

2023-2024 Annual Waterfowl Quota Report to NSW DPI Hunting, NSW Department of Primary Industries

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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 (DPI 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.

To derive annual quotas for waterfowl that can be harvested in NSW, the Vertebrate Pest Research Unit (NSW DPI) estimates waterfowl populations on artificial waterbodies in 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 May-July 2023. Abundance estimates and prescribed quotas for 2023-24 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 rhynchos*)
- Chestnut Teal (*Anas castanea*) and
- Plumed Whistling-Duck (*Dendrocygna eytoni*)

Methods

Small 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 or by ground counts.

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.

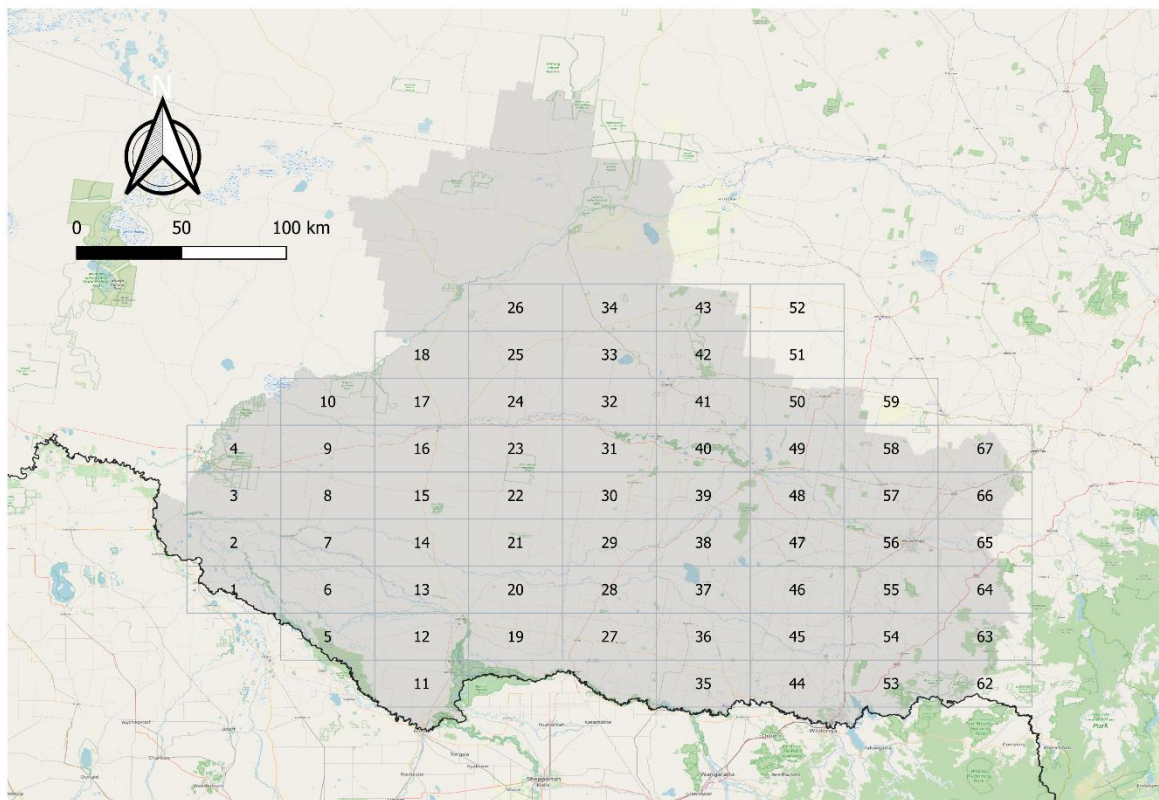


Figure 1: The area defined as the Riverina region as indicated by the Bureau of Meteorology forecast areas (<http://www.bom.gov.au/nsw/forecasts/map.shtml>). Potential survey blocks are also shown in this figure.

Sampling Strategy

The sampling strategy for small dams and channels was different from other 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 \times 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. 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.

