 0.25° latitude (approximately 46.1 × 27.7 km, with a total area of 1279 km2) (Figure 1). These sampling units formed the sampling frame. From the sampling frame, a random sample without replacement of 12 blocks (H) was selected, with each block (h) forming a sample stratum (Figure 3). Within each stratum, a further random sample of dams without replacement was made, for a total sample size (n) over the sampling frame of 767 dams (Figure 3).

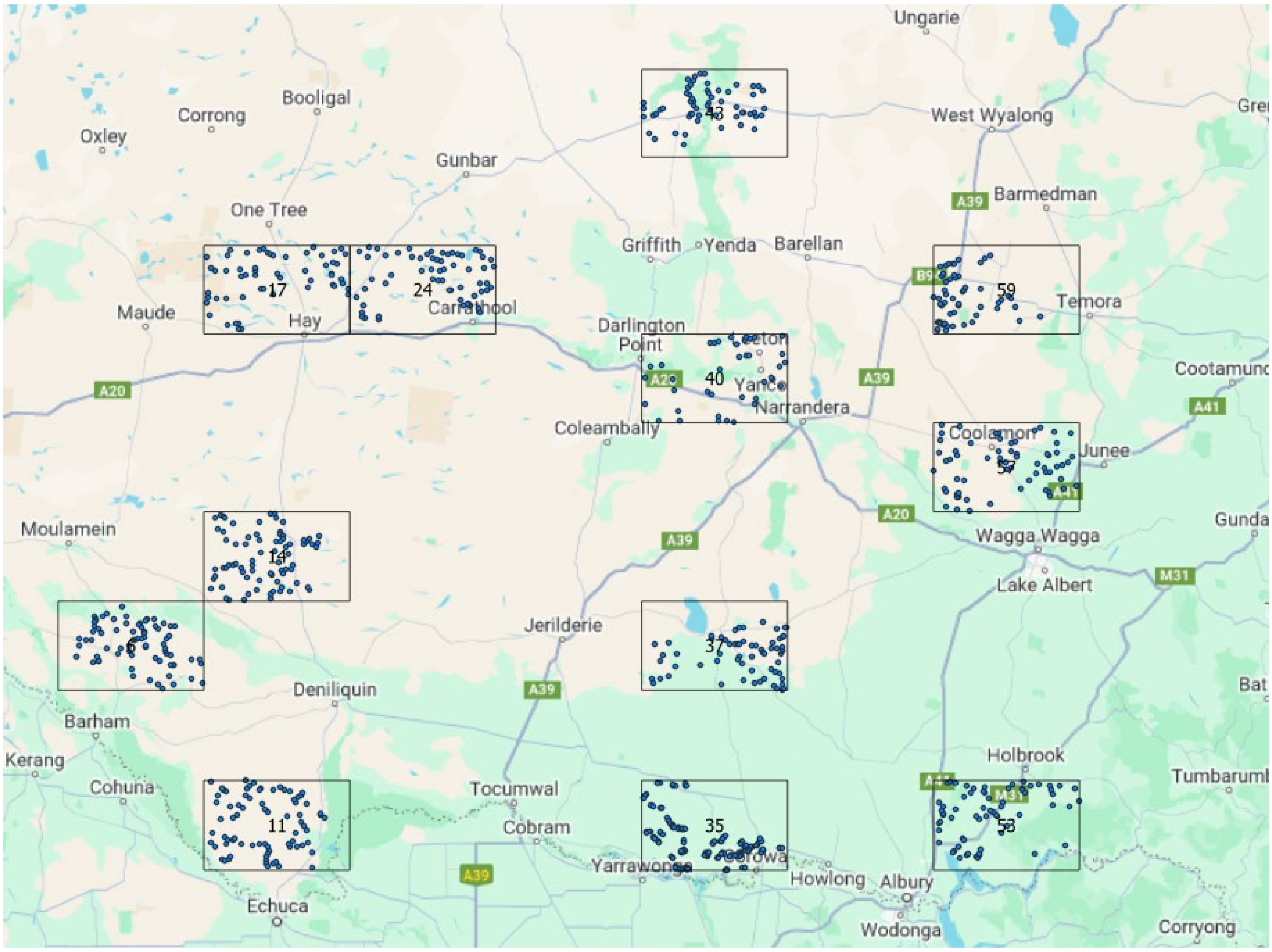

Figure 3: Map of sampled small farm dams for the 2024 surveys.

Channels

Each surveyed section was the sampling unit, and units were randomly selected from three channel systems (Figure 4) . Similar to the sampling strategy used for selecting small dam sample units, two-stage stratified random samples without replacement were taken. Sampling of channels was done by selecting 63 random starting points from the channels within a channel system and flying a randomly chosen direction along the sample channel section for between 770 m – 17,220 m (mean = 9000 m, total = 499,000 m).

