Game duck AHM – Recommendations on Game Duck Abundance Surveys and Estimation

Thomas A. A. Prowse[1], Steve McLeod[2], Peter Caley[3]

August, 2025

[1]School of Biological Sciences, The University of Adelaide, South Australia 5005, Australia

[2]Vertebrate Pest Research Unit, Department of Primary Industries and Regional Development, New South Wales

[3]CSIRO Data61, GPO Box 1700 Canberra, ACT 2601

Abstract

The most recent report detailing abundance estimates for game ducks in Victoria (Ramsey et al. 2025) also recommended a number of refinements to improve various aspects associated with modelling game duck abundances. This review details the panel's consideration of these suggestions. In summary, we recommend that:

(1) The spatial layer representing small dams in Victoria should be updated, given that this layer is now out-of-date and a large population proportion of many game duck species resides on farm dams;

(2) The inventory of Victorian water bodies should be updated to mirror changes associated with the update of the DEA water body layer from Version 2.0 to Version 3.0;

(3) The classification algorithm used to predict whether water bodies contain water (and are therefore included in the sampling frame) should be calibrated each year using water coverage data collected for surveyed water bodies;

(4) Until the classification algorithm is improved for small farm dams, survey data could be used to estimate the proportion of small dams containing water, thereby providing alternative abundance estimates for this stratum alongside those requiring satellite-based water coverage predictions; and

(5) Adjustments to the N-mixture model used to estimate game duck abundances could be usefully explored, including incorporating water body type, water coverage and/or time-since-filling explanatory variables within component models for game duck detectability and/or abundance, testing different statistical model formulations and error distributions, and evaluating additional model diagnostics.

1. Introduction

Victoria's recreational harvest arrangements for game ducks are based on population sizes estimated for Victoria. Dedicated aerial surveys of Victorian game ducks were conducted for the first time in 2020, based upon the survey design considerations of Ramsey (2020), and have been conducted annually since. These surveys are timed to occur in spring (October) and allow estimation of the total abundance of game ducks as well as species-specific estimates for the most abundant species (Ramsey and Fanson 2021, 2022, 2023, 2024).

The most recent report detailing abundance estimates for game ducks in Victoria (Ramsey et al. 2025) also recommended a number of refinements to improve various aspects associated with modelling game duck abundances. This review details the panel's consideration of five possible refinements presented in this report or presented verbally to the panel by the report's lead author:

- Revising the current approach to estimating surface water coverage in water bodies;
- Considering the impact of additional wetland characteristics and surface water coverage on game duck abundance and/or detectability;
- Replacement of survey sites for those lost when updating the inventory of Victorian water bodies from Digital Earth Australia (DEA) database from Version 2 to Version 3.
- Inclusion of a new section in the technical reports to highlight modelling performance assessments
- Cross-validation of the N-mixture model to test its performance on out-of-sample water bodies.

2. Overview of the game duck abundance estimation

In summary, the current method consists of the following components:

(1) An inventory of natural and artificial water bodies (including farm dams) has been compiled for Victoria based on the Digital Earth Australia (DEA) Version 2 water body database and a spatial layer represented small farm dams. Water bodies in this inventory are assumed to represent the potential habitat for game ducks.

(2) These water bodies are classified into different strata, based on attributes likely to influence the numbers of game ducks using them. The strata consist of water bodies of different types, including wetlands, dams, sewage treatment ponds, rivers, and large streams (small streams and irrigation channels were excluded from the 2024 surveys). The water bodies are also stratified according to size class (<6 ha, 6–50 ha, >50 ha) and broad geographic region (North, South, East and West Victoria) (Ramsey 2020).

(3) In the first year of the program, *c.* 850 water bodies were selected to be surveyed each year using a stratified random sampling design. Selection probabilities for water bodies in each stratum were calculated as inversely proportional to their availability in the sampling frame (Ramsey and Fanson 2022). Since that time, the same water bodies have been surveyed each year, in part because the aerial survey operator must check

all waterbodies are safe to fly with no obstacles, so it is simpler if surveyed sites remain consistent year to year.

