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1 Peak hour in the bush; linear anthropogenic clearings funnel

2 predator and prey species

3 Abstract

4 Linear clearings, such as roads and tracks, are an obvious anthropogenic feature in
5 many remote environments, even where infrastructure is sparse. Predator species have
6 been shown to prefer moving down linear clearings, and therefore clearings could increase
7 predation risk for other species. We investigated whether tracks cleared for seismic surveys
8 are preferentially used by predators and herbivores in a landscape inhabited by bilbies
9 (*Macrotis lagotis*), a vulnerable species of conservation concern. We used a paired camera
10 trap array to investigate the use of cleared seismic lines at four time points after clearing (1
11 mo, 3 mo, 7 mo, 48 mo) by six mammal species. Bilbies, cattle (*Bos indicus/B. taurus*),
12 dingoes (*Canis lupus dingo*), feral cats (*Felis catus*), and agile wallabies (*Macropus agilis*)
13 preferred to use seismic lines compared with adjacent undisturbed vegetation for almost all
14 surveys, while spectacled hare-wallabies (*Lagorchestes conspicillatus*) avoided them. Bilbies
15 and agile wallabies showed similar temporal activity patterns on and off seismic lines but
16 feral cats, dingoes, and cattle used seismic lines at different time of day to control areas.
17 We also investigated microhabitat selection by spool tracking individual bilbies. Bilbies
18 selected a route through vegetation that was more open than surrounding vegetation.
19 While spatial and temporal funnelling of bilbies and their predators (especially cats) may
20 increase the frequency of encounter between the two, it is important to note that bilbies
21 were active at significantly different times to predators both on and off seismic lines. The
22 identified selection for seismic lines, and changes in spatial and temporal overlap between
23 species, can be used to develop effective management strategies, to minimise potential
24 impacts on native species.

25

26 **Key words**

27 Activity patterns; avoidance; disturbance; linear clearings; roads

28

29

30 Introduction

31 Linear clearings in natural vegetation, such as roads and tracks, are often the only
32 obvious anthropogenic feature in many remote environments where infrastructure is
33 sparse, and once abandoned, these roads and tracks may take longer than 80 years to
34 recover (Bolling and Walker 2000). Such disturbances can create edge effects, disrupt
35 dispersal patterns, isolate populations, aid the spread of weeds, and increase human or
36 predator access (Fischer and Lindenmayer 2007; Laurance *et al.* 2009; Trombulak and Frissell
37 2000). These effects can influence species in different ways, with negative, neutral and
38 positive effects being identified (Cerboncini *et al.* 2015; Fahrig and Rytwinski 2009; Forman
39 2003; Laurance *et al.* 2009; Scott *et al.* 2006; see Taylor and Goldingay 2010 for Australian
40 review)

41 Prey vulnerability is defined in terms of two parameters: the frequency of encounter
42 between predator and prey, and the ease of capture (Greene 1986; Pastorok 1981); any
43 factor that modifies the probability of encounter between prey and predator can therefore
44 influence the predation pressure on species. One of the key concerns involving linear
45 clearing is the effect on predator-prey relationships. In Canada, wolves (*Canis lupus*) use
46 linear clearings for movement, increasing the predation risk for caribou (*Rangifer tarandus*
47 *caribou*) close to those features (Latham *et al.* 2011). The resulting avoidance of linear
48 clearings by caribou results in functional habitat loss (Latham *et al.* 2011).

49 In Australia, the response of predator species to linear clearings has been well-
50 studied. The dingo (*Canis lupus dingo*, a naturalised predator) and red fox (*Vulpes vulpes*, an
51 introduced predator) often use linear features such as roads and tracks for movement, with
52 both species following tracks for over 500m (Mahon *et al.* 1998; Read and Eldridge 2010).
53 Similarly, feral cats (*Felis catus*) are more likely to be recorded on linear features such as

54 roads, creeks, treelines, dune crests, or at the edge of patches than in a patch interior
55 (Bengsen *et al.* 2012; McGregor *et al.* 2014; Pastro 2013; see Doherty *et al.* 2015 for review).

56 By contrast with studies on predator species, the behavioural response of introduced
57 and native herbivore guilds to linear clearings is not well understood (Bond and Jones 2014).
58 Despite rangelands covering 80% of the Australian mainland, there have been few studies
59 investigating the response of domestic cattle (*Bos indicus/B. taurus*) to linear clearings. In
60 America, cattle have been recorded using logging tracks for movement throughout the
61 landscape (Roath and Krueger 1982). Similarly, two didelphid marsupials in South America
62 use plantation rows to orient their movements, using rows as guidelines for navigation
63 between habitat fragments (Prevedello and Vieira 2010), as have mice in Italy (Sozio *et al.*
64 2013). Where data on Australian native mammalian herbivore is available, it often suggests
65 that roads and tracks have a 'barrier effect', with many species avoiding roads (Goosem
66 2004; Laurance *et al.* 2009; Taylor and Goldingay 2010). Responses of native animals of
67 different species to linear clearing are highly variable, and identifying and understanding
68 responses by animals therefore warrants scientific investigation.