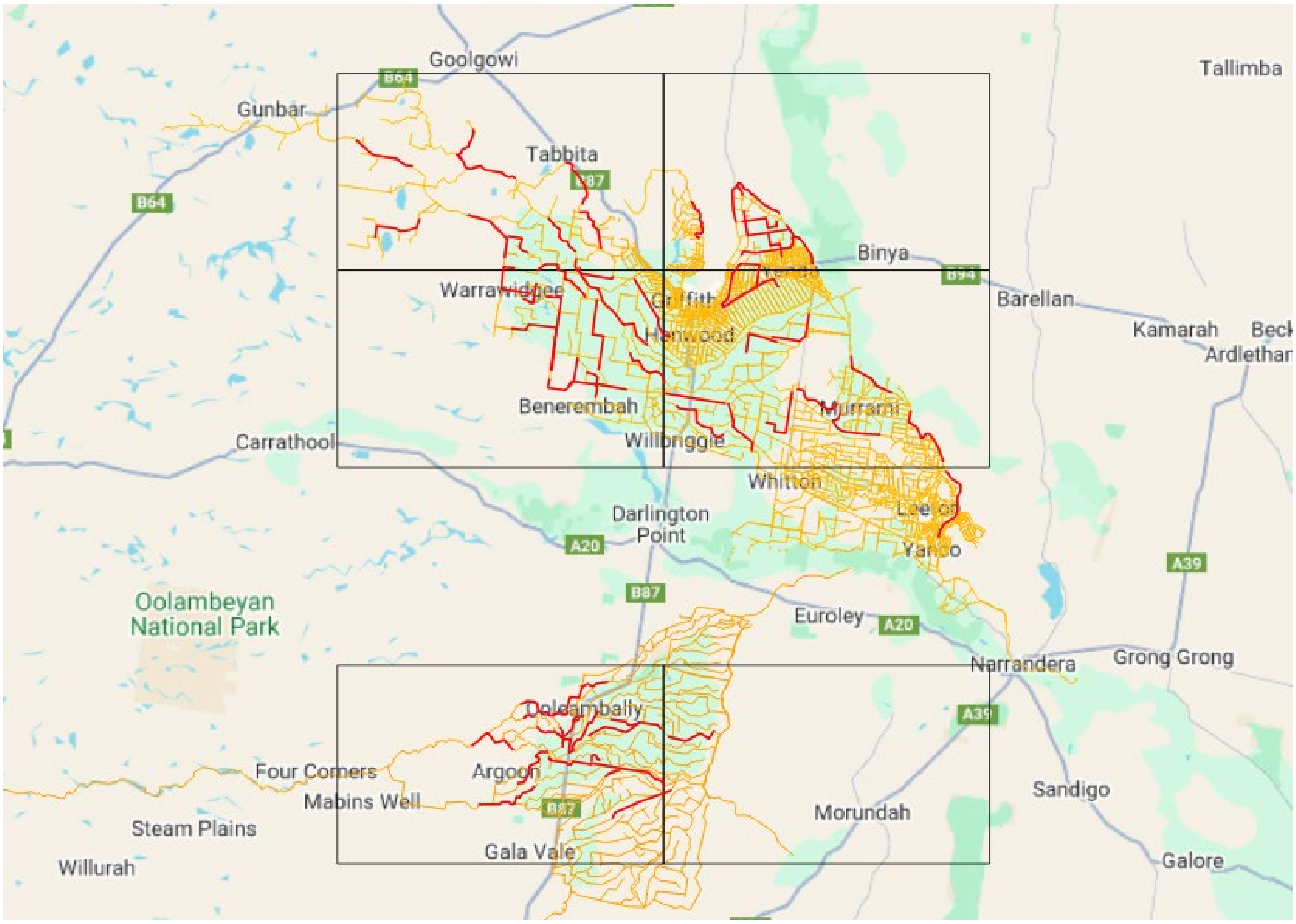

Figure 4: Map of randomly selected blocks with channels sampled in 2024 surveys.

Other waterbodies

For medium, large and extra-large dams, wastewater treatment ponds, a simple random sample without replacement was chosen. One extra-large water storage dam (Tombullen Storage) was chosen to survey, and 6% of the storage surface area was surveyed using a UAV. Access proves to be an issue around surveying natural lake/larger bodies of water. Wet conditions, drought and access permission limit the number of waterbodies able to be surveyed each year.

Natural waterbodies, including rivers, creek, swamps and floodwaters were not surveyed and have not contributed to the abundance estimates.

Helicopter surveys

Dams holding no water and those with water but not observed to have waterfowl were noted. For dams with waterfowl, a low and slow circuit was flown around the dam (no lower than 18m for safety purposes) and the observers identified and counted all waterfowl. The helicopter used was a Bell 206 L4, allowing three observers to observe from the helicopter. Aerial operations were conducted without the front and rear doors, allowing for much better visibility whilst counting.

Data collected during the helicopter surveys represents a multiple observer count (with two observers on the left side of the aircraft, front and back, making simultaneous observations and logging species counts on GPS-enabled tablets) with a third observer, seated next to the rear observer on the right, recording covariates identified by the front observer that may influence detection probability and occupancy of waterfowl (e.g. presence of trees or crops, vegetation on or around a dam or bare areas, presence of livestock). In addition, after confirmation by both the front and rear observers, the third observer recorded duck species and whether the dam was greater or less than one hectare.

Channels were surveyed again this year to expand monitoring to include other water sources occupied by waterfowl. Six blocks that included channels were surveyed (Figure 4).

For this year's surveys the weather was in our favour with average temperatures for June being 2.8 – 14.8 degrees Celsius (Bureau of Meteorology, 2024). Ideal conditions saw fine and clear skies with minimal wind each day flying took place (although cold mornings were definitely felt).

All data was collected simultaneously by two observers (helicopter small dam and channels, and dam ground counts) were analysed using N-mixture models (Royle 2004), using the pcount() function in the R package unmarked (Fiske and Chandler 2011) in the statistical programming language R (R Core Team 2024).

N-mixture models are useful 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, e.g., 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 (or channel section) were estimated from the highest-ranked model based on AIC (Appendices 1 and 2).

Drone and Ground Surveys

Unmanned aerial vehicles are particularly suited to sampling medium and large waterbodies (> 4.9 ha surface area), where helicopters can cause excessive reactive movement of waterfowl, particularly an issue when the waterbody has a large number of waterfowl. Nineteen waterbodies were sampled using the drone.

For this year's survey, we used a DJI Matrice 300 RTK fitted with a Zenmuse H20T camera. The camera has a 20MP sensor and recorded high resolution video (4K) at 60fps which provided the resolution to identify ducks to species.

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 waterbodies classed as extra-large, we surveyed a sub-sample of the surface area and calculated the area of the waterbody covered during the survey (~6%).

Depending on the reaction of waterfowl to the drone, the survey height 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 (duck-counter.bat) written as a simple animal counter app based on the open-source package labelme. For each video, a single observer went through all videos manually, identifying and tagging all waterfowl seen. The flightpath of the drone was calculated using maps provided by Airdata (linked to each UAV and displays individual flights), using this data a buffer was created around the flightpath, and this mapping information was then used to map the 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 (%). For all but one extra-large dam, the area covered was 100%.

For waterbodies surveyed by ground counts (n = 10), two observers carried out independent counts using a spotting scope. Survey samples collected using a drone (medium, large and extra-large dams and wetlands) were analysed assuming that detection probability was one. The whole surface of each dam was surveyed for medium, large, and extra-large dams. For wetlands, a subsample of the surface was taken and the proportion of the wetland surveyed weighted the observed count.

Statistical Analysis

Each species of waterfowl was analysed separately to calculate an independent quota for each species.

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 λ, such that the number of individuals at the ith 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 duck 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 the sample site i, is modelled as a Poisson distribution with mean λ. 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 (the likelihood that waterfowl occupy a dam) and the observation process (the likelihood that waterfowl, if present, are detected). Potential covariates were assessed and included in alternative models 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, λ, and detection probability, p. Covariates tested that potentially influenced detection included the observer, observer position (front, rear), and the presence of glare. Covariates that potentially affected occupancy included the presence of livestock (sheep, cattle), vegetation (grass, crops, trees, unspecified vegetation), vegetation in the water, and bare ground.

