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New culling technique provides localised reductions in interspecific aggression and density of Noisy Miners (*Manorina melanocephala*) without recolonisation

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ABSTRACT

The Noisy Miner (*Manorina melanocephala*) is a native Australian honeyeater that reduces avian biodiversity at sites it occupies through aggressive defence. Culling to remove miners has had limited success in some areas due to rapid recolonisation. This experiment trialled ‘doughnut culls’ as a new approach to reduce Noisy Miner aggression within a central area of colonies, by removing up to half the miners present within a 50 m radius of an identified central location in 29 different colonies on the New England Tablelands of NSW. Aggression from miners onsite within this central area was quantified before and after culling by presenting 3D printed models of three different bird species with accompanying vocal playback to resident miners at the centre of culled areas. These presentations identified a significant decline in Noisy Miner aggression onsite after doughnut culls, with this reduced rate of aggression (e.g. over 50% reduction in the maximum number of miners within a 20 m radius of models) remaining until the conclusion of the experiment at 28 days post culling, a timeframe commensurate with the duration of many passerine nesting attempts. Social hierarchy changes among remaining Noisy Miners may be the primary cause of this reduced aggression, with sufficient miners remaining onsite to prevent colony collapse and thus any recolonisation. While additional trials during peak Noisy Miner dispersal periods are warranted, this method provides an effective tool for land managers to reduce localised Noisy Miner aggression over the short to medium term when high conservation areas are identified.

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Introduction

Significant resources are directed towards the management of problem species in Australia, which we define as organisms that have an unnatural negative effect on the populations of other species, damage infrastructure or impact agricultural activities (Colautti and MacIsaac 2004). Overabundance of problem species is typically the result of anthropogenic causes such as landscape alterations and predator removal (Livezey 2010; Dexter *et al.* 2013; Pivello *et al.* 2018), with active management of overabundant problem species still commonplace (Whisson and Ashman 2020; Carpio *et al.* 2021). For example, the red fox (*Vulpes vulpes*) has become a widespread pest species requiring constant management to reduce their impact on Australian ecosystems (Abbott 2011; Radford *et al.* 2018).

The Noisy Miner (*Manorina melanocephala*) is a medium-sized honeyeater species endemic to the east coast of Australia that has come to dominate many urban and remnant regional environments in their range (Kath *et al.* 2009). Large colonies of Noisy Miners, up to 200 birds, can occupy eucalypt woodlands

and engage in cooperative breeding, with ‘helpers’ around the colony supplying food to the offspring of other colony members (Barati *et al.* 2018). The negative impact of this species on woodland bird diversity has grown over recent decades, as ongoing land use change and habitat fragmentation have increased the availability of the species’ preferred habitat, namely small remnant patches of relatively open eucalyptus woodland with abundant edge habitat (Piper and Catterall 2003; Oldland *et al.* 2009; Maron *et al.* 2013).

This increasing occupancy of human modified landscapes by Noisy Miners has a large impact on the abundance and distribution of other, smaller-bodied bird species, as miner colony boundaries are defended by socially coordinated and sustained mobbing behaviour (Montague-Drake *et al.* 2011). This willingness to mob, combined with an expanding colonisation of many woodland areas, has led to Noisy Miners being termed a despotic, negative keystone species in areas that they occupy (Mac Nally *et al.* 2012) and formal federal legislation listing the species as a Key Threatening Process to biodiversity (Commonwealth of Australia 2014). While

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miner aggression is directed towards all small birds, it can have a particularly large impact on species of conservation concern, such as the critically endangered Regent Honeyeater (*Anthochaera phrygia*; Crates *et al.* 2020).

Given the increasing impact of Noisy Miner aggression on woodland bird biodiversity, management interventions for miner control at a site have become more commonplace, however outcomes from these activities have been mixed. Translocations of miners to other areas are both logistically challenging and questionable from an ethics perspective, as relocated birds can return to their capture location (Clarke and Schedvin 1997) or negatively impact species at the translocation site. Revegetation aiming to enhance understorey cover and reduce edge habitat favoured by miners is a long-term strategy, however in the short term can create more habitat for Noisy Miners if not carefully implemented (Clarke *et al.* 2007; Lindenmayer *et al.* 2012; Mortelliti *et al.* 2016). In light of these difficulties, culling of Noisy Miners has been proposed as a more cost-effective and efficient solution, at least in the short term, for preventing further expansion and reducing Noisy Miner colony size in areas of high-quality habitat (Crates *et al.* 2020), with partial removal of colonies having been found to increase small passerine diversity by up to 50% (Melton *et al.* 2021), with benefits to passerine diversity persisting even post-recolonisation in some areas (Davitt *et al.* 2018). While the effectiveness of removal is not related to the degree of surrounding habitat suitable for miner occupation, in some cases reductions in miner density can be achieved with colony-level culling (*e.g.*, Crates *et al.* 2023). Other attempts have met with mixed success as removed colonies were rapidly replaced by dispersing miners from adjacent and surrounding colonies moving into the treated area (Davitt *et al.* 2018; Beggs *et al.* 2019; Etezadifar *et al.* 2023). Given this, in areas where recolonisation is rapidly occurring, or financial/logistical limitations prevent multiple rounds of culling, alternatives to a colony-wide removal protocol are needed. These are particularly important over the short to medium-term, as this would allow slower processes such as revegetation strategies to eventually take effect at a site.