69 The majority of published research on behavioural responses of animals to linear
70 clearings has dealt specifically with roads (Forman 2003; Forman and Alexander 1998;
71 Trombulak and Frissell 2000; van der Ree *et al.* 2015), usually defined as permanent or semi-
72 permanent access pathways, sealed or unsealed, that receive some degree of maintenance.
73 By contrast, seismic lines are temporary tracks (used for <6 months), during a seismic survey
74 for petroleum, then left to recover. Seismic surveys have been occurring in Australia for
75 over 40 years, often covering a large area (~20,000 ha). Recovering seismic lines are
76 therefore common features across much of remote Australia. Seismic lines differ from the
77 majority of roads by virtue of their extensive and broad spatial nature (a grid pattern with
78 lines ~250m apart), but they are usually not maintained and are therefore generally more

79 temporary in nature. Therefore the responses of animals to seismic lines likely differ from
80 their interactions with roads (e.g. Cerboncini *et al.* 2015).

81 We investigated the use of seismic line clearings by predator and prey species at a site
82 in the West Kimberley, northwest Australia, where there has been extensive anthropogenic
83 disturbance through livestock grazing, and recently at a localised scale, seismic surveys.
84 Populations of the medium-sized, nocturnal greater bilby (*Macrotis lagotis*) were present at
85 these sites. These marsupials have suffered a dramatic range contraction after European
86 colonisation of Australia (Southgate 1990a; Woinarski *et al.* 2014). Introduced predators
87 (feral cat and red fox) have been identified as a key factor threatening the bilby, along with
88 cattle grazing and inappropriate fire regimes (Pavey 2006; Woinarski *et al.* 2014).
89 Understanding whether linear clearings increase predation risk for bilbies is therefore key to
90 wildlife management of these disturbed areas (Goosem 2004; May and Norton 1996).

91 We used a paired camera trap array to investigate the activity patterns of six species,
92 on and off seismic lines. Firstly, we tested whether there was differential use of seismic
93 lines compared with adjacent undisturbed vegetation. We predicted that predators and
94 cattle were more likely to use seismic lines as part of movements across the landscape
95 towards and away from water or to access hunting sites, while herbivores (macropods) and
96 bilbies would more likely avoid the clearings. We synthesised the camera data with
97 microhabitat selection for two individual bilbies using spool tracking. Secondly, we
98 compared temporal activity patterns on and off the seismic lines, to identify changes in
99 behaviour associated with seismic line use. Thirdly, we compared use of seismic lines at
100 sites cleared at different times as the lines recovered and passively revegetated. Lastly, an
101 un-planned fire at one site allowed us to opportunistically test the effect of removal of all
102 vegetation on the selective use of seismic lines.

103 **Methods**

104 **Study Sites**

105 The West Kimberley region, in the northwest of Western Australia, has a tropical,
106 monsoonal climate, with an annual average of 500mm of rainfall during November to April
107 (Fig. S1). 'Pindan' vegetation, typical of the west Kimberley and Dampier Peninsula
108 (Kenneally *et al.* 1996), was dominant across all three sites.

109 Three populations of bilbies were surveyed in the current study: the Grass-seed
110 population (GSP), Judi population (JP), and Kurrajong population (KP), which was surveyed
111 twice (Table S1). The three sites were selected as they were the only bilby populations in
112 the area. Bilbies are not evenly distributed throughout the areas they occupy; rather they
113 exist in small isolated populations, and as such may be considered independent. A fire burnt
114 GSP on day 85 of the survey, consuming all understory vegetation. At all sites, seismic
115 surveys had been carried out, involving clearing ~4 m-wide tracks, in a grid pattern,
116 separated by approximately 250m (Table S1, Fig. S1). Two populations (KP and JP) were
117 located during clearing, and GSP was cleared prior to the commencement of the study,
118 therefore no populations were monitored prior to clearing. Seismic lines used in the current
119 study were in various stages of recovery, ranging from no vegetation on the track at 1 month
120 post-clearing, to minor differences to the surrounding vegetation at 48 months post-clearing
121 (Fig. 6, Buru Energy, unpub. data). The sites were subject to cattle grazing, and all seismic
122 lines showed signs of cattle use, evidenced by tracks, scats, and sightings.

123 **Camera Trapping**

124 Four surveys were undertaken between June 2015 and August 2016. A camera trap
125 array was made up of paired cameras, with one camera positioned on a seismic line (seismic
126 station), and another camera ~20 m from the seismic line in adjacent vegetation (control
127 station). The extent of each survey was determined by the area occupied by bilbies

128 (estimated by the extent of burrows), with cameras spaced to cover the full extent of the
129 burrows. Therefore, the spacing between camera pairs along seismic lines ranged between
130 50–150 m (Fig. S1, Table S1). Cameras were not baited and positioned at a height of 400mm
131 on a metal stake. Each camera station had a small area to the front cleared of grass in order
132 to minimise interference with the camera function. As each camera location was cleared of
133 vegetation, and all cameras faced the same direction, we assume equal detection probability
134 between seismic and control cameras (see Burton *et al.* 2015). Cameras on seismic lines
135 were designed to face approximately 22.5° to the track, in a southerly direction, to avoid
136 glare from the sun triggering the camera. Four camera models were used: three Reconyx
137 models (HC500, HC600, and PC900) and Scoutguard SG860C (white flash model). Cameras
138 were paired 'on' and 'off' track by type to avoid treatment bias due to camera model.

