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Assessment of Ground and Drone Surveys of Large Waterbird Breeding Rookeries: A Comparative Study

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Abstract: Assessing nesting metrics in large waterbird breeding rookeries is challenging due to their size and accessibility. Drones offer a promising solution, but their comparability with ground surveys remains debated. In our study, we directly compared ground and drone data collected simultaneously over the same breeding areas. Drones excel in accessing remote terrain, enhancing coverage, mapping colony extent and reducing sampling bias. However, flying at the low altitudes required to capture young chicks in nests within densely populated rookeries poses challenges, often requiring observer presence and diminishing the distance advantage. Drones enable rapid data collection and facilitate accurate ibis chick counts, particularly at the "runner" stage when chicks are very mobile, and our surveys found significant differences in the counts between drone and ground surveys at this nesting stage. Ground surveys, on the other hand, provide valuable contextual observations, including water variables and sensory cues concerning the health of the colony. Both methods offer unique insights, with drones providing high-resolution aerial data and ground surveys complementing with human observations. Integrating both methods is ideal for comprehensive waterbird monitoring and conservation.

Keywords: UAV; ecology; conservation; ibis; colonial waterbirds; wetlands

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1. Introduction

The utilisation of drones in ecological monitoring and conservation efforts has seen a remarkable surge in recent years, showcasing their versatility and effectiveness. However, it is crucial to recognise that while drones offer invaluable insights, they do not always supplant human observation but rather augment it with a distinct and complementary dataset.

When studying large aggregations of animals, drones are particularly useful in their ability to map boundaries, build high resolution maps and collect a fixed record of animals in time and space and have been used to study a wide range of vertebrates including birds, hippos, crocodiles and wombats [1–5]. Due to these added advantages, drones have been used extensively to monitor waterbird rookeries including seabirds [6–8] and wetland birds [9–12]. Drones can be used in conjunction with ground-based methods such as researcher visits, camera traps or acoustic sampling to measure abundance and reproductive success and monitor rookery conditions [13,14].

Waterbird rookeries have unique challenges for monitoring, which include restricted ground access, large numbers of birds (>'000′s) and a large spatial extent that may cover many 10s of hectares [8,12]. Consequently, this makes the accurate estimation of rookery size (both in area and number of birds) difficult to obtain by ground-based observers.

Drones can address many of these challenges. Drones can be flown from the outside of the rookery extent, making access potentially easier and quicker and causing less disturbance to the nesting birds [15,16]. They are useful in locating nests [17,18] and capture imagery that can later be analysed to derive the rookery extent and provide a count of nests and/or birds [11,19].

To further the utility of drones in monitoring waterbird rookeries, we aimed to compare ground-collected reproductive success data with drone-derived data to assess whether drone-captured nest data could replace ground-based nest visits. Similar studies have included the calculation of reproductive success but without ground truthing [9] or with focus on non-colonial nesting species [18], on small accessible colonies [20,21], on coastal nesting species [22] or on non waterbird species such as raptors [23]. We hypothesize that the two data collection methods will produce differing reproductive success values, as detection rates will differ between the methods. We predict these differences will vary across the nesting stage of the birds, reflecting the nuanced behaviours exhibited by birds at each developmental phase, with differences particularly prevalent as chicks get older and become more mobile.

2. Materials and Methods

2.1. Study Areas

Colonial waterbirds nested at two large floodplain wetlands in south-eastern Australia on the Lachlan River and Murrumbidgee River in the Murray–Darling Basin (Figure 1). Large rookeries (>40,000 birds) of Threskiornithidae established in September 2021–March 2022, and reproductive success monitoring was conducted to assess waterbird breeding responses to flooding and environmental water management.

