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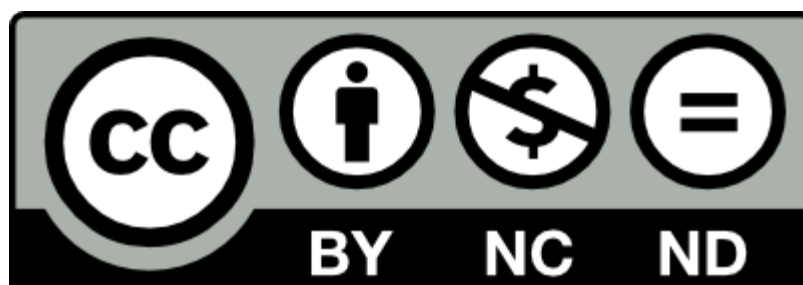
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1 **Title**

2 The importance of mature forest as bat roosting habitat within a production landscape.

3

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15 **Abstract**

16 Conserving biodiversity in production forest landscapes with on-going resource extraction, such
17 as mining and logging, is challenging. Habitat restoration is a strategy that is increasingly used to
18 ameliorate impacts to biodiversity in such landscapes. However, restored forest may have limited
19 value for species that require slow-developing microhabitats, such as tree hollows and logs, and
20 the role that restored forest can play in maintaining populations of these species in production
21 forest landscapes is poorly understood. We examined this issue by assessing the suitability of
22 post-mining restored jarrah (*Eucalyptus marginata*) forest as bat roosting habitat in a production
23 landscape in south-western Australia. We used radio telemetry to track Gould's long-eared bats
24 (*Nyctophilus gouldi*) and southern forest bats (*Vespadelus regulus*) to diurnal roosts during both
25 the maternity and mating seasons. No bats were tracked to a roost in restored forest despite one-
26 third of bats traveling through, or above, restored forest from capture to roosting locations. Both
27 *N. gouldi* and *V. regulus* preferentially roosted in large (>60cm DBH), mature trees in mid to late
28 stages of decay. Absence of roosts, and suitable roost trees, in young (<40 years old) restored
29 jarrah forest indicated that restored forest is poor roosting habitat in the short term, compared to
30 remnant forest, where bats selected mature roost trees (~150-200 years old). Our study suggests
31 that habitat restoration in production forest landscapes is unlikely to play a significant role in
32 conserving populations of species requiring slow-developing microhabitats, for decades if not
33 centuries. Retaining and managing forest remnants would be a more effective strategy to
34 conserve populations of these species.

35

36 **Key words**

37 *Nyctophilus gouldi*, *Vespadelus regulus*, forest restoration, tree hollows, mining

38 **1. Introduction**

39 Conserving global biodiversity is becoming increasingly challenging as humans continually alter
40 the Earth's habitats, leading to numerous species extinctions (Bradshaw, 2012; Fonseca, 2009).
41 In production landscapes, those used for anthropogenic purposes such as mining and logging,
42 conserving biodiversity provides many challenges but habitat restoration has recently emerged as
43 a potential tool to slow, or prevent biodiversity loss in these landscapes (Suding, 2011; Young,
44 2000). While many studies have examined the role habitat restoration can play in conserving
45 biodiversity in production landscapes, few have examined the relative importance of restored and
46 remnant forest, and the interaction between them (e.g., Craig et al., 2012). Yet understanding the
47 role that both habitats play in conserving biodiversity across production forest landscapes is
48 likely to be critical for species relying on microhabitats that are slow to develop in restored areas,
49 such as tree hollows and logs (Vesk et al., 2008).

50

51 Forest-dwelling bats are one group that may rely heavily on remnant forests in production
52 landscapes as they require tree hollows for roosting. Tree-hollow roosts are critical for forest-
53 dwelling bats as they buffer daily and long-term microclimates, reducing the energetic costs of
54 thermoregulating, (e.g., Sedgeley, 2001), facilitate predator evasion (e.g., Fenton et al., 1994),
55 support social relationships (e.g., Lewis, 1995), and are necessary for rearing young (e.g., Law
56 and Chidel, 2007). Roosting habitat for forest-dwelling bats typically comprises multiple
57 roosting structures within an area as many bat species exhibit roost site fidelity, switching
58 between a pool of suitable roosts in close spatial proximity (Threlfall et al., 2013; Webala et al.,
59 2010). As restored forest is unlikely to provide roosting habitat in the short-term (Vesk et al.,
60 2008), this requirement for multiple roosts suggests forest-dwelling bats may require the

61 retention of relatively large areas of remnant forest to persist in production landscapes.
62 Considerable research has focused on roosting preferences of forest-dwelling bats in timber-
63 managed landscapes and those re-vegetated after agricultural use (e.g., Elmore et al., 2004; Law
64 et al., 2011) but we know of no studies specifically examining roosting preferences in post-
65 mining landscapes. Consequently, the reliance of forest-dwelling bats on remnant forest for
66 roosting remains poorly understood in these production landscapes.

67
68 Forest-dwelling bats typically roost in large, mature trees but exhibit intra and interspecific
69 variations in roosting preferences (Broders and Forbes, 2004; Goldingay and Stevens, 2009;
70 Kalcounis-Ruppell et al., 2005; Vonhof and Gwilliam, 2007). Roosting preferences can differ at
71 multiple spatial scales: ‘roost’, a roosting structure such as a tree (Threlfall et al., 2013; Vonhof
72 and Gwilliam, 2007); ‘site’, the vegetation immediately surrounding the roost (Broders and
73 Forbes, 2004; Lumsden et al., 2002a; Perry et al., 2007); and ‘landscape’, the habitat(s)
74 surrounding the roost (Broders et al., 2006; Lumsden et al., 2002b; Pauli et al., 2015). Males and
75 non-breeding female forest bats are generally less selective in roosting requirements than
76 reproductive females at all three spatial scales. Reproductive females tend to select larger roost
77 trees than non-breeding females (Lumsden et al., 2002a; Threlfall et al., 2013) and maternity
78 roosts are typically farther from foraging sites than male roosts (e.g., Lumsden et al., 2002b). Bat
79 species exhibiting flexibility in roosting requirements may roost under decorticated bark or
80 within trunk fissures while more conservative species may be restricted to roosting in hollows
81 (e.g., Law et al., 2011). Understanding roost preferences at multiple spatial scales and across
82 seasons within a restored production landscape is imperative for ensuring effective conservation
83 and management of habitat for bat populations.

