## General comments

Designing an efficient survey strategy that covers multiple species simultaneously is far from trivial and the background work that has gone into the game duck monitoring system to date is world class. The detailed nature of the program, which has involved simulation studies to evaluate the performance and costs of different survey designs and the consideration of different population estimators, is extremely rigorous. In this report, we provide comments and recommendations which we hope might further strengthen the monitoring system and the sustainability of harvest regulations set for game duck species each year.

Our overarching, general comments are:

(1) It would be useful to have a vision statement about the sometimes-competing dual objectives around sustainable hunting and conservation of species. This is needed to guide the adaptive management program and could be taken from previous reports by these authors.

(2) The monitoring design and approach to model-based abundance estimates are robust. The estimates of detection probabilities are a key component of the statistical models that allow translation of game duck counts into abundance estimates. In the future, further development of the function used to model detectability is warranted. We recommend further simulation-based testing to confirm that detection probabilities are identifiable and not leading to bias in the latent population sizes estimated.

(3) The monitoring design process focused heavily on two species which have reliably high counts – Australian wood duck and grey teal – and total abundance estimates for these species are more precise than for the remaining three species considered (Australian shelduck, Pacific Black Duck, Hardhead). The impact of this uncertainty could be discussed in more detail, particularly if abundance estimates for these species are used to determine harvest quotas.

(4) It is important to clearly identify the uncertainties in the model-based estimates so that their use within subsequent decision-making processes does not lead to unintended population consequences for these species (i.e. determining quotas). Further, Victoria's game species do not only belong to or solely inhabit Victoria, and the current management system does not consider population drivers or data from outside Victoria.

(5) There are opportunities to utilise data (game species, wetland distribution) from the Eastern Australian Waterbird Survey as this is a complementary and not competing source of data and information (different methods, larger scale). In addition, the National Waterbird Survey data could also be used (most wetlands surveyed in Victoria in 2008).

## Recommendations

### *Recommendation to improve survey counts*

1. Review the sampling methodology to ensure that sampling is adequately sampling game species in relation to large natural wetlands. It may be worth considering stratifying on known areas of high concentrations of duck species (game species) first and then sampling farm dams and other ephemeral wetlands as a second tier. It is important to improve the precision of abundance estimates for the species that are not common on farm dams, if harvesting of those species it to be permitted. We acknowledge that Ramsey & Fanson (2021) have suggested a shift from a cluster-based to stratified random design for future surveys, to provide a sampling design that will cover more natural wetlands along with other waterways, and also include ground surveys of treatment points/ground surveys that cannot be aerially surveyed.

2. On large wetlands, consider altering the counting methodology by flying inside the perimeter (i.e., over water) and having two observers counting towards the edge, where most of the birds congregate, and two observers counting over water to the middle of the wetland to estimate detection probabilities. This would allow for a total count and an estimation of detection probabilities where there are most game species distributed.

3. Consider counting the entire wetland (>6 ha) if it is a medium to large wetland by positioning the aircraft inshore by about 100m and counting both sides to get a total count (as in the EAWS, i.e. circumnavigation).

4. Separate dams into large government built dams (deep, usually >50 ha) and small farm dams. Currently none of the large dams in Victoria have been counted, and it may be useful to consider which these dams could have large numbers of game species (e.g. EAWS surveys and National surveys). Information provided separately by the Arthur Rylah Institute indicates that some large (> 50 ha) dams have to date been included in the 'wetlands' stratum, and therefore that further work to correct some anomalies in the spatial layers used is required.

5. Provide more estimates of uncertainties for estimates of total numbers after addressing some of the issues raised.

6. Consider the possibility of using some of the spatially explicit data in the Eastern Australian Waterbird Survey and National Waterbird Survey (2008) to inform sampling of wetlands and waterbodies.

***Recommendation to verify and improve the model-based estimates used***

1. Consider performing a simulation study using the same statistical procedure used for model-based estimation in Ramsey & Fallon (2021) – or alternatively the statistical approach planned to be used in the future – to verify the identifiability of the binomial detectability function and latent population sizes inferred (under ideal simulated conditions).

