

1 **Playback experiments elicit temporary group repulsion, not attraction, in a globally**
2 **distributed pest parrot**

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4 **Running Head:** Behavioral responses to playbacks by a pest parrot

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28 **Abstract**

29 Human-wildlife interactions continue to increase due to anthropogenic disturbances, with some
30 interactions resulting in conflict. Leveraging a taxa's bias for a particular sensory cue is a
31 promising management avenue for reducing the potential and realized negative consequences of
32 human-wildlife conflict. For instance, many avian species heavily depend on acoustic
33 communication, and acoustic cues can provide opportunities to reduce conflict with a variety of
34 avian species. The monk parakeet (*Myiopsitta monachus*) is a gregarious parrot native to South
35 America that has established populations worldwide and is considered an urban and agricultural
36 pest in parts of its native and introduced ranges. We conducted playback experiments with a
37 captive population of monk parakeets to evaluate auditory cues that may be useful for designing
38 management protocols. Our experiment evaluated the efficacy of two stimuli that we expected to
39 either repulse or attract parakeets: predator vocalizations and conspecific vocalizations,
40 respectively. We measured two responses: (1) categorical group-level behavioral responses and
41 (2) time to cease vigilance and return to baseline behavior. In the repulsion playbacks, monk
42 parakeets were repelled by predator vocalizations in 80% of trials and took longer to cease
43 vigilance and return to baseline behavior compared to attraction playbacks. In the attraction
44 playbacks, monk parakeets exhibited vigilant behavior and weak or no attraction to the stimulus,
45 with attraction only being observed in 10% of trials. Our results demonstrate that predator
46 playbacks may be particularly useful for completing management objectives, such as temporary
47 removal from a location.

48

49 **Keywords**

- 50 Playback experiments, human-wildlife conflict, behavior, management, avian pests, *Myiopsitta*
- 51 *monachus*

52 **Introduction**

53 Anthropogenic disturbances and policies, including changes in human land use, continue to alter
54 ecosystems worldwide. These disturbances are bringing humans and wildlife into more frequent
55 and novel forms of contact, which are leading to changes in wildlife behavior (Wilson et al.
56 2020; Gaynor et al. 2018), increases in species mortality and habitat loss (Hill et al. 2020;
57 Kennedy et al. 2019; Hoekstra et al. 2004), and the alteration of ecological and evolutionary
58 processes in cities (Des Roches et al. 2021; Schell et al. 2020). These impacts on various species,
59 and the associated human-wildlife conflict, have prompted various management strategies to
60 reduce the negative consequences that may come from human-wildlife interactions, including
61 indirect practices such as building fences to exclude wildlife from specific areas and direct
62 approaches such as lethal management (Wilkinson et al. 2020; Khorozyan and Waltert 2019).
63 The effectiveness of management strategies is crucial for adequately preventing and resolving
64 current human-wildlife conflict consequences (Treves et al. 2006). To create effective
65 management strategies, wildlife management should be informed by an experimental approach
66 (Walters and Holling 1990, Enck et al. 2006; Richardson et al. 2020).

67 Recently, researchers have highlighted the benefits of incorporating sensory ecology into
68 management policies. These benefits can include reducing harm to wildlife and predicting how
69 wildlife will respond to environmental change (Elmer et al. 2021). Management strategies built
70 around a species' sensory ecology focus on a particularly relevant sense of the target species and
71 can function as repulsive or attractive signals that can cause animals to avoid or gather in areas
72 for specific management-related activities. For example, olfactory cues like wolf urine can
73 stimulate avoidance behavior in deer (Osada, Miyazono, and Kashiwayanagi 2014; Chamailé-
74 Jammes et al. 2014), while visual cues, such as changes in lighting or mounted specimen that

75 represent a high risk of predation, can cause target species to alter their foraging strategies and
76 overall activity (ship rats (*Rattus rattus*) Farnworth et al. 2020; black-capped chickadees (*Poecile*
77 *atricapillus*) Arteaga-Torres, Wijmenga, and Mathot 2020). Additionally, acoustic cues have
78 been used to investigate species reproduction and movement (bark beetles (Coleoptera:
79 Curculionidae) Hofstetter et al. 2014; fish (Putland and Mensinger 2019)), territoriality
80 (Frostman and Sherman 2004; Reif et al. 2015; Heinsohn 1997), vocal discrimination (Searcy,
81 Nowicki, and Hughes 1997; Searcy et al. 2002), and anti-predator behavior (Bshary 2001;
82 Adams and Kitchen 2020). With many species attuned to auditory cues for decision making,
83 auditory cues provide useful opportunities for nonlethal and widespread management strategies
84 that may reduce human-wildlife conflict.

85 Natural auditory stimuli, such as vocal signals, are easy to record and then broadcast to
86 implement population-level management strategies. These recorded stimuli can be used for two
87 types of management goals. First, repulsive signals can deter individuals from an area where they
88 are unwanted, such as deterring birds from buildings (Boycott et al. 2021) and reducing crop
89 damage on agricultural lands (Mahjoub, Hinders, and Swaddle 2015; Werrell et al. 2021).
90 Second, attraction signals can encourage individuals to move to an area where the presence of
91 those animals is desired, including inciting individuals to visit and remain in specific habitat
92 patches (DeJong et al. 2015; Buxton, Ward, and Sperry 2018). With these advances in
93 implementing biologically relevant auditory cues via playback experiments, auditory cues can
94 readily be used as a management approach, particularly when designing management strategies
95 to control of avian pests (Khan et al. 2011; Berge et al. 2007; Depino and Areta 2019; Budka et
96 al. 2019).