139 The duration of camera deployment was determined by the availability of cameras,
140 seasonal access to the sites, and the need to survey multiple sites for replication, resulting in
141 differences in effort between surveys. KP1 was surveyed for 40 days, JP for 65 days, KP2 for
142 91 days and GSP for 85 days before fire, and 40 days post-fire (Table. S1). In addition, there
143 was variation within surveys in total trap effort between treatments (seismic and control)
144 due to individual camera's memory or batteries being exhausted or physical disturbance (i.e.
145 being knocked to the ground) (Table S1). 'Disturbed' cameras still took photos, however the
146 altered field of view (and resulting detection probability) warranted exclusion. We
147 standardised trap data by the number of camera nights (one camera open for 24-h period)
148 by either calculating a trap rate (captures per day), or for analyses which required actual
149 numbers of captures (Chi-square test; χ^2), differences in trap effort were standardised by
150 multiplying the raw captures of one survey by a correction factor proportional to the
151 difference in trap nights (e.g. 20 captures in 20 days in A, and 20 captures in 19 days in B.
152 Therefore, we multiplied trap captures in B by 1.052 to correct for trap effort).

153 For each photo capture, we identified the time, species present, and approximate
154 distance from the camera (using known landmarks). Visibility was greater on seismic lines
155 due to reduced vegetation cover; therefore the depth of view of each control site was
156 estimated and animals captured beyond this distance on the paired seismic line camera
157 were discarded (0.007% of total captures). Captures of the same species were considered
158 independent if they were obviously different individuals, or separated by more than 10 min.
159 Large groups of highly gregarious species (cattle and agile wallabies) were considered as a
160 single capture. Only feral cats could be identified to individual (identification performed
161 using pelage).

162 *Spool Tracking*

163 Spool tracking is a simple and well used method of investigating habitat use, especially
164 for small species (Glen and Dickman 2006; Prevedello and Vieira 2010). Two bilbies were
165 trapped overnight from their burrow. Trapping was undertaken in June and July 2015 at GSP
166 (13 nights). Occupied burrows (identified based on camera trap monitoring and sign on the
167 sand apron) were trapped using the 'burrow trap' method (McGregor and Moseby 2014).
168 Traps were baited with rolled oats and peanut butter and were left for a maximum of two
169 consecutive nights. Bilbies had a ~230m length of nylon spool (mass = 6g) attached to their
170 tail using 'Leukoplast' tape, with the loose end of the thread tied to nearby vegetation.
171 Once processed the animal was released back into its burrow in which it was caught. When
172 it emerged from the burrow the following night (at least 10 h later), it was assumed to be
173 acting 'normally', therefore the movement trail should not show escape behaviour.

174 Following the spool the day after release, the density of vegetation the animal moved
175 through was recorded every 2m using a touchpole. The number of vegetation intercepts
176 was recorded for three height brackets (0-10 cm, 10-30 cm, and 30-100 cm). Two 'control'
177 paths were similarly measured: a 'path control' 1 m to the side of the thread, and a
178 'compass control', taken on straight line transects starting at the burrow on cardinal

179 compass bearings and not moving more than the maximum straight-line distance that the
180 spool went from the burrow (Fig. 1). Care was taken when sampling vegetation not to push
181 down any grasses on the transect (changing the measurements gained by the touch pole).
182 The path used was recorded using a handheld GPS.

183 *Statistical analyses*

184 Only the six most commonly caught species were included in statistical analysis
185 (cattle, dingo, cats, bilbies, agile wallabies and spectacled hare wallabies). To test for use or
186 avoidance of seismic lines, a χ^2 test was conducted on the standardised number of captures
187 on seismic and control cameras. Expected values were calculated by assuming equal
188 probability of captures on both treatments. Tests were conducted for each individual survey
189 (pooling camera data within each treatment), and then also for the data overall (pooling
190 camera data within each treatments across all surveys). To test for the frequency of
191 'capture strings' (i.e. animals following a seismic line and being captured on adjacent
192 cameras), we identified incidents of captures of the same species on adjacent cameras of
193 the same treatment, within 1 hour.

194 We tested for changes in the proportion of captures on seismic lines across the four
195 times since clearing using a χ^2 test, with expected values calculated assuming there was no
196 difference across the four time points. The post-fire period at GSP was excluded from this
197 analysis. Spectacled hare wallabies were also excluded from this analysis as they were
198 present at only one site.

