

1 **Temporary behavioral responses to playbacks by a pest parrot and implications for**
2 **management**

3 **Running Head:** Playback responses in a pest parrot

4
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27 **Abstract**

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

47

48 **Keywords**

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

51 **Introduction**

52 Anthropogenic disturbances and policies, including changes in human land use, continue to alter
53 ecosystems worldwide. These disturbances are bringing humans and wildlife into more frequent
54 and novel forms of contact, leading to changes in wildlife behavior. For example, disturbances
55 have been found to increase species' nocturnal activity (Gaynor et al., 2018; Wilson et al., 2020)
56 as well as species mortality and habitat loss (Hill et al., 2020; Hoekstra et al., 2004; Kennedy et
57 al., 2019). Disturbances can also alter ecological and evolutionary processes in cities, for
58 instance, by changing landscape heterogeneity that in turn influences resource availability and
59 biodiversity (Des Roches et al., 2021; Schell et al., 2020). These impacts on various species, and
60 the associated human-wildlife conflict, have prompted several management strategies to reduce
61 the negative consequences that may arise from human-wildlife interactions, including indirect
62 practices such as building fences to exclude wildlife from specific areas as well as direct
63 approaches such as lethal management (Khorozyan & Waltert, 2019; Wilkinson et al., 2020).
64 These strategies can potentially resolve the conflict presented (e.g., successfully deterring a
65 species from entering an area); however, the ecological response and effectiveness of
66 implemented strategies are important to consider for both direct and lateral impacts, for example,
67 when constructing fences for the exclusion of particular species (Jones et al., 2018; Wilkinson et
68 al., 2021). Moreover, evaluating the effectiveness of management strategies is crucial for
69 adequately preventing and resolving current human-wildlife conflict consequences (Treves et al.,
70 2006), which may be achieved by integrating an experimental approach (Enck et al., 2006;
71 Richardson et al., 2020; Walters & Holling, 1990).

72 Recently, researchers have highlighted the benefits of incorporating sensory ecology into
73 management policies. These benefits can include reducing harm to wildlife and predicting how

74 wildlife will respond to environmental change (Elmer et al., 2021). Management strategies built
75 around a species' sensory ecology focus on a particularly relevant sense of the target species and
76 can function as repulsive or attractive signals that cause animals to avoid or gather in areas for
77 specific management-related activities. For example, olfactory cues like wolf urine can stimulate
78 avoidance behavior in deer (Chamaillé-Jammes et al., 2014; Osada, Miyazono, &
79 Kashiwayanagi, 2014), while visual cues, such as changes in lighting or the use of predator
80 models, can cause target species to alter their foraging strategies and overall activity (e.g., black-
81 capped chickadees (*Poecile atricapillus*) (Arteaga-Torres, Wijmenga, & Mathot 2020); ship rats
82 (*Rattus rattus*) (Farnworth et al., 2020)). Moreover, acoustic cues have been used to address
83 management problems for particularly problematic populations via broadcasting biologically
84 relevant sounds to influence reproduction (e.g., bark beetles (Coleoptera: Curculionidae)
85 (Hofstetter et al., 2014)) or using acoustic deterrents, such as underwater speakers, to influence
86 movement (e.g., fish (Putland & Mensinger, 2019)). More generally, acoustic cues have been
87 used to investigate behaviors such as territoriality (Frostman & Sherman, 2004; Heinsohn, 1997;
88 Reif et al., 2015), vocal discrimination (Searcy, Nowicki, & Hughes, 1997; Searcy et al., 2002),
89 and anti-predator responses (Adams & Kitchen, 2020; Bshary, 2001). With many species attuned
90 to auditory cues for their ecology (e.g., primates (Ghazanfar & Santos, 2003), birds (Marler &
91 Slabbekoorn, 2004)), auditory cues provide useful opportunities for nonlethal and widespread
92 management strategies that may reduce human-wildlife conflict.

93 Natural auditory stimuli, such as vocal signals, are easy to record and broadcast to implement
94 population-level management strategies. These recorded stimuli can be used for two types of
95 management goals. First, repulsive signals can deter individuals from an area where they are
96 unwanted, such as deterring birds from buildings (Boycott et al., 2021) and reducing crop

97 damage on agricultural lands (Mahjoub, Hinders, & Swaddle, 2015; Werrell et al., 2021).
98 Second, attraction signals can encourage individuals to move to an area where the presence of
99 those animals is desired, including inciting individuals to visit and remain in specific habitat
100 patches (Buxton, Ward, & Sperry, 2018; DeJong et al., 2015). With these advances in
101 implementing biologically relevant auditory cues via playback experiments, auditory cues can
102 readily be used as a management approach, particularly when designing management strategies
103 to control avian pests (Berge et al., 2007; Budka et al., 2019; Depino & Areta, 2019; Khan et al.,
104 2011).

105 The strong foundation of playback experiments provides a robust framework for continuous
106 assessments of how auditory stimuli may contribute to alleviating human-avian conflict,
107 particularly in geographically widespread species. A prime example of widespread avian species
108 that can pose problems for human populations are parrots (Psittaciformes), a species-rich taxon
109 with global distribution (Calzada Preston & Pruett-Jones, 2021; Davies et al., 2007; Kosman et
110 al., 2019; Vergara-Tabares et al., 2020) that have become increasingly established in non-native
111 ranges (Joseph, 2014). As parrot species distributions change with increasing urbanization
112 (Huang et al., 2019; Liu et al., 2020) and movement via the pet trade (Edelaar et al., 2015;
113 Martin, 2018; Pires, 2015), parrots are often coming in close contact with humans. Human-parrot
114 conflict increases as parrots settle in or near human-modified habitats like farms or
115 suburban/urban greenspaces (de Matos Fragata et al., 2022; Menchetti & Mori, 2014), with
116 ~44% of parrot species using croplands as habitat (Barbosa et al., 2021). These conditions make
117 parrots opportune to explore how integrating auditory stimuli can alleviate not only human-
118 parrot conflict but human-wildlife conflict more generally.

119 The monk parakeet (*Myiopsitta monachus*) has become one of the most widely distributed parrot
120 species (Calzada Preston & Pruett-Jones, 2021), making them a well-suited species to
121 experimentally test approaches that may alleviate human-wildlife conflict. Monk parakeets are
122 gregarious parrots native to South America and have been introduced in over 20 countries in
123 North America, Europe, Africa, Asia, and at least four Caribbean islands as a byproduct of the
124 pet trade (Avery et al., 2020; Burgio, Rubega, & Sustaita, 2014; CABI, 2010; Hobson, Smith-
125 Vidaurre, & Salinas-Melgoza, 2017). Monk parakeets build communal and colonial nests that
126 range in size, with large multi-chambered nests hosting dozens of pairs (Avery et al., 2002;
127 Bucher et al., 1990; Eberhard, 1998;). Conflict between humans and monk parakeets typically
128 manifests in three ways: (1) economic and safety hazards in urban areas, (2) agricultural impacts,
129 and (3) human health concerns. Following their establishment of new populations, monk
130 parakeets have established nests throughout the urban sprawl on artificial structures as varied as
131 power poles, electricity substations, silos, and fire escapes (Avery & Lindsay, 2016), introducing
132 economic costs and safety concerns for humans (Avery et al., 2002; Stafford, 2003). In addition
133 to their role as an urban pest, monk parakeets' propensity to inhabit changing landscapes and
134 consume a wide variety of food resources (Bucher & Aramburú, 2014; Postigo et al., 2021) has
135 also led them to become agricultural pests in parts of their native and introduced ranges (Davis,
136 1974; MacGregor-Fors et al., 2011; Mott, 1973; Senar et al., 2016; Stafford, 2003). For instance,
137 damage in Barcelona ranges from 0.4% to 37% crop loss, depending on the particular crop
138 (Senar et al., 2016). Lastly, recent research indicates that monk parakeets may serve as a
139 reservoir for zoonotic diseases in some areas (Morinha et al., 2020), introducing a concern for
140 human health; however, this is not widely observed (Ortiz-Catedral et al., 2022). As a result of
141 these concerns and conflicts, monk parakeets have become a management priority in many areas.