Assumptions of the N-mixture model

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

Poisson and binomial distributions are true descriptions of state/observation processes

Abundance at each site is random and independent of abundance at all other sites

Population is closed between surveys

Observers do not double-count individuals

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 misspecification 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.

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

Horvitz-Thompson Estimator

A single-stage Horvitz-Thompson Estimator was used for medium, large, and extra-large dams, wastewater treatment ponds, and wetlands.

The Horvitz-Thompson estimator for the total Y is given by:

$$\hat{Y}_{HT} = \sum_{i \epsilon s} y_i/\pi_i$$

where:

y_i is the observation for the i^{th} unit in the sample.

π_i is the probability that the i^{th} unit is included in the sample.

s is the sample.

The variance for the Horvitz-Thompson estimator in one-stage sampling without replacement is:

$$Var(\hat{Y}_{HT}) = \sum_{i \epsilon s} \left[\sum_{j \epsilon s, j \neq i} \frac{\pi_i \pi_j}{\pi_{ij}} \left(\frac{y_i}{\pi_i} - \frac{y_j}{\pi_j} \right)^2 \right]$$

where:

π_{ij} is the joint probability that both units i and j are included in the sample.

For one-stage sampling without replacement, the joint inclusion probability π_{ij} is:

$$\pi_{ij} = \frac{\pi_i \pi_j}{\pi_i + \pi_j - \pi_i \pi_j}$$

The formula for the variance considers the joint inclusion probabilities of pairs of units in the sample. This is to account for the correlation introduced by sampling being without replacement. The more correlated two units are (in terms of their inclusion probabilities), the greater their impact on the estimator's variance.

When sampling is done in multiple stages, such as selecting primary sampling units (PSUs) first and then items within each PSU, with the secondary sample units (SSUs) having an unequal probability of inclusion, the Horvitz-Thompson estimator can be used to estimate unbiased totals from the selected samples.

Horvitz-Thompson Estimator for Multi-stage Sampling:

For a two-stage sample, let:

π_k = probability of selecting the k^{th} PSU in the first stage.

π_{jk} = probability of selecting the j^{th} item from the k^{th} PSU in the second stage.

y_{jk} = value of the j^{th} item from the k^{th} PSU.

The HT estimator for the total is:

$$\hat{Y}_{HT} = \sum_k \sum_j y_{kj}/(\pi_k \times \pi_{jk})$$

Where the double summation goes over all items in the sample.

Variance of the Horvitz-Thompson Estimator for Multi-Stage Sampling:

The variance calculation is:

$$\hat{V}_{HT}(\hat{Y}_{HT}) = \sum_{j \epsilon S} (1 - \pi_j) \frac{\hat{Y}_j^2}{\pi_j^2} + \sum_{j \epsilon S} \left[\sum_{k \epsilon S, k \neq j} \frac{\pi_{jk} - \pi_j \pi_k}{\pi_{jk}} \frac{\hat{Y}_j}{\pi_j} \frac{\hat{Y}_k}{\pi_k} \right] + \sum_{j \epsilon S} \frac{\hat{V}(\hat{Y}_j)}{\pi_j}$$

Where $\pi_{k'}$ is the probability of selecting the k^{th} PSU, and π_jk is the probability of selecting the j'^{th} item from the k'^{th} PSU.

Results

The helicopter, drone and ground surveys represent a sub-sample of the available waterbodies. To estimate the total abundance for each waterfowl species, a Horvitz-Thompson Estimator was used to correct for different inclusion probabilities of survey units. Where duplicate counts were made, detection probability was calculated so that uncertainty in estimated population size could be accounted for in the analysis.

The Horvitz-Thompson Estimator is a method used in survey sampling to estimate population totals from a sample. It is particularly useful for complex survey designs when sampling units have different probabilities of selection. Specifically, in stratified or cluster designs (like that used here), sampling units have different probabilities of being selected into the sample. The Horvitz-Thompson Estimator corrects for different inclusion probabilities, ensuring that the final estimates are unbiased. Additionally, the estimator assigns weights to sampled units that are the inverse of their selection probabilities. This means that units sampled with a lower probability are given a higher weight, and vice versa. This adjustment ensures that each unit represents its fair share of the population. Therefore, by considering the probabilities of selection for each unit, the Estimator can produce unbiased estimates of population totals, even when the probabilities of selection are not proportional to size.

The results of the survey (Table 1), combining helicopter, drone and ground counts of waterfowl on small, medium, large and extra-large dams, wastewater treatment ponds, wetlands and channels indicated that common species such as Pacific Black Duck, Grey Teal and Australian Wood Duck were most likely to be found on small dams and channels. These three species comprise more than 95% of the total number of waterfowl surveyed in the Riverina (46.7%, 25.4% and 24.3%, respectively), at the time of the survey.

The estimated population size of the most common species (Pacific Black Duck, Grey Teal and Australian Wood Duck) has decreased since the 2023 survey. The largest decrease was recorded in Pacific Black Duck. Other species showed either a modest increase in number or a small decrease.

Table 1 Estimated abundance of nine species of waterfowl in NSW Riverina region, May -July 2024. Estimates were made using an N-mixture model for small dams, channels and ground counts. Small dams and channels were surveyed by helicopter. Medium, large and extra-large dams, wastewater treatment ponds and wetlands were surveyed by a drone or by ground counts. (CI = confidence interval, and CV is coefficient of variation). *Confidence intervals could not be calculated. NaN = not a number (the coefficient of variation cannot be calculated if the denominator of CV is zero).

Species	Total	Lower 95% CI	Upper 95% CI	CV
Small dams				
Pacific Black Duck	233,272	69,743	396,801	0.36
Grey Teal	319,306	109,984	528,627	0.33
Australian Wood Duck	413,351	131,419	695,284	0.35
Blue-Winged Shoveler	0	0	0	NaN
Chestnut Teal	567	336	798	0.21
Hardhead	4,802	1,749	7,855	0.32
Mountain Duck	11,509	5,352	17,666	0.27
Pink-Eared Duck	21	21	21	0
Plumed Whistling Duck	14,563	6,963	22,164	0.27
Channels				
Pacific Black Duck	609,554	499,504	719,604	0.09
Grey Teal	90,224	74,830	105,618	0.09
Australian Wood Duck	24,577	20,065	29,090	0.09
Blue-Winged Shoveler	0	0	0	NaN
Chestnut Teal	21,135	17,994	24,276	0.08
Hardhead	1,441	1,441	1,441	0
Mountain Duck	0	0	0	NaN
Pink-Eared Duck	640	530	751	0.09
Plumed Whistling Duck	0	0	0	NaN