199 To identify temporal patterns in activity for the five most common species (spectacled
200 hare wallabies were excluded as they were found at only one site), and compare between
201 species and across treatments, we used the timestamp record from all captures in the
202 Overlap package version 0.2.6 (Meredith and Ridout 2014). Overlap uses non-parametric
203 kernel density curves using a default smoothing parameter to characterise the probability

204 density distribution of the activity pattern of each species. The smoothing parameter ($1/c$) is
205 the inverse of the von Mises kernel (corresponding to a circular distribution) concentration
206 parameter (c). For each species pair, we calculated the total overlap (Δ) as the measure of
207 overlap between the two species' estimated distributions, ranging from 0 (no overlap) to 1
208 (total overlap). Three estimators are available for use in the package; we used Δ_4 when the
209 smaller sample size in the pair was greater than 75, and Δ_1 when the smaller sample size in
210 the pair was less than 50 (Meredith and Ridout 2014). We estimated 95% confidence
211 intervals from 10,000 smoothed bootstrap samples, after correcting for the bootstrap bias.
212 For each comparison of temporal patterns (comparing species, or comparing treatments) a
213 Mardia-Watson-Wheeler test for homogeneity was conducted in the circular package
214 version 0.4-7 (Agostinelli and Lund 2013). This test detects difference in the mean angle of
215 circular temporal data, which is representative of temporal peaks in activity. This test
216 requires a minimum of 10 observations, and assumes no repeat data. Captures were
217 therefore pooled across the four surveys for the temporal analyses and captures recorded at
218 identical times were adjusted by 0.86 seconds [Overlap accepts 24 hour time on a 0
219 (00:00:00) -0.99999 (23:59:59) scale, meaning an adjustment of 0.00001 resulted in 0.86
220 seconds]. All statistical tests of temporal patterns were conducted using R version 3.3.2.

221 We monitored GSP pre- and post-fire (for 85 and 40 days respectively), comparing
222 selection between seismic and control stations pre- and post-fire using a χ^2 test. Expected
223 values were calculated assuming equal probability of capture between treatments and pre-
224 fire/post-fire.

225 Results

226 *1. Response to seismic lines*

227 In total, 3,068 separate trap events of 28 species were recorded over 10,610 trap days
228 from 822,648 images (Table S2). In total, 93.64% of the 120 camera captures of cats were

229 identified to individual, with a total of 15 individuals and an average of 5.25 (s.d. = 2.22)
230 individual cats in each population (range: 3–8). An asymptote was reached for 3 of the four
231 surveys, suggesting all individuals present during the survey had been recorded. This was
232 the only species where we could translate camera captures into numbers of individuals.

233 In descending order of frequency of observations, agile wallabies, cattle, bilbies, cats,
234 and dingoes were trapped on seismic line stations more than control stations (Fig. 2).
235 Spectacled hare-wallabies were trapped on control stations significantly more than on
236 seismic line stations (Fig. 2).

237 Two species were commonly seen on multiple consecutive cameras moving down a
238 seismic line, cattle (45.5% of total captures were as a string) and dingoes (39.7% of total
239 captures were as a string), with strings of greater than two captures recorded (12.7% for
240 cattle; 12.3% for dingoes). Recording the same species on multiple consecutive cameras in
241 control areas were much less common (4.3% for cattle; nil for dingoes) (Fig. 3). Less
242 commonly seen in string captures, were bilbies (17.9% of captures), and agile wallabies
243 (13.4% of captures), again with a greater likelihood of string captures on seismic line stations
244 than for control stations. Cats were seldom seen on consecutive cameras, except in the GSP
245 surveys, where 27.9% of captures on seismic line stations were part of a string, compared to
246 15.4% on control sites (Fig. 3).

247 **2. Spool tracking**

248 Two bilbies were caught and spool tracked, resulting in 320m (128m and 192m) of
249 movement being recorded. Both animals ('A' and 'B') showed selection for a more open
250 path at the 0-10cm level (A: $\chi^2 = 18.11$, $p < 0.001$, B: $\chi^2 = 26.32$, $p < 0.001$) and the 10-30cm
251 level (A: $\chi^2 = 25.04$, $p < 0.001$, B: $\chi^2 = 20.50$, $p < 0.001$); however only one animal showed
252 selection at the 30-100cm level (B: $\chi^2 = 57.62$, $p < 0.001$), a height which would be above the
253 animal (Fig. 1). The path taken by both animals was also more open than the compass

254 control transects, at both the 0-10cm (A: $\chi^2 = 12.04$, $p < 0.001$, B: $\chi^2 = 29.49$, $p < 0.001$), and
255 10-30cm levels (A: $\chi^2 = 6.78$, $p < 0.05$, B: $\chi^2 = 27.63$, $p < 0.001$), with one animal also showing
256 selection for more open movement paths at the 30-100cm level (B: $\chi^2 = 91.97$, $p < 0.001$).