97 The strong foundation of playback experiments provides a robust framework for continuous
98 assessments of how auditory stimuli may contribute to alleviating human-avian conflict,
99 particularly in widespread species. A prime example of widespread avian species that can pose
100 problems for human populations are parrots (Psittaciformes), a species-rich taxon with global
101 distribution (Davies et al. 2007; Kosman et al. 2019; Vergara-Tabares et al. 2020; Calzada
102 Preston and Pruett-Jones 2021) that have become increasingly naturalized (e.g., novel range
103 expansions) (Joseph, 2014). As parrot species distributions change with increasing urbanization
104 (Liu et al. 2020; Huang et al. 2019) and movement via the pet trade (Edelaar et al. 2015; Pires
105 2015; Martin 2018), parrots are often coming in close contact with humans. Human-parrot
106 conflict increases as parrots settle in or near human-modified habitats like farms or
107 suburban/urban greenspaces (de Matos Fragata et al. 2022; Menchetti and Mori 2014), with
108 ~44% of parrot species using croplands as habitat (Barbosa et al. 2021). These conditions make
109 this group opportune to explore how integrating auditory stimuli can alleviate not only human-
110 parrot conflict, but human-wildlife conflict more generally.

111 The monk parakeet (*Myiopsitta monachus*) has become one of the most widely distributed parrot
112 species (Calzada Preston and Pruett-Jones 2021), making them a well-suited species to
113 experimentally test approaches that may alleviate human-wildlife conflict. Monk parakeets are
114 gregarious parrots native to South America and have been introduced in over 20 countries in
115 North America, Europe, Africa, Asia, and at least four Caribbean islands as a byproduct of the
116 pet trade (Burgio, Rubega, and Sustaita 2014; Hobson, Smith-Vidaurre, and Salinas-Melgoza
117 2017) (Avery et al. 2020, CABI 2010). Monk parakeets build communal and colonial nests that
118 range in size, with larger multi-chambered hosting dozens of pairs (Bucher et al. 1990; Eberhard
119 1998; Avery et al. 2002). Conflict among humans and monk parakeets typically manifests in

120 three ways: (1) economic and safety hazards in urban areas, (2) agricultural impacts, and (3)
121 health concerns. Following their establishment of new populations, monk parakeets have
122 established nests throughout the urban sprawl on artificial structures as varied as power poles,
123 electricity substations, silos, and fire escapes (Avery and Lindsay 2016), introducing economic
124 costs and safety concerns for humans (Avery et al. 2002; Stafford 2003). In addition to their role
125 as an urban pest, monk parakeets' propensity to inhabit changing landscapes and consume a wide
126 variety of food resources (Postigo et al. 2021; Bucher and Aramburú 2014) have also led them
127 to become agricultural pests in parts of their native and introduced ranges (Davis 1974;
128 MacGregor-Fors et al. 2011; Mott 1973; Senar et al. 2016; Stafford 2003). For instance, damage
129 in Barcelona ranges from 0.4% to 37% crop loss depending on the particular crop (Senar et al.
130 2016). Lastly, recent research indicates that monk parakeets may serve as a reservoir for zoonotic
131 diseases in some areas (Morinha et al. 2020), introducing a concern for human health; however,
132 this is not widely observed (Ortiz-Catedral et al. 2022). As a result of these concerns and
133 conflicts, monk parakeets have become a management priority in many areas. Thus, ecologically
134 informed techniques for managing these parrot populations are essential to mitigate conflict
135 among human and monk parakeet populations.

136 Here, we explore group-level behavioral responses of a captive population of monk parakeets to
137 biologically relevant auditory stimuli and discuss our findings within a wildlife management
138 context. We used two auditory cues that we expected to serve as either repulsion or attractive
139 stimuli: predator vocalizations and conspecific vocalizations, respectively. We hypothesized (1)
140 that predator playbacks would result in the repulsion of the group away from the auditory source
141 in accordance with the literature on prey responses to predator stimuli (Smith et al. 2017;
142 Hettena, Munoz, and Blumstein 2014; Lönnstedt et al. 2012) and (2) that conspecific playbacks

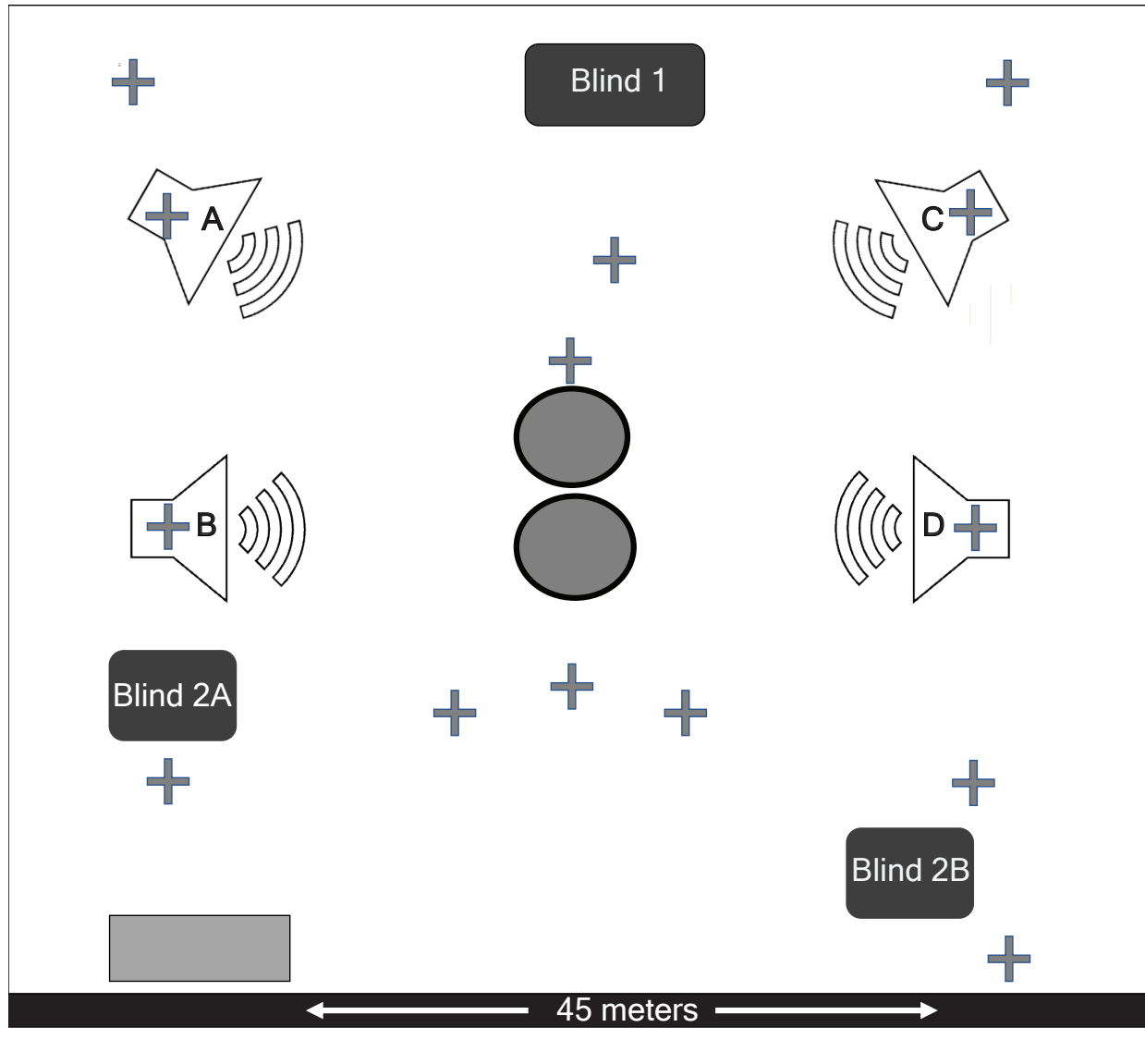
143 would result in the attraction of the group towards the auditory source, in line with previous
144 work that used conspecific vocalizations to attract individuals of a focal species and to attract
145 focal species to specific patches (Lewis, Williams, and Gilman 2021; Ahlering et al. 2010). We
146 then discuss how our results could help inform different management strategies and goals for
147 avian pest species.