142 Thus, ecologically informed techniques for managing these parrot populations are essential to
143 mitigate conflict among human and monk parakeet populations.

144 Here, we explore group-level behavioral responses of a captive population of monk parakeets to
145 biologically relevant auditory stimuli and discuss our findings within a wildlife management
146 context. We evaluated two auditory cues that we expected to serve as either repulsion (predator
147 vocalizations) or attractive (conspecific vocalizations) stimuli, as well as control stimuli
148 (vocalizations from a common bird we expected to serve as neither repulsive nor attractive). We
149 hypothesized that (1) predator playbacks would result in the repulsion of the captive group away
150 from the auditory source in accordance with the literature on prey responses to predator stimuli
151 (Hettena, Munoz, & Blumstein, 2014; Lönnstedt et al., 2012; Smith et al., 2017) and (2)
152 conspecific playbacks would result in the attraction of the captive group towards the auditory
153 source, in line with previous work that used conspecific vocalizations to attract individuals of a
154 focal species and to attract focal species to specific patches (Ahlering et al., 2010; Lewis,
155 Williams, & Gilman, 2021). We then discuss how our results could help inform different
156 management strategies and goals for avian pest species.

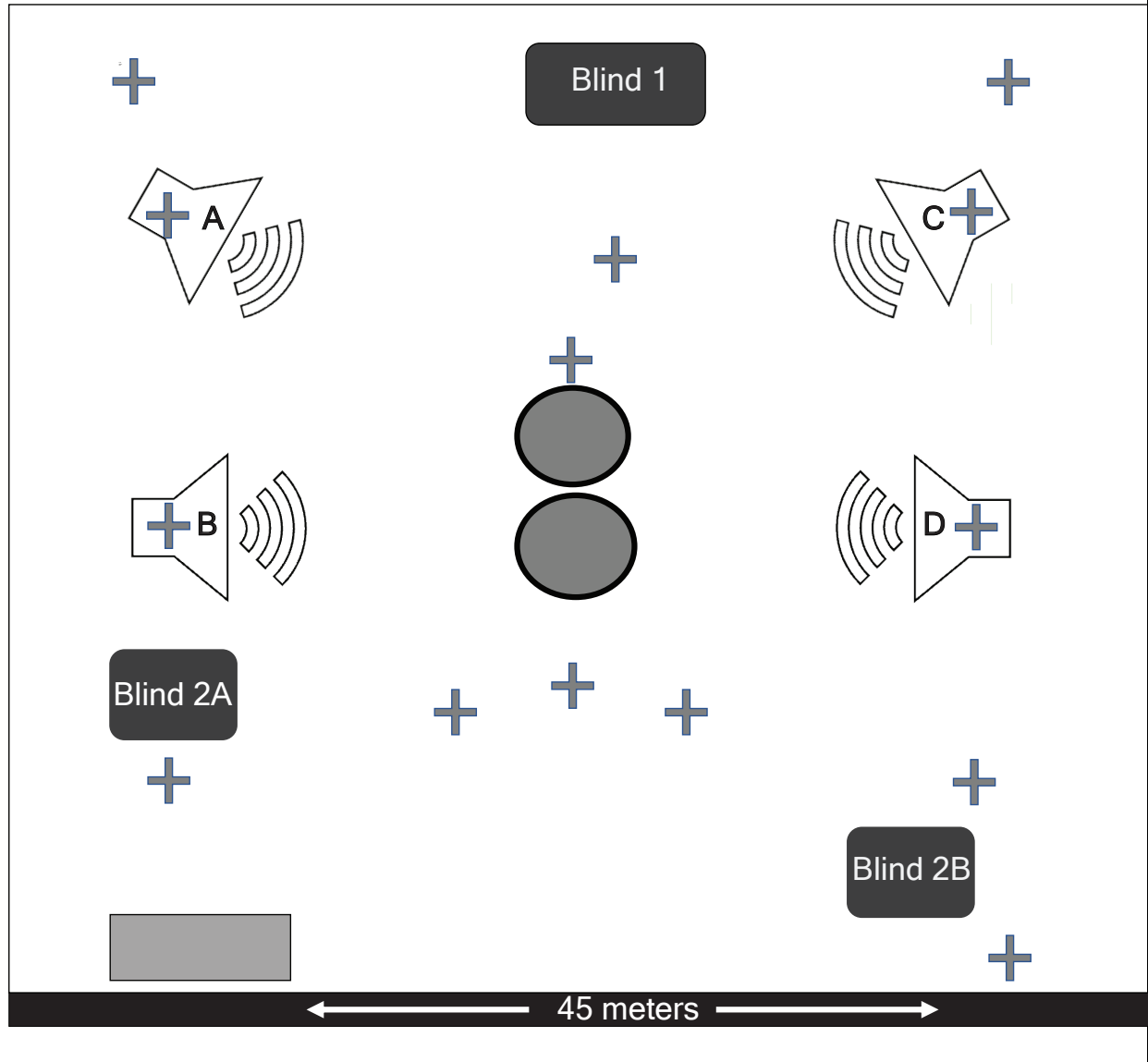
157 **Methods**

158 *Study Species and Location*

159 We conducted this study on a captive population of monk parakeets ($n = 20$) in Gainesville,
160 Florida at the USDA Wildlife Services National Wildlife Research Center Florida Field Station
161 from April to July 2021. This population of monk parakeets was captured just prior to our study
162 period (January – March 2021) by the USDA National Wildlife Research Center from feral
163 populations throughout Southern Florida. This population was held in a large 2,025 m² outdoor

164 semi-natural flight pen (Figure 1). Using newly caught feral monk parakeets in a semi-natural
165 flight pen allows us to (1) observe behavioral responses that would likely occur in natural
166 settings where these playbacks would be used as this population was only in captivity for a
167 month prior to our experiment and (2) maintain constant group size to consistently measure
168 behavioral responses in our captive population. All experiments were approved by the University
169 of Cincinnati (IACUC protocol #AM02-19-11-19-01) and the National Wildlife Research Center
170 (Quality Assurance protocol #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. Blinds are locations where observers are located during playback sessions.



172 ***Playback Stimuli***

173 We used three playback stimuli to conduct our experiments: a predator call to test for repulsion,
174 a conspecific call to test for attraction, and a control to ensure that attraction and repulsion
175 patterns were not due to our playback setup or speaker (see the following paragraphs for details
176 on playback file creation). For our predator playback, we used vocalizations from a local
177 predator, the red-tailed hawk (*Buteo jamaicensis*). For our conspecific playback, we used
178 vocalizations from monk parakeets that were strangers to the captive group. For our control
179 playback, we used vocalizations from a local bird species, the mourning dove (*Zenaida*
180 *macroura*). We maintained a consistent volume for the playback stimuli across all trials. We
181 created all playback tracks in Raven Lite version 2.0.1 (Bioacoustics Research Program 2014,
182 Cornell Lab of Ornithology) and used randomization in RStudio version 4.1.0 (R Core Team,
183 2021) to choose the variant of each playback track used in each trial.