In an effort to develop more effective short-term management strategies, we therefore assessed the feasibility of a new, smaller scale culling technique hereafter referred to as a ‘doughnut cull’, where up to half the number of miners in an existing colony were culled within a central area within a Noisy Miner colony, whilst retaining individuals occupying activity spaces more broadly across the colony. These areas within colonies were used as a proxy for a buffer zone around a high-value conservation location that might need to be

managed to reduce miner aggression, such as the detection of a nesting Regent Honeyeater, or the presence of a flowering gum of local significance within miner colonies. We tested if this partial, location-based removal resulted in a) reduced Noisy Miner aggression at the cull site across colonies in both large and small woodland patches, b) how long post-cull reductions in miner numbers and/or aggression persisted prior to recolonisation (relative to the typical duration of passerine nesting periods), and finally c) if aggressive responses were impacted by the species of bird intruding into the colony, tested by quantifying aggression directed towards 3D printed avian models of different taxa at the cull site. We aimed to test if our new suggested management strategy would provide a faster, effective solution for land managers seeking to control Noisy Miners, particularly at sites where full-scale colony removal was either unfeasible or had previously failed.

Methods

Study sites

For this study, 29 sites located within Travelling Stock Routes (TSR) on the New England Tablelands of north-eastern NSW were used (Figure 1; supplementary material 1). Seventeen of these sites were woodland patches that were below 200 m in radius (hereafter ‘small’) and twelve had a patch size radius that was greater than 200 m (‘large’), enabling the impact of patch size on results to be assessed. Patch size was measured in Google Earth (Version 7.3 March 7721) using the circle tool to determine the radius of the site and a TSR border overlay sourced from the NSW government. Minimum distance between sites was 2.8 km (more than 14 times larger than the mean activity space of this species), with woodland patches being comprised of a mix of understorey species with dominant canopy gums at sites including New England peppermint (*Eucalyptus nova-anglica*), grey box (*E. microcarpa*), yellow box (*E. melliodora*), mugga ironbark (*E. sideroxylon*), Blakely’s red gum (*E. blakelyi*), New England Stringybark (*E. caliginosa*) and apple box gum (*E. bridgesiana*). In between these trees sparse understorey vegetation was dominated by introduced pasture grasses, consistent with typical habitat adjacent to patches.

We generated life-sized 3D printed models of birds and added realistic texture and patterning using photogrammetry and a papercraft technique (see supplementary material 2), as these provide an effective substitute for a live or taxidermy specimen when testing miner mobbing responses (Mesken *et al.* 2022). The three model species used were the:

