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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Abstract

Human-wildlife interactions continue to increase due to anthropogenic disturbances, with some

interactions resulting in conflict. Leveraging a taxa's bias for a particular sensory cue is a

promising management avenue for reducing the potential and realized negative consequences of

human-wildlife conflict. For instance, many avian species heavily depend on acoustic

communication, and acoustic cues can provide opportunities to reduce conflict with various

avian species. The monk parakeet (*Myiopsitta monachus*) is a gregarious parrot native to South

America that has established populations worldwide and is considered an urban and agricultural

pest in parts of its native and introduced ranges. We conducted playback experiments with a

captive population of monk parakeets to evaluate auditory cues that may be useful for designing

management protocols. Our experiment evaluated the efficacy of two stimuli: predator

vocalizations as potential repulsion and conspecific vocalizations as potential attraction stimuli

for parakeets. We measured two responses: (1) categorical group-level behavioral responses and

(2) time to cease vigilance and return to behavior prior to playback. In the repulsion playbacks,

monk parakeets were repelled by predator vocalizations in 80% of trials and took longer to cease

vigilance and return to baseline behavior compared to attraction playbacks. In the attraction

playbacks, monk parakeets exhibited vigilant behavior and weak or no attraction to the stimulus,

with attraction only being observed in 10% of trials. Our results demonstrate that predator

playbacks may be particularly useful for completing management objectives, such as temporary

removal from a location.

Keywords

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

50   *monachus*

Introduction

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

Recently, researchers have highlighted the benefits of incorporating sensory ecology into 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.
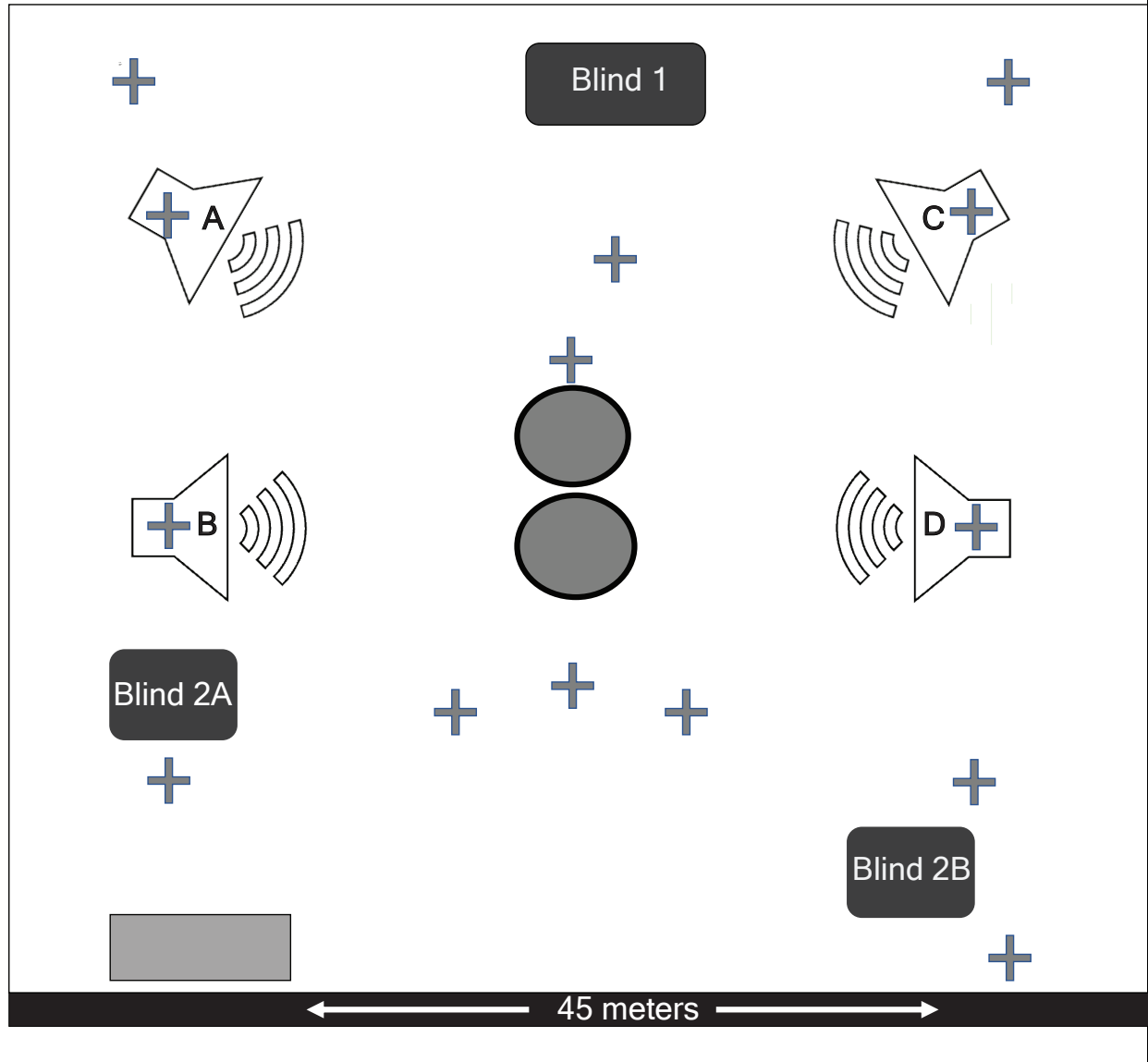
172   ***Playback Stimuli***