	Large and Extra-Large Dams			
Pacific Black Duck	4968	*	*	0.58
Grey Teal	11494	*	*	0.60
Australian Wood Duck	16141	1914	30367	0.45
Blue-Winged Shoveler	0	0	0	NaN
Chestnut Teal	0	0	0	NaN
Hardhead	0	0	0	NaN
Mountain Duck	3460	*	*	0.95
Pink-Eared Duck	816	*	*	0.98
Plumed Whistling Duck	3411	*	*	0.98
	Medium Dams			
Pacific Black Duck	30029	*	*	0.84
Grey Teal	55481	*	*	0.89
Australian Wood Duck	4342	*	*	0.81
Blue-Winged Shoveler	0	0	0	NaN
Chestnut Teal	0	0	0	NaN
Hardhead	234	*	*	0.76
Mountain Duck	0	0	0	NaN
Pink-Eared Duck	0	0	0	NaN
Plumed Whistling Duck	0	0	0	NaN
	Wastewater Treatment Ponds			
Pacific Black Duck	3204	671	5738	0.40
Grey Teal	3616	1200	6032	0.34

Australian Wood Duck	400	122	678	0.35
Blue-Winged Shoveler	0	0	0	NaN
Chestnut Teal	0	0	0	NaN
Hardhead	43	6	80	0.43
Mountain Duck	9	*	*	0.81
Pink-Eared Duck	55	0	109	0.51
Plumed Whistling Duck	4399	*	*	0.68
Wetlands				
Pacific Black Duck	700	*	*	0.82
Grey Teal	50	*	*	0.82
Australian Wood Duck	100	*	*	0.82
Blue-Winged Shoveler	0	0	0	NaN
Chestnut Teal	0	0	0	NaN
Hardhead	0	0	0	NaN
Mountain Duck	0	0	0	NaN
Pink-Eared Duck	100	*	*	0.82
Plumed Whistling Duck	0	0	0	NaN

Table 2 Estimated total abundance for the Riverina region of NSW, May-July 2024. Recommended quotas are based on maximum allowable harvest of 10% of the population size at the time of the survey.

Species	Total abundance	Quota
Pacific Black Duck	881,727	88,173
Grey Teal	480,171	48,017
Australian Wood Duck	458,911	45,891

Blue-Winged Shoveler	0	0
Chestnut Teal	21,702	2,170
Hardhead	6,520	652
Mountain Duck	14,978	1,498
Pink-Eared Duck	1,632	163
Plumed Whistling Duck	22,373	2,237

Recommended quotas for waterfowl in NSW

The extensive survey of waterfowl populations in the Riveria region represents the best scientific data that can currently be used to calculate annual quotas. The quotas determine the maximum number of waterfowl that can be sustainably harvested in a given year. We recommend that low-risk, conservative quotas be set for all duck species hunted in NSW due to some of the uncertainties in the factors influencing duck population dynamics and the effects that harvesting has on the survival of duck populations. Quotas may be revised if further information becomes available.

We recommend that a management quota be set at 10% of the estimated population size for species whose population dynamics respond predictably to climatic changes and are in high abundance, e.g., Pacific Black Duck, Grey Teal, and Australian Wood Duck. We advise that reactive quotas be set for the remaining species (Pink-eared Ducks, Plumed Whistling-Ducks, Chestnut Teal, Hardhead, and Australian Shelduck) because previous modelling has shown their population dynamics do not respond predictably to changes in climate or only occur in low abundance throughout the Riverina.

Management quotas are established for species where there is less risk from exploitation. These ducks have relatively large populations and are widely distributed, and some monitoring data suggest that their populations respond predictably to environmental changes. Reactive quotas are recommended for species with a higher risk of overharvesting due to smaller populations and/or uncertain dynamics. Unless a property is either (1) vulnerable to damage from certain species or (2) able to demonstrate that damage has happened or is extremely likely to do so, we advise against allocation of quota from species with reactive quota.

References

Bureau of Meteorology. (2024). Climate data online: Daily weather observations - June 2024. Bureau of Meteorology. http://www.bom.gov.au/climate/dwo/202406/html/IDCJDW2139.202406.shtml

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.

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.)

R Core Team (2024). 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”

Appendices

Appendix 1

Model selection for small dam surveys. The column Model is the statistical N-mixture model fitted using the R package unmarked. Mixture is the latent abundance distribution modelled using either a Poisson (P), or zero-inflated Poisson (ZIP) random variable. AIC is Akaike's Information Criterion, and ΔAIC the difference between the AIC of the model defined in column Model and the best AIC model.

Species	Model (~ detection covariates ~ abundance covariates)	Mixture	AIC	ΔAIC
Pacific Black Duck	~ observer + position ~ Vege	NB	3487.29	0
	~ observer + position ~ Trees	NB	3487.3	0.01
	~ observer + position ~ 1	NB	3487.43	0.14
	~ observer + position ~ Sheep	NB	3488.87	1.59
	~ observer + position ~ Vege + Trees + Grass + Crop	NB	3489.02	1.74
	~ observer + position ~ Grass	NB	3489.12	1.83
	~ observer + position ~ Cattle	NB	3489.35	2.07
	~ observer + position ~ Crop	NB	3489.41	2.12
	~ observer + position ~ Sheep + Cattle	NB	3490.79	3.5
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	NB	3491.95	4.66
	~ observer ~ 1	NB	3495.61	8.33
	~ 1 ~ 1	NB	3616.16	128.88
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	7198.27	3710.98
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	7215.92	3728.63
	~ observer + position ~ Vege	ZIP	7283.1	3795.82
	~ observer + position ~ Grass	ZIP	7422.01	3934.72
	~ observer + position ~ Sheep + Cattle	ZIP	7429.6	3942.32
	~ observer + position ~ Cattle	ZIP	7433.59	3946.31
	~ observer + position ~ Crop	ZIP	7446.91	3959.63
	~ observer + position ~ Sheep	ZIP	7470.47	3983.18
	~ observer + position ~ 1	ZIP	7474.49	3987.21
	~ observer + position ~ Trees	ZIP	7476.48	3989.2