84

85 In production forest landscapes where excavating fauna (e.g., woodpeckers) are absent, such as
86 Australia, the natural formation of hollows can occur very slowly (Whitford, 2002), potentially
87 limiting roosting structures available to forest-dwelling bats in restored forest. To determine the
88 relative importance of restored and remnant forest as roosting habitat, we radio-tracked two bat
89 species (Gould's long-eared bat *Nyctophilus gouldi* (Tomes 1858); and southern forest bat
90 *Vespadelus regulus* (Thomas 1906)) within a restored production landscape in the northern jarrah
91 (*Eucalyptus marginata*) forest of south-western Australia. Parts of the northern jarrah forest have
92 been mined for bauxite for over forty years with >15 000 ha already mined and ~600 ha of forest
93 still annually cleared, mined, and restored (Koch, 2007a). Mine restoration aims to return a fully-
94 functioning jarrah forest ecosystem and restored sites are similar floristically to remnant, i.e.,
95 unmined, forest but lack the large, mature trees (Koch and Hobbs, 2007) typically preferred by
96 forest-dwelling bats as roost sites. Furthermore, with only one study examining bat roosting
97 preferences during the mating season in a timber-harvested landscape of the southern jarrah
98 forest (Webala et al., 2010), bat roosting preferences in restored production landscapes of the
99 jarrah forest remain inadequately known.

100

101 We aimed to assess bat roosting preferences across a restored production landscape by
102 determining: (i) species specific bat roosting preferences at three spatial (roost, site and
103 landscape) and two temporal (mating and maternity seasons) scales; and (ii) the relative
104 availability of suitable roosts in restored and remnant unmined forest. We predicted bats would
105 preferentially roost in large, mature trees (Kalcounis-Ruppell et al., 2005; Webala et al., 2010)
106 that were in intermediate stages of decay (Broders and Forbes, 2004; Vonhof and Gwilliam,

107 2007) and situated in relatively open sites with low canopy cover (e.g., Elmore et al., 2004) and
108 that roosting sites would be absent in restored forests due to the absence of large, mature trees
109 (Law et al., 2011; Taylor and Savva, 1988). From roosting studies of the conspecifics, or
110 congeners, elsewhere in Australia we predicted *N. gouldi* would be more flexible in roosting
111 requirements than *V. regulus* (Lunney et al., 1988; Webala et al., 2010) and that males and non-
112 breeding females would have more flexible roosting requirements than reproductive females
113 (Law and Anderson, 2000; Threlfall et al., 2013).

114

115 **2. Materials and methods**

116 *2.1 Study area*

117 The study was conducted at Huntly minesite (32°36' S, 116°07' E), operated by Alcoa of
118 Australia (hereafter Alcoa), located ~90 km SSE of Perth, Western Australia. Huntly has a
119 Mediterranean climate with cool, wet winters and warm, dry summers. Annual rainfall for
120 Dwellingup, ~10 km S of Huntly, is 1237 mm, with >75% falling between May and September.
121 Mean minimum and maximum temperatures vary from 5 to 15 °C in July to 15 to 30 °C in
122 February. The original vegetation at Huntly was jarrah forest, a dry sclerophyll forest whose
123 overstory is dominated by two eucalypts, jarrah and marri (*Corymbia calophylla*), but with some
124 blackbutt (*E. patens*) and bullich (*E. megacarpa*) in gullies. Midstory species include sheoak
125 (*Allocasuarina fraseriana*) and bull banksia (*Banksia grandis*) while common understory species
126 include *Bossiaea aquifolium*, *Lasiopetalum floribundum* and *X. preissii* (Koch, 2007b). Post-
127 mining, Huntly minesite is a mosaic of unmined and restored forest of various ages (Figure 1).
128 Of 300-400 plant species found in unmined forest, >75% are returned to restored forests,
129 although restored sites are more homogenous floristically across the landscape than unmined,

130 forest (Koch, 2007b). Young (<15 years) unburnt restored forest typically has a two-tiered
131 vegetation structure with a jarrah and marri overstory and a thick senescent *Acacia* understory
132 (Grant, 2006). For further details on mining and restoration processes, see Koch (2007a).

133

134 2.2 Field methods

135 Bats were trapped and tracked during maternity (31 October to 9 December 2011, when bats give
136 birth and rear their young) and mating (30 January to 17 March 2012, when female bats are in
137 estrous and mating occurs) seasons. Bats were trapped for two to five hours from sunset using
138 harp traps (Two-Bank 4.2 m²; Ausbat Research Equipment) at five separate waterholes within
139 unmined forest (Figure 1) although the close proximity of two sets of waterholes meant we
140 effectively surveyed three general trapping areas (Figure 1). Trapping attempts within restored
141 forest failed to capture many, if any, bats, so we trapped bats at waterholes to capture sufficient
142 numbers for meaningful analyses. Position-sensitive radio transmitters (0.27 or 0.31 g for *N.*
143 *gouldi* and 0.22 g for *V. regulus*; model LB2X, Holohil Systems) were attached dorsally to 9
144 female and 12 male *N. gouldi* and ventrally (Bullen and McKenzie, 2001) to 11 female and 11
145 male *V. regulus* (Table 1) and weighed <5% of bat body mass (Aldridge and Brigham, 1988),
146 except for one *V. regulus*. Diurnal roost sites were located by tracking, on foot, individual bats
147 from the day following capture until transmitters dropped off or batteries failed (*N. gouldi* range
148 1-6 days; *V. regulus* range 1-5), using three element hand-held Yagi antennas and R-1000
149 Telemetry Receivers (Communications Specialists). Due to logistic constraints we could only
150 track 4 to 6 bats simultaneously. Transmitter signals may bounce off surrounding trees making it
151 difficult to pinpoint exact signal locations but we spent considerable time at each potential roost
152 tree, varying signal frequency and intensity from multiple locations around the tree so we are

153 confident we correctly identified all roost trees, whose location we then recorded using a GPS.
154 We only estimated roost height as jarrah and marri hollows are difficult to detect from the
155 ground and numbers of visible hollows correlate poorly with true hollow numbers (Stojanovic et
156 al., 2012; Whitford, 2002).

157

158 To determine bat roosting preferences at the roost scale we compared roost trees with available
159 trees. We identified one available tree for every roost tree by selecting the nearest tree (≥ 20 cm
160 DBH) to random points between 50 and 100 m in random directions from each roost tree
161 (adapted from Webala et al., 2010). As all bats roosted in unmined forest, we ensured each
162 available tree was also in unmined forest. For each roost and available tree we recorded tree
163 species and measured tree height and diameter breast height over bark (DBH) and estimated tree
164 health using five ordinal variables based on Whitford (2002): snag class (1 = all live tree, 2 =
165 $< 30\%$ dead, 3 = $> 30\%$ dead, 4 = 100% dead); dead branch order (DBO: from 1 where terminal
166 dead branch is a twig to 9 where terminal dead branch is the trunk); crown senescence (from 1
167 for a crown with no senescence to 9 where no crown remains); bark cover (1 = none; 2 = $< 10\%$;
168 3 = 10-25%; 4 = $> 25\%$); and presence/extent of a fire scar (1 = no visible scar; 2 = small scar; 3
169 = large scar).