Small Dams

A stratified random sample of dams, ≤ 4.9 ha in size, was selected. Sampling units (dams) were selected randomly without replacement following a two-stage stratified sampling design (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 \times 0.25° latitude (approximately 46.1×27.7 km, with a total area of 1279 km^2) (Figure 1). These sampling units formed the *sampling frame*. From the sampling frame, a random sample without replacement of 14 blocks (H) was selected, with each block (h) forming a *sample stratum* (Figure 2). Within each stratum, a further random sample without replacement was made for 85 dams, selected from all dams within the stratum, for a total sample size (n) over the sampling frame of 1190 dams (Figure 2).

Channels

Each surveyed section was the sampling unit, and units were selected from three channel systems (Figure). Similar to the sampling strategy used for selecting small dam sample units, two-stage stratified random samples without replacement was used. Sampling of channels was done by selecting 62 random starting points from the channels within a channel system and flying a randomly chosen direction along the sample channel section for between 654 m – 13916 m (mean = 7600 m, total = 471,360 m).

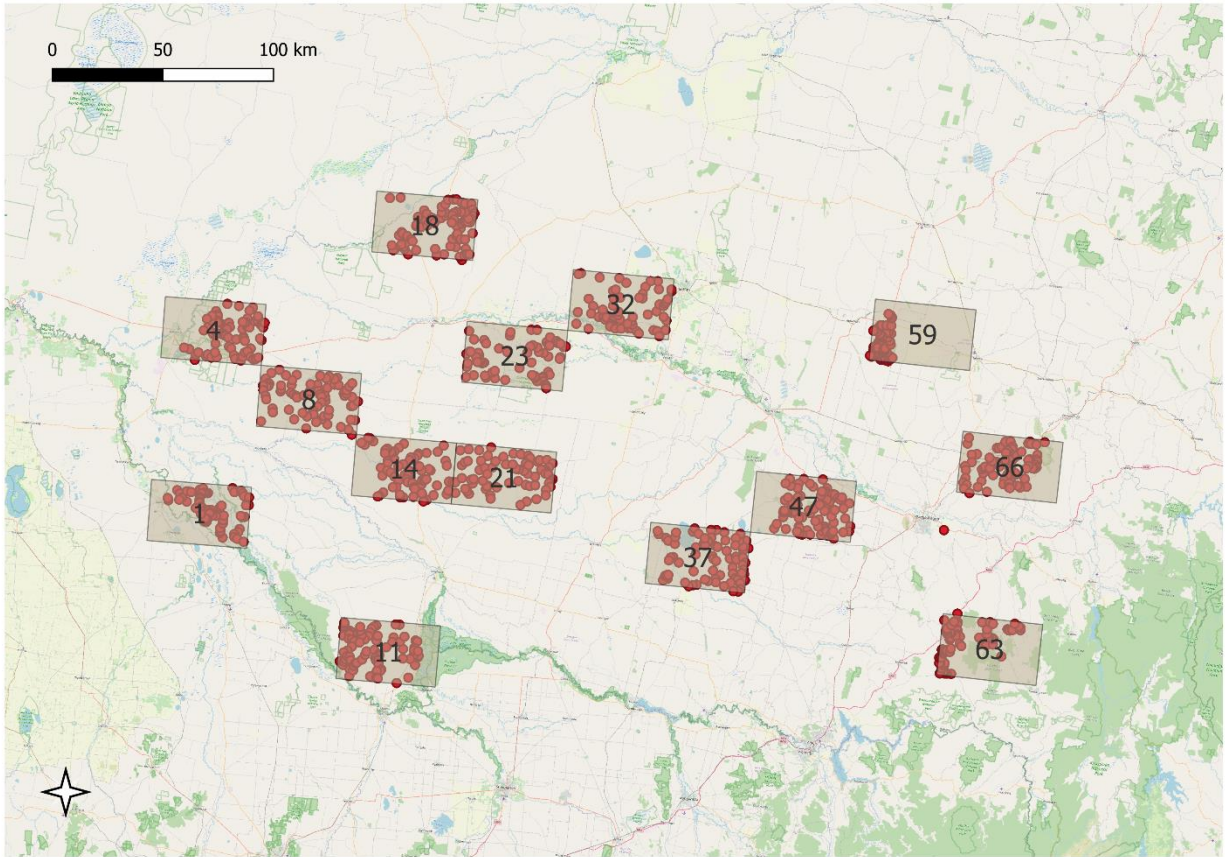


Figure 2: Small farm dams (0-4.9ha) surveyed with a helicopter during 2023.

