A protocol for using drones to assist monitoring of large breeding bird colonies

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Abstract

Drones are rapidly becoming part of environmental monitoring and management applications. They provide an opportunity to improve a number of activities related to monitoring population dynamics of aggregations of wildlife. Bird surveys using drones have attracted particular attention, with a range of potential metrics able to be derived from high resolution drone imagery. Whilst a number of papers have shown that drone-based data can be used to effectively and accurately count and monitor features in bird colonies, the use of drone-derived data in real management and monitoring applications remains rare. This is in part due to a lack of clear guidelines as to the capability of drones and how to plan and successfully execute flights, but also due to a lack of information pertaining to specific target species and related contextual and environmental considerations. In this paper we outline a protocol for using drones to assist in the monitoring of colonies of breeding colonial waterbirds. We base the protocol on experience carrying out drone-based surveys of several colonies ranging in population from ~1000 to ~250,000 individuals. These are among the largest colonies ever surveyed via drone. We provide end-to-end guidelines, including detectability, flight planning and execution, on-ground data collection, image processing and target feature counting.

Introduction

Population dynamics are a key indicator of the magnitude of impacts on nature, and are increasingly used for assessing the efficacy of conservation and rehabilitation actions (Kushlan 1993, Frederick et al. 2009, Kingsford and Porter 2009). Waterbird populations are often of particular interest, as they are intricately linked to the status and health of wetlands and their surrounding catchments (Kingsford 1999). A range of metrics are used to assess population dynamics, including direct measures of abundance and vital rates, such as survival, recruitment and population growth (Brandis et al. 2011). In colonially nesting populations, understanding abundance and recruitment dynamics is particularly important to understand the varying influence of habitat availability, flood regimes, predation and environmental conditions. Data collection at appropriate spatial and temporal scale is critical for appropriately monitoring colony status, but also to understand the influence of biotic and abiotic drivers on population status (Murray et al. 2017).

For large waterbird colonies, ground surveys alone may be unable to achieve comprehensive census of a colony. In these cases, monitoring breeding waterbird colonies usually involves aerial surveys (Kingsford and Porter 2009, Buckland et al. 2012, Chabot and Bird 2015). Typically, aerial surveys are conducted with observers estimating the number individuals from an aircraft or via counting from remotely sensed images taken from an aircraft. These methods have been shown to be effective for accurately estimating populations or the number of nests in a colony (Trathan 2004, Chabot and Bird 2015, Lyons et al. 2018a). However, detailed information about nesting status and reproductive success requires higher spatial and temporal resolution data that can typically only be measured from repeated on-ground surveys or in situ cameras (Brandis et al. 2014).

The increasing use of drones (or unmanned aerial vehicles) for ecological and environmental monitoring (Chabot and Bird 2015) has seen a commensurate increase in their use for counting individuals and nests in bird colonies, across a range of species and colony sizes (Chabot and Francis 2016). The research surrounding these applications has mainly focused on ethical guidelines (Vas et al. 2015), wildlife interactions (Lyons et al. 2018a, Weimerskirch et al. 2018) and methods for both manual and automated detection (Trathan 2004, Chabot and Francis 2016, Lyons et al. 2019). Drones offer very high spatial resolution data, which has led to research on the use of drone-acquired imagery to monitor more specific biological metrics like nesting status (Weissensteiner et al. 2015) and nesting success (Sarda-Palomera et al. 2017). However, studies investigating limitations of drone-based surveys relative to on-ground or in situ data have highlighted the critical importance of considering appropriate planning (Callaghan et al. 2018).

In this paper we outline a protocol for using drones to assist in monitoring large aggregations of wildlife, focusing on colonial waterbirds. More general guidelines to using drones for designing ecological surveys are available (e.g. Baxter & Hamilton 2018), but this paper focuses on bird colonies, drawing on our experience surveying several large breeding colonies with drones (ranging from ~15,000–100,000 breeding pairs; (Lyons et al. 2018a)), along with long-term experience monitoring nesting success (Brandis et al. 2011, Brandis et al. 2014). We provide end-to-end guidelines, to ensure that flight planning, in situ data collection and image processing are collected to promote the ethical use of drones while maximising the value of remotely-collected data for monitoring population dynamics.