170

171 To determine bat roosting preferences at the site scale we compared vegetation structure
172 surrounding roost and available trees by centring a 5 x 5 m plot on each tree. We measured,
173 using a tree vertex, canopy height (average of five tallest overstory plants < 10 m from plot),
174 height difference (difference between roost/available tree height and canopy height) and average
175 heights of, and distances to, five nearest overstory plants (≥ 20 cm DBH) from roost/available

176 trees. For canopy cover we digital photographs, with a camera positioned at breast height on a
177 tripod and pointed directly up at the canopy, and used gap fraction analysis to calculate canopy
178 cover (Macfarlane et al., 2007). We took photographs at the four corners of the plot and averaged
179 these values for an overall plot canopy cover value. We also visually estimated percent (to the
180 nearest 5%) cover of litter, logs, ground vegetation (< 0.75 m) and shrub vegetation (0.75 to 5 m)
181 within each plot.

182

183 To determine bat roosting preferences at the landscape scale we randomly identified an equal
184 number of locations (65) as roost locations within unmined forest (<3 km from each trapping
185 area) using GIS (ArcMap 10.1, ESRI, Redlands, CA, USA). For roost and random locations we
186 calculated 12 variables derived from GIS spatial layers: elevation, slope (1 = <3°, 2 = 3-5°, 3 =
187 6-7°, 4 = 8-9°, 5 = 10-11°, 6 = 12-14°, 7 = 15-17°, and 8 = ≥18°); number of years since last fire;
188 distance to nearest restored mine-pit edge; distance to nearest stream; distance to nearest
189 track/road; area of unmined forest within three radii (250 m, 1000 m, and 3000 m); and length of
190 restored mine-pit edge within three radii (250 m, 1000 m, and 3000 m). We initially calculated
191 area and length values for five radii that incorporated the range of distances bats travelled
192 between trapping and first roosting site both in this study (250 m, 500 m, 1000 m, 1500 m, 3000
193 m; Table 1). As 250 m was correlated with 500 m and 1500 m with both 1000 m and 3000 m (all
194 Pearson >0.70) we retained 250 m, 1000 m and 3000 m as the final three radii. In addition, we
195 also quantified, for individual bats, the number of times the straight-line travel path travelled
196 between trapping and first roosting sites (in all but three cases, all in the mating season, this was
197 the roost recorded the day immediately following capture) crossed over restored forest, roost site
198 fidelity, and distances travelled between roost trees.

199
200 To determine the suitability of restored forest as bat roosting habitat we compared vegetation
201 structure at roost sites with vegetation structure within 56 restored sites, from a concurrent bat
202 study (Burgar, 2014). Alcoa has adapted their seeding mix to reduce eucalypt densities in recent
203 years, categorising restored sites as desirable or dense (500 to 2500 or >2500 eucalypt stems ha⁻¹
204 respectively) based on nine month monitoring data (Grant, 2006). To capture differences in
205 eucalypt densities over time we sampled eight sites each from the following restored forest types:
206 0 to 4 years desirable, 5 to 9 years desirable, 5 to 9 years dense, 10 to 14 years desirable, 10 to 14
207 years dense, >15 years desirable, and >15 years dense. We measured vegetation structure in five
208 5 x 5 m plots within each site following the same methodology as for roost/available trees,
209 except for canopy cover we took only one photograph at the centre of each plot, and measured
210 the same variables except for height difference and average heights of, and distances to, the five
211 nearest overstory plants. We averaged measurements over the five plots for an overall site value.

212

213 *2.3 Statistical analyses*

214 All covariates were scaled, standardized around 0 with standard deviation of 1, prior to analysis.
215 To determine if bats chose specific trees for roosting we compared overall characteristics of roost
216 to available trees. We removed three non-eucalypt trees (two sheoak and one bull banksia) from
217 analyses as eucalypts are the predominant canopy trees and the only ones used in restoration. We
218 removed DBO (highly correlated with crown senescence: $r = 0.84$), before constructing a
219 Euclidean resemblance matrix of remaining scaled roost tree variables (DBH, height, snag class,
220 crown senescence, bark cover and fire scar) for each bat species. We ran an ANOVA to test for
221 differences in overall characteristics between the three eucalypt tree species (bullich, jarrah, and

222 marri); there were no differences for either *N. gouldi* ($F_{2,58} = 1.40, P = 0.180$) or *V. regulus* ($F_{3,62}$
223 $= 0.92, P = 0.494$), so we pooled eucalypts for all analyses. To determine bat roosting
224 preferences at site and landscape scales, we compared overall vegetation structure and landscape
225 variables, respectively, of roost to available/random sites and included all roost and
226 available/random sites in the analyses. No site scale variables were highly correlated (all $r <$
227 0.80) so we retained all nine site variables for multivariate analyses but, at the landscape scale,
228 we excluded distance to restored forest, which was highly correlated with length of edge
229 perimeter within 250 m ($r = -0.91$). We then constructed Euclidean resemblance matrices for
230 each of the nine scaled site variables and 11 remaining scaled landscape variables. We used
231 permutational multivariate analyses of variance (PERMANOVA) at each scale (roost, site and
232 landscape) to test for differences between roosts of each bat species and random/available
233 characteristics with the relevant resemblance matrices as dependent variables against a three
234 level categorical fixed factor (*N. gouldi*, *V. regulus* and random/available) and individual bat as a
235 random factor. We used the Adonis function, over 9999 permutations, in R vegan package
236 (Oksanen et al., 2012).

237

238 To identify whether individual variables were related to bat roost preferences at roost, site and
239 landscape scales we ran Gaussian generalized linear mixed models, at each scale separately,
240 using R lmerTest package (Kuznetsova et al., 2014) for each bat species. Although we measured
241 a “paired” available/random for each roost we had no reason to assume individual bats were
242 associated with a paired available/random so tested each bat group (male, female, maternity and
243 mating) against all available/random trees. Thus, each roost, site or landscape variable was the
244 dependent variable with categorical fixed factors of sex (male, female, and available/random) or

245 season (maternity, mating, and available/random), with individual bat as a random factor. We
246 specified available/random as the reference level so model parameters are in relation to the
247 available/random category. Small sample sizes precluded us from analyzing further interactions
248 (e.g., sex by season). Due to the number of tests conducted only those with $P < 0.01$ are
249 presented and discussed, although all are provided in the Appendix (*N. gouldi*: Tables A.1 &
250 A.2, *V. regulus*: Tables A.1 & A.3).