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   ($\leq$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; ($\pm$ 0.5): less than

304   50% of birds fly; ($\pm$ 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 R^2 is the proportion of variance

335 in the dependent variable that can be explained by the selected independent variable(s). R^2 is not

336 available for group response.

| Response Variable	Variable(s)	K	LL	AICc	Delta	Weight	R^2
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.
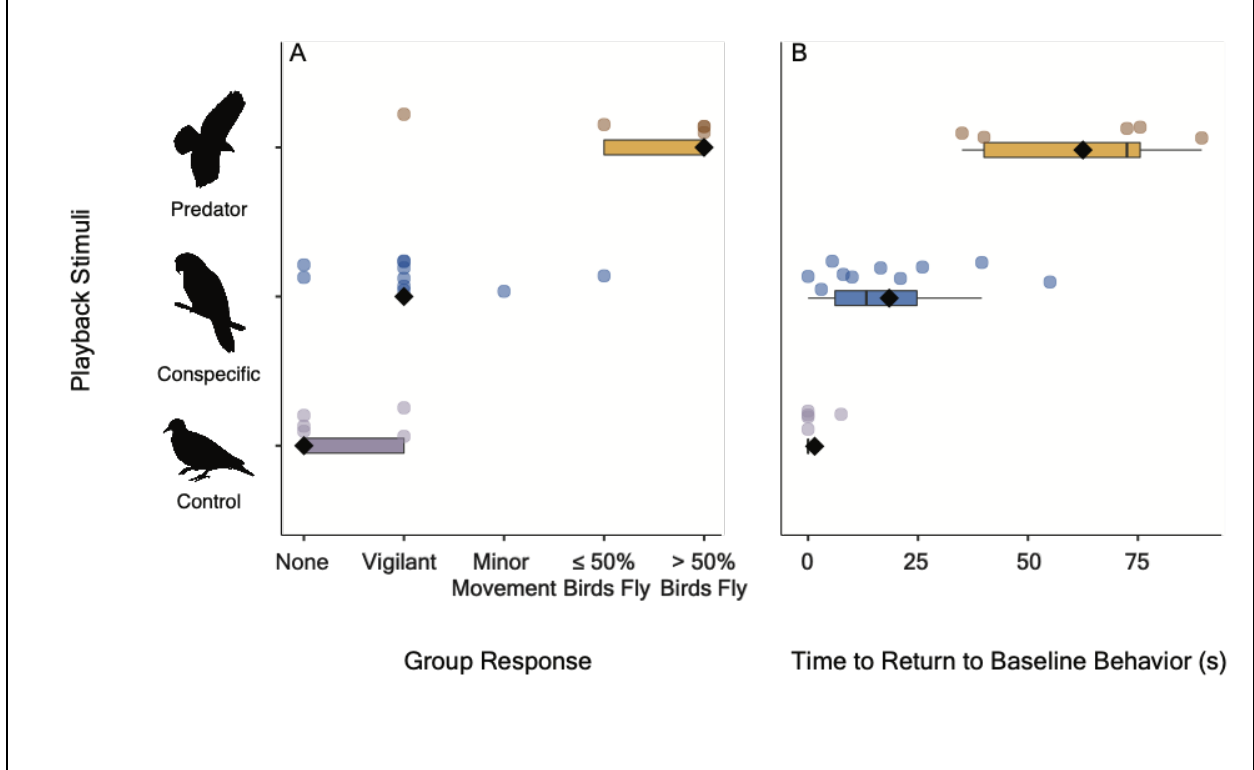
Figure 3. The percentage of group responses in response to playback stimuli. Stronger group responses are shown in darker blue and weaker behavioral responses in lighter blue.
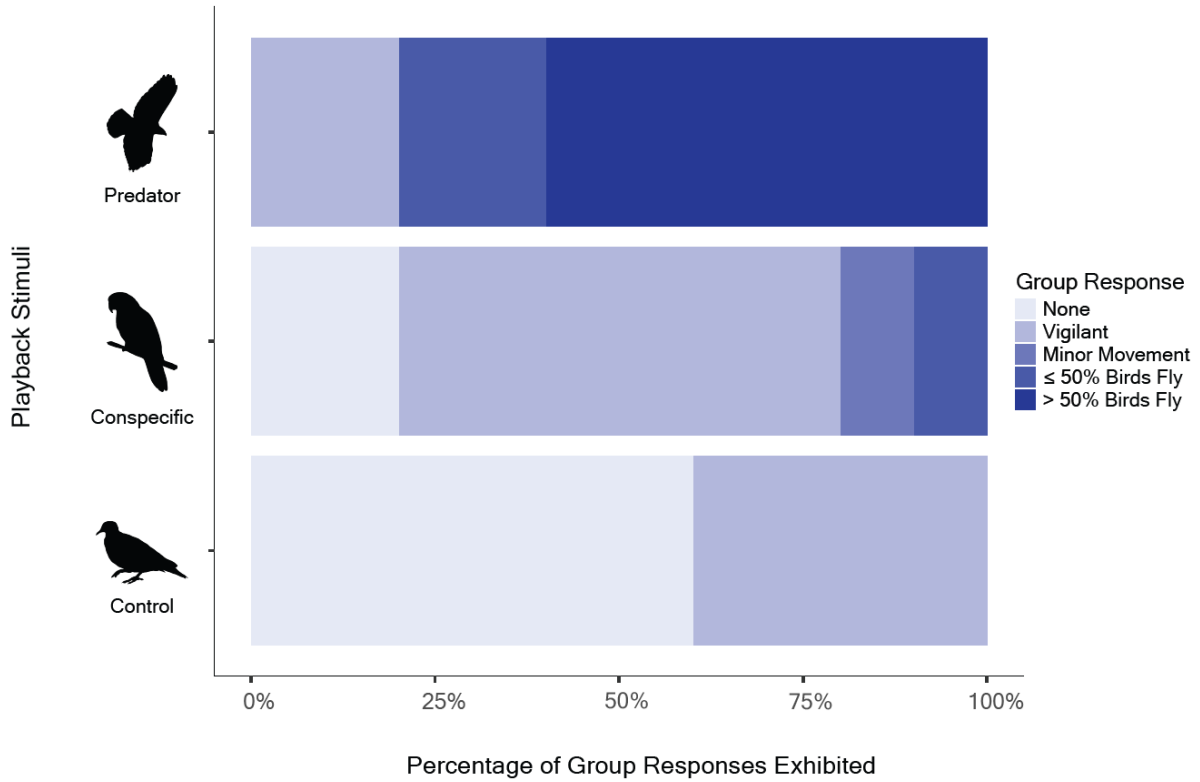
How Long do Monk Parakeets Take to Return to Baseline Behavior?

The model that best explained latency included playback stimuli and trial (LRT: $\Lambda = 30.70$, $p <$

0.001; Table 1). We found significant differences in latency among playback stimuli (LRT: $\Lambda =$

28.22, $p < 0.001$; Fig. 2B), but we did not find a significant effect of trial on latency (LRT: $\Lambda =$

8.64, $p = 0.07$; Table 1, Figure S4). Average latency to return to baseline behavior in response to

predator playbacks (62.50 ± 23.77 s) was longer and had more variation than conspecific (18.50

$\pm$ 17.56 s; Tukey's $p < 0.01$) and control (1.50 ± 3.35 s; Tukey's $p < 0.001$) playbacks (Table 2,

Figure 2B). Unlike overall group response, the effect of conspecific playbacks on latency to

return to baseline behavior was not significantly different compared to control playbacks

(Tukey's $p = 0.18$; Table 2, Figure 2B), although the confidence interval did not include zero

(Table 2).