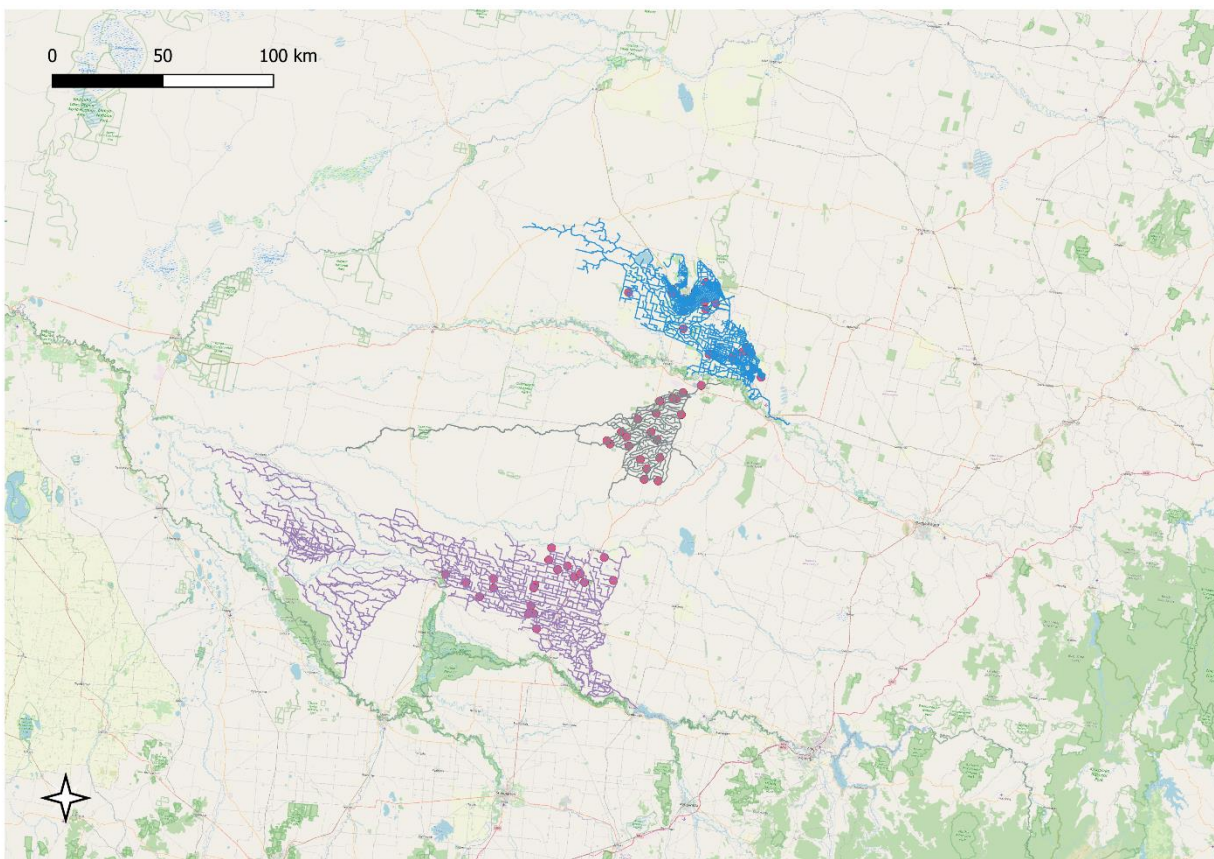


Figure 3: The Murray, Murrumbidgee and Coleambally irrigation channel network surveyed using a helicopter in 2023.

Other waterbodies

For medium, large and extra-large dams, wastewater treatment ponds, a simple random sample without replacement was chosen. One wetland (Barren Box Storage and Wetland) was chosen to survey, and 5% of the storage surface area was surveyed.

Natural waterbodies, including rivers, creek, swamps, natural lakes, 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, we flew a low and slow circuit around the dam (no lower than 18m) and the observers identified and counted all waterfowl. We used a Bell 206 L4 helicopter, allowing three observers to observe on the same side of the helicopter. Aerial operations were conducted without the front and rear doors, allowing for better visibility.

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 next to the rear observer, 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, the third observer recorded duck species after confirmation by both the front and rear observers.