Case study colonies

In this paper we draw on previous surveys of six breeding waterbird colonies, primarily composed of Straw-necked Ibis (*Threskiornis spinicollis*). At the colonies there were notable abundances (~500–2000) of Australian White Ibis (*T. moluccus*) and Glossy Ibis (*Plegadis falcinellus*), along with low numbers (<500) of other waterbird species (e.g. ducks, spoonbills, egrets). Ibis typically build their nests from trampled vegetation, which in New South Wales is usually lignum (*Duma florulenta*) and Common Reed (*Phragmites australis*). Nests are typically up to 1 m above ground level or water level. Individuals may nest in isolation, but more commonly they form large clumps of irregularly shaped nests consisting of up to 100–200 nests. The colonies we surveyed ranged in size from several hundred individuals up to about 200,000–250,000 individuals, with highly variable nest densities. Table 1 provides additional detail about each of the colonies.

A protocol for drone-assisted monitoring

Baxter & Hamilton (2018) outline a useful set of considerations for a drone-based monitoring exercise relating to survey objectives, detectability and ecological context. We provide a detailed protocol that examines these considerations in context of large breeding colonial waterbird colonies, including detectability within an ecological context, potential bird behaviour, executing drone flights, on-ground data collection, image processing and options for detection of target features.

Ecological context and detectability

The primary motivation in monitoring our case study colonies was to count nests. Aside from not being the primary ecological indicator of interest, explicitly counting individuals for large colonies (i.e. > 10–20,000) of waterbirds may not realistic. In our case, many thousands of birds were mobile at any one time making it impossible to ensure individuals were only photographed once. For example, at the Merrimajeel colony, we estimate well over 10,000 birds were mobile at one time. Notwithstanding this, the same method we use here could be used to count individuals if birds in the colony were stationary, or at least much less mobile. This highlights the critical importance of considering detectability and ecological context at the very early stages of planning (Baxter & Hamilton 2018).

Bird behaviour considerations

A key consideration of flight planning must include the behaviour and status of the target species, the presence of other fauna species in the survey area, and whether there are existing any related research, guidelines or licensing requirements requiring compliance. Generalised guidelines (e.g. (Vas et al. 2015)) are available but, increasingly, more specific studies have shown that that interactions between drones and fauna are complex, and may be specific to species and time of year (Hollings et al. 2018). Key considerations should include whether the species present are i) territorial or breeding (including stage of breeding), ii) sensitive to disturbance iii) are listed on or have any relevant conservation status, and iv) whether there are predatory birds (i.e. raptors, which are very common at breeding colonies) present. (Lyons et al. 2018a) provides some guidance on avoiding negative interactions with territorial birds and raptors.

The effect of the drone on the target species should be specifically manage during flight. In the absence of existing experience, we recommend a precautionary routine to first determine the level of disturbance to both birds in flight and on-ground (particularly those on-nest). This involves beginning a flight an appropriate distance away from target birds (guided by literature review, or at least 100 m in the first instance), ascending to an altitude unlikely to cause distress (we suggest at least 100 m), and sequentially reducing flying height down to an altitude of ~10 m, while monitoring bird behaviour (Lyons et al. 2018a, Weimerskirch et al. 2018). If users have no direct field experience in monitoring animal behaviour, a literature review should be used to become familiar with potential behavioural signs of adverse reactions. These initial test flights should be recorded either by an observer or by in situ cameras. We provide an annotated video that demonstrates such a procedure (https://youtu.be/86cgvCCcNto), detailing the reactions of the nesting birds directly under the drone and the adjacent nest clumps. Figure 1 shows a summarised version of this sequence. If the level of disturbance is deemed to be potentially dangerous (e.g. collisions likely, birds leaving their nests for too long) then this data should be reviewed before continuing with drone surveys.