2. Consider testing more complex formulations of the detectability function estimated, accounting for waterbody size and type and differences in the ability of observers at the front and rear of the aircraft to detect game ducks. Information provided separately by the Arthur Rylah Institute indicates that further development of the

detectability model component to include waterbody size is planned (and we strongly support this further work), along with testing of a multinomial version of the N-mixture model that uses time-stamped observations (i.e., a set of double-observer counts for each wetland). The latter approach is worth further testing provided time-stamped data can be provided, although it may be complicated further by variation in detectability between different portions of large wetlands.

***Additional minor comments***

1. Pooling counts of grey teal and chestnut teal is essential due to the difficulty in correctly separating these species from aerial surveys.
2. Use of UAV may be promising but will not replace aerial surveys because such technology can only be used in a few wetlands, not allowing widespread coverage. It also needs to be more rigorously demonstrated as to its efficacy. There are also considerable challenges in developing repeatable and dependable algorithms for identifying species.

**How well does the monitoring program (including survey design, implementation, data analysis and interpretation of results) address the aims/objectives as set out in Ramsey 2020 and Ramsey and Fanson 2021?**

***General response***

The monitoring program does address the key aims and objectives but it is dependent on some key data sets in relation to the design and needs to acknowledge uncertainties more explicitly so that there is a focus on continual improvement. In particular, the following broad areas can be a focus.

***The Frame***

It is understandable that the main focus is Victoria, captured by the following: *"Since seasonal arrangements for recreational duck hunting involve the setting of bag limits and season length for the entire state of Victoria, it makes sense that population abundance and total harvest offtake are also estimated over the same spatial scale"* (Ramsey 2020). However, there are drawbacks because of the mobility of game species into other states. There needs to be a more explicit acknowledgement that not the whole population is being surveyed but just areas in Victoria and its abundance at any one time.

This challenge has been acknowledged: "Once the target population has been identified, the sampling frame ideally should include the entire target population" (Ramsey 2020). The issue quite clearly here is that the 'entire target population' is well beyond Victoria's borders.

***Wetland distribution***

There is a good sampling approach, reflecting the non-random distribution of wetlands. The design relies considerably on water body data from satellite imagery. This is excellent but not perfect. In particular, there are some serious uncertainties related to vegetated wetlands which are not easily identified using satellite imagery because they have a poor water signature, often requiring development of indices that track flooded vegetation (Thomas et al. 2015).

These have the potential for constant improvement but may have affected the design and subsequent estimates of abundance. Pointing out some of the uncertainties of the waterbody layers and the implications for estimates is important. Some of these were acknowledged. The comparison between 'onground' (i.e. helicopter data on wetland distribution) and satellite data is useful, and should continue, to better understand these uncertainties.

***Wetland typology (and attributes)***

There was a typology/ classification imposed on the survey design, summarised by "Waterbodies were classified into different strata, based on attributes likely to influence numbers of game ducks" (Ramsey 2020).

There are a range of natural wetlands with significantly different habitat quality for game species, depending on size, type, and drivers. It might be useful to obtain more understanding of which wetlands are most important for game species. This classification drove the sampling design. "Hence, a disproportionate allocation was used by constructing selection probabilities for each stratum based on their relative abundance in the sampling frame" (Ramsey 2020).

The classification between natural wetlands, dams and sewage ponds, with category sizes is simplistic. For dams, there are large farm dams (>6 ha) which are significantly different to large storages (e.g. Dartmouth Dam). Large public storages and farm dams have varying characteristics that either support or do not support game species. For example, Dartmouth Dam does not support any game species, despite its considerable size. Also, some wetlands classified as "natural" might have their water levels artificially maintained for storage. The 2020 survey of only two sewage ponds would seem to make this category difficult to justify. Rivers were not included. Some estuarine systems can be particularly important. We note that this issue is to be further considered.