All data that 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 2023). Survey samples collected using a drone (medium, large and extra-large dams and wetlands) were analysed assuming that detection probability was one. For medium, large, and extra-large dams, the whole surface of each dam was surveyed. For wetlands, a subsample of the surface was taken and the observed count was weighted by the proportion of the wetland surveyed.

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., 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 (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. Eighteen 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 natural lakes, we surveyed a sub-sample of the lake and calculated the area of the lake covered during the survey (~5%).

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 (Birdtags, Mathworks) written for MATLAB. For each video, one observer went through all videos manually and identified and tagged 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 ($n = 19$), two observers carried out independent counts using a spotting scope.

Statistical Analysis

Each species of waterfowl was analysed separately so that an independent quota for each species could be calculated.

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 i th site can be described by the equation

$$N_i \sim \text{Poisson}(\lambda)$$

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

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

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 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). A range of

potential covariates were assessed and included in alternative models that were fitted to the data. Models with high levels of support ($\Delta AIC < 2$) 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: observer; observer position (front, rear); and the presence of glare. Covariates that potentially affected occupancy included: the presence of livestock (sheep, cattle); the presence of vegetation (grass, crops, trees, unspecified vegetation); the presence of vegetation in the water; and the presence of 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,

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 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:

$$\hat{Y}_{HT} = \sum_{i \in S} \frac{y_i}{\pi_i}$$

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:

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

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 consider the correlation introduced by the fact that sampling is without replacement. The more correlated two units are (in terms of their inclusion probabilities), the greater their impact on the variance of the estimator.

When sampling is done in multiple stages, such as selecting primary sampling units (PSUs) first and then selecting 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 samples selected.

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.

$\pi_{j|k}$ = 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:

$$\hat{Y}_{HT} = \sum_k \sum_j \frac{y_{kj}}{\pi_k \times \pi_{j|k}}$$

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:

$$Var(\hat{Y}_{HT}) = \sum_k \sum_{j \neq j'} \frac{\pi_{j|k} - \pi_{j|k} \times \pi_{j'|k}}{\pi_k \times \pi_{j|k} \times \pi_{j'|k}} y_{kj} y_{kj'} + \sum_{k \neq k'} \frac{\pi_k - \pi_k \times \pi_{k'}}{\pi_k \times \pi_{k'}} \sum_j \frac{y_{kj}}{\pi_{j|k}} \sum_{j'} \frac{y_{k'j'}}{\pi_{j'|k'}}$$

Where π_k is the probability of selecting the k^{th} PSU, and $\pi_{j'|k'}$ 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 where 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 these differing 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 Horvitz-Thompson Estimator can provide unbiased estimates the observed numbers of waterfowl collected during the aerial survey are extrapolated to a known number of dams in the Riverina region (minus the estimated proportions of dry dams).

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 97% of the total number of waterfowl surveyed in the Riverina (63.3%, 17.6% and 16.3%, respectively).

The estimated population size of most species has increased since the 2022 survey. The two largest increases were recorded in Pacific Black Duck and Chestnut Teal, which were likely to be partly due to the increase of survey effort in channels to provide a more representative sample of waterfowl habitats and populations. 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 2023. 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). *Confidence intervals could not be calculated for wastewater treatment ponds.*

Species	Total	Lower 95% CI	Upper 95% CI
Small dams			
Pacific Black Duck	133,186	39,560	226,813
Grey Teal	96,219	25,127	167,311
Australian Wood Duck	237,357	59,546	415,167
Pink-eared Duck	3,165	896	5,433
Chestnut Teal	36	17	54
Hardhead	4,673	1,294	8,052
Australian Shelduck	2,856	967	4,745
Plumed-Whistling Duck	2,783	1,208	4,359
Blue-Winged Shoveler	1,061	699	1,423
Channels			
Pacific Black Duck	2,578,887	1,620,013	3,537,762
Grey Teal	628,006	339,235	916,778
Australian Wood Duck	471,306	319,112	623,500
Pink-eared Duck	0	0	0
Chestnut Teal	13,280	1567	24993
Hardhead	1,832	205	3,459
Australian Shelduck	0	0	0
Plumed-Whistling Duck	0	0	0
Blue-Winged Shoveler	0	0	0
Large and Extra-Large Dams			
Pacific Black Duck	38326	24540	52111