184 Both red-tailed hawk and mourning dove vocalizations were selected for their biological
185 relevance as predatory and non-predatory species, respectively, and their common occurrence in
186 Florida. Neither of these species was abundant around the flight pen, which lessened the chance
187 of attracting local birds when playing conspecific calls and confounding parakeets' responses to
188 our experimental stimuli. Despite the low abundance of both species near our experimental
189 setup, we expected that the newly caught group of monk parakeets would reliably respond to the
190 respective calls, since these species are both abundant where the feral parakeets were captured
191 from wild populations in Southern Florida. We downloaded screech calls of adult red-tailed
192 hawks and perched songs of adult mourning doves from xeno-canto, a non-profit website that
193 stores recordings of bird vocalizations uploaded by recordists worldwide (Planqué & Vellinga,
194 2008; Vellinga & Planqué, 2015). We chose recordings that did not contain any background

195 vocalizations of conspecifics or heterospecifics. We chose three unique files per species and
196 selected the first 30 seconds of each file to create a playback track. This method resulted in three
197 unique tracks (exemplars) per stimuli. Predator playback tracks contained four to ten
198 vocalizations per track, and control playback tracks contained three vocalizations per file
199 (exemplars). We did not edit the number of vocalizations after selecting the first 30 seconds of
200 each file as we wanted to accurately replicate vocalizations evoked in natural settings. In each
201 repulsion and control trial, we randomly selected one of the three exemplars to broadcast to the
202 captive parakeets.

203 For conspecific vocalizations, we randomly selected non-native ($n = 3$) and native ($n = 3$) range
204 monk parakeet contact calls collected in previous studies (Smith-Vidaurre, Araya-Salas, &
205 Wright, 2020; Smith-Vidaurre, Perez-Marrufo, & Wright, 2021). We used contact calls as our
206 stimuli because parrots often use these vocalizations to maintain auditory contact within pairs
207 and flocks (Bradbury & Balsby, 2016). We included non-native calls in addition to native calls to
208 reduce the chances of novelty responses, as non-native calls should be less novel to birds from a
209 non-native population. In addition, when selecting non-native range calls, we controlled for
210 biases in behavioral responses to familiar birds by selecting monk parakeet contact calls recorded
211 outside of Florida, but still within the United States of America, which allowed us to present
212 calls of individuals that were likely unfamiliar to the captive birds. We created three unique
213 playback tracks (exemplars) for each native and non-native range call. Each track represents a
214 unique individual. For each playback track, we randomly selected one call and repeated the
215 selected call ten times, separated by three-second gaps to simulate natural calling behavior
216 (Hobson et al., 2015). Each conspecific playback was 30 seconds long and contained nine

217 replicates of each exemplar. In each conspecific trial, we randomly selected one of these
218 playback tracks to broadcast to the captive parakeets.

219 All playback tracks contain vocalizations from unique individuals. The predator/control playback
220 tracks are similar in duration to the conspecific playback tracks. The difference between the
221 predator/control tracks and the conspecific tracks is that we used different vocalizations for the
222 predator/control tracks but repeated one vocalization for the conspecific tracks (Figure S1).

223 *Experiment and Setup*

224 We conducted playback sessions between 09:00 and 18:00 using a wireless speaker (JBL Charge
225 4 Wireless speaker). We randomized the speaker's placement to four locations within the flight
226 pen to reduce the probability of habituation to playback stimuli (Figure 1). We also randomized
227 the order of playback stimuli (predator, conspecific, and control) and the track used per trial to
228 reduce the chances of habituation. Each playback trial was separated by a minimum of five hours
229 to reduce the chance of habituation (we conducted most trials with about 48 hours between
230 playback sessions).

231 Before playback sessions, observers verified that red-tail hawks and mourning doves were not
232 present in the vicinity of the flight pen. To maximize the chances that the parakeets heard the
233 selected playbacks, we did not begin a playback session until we observed low levels of parakeet
234 activity in the flight pen (e.g., low call rates, individuals perching in trees behaving non-
235 agonistically). When activity was low, we set up the speaker in the pre-designated, randomized
236 location. After setting up the speaker, the observer returned to their respective blind, and we
237 waited at least fifteen minutes to begin playback sessions. If birds did not return to baseline
238 behavior, we waited longer until birds returned to baseline behavior or low activity levels were

239 observed. We removed the speaker following each trial to reduce damage from monk parakeets
240 and recharge speakers.

241 ***Data Collection***

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

248 To measure group responses, we scored group-level behaviors on a scale of 0-4: (0) no response
249 (birds continue their activities without becoming vigilant); (1) vigilant (birds stop the behaviors
250 they were performing, do not move, and become alert); (2) minor movement (birds become alert
251 and there is slight movement in trees (e.g., hopping between branches)); (3) less than 50% fly
252 (≤ 10 birds take flight and become vigilant); (4) more than 50% birds fly (> 10 birds take flight
253 and become vigilant). We used the animal behavior data collection app Animal Observer
254 (version 1.0, Dian Fossey Gorilla Fund International 2012; van der Marel et al., 2022) to score
255 responses. Observers narrated into the voice recorder function of Animal Observer to record the
256 behavior of visible birds starting 5 min prior to the playback to establish baseline behavior and
257 ending narration 5 min after the playback, or until birds returned to baseline behavior. Observers
258 also narrated when the playback session began, when the playback session ended, and when the
259 majority of the birds ($> 50\%$ of the captive group) resumed baseline behavior after the playback
260 ended. Narrations should not alter behaviors of our captive group due to (1) habituation to

261 hearing human voices due to radio communication throughout the field season, (2) blind 1 is a
262 large, closed structure which sound cannot easily travel through, 3) blinds 2A and blinds 2B are
263 placed where parakeets rarely frequent, and (4) observers spoke low enough for birds to not hear
264 the reporting of observations. Upon completion of the playback session, we determined the
265 latency of all responses as the difference between the playback end time and the time at which
266 the majority of birds resumed baseline behavior. We averaged latency measurements between
267 blind 1 and the second blind we used (either blind 2A or 2B, see Figure 1), depending on which
268 blind was randomly selected for observation.

269 ***Data Analysis***

270 We used mixed models to examine the effect of the three different playback stimuli (predator,
271 conspecific, control) on group behavior and latency (Figure S2). We included playback stimuli
272 and trial as independent factors. We included trial ($n = 5$) to test for the effect of habituation on
273 both group response and latency. We used playback track and observer as random factors in the
274 group response model but only track as a random factor in the latency model. To begin model
275 selection, we tested for the effect of each random factor by sequentially excluding one of the
276 random factors. We then compared the AICc values of the different random effect models using
277 the *performance* package (Lüdecke et al., 2021) and selected the model that best fits the data. We
278 did not find a significant effect of observers on the model, indicating that this random factor
279 would not bias our results. Therefore, we did not run a Z-test to control for observer bias and
280 excluded observer for further analyses. We then built four models to examine which independent
281 variables fit our data: a full model with all independent variables, two models where either
282 playback stimuli or trial were omitted, and a null model where both independent variables were
283 omitted (Figure S2). We fit these models to the data again with the *performance* package

284 (Lüdecke et al., 2021) and selected the model with the lowest AICc value. After model selection
285 for both group responses and latency models, we tested for significant differences between the
286 best fitted and null model from the *lmtest* package (Zeileis & Hothorn, 2002) using likelihood
287 ratio tests (LRT). When the best-fitted model was significantly different from the null model, we
288 performed an LRT to investigate the effect of that independent variable by comparing the best-
289 fitted model with the independent variable of interest to a model without that independent
290 variable. If the independent variable showed a significant effect, we assessed the statistical
291 significance using Tukey's Honest Significant Differences.