Analyses of waterbird use (including most of the rarer game species other than Australian wood duck or grey teal) indicates that most are found on a relatively small number of usually natural wetlands (see Kingsford et al. 2012, Kingsford et al. 2017). If insufficient numbers of these wetlands are surveyed, then there may be a biased sampling of game species. Ideally the stratified sampling approach focuses on the habitats with the highest concentrations of species. This could be tested using the EAWS survey data by combining estimates of farm dams with the surveys of the EAWS of farm dams to extrapolate up the EAWS data to estimate the proportion of game species on farm dams compared to natural wetlands, within survey bands and also part of the National Waterbird survey in 2008. Although the EAWS does not attempt to account for observation error (i.e., imperfect detectability), detectability estimates for different waterbody types are available from the game duck monitoring program (e.g., Fig 7 of Ramsey and Fanson 2021 but also noting the detectability model component could be improved further), and these estimates could perhaps be used to derive correction factors to be applied to the EAWS, to improve comparability of the two monitoring methods, although issues relating to different aircraft platforms for survey will remain.

**Review of 2020 game species abundance estimates**

Three key areas are critically important: the methodology of data collection, the sampling coverage and subsequent extrapolation, and the statistical approach to model-based abundance estimation.

***Counting of waterbirds***

Two observers can effectively count small wetlands (e.g. 90% of all wetlands counted, n=576 (<6ha)) (Ramsey and Fanson 2021). This is an excellent methodology and provides a precise and likely highly accurate count of these small dams. Counts of small farm dams on the Eastern Australian Aerial Survey of Waterbirds (Kingsford and Porter 2009) are considered relatively precise and unbiased.

Precision and bias on large wetlands, particularly if they have significant diversity of game species and high abundance is a lot less clear. Also, relatively large proportions of game species are usually found on these wetlands (see below). It was not clear how a count was made for an entire large wetland. For wetlands in the 6-50 ha group (30 natural, 9 dams), this could be problematic if the aircraft is circumnavigating outside the edge of the wetland. The methodology is described as the following.

"For eight of the larger waterbodies (> 50 ha), only a portion of the waterbody (selected at random) was surveyed, and the proportion of the surface area searched was recorded using GPS. The counts for each observer for the entire surface area were then imputed using the proportion of the waterbody surveyed" (Ramsey and Fanson 2021).

"During each survey, the observers were assumed to sample the entire waterbody and that all ducks present within the waterbody could potentially be detected. However, in practice, only a selected portion of larger waterbodies may be sampled, which is then extrapolated to the entire waterbody (Dundas *et al.* 2019, Ramsey 2020).

There is no reference to the middle of a large wetland. Most waterbirds congregate on the edge of large wetlands (see (Kingsford and Porter 1994). Extrapolation from an edge to a whole will produce a positive bias because most waterbirds are found on the edge (perhaps as many as 80%). So an extrapolation to the entire area will inflate counts. Further, birds are highly clumped in their distribution around the edge of a wetland. This highly clumped distribution is often not predictable as it may reflect factors such wind strength or aerial predator presence. So unless the entire wetland is surveyed, a proportion may considerably under or overestimate the numbers. In the Eastern Australian Waterbird Aerial Survey, surveys are usually completed for the entire large natural wetland except with large dams with few waterbirds to avoid this problem. Further, for large wetlands, there will be increasing issues related to distance of ducks from the aircraft and in relation to counts.

***Sampling coverage***

Most of the estimate was based on counts of small wetlands (e.g. 90% of all wetlands counted, n=576 (<6ha)), mostly small farm dams (Ramsey and Fanson 2021). This is an excellent methodology.

These are obviously the largest majority of wetlands counted and mapped in the survey. However, many waterbirds including some game species of ducks, occur on large natural wetlands, based on extensive data from the Eastern Australian Aerial Survey of Waterbirds and the National Survey of Australia (Kingsford et al. 2012, Kingsford et al. 2017). These surveys also cover many small wetlands, including farm dams (contrary to the criticism in (Ramsey 2020), see below).

Despite the rigorous approach to sampling wetlands in the 2020 aerial survey, there were some clear gaps in wetland coverage which were not obviously explained. It was not clear why no wetlands in western Victoria were surveyed. There are a range of ephemeral wetlands in this region which could have held water.