	~ observer ~ 1	ZIP	7511.17	4023.89
	~ 1 ~ 1	ZIP	7601.11	4113.83
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	P	13706.21	10218.93
	~ observer + position ~ Trees	P	13758.1	10270.82
	~ observer + position ~ Vege + Trees + Grass + Crop	P	13815.67	10328.39
	~ observer + position ~ Sheep + Cattle	P	13937.99	10450.7
	~ observer + position ~ Sheep	P	13944.31	10457.02
	~ observer + position ~ Vege	P	13972.51	10485.22
	~ observer + position ~ Cattle	P	13973.45	10486.17
	~ observer + position ~ Grass	P	13973.52	10486.23
	~ observer + position ~ Crop	P	13978.38	10491.1
	~ observer + position ~ 1	P	13978.41	10491.12
	~ observer ~ 1	P	14002.46	10515.18
	~ 1 ~ 1	P	14179.19	10691.9

Species	Model (~ detection covariates ~ abundance covariates)	Mixture	AIC	∆AIC
Blue-Winged Shoveler	~ 1 ~ 1	P	4	0
	~ 1 ~ 1	NB	6	2
	~ 1 ~ 1	ZIP	6	2
	~ observer ~ 1	P	10	6
	~ observer + position ~ 1	P	12	8
	~ observer ~ 1	NB	12	8
	~ observer ~ 1	ZIP	12	8
	~ observer + position ~ Sheep	P	14	10
	~ observer + position ~ Cattle	P	14	10
	~ observer + position ~ Vege	P	14	10
	~ observer + position ~ Trees	P	14	10
	~ observer + position ~ Grass	P	14	10

	~ observer + position ~ Crop	P	14	10
	~ observer + position ~ 1	NB	14	10
	~ observer + position ~ 1	ZIP	14	10
	~ observer + position ~ Sheep + Cattle	P	16	12
	~ observer + position ~ Sheep	NB	16	12
	~ observer + position ~ Cattle	NB	16	12
	~ observer + position ~ Vege	NB	16	12
	~ observer + position ~ Trees	NB	16	12
	~ observer + position ~ Grass	NB	16	12
	~ observer + position ~ Crop	NB	16	12
	~ observer + position ~ Sheep	ZIP	16	12
	~ observer + position ~ Cattle	ZIP	16	12
	~ observer + position ~ Vege	ZIP	16	12
	~ observer + position ~ Trees	ZIP	16	12
	~ observer + position ~ Grass	ZIP	16	12
	~ observer + position ~ Crop	ZIP	16	12
	~ observer + position ~ Sheep + Cattle	NB	18	14
	~ observer + position ~ Sheep + Cattle	ZIP	18	14
	~ observer + position ~ Vege + Trees + Grass + Crop	P	20	16
	~ observer + position ~ Vege + Trees + Grass + Crop	NB	22	18
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	22	18
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	P	24	20
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	NB	26	22
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	26	22

Species	Model (~ detection covariates ~ abundance covariates)	Mixture	AIC	ΔAIC
Chestnut Teal	~ observer + position ~ Grass	ZIP	60.65	0
	~ observer + position ~ Crop	ZIP	60.83	0.18
	~ observer + position ~ Trees	NB	60.98	0.33
	~ observer ~ 1	NB	61.12	0.47
	~ observer + position ~ 1	NB	63.12	2.47

	~ observer + position ~ Sheep	NB	63.6	2.95
	~ 1 ~ 1	NB	63.82	3.17
	~ observer + position ~ Vege + Trees + Grass + Crop	NB	64.06	3.41
	~ observer + position ~ Cattle	NB	64.49	3.84
	~ observer + position ~ 1	ZIP	64.49	3.84
	~ observer + position ~ Vege	NB	64.69	4.04
	~ observer + position ~ Grass	NB	64.87	4.22
	~ observer + position ~ Sheep	ZIP	64.9	4.25
	~ observer + position ~ Sheep + Cattle	NB	64.93	4.28
	~ observer + position ~ Crop	NB	64.98	4.33
	~ observer + position ~ Trees	ZIP	65.26	4.61
	~ observer ~ 1	ZIP	65.4	4.75
	~ observer + position ~ Cattle	ZIP	65.84	5.2
	~ observer + position ~ Vege	ZIP	66.08	5.43
	~ observer + position ~ Sheep + Cattle	ZIP	66.21	5.56
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	67.44	6.79
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	NB	68.3	7.65
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	69.63	8.98
	~ 1 ~ 1	ZIP	70.83	10.18
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	P	111.65	51
	~ observer + position ~ Trees	P	112.26	51.61
	~ observer + position ~ Vege + Trees + Grass + Crop	P	113.83	53.18
	~ observer + position ~ Sheep + Cattle	P	117.8	57.15
	~ observer + position ~ Sheep	P	117.84	57.19
	~ observer ~ 1	P	122.69	62.04
	~ observer + position ~ Cattle	P	123.4	62.75
	~ observer + position ~ Vege	P	124.15	63.5
	~ observer + position ~ Crop	P	124.5	63.85
	~ observer + position ~ 1	P	124.68	64.04
	~ observer + position ~ Grass	P	125.32	64.67
	~ 1 ~ 1	P	128.99	68.34

Species	Model (~ detection covariates ~ abundance covariates)	Mixture	AIC	ΔAIC
Grey Teal	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	NB	4013.71	0
	~ observer + position ~ Vege + Trees + Grass + Crop	NB	4014.32	0.61
	~ observer + position ~ Trees	NB	4031.23	17.52
	~ observer + position ~ Crop	NB	4033.83	20.12
	~ observer + position ~ Sheep	NB	4043.22	29.51
	~ observer + position ~ Sheep + Cattle	NB	4046.54	32.82
	~ observer + position ~ Cattle	NB	4050.16	36.45
	~ observer + position ~ 1	NB	4052.24	38.53
	~ observer + position ~ Vege	NB	4053.42	39.71
	~ observer + position ~ Grass	NB	4053.97	40.26
	~ observer ~ 1	NB	4204.16	190.45
	~ 1 ~ 1	NB	5266.53	1252.82
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	14145.36	10131.64
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	14348.68	10334.97
	~ observer + position ~ Trees	ZIP	14960.82	10947.11
	~ observer + position ~ Crop	ZIP	15639.3	11625.59
	~ observer + position ~ Sheep + Cattle	ZIP	15776.31	11762.6
	~ observer + position ~ Sheep	ZIP	15947.97	11934.26
	~ observer + position ~ Cattle	ZIP	16131.39	12117.68
	~ observer + position ~ Vege	ZIP	16225.48	12211.77
	~ observer + position ~ Grass	ZIP	16244.62	12230.91
	~ observer + position ~ 1	ZIP	16247.06	12233.34
	~ observer ~ 1	ZIP	16570.95	12557.24
	~ 1 ~ 1	ZIP	17738.59	13724.88
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	P	26990.07	22976.36
	~ observer + position ~ Vege + Trees + Grass + Crop	P	28449.14	24435.43
	~ observer + position ~ Sheep + Cattle	P	29653.46	25639.75
	~ observer + position ~ Trees	P	30059.27	26045.56
	~ observer + position ~ Crop	P	30756.87	26743.16
	~ observer + position ~ Sheep	P	30836.62	26822.91