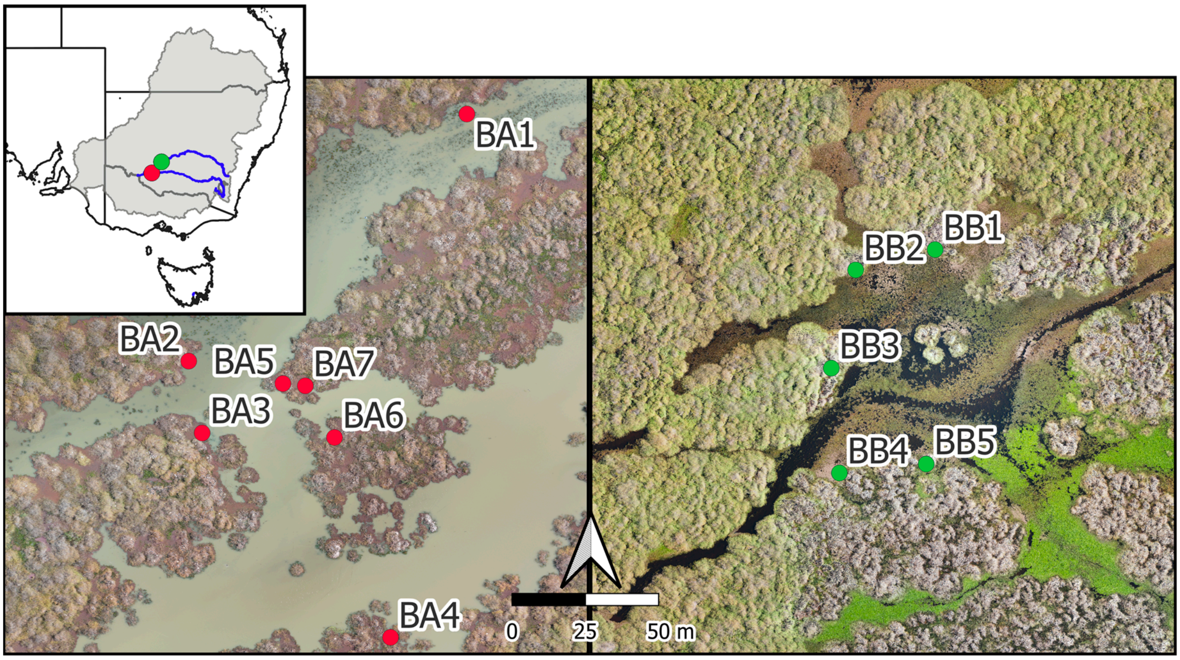


Figure 1. Nest clumps were surveyed using ground survey and drone survey methods at the Bala rookery (red markers) on the Murrumbidgee River and the Block Bank rookery (green markers) on the Lachlan River within the Murray–Darling Basin (light grey), Australia.

Two rookeries, the Bala rookery (Murrumbidgee River) and Block Bank rookery (Lachlan River), were surveyed using both ground-based and drone methods. The rookeries were predominantly made up of straw-necked ibis *Threskiornis spinicollis* but included other colonial waterbird species such as Australian white ibis *Threskiornis moluccus*, royal spoonbills *Platalea regia* and great cormorants *Phalacrocorax carbo.* The vegetation at both rookery sites was dominated by lignum *Duma florulenta*. Straw-necked ibis built nesting platforms on the lignum following a period of vegetation flattening, referred to as trampling. Nesting platforms consisted of multiple nests ranging from <10–>50, hereafter referred to as nest clumps.

2.2. Ground-Based Surveys

The two rookeries were each surveyed fortnightly between November 2021 and January 2022 as part of a longer-term survey program [24,25]. Ground-based nest surveys were completed by two people in a canoe. During the first survey at each rookery, a sub-set of randomly selected straw-necked ibis nest clumps and individual nests were assigned a unique number, and their GPS locations were recorded. These nest clumps were then revisited on each subsequent survey. During each survey, the following variables were recorded; number of eggs or chicks, chick development stage (Table 1), evidence of predation, disease and nest abandonment. Individual nest counts continued fortnightly until chicks had reached the runner stage, where chicks become highly mobile and begin créching behaviour, congregating on nest clumps as large groups of chicks (Table 1). At this stage, it is not possible to attribute chicks to specific nests, so counts were conducted at a nest-clump scale.

