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Using high-definition aerial photography to search in 3D for malleefowl mounds is a cost-effective alternative to ground searches

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Abstract. The threatened malleefowl (*Leipoa ocellata*) constructs a large (often >3 m) incubator mound (nest) that is considered a useful proxy for surveying its presence and abundance in the context of an environmental impact assessment. Here we report on the effectiveness and relative cost of using high-definition aerial photography to search in 3D for malleefowl mounds by comparing results to those of earlier ground-based searches. High-definition colour aerial photography was taken of an area of ~7014 ha and searched in 3D for malleefowl mounds. All 24 active (i.e. in use) malleefowl mounds known before the examination of aerial photography were detected using the new assessment technique. Of the 108 total mounds (active and inactive) known from earlier on-ground surveys, 94 (87%) were recorded using the new technique. Mounds not detected were all old and weathered, many barely above ground level and some with vegetation growing in the crater. Approximately 6.3% of the identifications considered 'confident' and ~35.0% considered 'potential' based on the aerial photography proved to be false positives. The cost of detecting malleefowl mounds using the interpretation of high-definition 3D colour aerial photography and then subsequently examining these areas on the ground is appreciably cheaper than on-ground grid searches.

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Introduction

Malleefowl (*Leipoa ocellata*) is listed as vulnerable under the national *Environment Protection and Biodiversity Conservation Act 1999* and as Schedule 1 (Fauna that is rare or is likely to become extinct) under the Western Australian (WA) *Wildlife Conservation Act 1950*. The consequence is that the presence of malleefowl in a potential disturbance area should be identified during the environmental impact assessment (EIA). This assessment should indicate the relative abundance and spatial distribution of malleefowl.

Malleefowl are relatively large, mostly terrestrial birds that tend to be sedentary, nesting in the same general area year after year (Frith 1962*a*; Priddel and Wheeler 2003). The density of the birds is generally highest in areas of higher rainfall and on more fertile soils (Frith 1962*a*; Copley and Williams 1995; Benshemesh 2007) and where shrub diversity is greatest (Woinarski 1989). Malleefowl are now primarily found in semiarid and arid shrublands and low woodlands dominated by mallee (*Eucalyptus* sp.) in the more temperate areas (Frith 1962*a*, 1962*b*). Grazed areas generally have lower densities (Frith 1962*a*; Benshemesh 2007).

A sandy or gravelly substrate and abundance of leaf litter are requirements for the construction of the birds' incubator mounds (Fig. 1) (Frith 1959, 1962*a*). Malleefowl excavate a pit or crater, into which they scrape copious amounts of leaf litter during winter. In late winter and early spring, assuming rainfall has been adequate, the birds then cover this leaf litter with soil. The heat from the decomposing organic matter incubates the eggs. This heat, though, can become excessive; therefore the birds will uncover or open the top of the mound to regulate its temperature (Frith 1956). Jones and Goth (2008) indicated that malleefowl mounds were 60–90 cm high and 3.7 m wide; however, there is considerable variability in their size, which is often influenced by how often the mound has been used. Malleefowl frequently use already constructed mounds instead of building a new mound each year (Priddel and Wheeler 2003). Malleefowl that reuse an existing mound tend to incorporate more material from the surrounding area into the existing mound, with the consequence that some of the older mounds are higher than 100 cm and wider than 5 m. Clutch size and the duration of the breeding period (i.e. the period of mound usage) can vary from year to year. Breeding activity is influenced by winter rainfall (Frith 1959) and in the years when winter rainfall is very low, breeding activity can be greatly reduced or even non-existent. Insufficient rain prevents organic matter in the centre of the mound from decomposing at a rate sufficient to generate enough heat to

Fig. 1. A malleefowl mound with a bird on the mound in the typical dense surrounding vegetation.

incubate the eggs (Frith 1956). Density of the canopy cover is an important feature associated with high breeding densities (Frith 1962*a*; Benshemesh 2007) and it is this dense mallee vegetation that can make ground searches for malleefowl mounds difficult.