	~ observer + position ~ Cattle	P	31057.05	27043.34
	~ observer + position ~ Grass	P	31912.44	27898.73
	~ observer + position ~ Vege	P	32063.04	28049.33
	~ observer + position ~ 1	P	32099.27	28085.56
	~ observer ~ 1	P	32271.65	28257.94
	~ 1 ~ 1	P	33134.46	29120.75

Species	Model (~ detection covariates ~ abundance covariates)	Mixture	AIC	ΔAIC
Hardhead	~ observer + position ~ Vege + Trees + Grass + Crop	NB	436.07	0
	~ observer + position ~ Trees	NB	436.91	0.84
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	NB	438.93	2.86
	~ observer + position ~ Crop	NB	439.35	3.28
	~ observer + position ~ Vege	NB	441.62	5.55
	~ observer + position ~ 1	NB	443.41	7.34
	~ observer + position ~ Sheep	NB	444.56	8.48
	~ observer + position ~ Grass	NB	445.19	9.12
	~ observer + position ~ Cattle	NB	445.26	9.18
	~ observer + position ~ Sheep + Cattle	NB	446.34	10.26
	~ observer ~ 1	NB	446.8	10.73
	~ 1 ~ 1	NB	449.5	13.42
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	475.29	39.21
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	495.03	58.96
	~ observer + position ~ Crop	ZIP	505.16	69.09
	~ observer + position ~ Trees	ZIP	513.95	77.88
	~ observer + position ~ Sheep + Cattle	ZIP	516.62	80.54
	~ observer + position ~ Grass	ZIP	519.3	83.23
	~ observer + position ~ Cattle	ZIP	520.68	84.61
	~ observer + position ~ Sheep	ZIP	521.96	85.89
	~ observer + position ~ Vege	ZIP	522.76	86.68
	~ observer + position ~ 1	ZIP	524.52	88.44
	~ observer ~ 1	ZIP	529	92.92

	~ 1 ~ 1	ZIP	538.89	102.82
	~ observer + position ~ Vege + Trees + Grass + Crop	P	989.59	553.51
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	P	991.21	555.14
	~ observer + position ~ Trees	P	1032.77	596.7
	~ observer + position ~ Crop	P	1071.51	635.44
	~ observer + position ~ Vege	P	1095.98	659.9
	~ observer + position ~ Sheep + Cattle	P	1100.28	664.21
	~ observer + position ~ Sheep	P	1101.28	665.21
	~ observer + position ~ Cattle	P	1111.1	675.03
	~ observer + position ~ Grass	P	1111.35	675.28
	~ observer + position ~ 1	P	1111.68	675.6
	~ observer ~ 1	P	1117.29	681.22
	~ 1 ~ 1	P	1143.57	707.5

Species	Model (~ detection covariates ~ abundance covariates)	Mixture	AIC	ΔAIC
Mountain Duck	~ observer + position ~ Sheep + Cattle	NB	402.53	0
	~ observer + position ~ Cattle	NB	402.61	0.08
	~ observer + position ~ Trees	NB	407.3	4.76
	~ observer + position ~ 1	NB	407.55	5.01
	~ observer ~ 1	NB	407.97	5.44
	~ observer + position ~ Crop	NB	408.06	5.53
	~ observer + position ~ Grass	NB	408.52	5.99
	~ observer + position ~ Vege	NB	409.5	6.97
	~ observer + position ~ Sheep	NB	409.54	7
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	NB	409.69	7.16
	~ observer + position ~ Vege + Trees + Grass + Crop	NB	411.92	9.38
	~ 1 ~ 1	NB	416.77	14.24
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	418.88	16.34
	~ observer + position ~ Sheep + Cattle	ZIP	487.58	85.04
	~ observer + position ~ Cattle	ZIP	495.74	93.21
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	577.71	175.17

	~ observer + position ~ Grass	ZIP	603.51	200.98
	~ observer + position ~ Crop	ZIP	624.6	222.07
	~ observer + position ~ Trees	ZIP	644.98	242.44
	~ observer + position ~ Sheep	ZIP	662.48	259.94
	~ observer + position ~ 1	ZIP	663.02	260.49
	~ observer + position ~ Vege	ZIP	663.25	260.72
	~ observer ~ 1	ZIP	684.34	281.8
	~ 1 ~ 1	ZIP	703.27	300.73
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	P	1177.15	774.61
	~ observer + position ~ Cattle	P	1237.88	835.35
	~ observer + position ~ Sheep + Cattle	P	1239.5	836.97
	~ observer + position ~ Vege + Trees + Grass + Crop	P	1335.82	933.29
	~ observer + position ~ Trees	P	1358.94	956.4
	~ observer + position ~ Crop	P	1381.33	978.8
	~ observer + position ~ Grass	P	1385.09	982.55
	~ observer ~ 1	P	1396.24	993.71
	~ observer + position ~ 1	P	1397.43	994.89
	~ observer + position ~ Vege	P	1398.55	996.02
	~ observer + position ~ Sheep	P	1399.42	996.89
	~ 1 ~ 1	P	1445.9	1043.37

Species	Model (~ detection covariates ~ abundance covariates)	Mixture	AIC	ΔAIC
Pink-Eared Duck	~ 1 ~ 1	P	19.02	0
	~ 1 ~ 1	ZIP	21.02	2
	~ observer ~ 1	P	25.02	6
	~ observer ~ 1	NB	27.02	8
	~ observer + position ~ 1	P	27.02	8
	~ observer ~ 1	ZIP	27.02	8
	~ observer + position ~ Trees	P	27.62	8.6
	~ observer + position ~ Grass	P	28.39	9.37
	~ observer + position ~ Crop	P	28.51	9.49