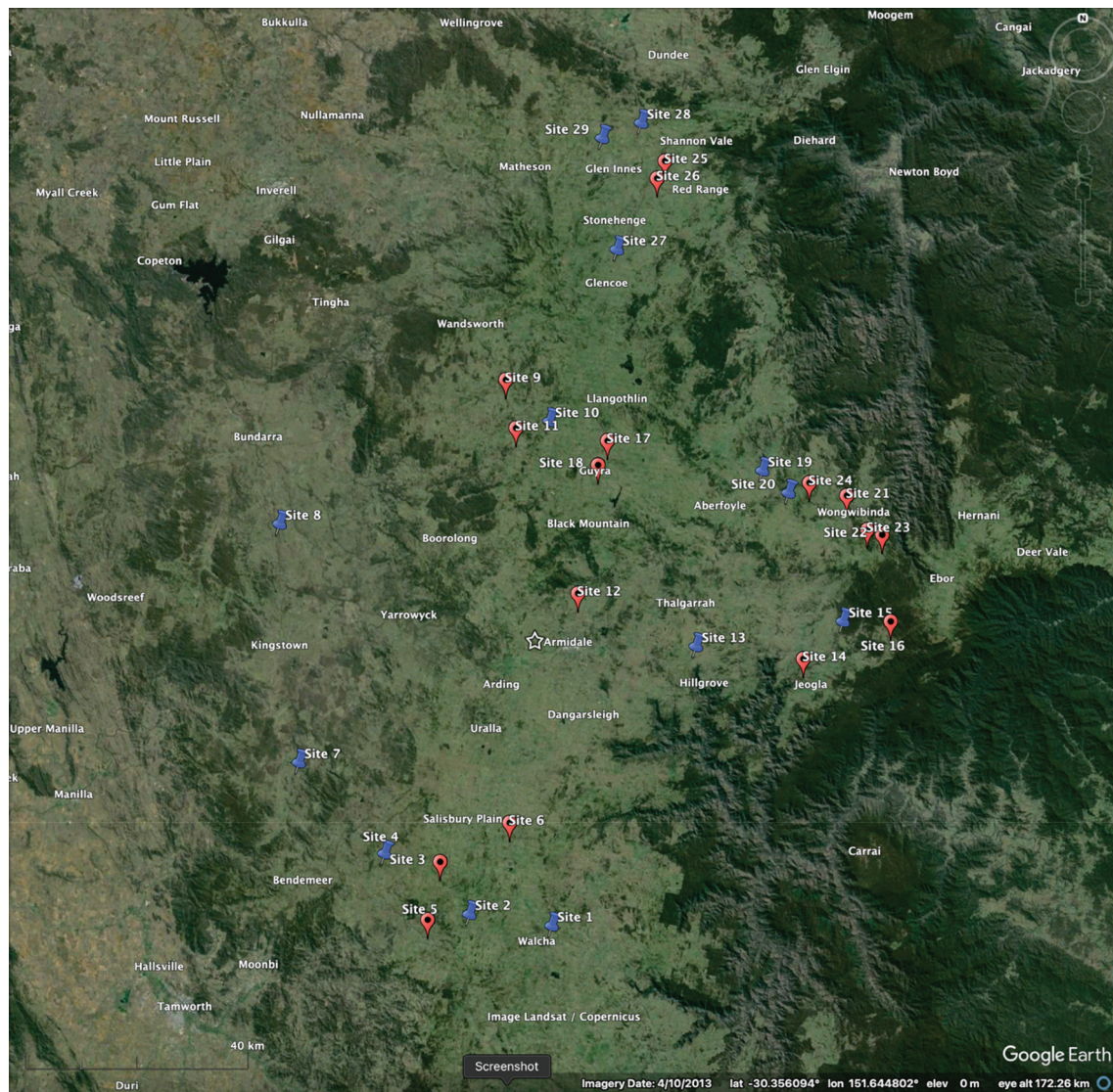


Figure 1. Map of the used site locations around the New England region of New South Wales, with blue push pin icons indicating 'large', and red balloon icons 'small' patch size, respectively. Site number refers to the labels presented in supplementary material 1 where further site details are provided.

- Sacred Kingfisher (*Todiramphus sanctus*; hereafter 'kingfisher'), a species frequently found near miner colonies that does not overlap in diet or resources such as nesting sites,
- Regent Honeyeater ('honeyeater'), a species that directly competes with miners for access to flowering tree species, and
- Southern Boobook (*Ninox boobook*; 'owl'), a potential predator of Noisy Miners.

Model presentation

The model species selected to be presented at each site and trial was randomised (without replacement to ensure a balanced experimental design) using a random number generator (Pretty random – RNG,

Steven Burnett, Apple Appstore) on an iPhone XS (Apple, USA). A minimum of 2 models of each species presented were used, with the order of presentation rotated randomly to remove the possibility of pseudoreplication and enable generalisation of responses across the different model types. Models were placed 1.5–2 m above ground in a tree that was used as the 'focal point' of the presentation. Focal points were a minimum of 40 m from the edge of a colony, which was typically easily identified by the presence of a road or cleared adjacent land. Whilst the degree of edges was not quantified at different patches, using TSRs for all sites meant that all patches were roadside, and thus patches of a similar size tended to have a similar level of edge habitat. To prevent the 3D model being sighted by miners or other species before beginning the presentation, these were

transported while enclosed within a bag along with the other equipment used such as a tripod and camera (GoPro Hero 3 and Nikon 5600D as a backup) used as a contingency in case any of the aggression parameters that were being documented live were missed or required confirmation following presentations. A portable Bluetooth speaker (JBL Xtreme 2) was used for audio playback and placed as close to the model as possible to ensure that any miners attracted to the playback were likely to detect the model. Once everything was in place and the model was attached to the tree, visual recording and the presentation began. The observer was a minimum of 25 m away from the model during presentations, thus at least 5 m outside the presentation radius.

During each presentation, response levels from miners to 3D models were assayed across three consecutive 10-min periods with three different types of accompanying vocal playback: (i) no calls, (ii) calls from the 3D model species only, and finally (iii) 3D model species calls that were also accompanied by Noisy Miner mobbing calls. In this way, the three different 10 min periods were designed to represent a simulated intrusion of i) a quiet, relatively unobtrusive bird, ii) a vocal intruder, and finally iii) a vocal intruder that was also in the process of being mobbed by other miners. Calls of model species were sourced from a bird guide app for an iPhone XS (The Michael Morcombe and David Stewart eGuide to Australian Birds, Cool Ideas LIG, Apple Appstore). When intruding species calls were broadcast during a 10-min period of presentation (type ii above), broadcasts of the intruding species alternated between 30 sec of call playback, then 30 sec of silence. In the third treatment (type iii), playback was also restricted to 30 sec calls per minute, however the 30 sec consisted of 15 sec of miner call playback, followed by 15 sec of the model species calls without overlap, then 30 sec silence. Noisy Miner mobbing behaviour towards models was assessed through quantifying eight behavioural measures for each 10-min observation period (Table 1). In addition to these measures, the maximum number of miners attracted across the 10 min of presentation was also recorded. Prior to deployment, once

a mounting site had been selected, surrounding trees were marked at the 10 m and 20 m radius zones for use as reference points during presentations.

Culling and model presentation timing

The first round of culls/presentations were carried out between November and December 2021 and the second in January 2022, coinciding with the late breeding season for many passerines (COVID-19 restrictions prevented a spring commencement). The presentations were repeated at four different Stages across all 29 replicates:

- Pre: a pre-cull stage no more than 14 days before the cull date (day 0)
- Post 1: 3 days post cull
- Post 2: 7 days post cull
- Post 3: 28 days post cull

Estimations of the required number of miners to cull at each site were formulated by using the pre-cull survey and the initial, 10-min model-only presentation (without audio) to assay the number of miners present within 20 m of where playback occurred. This allowed the number of birds using the area to be estimated prior to audio potentially attracting those from other areas of the colony to the speaker. This figure was used as an indicator of how many miners were to be removed from each cull site, with 40–60% of the number of miners identified as the target number for culling. A professional shooter was contracted to perform these culls and operated under the direction of the co-authors (see Barati and McDonald [under review](#) for detailed culling protocol). Each cull lasted a maximum duration of 2 h. For the first hour, shooting was restricted to a circular area within a 20 m radius of the presentation site, and miners were attracted with playback of a range of Noisy Miner vocalisations to minimise the time spent culling at each site, and thus disturbance. If the target number of miners culled was not achieved in the first hour ($n = 4$ of the 29 trials), the radius of the area where miners were culled was extended to 50 m for an additional hour of shooting.