2.3. Drone Surveys

Drone surveys were conducted three times at each rookery to coincide with the ground-based surveys. A black DJI (Shenzhen, China) Mavic 2 Enterprise Dual quadcopter drone (905 g), with the stock standard camera (24 mm with a 1/2.3″ CMOS 12 Megapixel (MP) sensor) was used to capture still images of the same nest clumps monitored using ground-based methods during the same survey. The drone was launched from the canoe at a distance of approximately 5 m in the first survey when rookeries were at the egg laying stage, using the direction of the canoe to point toward the correct clump. In later surveys, when it was already clear which clump was being counted in aerial imagery, the drone could be launched from up to 10–15 m from the intended nest clump. The drone was manually manoeuvred over the nest clump, using the built-in DJI Pilot application in the smart controller, and still images were taken at a height of approximately 16 m directly above the clump at a resolution of approximately ~4.4 mm pixel^{-1}. Survey height was chosen as a balance between flying low enough to differentiate between nesting ages based on prior experience [9] and causing unnecessary disturbance. Other surveys have tested anywhere from 3–21 m, however, bird responses vary with species and vary based on the size and volume of the drone, and differing survey goals require different resolutions [26,27]. In this study, as the pilot was already present in the colony for ground surveys, the adults had often already flown from the nests anyway, as per traditional ground survey standards [25]. As a result, surveys needed to be completed quickly to protect young chicks and eggs from weather, particularly on hot days. If we felt that the adults were gone for too long, we left the nest clump and watched them quickly return. The continuation of nesting throughout the season is confirmation that little disturbance was caused, as these species can abandon nests on mass when under stress [28]. When chicks were at the flyer stage (Table 1), we flew the drone from ~20 m from the nest clump and took photos at a horizontal approach to minimise the flushing of young birds from the nest clump.

Post survey, images were viewed, and nests were manually counted by assigning nest numbers to each visible nest in the nest clump images. The same nests were then located in each set of subsequent images. Eggs and chicks were counted for each drone survey (see example in Appendix A) [9]. Identifying features of each age group such as the black head and grey body of squirters, or the development of wing feathers in the runners could be seen in the drone imagery (see examples in Table 1), and these were used to assign an age group to chicks.

Table 1. Chick development stages recorded during each ground and drone survey, with example images as collected by an on-ground observer (Canon EOS 5d Mark II, ~21 MP) and using a DJI Mavic 2 Enterprise Dual quadcopter drone (12 MP) [29,30].

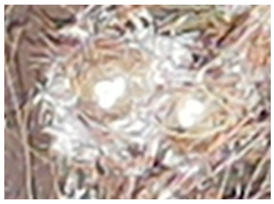
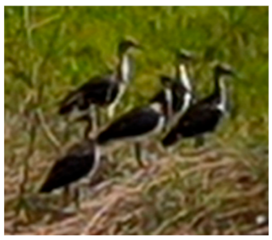
Development Stage	Characteristics	Age (Days)	Ground Observer View	Drone View
Eggs	Whole egg, incubated by adult.	1–20		
Chicks	Recently hatched (1–5 days old), downy feathers, immobile.	21–25		
Squirters	Early sheathed feathers starting on wings, still in nest, immobile.	26–30		
Runners	Development of pin feathers. Mix of down and feathers, walking awkwardly, can leave nest on foot.	31–35		
Flappers	Nearly fully feathered, cannot fly but flaps between nests.	36–40		
Flyers	Fully feathered, able to fly and leave nests, still attended by parents at nest.	41–47		

Table 1. *Cont.*

Development Stage	Characteristics	Age (Days)	Ground Observer View	Drone View
Fledglings	Independent, does not return to nest but roosts in nearby trees. (Normally not counted by ground observers or drone).	>48		

2.4. Analysis

To begin, we counted the number of unique nests observed using each survey method within the designated clumps—ground surveyed nests had unique tag identifiers, whereas drone-surveyed nests were identified as the same nest over time based on their spatial location in the drone images (Appendix A). All further analyses were undertaken at the nest clump scale, as chicks began to creche. As there are differing numbers of nests per clump and differing numbers of nests surveyed using each technique, we took the total number of nests surveyed in each nest clump and used this value to develop the mean number of eggs, chicks, squirters, runners, flappers and flyers per nest clump. We then ran all statistical models on this mean nest clump value, rather than the raw counts.