Existing survey techniques

Because malleefowl are relatively cryptic and mobile, and spend a considerable amount of time during the day on the ground, they can be difficult to find and count, with the consequence that recording active malleefowl mounds in an area is generally used as a proxy for the presence of a current population (Brickhill 1985; Benshemesh and Emison 1996; Priddel and Wheeler 2003, 2005). An 'active mound' is defined here as one that has been used in the previous breeding season or is currently in use, and a 'recently active mound' is one that has been used in the last couple of years. A 'closed' mound is an active mound that has had material raked over the centre crater and internal eggs to form a dome. Active mounds confirm the species' presence in an area, and, as they directly relate to the number of reproductively active birds, provide a rough estimate of the number of local adult malleefowl.

The long-standing practice for finding malleefowl mounds has been to grid search an area. This involves a group of people (typically, 4–10) walking in a line, spaced at a distance so that they can see all of the land between two adjacent searchers. The National Manual for Malleefowl Monitoring (Hopkins, undated) suggested two search procedures: (1) grid searching an area on foot, and (2) aerial surveys. The Commonwealth Government Guidelines (Department of Sustainability Environment Water Population and Communities 2010) recommended that in semi-arid and agricultural areas, searches in suitable habitat for active mounds, tracks and sightings were the best methods of detection. These guidelines also indicate that aerial surveys may be useful in extensive areas of relatively open habitat, and, in arid regions, transect searches for footprints in sandy areas were the most effective.

Alternative methods of searching for malleefowl mounds have been explored. Brickhill (1985) undertook an aerial observation survey using an Aerospatiale Gazelle 341G helicopter flown at ~76 m above ground at ~90 km h^{-1} over 20 800 ha of the Round Hill Nature Reserve in New South Wales and the adjoining land. Search transects were ~400 m apart followed by a similar pattern at right angles. The search area was relatively flat country with mallee growing to 5–6 m high. Most of the surveyed area had been burnt in 1957 and the aerial surveys were undertaken between 1977 and 1984. Four of the nine surveys were flown in August, the time when active mounds are piled high with litter in preparation for breeding and were therefore likely to be more visible. However, Brickhill (1985) concluded that even with a relatively slow flying speed, the ground survey showed that many transects were necessary before half of the mounds were found. Benshemesh and Emison (1996) examined the feasibility of using thermal scanning during aerial surveys of open mounds with subsequent ground-truthing to detect active malleefowl mounds. Four areas were flown in Victoria with sites of 300–500 ha in size. These four areas contained 39 active mounds during the trial. Survey sites were characterised by a relatively thick canopy of mallee and variable understorey of shrubs. A Daedalus 1240/60 thermal scanner mounted in a Queenair aeroplane that flew at ~250 km h^{-1} at an altitude of 305 m was used. The thermal scanning technique recorded 26% of known active mounds. Thompson and Thompson (2008) examined the possible use of a tricamera system (i.e. ultraviolet-sensitive camera, infrared long-wave radiometric camera and a high-resolution digital video camera working in unison) to detect active mounds, but this approach was also limited to mounds that were open during the survey and is therefore not a suitable methodology for searching for malleefowl mounds for the purposes of an EIA, as active mounds could be easily missed when they are closed. A comparison of the effectiveness of on-ground searches, visual searches by helicopter, and use of LiDAR indicated that ground searches were the most reliable (finding 33 of 35 mounds; 94%), followed by LiDAR (6 of 10; 60%), with only 11 of 30 (37%) mounds being found by visually searching from a helicopter (Read *et al.* 2014).

Study objective

The objective of this study was to compare the results of interpreting high-definition 3D aerial-photography with known records of malleefowl mounds and subsequent ground-truthing, and to determine whether this approach was a reliable and cost-effective alternative to on-ground searches.