Grey Teal	28602	20746	36459
Australian Wood Duck	2425	2149	2701
Pink-eared Duck	8252	5611	10893
Chestnut Teal	0	0	0
Hardhead	3106	2212	4000
Australian Shelduck	239	120	358
Plumed-Whistling Duck	0	0	0
Blue-Winged Shoveler	0	0	0
Medium Dams			
Pacific Black Duck	8776	7945	9606
Grey Teal	5709	4255	7162
Australian Wood Duck	7514	4942	10085
Pink-eared Duck	0	0	0
Chestnut Teal	133	101	165
Hardhead	1228	847	1608
Australian Shelduck	6379	4083	8675
Plumed-Whistling Duck	0	0	0
Blue-Winged Shoveler	0	0	0
Wastewater Treatment Ponds*			
Pacific Black Duck	1860	-	-
Grey Teal	3328	-	-
Australian Wood Duck	473	-	-
Pink-eared Duck	829	-	-
Chestnut Teal	5	-	-
Hardhead	168	-	-
Australian Shelduck	0	-	-
Plumed-Whistling Duck	1,920	-	-

Blue-Winged Shoveler	13	-	-
Wetlands			
Pacific Black Duck	540	187	893
Grey Teal	360	125	595
Australian Wood Duck	0	0	0
Pink-eared Duck	0	0	0
Chestnut Teal	0	0	0
Hardhead	0	0	0
Australian Shelduck	0	0	0
Plumed-Whistling Duck	0	0	0
Blue-Winged Shoveler	0	0	0

Table 2 Estimated total abundance for the Riverina region of NSW, May-July 2023. 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	2,761,575	276,158
Grey Teal	762,224	76,222
Australian Wood Duck	719,075	71,907
Pink-eared Duck	12,246	1,225
Chestnut Teal	13,454	1,345
Hardhead	11,007	1,101
Australian Shelduck	9,474	947
Plumed-Whistling Duck	4,703	470
Blue-Winged Shoveler	1,074	107

Recommended quotas for waterfowl in NSW

The extensive survey of waterfowl populations in the Riverina region represents the best scientific data that can currently be used to calculate annual quotas. The quotas determine the maximum number for each species 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 only for these species because the population dynamics of the other species (such as Pink-eared Ducks, Plumed Whistling-Ducks, Blue-winged Shoveler, Chestnut Teal, Hardhead, and Australian Shelduck) have not shown to 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, are widely distributed, and some monitoring data suggest that their populations respond predictably to environmental changes. For species with a higher risk of overharvesting due to smaller populations and/or uncertain dynamics, reactive quotas are recommended. 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.

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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 model defined in column Model and the best AIC model.

Species	Model	Mixture	AIC	ΔAIC
Blue-Winged Shoveler	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	129.83	0
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	131.06	1.23
	~ observer + position ~ Trees	ZIP	132.37	2.54
	~ observer ~ 1	ZIP	132.63	2.8
	~ observer + position ~ Crop	ZIP	133.97	4.14
Australian Black Duck	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	9617.6	0
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	9777.33	159.73
	~ observer + position ~ Vege	ZIP	10012.7	395.1
	~ observer + position ~ Sheep + Cattle	ZIP	10298.43	680.83
	~ observer + position ~ Grass	ZIP	10419.93	802.34
Chestnut Teal	~ observer + position ~ Trees	ZIP	42.3	0
	~ observer + position ~ Sheep	ZIP	42.82	0.52
	~ observer ~ 1	ZIP	44.35	2.05
	~ observer + position ~ Sheep + Cattle	ZIP	44.35	2.05
	~ observer + position ~ Cattle	ZIP	44.46	2.15
Grey Teal	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	9357.05	0
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	9456.19	99.14
	~ observer + position ~ Vege	ZIP	9675.43	318.38
	~ observer + position ~ Crop	ZIP	10300.17	943.12
	~ observer + position ~ Sheep + Cattle	ZIP	10350.75	993.7
Hardhead Duck	~ observer + position ~ Grass	ZIP	837.86	0
	~ observer + position ~ Sheep + Cattle	ZIP	838.76	0.91
	~ observer + position ~ Sheep	ZIP	839.46	1.6
	~ observer + position ~ Crop	ZIP	840.19	2.34
	~ observer + position ~ 1	ZIP	840.22	2.36
Mountain Duck	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	273.92	0
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	276.18	2.26
	~ observer + position ~ Crop	ZIP	277.55	3.62
	~ observer + position ~ Grass	ZIP	278.03	4.11
	~ observer + position ~ Trees	ZIP	281.5	7.58
Pink-Eared Duck	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	779.69	0
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	797.48	17.79
	~ observer + position ~ Sheep	ZIP	803.3	23.61
	~ observer + position ~ Grass	ZIP	805.24	25.55