	~ observer + position ~ Sheep	P	28.52	9.49
	~ observer + position ~ Vege	P	28.88	9.86
	~ observer + position ~ 1	NB	29.02	10
	~ observer + position ~ 1	ZIP	29.02	10
	~ observer + position ~ Trees	ZIP	29.62	10.6
	~ observer + position ~ Trees	NB	29.62	10.6
	~ observer + position ~ Sheep + Cattle	P	30.29	11.27
	~ observer + position ~ Grass	NB	30.39	11.37
	~ observer + position ~ Grass	ZIP	30.39	11.37
	~ observer + position ~ Crop	ZIP	30.51	11.49
	~ observer + position ~ Crop	NB	30.51	11.49
	~ observer + position ~ Sheep	NB	30.52	11.49
	~ observer + position ~ Sheep	ZIP	30.52	11.5
	~ observer + position ~ Cattle	NB	30.81	11.79
	~ observer + position ~ Cattle	ZIP	30.81	11.79
	~ observer + position ~ Vege	NB	30.88	11.86
	~ observer + position ~ Vege	ZIP	30.88	11.86
	~ observer + position ~ Sheep + Cattle	ZIP	32.29	13.27
	~ observer + position ~ Sheep + Cattle	NB	32.45	13.43
	~ observer + position ~ Vege + Trees + Grass + Crop	P	32.66	13.64
	~ 1 ~ 1	NB	32.94	13.92
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	34.66	15.64
	~ observer + position ~ Vege + Trees + Grass + Crop	NB	34.66	15.64
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	P	35.51	16.49
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	NB	37.51	18.49
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	37.51	18.49
	~ observer + position ~ Cattle	P	158.92	139.9

Species	Model (~ detection covariates ~ abundance covariates)	Mixture	AIC	ΔAIC
Plumed Whistling Duck	~ observer + position ~ 1	ZIP	65.48	0
	~ observer + position ~ Trees	ZIP	67.03	1.54
	~ observer + position ~ Vege	ZIP	67.03	1.54
	~ observer + position ~ Crop	ZIP	67.48	2
	~ observer + position ~ Cattle	ZIP	67.48	2
	~ observer + position ~ Sheep	ZIP	67.48	2
	~ observer + position ~ Sheep + Cattle	ZIP	69.48	4
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	73.03	7.54
	~ observer ~ 1	ZIP	74.78	9.3
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	77.03	11.54
	~ observer ~ 1	NB	77.11	11.63
	~ observer + position ~ 1	NB	79.11	13.63
	~ observer + position ~ Sheep	NB	80.07	14.59
	~ observer + position ~ Crop	NB	80.08	14.6
	~ observer + position ~ Cattle	NB	80.67	15.18
	~ observer + position ~ Vege	NB	80.69	15.21
	~ observer + position ~ Grass	NB	80.97	15.48
	~ observer + position ~ Trees	NB	81.1	15.61
	~ observer + position ~ Sheep + Cattle	NB	81.65	16.17
	~ observer + position ~ Vege + Trees + Grass + Crop	NB	83.43	17.95
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	NB	85.33	19.85
	~ 1 ~ 1	NB	113.85	48.37
	~ 1 ~ 1	ZIP	117.73	52.25
	~ observer + position ~ Grass	ZIP	1460.11	1394.62
	~ 1 ~ 1	P	2837.59	2772.1
	~ observer ~ 1	P	2843.59	2778.1
	~ observer + position ~ 1	P	2845.59	2780.1
	~ observer + position ~ Sheep	P	2847.59	2782.1
	~ observer + position ~ Cattle	P	2847.59	2782.1
	~ observer + position ~ Vege	P	2847.59	2782.1

	~ observer + position ~ Trees	P	2847.59	2782.1
	~ observer + position ~ Grass	P	2847.59	2782.1
	~ observer + position ~ Crop	P	2847.59	2782.1
	~ observer + position ~ Sheep + Cattle	P	2849.59	2784.1
	~ observer + position ~ Vege + Trees + Grass + Crop	P	2853.59	2788.1
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	P	2857.59	2792.1

Species	Model (~ detection covariates ~ abundance covariates)	Mixture	AIC	ΔAIC
Australian Wood Duck	~ observer + position ~ Grass	NB	4873.22	0
	~ observer ~ 1	NB	4873.28	0.06
	~ observer + position ~ 1	NB	4873.66	0.44
	~ observer + position ~ Sheep	NB	4875	1.78
	~ observer + position ~ Vege	NB	4875.41	2.18
	~ observer + position ~ Trees	NB	4875.49	2.27
	~ observer + position ~ Crop	NB	4875.65	2.43
	~ observer + position ~ Cattle	NB	4875.66	2.44
	~ observer + position ~ Sheep + Cattle	NB	4877	3.78
	~ observer + position ~ Vege + Trees + Grass + Crop	NB	4877.62	4.4
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	NB	4880.37	7.15
	~ 1 ~ 1	NB	4907.57	34.35
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	7364.54	2491.32
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	7382.45	2509.23
	~ observer + position ~ Grass	ZIP	7416.35	2543.13
	~ observer + position ~ Trees	ZIP	7436.31	2563.09
	~ observer + position ~ Sheep	ZIP	7436.87	2563.65
	~ observer + position ~ Sheep + Cattle	ZIP	7438.43	2565.21
	~ observer + position ~ Crop	ZIP	7445.16	2571.94
	~ observer + position ~ 1	ZIP	7447.44	2574.22
	~ observer + position ~ Cattle	ZIP	7448.96	2575.74
	~ observer + position ~ Vege	ZIP	7449.3	2576.08

	~ observer ~ 1	ZIP	7451.09	2577.87
	~ 1 ~ 1	ZIP	7584.11	2710.88
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	P	14304.43	9431.21
	~ observer + position ~ Vege + Trees + Grass + Crop	P	14351.77	9478.55
	~ observer + position ~ Grass	P	14385.88	9512.66
	~ observer + position ~ Sheep	P	14449.99	9576.77
	~ observer + position ~ Sheep + Cattle	P	14451.28	9578.06
	~ observer + position ~ Vege	P	14472.57	9599.35
	~ observer + position ~ Trees	P	14477.09	9603.87
	~ observer + position ~ 1	P	14482.57	9609.35
	~ observer + position ~ Crop	P	14483.36	9610.14
	~ observer + position ~ Cattle	P	14484.18	9610.96
	~ observer ~ 1	P	14486.4	9613.18
	~ 1 ~ 1	P	14706.37	9833.15

Appendix 2

Model selection for channel surveys. The column Model is the statistical N-mixture model fitted using the R package unmarked. Mixture is the latent abundance distribution modelled using either a Poisson (P), or zero-inflated Poisson (ZIP) random variable. AIC is Akaike's Information Criterion, and ΔAIC the difference between AIC of the model defined in column Model and the best AIC model