148 **Methods**

149 *Study Species and Location*

150 We conducted this study on a captive population of monk parakeets ($n = 20$) in Gainesville,
151 Florida at the USDA Wildlife Services National Wildlife Research Center Florida Field Station
152 from April to July 2021. This population was held in a large 2,025 m² outdoor semi-natural flight
153 pen (Figure 1). All experiments were approved by University of Cincinnati (IACUC protocol
154 #AM02-19-11-19-01) and the National Wildlife Research Center (Quality Assurance protocol
155 #3203).

Figure 1: Overview of the flight pen at the USDA Wildlife Services National Wildlife Research Center, Florida Field Station. Positions for speakers during playback trials are shown as outlined speakers with locations A, B, C, and D. Crosses and boxes represent perch areas throughout the flight pen, and circles represent trees.



157 ***Playback Stimuli***

158 We used three playback stimuli to conduct our experiments: a predator call to test for repulsion,
159 a conspecific call to test for attraction, and a control to ensure that attraction and repulsion
160 patterns were not due to our playback setup or speaker. For our predator playback, we used
161 vocalizations from a local predator, the red-tailed hawk (*Buteo jamaicensis*). For our conspecific
162 playback, we used vocalizations from monk parakeets that were strangers to the group. For our
163 control playback, we used vocalizations from a local bird species, the mourning dove (*Zenaida*
164 *macroura*). We maintained a consistent volume for the playback stimuli across all trials. We
165 created all playback tracks in Raven Lite version 2.0.1 (Bioacoustics Research Program 2014,
166 Cornell Lab of Ornithology) and used randomization in RStudio version 4.1.0 (R Core Team
167 2021) to choose the variant of each playback track used in each trial.

168 Both red-tailed hawk and mourning dove vocalizations were selected for their biological
169 relevance as predatory and non-predatory species, respectively, and their common occurrence in
170 Florida. Neither of these species was abundant around the flight pen, which lessened the chance
171 of attracting local birds when playing conspecific calls and confounding parakeets' responses to
172 our experimental stimuli. We downloaded screech calls of red-tailed hawks and perched songs of
173 mourning doves from xeno-canto, a non-profit website that stores recordings of bird
174 vocalizations uploaded by recordists worldwide (Planqué and Vellinga 2008; Vellinga and
175 Planqué 2015). We chose recordings that did not contain any background vocalizations of
176 conspecifics or heterospecifics. We chose three unique files per species and selected the first 30
177 seconds of each file to create a playback track. This method resulted in three unique tracks
178 (exemplars) per stimuli. Predator playback tracks contained four to ten vocalizations per track,
179 and control playback tracks contained three vocalizations per file (exemplars). In each repulsion

180 and control trial, we randomly selected one of the three exemplars to broadcast to the captive
181 parakeets.

182 For conspecific vocalizations, we randomly selected non-native ($n = 3$) and native ($n = 3$) range
183 monk parakeet contact calls collected in previous studies (Smith-Vidaurre, Araya-Salas, and
184 Wright 2020; Smith-Vidaurre, Perez-Marrufo, and Wright 2021). We used contact calls as our
185 stimuli because parrots often use these vocalizations to maintain auditory contact within pairs
186 and flocks (Bradbury and Balsby 2016). When selecting non-native range calls, we selected
187 monk parakeet contact calls collected from outside Florida but within the United States of
188 America to avoid possible skews in behavioral responses due to previous exposure to local calls.
189 We created three unique playback tracks (exemplars) for each native and non-native range call.
190 For each playback track, we randomly selected one call and repeated each call ten times,
191 separated by three-second gaps to simulate natural calling behavior (Hobson et al. 2015). Each
192 conspecific playback was 30 seconds long and contained ten replicates of each exemplar. In each
193 conspecific trial, we randomly selected one of these playback tracks to broadcast to the captive
194 parakeets.