To model differences in the mean number of eggs and young per nest in each nest clump between the two survey methods, we used the package glmmTMB [31] with each nesting stage modelled separately, i.e., chicks, then squirters, then runners, etc. We took the log and sqrt of the counts to account for the non-normality of the response data and used the AIC function to determine the best model fit [32]. We included the rookery, survey expedition (trip 1, 2 or 3) and survey type as fixed variables, and we included the nest clump as a nested variable to account for repeat sampling over time.

Reproductive success was calculated twice for each rookery, summing the number of eggs in survey 1 and comparing this to the number of offspring in survey 2, and again comparing the number of eggs in survey 1 to the offspring in survey 3. All offspring age groups were combined and summed in order to allow reproductive success comparisons across the two methods. This was necessary as assigned chick development stages differed between survey methods.

3. Results

In total, data from 490 nests were analysed. At the Block Bank rookery, 93 nests were counted on the ground, and 148 from drone imagery (additional nests were visible and therefore counted in the drone imagery). At the Bala rookery, 122 nests were counted in the ground surveys, whereas 127 were counted from the drone imagery (an additional 5 nests were visible in the selected clumps in the drone imagery). If the analyses were not limited to within the assigned ground counted clumps as a comparison study, many more hundreds of nests could have been seen and therefore counted in the drone imagery.

Rookery counts were aligned with chick development stages, with early surveys dominated by egg counts, followed by chicks and squirters, which then progressed into the highly mobile chick stages of runners, flappers and flyers (Figure 2). Flyers were observed only at the Block Bank rookery as the surveys continued later into the breeding season (Figure 2).

Mean clutch sizes, i.e., the number of eggs per nest, were comparable between the ground-based and drone derived counts, with a mean of 1.95 ± 0.6 in ground counts and 1.92 ± 0.6 in drone counts (excluding nests with no eggs), and this was not significantly different between survey methods (χ^2 (1, N = 62) = 0.001, $p = 0.97$).