257 *3. Time since clearing*

258 Agile wallabies and bilbies showed significant changes in microhabitat selection
259 between the four times since clearing, encapsulated in the four surveys (agile wallabies: $\chi^2 =$
260 144.68, $p < 0.001$; bilbies: $\chi^2 = 22.535$, $p < 0.001$) (Fig. 5). At 1 month post-clearing, 78% of
261 bilby captures were on seismic lines, which fell to 60% at 7 months, but then rose to 81% at
262 48 months. The proportion of agile wallaby captures on seismic lines declined with time
263 since clearing from 90% of captures on seismic lines at 1 month, to 41% of captures at 48
264 months. Cattle ($\chi^2 = 6.76$, $p = 0.08$), cats ($\chi^2 = 3.26$, $p = 0.35$), and dingoes ($\chi^2 = 2.89$, $p =$
265 0.44) showed no difference in the proportion of captures on seismic lines across the 4
266 surveys; all three consistently selected for seismic lines (Fig. 5).

267

268 *4. Temporal activity patterns on and off seismic lines*

269 Native prey species showed no significant difference in activity times between seismic
270 lines and control areas (bilbies $W = 0.46$, $p = 0.79$; agile wallabies $W = 0.18$, $p = 0.91$).
271 Conversely, predator species and cattle showed a significant difference in activity times
272 between treatments (cats: $W = 10.92$, $p < 0.01$; dingoes: $W = 6.45$, $p < 0.05$; cattle: $W =$
273 11.44, $p < 0.01$).

274 All species in the current study were nocturnal or crepuscular; regardless of high
275 levels of overlap, however, the majority of species were active at different times to each
276 other (Fig. 4, Table S3). The only exceptions were cats and dingoes in control areas, and cats
277 and cattle in control areas, which showed no significant difference in peak activity times,

278 although this result may be an artefact of low sample sizes of those species/treatment
279 combinations (n = 53 captures of cats and n = 10 for dingoes were for control stations).

280 Bilbies had the lowest overlap with all other species across both treatments, with
281 significant differences in activity times (Table S3). Bilbies showed greater temporal overlap
282 with herbivorous species (agile wallaby and cattle) at control stations than on seismic lines,
283 but showed greater temporal overlap with carnivorous species (dingo and cat) on seismic
284 lines compared with control stations (Fig. 4, Table S3).

285 *5. Effect of fire on the selective use of seismic lines*

286 The capture rate during the survey period after the fire at GSP was reduced for bilbies
287 (94% reduction, $\chi^2 = 35.098$, $p < 0.001$), cats (78% reduction, $\chi^2 = 12.925$, $p < 0.001$), dingoes
288 (84% reduction, $\chi^2 = 4.341$, $p < 0.05$) and SH wallabies (85% reduction, $\chi^2 = 36.564$, $p <$
289 0.001). There was no significant difference in capture rate before and after fire for cattle
290 and agile wallabies. Due to the reduction in capture rates, statistical tests could only be
291 conducted for data on cats, cattle, and agile wallabies. Cattle showed significant selection
292 for seismic lines both before (73% of captures on seismic lines, $\chi^2 = 57.499$, $p < 0.001$) and
293 after fire (64% of captures on seismic lines, $\chi^2 = 21.706$, $p < 0.001$). There was an increase in
294 the capture rate of cattle for control stations post-fire ($\chi^2 = 3.402$, $p < 0.05$), resulting in the
295 strength of selection being weaker post-fire. Cats showed strong selection for seismic lines
296 before fire ($\chi^2 = 9.857$, $p < 0.01$), but no significant selection post-fire ($\chi^2 = 0.278$, $p = 0.658$).
297 Agile wallabies showed no selection before fire ($\chi^2 = 1.105$, $p = 218$), but significant
298 avoidance of seismic lines post-fire ($\chi^2 = 6.876$, $p < 0.01$).

299 **Discussion**

300 Our study shows that bilbies, cats, dingoes, cattle, and agile wallabies are funnelled on
301 seismic lines at both a spatial and temporal scale. The only species that avoided seismic
302 lines was spectacled hare wallabies. Individual bilbies selected for the most open route

303 while moving through the undergrowth, explaining the observed selection for seismic lines.
304 The use of seismic lines by bilbies and agile wallabies varied with the age of clearing, while
305 cats, dingoes and cattle consistently used the lines as they recovered over time, and cattle
306 movements are likely to have kept the paths relatively clear of vegetation. Removal of the
307 grassy understorey by fire caused a dramatic decrease in capture rate of all species except
308 cattle, which were unaffected by the removal of vegetation and continued to use the seismic
309 lines in preference to adjacent paths through the bush.

310 *1. Response to seismic lines*

311 Five of the six species in the current study selected for seismic lines. While this result
312 corroborates previous studies on predators in Australia (Bengsen *et al.* 2012; Mahon *et al.*
313 1998; Pastro 2013; Read *et al.* 2015; Robley *et al.* 2010), it is unexpected for native
314 herbivores. Generally, studies of the effect of linear clearing on native herbivores have
315 focused on roads with traffic, and have identified a 'barrier effect', where animals avoid a
316 linear disturbance (Goosem 2004; Laurance *et al.* 2009; Taylor and Goldingay 2010); none
317 have identified selection for linear clearing by such species in Australia. The use of linear
318 clearings by small mammals has been identified previously in other regions (Prevedello and
319 Vieira 2010).