Drone flight execution

The described animal interaction planning is relevant to both multi-rotor and fixed-wing drone platforms. The primary motivation for choice of platform will usually be environmental factors, combined with the extent of the colony to be monitored and the desired sensor payload. Waterbird colonies are often in flooded environments, which may limit choice to multi-rotor platforms. In our case, a safe landing site for a fixed-wing platform was not available within a safe flying distance to the colonies, so all surveys were performed with multi-rotor drones. We used the *DJI Phantom 3* and *4 Professional* models.

Typically, we used an amphibious vehicle as a take-off surface and performed catch-landings, but occasionally small patches of dry land were available for normal take-off and landing. For reference, we provide a video of a take-off from the amphibious vehicle (https://youtu.be/tLpUiSFvGtI). Fixed-wing drones would be preferable for surveying large colonies due to their extended battery life and range, but cheap, light weight, multi-rotor drones (e.g. *DJI Phantom* and *3DR Solo* families) are quite capable of surveying large (i.e. km's) colonies provided access is possible. For the colonies we surveyed, with varying weather and environmental conditions, an individual flight was able to survey ~10–40 Ha (0.1–0.4 km^2).

Since the primary motivation of using drones is often to generate very high resolution imagery (Chabot and Francis 2016), appropriate flight patterns must be used to collect image data. The underlying premise for generating seamless image mosaics (typically via structure-from-motion methods) is detection of the same features in multiple overlapping images (see *Image Processing* below). This is achieved by flying many parallel flight lines at a fixed altitude, where a proportion of each photo overlaps at the edges. General guidelines suggest around 70% forward and horizontal overlap, and in topographically simple environments like waterbird colonies, 70% will be sufficient (Lyons et al. 2018b). These parameters can be programmed into flight planning software for most drone platforms, or experienced pilots can also manually fly these flight lines. The ability to take manual control of flight should always be maintained when flying within a breeding bird colony, allowing for the operator to avoid unexpected interactions. Another specific note for waterbird colonies is that large water bodies can disrupt a drone's compass and disable GPS-assisted flight (this happened occasionally in our experience), so pilots should be able to maintain safe flight in that scenario.

The final spatial resolution of image mosaic products depends on camera specifications and flying height, but as a general guideline, flying heights of ~50–120 m will generate imagery with a pixel size of ~2–5 cm. Pixel size should be considered in context of the interaction between the targets needing identification and their physical appearance and structure. Baxter

& Hamilton (2018) provide a specific decision tree protocol to guide flying height and speed, which should also be considered in context of the target and required detection probability. If multi-temporal imagery and spatially explicit change detection is required, then users should consider gathering higher accuracy GPS coordinates (e.g. differential or RTK) for ground control points (sensu (James and Robson 2014)). These can be unambiguous existing in situ features or users can deploy artificial ground control points.

On-ground data collection

In situ data collection is a critical component of monitoring breeding colonies in the context of monitoring nesting success and recruitment (Brandis et al. 2011, Brandis et al. 2014). Therefore, when using drones to assist in monitoring, there are two key purposes for collecting additional on-ground data. Firstly, spatially explicit ground counts can be used for determining the accuracy of image derived counts (e.g. individuals, nests) when targets are ambiguous in the imagery. Secondly, on-ground measures of nesting and breeding success are critical for validation of the corresponding colony wild measures being derived from imagery. Detailed description of these measures can be found in Brandis et al. (2014). If standard accuracy GPS (i.e. 5–10 m) is being used to record the location of in situ data or photos, then care must be taken to ensure these data can be accurately linked back to the correct features (e.g. nest clump) in the resulting drone imagery. These considerations can be more broadly thought of in context of ground-truth validation, in which case both traditional and more modern accuracy assessment metrics can be employed (Lyons et al. 2018c).