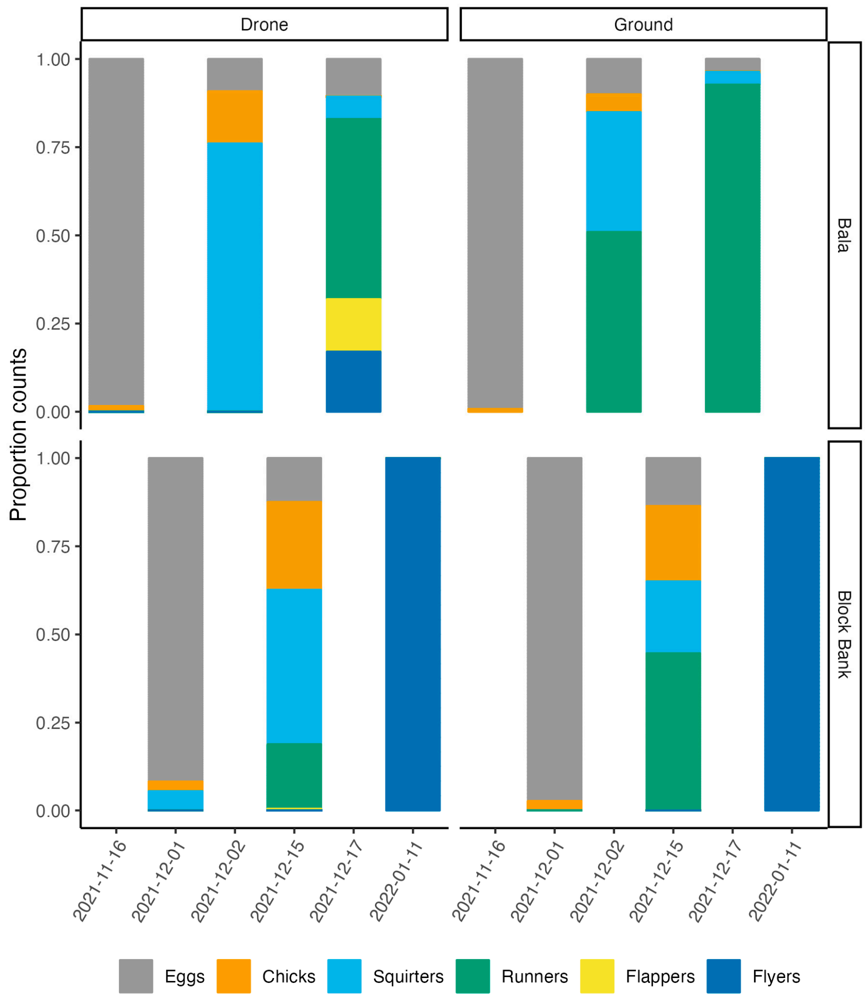


Figure 2. Chick development stage and survey method at two straw-necked ibis breeding rookeries: Bala rookery on the lower Murrumbidgee River and Block Bank rookery on the Lachlan River from 16 November 2021 to 11 January 2022.

Similarly, the mean numbers of chicks at each nest clump (χ^2 (1, N = 66) = 0.73, p = 0.394), squirters at each nest clump (χ^2 (1, N = 66) = 0.74, p = 0.391), flappers (χ^2 (1, N = 41) = 0.16, p = 0.687) and flyers (χ^2 (1, N = 41) = 2.88, p = 0.08) did not significantly differ between survey types. Runner counts, however, were significantly different between survey methods, higher in ground counts than in drone counts (χ^2 (1, N = 59) = 10.5, p = 0.001).

Differences in mean counts per nest clump (accounting for the number of nests) between the drone imagery and ground-based counts were more pronounced at different developmental stages (Figure 3), with the largest differences occurring from the runner stage onward, when the young are highly mobile.

When calculating reproductive success using drone-derived or ground-based data final, the estimates were similar. Final ground-based reproductive estimates were higher for both rookeries at 21% at the Bala rookery and 32% at the Block Bank, compared to 17% and 19%, respectively, in the drone surveys (Figure 4). The difference between the two methods was smaller at the Bala rookery (±5%) than at the Block Bank (±13%) (Figure 4).