320 Cattle showed strong selection for seismic lines, quantifying anecdotal records for
321 rangeland cattle throughout northern Australia. Similarly, studies from America have
322 identified road use by cattle (Roath and Krueger 1982). The use of seismic lines by cattle
323 may maintain their open structure and hinder regrowth of vegetation along the lines. Their
324 continued use of these paths may therefore sustain the impact of seismic clearings.

325 Dingoes and cats both showed selection for seismic lines in the current study,
326 supporting previous published studies that these predators show preference for open
327 cleared tracks (Mahon *et al.* 1998; Read and Eldridge 2010; Robley *et al.* 2010). The
328 incursion of predators using roads for access is one of the consequences of the creation of

329 linear clearings (Forman and Alexander 1998; May and Norton 1996; Trombulak and Frissell
330 2000). The additional selection for seismic lines by bilbies and agile wallabies suggest that
331 the creation of seismic lines has funnelled both predator and prey species into a reduced
332 movement corridor, which may increase the chance of encounter, thereby increasing
333 predation risk for these prey species (Pastorok 1981).

334 By contrast with the other species we recorded, spectacled hare-wallabies
335 significantly avoided seismic lines overall. This difference could reflect their antipredator
336 responses. Spectacled hare-wallabies require shelter sites in close proximity to feeding
337 areas in order to remain hidden from predators (cats and dingoes) (Ingleby and Westoby
338 1992). We hypothesise that spectacled hare-wallabies avoid seismic lines to remain within
339 cover, and studies of the closely related rufous hare-wallaby (*Lagorchestes hirsutus*) indicate
340 that they retreat to cover when disturbed (McLean *et al.* 1996). By comparison, the larger
341 agile wallaby (9-27 kg vs. 1.6-4.5 kg for SHW) (Menkhorst and Knight 2010) appears to rely
342 on speed for escape rather than remaining hidden, and therefore rather than aiding
343 concealment, dense understorey would be an obstruction to escape. Similar differences in
344 antipredator responses with body size have been noted for tammar wallabies (*Macropus*
345 *eugenii* 6-10 kg; which uses understorey as cover and forages close to vegetation) and
346 western grey kangaroos (*Macropus fuliginosus* 28-54 kg forage in the centre of clearings and
347 perceive vegetation as an obstruction) (Blumstein and Daniel 2002). The behaviour of
348 bilbies is therefore interesting, because despite their small size (1.1-2.5 kg), these animals
349 appear to rely on escape running rather than use of cover for protection, and they select to
350 use linear clearings for movement.

351 **2. Spool tracking**

352 The unexpected selection of seismic lines by bilbies is congruent with their
353 microhabitat selection recorded during spool tracking. Bilbies selected vegetation that was
354 more open than surrounding vegetation at heights relevant to their stature (0-10 cm and 10-

355 30 cm categories), both at a fine scale (compared to the vegetation within 1 m) and a
356 broader scale (compared to available habitat). This indicates that, during natural movement
357 patterns, bilbies selected an open route for movement. This corroborates with anecdotal
358 observations that bilbies show limited avoidance of vegetation during escape running
359 (Moseby pers. obs.), making selection of a more open route beneficial for survival.
360 Additionally, the path control of both animals spool-tracked was more open than the
361 compass control, indicating that they selected both a more open area to move through, and
362 a more open path within that area to travel along. It is important to note that given the
363 small sample size, these results are only considered in the context of the broader camera
364 trapping data presented in the current study.

365 In addition to broader scale preference for open understory recorded for bilbies
366 (Southgate 1990b), the use of open 'runways' through the understory for movement has
367 been shown in other species (Prevedello and Vieira 2010; Tasker and Dickman 2001). The
368 use of runways is likely to be a preference for ease of movement, as creating a new path
369 through a grassy understory would be energetically expensive. Bilbies use multiple burrows
370 throughout their home range during the night, and will retreat to a burrow if startled
371 (Johnson and Johnson 1983). Regular use of the same open routes throughout the night
372 might increase the efficiency and speed with which they can find, and retreat to, a burrow.
373 In addition, regular use may keep such routes more open.

374 **3. Time since clearing**

375 Cats, dingoes, cattle and bilbies showed a consistent selection for seismic lines over
376 time, even as vegetation regrows and the seismic line become less distinguishable from the
377 adjacent vegetation (Fig. 6). Large, hard-hooved mammals are likely to disrupt topsoil and
378 trample vegetation (Dunne *et al.* 2011) more than smaller, native herbivore species. The
379 high levels of use of seismic lines by cattle throughout the study may hinder the recovery of
380 vegetation on seismic lines. Surveys of sentinel sites spread across the exploration lease

381 indicate that vegetation cover on seismic lines is slightly lower than control sites after 4
382 years, and cattle tracks are present on seismic lines at many sites (Buru Energy, unpub.
383 data.). Agile wallabies selected for seismic lines soon after clearing, but the strength of
384 selection faded over time.