(4) Selected water bodies are surveyed using a double-observer count method, preferentially from aircraft but also from the ground (if aircraft access is limited). The observers also record whether water bodies are wet or dry when surveyed.

(5) The abundance of each game duck species at each sampled water body is estimated using an N-mixture model, assuming a zero-inflated Poisson (ZIP) distribution for the counts. A key feature of this approach is that data from the two observers allows for the estimation of imperfect detection probabilities (as a function of survey type and water body characteristics), and thereby enabling the translation of game duck counts into abundance estimates.

(6) The parameters governing functions for probability of presence and abundance conditional on presence and (i.e., the ZIP parameters) are estimated separately for each duck species, while the parameters governing the probability of detection are assumed to be the same for all duck species.

(7) Each year, a sampling frame of “wet” water bodies in Victoria is derived from a classification algorithm which uses the most recent satellite-derived surface water observations (from the LandSat and Sentinel-2 products). This sampling frame must be re-estimated each year because surface water changes annually due to variation in the prevailing environmental conditions and rainfall patterns.

(8) Statewide abundance estimates are estimated by extrapolating abundance estimates from sampled waterbodies to the annual sampling frame (i.e., to the total number of waterbodies predicted to contain surface water within each stratum).

3. Evaluation of options

3.1 Revising the current approach to estimating surface water coverage in water bodies

Surface water observations are critical to the current approach to abundance estimation. They are used to define the water body sampling frame each year and provide the basis for extrapolating abundances from the sampled wetlands to the whole of Victoria.

To define surface water extent and therefore the sampling frame for 2024, Ramsey et al. (2025) classified each water body as being wet or dry. They performed this classification for:

- wetlands and sewage ponds, using the DEA waterbody layer which combines mapped water body boundaries with Water Observation from Space (WOfS) data derived from 30-metre resolution LandSat imagery taken every 16 days;
- farm dams, using a Victorian farm dam spatial layer (denoting all farm dams present pre-2015 as polygons) and 10-metre resolution Sentinel-2 (‘S2’) satellite imagery taken every 5 days; and
- rivers and large streams, using flow gauge information to assess flow conditions in the river/stream around the time of the survey, supplemented with information from S2 imagery.

When using the LandSat and S2 imagery, Ramsey et al. (2025) obtained the most recent estimates of surface water extent preceding the surveys at each water body, and averaged the three most recent observations. A range of possible improvements to this process of surface water estimation could be considered.

First, the small farm dam layer collated by ARI in 2015 is now out of date. Ramsey et al. (2025) noted that newer classification approaches for farm dams have highlighted the increasing inaccuracy of this layer, with around 11% of existing farm dams now missing from the dataset (Malerba et al. 2021). For at least five game duck species, a very large proportion of estimated Victorian abundance is located on small farm dams. Therefore, it is important to update this layer to ensure it is as accurate as possible. Ideally, a repeatable workflow might be produced, to enable further rapid, low-cost updates in coming years.

Second, Ramsey et al. (2025) showed that the classification of water bodies as wet or dry was far from perfect using S2 satellite imagery. For example, of 197 small dams observed to contain water during surveys in 2024, only 109 (55%) were predicted to contain water based on S2 imagery, which could be due to vegetation obscuring water occurrence. Therefore, until a more accurate classification algorithm for the wet/dry status of water bodies is developed and validated, we suggest survey data could be used to estimate the proportion of small dams containing water. This estimate could then be used to produce alternative abundance estimates for this stratum alongside those requiring satellite-based water coverage predictions.

Third, and on a related point, many water bodies were predicted to be wet but were found to be dry when surveyed, potentially reflecting the time lag between the three most recent, cloud-free, satellite observations for a water body and the date on which the survey is conducted. Hence, the classification algorithm used to generate the sampling frame of “wet” water bodies might be improved by conducting a calibration exercise that uses water coverage data collected during the game duck surveys. We consider this possibility in Section 3.2 below.