195 All playback tracks contain vocalizations from unique individuals. The predator/control playback
196 tracks are similar in duration to the conspecific playback tracks. The difference between the
197 predator/control tracks and the conspecific tracks is that we used different vocalizations for the
198 predator/control tracks but repeated one vocalization for the conspecific tracks.

199 ***Experiment and Setup***

200 We conducted playback sessions between 09:00 and 18:00 using a wireless speaker (JBL Charge
201 4 Wireless speaker). We randomized the placement of the speaker to four locations within the
202 flight pen (Figure 1). We also randomized the order of playback stimuli (predator, conspecific,

203 and control) and the track used per trial to reduce the chances of habituation. Each playback trial
204 was separated by a minimum of five hours to reduce the chance of habituation (we conducted
205 most trials with about 48 hours between playback sessions).

206 Before playback sessions, observers verified that red-tail hawks and mourning doves were not
207 present in the vicinity of the flight pen. To maximize the chances that the parakeets heard the
208 selected playbacks, we did not begin a playback session until we observed low levels of parakeet
209 activity in the flight pen was low (e.g., low call rates, individuals perching in trees behaving non-
210 agonistically). When activity was low, we set up the speakers in the pre-designated, randomized
211 location, and then gave the birds fifteen minutes to return to baseline behavior prior to starting
212 the playback trials.

213 ***Data Collection***

214 During each trial, two observers recorded the behavioral response of the birds, one in blind 1 and
215 one in either blind 2A or 2B (Figure 1). We observed group-level behavior for five minutes prior
216 to each playback session to establish baseline group-level behavior. We recorded two responses
217 to playbacks for at least 50% of the group: (1) categorical group behavioral responses; (2) the
218 time it took birds to cease response behavior and return to baseline behavior (latency in seconds).
219 We then used group responses to score the overall flight responses observed.

220 To measure group responses, we scored group-level behaviors on a scale of 0-4: (0) no response
221 (birds continue their activities without becoming vigilant); (1) vigilant (birds do not move, stop
222 the behaviors they were performing, and become alert); (2) minor movement (birds become alert,
223 and there is slight movement in trees (e.g., hopping between branches)); (3) less than 50% fly (\leq
224 10 birds take flight and become vigilant); (4) more than 50% birds fly ($>$ 10 birds take flight and

225 become vigilant). We used the animal behavior data collection app Animal Observer (version
226 1.0, Dian Fossey Gorilla Fund International 2012; van der Marel et al. 2021) to score responses.
227 Observers narrated into the voice recorder function of Animal Observer to record the behavior of
228 visible birds starting 5 min prior to the playback to establish baseline behavior and ending
229 narration 5 min after the playback, or until birds returned to baseline behavior. Observers also
230 narrated when the playback session began, when the playback session ended, and when the
231 majority of the birds (>50% of the group) resumed baseline behavior after the playback ended.
232 Upon completion of the playback session, we determined the latency of all responses as the
233 difference between the playback end time and the time at which the majority of birds resumed
234 baseline behavior. We averaged measurements between blind 1 and the second blind we used
235 (either blind 2A or 2B, see Figure 1), depending on which blind was randomly selected for
236 observation.

237 *Data Analysis*

238 We examined the effect of the three different playback stimuli (predator, conspecific, control) on
239 group behavior and latency using mixed models. We included playback stimuli and trial as
240 independent factors. We included trial ($n = 5$) to test for the effect of habituation on both group
241 response and latency. We used playback track and observer as random factors in the group
242 response model but only track as a random factor in the latency model. To begin model selection,
243 we tested for the effect of each random factor by sequentially excluding one of the random
244 factors. We then compared the AICc values of the different random effect models using the
245 *performance* package (Lüdecke et al. 2021) and selected the model that best fit the data. We did
246 not find a significant effect of observers on the model, indicating that this random factor would
247 not bias our results. Therefore, we did not run a Z-test to control for observer bias and excluded

248 observer for further analyses. We then built four models to examine which independent variables
249 fit our data: a full model with all independent variables, two models where either playback
250 stimuli or trial were omitted, and a null model where both independent variables were omitted.
251 We fit these models to the data again with the *performance* package (Lüdecke et al. 2021) and
252 selected the model with the lowest AICc value. After model selection for both group responses
253 and latency models, we tested for significant differences between the best fitted and null model
254 from the *lmtest* package (Zeileis and Hothorn 2002) using likelihood ratio tests (LRT). When the
255 best-fitted model was significantly different from the null model, we performed an LRT to
256 investigate the effect of that independent variable by comparing the best-fitted model with the
257 independent variable of interest to a model without that independent variable. If the independent
258 variable showed a significant effect, we assessed the statistical significance using Tukey's
259 Honest Significant Differences.

260 We first examined the effect of the playback stimuli (predator, conspecific, control) on group
261 behavior. Group behavior followed an ordinal distribution, so we used a cumulative link mixed
262 model (CLMM) from the *ordinal* package (Christen 2019). Then, since latency was a continuous
263 variable, we used the *car* and *MASS* packages (Fox and Weisberg 2019; Venables and Ripley
264 2002) to examine which distribution best fit the data. We found that a normal probability
265 distribution best fit our latency data, so we analyzed latency using linear mixed models (LMMs)
266 in the *lme4* package (Douglas et al. 2015). We checked for heteroscedasticity and overall model
267 performance using the *performance* package. We reported the mean and standard deviation for
268 latency for each playback stimuli below. Finally, we derived flight responses from group
269 behaviors using a scale from 1 to -1, with the sign contingent on whether it was a repulsion
270 behavior (positive) or an attraction behavior (negative). Flight responses were given a score

271 based on these criteria: (0): no behavior, vigilant, and minor movement; (± 0.5): less than 50% of
272 birds fly; (± 1): more than 50% of birds fly. To examine differences in flight behaviors among
273 the playback stimuli, we analyzed the flight responses using Kruskal-Wallis' one-way analysis of
274 variance followed by a pairwise comparison using Wilcoxon's rank-sum test.