Table 1. Variables used in this experiment to quantify changes in Noisy Miner aggression directed towards 3D printed models during presentations.

Variable	Method of measurement
Speed of response	Time (sec) for the first miner to land within 20 m of the model.
Distance of closest miner to model	Estimated closest approach distance by a miner towards the model (nearest m).
Strikes on model	Number of times that a Noisy Miner made physical contact with the model.
Approaches towards model	Total number of times a miner approached within 2 metres of the model.
First miner within 10 m of model	Time (sec) that first miner approached to within 0–10 m of the model.
First miner to land in tree with model	Time (sec) until the first miner landed in the same tree as model was placed.
Mean number of miners within a 20 m radius of model	The average number of miners within a 20 m radius of models taken across point counts separated by 60 sec during each 10 min playback.

All culls were able to reach the required number of birds being removed within 2 h ($n = 29$). All carcasses were collected and numbered accordingly for frozen storage at the University of New England and subsequent molecular analysis, although leaving carcasses and their nutrients within the system could be considered when implementing the technique.

Statistical analyses

Data analysis was performed using the open-source software R on version 4.2.0 (R Core Team 2022) and RStudio (version 2022.02.03 + 492 'Prairie Trillium'). The *hmsic* (Harrell 2021) and *dplyr* (Wickham *et al.* 2021) packages were utilised to analyse correlations between response data collected during stimulus presentations with Pearson's correlation matrices. A Principal Components Analysis (PCA) was used to extract two orthogonal components after significant correlations were observed across many of the measures presented in Table 1 using a Pearson's correlation matrix (majority $p < 0.05$, data not presented for brevity). The PCA separated the data into six principal components, with the first two (PC1 and PC2) having eigenvalues greater than 1. PC1 accounted for 46.6% of variation with an eigenvalue of 2.797. PC2 accounted for a further 24.6% of variation and had an eigenvalue of 1.475. PC1 was most heavily correlated with the mean number of miners observed in the presentation area (-0.493), how quickly the miners would first respond (0.432), the closest distance a miner moved towards a model (0.467) and the time that a miner first entered the 0–10 m radius (0.449). PC2 was most heavily correlated with the time that a miner first landed in the tree that contained the model (0.603), how quickly the miners would first respond (0.467) and the time that a miner first entered the 0–10 m radius (0.430). Both components were therefore multiplied by -1 so that larger values were indicative of a greater number of birds responding in a faster, more intense manner during model presentations.

Initially, binomial Generalised Linear Mixed Models (GLMMs) were fitted to assess the factors that impacted whether or not at least one Noisy Miner moved to within 20 m of models during presentations. Secondly, for only those data where at least one miner responded, Linear Mixed Models (LMMs) were fitted with the two extracted principal components used as the dependent variables in two analyses. For both types of analyses, the fixed factorial effects (italicised for clarity) used were model '*Species*' presented (owl, honeyeater and kingfisher), the '*Stage*' of presentation (pre, post 1, post 2 or post 3), the type of '*Playback*' used (none, model calls

or miner and model calls together), and the '*Patch size*' of the site (small or large). A unique identity for each of the 29 sites sampled was also fitted as a random variable. Significance of removing a term from models was tested by a Likelihood Ratio Test (LRT) for GLMMs using the *lme4* package (Bates *et al.* 2015), and for LMMs we examined the significance of fixed effect predictors based on Type III ANOVA with Satterthwaite's approximation for the denominators degree of freedom using the *lmerTest* package (Kuznetsova *et al.* 2017). Tukey post-hoc comparisons provided context for within factor level differences using the *emmeans* package (Lenth *et al.* 2018). Packages for graph generation included *ggplot2* (Wickham 2016), *ggpubr* (Kassambara 2020), *effects* (Fox and Weisberg 2018) and the *lattice* package (Grothendieck 2008). Model fit was assessed and found to be acceptable using the *performance* package (Lüdtke *et al.* 2021).

Results

A total of 203 miners were culled across the 29 sites (mean 7.0 ± 1.9 SD), and no detectable recolonisation of Noisy Miners occurring at sites over the experimental period. General observations were commensurate with non-culled miners remaining in the typical locations where they were found prior to treatment. There was a drop in the maximum number of miners observed responding to model presentations of over 50% from pre-cull to the initial post-cull presentations that is explored below (Figure 2(a)).

Factors related to whether 3D models were mobbed during the trial

Initial analyses used binomial GLMMs to examine the importance of different factors in shaping whether or not at least one Noisy Miner mobbed a 3D model presented where culling took place. Whilst there was no significant impact of patch size on responses ($\chi^2_1 = 0.203$, $p = 0.652$), there were significant relationships observed for the other factors tested, including *Species* upon which models were based ($\chi^2_2 = 8.521$, $p = 0.014$), *Playback* type broadcast with models ($\chi^2_2 = 164.24$, $p < 0.005$) and, most importantly, *Stage* of the experiment ($\chi^2_3 = 9.876$, $p = 0.020$; Figure 2). Tukey posthoc comparisons identified that the probability of miners responding to a model presentation significantly declined from the pre-cull stage to all post-cull observations, with no statistical difference in response intensity across the three post-cull presentations (Figure 2(b); supplementary material 3). Posthoc analyses found that all three types of playback broadcast differed from each