Methods

Study site

The study area was adjacent to Mt Gibson in mid-west Western Australia, which is ~320 km north-north-east of Perth, and is core habitat for malleefowl. Much of the study site had been searched on multiple occasions and the location of many malleefowl mounds was known (ATA Environmental 2005). This study site therefore provides an opportunity to compare the results from aerial photography with those of previous ground-transect searches.

The study area consisted of woodlands, mallee and sand plain vegetation communities. Bennett Environmental Consulting (2000) identified five woodland communities, four mallee communities, 12 thicket communities and two heath communities in the study area. Typically, the area below the banded ironstone formation, which was central to the study area, was *Acacia* spp. thickets with emergent *Eucalyptus* spp. and *Callitris glaucophylla* (white cypress-pine). The most common eucalypts were *E. loxophleba* (York gum) and *E. brachycorys* (cowcowing mallee), which grew on the flat and along the gullies of the hillsides. *C. glaucophylla* was the dominant tree on the sandy soil but was often associated with *Ecdeicolea monostachya*. Vegetation on the top of the banded ironstone formations varied considerably and the dominant species on the hill slopes were *Allocasuarina acutivalvis*, *Melaleuca nematophylla* (wiry honey-myrtle) and *Grevillea obliquistigma*. Vegetation was particularly dense in some areas on the sand plain, making ground searches for malleefowl mounds slow and often difficult.

On-ground searches

Approximately 4941 ha around a potential mining development was searched in 2004–05. During 8–16 March 2004 a vertebrate fauna survey was undertaken over part of the area, which included incidental searches for malleefowl mounds (ATA Environmental 2005). Then, during 20–24 September 2004 and 13–21 January 2005 eight people grid-searched the area for malleefowl mounds. The distance between each observer varied depending on vegetation density but ranged between 5 and 50 m. Malleefowl mounds in open areas were easily located; however, those in dense vegetation were often cryptic and difficult to see, particularly those that were weathered over a period of many years. The status (i.e. active or inactive) and a GPS location for each malleefowl mound were recorded. Finally, Mount Gibson Iron Ltd, as a condition of its approval to mine, is required to monitor malleefowl mounds on an annual basis (Mount Gibson Mining Ltd and Extension Hill Pty Ltd 2013). 'Known' malleefowl mounds were all mounds that had been recorded by the mining company before our aerial surveys, and from the above-mentioned surveys, other surveys and incidental observations.

Aerial photography

In October 2013, aerial photography images of an area of ~7014 ha were captured using a Microsoft Ultracam D large-format camera mounted in a Shrike Aero Commander 500. A forward overlap of 70% and a side overlap of 60% were used to provide stereo images suitable for searching on a computer. Cross strips were added to the flight paths to aid in determining vertical accuracy. The quality of the images enabled a ground sample distance of 4 cm. This aerial photography was then postprocessed to provide images able to be searched on a computer and then loaded and examined in DTMaster (INPHO). Stereo images were examined using NVIDIA 3D Vision Glasses.

Coverage of on-ground and aerial searches

Small sections of the 4941 ha area searched in 2004–05 and in subsequent years were outside the area covered by the aerial photography (7014 ha) and large parts of the area covered by the aerial photography had not previously been searched on the ground. However, all malleefowl mounds located during previous on-ground searches were within the area searched on the aerial photography. Some malleefowl mounds identified in 2004–05 had subsequently been cleared for mining infrastructure and the mining pit, and therefore no longer exist.

Interpretation of aerial photography

Two of the authors (ST and GT) spent two days examining the aerial photography and developing a search procedure for detecting malleefowl mounds. The locations of known mounds were examined on the images so that a 'search image' of a mound could be developed by the viewers, then selected areas with known mounds were searched to determine whether they could be found. Cues that identified a malleefowl mound included a circular elevated area, small area devoid of vegetation, and different-coloured substrate. This procedure was repeated on multiple occasions using both black and white, and colour aerial photography from various distances above the ground (i.e. scaling).