292 We first examined the effect of the playback stimuli (predator, conspecific, control) on group
293 behavior. Group behavior followed an ordinal distribution, so we used a cumulative link mixed
294 model (CLMM) from the *ordinal* package (Christen, 2019). Then, since latency was a
295 continuous variable, we used the *car* and *MASS* packages (Fox & Weisberg, 2019; Venables &
296 Ripley, 2002) to examine which distribution best fits the data. We found that a normal
297 probability distribution best fits our latency data, so we analyzed latency using linear mixed
298 models (LMMs) in the *lme4* package (Bates et al., 2015). We checked for heteroscedasticity and
299 overall model performance using the *performance* package. We reported the mean and standard
300 deviation for latency for each playback stimulus below. Finally, we derived flight responses from
301 group behaviors using a scale from 1 to -1, with the sign contingent on whether it was a
302 repulsion behavior (positive) or an attraction behavior (negative). Flight responses were given a
303 score based on these criteria: (0): no behavior, vigilant, or minor movement; (± 0.5): less than
304 50% of birds fly; (± 1): more than 50% of birds fly. To examine differences in flight behaviors
305 among the playback stimuli, we analyzed the flight responses using Kruskal-Wallis' one-way
306 analysis of variance followed by a pairwise comparison using Wilcoxon's rank-sum test.

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

310 **Results**

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

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

316 We found significant differences in group response among playback stimuli (LRT: $\Lambda = 17.70$, p
317 < 0.001 ; Table 2). Monk parakeets exhibited significant differences in group responses to
318 predator playbacks compared to conspecific playbacks (Tukey's $p < 0.05$) and control playbacks
319 (Tukey's $p < 0.05$) (Table 2, Figure 2A and 3). In response to predator playbacks, monk
320 parakeets exhibited more than half-flock dispersal for 60% of trials, at least half-flock dispersal
321 for 20% of trials, and vigilance for 20% of trials (Figure 3). We did not find significant
322 differences in group responses to conspecific playbacks compared to control playbacks (Tukey's
323 $p = 0.15$) (Table 2, Figure 2A and 3). In response to conspecific playbacks, monk parakeets
324 exhibited half-flock dispersal in 10% of trials, with no change in behavior, minor movement, and
325 vigilance making up 20%, 10%, and 60% of trials, respectively (Figure 3). In response to control
326 playbacks, monk parakeets exhibited vigilance for 40% of trials and no change in behavior for
327 60% of trials (Figure 3). We found no evidence that monk parakeets habituated regarding group

328 response to playback stimuli as trial was not included in the model with the lowest AICc value
329 (Table 1, Figure S3).

330 **Table 1.** AIC model selection results for the effects of playback stimuli on group response and
 331 latency. Exemplar was included as a random factor for each model. K is the number of estimated
 332 parameters for each model, LL is the log-likelihood of each model, AICc is the second-order
 333 AIC, Delta is the difference in AIC score between the best model and the model being compared,
 334 Weight is the weight of evidence in favor of a given model, and R² is the proportion of variance
 335 in the dependent variable that can be explained by the selected independent variable(s). R² is not
 336 available for group response.

Response Variable	Variable(s)	K	LL	AICc	Delta	Weight	R²
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

337

338 **Table 2.** 95% confidence interval results for effects of playback stimuli on group response and
 339 latency. 95% confidence interval is reported as (LL, UL) such that LL = lower limit for 95%
 340 confidence interval and UL = upper limit for 95% confidence interval. Intercept is not available
 341 for group response.

	Group response	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)

342

Figure 2. Behavioral responses 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 black diamonds. Error bars indicate 95% confidence intervals.

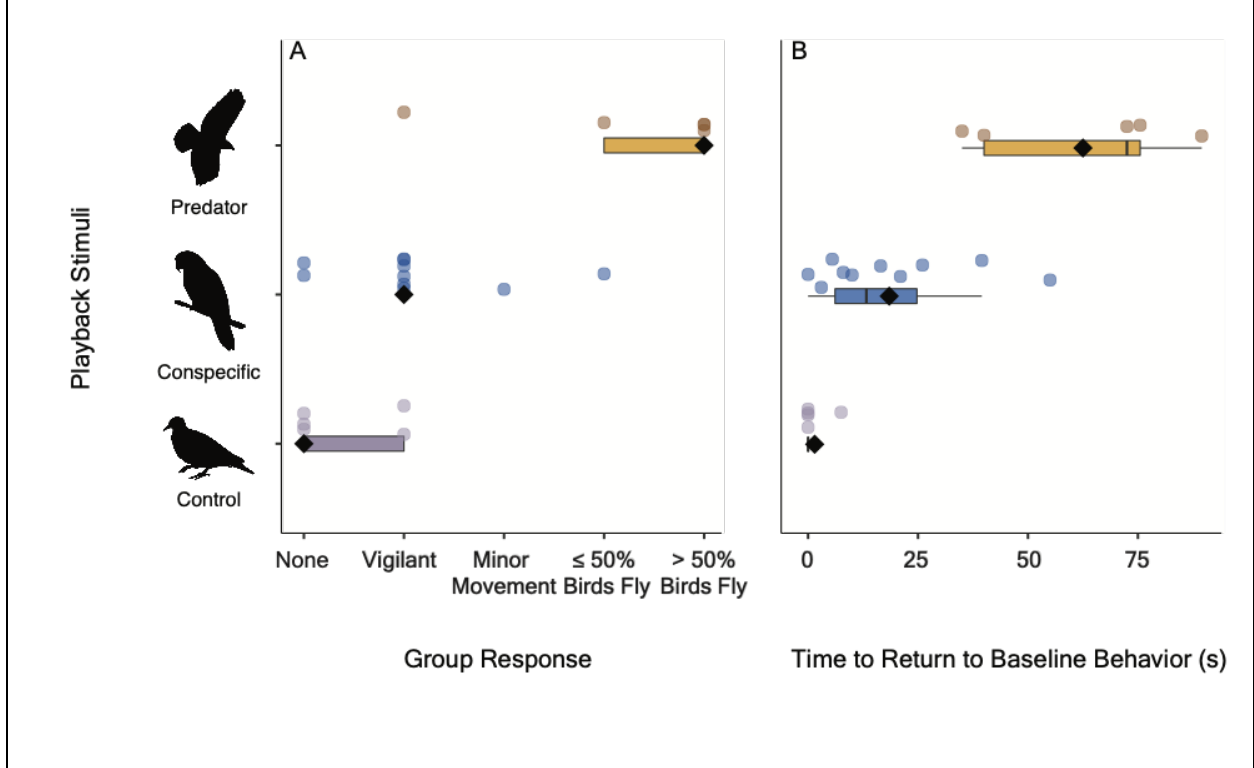
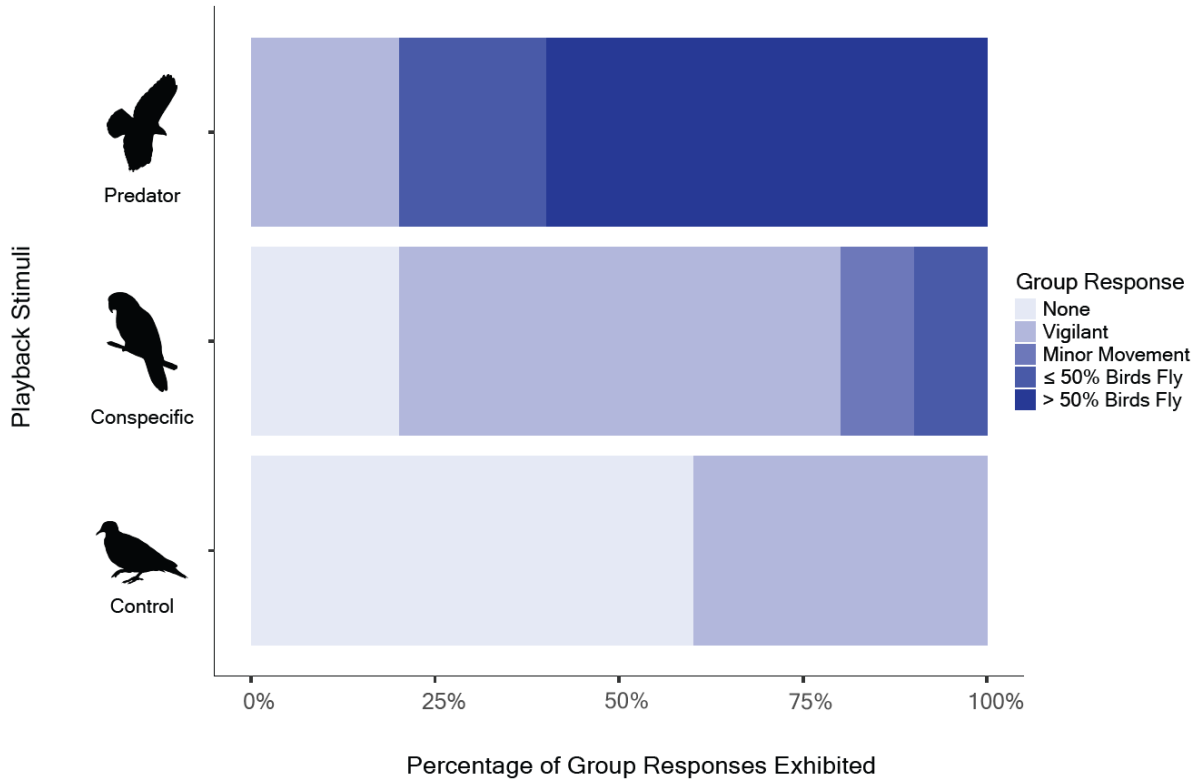