251
252 To determine the suitability of restored forest as roosting habitat, we compared vegetation
253 structure at roost sites with restored sites. We constructed a Euclidean resemblance matrix of six
254 site vegetation variables (scaled) collected at both roost and restored sites (canopy height and
255 canopy, shrub, ground, litter and log cover). There were no significant differences in tree density
256 between Alcoa's desirable and dense categories (5 to 9 year old restoration $t_{14} = 1.40$ $P = 0.184$;
257 10 to 14 year old restoration $t_{14} = -0.35$, $P = 0.786$; >15 year old restoration $t_{14} = -0.84$, $P =$
258 0.416) so we grouped desirable and dense sites within each restored forest age group and
259 considered forest type as a fixed factor with five levels: roost (36) and restored forest of ages 0 to
260 4 (8), 5 to 9 (16), 10 to 14 (16), and >15 (16) years. To test for multivariate differences in site
261 characteristics between forest types we ran PERMANOVAs with the resemblance matrix of site
262 variables as the dependent factor and forest type as the fixed factor. We used the Adonis
263 function, over 9999 permutations, in R vegan package (Oksanen et al., 2012). To identify how
264 individual structural variables differed between roost sites and restored sites we ran separate
265 generalized linear models for each of the seven vegetation structure variables with forest type as
266 the explanatory variable. To account for lack of independence of individual bats with multiple

267 roost sites, we averaged vegetation structure values across individual bats to give a single value
268 for each bat.

269

270 For intra and interspecific comparisons of roost site fidelity we ran Welch's two sample *t*-tests to
271 compare between bat species and two-factor ANOVAs to compare within species (i.e., between
272 sexes, seasons and their interaction), testing significant results with Tukey's post-hoc tests. All
273 statistical analyses were performed in R (R Core Team, 2013).

274

275 **3. Results**

276 *3.1 Radio-tracking*

277 Of 43 bats affixed with transmitters, three transmitters attached to *N. gouldi* and four attached to
278 *V. regulus* either failed, or bats could not be located, while the remaining 36 bats were tracked to
279 59 different roost trees for a total of 101 fixes (i.e. one bat tracked to the same roost three times
280 counted as three fixes but only one roost tree) of which 46 were for *N. gouldi* and 55 for *V.*
281 *regulus* (Table 1).

282

283 *3.2 Roost scale roost preferences*

284 All bats roosted in trees in unmined forest (Figure 1). Bats roosted predominantly in jarrah (*N* =
285 43) but also in marri (*N* = 6), bullich (*N* = 7), sheoak (*N* = 2) and one bull banksia. Both *N.*
286 *gouldi* and *V. regulus* roosted in jarrah and marri but only *N. gouldi* roosted in sheoak and
287 banksia while only *V. regulus* roosted in bullich (Table 1). While we could not pinpoint exact
288 roost locations within trees, we made general observations, surmising that most roosts were
289 hollows (54 of 62 roosts) in the top half of trees (≥ 10 m above the ground). Exceptions to hollow

290 roosting were observed during the mating season with one *N. gouldi* male roosting 5.7 m above
291 the ground in foliage of a bull banksia, one *V. regulus* male roosting 1.5 m above the ground in a
292 trunk fissure of a dead jarrah, and one female *V. regulus* roosting 0.8 m above the ground in a
293 hollow in a fallen branch.

294

295 Overall, eucalypt tree characteristics differed between available, *N. gouldi* roost and *V. regulus*
296 roost trees ($F_{2,124} = 7.25$, $P < 0.001$) *N. gouldi* preferred roost trees in greater stages of decay
297 (snag class, mating season $P = 0.003$, both sexes $P < 0.010$: DBO and crown senescence, all $P <$
298 0.01) than available trees (Figure 2). Female *N. gouldi* and all *N. gouldi* during the maternity
299 season preferred roost trees with significantly larger DBHs (both $P < 0.001$) than available trees
300 (Figure 2). Female *V. regulus*, and *V. regulus* during the mating season, preferred roost trees in
301 greater stages of decay (mating season, DBO and crown senescence $P < 0.001$: female, snag
302 class $P = 0.002$, DBO $P = 0.006$ and crown senescence $P < 0.001$; Figure 2) than available trees
303 (Figure 2). During the mating season all *V. regulus* preferred trees with larger DBHs ($P < 0.001$).

304

305 3.3 Site scale roost preferences

306 At the site scale, overall vegetation structure differed between available, *N. gouldi* roost, and *V.*
307 *regulus* roost sites ($F_{2,125} = 1.93$, $P = 0.030$). *N. gouldi* males preferred roost sites with more log
308 cover than available sites ($P = 0.005$; Figure 3). Female *V. regulus*, and all *V. regulus* during the
309 mating season, also preferred roost sites with more log cover (female, $P = 0.003$: mating, $P =$
310 0.010) than available sites. All *V. regulus* during the maternity season preferred roost sites with
311 less shrub cover than available sites ($P = 0.007$, Figure 3).

312

313 3.4 Landscape scale roost preferences

314 Overall landscape scale characteristics differed between random, *N. gouldi* roost, and *V. regulus*
315 roost locations ($F_{2,127} = 5.34$, $P = 0.001$). Univariate analyses found that female *N. gouldi*
316 selected roosts at higher elevations ($P = 0.003$), on ground with flatter slopes ($P = 0.007$), farther
317 from both streams ($P = 0.002$) and tracks ($P = 0.004$), and surrounded by less unmined forest
318 <3000 m ($P = 0.002$), than random locations (Figure 4). During the maternity season, *N. gouldi*
319 selected roosts on ground with flatter slopes ($P = 0.001$) while, in the mating season, roosts were
320 further from tracks ($P = 0.005$) and with more unmined forest within 3000 m ($P = 0.002$) than
321 random locations.

322

323 All *V. regulus* selected roosts with more restoration edge within 3000 m than random locations
324 (male, female, and maternity $P < 0.010$, mating $P = 0.009$; Figure 5). Female *V. regulus* also
325 preferred more recently burnt roost locations ($P = 0.010$), surrounded by less unmined forest
326 within 1000 m ($P < 0.001$) and more restoration edge at all three spatial scales (250 m $P = 0.002$,
327 1000 m and 3000 m $P < 0.001$), than random locations. Male *V. regulus* and all *V. regulus* during
328 the mating season preferred roost locations at lower elevations than random locations (male $P <$
329 0.001 , mating $P = 0.006$). Also during the mating season *V. regulus* preferred roosts with less
330 unmined forest within 1000 m than random locations ($P = 0.009$). During the maternity season
331 *V. regulus* selected roost locations with less unmined forest (all $P < 0.001$) and more restoration
332 edge (250 m $P = 0.002$, 1000 and 3000 m $P < 0.001$) than random locations, at all three spatial
333 scales.

334

335 3.5 Suitability of the restored forest as roosting habitat

336 Overall vegetation structure differed significantly between roost sites and restored sites ($F_{1,90} =$
337 46.18, $P < 0.001$), although restored forest became structurally more similar to roosts as it
338 matured. Univariate analyses revealed vegetation structure was significantly different between
339 roost sites and restored sites for all structural variables (Figure A1; canopy height $F_{4,87} = 226.50$,
340 $P < 0.001$; canopy cover $F_{4,87} = 58.07$, $P < 0.001$; shrub cover $F_{4,87} = 8.23$, $P < 0.001$; ground
341 cover $F_{4,87} = 6.47$, $P = 0.001$; log cover $F_{4,87} = 18.93$, $P < 0.001$; and litter cover $F_{4,87} = 95.14$, P
342 < 0.001).