385 *4. Temporal patterns*

386 Native prey species (bilbies and agile wallabies) showed no difference in activity times
387 between treatments (presumably because they use them as part of their foraging activities)
388 while predator species and cattle showed a significant difference in activity times between
389 treatments. Bilbies were strictly nocturnal with a peak in activity at around 3 a.m., similar to
390 the patterns reported in previous studies (Johnson and Johnson 1983). Given the activity
391 patterns of bilbies did not change between treatments (highly nocturnal with a marked peak
392 at 3 a.m.), a higher overlap between bilbies and their predators on seismic lines is likely due
393 to a shift in the spatiotemporal patterns of dingoes and cats. On seismic lines, cats show a
394 small peak in activity at 3 a.m., corresponding to the peak activity time of bilbies. Such
395 temporal funnelling of species on seismic lines may affect the vulnerability of prey species to
396 predation (Pastorok 1981). However, an important caveat is that while temporal overlap
397 between bilbies and cats was greater on seismic lines than in control areas, there were still
398 significant differences in overall activity times for these two species across both treatments.
399 As such, we believe that that the relationship between bilby and cat activity times should
400 not be considered a causal relationship.

401 Predators and cattle may use seismic lines for different activities compared with
402 control areas, and therefore show activity at different times. Dingoes and cats have large
403 home ranges (Moseby *et al.* 2009), and are likely to be using seismic lines as movement
404 pathways and control areas for hunting or sheltering. For example, dingoes are highly
405 nocturnal/crepuscular on seismic lines, while activity in control areas is largely diurnal. This
406 may represent two discrete behaviours; movement on seismic lines, and shelter during the

407 hot daytime hours in control areas, where cover is more plentiful, consistent with previous
408 studies (Thomson 1992).

409 *5. Effect of fire*

410 The removal of vegetation at GSP by fire dramatically reduced the capture rate of all
411 species except cattle and agile wallabies. Cattle still showed strong selection for seismic
412 lines after fire, in the absence of vegetation, indicating that the use of the seismic line is at
413 least partly independent of the vegetation. This suggests that cattle follow tracks using cues
414 other than vegetation in their daily routine movement away from, and returning to water,
415 (Lange 1969). We recorded a reduction in the capture rate of cats, but no selection or
416 avoidance of seismic lines by cats after fire. This suggests that the primary reason for
417 selection of seismic lines by cats was for ease of movement through the understory, the
418 removal of which enabled them to move 'randomly' through the landscape, independent of
419 seismic lines. Although they were still present at this site post-fire, agile wallabies avoided
420 seismic lines after fire. With no difference in vegetation between treatments after fire (both
421 were bare), this avoidance is possibly explained by an avoidance of disturbance by cattle.

422 Removal of the grassy understory by fire appears to have resulted in reduced activity
423 of bilbies, dingoes, and spectacled hare wallabies, with dramatic reduction in capture rates.
424 The removal of cover is likely to make small herbivore species more susceptible to predation
425 (Conner *et al.* 2011) which may explain their avoidance of the area. Complete removal of
426 the understory is likely to remove food items, making the area unattractive for herbivores.
427 Even though bilbies are reported to use fire promoted plant species (Southgate and Carthew
428 (2007), these plants can take months to germinate and grow, depending on rainfall. Burnt
429 areas are also likely to be less favoured by dingoes for diurnal rest sites or hunting.

430 *Methodology and limitations*

431 A limitation of this study was that we were not able to identify how many individuals
432 contributed to the activity data recorded at each site. Bilbies are found in isolated groups,
433 which generally contain less than three individuals (Johnson 1989). Bilby populations were
434 not selected as random, as all populations exposed to seismic clearing during the study
435 period were included. Therefore, as this study examined three populations, it is likely that
436 the camera trapping component represents the habitat selection of less than 10 individuals.
437 Similarly, the spool tracking data from two individuals is a small sample size. However, the
438 consistency of the selection for a more open route (from both spool tracking, and camera
439 trapping) suggest that the observed patterns are ecologically meaningful. The only species
440 for which individuals could be reliably identified from photos was cats. We recorded 3–8
441 individual cats across the 4 surveys, making a total of 15 cats. Despite these arguably low
442 numbers of individuals, the experimental design was such that it enabled direct comparison
443 of activity patterns between seismic lines and adjacent control sites, and is therefore
444 independent of requiring population density estimates (see Burton *et al.* 2015).

445 The timeline of the study precluded individual populations being monitored over
446 more than 7 months, with different populations being used to represent different time since
447 clearing. As such, variability between sites may influence the habitat selection at each.
448 Further, no vegetation surveys were conducted to measure the density of vegetation over
449 the recovery process. We believe that the consistency of response shown by numerous
450 species indicates that the behaviour is representative of the wider population.