Finally, we also note that, for the 2024 abundance estimates, the sampling frame excluded irrigation channels, estuaries and small streams. Given game ducks will use these habitats to some extent, excluding them could lead to underestimation of game duck abundance in Victoria. However, this will lead to reduced proportional harvest quotas and is therefore precautionary.

3.2 Considering the impact of additional wetland characteristics and surface water coverage on game duck abundance and/or detectability

Currently, N-mixture modelling used to derive abundance estimates for surveyed waterbodies estimates parameters for functions governing:

(1) latent (unobserved) abundance, which is assumed to vary by stratum (region and water body type and size) only, and

(2) detectability, which is assumed to vary by stratum, habitat type (open, reeds or woodland), survey type (aerial or ground), and the presence of glare off the water surface (present or absent).

Since the abundance model allows variation between strata only, extrapolation of abundance estimates for surveyed water bodies to the entire sampling frame is also based solely on these groupings. The abundance model could be refined further to include additional wetland characteristics (including water levels) but, to permit extrapolation beyond the surveyed water bodies, these covariates would need to be available for all water bodies in the sampling frame.

First, the influence of habitat type on abundance might be explored using data for surveyed water bodies. If shown to be an important predictor of abundance, habitat type for unsurveyed wetlands in the annual sampling frame might be reasonably inferred from satellite layers.

Second, the ephemerality of water bodies could be important for game ducks. Recently filled ephemeral wetlands can be highly productive for ducks, and some species (e.g., Pacific black duck, chestnut teal) commonly reproduce in ephemeral wetlands. Using historical satellite imagery such as the time series of WOfS data (available for > 40 years), the ephemerality of different water bodies could be categorised, and potentially used for additional stratification of the sampling frame and abundance modelling. We consider that including information on ephemerality would not clearly improve the abundance survey and estimation procedure, largely because water body ephemerality itself will be less important for game duck abundance than recent environmental conditions. As AHM progresses, however, the environmental drivers of game duck population change should be explored and conditions at ephemeral wetlands could be considered in such analyses. For example, there is a lag between the filling of a wetland and the development of aquatic vegetation that provides useful food resources for game ducks. Therefore, satellite imagery might be used to develop a time-since-filling variable for ephemeral water bodies, which could then be used within N-mixture models and might explain some variation in game duck abundance in time and space.

Third, the current method defines water bodies as wet or dry but does not use information on the surface water coverage at each water body. Collecting information on water coverage at surveyed water bodies at the time of sampling might be used in two ways:

(a) This information could be used for calibration of the classification algorithm used to define the yearly sampling frame of water bodies containing surface water. In year 1 of the AHM program, survey data were used to calibrate the algorithm, but that has not been done since. Initially, classification of wet/dry water bodies was reasonably good, but accuracy has been poorer recently (for farm dams especially). To improve definition of the 'wet' sampling frame, we suggest calibration of the classification algorithm could be done every year, which would help account for the lag between satellite observations and the game duck surveys.

(b) Water coverage data collected during the surveys might improve modelling of detectability and/or abundance within the N-mixture models, since both components likely depend on water coverage to some extent. At the very least, the relationship between % water coverage during surveys and game duck abundance could be explored. However, water coverage itself might be less important for game ducks than the area of foraging habitat within a suitable depth range. For example, dabbling ducks require foraging habitat 0-30 cm deep. Given that digital elevation models do not cover water bodies well, it would likely be difficult to equate water coverage with areas at different foraging depths. Hence the panel considered that the relationship between duck abundance and % water coverage might be weak, very likely non-linear, and potentially differ between species. Finally, to permit extrapolation beyond the surveyed water bodies, water coverage data would also be required for all water bodies in the sampling frame. This variable might be estimated from S2 data but the accuracy of such water coverage predictions would need to be validated.

3.3 Replacement of survey sites for those lost when updating the inventory of Victorian water bodies from Digital Earth Australia (DEA) database from Version 2 to Version 3.

Ramsey et al. (2025) noted that the DEA water body layer has recently been updated from Version 2.0 to Version 3.0 (Dunn et al. 2024). Some previously mapped water bodies have been dropped from this latest version which therefore affects the sampling frame. Ramsey et al. (2025) also showed that sensitivity and specificity of wet/dry predictions for DEA v3 water bodies were similar to those for DEA v2. Although switching between versions will affect the sampling frame and potentially cause some discontinuity in abundance time series and associated model development, the panel support the transition to DEA v3.