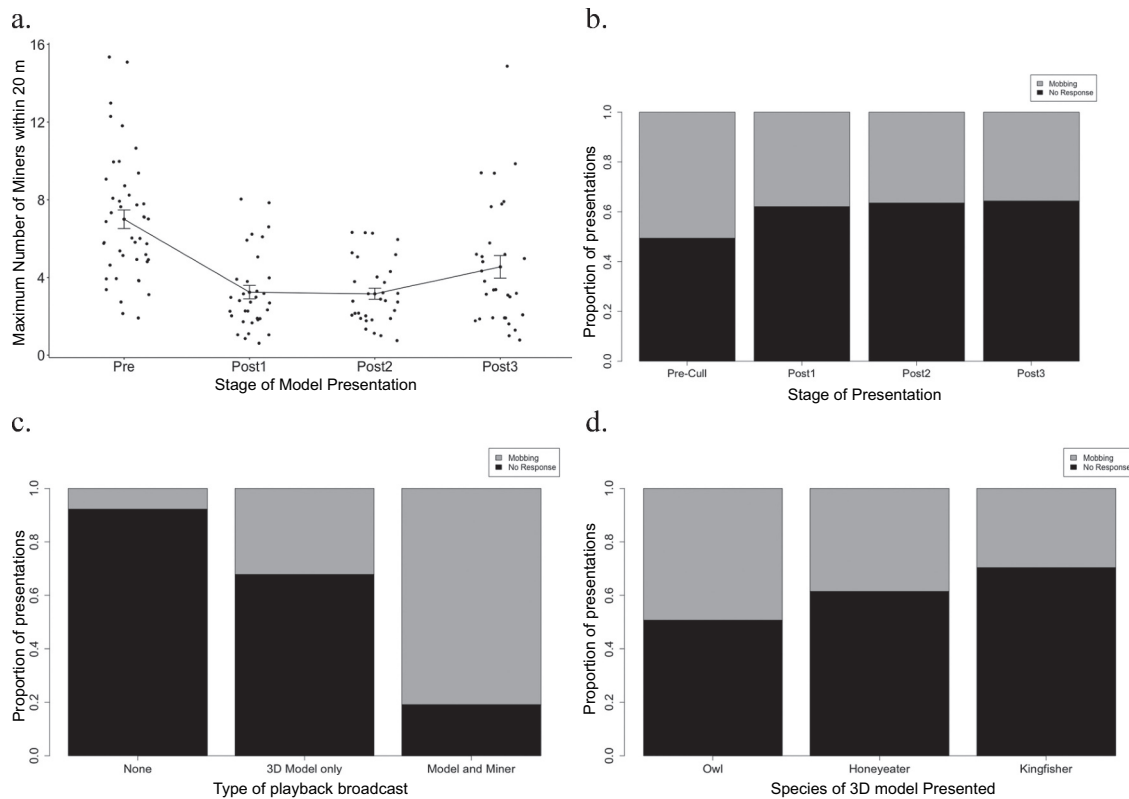


Figure 2. Responses of Noisy Miners to the presentation of 3D models of different species of bird in areas subject to culling, showing a) the maximum number of miners observed within 20 m of models during presentations at the four different presentations of the experiment, and then the proportion of model presentations where at least one Noisy Miner approached within 20 m according to b) the stage of the experiment relative to culling, c) the type of vocal playback broadcast with 3D models, and d) the species of bird depicted in the used 3D model. Dot points denote individual counts at each site at each stage, whilst black points with error bars indicate means and one standard error for (a), whereas for b-d) black bars indicate observations without a miner approach, grey bars observations with at least one Noisy Miner ($n = 87$ presentations per stage).

other in responses, with increasing likelihood of a mobbing event occurring when models were accompanied by model species only, and both model with miner calls as opposed to no audio (Figure 2(c)). Finally, the *Species* of model presented saw a significant increase of mobbing probability towards owl over kingfisher models, but no difference between the other two pairs of models (Figure 2(d); supplemental material 3).

Factors that explained a significant degree of variation in the strength of miner responses to 3D models

A LMM was performed on PC1 to ascertain what factors influenced the level of mobbing behaviour observed, with statistically significant variation explained by the *Stage* of presentation ($F_{3, 118.862} = 16.975$, $p < 0.005$), type of *Playback* presented ($F_{2, 122.912} = 22.949$, $p < 0.005$) and finally the *Species* of 3D model presented ($F_{2, 26.133} = 7.529$, $p = 0.003$; Figure 3). *Patch size* where presentations took place

did not impact strength of miner mobbing ($F_{1, 22.572} = 2.947$, $p = 0.100$). When Tukey post-hoc analyses were conducted (supplemental material 3), it was clear that the strength of mobbing response mirrored the result observed for the probability of mobbing occurring above, with the level of aggression observed from miners dropping significantly from the pre-cull to the first post-cull presentation, then remaining similarly low thereafter (Figure 3(a)). As lower values of PC1 indicated a reduced response, these results show a reduction in aggression directed towards models post-culling that remained throughout the 28 days of the experiment. When the type of Playback broadcast was assessed, aggression intensity (PC1) was significantly greater during presentations accompanied by playback of miner and model species calls, with no significant differences between the other two playback combinations (Figure 3(b); supplementary material 3). Model Species also impacted PC1 values, and post-hoc analyses showed greater responses to owl models, however this difference only reached statistical