Species	Model	Mixture	AIC	ΔAIC
Pacific Black Duck	~ observer ~ 1	NB	1198.41	0
	~ observer + position ~ 1	NB	1198.91	0.5
	~ observer * position ~ 1	NB	1203.37	4.96
	~ 1 ~ 1	NB	1354.54	156.13
	~ observer + position ~ 1	ZIP	8956.7	7758.29
	~ observer * position ~ 1	ZIP	8962.54	7764.13
	~ observer ~ 1	ZIP	8997.49	7799.07
	~ 1 ~ 1	ZIP	9171.72	7973.31
	~ observer + position ~ 1	P	10248.5	9050.09

	~ observer * position ~ 1	P	10254.41	9055.99
	~ observer ~ 1	P	10276.72	9078.31
	~ 1 ~ 1	P	10465.7	9267.29

Species	Model	Mixture	AIC	ΔAIC
Blue-Winged_Shoveler	~ 1 ~ 1	P	4	0
	~ 1 ~ 1	NB	6	2
	~ 1 ~ 1	ZIP	6	2
	~ observer ~ 1	P	10	6
	~ observer + position ~ 1	P	12	8
	~ observer ~ 1	NB	12	8
	~ observer ~ 1	ZIP	12	8
	~ observer + position ~ 1	NB	14	10
	~ observer + position ~ 1	ZIP	14	10
	~ observer * position ~ 1	P	18	14
	~ observer * position ~ 1	NB	20	16
	~ observer * position ~ 1	ZIP	20	16

Species	Model	Mixture	AIC	ΔAIC
Chestnut Teal	~ observer * position ~ 1	NB	247.4	0
	~ observer + position ~ 1	NB	249.68	2.28
	~ observer ~ 1	NB	252.3	4.89
	~ 1 ~ 1	NB	266.31	18.9
	~ observer * position ~ 1	ZIP	365.4	118
	~ observer + position ~ 1	ZIP	369.93	122.53
	~ observer ~ 1	ZIP	396.16	148.76
	~ 1 ~ 1	ZIP	470.34	222.94
	~ observer * position ~ 1	P	812.67	565.27

	~ observer + position ~ 1	P	814.82	567.42
	~ observer ~ 1	P	922.3	674.9
	~ 1 ~ 1	P	1078.24	830.84

Species	Model	Mixture	AIC	ΔAIC
Grey Teal	~ observer ~ 1	NB	582.35	0
	~ observer + position ~ 1	NB	583.8	1.45
	~ observer * position ~ 1	NB	588.18	5.83
	~ 1 ~ 1	NB	617.43	35.08
	~ observer * position ~ 1	ZIP	2106.84	1524.49
	~ observer + position ~ 1	ZIP	2288.01	1705.66
	~ observer ~ 1	ZIP	2288.56	1706.21
	~ 1 ~ 1	ZIP	2508.99	1926.64
	~ observer + position ~ 1	P	3036.06	2453.71
	~ observer * position ~ 1	P	3036.4	2454.05
	~ 1 ~ 1	P	3075.21	2492.86
	~ observer ~ 1	P	3078.61	2496.26

Species	Model	Mixture	AIC	ΔAIC
Hardhead	~ 1 ~ 1	ZIP	54	0
	~ observer ~ 1	ZIP	56.59	2.58
	~ 1 ~ 1	NB	58.38	4.38
	~ observer + position ~ 1	ZIP	58.7	4.7
	~ observer ~ 1	NB	60.41	6.41
	~ observer + position ~ 1	NB	61.2	7.2
	~ observer * position ~ 1	ZIP	63.12	9.12
	~ observer * position ~ 1	NB	67.2	13.2
	~ observer + position ~ 1	P	112.52	58.51

	~ observer ~ 1	P	118.25	64.25
	~ observer * position ~ 1	P	118.51	64.51
	~ 1 ~ 1	P	138.57	84.57

Species	Model	Mixture	AIC	ΔAIC
Mountain Duck	~ 1 ~ 1	P	4	0
	~ 1 ~ 1	NB	6	2
	~ 1 ~ 1	ZIP	6	2
	~ observer ~ 1	P	10	6
	~ observer + position ~ 1	P	12	8
	~ observer ~ 1	NB	12	8
	~ observer ~ 1	ZIP	12	8
	~ observer + position ~ 1	NB	14	10
	~ observer + position ~ 1	ZIP	14	10
	~ observer * position ~ 1	P	18	14
	~ observer * position ~ 1	NB	20	16
	~ observer * position ~ 1	ZIP	20	16

Species	Model	Mixture	AIC	ΔAIC
Pink-Eared Duck	~ 1 ~ 1	P	15.74	0
	~ 1 ~ 1	NB	17.74	2
	~ 1 ~ 1	ZIP	17.74	2
	~ observer ~ 1	P	19.11	3.38
	~ observer + position ~ 1	P	21.11	5.37
	~ observer ~ 1	NB	21.11	5.38
	~ observer ~ 1	ZIP	21.11	5.38
	~ observer + position ~ 1	NB	23.11	7.37
	~ observer + position ~ 1	ZIP	23.11	7.38

	~ observer * position ~ 1	P	27.11	11.37
	~ observer * position ~ 1	NB	29.11	13.37
	~ observer * position ~ 1	ZIP	29.11	13.37

Species	Model	Mixture	AIC	ΔAIC
Plumed Whistling Duck	~ 1 ~ 1	P	4	0
	~ 1 ~ 1	NB	6	2
	~ 1 ~ 1	ZIP	6	2
	~ observer ~ 1	P	10	6
	~ observer + position ~ 1	P	12	8
	~ observer ~ 1	NB	12	8
	~ observer ~ 1	ZIP	12	8
	~ observer + position ~ 1	NB	14	10
	~ observer + position ~ 1	ZIP	14	10
	~ observer * position ~ 1	P	18	14
	~ observer * position ~ 1	NB	20	16
	~ observer * position ~ 1	ZIP	20	16

Species	Model	Mixture	AIC	ΔAIC
Australian Wood duck	~ observer ~ 1	NB	353.83	0
	~ observer + position ~ 1	NB	355.57	1.73
	~ 1 ~ 1	NB	360.97	7.14
	~ observer * position ~ 1	NB	360.98	7.15
	~ observer * position ~ 1	ZIP	462.68	108.85
	~ observer + position ~ 1	ZIP	464.63	110.8
	~ observer ~ 1	ZIP	467.47	113.63
	~ 1 ~ 1	ZIP	479.67	125.84

	~ observer * position ~ 1	P	727.56	373.72
	~ observer ~ 1	P	729.44	375.6
	~ observer + position ~ 1	P	731.17	377.34
	~ 1 ~ 1	P	762.45	408.62

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