Figure 3. The percentage of group responses in response to playback stimuli. Stronger group responses are shown in darker blue and weaker behavioral responses in lighter blue.



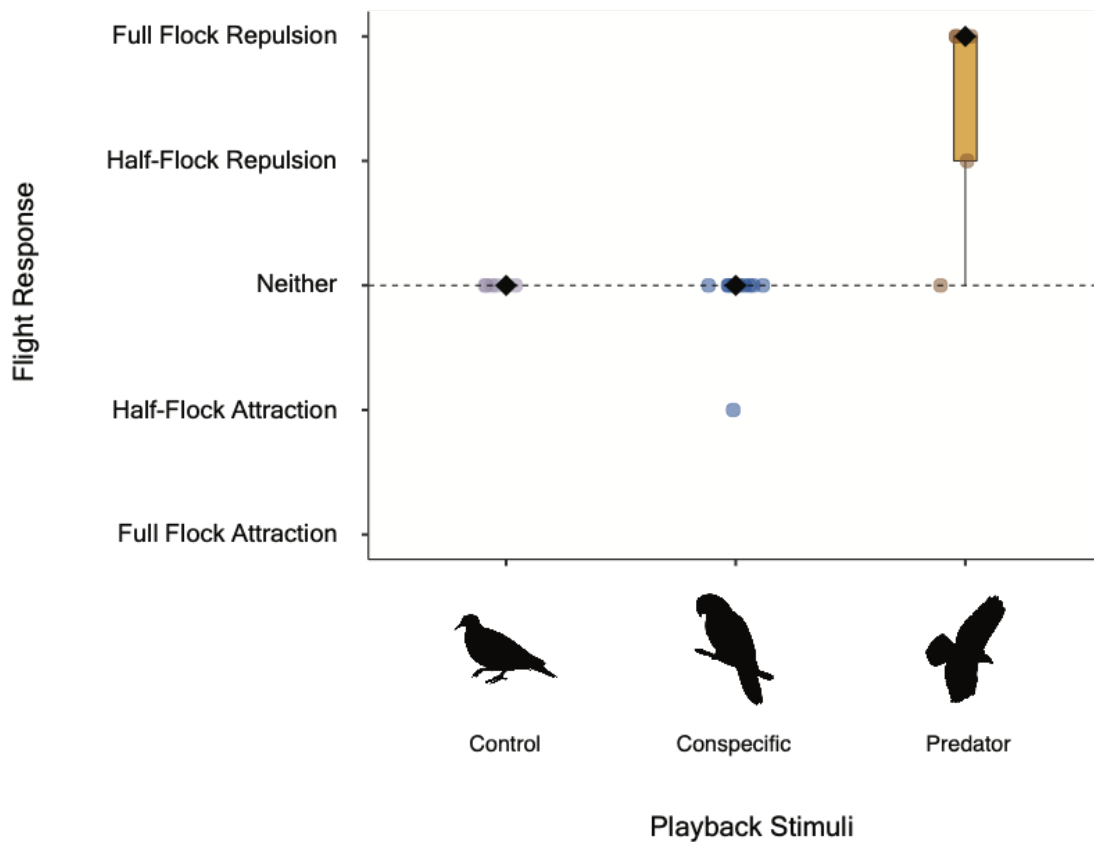
345 ***How Long do Monk Parakeets Take to Return to Baseline Behavior?***

346 The model that best explained latency included playback stimuli and trial (LRT: $\Lambda = 30.70$, $p <$
347 0.001 ; Table 1). We found significant differences in latency among playback stimuli (LRT: $\Lambda =$
348 28.22 , $p < 0.001$; Fig. 2B), but we did not find a significant effect of trial on latency (LRT: $\Lambda =$
349 8.64 , $p = 0.07$; Table 1, Figure S4). Average latency to return to baseline behavior in response to
350 predator playbacks (62.50 ± 23.77 s) was longer and had more variation than conspecific (18.50
351 ± 17.56 s; Tukey's $p < 0.01$) and control (1.50 ± 3.35 s; Tukey's $p < 0.001$) playbacks (Table 2,
352 Figure 2B). Unlike overall group response, the effect of conspecific playbacks on latency to
353 return to baseline behavior was not significantly different compared to control playbacks
354 (Tukey's $p = 0.18$; Table 2, Figure 2B), although the confidence interval did not include zero
355 (Table 2).