***Modelling***

The model-based procedure used for abundance estimation, involving N-mixture modelling which accounts for imperfect detection of game ducks by the observers, is appropriate to the goal of estimating actual population sizes in each bioregion. We acknowledge this is a key goal of the adaptive management program and can assist with the setting of harvest regulations designed to ensure a sustainable proportional harvest each year. We provide some comments on the abundance and detection components of these models in turn.

*The abundance model*

The abundance model component, which is different for each species, assumes a zero-inflated model for latent abundance which is a function of waterbody type (wetland, dam, sewage pond), waterbody size class (< 6 ha, 6 – 50 ha, > 50 ha) and bioregion (north, south, east, west). Given the focus of the program on generating population estimates for the bioregions to guide harvest regulation within each, this is a simple yet appropriate way to model abundance. However, this abundance model is reasonably simple, particularly in relation to typology. It is also unclear how well the simple abundance model performs for species other than teal and Australian wood duck, and how uncertainties in the model-based estimates for rarer species would be incorporated within harvest regulations. The high uncertainty for these species should have implications for setting bag limits and seasons.

*Estimation of detection*

In Ramsey and Fanson (2021), the per-individual probability of detection is assumed to be the same for all species and is modelled as a function of glare from the water surface (absent, present) and habitat within the vicinity of each waterbody (open, reeds, woodland). This is an important component because estimates of detectability have a relatively large impact on the estimation of the latent abundances. That is, when the probability of detection is low the abundance estimates are effectively corrected upwards relative to the actual counts obtained. In Ramsey and Fanson (2021), the replicate counts of game ducks from the two observers for sampled waterbody were used to estimate the abundance of ducks at each waterbody, corrected for imperfect detection. This is an appropriate model for the probability of detection. However, given its importance we make a number of comments regarding this component:

(1) The earlier report of Ramsey (2020) used simulation-based studies to consider the performance of model-based population estimates for game ducks but used a different multinomial formulation for the probability of detection. Hence the ability of the model of

Ramsey and Fanson (2021) to correctly identify probabilities of detection has not been formally evaluated as yet. Given the identifiability of the detectability parameter from binomial N-mixture models has been questioned previously (Barker et al 2018), it would be useful to conduct a small simulation study to evaluate the ability of the model used to produce population estimates to capture probabilities of detection and latent abundance accurately.

(2) The estimates for per-individual probability of detection range from around 0.6 in open habitats in the absence of glare, down to about 0.25 in woodlands with glare present. These detectability estimates are very precise (Fig 7 of Ramsey and Fanson 2021). In comparison, it is the experience of EAWS that for small wetlands, detection probability is reasonably good (0.7-1.0), although not formally tested. Discussion between observers indicates reasonable agreement. We should therefore consider the possibility that probabilities of detection are underestimated in Ramsey and Fanson (2021), in which case the estimates of game duck abundance will be inflated and the harvest regulations might be set above unsustainable levels. While stressing that this component is statistically valid, we identify three possible problems and, where possible, highlight further possible improvements that could be considered as the program continues:

**(a) Unavoidable statistical assumptions.** The binomial model used to model detection assumes that counts derived from each observer represent some fraction of the true abundance at any given site. That is, the model assumes a constant probability of detection for each individual bird. This assumption is potentially violated because birds tend to occur in flocks (i.e., observers might detect or fail to detect whole flocks at a time) and because bird species could be mis-identified at times (i.e., an observer's count might exceed the true count). In addition, observers count and record groups (flocks) of birds rather than individuals, especially when numbers are high. Such assumption violations will tend to increase the variance of the double-observer counts above the idealised binomial variance, and flow on to under-estimation of the probabilities of detection and over-estimation of population sizes. However, from a modelling standpoint there is little that can be done about this if only the total count from each observer is available.

**(b) Incomplete consideration of the wetland attributes that influence detection probability.** As mentioned above, probabilities of detection are modelled independent of species as a function of glare and habitat type. However, waterbody type (wetland, dam, sewage pond) and waterbody size class (< 6 ha, 6 – 50 ha, > 50 ha) might also influence detection probabilities, and these variables could be tested in future iterations. In particular, intuitively it seems reasonable that detection probabilities for dams < 6 ha are likely to be greater than c. 0.6 as estimated (Fig. 7 of Ramsey and Fanson 2021) but this could be tested with further model development.