The protocol adopted involved placing lines that were 40 m apart on the ground and running north–south over the aerial photograph, with the height above the ground adjusted so that these lines were the width of a 23″ (58 cm) computer monitor, providing a scaling of 1 : 80. The aerial images were then systematically moved vertically up or down the screen to search each 40 m-wide strip until the entire area had been searched. These parallel lines ensured that the aerial photography was moved vertically and all areas were searched.

A third person (TB), who was not familiar with the study area nor the location of known malleefowl mounds, was subsequently trained by one of the authors (ST) in what malleefowl mounds looked like and then the entire extent aerial photography was

Table 1. Summary of data to compare on-ground with aerial photography searches

	2004–12	2013
Area surveyed (ha)	4941	7014
No. of mounds recorded	108	274
No. of active mounds recorded in on-ground surveys	24	29
Total no. of 2005–12 known mounds found in the aerial survey		94 (87%)
No. of 'confident' mounds recorded in 2013 aerial survey		207
No. of 'confident' mounds that were actual mounds		194 (93.7%)
No. of 'confident' mounds that were false positives		13 (6.3%)
No. of 'confident' mounds (i.e. actual) previously known		94
No. of 'confident' mounds (i.e. actual) previously unrecorded		100
No. of 'potential' mounds in 2013 aerial survey		123
No. of 'potential' mounds that were actual mounds		80 (65%)
No. of 'potential' mounds that were false positives		43 (35%)
No. of 'potential' mounds previously known		1
No. of 'potential' mounds previously unrecorded		79
Cost per hectare	$21.36	$9.55
Cost per hectare if the aerial photography was prepared, and paid for, for another purpose		$6.99

searched for mounds. All areas identified as possible malleefowl mounds were rated as either 'confident' (i.e. it was a mound) or 'potential' (i.e. it was possibly a mound).

Ground-truthing

Malleefowl mounds known before the 2013 aerial survey had been checked recently (in October/November 2008, January 2010, November 2010, November 2011 and November/December 2012) to determine whether they had been used for breeding purposes (i.e. were active), and so were not checked again following the aerial survey. However, areas designated as a mound based on the aerial photography and not previously recorded were ground-truthed by Mount Gibson mine staff between January and May 2014 and, if found, the mound dimensions were recorded. If there was evidence that a mound had been used for breeding purposes in the previous season, it was deemed to be an 'active' mound.

Cost comparison

The area searched on the ground was different to that searched on the aerial photography, so a direct comparison of the costs for the two areas was not appropriate. To provide a comparable costing, the cost comparison has been done on a per-hectare (ha) basis. All costs were calculated using Terrestrial Ecosystems and Aerometrex normal costing regimes in 2013 Australian dollars. Terrestrial Ecosystems staff undertook the original on-ground searches in 2004–05 and were therefore able to accurately cost this work in 2013 dollars. The costs indicated for the two methods provide an indication of the real cost to a potential client that requires a search of an area for malleefowl mounds in 2013 dollars.

Results

Mounds located by aerial survey

All 24 mounds known to have been recently active, and five additional active mounds not previously recorded in ground surveys were identified in the search of the aerial photographs. Of the 108 total (inactive plus active) mounds known from previous on-ground searches, 94 (87%) were recorded from the aerial photographs (Table 1). The 14 mounds not identified by aerial photography were old and weathered; many were barely above ground level and some had vegetation growing in the crater. The average height of mounds not found in searches of aerial photography was 7.64 cm (s.e. = 1.460, range = 1–20 cm) compared with an average height of 26.27 cm for all mounds measured (s.e. = 1.952, range = 1–110 cm).