Image processing

Typically, waterbird colonies will cover areas vastly bigger than individual photos, which necessitates capturing many (100's – 1000's) photos and combining them into high resolution image mosaics. The most common method for achieving this is structure-from-motion photogrammetry, which can be performed using a variety of open source or proprietary software packages (Turner et al. 2012, Westoby et al. 2012). We used the proprietary software Pix4DMapper (v4+, Pix4D SA). The processing results in a 3D point cloud, a digital surface model, and an orthorectified image mosaic. As our survey objectives were to develop colony-wide estimates of breeding bird nest abundance, we were only concerned with using the image mosaics. We generally used a flying height of ~100 m, which resulted in imagery with a pixel size of ~3 cm. Figure 2 shows an example of some imagery from some example colonies.

Counting target features within colonies

For large colonies, manual counting of individuals or other features (e.g. nests) remains popular, as automated counting methods are still in their infancy with respect to being generally applicable by managers and non-technical scientists (Chabot and Francis 2016, Hollings et al. 2018). This is largely because most automated methods to date have been demonstrated on either small congregations of birds of one species (e.g. < 5,000 individuals) or in relatively simple, homogenous environments (Hollings et al. 2018). Aside from technical barriers, there is a disconnect between the ecological motivations for image analysis and the literature on technical development – the literature focuses on counting relatively small groups of individuals, which typically do not cross the cost benefit threshold for drone-based automated counting (Chabot and Francis 2016). Nevertheless, automated methods are continuously improving and will certainly become more prevalent and popular in the near future.

In our case, we used a systematic method of dividing the imagery into grids of 50 m or 100 m quadrats (depending on colony density) and manually counted the number of nests within each grid. We performed the counting within a GIS environment, developing a vector file (i.e. shapefile) and recording a point for every nest location with reference to the georeferenced image mosaic, using a touch screen tablet. Using the GPS tagged in situ data described above, we calculated the accuracy of the manual counting method.

Manual counting was not totally accurate for all colonies (Table 1). This is because large breeding waterbird colonies can be visually and structurally complex, and even in very high-resolution drone imagery, it can be difficult to delineate nests. Nests can be highly variable in their physical appearance (Fig. 1), they can be: round or irregular; isolated or in large clumps (100+ nests); made from green or brown vegetation, covered in white guano; unoccupied or occupied by adults, chicks or eggs. These properties make available automated methods quite difficult to implement, however, we are close to providing a semi-automated method able to be implemented across all our colonies, with similar comparable accuracy to the manual counting method (Lyons et al. *submitted*).

Some literature has begun to take these monitoring activities further by inferring other ecological indicators like nesting status (Weissensteiner et al. 2015) and nesting success (Sarda-Palomera et al. 2017) directly from drone imagery. We did not pursue this line of monitoring for the colonies we surveyed, but have offered advice elsewhere about considerations in this context (Chabot and Bird 2015).

Concluding remarks

Drones are radically advancing the spatial and temporal resolution of ecological data, and the methods with which field studies are being conducted (e.g., Lyons et al. 2018b). It's important to recognise drones as part of the toolkit for monitoring and avoid over-selling their capacity, which can inadvertently motivate premature shifts in resources or funding. An important consideration for using drones to assist in ecological and environmental monitoring are associated start-up costs. Much literature references the increasing affordability of drones, but there is more to consider than just hardware costs. For example, animal ethics approvals, pilot training and certification, weather delays, processing hardware and software costs, and lag-time in reporting monitoring results are all considerations that are frequently neglected. In our case, a number of factors, including colony size, location, monitoring requirements, equipment and expertise availability, and ethics considerations were all considered in our use of drones. Nevertheless, we provide a few considerations when determining the cost-effectiveness of drone-based monitoring.