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

357 We found significant differences in flight responses (Kruskal-Wallis's $p < 0.01$) and that the
358 flight response of predator playbacks was more consistent than conspecific playbacks (Figure 4).
359 Predator playbacks elicited repulsion behavior in 80% of playback trials and showed significant
360 differences in flight response when compared to conspecific (Wilcoxon's $p < 0.05$) and control
361 flight responses (Wilcoxon's $p = 0.01$). Unlike predator playbacks, conspecific playbacks only
362 produced the predicted behavior (attraction) in 10% of trials (Figure 3). Conspecific playbacks
363 showed no significant difference in flight response compared to the control playbacks
364 (Wilcoxon's $p = 0.57$).

Figure 4. Repulsion and attraction behavior in response to playback stimuli. Group responses to predator playbacks ($n = 5$), conspecific playbacks ($n = 10$), and control playbacks ($n = 5$) 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 median indicated by black diamonds. Error bars indicate 95% confidence intervals.



366 **Discussion**

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

372 Our results support the hypothesis that predator vocalizations cause flock dispersal away from
373 auditory sources (repulsion). Predator playbacks produced stronger behavioral responses in
374 monk parakeets than conspecific and mourning dove playbacks. Predator playbacks resulted in
375 flight 80% of the time, whereas conspecific playbacks resulted in flight 10% of the time, and
376 mourning dove playbacks never produced flight behavior. Additionally, predator playbacks with
377 few and many vocalizations elicited mostly repulsion behavior and exhibited variation in latency.
378 This variation in latency is likely not due to the number of vocalizations per track but may be a
379 consequence of an individual's social environment, such as the vigilance of their nearest
380 neighbor (e.g., van der Marel et al., 2021). Overall, our results align with studies that showcase
381 strong behavioral responses to predators in the form of mobbing, movement, and/or vocalizing
382 (Crawford et al., 2022; Dutour, Lena, & Lengagne, 2017; Manser, Seyfarth, & Cheney, 2002;
383 Zuberbühler, 2001). For example, predator playbacks of the sparrow hawk (*Accipiter nisus*)
384 successfully repelled house sparrows (*Passer domesticus*), with no habituation observed after six
385 days of exposure (Frings & Frings, 1967), and playbacks of a peregrine falcon (*Falco*
386 *peregrinus*) call was also effective at dispersing gulls from Vancouver International Airport
387 (Gunn, 1973). Because of these strong responses, managers seeking to temporarily displace
388 monk parakeets from a specific area may have success using predator calls.

389 In contrast, our results do not support the hypothesis that conspecific calls attract parakeets to the
390 auditory source, with no significant differences found between the conspecific and control
391 stimuli. We found that conspecific calls resulted in weak or no attraction of parakeets to the
392 stimulus despite support for attraction to conspecific vocalizations across taxa (see Buxton et al.,
393 2020), with half-flock movement towards the auditory source observed only once across all ten
394 playbacks. From a management perspective, our results indicate that conspecific calls may not be
395 effective stimuli to attract parakeets to a specific area, for example, to facilitate trapping.
396 However, other variables may need to be considered when selecting conspecific vocalizations for
397 playbacks, which may affect their effectiveness for management aims. For example, Nocera et
398 al. (2006) showed that, due to a lack of experience, natal dispersers (i.e., juveniles) might be
399 more receptive to conspecific vocalizations. Kelly and Ward (2017) suggested that in yellow
400 warblers (*Setophaga petechia*), site selection via conspecific attraction is more successful when
401 vocalizations from paired males are used, while Connell et al. (2019) suggested that in black-
402 tailed prairie dogs (*Cynomys ludovicianus*), other cues, such as the physical presence of and/or
403 relationship to the caller, may be essential factors to consider for playbacks.

404 An individual's response to an auditory cue may depend on the social information communicated
405 through vocalizations in a particular social system. For example, monk parakeets may respond to
406 conspecific calls based on their relationship to the caller (Hobson et al., 2015), which has been
407 seen in other birds such as acorn woodpeckers (*Melanerpes formicivorus*) (Pardo et al., 2018),
408 carrion crows (*Corvus corone*) (Wascher et al., 2012), and ravens (*Corvus corax*) (Szipl et al.,
409 2015). Parakeets may also respond based on the locality of the call, which has been observed in
410 rufous-collared sparrows (*Zonotrichia capensis*) (Danner et al., 2011), yellow-naped Amazons
411 (*Amazona auropalliata*) (Wright & Dorin, 2001), and stonechats (*Saxicola torquata*)(Mortega,

412 Flinks, & Helm, 2014). Moreover, monk parakeets exhibit unique vocal signatures in contact
413 calls tied to individual identities, and these individual signatures are simpler in smaller non-
414 native range populations, which suggests that monk parakeets use contact calls to recognize
415 distinct individuals (Smith-Vidaurre, Araya-Salas, & Wright, 2020; Smith-Vidaurre, Perez-
416 Marrufo, & Wright, 2021). Therefore, it may be useful for researchers to explore behavioral
417 responses to familiar or unfamiliar individuals to determine which calls may be best for
418 management purposes.

419 We did not examine differences in individual responses to playbacks with this study design.
420 However, it can be important to understand how individual characteristics (e.g., sex or age) and
421 social relationships (e.g., partnered with another individual) influence an individual's response to
422 stimuli and how this may influence overall group-decision making for a robust management
423 approach. For example, Kerman (2018) found that male monk parakeets that are risk-averse
424 while foraging become bolder in the presence of conspecifics, and it has been observed that
425 monk parakeets decrease vigilance effort as flock size increases (South & Pruett-Jones, 2000).
426 Thus, assessing how social context (e.g., flock size) may underlie behavioral responses to
427 external stimuli could be necessary for management success. When managing group-living
428 species such as monk parakeets, it may be important to adjust for population-level differences
429 due to possible individual and group-level behavioral variation as a result of unique ecological
430 pressures (Maldonado-Chaparro & Chaverri, 2021). Future studies should explicitly consider
431 how individual, population, and temporal characteristics, including variation in group size and
432 season, influence responses to sensory cues that may be useful for management.

433 ***Management Implications***

434 Our results showcase clear behavioral outcomes based on the playback stimuli used, with no
435 evidence of habituation, that are promising for management purposes. Auditory cues can be used
436 at a very low cost, with little to no ecosystem disturbance, and are readily available.
437 Furthermore, auditory cues may not come with conflicts of interest compared to other forms of
438 management, such as culling via poisons (van Eeden et al., 2017).

439 Our results show that predator playbacks produced a momentary change in behavior in captive
440 monk parakeets. Predator stimuli may be useful when management objectives require the
441 temporary dispersal of individuals from a small area. For example, once monk parakeets are
442 detected at a site, predator playbacks may help disperse birds and prevent site-specific nest
443 building (Burgio, Rubega, & Sustaita, 2014). When implementing predator playbacks, managers
444 should consider the geographic location of the monk parakeet population to select the
445 appropriate predator(s). In Florida, common avian predators include the red-tailed hawk, red-
446 shouldered hawk (*Buteo lineatus*), and Cooper's hawk (*Accipiter cooperii*), but in other
447 introduced locations such as the Iberian Peninsula, avian predators such as the Eurasian
448 sparrowhawk (*Accipiter nisus*) and Eurasian kestrel (*Falco tinnunculus*) may be more
449 appropriate choices.