275 We completed all analyses in RStudio v.4.1.0 (R Core Team 2021). We made all plots using the
276 *ggplot2* package (Wickham 2016) and aestheticized plots (e.g., adding species icons) in Adobe
277 Illustrator (Adobe Illustrator, Adobe Inc.).

278 **Results**

279 We conducted 20 playback trials: 5 repulsion playbacks (predator calls), 10 attraction playbacks
280 (conspecific calls: 5 non-native range and 5 native range), and 5 control playbacks (mourning
281 dove calls). We assessed whether playback stimuli influenced group response, latency, and flight
282 response.

283 ***How Do Monk Parakeets Behaviorally Respond to Playbacks?***

284 We found significant differences in group response among playback stimuli (LRT: $\Lambda = 17.70$, p
285 < 0.001 ; Table 2). Monk parakeets exhibited significant differences in group responses to
286 predator playbacks compared to conspecific playbacks (Tukey's $p < 0.05$) and control playbacks
287 (Tukey's $p < 0.05$; Table 2) (Figure 2A and 3). In response to predator playbacks, monk
288 parakeets exhibited more than half-flock dispersal for 60% of trials, at least half-flock dispersal
289 for 20% of trials, and vigilance for 20% of trials (Figure 4). We did not find significant
290 differences in group responses to conspecific playbacks compared to control playbacks (Tukey's
291 $p = 0.15$; Table 2, Figure 2A and 3). In response to conspecific playbacks, monk parakeets
292 exhibited half-flock dispersal in 10% of trials, with no change in behavior, minor movement, and

293 vigilance making up 20%, 10% and 60% of trials, respectively (Figure 3). In response to control
294 playbacks, monk parakeets exhibited vigilance for 40% of trials and no change in behavior for
295 60% of trials (Figure 4). We found no evidence that monk parakeets habituated regarding group
296 response to playback stimuli as trial was not included in the model with the lowest AICc value
297 (Table 1, Figure S1).

298 Table 1. AIC model selection results for our response variables: (1) group response and (2)
 299 latency. Exemplar was included as a random factor for each model. K is the number of estimated
 300 parameters for each model, LL is the log-likelihood of each model, AICc is the second-order
 301 AIC, Delta is the difference in AIC score between the best model and the model being compared,
 302 weight is the weight of evidence in favor of a given model, and R² is the proportion of variance
 303 in the dependent variable that can be explained by the selected independent variable(s).

| Response Variable | Variable(s) | K | LL | AICc | Delta | Weight | R²₁ |
|--------------------------|---------------------------------|----------|---------------|---------------|--------------|---------------|----------------------------------|
| Group response | Playback Stimuli + Trial | 11 | -15.14 | 85.28 | 24.82 | < 0.001 | NA |
| | Playback Stimuli | 7 | -18.56 | 51.12 | 0 | 0.99 | NA |
| | Trial | 9 | -25.88 | 87.76 | 27.31 | < 0.001 | NA |
| | Null | 5 | -27.41 | 69.11 | 8.65 | 0.01 | NA |
| Latency | Playback Stimuli + Trial | 9 | -59.16 | 154.32 | 0 | 0.995 | 0.71 |
| | Playback Stimuli | 5 | -75.33 | 164.95 | 10.63 | 0.005 | 0.64 |
| | Trial | 7 | -75.78 | 174.89 | 20.58 | < 0.001 | 0.09 |

| | | | | | | |
|------|---|--------|--------|-------|---------|---------|
| Null | 3 | -92.02 | 191.55 | 37.23 | < 0.001 | < 0.001 |
|------|---|--------|--------|-------|---------|---------|

NA = not available.

¹R² is not available for group response.

304

305 Table 2. 95% confidence interval for the group response and latency of monk parakeets in
 306 response to playback stimuli for the model selected. 95% confidence interval is reported as (LL,
 307 UL) such that LL = lower limit for 95% confidence interval and UL = upper limit for 95%
 308 confidence interval.

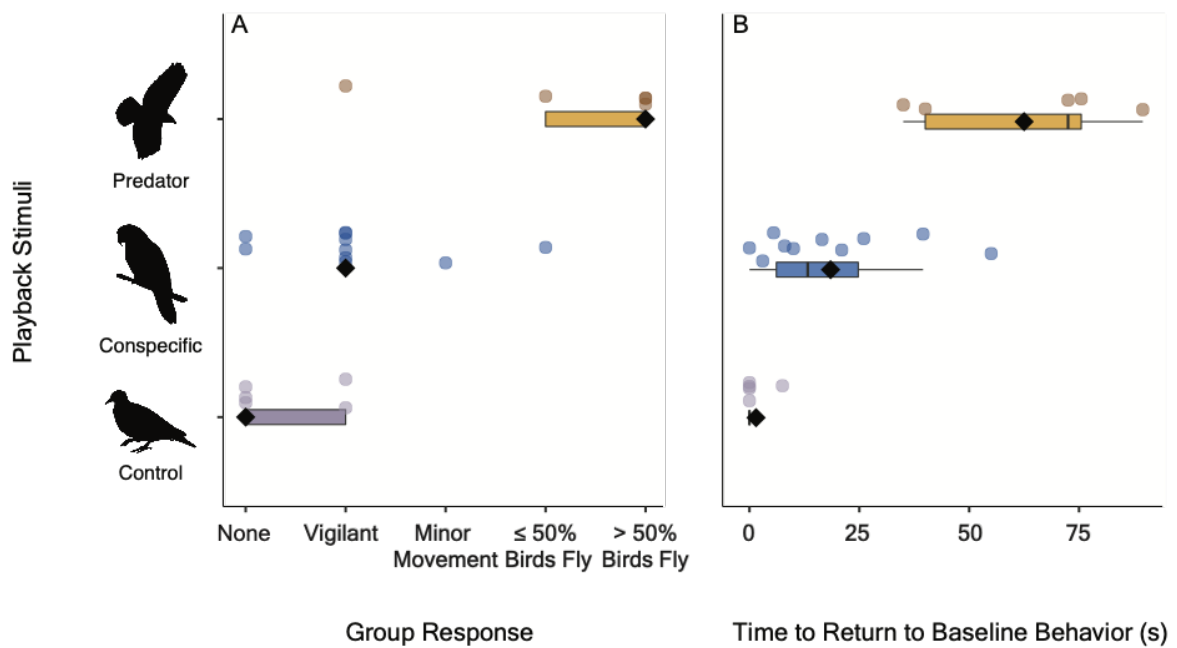
| | Group response¹ | Latency |
|----------------------|-----------------------------------|-----------------------|
| Family | Ordinal | Gaussian |
| Intercept | NA | (-2.86, 26.06) |
| Conspecific playback | (-0.16, 6.78) | (2.48, 31.42) |
| Predator playback | (2.32, 16.68) | (44.29, 77.71) |