451 Because we were not able to estimate bilby population density, or calculate any
452 measure of the persistence of bilby populations, no comment can be made regarding the
453 direct effect of funnelling bilbies onto seismic lines on their predation risk. Long-term studies
454 of bilby population exposed to cats and linear clearing are required to identify impacts.

455 However we note that the discontinuous distribution of these species across the landscape
456 would make it very difficult to obtain sufficient statistical power to quantify this relationship.

457 Another issue that we noted was the temperature-dependence of camera data and
458 therefore its influence on temporal patterns. Camera traps detect animals using a passive
459 infrared (PIR) sensor, which identifies heat differential, i.e. a body (animal) is hotter or
460 colder than the ambient temperature. When the body temperature of the animal is close to
461 the ambient temperature, the chance of triggering the camera is reduced (Meek *et al.* 2012).
462 We therefore expect that we captured less diurnal activity using our camera traps due to hot
463 daytime temperatures reducing the detection probability of cameras. This should not
464 influence conclusions made regarding the difference between seismic lines and control
465 stations, but may somewhat underestimate diurnal activity records.

466 Seismic camera sites were 'connected' by a seismic line, while control cameras had no
467 such connection to each other. Dingoes, cattle, and bilbies were seen in 'strings' of captures
468 more commonly on seismic lines. This indicates that animals followed seismic lines for long
469 distances (>100m), which has been recorded previously (Mahon *et al.* 1998; Read and
470 Eldridge 2010; Robley *et al.* 2010). While this may suggest a degree of spatial
471 autocorrelation of cameras on seismic lines and resulting pseudo-replication, it actually
472 illustrates the very point of the current study.

473 **Conclusions**

474 The current study shows that spatial and temporal overlap of bilbies, cats, dingoes,
475 cattle, and agile wallabies is greater on seismic lines than in control areas, a finding that was
476 consistent throughout the recovery process recorded (with the exception of agile wallabies).
477 By contrast, spectacled hare wallabies avoided seismic lines. The removal of vegetation by
478 fire removes the selection of seismic lines by cats, and causes agile wallabies to avoid them,
479 while having no impact on the selection by cattle. The strong selection for seismic lines by

480 cattle, and the resulting potential effects on vegetation recovery, suggest that further
481 research should be conducted into the impact of cattle use on seismic line recovery.

482 Previous studies of predator-prey relationships around seismic lines have identified
483 use of the lines by wolves, causing avoidance by caribou (in response to an increased
484 predation risk), resulting in functional habitat loss (Latham *et al.* 2011). In contrast, the
485 current study identifies selection for seismic lines by prey species. The spatial and temporal
486 funnelling of bilbies (a vulnerable species) and cats may increase the frequency of
487 encounter, which in turn may increase the vulnerability of bilbies to predation. The impact
488 of landscape level disturbances, such as fire, on feral cats, has recently been brought to light
489 (McGregor *et al.* 2014, 2017). Similarly, understanding the effects of clearing on feral cats,
490 and the native species that they threaten, is key to informing management strategies. We
491 suggest investigation of the efficacy of feral cat management targeted areas subject to
492 clearing for seismic surveys may inform potential threat mitigation strategies.

493

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502

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625

626

627

Figure Captions

628

Figure 1. The vegetation density, measured as number of intercepts of touch pole, at three height brackets, at 2m intervals along the bilby path, path control, and four compass controls. Bilbies *a* and *b* are labelled

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630

accordingly. Error bars are standard deviation. Significance was calculated by comparison with bilby path. ●●●

631

indicates $P < 0.001$. ●● indicates $P < 0.01$.

632

633

Figure 2. The proportion of captures in each treatment, pooled across all 4 surveys. *n* in each treatment

634

indicated in each bar. '*' indicates species found at only one site. ●●● indicates $P < 0.001$. ● indicates $P < 0.05$.

635

Figure 3. The proportion (%) of total captures that were part of a 'string' of captures of differing length (> 1, and > 2). Error bars represent standard error.

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637

Figure 4. Temporal patterns in activity between bilbies and other study species. Area under both curves shaded

638

in grey. Grey bars below x-axis *s* indicate hours of darkness, with the light grey buffers indicating season changes

639

in sunrise and sunset. Vales in the top left hand corner of each graph represent the proportion overlap in

640

temporal activity (with 95% confidence intervals in brackets).

641

Figure 5. Proportion of captures at seismic and control sites over time since clearing, of only the species found in

642

all 4 surveys. Markers indicate trap proportions pooled into 30 days bins. Trend lines of predators are shown in

643

solid lines, herbivores in small dashed lines, and cattle in large dashed lines. Only 30-day bins with more than 10

644

captures in total were plotted.

645

Figure 6. Examples of variation in vegetation across sites. A) JP, showing a 3 mo seismic line, and the associated

646

Acacia woodland, characteristics of both JP and KP. B) is GSP, showing a 48 mo seismic line, and the associated

647

grassland. Note the presence of a 'cattle track' in GSP.

648