Drone-based monitoring is unlikely to be cost-effective when:

- Only a one-off survey is required and/or the colony is less than about 2,000 –3,000 individuals, and drone related costs (e.g. drone, pilot, ethics, image-processing) are not available in-kind
- The time-period in which monitoring is required is likely to have inhibitory weather (i.e. high winds, frequent rainfall)
- Study species don't allow for it. For example: black cormorants or penguins among rocks; communally nesting species like hammerkop; threatened species where any disturbance has been banned; cryptic species like shorebirds in tundra; and very sensitive species with huge alert distances (e.g. roosting shorebirds).

- Experts are available and their error has been quantified (people can do massive counts quite effectively in the right circumstances, e.g. Kingsford & Porter 2009)
- Issues around detectability can be solved with the use of appropriate statistical procedures
- Good vantage points can be found to use something like a gigapixel camera or terrestrial laser scanner (e.g. on top of a cliff, like at Murawai gannet colony in NZ)
- Species require some type of active searching
- Nest success measures, such as number of eggs, fledglings cannot be determined from above.
- The successful fledging of a nestling requires direct observation (e.g. for precocious birds)

Drone-based monitoring should be cost-effective when:

- The issues around detectability discussed in this paper suggest drone-based surveys might be more accurate than in situ monitoring
- Multiple, accurate repeat surveys are required
- Large areas of the colony are inaccessible by foot or vehicle
- The indicators that require quantification are difficult or impossible to observe on-ground from a distance or from other higher elevation aerial imagery (e.g. nests)

In this paper we have outlined the relative advantages and potential pitfalls to the use of drones, and shown that they are a useful additional tool in an ecologists tool kit. They are likely to be best deployed when careful consideration is given to the application. We hope this manuscript and our protocol supports that decision making process for colonial waterbird monitoring. Drone use can be conceptualised by a technology hype cycle (e.g. Gartner hype cycle (Gartner 2018)) – an early *peak of inflated expectations* followed by *a trough of disillusionment* when confronted with the realities of using drones to survey large and complex ecological features. This is reflected in the literature by studies that highlight the disconnect between drone-based methods and their use in ecological management and monitoring applications (Chabot and Francis 2016, Hollings et al. 2018). On the bright side, the hype cycle ends with the *slope of enlightenment* and *plateau of productivity* where there is mainstream adoption of drone-based monitoring, and the cost-effectiveness threshold is much lower than at present.

Tables & Figures

Table 1. Location and information on the surveyed bird colonies. All bird colonies were located within New South Wales, Australia. Nests were manually counted from the drone-based imagery. Ground-based nest count error is based on in situ counts cross-referenced with manual nest counts from drone imagery. *From Lyons et al. (2018a) – the estimated number of birds and colony extent incorporates site-specific information.

Location	**Date**	**Manual nest count**	**Manual nest count error**	**Estimated number of birds***	**Colony extent (km^2)**	**Drone survey (km^2)**
Lachlan River (Merrimajeel)	Oct 2016	101,360	±6.1%	200-250,000	1	1.9
Macquarie Marshes (Zoo Paddock)	Nov 2016	21,210	±8.8%	40-50,000	1.5	2
Murrumbidgee River (Eulimbah)	Nov 2016	14,994	±8.4%	30-40,000	0.4	0.5
Lachlan River (Block Bank)	Sep 2017	8,225	±12.1%	15-20,000	0.3	0.8
Barmah Millewa Forest	Dec 2016	1,645	N/A	2-3,000	0.6	3
Barmah Millewa Forest	Dec 2017	260	N/A	<1,000	1.1	3