Which Playback Stimulus Produced a Flight Response?

We found significant differences in flight responses (Kruskal-Wallis's $p < 0.01$) and that the

flight response of predator playbacks was more consistent than conspecific playbacks (Figure 4).

Predator playbacks elicited repulsion behavior in 80% of playback trials and showed significant

differences in flight response when compared to conspecific (Wilcoxon's $p < 0.05$) and control

flight responses (Wilcoxon's $p = 0.01$). Unlike predator playbacks, conspecific playbacks only

produced the predicted behavior (attraction) in 10% of trials (Figure 3). Conspecific playbacks

showed no significant difference in flight response compared to the control playbacks

(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.

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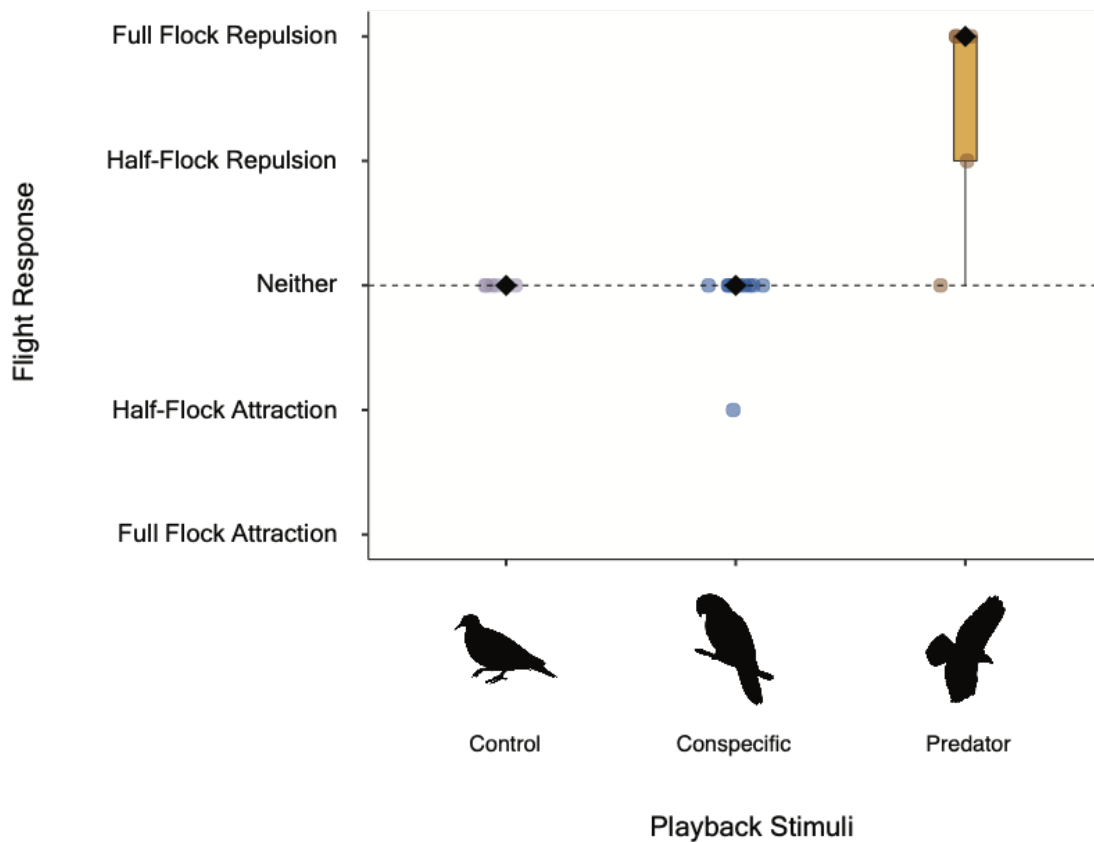
Discussion

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

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

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.

Management Implications

433

Our results showcase clear behavioral outcomes based on the playback stimuli used, with no

434

evidence of habituation, that are promising for management purposes. Auditory cues can be used

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at a very low cost, with little to no ecosystem disturbance, and are readily available.