	~ observer + position ~ Sheep + Cattle	ZIP	805.29	25.6
Plumed Whistling Duck	~ observer + position ~ Sheep	ZIP	109.26	0
	~ observer + position ~ Sheep + Cattle	ZIP	111.26	2
	~ observer + position ~ Trees	ZIP	117.37	8.1
	~ observer ~ 1	ZIP	119.12	9.86
	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	119.26	10
Australian Wood Duck	~ observer + position ~ Sheep + Cattle + Vege + Trees + Grass + Crop	ZIP	15735.44	0
	~ observer + position ~ Vege + Trees + Grass + Crop	ZIP	15754.3	18.85
	~ observer + position ~ Sheep + Cattle	ZIP	15785.3	49.85
	~ observer + position ~ Sheep	ZIP	15787.03	51.58
	~ observer + position ~ Trees	ZIP	15796.36	60.91

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 the model defined in column Model and the best AIC model

Species	Model	Mixture	AIC	ΔAIC
Blue-Winged Shoveler	~ 1 ~ 1	P	4	0
	~ 1 ~ 1	ZIP	6	2
	~ observer ~ 1	P	8	4
	~ observer + position ~ 1	P	10	6
Australian Black Duck	~ observer ~ 1	ZIP	10	6
	~ observer * position ~ 1	ZIP	4535.53	0
	~ observer + position ~ 1	ZIP	4541.24	5.71
	~ observer ~ 1	ZIP	4552.71	17.19
	~ 1 ~ 1	ZIP	4653.6	118.07
	~ observer * position ~ 1	P	5114.55	579.02
Chestnut Teal	~ 1 ~ 1	P	24.18	0
	~ 1 ~ 1	ZIP	26.17	2
	~ observer ~ 1	P	26.23	2.06
	~ observer + position ~ 1	P	28.19	4.01
Grey Teal	~ observer ~ 1	ZIP	28.23	4.06
	~ observer * position ~ 1	ZIP	1336.61	0
	~ observer + position ~ 1	ZIP	1339.96	3.35
	~ observer ~ 1	ZIP	1350.08	13.47
	~ 1 ~ 1	ZIP	1387.58	50.97
	~ observer * position ~ 1	P	1782.37	445.76
Hardhead Duck	~ 1 ~ 1	P	32.86	0
	~ 1 ~ 1	ZIP	34.86	2
	~ observer ~ 1	P	35.49	2.62
	~ observer + position ~ 1	P	36.44	3.58
	~ observer ~ 1	ZIP	37.49	4.62
Mountain Duck	~ 1 ~ 1	P	4	0
	~ 1 ~ 1	ZIP	6	2
	~ observer ~ 1	P	8	4
	~ observer + position ~ 1	P	10	6
Pink-Eared Duck	~ observer ~ 1	ZIP	10	6
	~ 1 ~ 1	P	4	0
	~ 1 ~ 1	ZIP	6	2

	~ observer ~ 1	P	8	4
	~ observer + position ~ 1	P	10	6
	~ observer ~ 1	ZIP	10	6
Plumed Whistling Duck	~ 1 ~ 1	P	4	0
	~ 1 ~ 1	ZIP	6	2
	~ observer ~ 1	P	8	4
	~ observer + position ~ 1	P	10	6
	~ observer ~ 1	ZIP	10	6
Australian Wood Duck	~ observer ~ 1	ZIP	1275.08	0
	~ observer + position ~ 1	ZIP	1276.52	1.44
	~ observer * position ~ 1	ZIP	1278.71	3.64
	~ 1 ~ 1	ZIP	1285.24	10.16
	~ observer * position ~ 1	P	1859.55	584.47