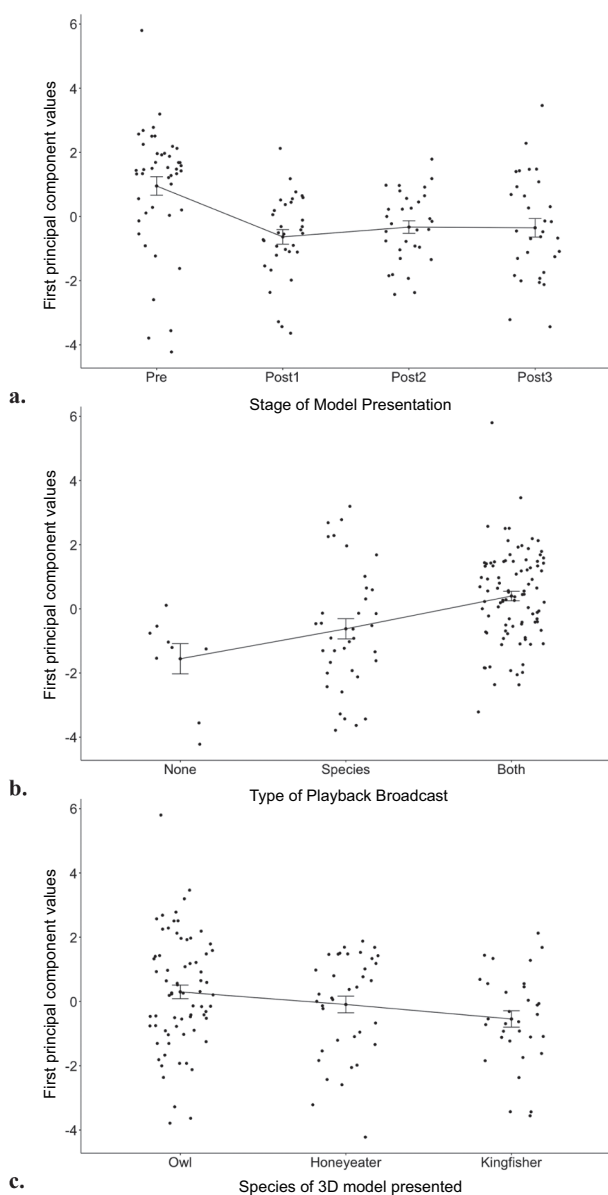


Figure 3. Responses of Noisy Miners to the presentation of 3D models of different species of bird in areas subject to culling expressed as a first extracted principal component relative to a) the stage of the experiment relative to culling, b) the type of vocal playback broadcast with 3D models, and c) the species of bird depicted in the used 3D model. Scatter dots denote individual counts, whereas central tendencies with variance bars indicate means and 1 standard error. Larger values of PC1 are indicative of more miners approaching models both more closely and more quickly, thus commensurate with a more intense mobbing response.

significance for comparisons with kingfisher models (Figure 3(c)).

This approach was repeated using the same model structures outlined above, but with PC2 as the dependent variable. Similar results to PC1 were obtained, with significant relationships to *Stage* of presentation ($F_{3, 114.72} = 5.404, p = 0.002$) and type of *Playback* ($F_{2, 118.87}$

$= 5.902, p = 0.004$); however, model *Species* ($F_{2, 21.95} = 1.5466, p = 0.235$) and *Patch size* ($F_{1, 19.31} = 0.2396, p = 0.630$) did not reach statistical significance. Tukey post-hoc comparisons of *Stage* of presentation PC2 levels found that there was a difference between first and second, but not third, post-culling presentation stages and those measured during the pre-cull stage (see supplemental material 3), with relatively small differences between stages compared to PC1. The impact of *Playback* type also only reached significance for comparisons between presentations with model species alone compared to those with both miner and model species (supplemental material 3).

Impact of doughnut cull on Regent Honeyeater models specifically

To highlight what these data might mean for a live passerine entering the treated area following an applied doughnut cull, we further present responses of miners to the presentation of the Regent Honeyeater model alone (Figure 4). This model depicts a species of conservation concern, but also a good representative of how our techniques might impact many woodland birds that are smaller than miners and therefore being excluded from areas of habitat due to miner aggression. Patterns of response to the Regent Honeyeater models mirrored those of the broader dataset, with a reduction in the probability of a mobbing event occurring post-cull (Figure 4(a)), and further a reduction in the maximum number of miners responding dropping nearly 50% (Figure 4(b)). A miner was recorded as responding if it was within 20 m of the model, so as a measure of mobbing intensity we further examined the number of approaches by a Noisy Miner to within 2 m of the model, a reasonable proxy for increased aggression by miners (Figure 4(c)). Following the doughnut cull, the number of these close approaches dropped to near zero.