436

Furthermore, auditory cues may not come with conflicts of interest compared to other forms of

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management, such as culling via poisons (van Eeden et al., 2017).

438

Our results show that predator playbacks produced a momentary change in behavior in captive

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monk parakeets. Predator stimuli may be useful when management objectives require the

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temporary dispersal of individuals from a small area. For example, once monk parakeets are

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detected at a site, predator playbacks may help disperse birds and prevent site-specific nest

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building (Burgio, Rubega, & Sustaita, 2014). When implementing predator playbacks, managers

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should consider the geographic location of the monk parakeet population to select the

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appropriate predator(s). In Florida, common avian predators include the red-tailed hawk, red-

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shouldered hawk (*Buteo lineatus*), and Cooper's hawk (*Accipiter cooperii*), but in other

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introduced locations such as the Iberian Peninsula, avian predators such as the Eurasian

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sparrowhawk (*Accipiter nisus*) and Eurasian kestrel (*Falco tinnunculus*) may be more

448

appropriate choices.

449

When considering playbacks as part of a management plan, the timing of the intervention should

450

also be carefully considered, as the parakeets may be more or less responsive to predator stimuli.

451

For example, monk parakeet site fidelity increases once nests have been established (Dawson

452

Pell et al., 2021), so management interventions could be timed to occur prior to this increased

453

fidelity. Because of this high nest fidelity, it is unlikely that predator playbacks would cause nest

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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.

Supplementary Materials

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.

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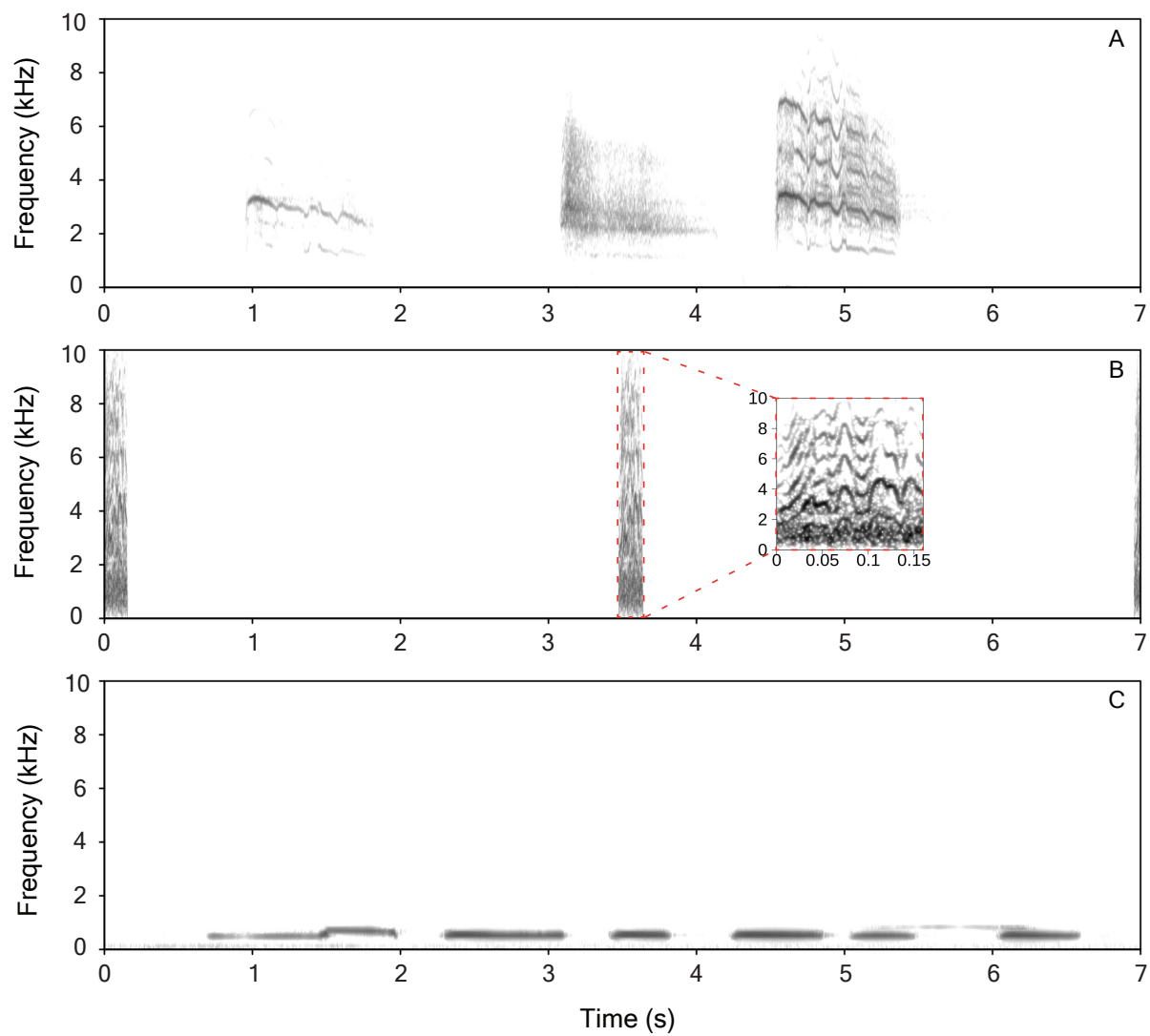
Figure S2. Equations used in mixed-models.