NA = not available

¹Intercept is not available for group response.

309

Figure 2: Behavioral responses measured in response to playback stimuli. In panel A, group-level responses are on the x-axis. In panel B, the time to return to baseline behavior in seconds (latency) is on the x-axis. Repulsion (predator – red-tailed hawk, $n = 5$), attraction (conspecific – monk parakeet, $n = 10$), and control (non-predatory – mourning dove, $n = 5$) stimuli are on the y-axis. Measurements are shown in box plots with the median (panel A) and mean (panel B) shown as a black diamond. Error bars indicate 95% confidence intervals.

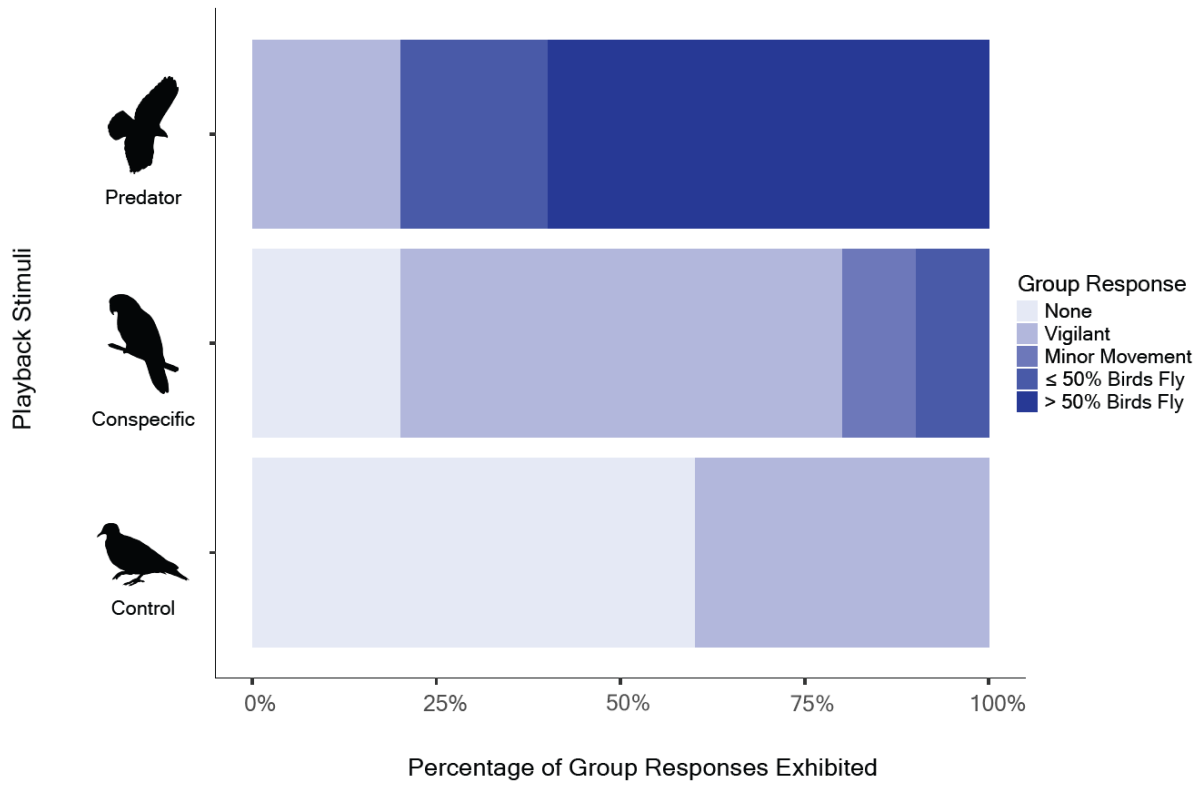


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311

Figure 3: The percentage of group responses measured in response to each playback stimuli.

Stronger group responses are shown in darker blue and weaker behavioral responses in lighter blue.