**(c) Differences in the probability of detection between observers at the front and rear of the aircraft.** The two observers occupy different positions in the aircraft. The observer at the front generally has more visibility and can also see waterbirds earlier. Again, this violates the constant per-individual detection probability which is assumed to be the same for both observers. Future development of the model-based estimation procedure could explore allowing for differences in detectability between observers and position of observers.

**Are the estimates of waterfowl abundance and survey accuracy sound and reasonable?**

Please see the comments above.

**Is the monitoring program (including methodology, implementation and data analysis), including recommendations for improvement as set out in Ramsey and Fanson 2021, consistent with international or Australian best practice? Does it represent an improvement on international or Australian best practice?**

The sampling design is rigorous but uncertainties remain in terms of estimating total abundances of the eight game species (please see comments above).

**How could the monitoring program be improved in 2021?**

Please see the recommendations above.

**Any other observations or comments on the monitoring program and November 2020 survey trial?**

Please see the comments above.

**Comments on how the survey relates to the Eastern Australian Waterbird Survey – are the differences primarily due to scale, or are there also methodological differences that have a significant influence on waterfowl counts?**

(1) **Methodological.** There are a range of methodological differences and similarities. All these factors may affect counts and so the two approaches are not comparable.

i. *Different aircraft*. The greatest difference relates to the aircrafts used. A helicopter travels slower allowing better identification of species, although this is not a panacea. It is also more manoeuvrable, allowing for surveying difficult areas where ducks may congregate.

ii. *Access to wetlands*. There are similarities in terms of difficulties such as not always being able to survey wetlands proximate to built-up areas.

iii. *Survey methodology*. There are differences in the approach of surveying large wetlands. The Victorian approach is circumnavigate the edge of a wetland from the outside. The EAWS approach is to attempt to get a total count for a wetland, requiring the aircraft to be in the best position to effect this. So for small wetlands such as farm dams, the aircraft is flown with one observer over a wetland to obtain a total count. For large wetlands where the aircraft can circumnavigate, one observer counts the edge of the wetland and the other counts towards the middle obtaining a total count (see comments above). For medium sized wetlands, the aircraft can be flown down the centre of the wetland. Sampling error estimates are incorporated into UNSW surveys in the Murray-Darling Basin by replicate counts. There are currently no replicate counts done (i.e., on different days) for the Victorian surveys, so presumably uncertainty estimates do not incorporate uncertainty due to variation in waterbird abundances over short time-scales.

iv. *Wetlands surveyed*. The EAWS attempts to survey all wetlands within survey bands 30km wide. This includes all natural and artificial wetlands. It includes large dams, natural wetlands, including estuaries, and small farm dams. The claim is made that "…the EAWS surveys have inadequate coverage and/or sampling designs for Victorian waterbodies to enable a robust estimation of duck abundances. In addition, these surveys also have other drawbacks including being unable to account for birds missed by observers (imperfect detection) and being unsuitable for the detection of species inhabiting smaller waterbodies such as farm dams." (Ramsey 2020). It surveys small farm dams and treats data as an index.

v. *Cost*. The EAWS uses fixed wing aircraft which are cheaper, faster, and have far greater range, allowing for considerable efficiencies in terms of surveying large spatial scale, including remote areas (i.e. eastern Australia).

vi. *Focus species*. The EAWS focuses on all waterbirds, not just game species of ducks. There are advantages and disadvantages. The advantages are that this provides information on a wide range of species for which governments have responsibilities for conservation (e.g. migratory species). This also allows for informing policy decisions related to wetland loss and degradation as all waterbirds can be used as an indicator of long-term changes (e.g. Kingsford et al. 2017). The disadvantage is that there are considerably more species to identify and estimate.

(2) **Analytical.** No attempt is made to develop an overall estimate of population sizes from the EAWS data. It is treated as an index over time with all survey measures kept standardised as far as practicable (i.e. survey time, route, methodology).

(3) There is also value in considering the data from the 2008 National Survey where all major wetlands in Victoria (and other States and Territories) were surveyed, particularly if there is a focus on identifying the areas of high concentration.

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