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))

504

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.

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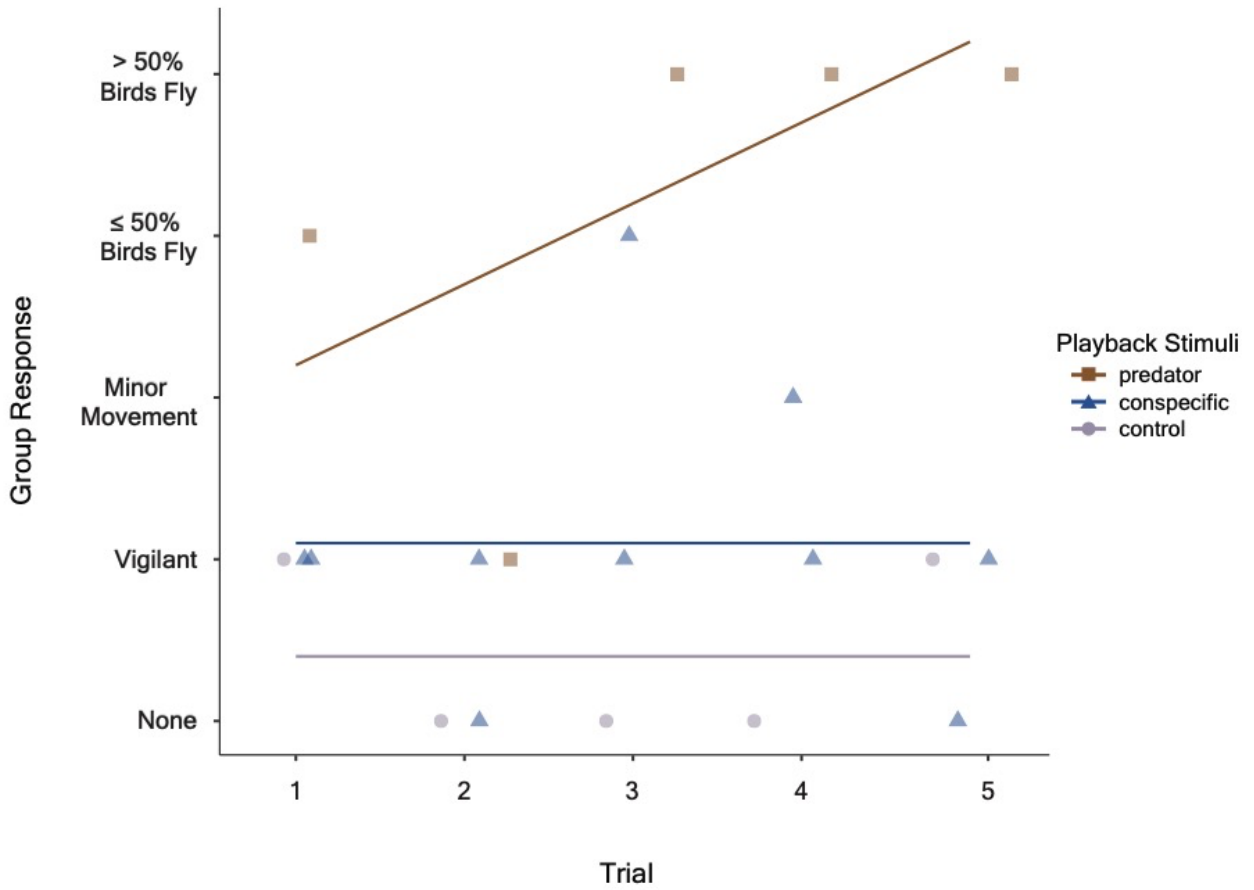
Figure S4. Latency in response to playback stimuli over the test period. Latency is colored by playback stimuli: predator playbacks (brown), conspecific playbacks (blue), and control playbacks (purple). Monk parakeets did not show habituation in their latency to playbacks over all trials.