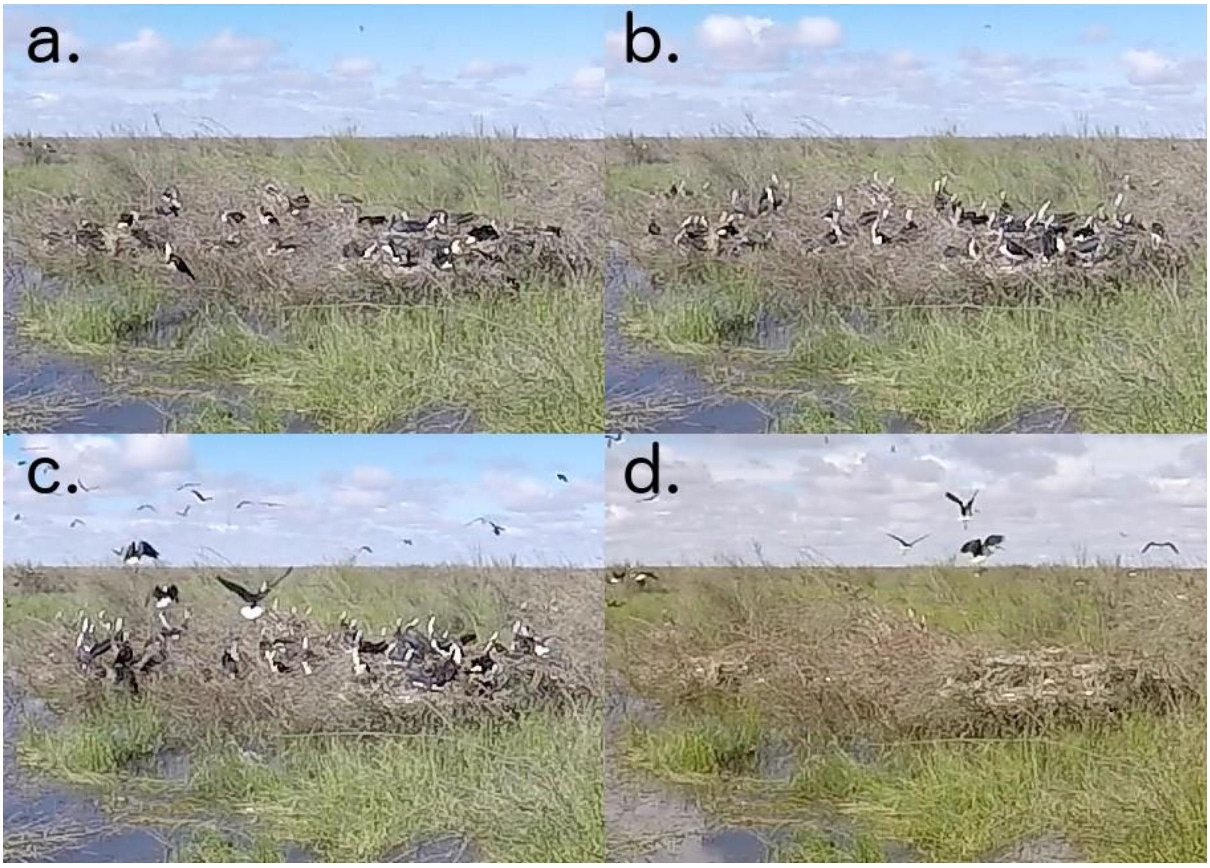

Figure 1. Images of a group of Straw-necked Ibis on nests in the Merrimajeel colony, Lower Lachlan River,New South Wales. Images captured using a remote camera trap. The nests shown are ~15 m away from another group of nests over which a quad-copter drone was being flown. (a) shows a typical state pre-disturbance of any kind; (b) vigilant behaviour when the drone was lowered to ~20 m above the adjacent nests, when birds from the nests under the drone; (c) more highly vigilant behaviour when the drone was lowered to ~10 m above the adjacent nests; and (d) birds flushed from nests as the remote camera was retrieved on foot. Figure adapted from Lyons et al. (2018a).


a.
b.
c.
d.
e.
f.
g.
h.

Figure 2. Example drone imagery showing the variation in nest types and environments across four Ibis colonies surveyed: **a & b –** Merrimajeel; **c & d** – Zoo Paddock; **e & f –** Eulimbah; **g & h** – Block Bank. Table 1 gives location and size details for each of these colonies.

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