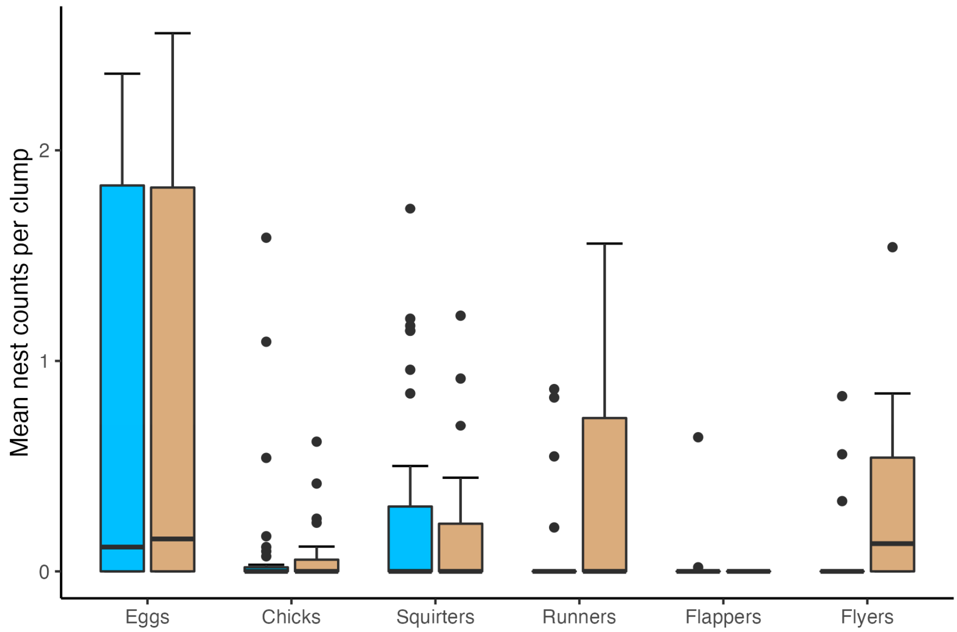


Figure 3. Mean count of offspring per nest across all nest clumps in two breeding rookeries: Bala rookery on the lower Murrumbidgee River and Block Bank on the Lachlan River, as surveyed using two techniques: drone surveys (blue) and ground surveys (brown), counting development stages of chicks from eggs to flyers from November 2021 to January 2022.

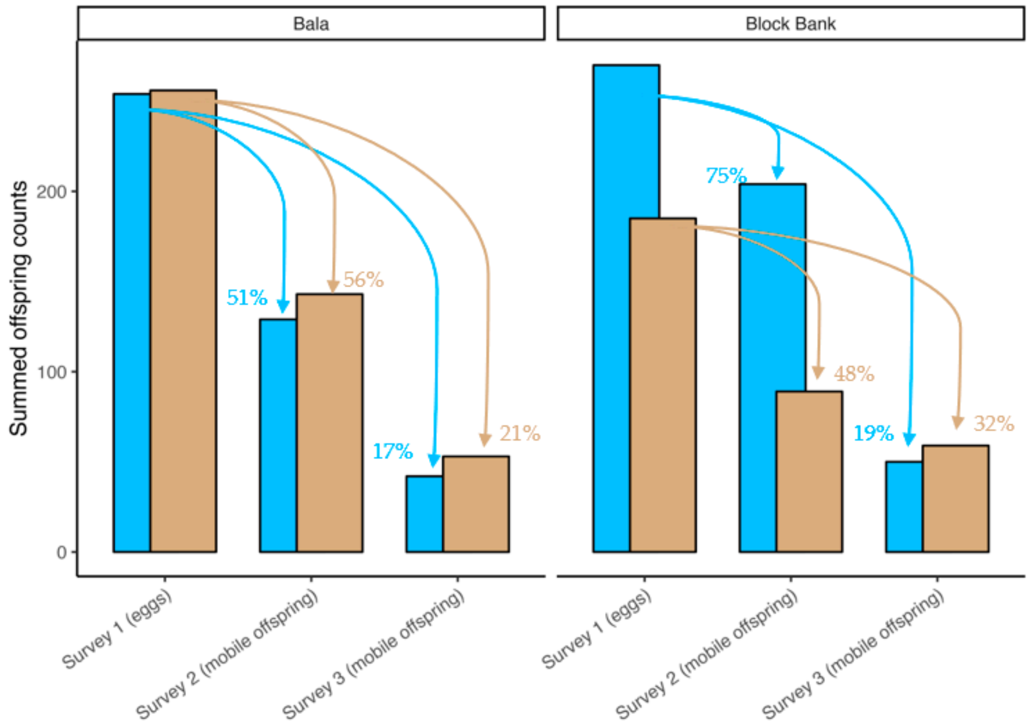


Figure 4. Reproductive success as a percentage (number of young/number of eggs laid) for straw-necked ibis nests estimated based on drone (blue) and ground-based (brown) surveys at two rookeries: Bala rookery on the lower Murrumbidgee River and Block Bank on the Lachlan River from November 2021 to January 2022.