Of the 207 mounds recorded as 'confident' during the search of the aerial photography, 94 were previously known and 100 were previously unrecorded; thus 93.7% of the areas recorded as 'confident' mounds were actual mounds and there were 6.3% false positives. Of these 100 unrecorded mounds, 60 were in the area searched before 2013. Most of the false positives were small cleared areas that had a substrate of pebbles or rock in an area surrounded by vegetation; or were piles of sand or organic matter created by machinery. Of the 123 areas recorded as 'potential' mounds, 80 (65%) were actual mounds and 43 (35%) were false positives. Of these 80 records, 49 were in the area searched before 2013.

Aerial photography search protocol

The two days spent developing an effective protocol for searching the aerial photography resulted in a methodology that was demonstrated to be effective. Coloured images were superior to black and white images, and were used to search for mounds. We took a very conservative approach and tended to record false positives instead of possibly failing to record a mound.

Costs

Approximately 100 person-days were spent conducting ground searches for malleefowl mounds in ~4941 ha and it took 90 h to search 7014 ha of aerial photography. The total cost for the aerial photography and the desktop searches of the aerial photography was approximately $47 000. If the aerial photography was flown for another purpose, then the extra cost associated with obtaining the higher-definition aerial photography and searching the aerial photography was reduced to approximately $29 000. If the identified mounds were then ground-truthed by environmental consultants there would be an additional cost of approximately $20 000 to categorise and measure all of the mounds found in the search of the aerial photography. The estimated cost for ground searching the 4941 ha was approximately $105 000 (excluding the cost of food and accommodation, which are paid for by the mine) or $21.36 per hectare in comparison to the maximum of $67 000 or $9.55 per hectare using aerial photography; and if the aerial photography was flown for another purpose, $49 000 or $6.99 per hectare. The cost of preparing reports has been excluded from these costs as these vary based on the intended purpose.

Discussion

In areas where malleefowl are potentially present, there is an expectation by the State and Commonwealth government environmental regulators that their presence and relative abundance will be determined and addressed in the EIA. With the contraction of the geographic distribution of malleefowl over the last century in Western Australia (Parsons *et al.* 2008), they are now mostly found in areas of dense vegetation as this provides the best protection against potential predators, with the red fox (*Vulpes vulpes*) being one of the most significant predators (Priddel and Wheeler 1996; Priddel *et al.* 2007).

Historically, habitat potentially supporting malleefowl has been grid searched by environmental consultants in areas for future development. In relatively open areas, searchers can be up to 50 m apart, but in areas of dense vegetation the distance between searchers can be reduced to 5 m. It is our experience that malleefowl in the mid-west and the goldfields of Western Australia are more likely to be found in areas of dense vegetation, where grid searching can be difficult, time consuming and therefore expensive. Because of the density of the vegetation, searchers are continually protecting their faces and eyes from branches, twigs and leaves as they push their way through the vegetation. Often the head is lowered to force through particular thickets and mounds can be missed in these searches. Unused mounds progressively weather over many years, with very old mounds often being a roughly circular area of bare ground perhaps with a shallow depression in the centre. Old weathered mounds can also support vegetation growth, with the consequence that they are easily missed in searches. In the context of undertaking malleefowl-mound searches to support an EIA, old and long-unused mounds indicate that malleefowl were once present in the area but provide no indication of current use. What is important in the context of an EIA is determining whether malleefowl are currently in the area and their relative abundance. Recording of all active and recently active mounds is therefore the focus and the criterion for a successful survey.

The 3D interpretation of high-definition aerial photography, as shown by this investigation, indicated that all recently active mounds can be recorded, and is therefore suitable for use in surveys to support EIAs. However, ~13% of all mounds were not detected, albeit old and long-unused ones, which is of little concern in an EIA. Malleefowl mounds that are not used will progressively weather, with dispersal or reduction of the volume of soil and likely growth of vegetation in the mound occurring, which reduces mound height and detectability. Even with on-ground searches these very old mounds in the final stages of weathering can be difficult to detect as they are often just slightly raised circular areas that often support vegetation. These areas are therefore very difficult to detect in aerial photography when the view of the substrate is from above, and the cues that are used for finding a malleefowl mound in the interpretation of the aerial photography (e.g. circular elevated area, small area devoid of vegetation, different coloured substrate) are significantly diminished.