Discussion

Our experimental assessment of Noisy Miner mobbing indicated that partial culling of up to 50% of a colony around a specific location within the colony led to a reduction in both the probability of a model bird being mobbed and also the intensity of a mobbing event if one occurred within the treated area. This reduction in aggression remained for the duration of the experiment (28 days post-cull), a timeframe that would enable a typical passerine to fledge young from a nest. As expected, the addition of vocalisations to model species presentations, particularly Noisy Miner vocalisations, increased mobbing responses. In contrast,

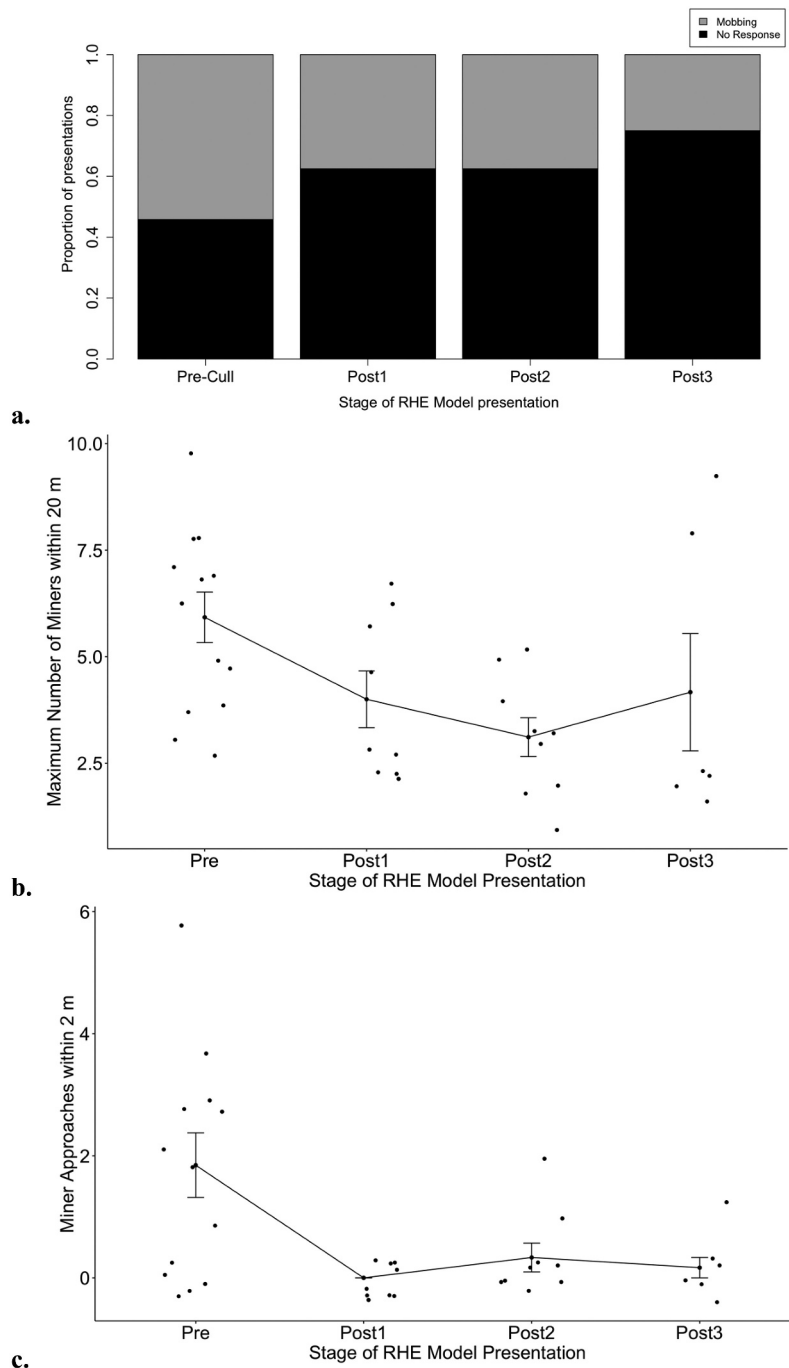


Figure 4. Responses of Noisy Miners to the presentation of 3D models of a Regent Honeyeater in areas subject to culling expressed relative to the stage of the experiment pre and post-culling according to a) the proportion of presentations resulting in mobbing event (black bars indicate no miners mobbing, grey bars observations with at least one Noisy Miner approaching, $n = 24$ presentations per stage), b) the maximum number of Noisy Miners recorded within 20 m of the model across the presentation, and c) the total number of times a miner approached within 2 m of the Regent Honeyeater model. Scatter dots denote individual counts, whereas central tendencies with variance bars indicate means ± 1 standard error.

patch size was unimportant in shaping miner responses. Finally, while owl models received more mobbing than the other model types, the Regent Honeyeater model as a typical, woodland bird that is being adversely impacted by Noisy Miner aggression experienced a similar reduction in miner aggression post-culling.

Together, these results strongly suggest that the technique offers an alternative option for land managers seeking to reliably reduce miner aggression over the short term in an area where recolonisation risk is either high or unknown, and also where resources may prevent a full scale colony removal.

Did doughnut culls reduce the level of Noisy Miner aggression displayed?

None of the colonies treated with the new, partial culling method (the ‘doughnut cull’) exhibited colony collapse or recolonisation within the experimental timeframe, despite recolonisation rates being very high in this area previously (e.g., Davitt *et al.* 2018). Instead, regardless of model species presented (owl, honeyeater, or kingfisher), the probability of any model generating a response was reduced after doughnut culls had been carried out at a site across the 28-day experimental window. The intensity of mobbing when it did occur was similarly reduced, with the mean number of miners engaging in mobbing behaviour inside the 20 m radius around the cull zone approximately halved after culling. This established 28-day window is important as it is in-line with the average breeding cycle of nesting passerines in the region, particularly threatened taxa of high importance such as the Regent Honeyeater (Oliver *et al.* 1998). The average duration of *Eucalyptus* species flowering in the region is a similar time period (Savva *et al.* 1988). While longer benefits may be possible, our study provides assurance to land managers that the method’s impact can reduce miner aggression around locations of high conservation value across a biologically relevant timescale.