4. Discussion

The measurement of nesting metrics such as numbers of nests, eggs, chicks, etc., associated with large waterbird rookeries comes with many challenges; the most difficult challenge is often related to the expanse and accessibility. Consequently, the use of drones to survey rookeries has become a natural next step in the development of survey techniques [9]. The ability of drones to collect similar data to traditional ground surveys, however, has been debated [33] and is an area of research that has required further exploration [10]. Our study had the advantage of obtaining both ground and drone data over the same nesting areas in the same survey, allowing us to directly compare the collected counts in both methods. This work further highlights the utility of drones in monitoring waterbird breeding rookeries. However, there are key differences between the survey techniques that suggest both have their unique challenges and advantages.

Perhaps the most significant advantage of the use of drones in waterbird rookeries is the ability to access them from afar. Many wading waterbird species are dependent on inundation regimes to breed and require nests to be built over water [34,35]. Further, they can be sensitive to human disturbance [36], and as a result of a combination of these requirements, they are often found in remote wetland landscapes. This is particularly apparent in Australia, where many major waterbird breeding colonies are located in large floodplain wetlands in the arid and semi-arid zones of Australia [37,38]. Further, their vegetation requirements for nesting often make their nests difficult to see into (particularly tree nesters) or difficult to approach when limited by dense shrubbery [29,39]. As such, drones are a logical approach to gain visual access into these difficult areas.

When aiming to capture information similar to that of ground surveys, however, drones must be flown at low altitudes (~15 m above nests, camera dependant) to obtain the necessary resolution needed to accurately identify and count eggs and determine chick development stages. As drone camera technology improves, flights can be higher above nests. Drone flights over colonial waterbird rookeries are, by definition, in areas of high bird density. This poses a risk to the birds and the drone and requires the drone pilot to have very clear sight of the drone to avoid collisions with birds in the air. The research on drone impacts on birds and other wildlife is growing, with overall low evidence of disturbance to birds [12,40], even when flying at altitudes as low as 12 m [41] and up to a 4 m distance from the birds [42]. This does, however, come with caveats, as some species, particularly some seabirds and swifts, appear to be more sensitive to drones [26,27,43,44]. Amongst waterfowl, some species show more sensitivity to drones than others, but overall behaviour is largely unaffected [45]. Smaller drones that produce less noise have been shown to result in even lower levels of disturbance to wildlife than larger drones [46]. Despite the minimal disturbance of drones to many species of birds, researchers looking to use drones should first check the species-specific literature, watch carefully for signs of disturbance and monitor flights closely to avoid impacts. As such, in many cases, an observer must still be present in the rookery, negating the distance advantage of the drone when the goal is to calculate reproductive success.

An advantage of using drones is the ability to collect large amounts of data in a short amount of time, particularly when flying directly from nest clump to nest clump. The bird's-eye view of the imagery facilitates the counting of a greater number of nests within the same survey area, particular in areas with dense nesting [47]. Ground-based surveys cover fewer nest clumps due to the difficulties in moving through wetlands and detectability. This was demonstrated in our nest count result at the Block Bank rookery (148 nests captured by the drone vs. 93 in the ground survey). This is particularly important when wanting to increase the number of data points to estimate accurate numbers of eggs for clutch size estimates, or even to assess the number of nests per clump. The ability to see into the areas of the rookery with a drone that are difficult to access can reduce sampling bias, which naturally arises as surveyed nests can be biased toward those that are easily accessible. These nests may be misrepresentations of the entire rookery due to other factors such as higher levels of predation or greater exposure to adverse weather [48,49].