A drawback of this approach is the number of false positives recorded. Approximately 6.3% of areas that were rated as 'confident', and 35% rated as 'potential' mounds, were found not to be mounds when the area was examined on the ground. The 3D Vision Glasses exaggerate height in stereo photographic images. Malleefowl mounds are elevated, often in small areas devoid of vegetation and the surface soil is often a slightly different colour to the surrounding area. The person searching the aerial photographs has the option of enlarging an area to examine an area in more detail. Thirteen false positive 'confident' areas were mostly small cleared areas that had a substrate of pebbles or rock surrounded by vegetation, or piles of sand/organic matter created by machinery or ants. There is a cost associated with false positives, as all areas identified in the aerial photography as a potential mound must be ground-truthed. In this study a very conservative approach was taken to identifying malleefowl mounds so that we recorded as many mounds as possible. A less conservative approach, and thus fewer false positives, may be appropriate if the intent of the survey was to identify recently active malleefowl mounds with less concern about old and long-unused mounds.

The search of the aerial photography identified malleefowl mounds previously not detected in the area searched before 2013, indicating the value of this alternative approach. Ground truthing is necessary both to confirm an actual mound and determine whether it has been recently used. The use of aerial photography to identify malleefowl mounds in this research was more reliable (i.e. recorded 100% of active mounds) than ground searches (94%), LiDAR (60%) and visual searches undertaken from a helicopter (37%) on the Eyre Peninsula (Read *et al.* 2014).

Conclusion

Searching aerial photography in 3D is a more reliable and cost-effective method for locating recently active malleefowl mounds in mallee and sand plain vegetation communities in the mid-west of Western Australia than on-ground grid searches. If there were another purpose for preparing the aerial photography and this can be used to offset the cost, then the cost of interpreting aerial photography for searching for malleefowl mounds would be appreciably cheaper than on-the-ground grid searching. Because of the cost of aircraft mobilisation and postdata analysis, there are economies of scale that can further reduce the costs. The number of mounds in a search area will also affect the cost-effectiveness as it determines the cost of ground-truthing. As high-definition aerial photography is now available because of improved cameras and larger computing capacity, this approach is likely to get cheaper once it becomes more commonly used. The use of drones to fly areas is also likely to be a cost-saving possibility in the future when the size and weight of cameras is further reduced. However, before this approach is more widely adopted, it would be useful for it to be implemented in other habitats where malleefowl mounds are known (e.g. parts of the goldfields, sandy desert or remnant plots in the agricultural area).

Implications for management

Land developers, land managers, mining companies and the environmental consulting industry are always endeavouring to undertake tasks in a more cost-effective manner. The technique outlined here achieves that whilst increasing the accuracy of malleefowl mound surveys. This technique also provides a verifiable record of mounds that is able to be examined by a third party (e.g. government environmental assessors, in EIA assessments) and is therefore a more trustworthy methodology. The technique is also applicable for large and remote areas; for example, if a large section of the Great Victoria Desert were to be surveyed for malleefowl, then this could be the most cost-effective and appropriate method. Aerial photography also provides a useful long-term record of mound locations and the surrounding habitat (e.g. vegetation density, recent burns, etc), which may have other applications.

It is also possible that searching high-definition aerial photography in 3D has applications in surveying for other fauna. For example, this technique may be applicable to detect the mounds of brush turkeys (*Alectura lathami*) and pebble mound-mice (*Pseudomys chapmani*), warrens of burrowing bettongs (*Bettongia lesueur*) and wombats (*Vombatus* sp.), and perhaps the burrows of bilbies (*Macrotis lagotis*).

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