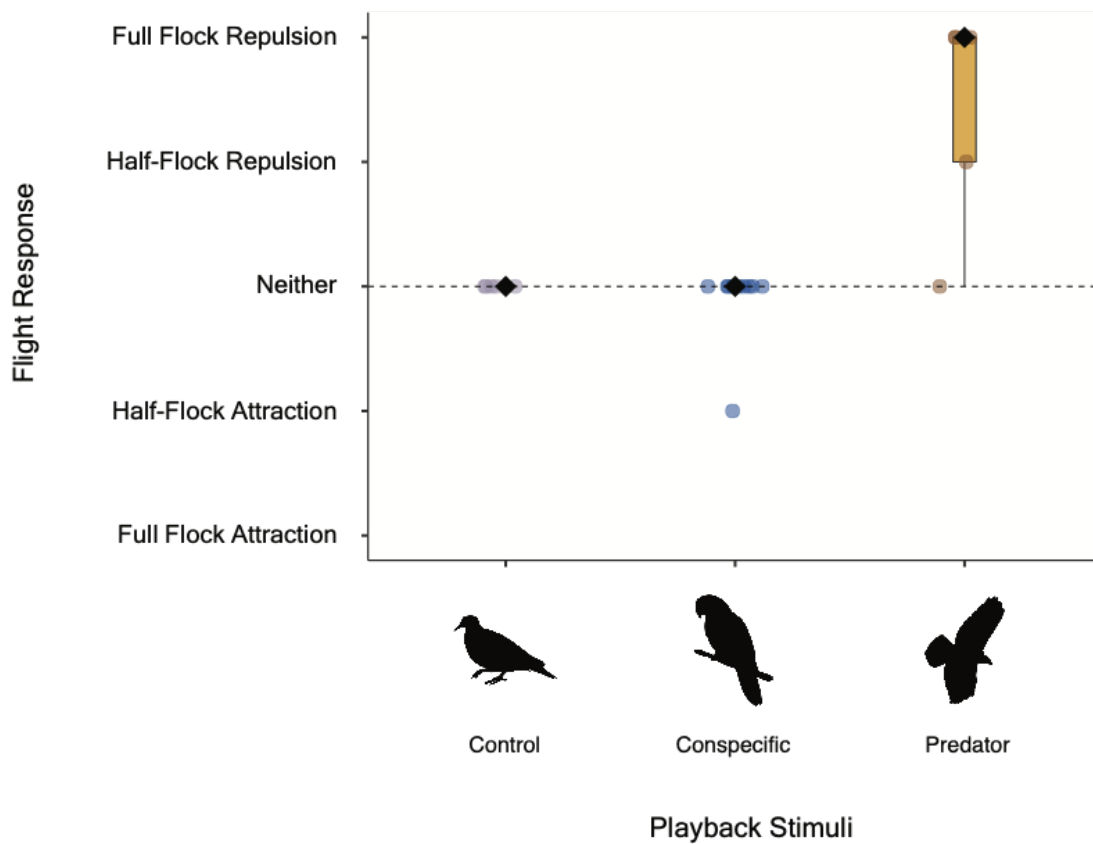
313 ***How Long do Monk Parakeets Take to Return to Baseline Behavior?***

314 The model that best explained latency included playback stimuli and trial (LRT: $\Lambda = 30.70$, $p <$
315 0.001 ; Table 1). We found significant differences in latency among playback stimuli (LRT: $\Lambda =$
316 28.22 , $p < 0.001$; Fig. 3B), but we did not find a significant effect of trial on latency (LRT: $\Lambda =$
317 8.64 , $p = 0.07$; Figure S2). Average latency to return to baseline behavior in response to predator
318 playbacks (62.50 ± 23.77 s) was longer and had more variation than conspecific (18.50 ± 17.56
319 s; Tukey's $p < 0.01$) and control (1.50 ± 3.35 s; Tukey's $p < 0.001$) playbacks (Table 2, Figure
320 2B). Unlike overall group response, the effect of conspecific playbacks on latency to return to
321 baseline behavior was not significantly different compared to control playbacks (Tukey's $p =$
322 0.18 ; Table 2, Figure 2B), although the confidence interval did not include zero (Table 2).

323 ***Which Playback Stimulus Produced a Flight Response?***

324 We found significant differences in flight responses (Kruskal-Wallis's $p < 0.01$) and that the
325 flight response of predator playbacks was more consistent than conspecific playbacks (Figure 4).
326 Predator playbacks elicited repulsion behavior in 80% of playback trials and showed significant
327 differences in flight response when compared to conspecific (Wilcoxon's $p < 0.05$) and control
328 flight responses (Wilcoxon's $p = 0.01$). Unlike predator playbacks, conspecific playbacks only
329 produced the predicted behavior (attraction) in 10% of trials (Figure 3). Conspecific playbacks
330 showed no significant difference in flight response compared to the control playbacks
331 (Wilcoxon's $p = 0.57$).

Figure 4: Repulsion and attraction behavior shown in response to predator playbacks (n = 5), conspecific playbacks (n = 10), and control playbacks (n = 5). Group responses were rescaled and categorized in the context of repulsion and attraction. Predator playbacks showed significant differences in flight response compared to both conspecific and control playbacks. Measurements are shown in box plots with the mean indicated by black diamonds. Error bars indicate 95% confidence intervals.



333 **Discussion**

334 The primary objective of this study was to test how different auditory stimuli (predator or
335 conspecific) produced repulsion or attraction behaviors in a captive group of monk parakeets.
336 We found differences in how strongly the parakeets responded to both types of stimuli, which
337 could be important to consider when integrating auditory stimuli into management strategies for
338 this species.

339 Our results support the hypothesis that predator vocalizations cause flock dispersal away from
340 auditory sources (repulsion). Predator playbacks produced stronger behavioral responses in
341 monk parakeets than conspecific and mourning dove playbacks. Predator playbacks resulted in
342 flight 80% of the time, whereas conspecific playbacks resulted in flight 10% of the time, and
343 mourning dove playbacks never produced flight behavior. These results align with studies that
344 showcase strong behavioral responses to predators in the form of mobbing, movement, and/or
345 vocalizing (Crawford et al. 2022; Dutour, Lena, and Lengagne 2017; Zuberbühler 2001; Manser,
346 Seyfarth, and Cheney 2002). For example, predator playbacks of the sparrow hawk (*Accipiter*
347 *nisus*) successfully repelled house sparrows (*Passer domesticus*), with no habituation observed
348 after six days of exposure (Frings and Frings 1967), and playbacks of a peregrine falcon (*Falco*
349 *peregrinus*) call was also effective at dispersing gulls from Vancouver International Airport
350 (Gunn 1973). Because of these strong responses, managers seeking to displace monk parakeets
351 from a specific area temporarily may have success in using predator calls.