A common difficulty in surveying ibis nests is the mobility of chicks once they reach the “runner” stage, when they are approximately 31–35 days old. At this point, chicks flee, hide in the vegetation or dive into the water when human observers approach, making counts at this stage very difficult, inaccurate and variable between observers. This issue is highlighted in our ground count data, with Bala ground counts having much higher runner proportions compared to the drone surveys (Figure 2), resulting in overall elevated mean runner numbers (Figure 3) and significant differences between survey types. These ground counts outnumber the previous development stages of chicks and squirters, so they are likely to be an overestimate (Figure 3). This likely contributed to the higher success rates in the ground surveys (Figure 4). The drone has an advantage at this development stage in the rookery and can help obtain more accurate counts as runner stage chicks are less likely to flee as the pilot can remain at a greater distance from the nest clump while keeping the drone within visual line of sight. In this approach, chicks are not alerted to an observer’s presence and remain in their nests or nest clump. The drone-obtained photographs of a nest clump is a fixed record in time, allowing for comparisons of observer counts and reducing the variation between observers who must make a rapid count before chicks flee. These images can be assessed at a later date. Note that the analyses of images adds time to the data acquisition process.

Once chicks reach the flyer stage, both ground observers and drone surveys face the same challenges; neither can approach the nest clump without the flyer-stage chicks taking flight. Knowing this in advance can allow observers to perform counts of the nest clump from a distance (perhaps through binoculars if there is clear line of sight), avoiding getting too close and alarming the birds. An alternative method with the drone is to approach the nest clumps with the camera at a 45-degree angle, taking photos of the clump upon approach. In future surveys, a drone could be flown much higher during the flyer stage to reduce the risk of alarming the birds while still capturing useful images as the chicks are bigger and easier to identify at this age. It is clear, therefore, that at the flyer stage, methods must be altered for both the ground and drone counts to be accurate. Regardless of the survey method, assessing breeding success in colonies with highly mobile chicks is difficult and will likely be plagued with low levels of precision.

An advantage of ground-based surveys is the ability of observers to use chick behaviour and movement as a way of determining the ages of the young. For example, chicks at the “flapper” stage are called so because they naturally start stretching and flapping their wings (Table 1). These behavioural changes and motions cannot be seen in a still image collected by a drone, which can lead to the assignation of different age groups between the drone and ground surveys (Figure 3). Such differences can be seen in the inconsistencies between the mean counts across the drone and ground surveys for the squirter and runner age groups (Figure 3). One potential rectification to this issue is to collect video above each of the survey clumps, rather than still images. If a drone was to hover above a clump while recording 30 s of video, this may reduce the inconsistencies between chick development stages observed in the drone data and ground data (Figure 3).

Another important component of ground surveys is the ability of observers to record data on a range of other factors while in the rookery, for example, evidence of disease (behavioural symptoms, e.g., limber neck, lethargy), and predation (destroyed eggs, dead chicks), which are all important predictors of reproductive success [50,51]. These human-derived observations of a rookery’s condition cannot be easily replaced with a drone and are often very valuable additions to the holistic interpretation of the rookery.

Our work has described and demonstrated the differences in nest metrics derived from drone and ground-based surveys. Each method has unique advantages, and the methods do produce different success estimates (Figure 4) that require different interpretations and analyses of the data. The bird's-eye view of the drone significantly increased the detection rates of individuals and provided a permanent record in time, but it does not negate the need for a human observer to be present in the rookery, who can assess conditions using other senses. We believe that both survey methods make valuable contributions to waterbird monitoring and neither can totally eliminate the need of the other.

5. Conclusions

Our study directly compared ground and drone surveys conducted simultaneously over the same breeding areas of large waterbird rookeries. Drones enabled rapid data collection and reduced observer bias, particularly during the "runner" stage when ibis chicks are highly mobile. However, challenges arise when flying at low altitudes within densely populated rookeries.

Ground surveys provide valuable contextual observations and allow for the assessment of additional factors such as water variables, disease symptoms and evidence of predation. They also offer the ability to determine the age chicks based on behavioural cues, which may be challenging to capture with drones.

In conclusion, both drone and ground surveys offer unique insights into waterbird nesting dynamics, and integrating both methods is ideal for comprehensive waterbird monitoring and conservation efforts.

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Data Availability Statement: Data are contained within the article.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Figure A1. Example annotation of nest numbers in drone imagery at the Bala waterbird breeding rookery in a single nest clump.

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