Two factors likely explain why mobbing pressure was reduced at the culling location site. First, analysis of bioacoustic recordings recorded over the same period as the experiment showed a non-significant trend for an increase in the proportion of social facilitation calls produced by remaining birds in colonies post-culling (authors unpubl. data). These vocalisations are utilised by birds to determine dominance relationships and interactions between colony members (Holt *et al.* 2017), so an increase in their use likely indicates a colony undergoing social disruption as miners focused on intraspecies rather than interspecific interactions. There are currently little data on what effect the culling of Noisy Miners has on a colony hierarchy, but a detailed study of marked birds of known kinship and sex would be highly useful.

In conjunction with a likely increase of social disruption post-cull of any remaining birds, removing miners only within a limited central area during doughnut culls appears to reduce the number of miners incorporating the treated area in their general activity space, and thus reduce the density of miners in the treated area. This, in turn, likely leads to a reduced probability of another intruding bird species being detected and triggering a mobbing event, thus attracting even more miners to the immediate area, as vocalisations clearly increase

mobbing intensity as shown by our playback data and other research on miners (Kennedy *et al.* 2009; Cunningham and Magrath 2017). Our playbacks also show that intruding species would likely experience a reduced probability of being detected and thus mobbed by remaining silent. There is precedence for this behaviour, as other bird species reduce their own vocalisation rates in response to the playback of Bell Miner (*Manorina melanophrys*) vocalisations at a site (Heathcote 1989). Further research is required to determine how long a disturbed Noisy Miner colony takes to recolonise and resume typical defence of the doughnut ‘hole’ in colony occupancy footprints, however these results offer a great deal of promise for reducing miner impacts on a local scale, at least in the short term.

Given the failure of complete colony removal to reduce miner density in some studies (Melton *et al.* 2021; Crates *et al.* 2023), our method offers an improved approach if an area is likely to face high recolonisation pressure. The smaller and faster removal process in comparison to complete colony removal at patches (e.g., Beggs *et al.* 2019) would also be more achievable, and the location of colony areas to treat can be based on the flowering of an important gum in the area, or the detection of a nesting threatened species, such as the Regent Honeyeater, which is known to be negatively impacted by miner aggression near nests (Crates *et al.* 2018). While it is possible that shooting around an active nest may impact the threatened taxa, the rapid application time of this method (85% of trials completed within an hour) makes this unlikely, with rapid increases in woodland bird diversity following immediately after extensive miner removal typical. The technique also only required one treatment, in contrast to often multiple culls needed to remove miners from an area (Melton *et al.* 2021).

The impact of 3D model species on Noisy Miner mobbing

The type of model used influenced both the chance of and intensity of observed mobbing behaviour, with owl models receiving the largest mobbing responses of the greatest intensity, as expected for a potential predator of Noisy Miners (Cunningham and Magrath 2017). Spotted Pardalotes (*Pardalotus punctatus*) have previously been noted to receive the most mobbing by Noisy Miners in another experimental study (Fountain and McDonald 2022), however this enhanced aggression towards a competitor may reflect differences in relative body size of miners to the model species, as pardalotes are considerably smaller than Regent

Honeyeaters. Regardless, while the mobbing response intensity directed towards Regent Honeyeater models was intermediate, our experiment still showed a significant reduction in both the probability of mobbing and its intensity post-cull, as visible in the number of miners attracted to models and the number of close approaches towards models. Our proposed culling treatment can therefore be used to reduce mobbing pressure on passerines as well as more dangerous potential predators such as the owl model. Given the high level of conservation concern associated with woodland passerines, this result is important in providing managers with an efficient, effective short-term option for reducing miner aggression at key locations. Future studies monitoring actual reproductive success and feeding rates of live honeyeaters and similar taxa would help confirm this.

There is a possibility that the miners studied may have reduced their aggression during the trial in response to the presence of a human following shooting, and that aggression towards live birds remained unchanged outside of the experiment. Miners that heard playback during presentations may also have learned to associate our broadcast stimuli with danger, as the species possesses excellent vocal recognition (McDonald 2012; Farrow *et al.* 2019). We reduced the latter risk by randomising call playback during trials, however the importance of a human's impact on mobbing intensity post-culling is currently unknown and a potential focus of future research in this space. Other avenues that should be explored include the most effective timing of culls for maximum impact (e.g. spring vs winter), and further if measured reductions are sustained beyond the 28-day time period measured herein.

Conclusion

The negative impacts of Noisy Miner presence on avian biodiversity are increasing due to human-induced land use change, and have been formally identified as a Key Threatening Process for declining woodland birds (Commonwealth of Australia 2014). While large-scale revegetation offers a potential solution, this intervention is a long-term process, and more rapid solutions are needed to preserve biodiversity. Our new doughnut cull method provides a short-term, smaller scale solution to reducing miner aggression towards a range of model taxa when compared to complete colony removal. This reduction lasted for at least 28 days post-cull with no evidence of recolonisation by other miners, in contrast to the mixed success of attempts to fully remove entire colonies. Given the similar ecological impact and responses to removal observed in other

highly aggressive colonial *Manorina* species, the technique could also prove useful in the management of other taxa (Robertson *et al.* 2013; Kutt *et al.* 2016; Lambert *et al.* 2022). Our methods provide land managers with a tool for the rapid reduction of Noisy Miner impact at specific, high conservation priority areas when resources are limited, or if past colony-wide removals have proven unsuccessful.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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