343

344 3.6 Roost site fidelity

345 Of the 36 bats tracked, eight were only tracked to one diurnal roost for one day before the
346 transmitter fell off or we could not locate the bat. Of those bats tracked for multiple days, 70%
347 switched roosts after the first day. During the maternity season, all three female *N. gouldi* and
348 four female *V. regulus* switched roosts after the first day, compared to only one of three male *V.*
349 *regulus*. During the mating season, all three male and five female *N. gouldi* switched roosts after
350 the first day. In contrast, only one female *V. regulus* switched roosts after the first day; two
351 females did not change roosts during the tracking period (four and five days) while one female
352 switched roosts between the second and third day. Only one male *V. regulus* was tracked for
353 multiple days during the mating season and it did not change roosts. There was no difference in
354 distances between roosts between sexes or seasons for either *N. gouldi* (sex, $F_{1,9} = 2.88$, $P =$
355 0.124; season $F_{1,9} = 1.75$, $P = 0.218$) or *V. regulus* (sex, $F_{1,7} = 0.07$, $P = 0.804$; season $F_{1,7} =$
356 1.07, $P = 0.336$) or the interaction between the two for *V. regulus* ($F_{1,7} = 0.34$, $P = 0.578$). Small
357 sample sizes meant we could not test the interaction for *N. gouldi*. *N. gouldi* travelled farther
358 between subsequent roosts (i.e., roost to roost distances) than *V. regulus* (218 ± 51 m and 88 ± 21

359 m, respectively; $t_{15} = 2.35$, $P = 0.033$; Table 1). Considering straight-line flight paths from
360 capture to first roosting site, 13 bats (36%) potentially travelled through restored forest to reach
361 their first diurnal roost.

362

363 **4. Discussion**

364 Faunal recolonization of restored forest may be relatively quick for some species, such as the
365 pygmy possum *Cercartetus concinnus*, but take decades or centuries for others, such as the skink
366 *Egernia napoleonis* (Craig et al., 2012). This was the first study to examine the roosting
367 preferences of bats across a restored production landscape and our results indicate that these bat
368 species require slow-developing microhabitats, not yet present in restored forest. Absence of
369 roosts, suitable roost trees and suitable roost sites in young restored jarrah forest suggests that
370 restored forest <40 years of age is poor roosting habitat, compared to unmined forest, for both *N.*
371 *gouldi* and *V. regulus*.

372

373 *4.1 Roost trees characteristics consistent with trees having maximum number of hollows*

374 Like other studies, we found that forest-dwelling bats generally prefer roosting in large, mature
375 trees with some intra and interspecific preferences (e.g., Lumsden et al., 2002a; Vonhof and
376 Gwilliam, 2007). In concordance with predictions, and similar to previous findings (Threlfall et
377 al., 2013; Webala et al., 2010), both *N. gouldi* and *V. regulus* selected eucalypt roost trees based
378 on tree size and decay stage, preferring larger and more senescent roost trees. Regardless of sex
379 or species, bats selected roost trees in mid-decay stages, consistent with sexual preferences of
380 North American *Myotis* species (Broders and Forbes, 2004). Contrary to our predictions, female
381 *V. regulus* and *N. gouldi* had similar roost tree preferences but during the maternity season *V.*

382 *regulus* were considerably more flexible in roost selection than *N. gouldi*. Hollow occurrence
383 and abundance increases in eucalypts as DBH and senescence increases (Rayner et al., 2014)
384 with jarrah and marri hollow abundance peaking in trees with intermediate levels of DBO and
385 crown senescence (Whitford, 2002). Tree characteristics preferred by both *N. gouldi* and *V.*
386 *regulus* likely correspond to jarrah and marri trees with the most hollows.

387

388 *N. gouldi* and *V. regulus* collectively selected jarrah and marri trees that were ~60 and 80 cm
389 DBH, respectively, slightly smaller than mating season roost trees in the southern jarrah forest
390 (Webala et al., 2010) but substantially larger than trees in restored forest (~24 cm DBH in 15
391 year old restored forest; Burgar, 2014). Trees selected for roosting are estimated to be ~150-200
392 years old and contain one or more hollows (Whitford, 2002). By ~60 years old both jarrah and
393 marri trees are estimated to contain at least one hollow with a slit entrance of 20 mm (Whitford,
394 2002). As bats roost in hollows with entrances only slightly larger than themselves (e.g.,
395 Goldingay, 2009; Tidemann and Flavel, 1987) bats may not be as restricted by hollow size, and
396 tree age, as many other hollow-dependent fauna, at least during the mating season. Small
397 hollows are less likely to be used during the maternity season as maternity colonies may number
398 ≥ 50 females, in addition to their young (Law and Anderson, 2000; Vonhof and Gwilliam, 2007).

399 Studies of maternity colony sizes for jarrah forest bat species suggest colonies of 10-19 *N. gouldi*
400 adults (Lunney et al., 1988; Threlfall et al., 2013) and 25-66 *V. regulus* adults (Taylor and Savva,
401 1988; Tidemann and Flavel, 1987). *N. gouldi*'s preference for roost trees almost twice as large in
402 the maternity season, compared to the mating season, is consistent with studies of *N. gouldi* in
403 suburban eastern Australia (Threlfall et al., 2013) and emphasizes the importance of moderate
404 sized hollows for bats during the maternity season.

405
406 Bats generally prefer relatively open roost sites with lower levels of surrounding vegetation
407 cover than available sites (e.g., Elmore et al., 2004; Webala et al., 2010), but contrary to
408 predictions and research from the southern jarrah forest (Webala et al., 2010), we did not find
409 bats preferentially roosting in relatively open sites with low canopy cover. However, we did find
410 that, during the maternity season, *V. regulus* preferred roosts with less shrub cover, compared to
411 available sites. In North America *Lasiuris borealis* roost sites have also been associated with low
412 understory cover and this has been attributed to increased plant growth from reduced shading by
413 midstory and/or small overstory trees in these sites (Perry et al., 2007). It is possible that this is a
414 correlative association for *V. regulus* as well. The preference by female *V. regulus* for roosts in
415 more recently burnt forests, compared to available sites, and the fact that all bats roosted in
416 unmined forest which is regularly subjected to prescribed fires, is consistent with research in
417 North America, where forest bat communities are generally resilient to fires (Buchalski et al.,
418 2013; Lacki et al., 2009). While fires only likely cause formation of 10% of hollows (Whitford,
419 2002), fires may assist in hollow formation where limbs have already been broken (Lacki et al.,
420 2009; Whitford, 2002). The preference for more log cover at roost sites, compared to available
421 sites, by male *N. gouldi*, female *V. regulus* and all *V. regulus* during the mating season suggests
422 these bats may select roosting sites close to foraging opportunities as coarse woody debris
423 contains a rich invertebrate fauna (Horn and Hanula, 2008; Koch et al., 2010), including orders
424 consumed by both bat species (Burgar et al., 2014). We acknowledge this is speculative and
425 suggest future research evaluates the value of coarse woody debris as habitat for prey species of
426 jarrah forest bats.
427