352 In contrast, our results do not support the hypothesis that conspecific calls attract parakeets to the
353 auditory source. We found that conspecific calls resulted in weak or no attraction of parakeets to
354 the stimulus, with half-flock movement towards the auditory source observed only once across

355 all ten trials. From a management perspective, our results indicate that conspecific calls may not
356 be effective stimuli to attract parakeets to a specific area, for example, to facilitate trapping.
357 However, other variables may need to be considered when selecting conspecific vocalizations for
358 playbacks, which may affect their effectiveness for management aims. For example, Nocera et
359 al. (2006) showed that, due to a lack of experience, natal dispersers (i.e., juveniles) might be
360 more receptive to conspecific vocalizations. Kelly and Ward (2017) suggested that in yellow
361 warblers (*Setophaga petechia*), site selection via conspecific attraction is more successful when
362 vocalizations from paired males are used, while Connell et al. (2019) suggested that in black-
363 tailed prairie dogs (*Cynomys ludovicianus*), other cues, such as the physical presence of and/or
364 relationship to the caller, may be essential factors to consider for playbacks. Thus, an
365 individual's response to an auditory cue may also depend on the social information
366 communicated through vocalizations in a particular social system.

367 Monk parakeets may respond to conspecific calls based on their relationship to the caller
368 (Hobson et al. 2015), which has been seen in other birds such as acorn woodpeckers (*Melanerpes*
369 *formicivorus*) (Pardo et al. 2018), carrion crows (*Corvus corone*) (Wascher et al. 2012), and
370 ravens (*Corvus corax*) (Szipl et al. 2015). They may also respond based on the locality of the
371 call, which has been observed in rufous-collared sparrows (*Zonotrichia capensis*) (Danner et al.
372 2011), yellow-naped amazons (*Amazona auropalliata*) (Wright and Dorin 2001), and stonechats
373 (*Saxicola torquata*)(Mortega, Flinks, and Helm 2014). Moreover, monk parakeets exhibit unique
374 vocal signatures in contact calls tied to individual identities, and these individual signatures are
375 simpler in smaller non-native range populations, which suggests that monk parakeets use contact
376 calls to recognize distinct individuals (Smith-Vidaurre, Perez-Marrufo, and Wright 2021; Smith-
377 Vidaurre, Araya-Salas, and Wright 2020). Therefore, it may be useful for researchers to explore

378 behavioral responses to familiar or unfamiliar individuals to determine which calls may be best
379 for management purposes.

380 We did not examine differences in individual responses to playbacks with this study design.
381 However, it can be important to understand how individual characteristics (e.g., sex or age) and
382 social relationships (e.g., partnered with another individual) influence an individual's response to
383 stimuli, and how this may influence overall group-decision making, for a robust management
384 approach. For example, Kerman (2018) found that male monk parakeets that are risk-averse
385 while foraging become bolder in the presence of conspecifics, and it has been observed that
386 monk parakeets decrease vigilance effort as flock size increases (South and Pruett-Jones 2000).
387 Thus, assessing how social context (e.g., flock size) may underlie behavioral responses to
388 external stimuli could be necessary for management success. When managing group-living
389 species such as monk parakeets (e.g., red-backed fairy-wrens (*Malurus melanocephalus*)), it may
390 be important to adjust for population-level differences due to possible individual and group-
391 dynamic behavioral variation as a result of unique ecological pressures (Maldonado-Chaparro
392 and Chaverri 2021). Future studies should explicitly consider how individual, population, and
393 temporal characteristics, including variation in group size and season, influence responses to
394 sensory cues that may be useful for management.

395 ***Management Implications***

396 Our results showcase clear behavioral outcomes based on the playback stimuli used, with no
397 evidence of habituation, that are promising for management purposes. Auditory cues can be used
398 at a very low cost, with little to no ecosystem disturbance, and are readily available.
399 Furthermore, auditory cues may not come with conflicts of interest compared to other forms of

400 management, such as culling via poisons (van Eeden et al. 2017). Our results show that in
401 captive monk parakeets, predator playbacks produced a momentary change in behavior. Predator
402 stimuli may be useful when management objectives require the temporary dispersal of
403 individuals from a small area. For example, once monk parakeets are detected at a site, predator
404 playbacks may help disperse birds and prevent site-specific nest building (Burgio, Rubega, and
405 Sustaita 2014). When implementing predator playbacks, managers should consider the
406 geographic location of the monk parakeet population to select the appropriate predator(s). In
407 Florida, common avian predators include the red-tailed hawk, red-shouldered hawk (*Buteo*
408 *lineatus*), and Cooper's hawk (*Accipiter cooperii*), but in introduced locations such as the Iberian
409 Peninsula, avian predators such as the Eurasian sparrowhawk (*Accipiter nisus*) and Eurasian
410 kestrel (*Falco tinnunculus*) may be more appropriate choices.

411 When considering playbacks as part of a management plan, the timing of the intervention should
412 also be carefully considered, as the parakeets may be more or less responsive to predator stimuli.
413 For example, monk parakeet site fidelity increases once nests have been established (Dawson
414 Pell et al. 2021), so management interventions could be timed to occur prior to this increased
415 fidelity. Because of this high nest fidelity, it is unlikely that predator playbacks would cause nest
416 and site abandonment once the parakeets have initiated nest building. Although auditory cues
417 alone may not be enough to control a particular group or population, coupling auditory cues with
418 additional management strategies may be powerful for desired outcomes. In this case, it may be
419 useful to leverage an integrated approach, including other currently implemented avian
420 management tools (e.g., frightening devices (Enos, Ward, and Hauber 2021)). For example, in
421 areas where lethal shooting is authorized and safe to implement, using predator playbacks to
422 prompt flocking behavior could help maximize the efficacy of culling as a management tool.

423 ***Conclusion***

424 Our experiments show the potential for repulsion stimuli to be an effective tool for some
425 management plans for monk parakeet populations, where the goal is to temporarily displace a
426 group of parakeets and induce flight and vigilance behaviors. Our results re-emphasize the
427 importance of informing management with data from experiments. These results can then be
428 framed to recommend options managers can consider when managing monk parakeet
429 populations and other populations that rely on ecological information in the form of auditory
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