3.4 Inclusion of a new section in the technical reports to highlight modelling performance assessments

Recent reports have evaluated the accuracy of predicting whether water bodies are wet or dry at the time of surveys based on prior WOfS or S2 satellite data. They also present posterior predictive checks that compare illustrating observed game duck counts on different water bodies with the predicted counts under the N-mixture model and compare summary statistics of the predicted counts for each game duck species to the true data. The latter checks suggest that, in some cases, the range of model estimates do not include the true data, which could indicate the variance of the Poisson count distribution component of the ZIP model is too restrictive for the dataset. Therefore, alternative model formulations such as a hurdle model could be compared with a Poisson, Negative Binomial, ZIP or ZINB count distribution. Alternatively, posterior diagnostics might be improved by including additional predictor variables in the abundance modelling component (see section 3.3 above). Additional performance assessments that might be worth exploring are posterior predictive checks of observed versus predicted counts aggregated to strata levels, to ascertain whether model fit varies between strata (which could also help suggest possible reasons for these problems).

3.5 Cross-validation of the N-mixture model to test its performance on out-of-sample water bodies.

Model performance is currently based on assessment of goodness-of-fit diagnostics. Cross-validation is a resampling approach which can be used to assess how well a model can predict new values in an out-of-sample (independent) dataset. This approach involves dividing the dataset into training and test subsets, evaluating the ability of a model fitted to the training data to predict the values in the test dataset, repeating this process until all data has been used for testing once, and summarising predictive performance across these multiple iterations. A range of cross-validation options are available for this dataset, but the simplest might be a stratified design where training and test data are randomly allocated within strata while ensuring all strata are represented in the sampled training and test datasets at each iteration. The panel considers cross-validation is an important tool to understand the predictive capacity of the N-mixture models used, particularly given results are extrapolated to unsurveyed wetlands. Furthermore, cross-validation metrics might be used as a basis for variable selection within the abundance and detectability model components.

4. References

Dunn, B., C. Krause, V. Newey, L. Lymburner, M. Alger, C. Adams, F. Yuan, S. Ma, A. Barzinpour, D. Ayers, C. McKenna, and L. Shenk. 2024. Digital Earth Australia Waterbodies v3.0. Geosciences Australia, Canberra https://dx.doi.org/10.26186/148920.

Ramsey, D. S. L. 2020. Design of a monitoring program for game ducks in Victoria. Arthur Rylah Institute for Environmental Research Technical Report Series No. 314. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Ramsey, D. S. L., and B. Fanson. 2021. Abundance estimates of game ducks in Victoria: results from the 2020 aerial survey. Arthur Rylah Institute for Environmental Research Technical Report Series No. 325. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Ramsey, D. S. L., and B. Fanson. 2022. Abundance estimates for game ducks in Victoria: results from the 2021 aerial and ground surveys. Arthur Rylah Institute for Environmental Research Technical Report Series No. 335. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Ramsey, D. S. L., and B. Fanson. 2023. Abundance estimates of game ducks in Victoria: results from the 2022 aerial and ground surveys. Arthur Rylah Institute for Environmental Research Technical Report Series No. 357. Department of Energy, Environment and Climate Action, Heidelberg, Victoria.

Ramsey, D. S. L., and B. Fanson. 2024. Abundance estimates of game ducks in Victoria: results from the 2023 aerial and ground surveys. Arthur Rylah Institute for Environmental Research Technical Report Series No. 376. Department of Energy, Environment and Climate Action, Heidelberg, Victoria.

Ramsey, D. S. L., B. Fanson, and J. G. Cally. 2025. Abundance estimates for game ducks in Victoria: Results from the 2024 aerial and ground surveys., Arthur Rylah Institute for Environmental Research Technical Report Series No. 386. Department of Energy, Environment and Climate Action, Heidelberg, Victoria.