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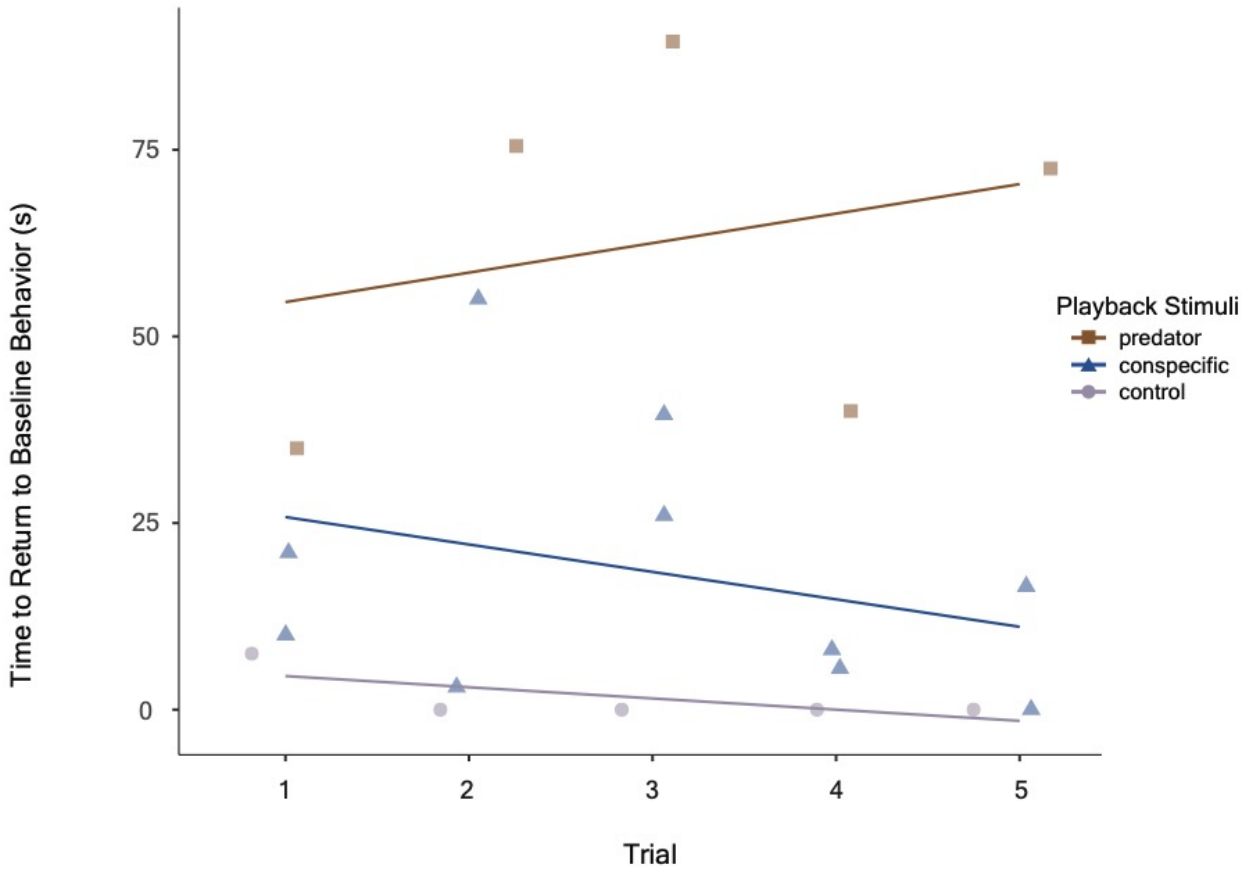
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