450 When considering playbacks as part of a management plan, the timing of the intervention should
451 also be carefully considered, as the parakeets may be more or less responsive to predator stimuli.
452 For example, monk parakeet site fidelity increases once nests have been established (Dawson
453 Pell et al., 2021), so management interventions could be timed to occur prior to this increased
454 fidelity. Because of this high nest fidelity, it is unlikely that predator playbacks would cause nest

455 and site abandonment once the parakeets have initiated nest building. Although auditory cues
456 alone may not be enough to control a particular group or population, coupling auditory cues with
457 additional management strategies may be powerful for desired outcomes. In this case, it may be
458 useful to leverage an integrated approach, including other currently implemented avian
459 management tools, e.g., frightening devices (Enos, Ward, & Hauber, 2021). For example, in
460 areas where lethal shooting is authorized and safe to implement, using predator playbacks to
461 prompt flocking behavior could help maximize the efficacy of culling as a management tool.

462 Several variables should be considered when incorporating playback stimuli into management
463 strategies to optimize success and effectiveness: (1) the establishment stage in settlement of non-
464 native populations of monk parakeets (e.g., the arrival of new founders vs more established
465 breeding populations) (Dawson Pell et al., 2021), (2) the estimated flock-size of the focal group
466 of monk parakeets (South & Pruett-Jones, 2000), and (3) the ecological and/or management
467 purpose of the playback. For instance, strategies resulting in temporary repulsion could be used
468 when the return of the focal species is an acceptable management outcome, but methods that
469 facilitate permanent deterrence would be necessary to ensure that a focal species will not return
470 to a given area. These factors will influence the type of playback a manager is interested in using
471 (e.g., heterospecific vs conspecific) and, consequently, the efficacy of the selected playback to
472 alter the behavior of monk parakeets in a manner deemed useful for management purposes.

473 ***Conclusion***

474 Our experiments show the potential for repulsion stimuli to be an effective tool for some
475 management plans for monk parakeet populations, where the goal is to temporarily displace a
476 flock of parakeets and induce flight and vigilance behaviors. Our results re-emphasize the

477 importance of informing management with data from experiments. These results can then be
478 framed to recommend options managers can consider when managing monk parakeet
479 populations and other avian populations that rely on ecological information in the form of
480 auditory cues.

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Figure S1. Spectrogram images of playback files. A multi-panel comprised of spectrograms for the first seven seconds of each call category. Panel A displays calls from the predator vocalization (red-tailed hawk). Panel B displays calls from the conspecific vocalization (monk parakeet). Panel C displays a call from the control vocalization (mourning dove). Frequency in kilohertz (kHz) is shown on the y-axis and time in seconds is shown on the x-axis.

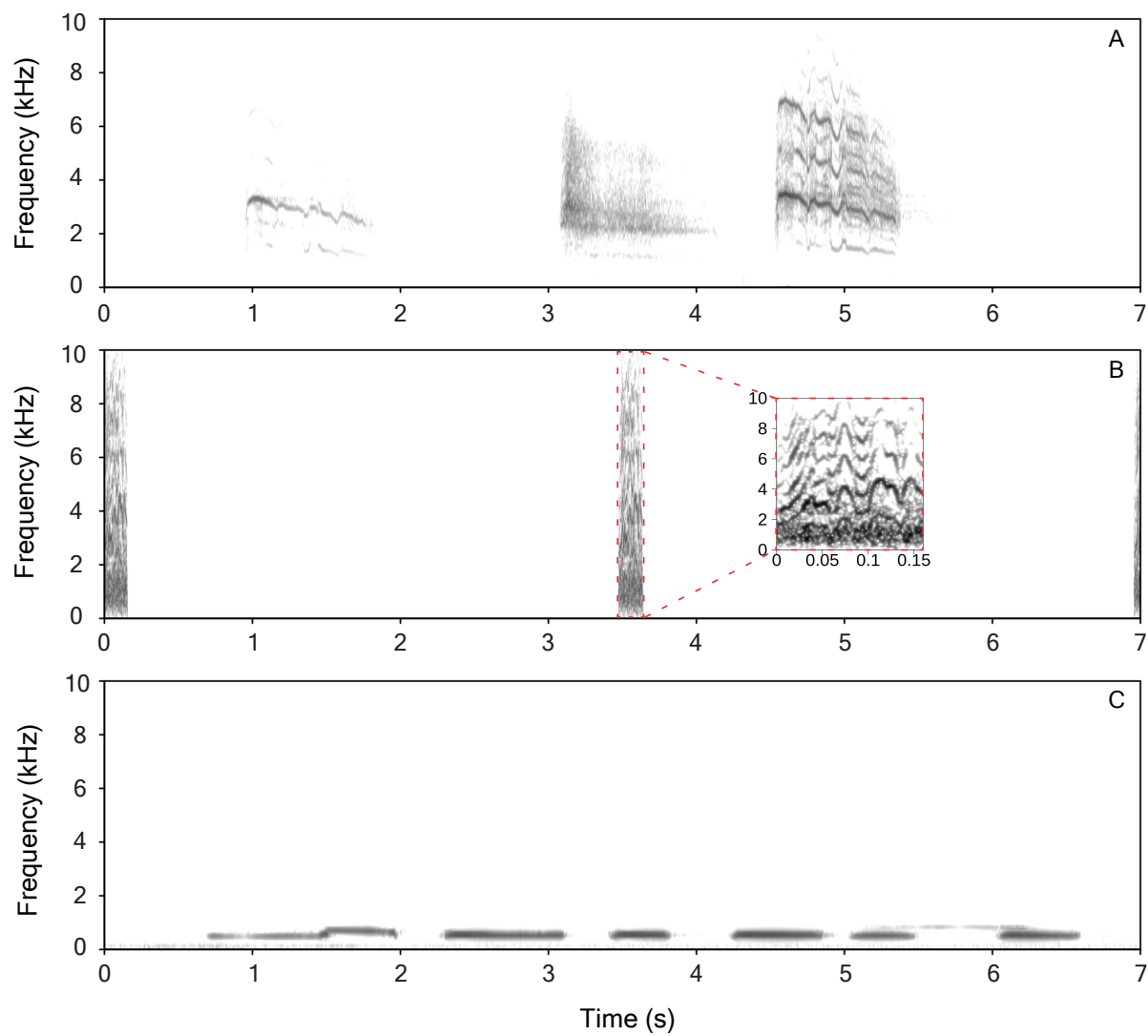


Figure S2. Equations used in mixed-models.

Mixed-Model Equations for Group Response:

```
ordinal_1 <- clmm(group response ~ call category + (1|exemplar))  
ordinal_2 <- clmm(group response ~ call category + trial + (1|exemplar))  
ordinal_3 <- clmm(group response ~ trial + (1|exemplar))  
ordinal_null <- clmm(group response ~ 1 + (1|exemplar))
```

Mixed-Model Equations for Latency:

```
LM_1 <- lmer(latency ~ call category + (1|exemplar))  
LM_2 <- lmer(latency ~ call category + trial + (1|exemplar))  
LM_3 <- lmer(latency ~ trial + (1|exemplar))  
LM_null <- lmer(latency ~ 1 + (1|exemplar))
```

Figure S3. Groups' responses to playback stimuli over the test period. Group responses are colored by playback stimuli: predator playbacks (brown), conspecific playbacks (blue), and control playbacks (purple). Monk parakeets did not show habituation in their responses to playbacks over all trials.