428 4.2 Suitability of the restored landscape as roosting habitat

429 We trapped bats at five locations during both maternity and mating seasons and no bats were
430 observed roosting in restored forest. This was despite >35% of bats presumably travelling
431 adjacent to, or through, restored forest to reach roosting sites from trapping locations.
432 Concordant with our predictions, roosting sites were lacking within restored forests due to the
433 absence of roosting structures, i.e., hollow bearing trees, and this is likely driving roost
434 preferences at the landscape level. A concurrent study investigating bat box use in the northern
435 jarrah forest suggests that some bat species are capable of roosting in restored forest when roost
436 structures are available (Burgar, 2014). Our findings are consistent with bat roosting research in
437 production landscapes elsewhere in Australia where tracked bats were always found roosting in
438 remnant forest, either avoiding regrowth or selecting retained mature trees for roosting (Law et
439 al., 2011; Webala et al., 2010). In timber-harvested landscapes, *N. gouldi* roosted in forests
440 logged within 10-25 years, albeit in large trees retained during harvesting (Webala et al., 2010)
441 whereas *V. regulus* avoided roosting in regrowth, preferring mature forest (Taylor and Savva,
442 1988; Webala et al., 2010). In south-eastern Australia the congeneric *V. pumilus* preferred
443 roosting in mature forest when available, but was capable of roosting in remnant, regrowth and
444 eucalypt plantation forest when mature forest was absent (Law and Anderson, 2000). Restored
445 jarrah forest is a relatively young (<40 years), developing ecosystem and once hollows form it is
446 anticipated restored areas will provide roosting habitat for bats. In the meantime, it is important
447 to both retain patches of mature trees during mining and manage these patches through
448 sustainable harvesting and fire management practices to ensure sufficient habitat for bats is
449 retained across the landscape.

450

451 A meta-analysis of North American bat research found that hollow roosting bats selected trees
452 that were closer to the nearest water source than available trees (Kalcounis-Ruppell et al., 2005),
453 which may suggest bats select roosts based on proximity to optimal foraging habitats (e.g.,
454 Broders et al., 2006). However, reproductive females that consume large quantities of insects
455 each night (e.g., Kalka and Kalko, 2006) have to balance their energetic needs with roosting
456 requirements as suitable maternity roosts may not be near highly profitable foraging areas (e.g.,
457 Pauli et al., 2015). In eastern Australia, bat maternity roosts were typically farther from foraging
458 sites than male roosts (Lumsden et al., 2002b) as we indirectly found in our study. As stream
459 zones are generally excluded from mining, streams are absent from restored forest, occurring
460 instead in unmined forests. The selection of sites that were further from optimal foraging habitat
461 (i.e., tracks and streams) for *N. gouldi* females and all *N. gouldi* during the mating season may
462 explain why these bats preferred roost sites with more log cover than available sites; they
463 compensated by selecting roosting sites where more prey was potentially available. We also
464 found female *V. regulus* and all *V. regulus* during the maternity season preferentially roosted in
465 locations with less surrounding unmined forest and more restoration edge, regardless of spatial
466 scale, than available locations. Edges may provide foraging opportunities, orientation clues and
467 established routes that decrease commuting time to foraging grounds, and provide shelter from
468 wind and/or predators (Verboom and Huitema, 1997). Our results suggest that foraging resources
469 may influence roosting preferences by *V. regulus*, as *V. regulus* seems to prefer a mosaic forest
470 landscape comprising unmined and restored forest of various ages. Similarly, in North America
471 *Myotis sodalis* selected maternity roosts in areas with high local forest cover within broader
472 landscapes with low forest cover (Pauli et al., 2015). A landscape-scale bat roosting study
473 concluded that multiple species of UK bat likely benefited from a network of forest patches

474 across a landscape where woodland cover was reduced (Boughey et al., 2011). While it is
475 encouraging that *V. regulus* exploited roosting structures close to restored forest, the percentage
476 of unmined forest surrounding roosts still never fell below 60% at the 250 m scale. Future
477 studies are needed to identify the minimum amount of remnant forest surrounding roosts that
478 bats can tolerate.

479

480 *4.3 Roost site fidelity*

481 Roost switching, by both *N. gouldi* and *V. regulus*, while maintaining fidelity to a roosting area
482 suggests roost availability in the northern jarrah forest may not be limiting in unmined forest.
483 Many bat species frequently switch roosts while maintaining fidelity to an area (e.g., Lacki et al.,
484 2009; Law et al., 2011), a beneficial behavior that increases familiarity with several roosts of
485 potentially different microclimates and lowers both predation risk and ectoparasite loads (Lewis,
486 1995). Mine-pits, typically 10-20 ha in size (Grant, 2006), potentially encompass entire roosting
487 areas given that *N. gouldi* and *V. regulus* travelled an average of 218 and 88 m between roosts,
488 respectively. Assuming bats travelled within a circular area, distances travelled equate to 15 and
489 2 ha roosting area for *N. gouldi* and *V. regulus*, respectively. These distances were substantially
490 shorter than in the southern jarrah forest (Webala et al., 2010), but similar to distances in south-
491 eastern Australia for *N. gouldi* (e.g., Lunney et al., 1988; Threlfall et al., 2013). Retention of
492 mature forest should aim to capture enough roost trees to ensure roost area fidelity is maintained.
493 Additionally, mature forest patches interspersed across the landscape would best cater to both
494 intra and interspecific landscape scale roost requirements. Similar to the southern jarrah forest
495 (Webala et al., 2010), retention of roosting habitat at low elevations will benefit *V. regulus* while
496 retaining roosting habitat on relatively flat ground, which tends to be high in the landscape in the

497 jarrah forest, will benefit *N. gouldi*. We suggest future research be designed specifically from the
498 landscape perspective to elucidate minimum roosting areas for bats within restored landscapes
499 and causal mechanisms influencing roost fidelity requirements.

500

501 **5. Conclusions**

502 The lack of roosting in restored forest underscores the importance of remnant mature forest
503 patches in conserving and maintaining bat populations across production landscapes. Bats'
504 resilience and adaptability generally make them tolerant to disturbance (Arnett, 2003) and, while
505 affected by habitat destruction such as the loss of canopy trees, their vagility reduces the
506 immediate impact of habitat loss for many species (Fenton et al., 1998). During our study neither
507 species was found roosting in restored forest of any age (all <40 years old at Huntly minesite),
508 despite having relatively flexible roosting preferences and the occurrence of *N. gouldi* in bat
509 boxes within restored forest. While records of bats roosting in regrowth in other studies are
510 encouraging (Law and Anderson, 2000; Lumsden et al., 2002b), the general avoidance of
511 restored forest as roosting habitat in our study, and of regrowth elsewhere (Law et al., 2011;
512 Webala et al., 2010), reinforces the importance of remnant forest to the conservation of bat
513 populations in production landscapes. Our study suggests that restored forest is unlikely to
514 contribute significantly to the conservation of species requiring slow-developing microhabitats in
515 production forest landscapes as these microhabitats will be lacking in restored forest for decades,
516 or even centuries. These species will be best conserved in production landscapes by retaining
517 suitably sized forest remnants and ensuring these remnants are managed effectively to maintain
518 the microhabitats these species require.

519

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526

527

528 **References**

- 529 Aldridge, H.D.J.N., Brigham, R.M., 1988. Load carrying and Maneuverability in an
530 insectivorous bat: A test of the 5% “rule” of radio-telemetry. *J. Mammal.* 69, 379–382.
- 531 Arnett, E.B., 2003. Advancing science and partnerships for the conservation of bats and their
532 habitats. *Wildl. Soc. Bull.* 31, 2–5.
- 533 Boughey, K.L., Lake, I.R., Haysom, K.A., Dolman, P.M., 2011. Effects of landscape-scale
534 broadleaved woodland configuration and extent on roost location for six bat species across
535 the UK. *Biol. Conserv.* 144, 2300–2310. doi:http://dx.doi.org/10.1016/j.biocon.2011.06.008
- 536 Bradshaw, C.J.A., 2012. Little left to lose: Deforestation and forest degradation in Australia
537 since European colonization. *J. Plant Ecol.* 5, 109–120.
- 538 Broders, H.G., Forbes, G.J., 2004. Interspecific and intersexual variation in roost-site selection of
539 northern long-eared and little brown bats in the Greater Fundy National Park Ecosystem. *J.*
540 *Wildl. Manage.* 68, 602–610. doi:10.2307/3803394
- 541 Broders, H.G., Forbes, G.J., Woodley, S., Thompson, I.D., 2006. Range extent and stand
542 selection for roosting and foraging in forest-dwelling northern long-eared bats and little
543 brown bats in the Greater Fundy Ecosystem, New Brunswick. *J. Wildl. Manage.* 70, 1174–
544 1184.
- 545 Buchalski, M.R., Fontaine, J.B., Heady III, P.A., Hayes, J.P., Frick, W.F., 2013. Bat response to
546 differing fire severity in mixed-conifer forest California, USA. *PLoS One* 8, e57884.
547 doi:10.1371/journal.pone.0057884
- 548 Bullen, R., McKenzie, N.L., 2001. Bat airframe design: flight performance, stability and control
549 in relation to foraging ecology. *Aust. J. Zool.* 49, 235–261.
- 550 Burgar, J.M., 2014. Bat habitat use of restored jarrah eucalypt forests in south-western Australia.
551 *Sch. Vet. Life Sci. Murdoch University, Murdoch.*
- 552 Burgar, J.M., Murray, D.C., Craig, M.D., Haile, J., Houston, J., Stokes, V., Bunce, M., 2014.
553 Who’s for dinner? High-throughput sequencing reveals bat dietary differentiation in a
554 biodiversity hotspot where prey taxonomy is largely undescribed. *Mol. Ecol.* 23, 3605–
555 3617. doi:10.1111/mec.12531
- 556 Craig, M.D., Hardy, G.E.S.J., Fontaine, J.B., Garkakalis, M.J., Grigg, A.H., Grant, C.D.,
557 Fleming, P.A., Hobbs, R.J., 2012. Identifying unidirectional and dynamic habitat filters to
558 faunal recolonisation in restored mine-pits. *J. Appl. Ecol.* 49, 919–928. doi:10.1111/j.1365-
559 2664.2012.02152.x

- 560 Elmore, L.W., Miller, D.A., Vilella, F.J., 2004. Selection of diurnal roosts by red bats (*Lasiurus*
561 *borealis*) in an intensively managed pine forest in Mississippi. *For. Ecol. Manage.* 199, 11–
562 20. doi:<http://dx.doi.org/10.1016/j.foreco.2004.03.045>
- 563 Fenton, M.B., Cumming, D.H.M., Rautenbach, I.L., Cumming, G.S., Cumming, M.S., Ford, G.,
564 Taylor, R.D., Dunlop, J., Hovorka, M.D., Johnston, D.S., Portfors, C. V., Kalcounis, M.C.,
565 Mahlangu, Z., 1998. Bats and the loss of tree canopy in African woodlands. *Conserv. Biol.*
566 12, 399–407. doi:10.1046/j.1523-1739.1998.96376.x
- 567 Fenton, M.B., Rautenbach, I.L., Smith, S.E., Swanepoel, C.M., Grosell, J., van Jaarsveld, J.,
568 1994. Raptors and bats: threats and opportunities. *Anim. Behav.* 48, 9–18.
569 doi:<http://dx.doi.org/10.1006/anbe.1994.1207>
- 570 Fonseca, C.R., 2009. The Silent Mass Extinction of Insect Herbivores in Biodiversity Hotspots.
571 *Conserv. Biol.* 23, 1507–1515. doi:10.1111/j.1523-1739.2009.01327.x
- 572 Goldingay, R.L., 2009. Characteristics of tree hollows used by Australian birds and bats. *Wildl.*
573 *Res.* 36, 394–409. doi:10.1071/wr08172
- 574 Goldingay, R.L., Stevens, J.R., 2009. Use of artificial tree hollows by Australian birds and bats.
575 *Wildl. Res.* 36, 81–97. doi:10.1071/wr08064
- 576 Grant, C.D., 2006. State-and-transition successional model for bauxite mining rehabilitation in
577 the jarrah forest of western Australia. *Restor. Ecol.* 14, 28–37.
- 578 Horn, S., Hanula, J., 2008. Relationship of coarse woody debris to arthropod availability for red-
579 cockaded woodpeckers and other bark-foraging birds on loblolly pine boles. *J. Entomol.*
580 *Sci.* 43, 153–168.
- 581 Kalcounis-Ruppell, M.C., Psyllakis, J.M., Brigham, R.M., 2005. Tree roost selection by bats: an
582 empirical synthesis using meta-analysis. *Wildl. Soc. Bull.* 33, 1123–1132.
- 583 Kalka, M., Kalko, E.K. V, 2006. Gleaning bats as underestimated predators of herbivorous
584 insects: diet of *Micronycteris microtis* (Phyllostomidae) in Panama. *J. Trop. Ecol.* 22, 1–10.
585 doi:10.1017/s0155467405002990
- 586 Koch, J., Grigg, A., Gordon, R., Majer, J., 2010. Arthropods in coarse woody debris in jarrah
587 forest and rehabilitated bauxite mines in Western Australia. *Ann. For. Sci.* 67, 106.
588 doi:10.1051/forest/2009087
- 589 Koch, J.M., 2007a. Alcoa's mining and restoration process in south Western Australia. *Restor.*
590 *Ecol.* 15, S11–S16.
- 591 Koch, J.M., 2007b. Restoring a jarrah forest understorey vegetation after bauxite mining in
592 Western Australia. *Restor. Ecol.* 15, S26–S39.