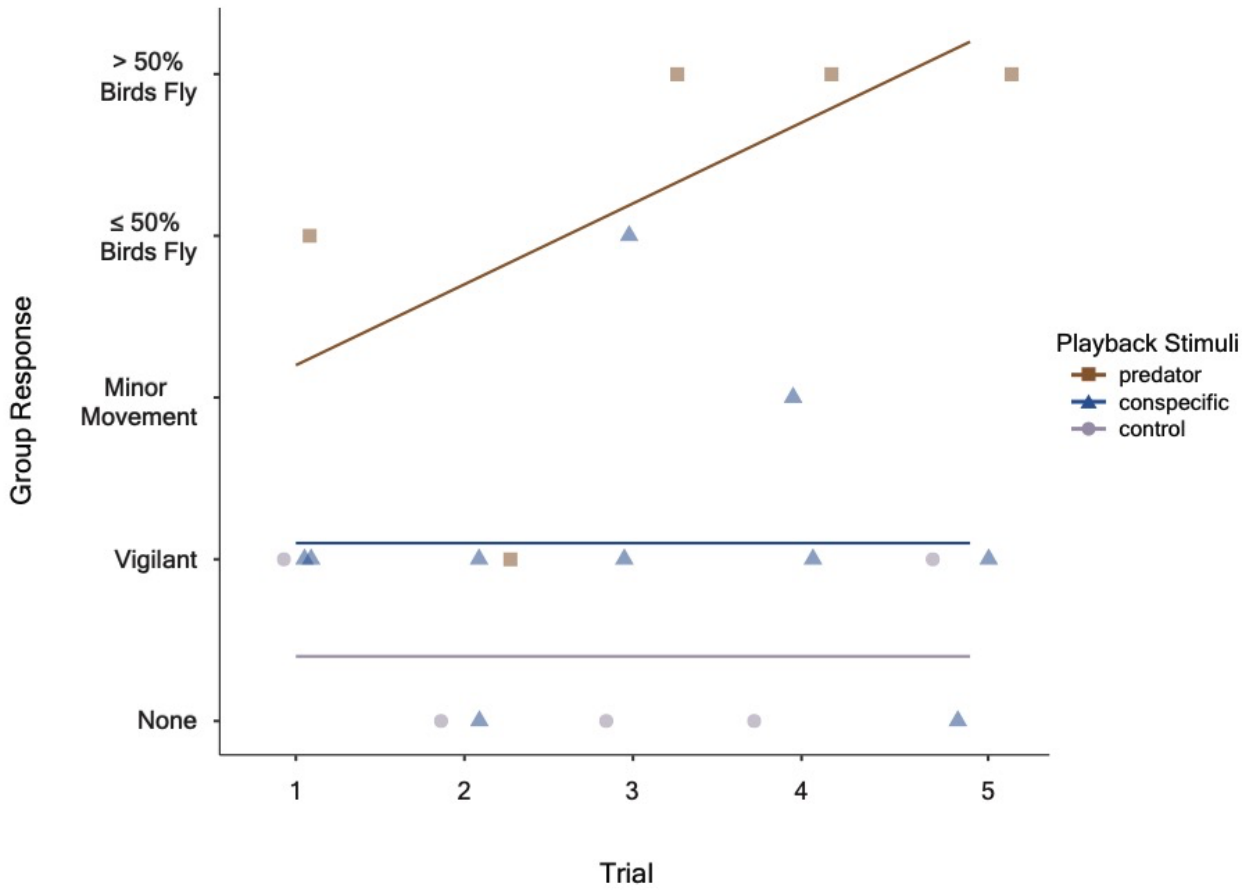
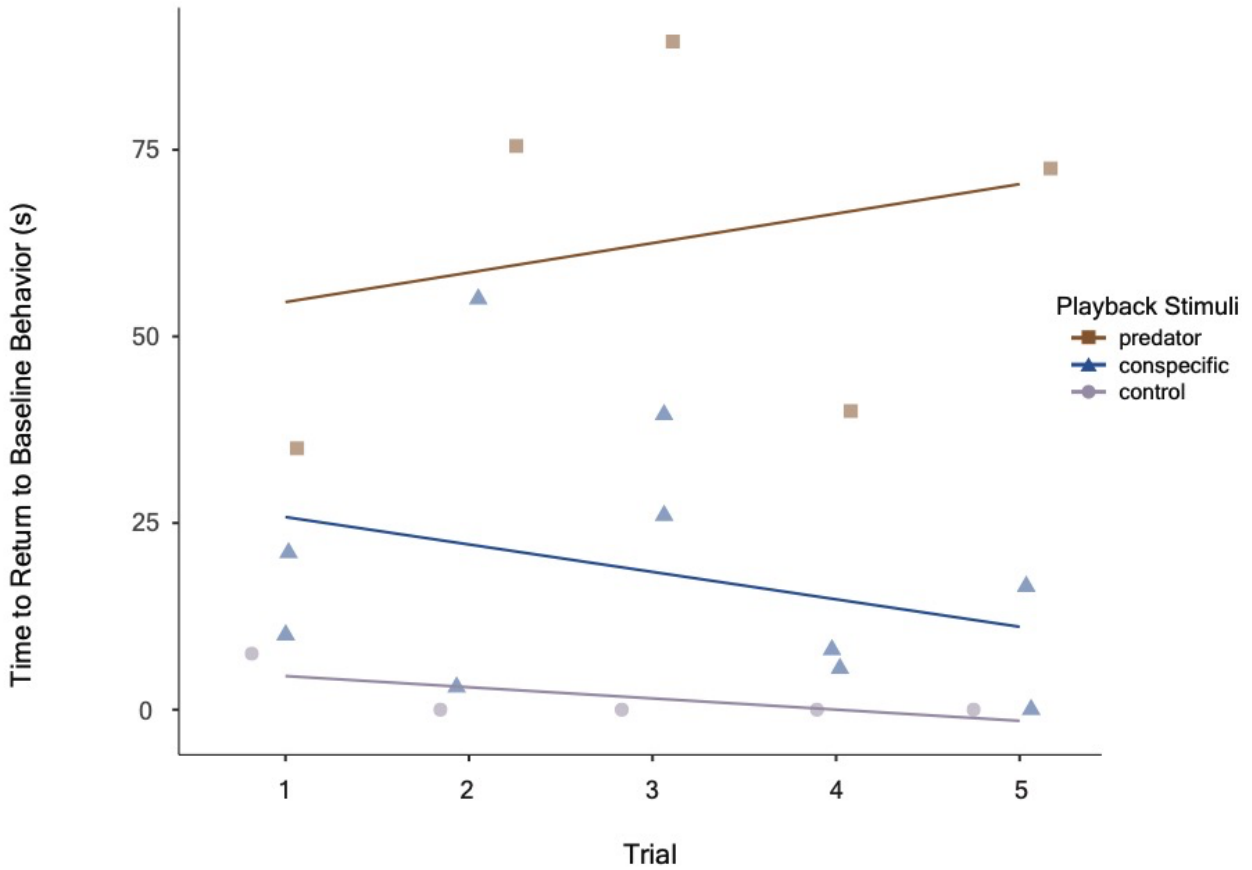


Figure S4. Latency in response to playback stimuli over the test period. Latency is colored by playback stimuli: predator playbacks (brown), conspecific playbacks (blue), and control playbacks (purple). Monk parakeets did not show habituation in their latency to playbacks over all trials.



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