- 593 Koch, J.M., Hobbs, R.J., 2007. Synthesis: is Alcoa successfully restoring a jarrah forest
594 ecosystem after bauxite mining in Western Australia? *Restor. Ecol.* 15, S137–S144.
- 595 Kuznetsova, A., Bruun Brockhoff, P., Bojesen Christensen, R.H., 2014. lmerTest: Tests for
596 random and fixed effects for linear mixed effect models (lmer objects of lme4 package).
- 597 Lacki, M.J., Cox, D.R., Dodd, L.E., Dickinson, M.B., 2009. Response of northern bats (*Myotis*
598 *septentrionalis*) to prescribed fires in eastern Kentucky forests. *J. Mammal.* 90, 1165–1175.
- 599 Law, B.S., Anderson, J., 2000. Roost preferences and foraging ranges of the eastern forest bat
600 *Vespadelus pumilus* under two disturbance histories in northern New South Wales,
601 Australia. *Austral Ecol.* 25, 352–367. doi:10.1046/j.1442-9993.2000.01046.x
- 602 Law, B.S., Chidel, M., 2007. Bats under a hot tin roof: comparing the microclimate of eastern
603 cave bat (*Vespadelus troughtoni*) roosts in a shed and cave overhangs. *Aust. J. Zool.* 55, 49–
604 55. doi:10.1071/zo06069
- 605 Law, B.S., Chidel, M., Penman, T., 2011. Do young eucalypt plantations benefit bats in an
606 intensive agricultural landscape? *Wildl. Res.* 38, 173–187. doi:10.1071/wr10204
- 607 Lewis, S.E., 1995. Roost Fidelity of Bats: A Review. *J. Mammal.* 76, 481–496.
- 608 Lumsden, L.F., Bennett, A.F., Silins, J.E., 2002a. Selection of roost sites by the lesser long-eared
609 bat (*Nyctophilus geoffroyi*) and Gould’s wattled bat (*Chalinolobus gouldii*) in south-eastern
610 Australia. *J. Zool.* 257, 207–218. doi:10.1017/s095283690200081x
- 611 Lumsden, L.F., Bennett, A.F., Silins, J.E., 2002b. Location of roosts of the lesser long-eared bat
612 *Nyctophilus geoffroyi* and Gould’s wattled bat *Chalinolobus gouldii* in a fragmented
613 landscape in south-eastern Australia. *Biol. Conserv.* 106, 237–249.
- 614 Lunney, D., Barker, J., Priddel, D., Oconnell, M., 1988. Roost selection by Goulds Long-eared
615 Bat, *Nyctophilus gouldi* tomes (Chiroptera, Vespertilionidae) in logged forest on the south
616 coast of New South-Wales. *Aust. Wildl. Res.* 15, 375–384.
- 617 Macfarlane, C., Hoffman, M., Eamus, D., Kerp, N., Higginson, S., McMurtrie, R., Adams, M.,
618 2007. Estimation of leaf area index in eucalypt forest using digital photography. *Agric. For.*
619 *Meteorol.* 143, 176–188. doi:10.1016/j.agrformet.2006.10.013
- 620 Oksanen, J., Blanchet, G., Kindt, R., Legendre, P., Minchin, P.R., O’Hara, R.B., Simpson, G.L.,
621 Solymos, P., Stevens, M.H.H., Wagner, H., 2012. vegan: Community Ecology Package.
- 622 Pauli, B., Badin, H., Haulton, G.S., Zollner, P., Carter, T., 2015. Landscape features associated
623 with the roosting habitat of Indiana bats and northern long-eared bats. *Landsc. Ecol.* 1–15.
624 doi:10.1007/s10980-015-0228-y

- 625 Perry, R.W., Thill, R.E., Carter, S.A., 2007. Sex-specific roost selection by adult red bats in a
626 diverse forested landscape. *For. Ecol. Manage.* 253, 48–55. doi:DOI:
627 10.1016/j.foreco.2007.07.007
- 628 R Core Team, 2013. R: A language and environment for statistical computing.
- 629 Rayner, L., Ellis, M., Taylor, J.E., 2014. Hollow occurrence and abundance varies with tree
630 characteristics and among species in temperate woodland Eucalyptus. *Austral Ecol.* 39,
631 145–157. doi:10.1111/aec.12052
- 632 Sedgley, J.A., 2001. Quality of cavity microclimate as a factor influencing selection of
633 maternity roosts by a tree-dwelling bat, *Chalinolobus tuberculatus*, in New Zealand. *J.*
634 *Appl. Ecol.* 38, 425–438.
- 635 Stojanovic, D., Webb, M., Roshier, D., Saunders, D., Heinsohn, R., 2012. Ground-based survey
636 methods both overestimate and underestimate the abundance of suitable tree-cavities for the
637 endangered Swift Parrot. *Emu* 112, 350–356. doi:http://dx.doi.org/10.1071/MU11076
- 638 Suding, K.N., 2011. Toward an Era of Restoration in Ecology: Successes, Failures, and
639 Opportunities Ahead, in: Futuyma, D.J., Shaffer, H.B., Simberloff, D. (Eds.), *Annual*
640 *Review of Ecology, Evolution, and Systematics*, Vol 42. Annual Reviews, Palo Alto, pp.
641 465–487. doi:10.1146/annurev-ecolsys-102710-145115
- 642 Taylor, R.J., Savva, N.M., 1988. Use of roost sites by four species of bats in state forest in south-
643 eastern Tasmania, Australia. *Aust. Wildl. Res.* 15, 637–646.
- 644 Threlfall, C.G., Law, B., Banks, P.B., 2013. Roost selection in suburban bushland by the urban
645 sensitive bat *Nyctophilus gouldi*. *J. Mammal.* 94, 307–319.
- 646 Tidemann, C.R., Flavel, S.C., 1987. Factors affecting choice of diurnal roost site by tree-hole
647 bats (Microchiroptera) in southeastern Australia. *Aust. Wildl. Res.* 14, 459–473.
- 648 Verboom, B., Huitema, H., 1997. The importance of linear landscape elements for the
649 pipistrelle *Pipistrellus pipistrellus* and the serotine bat *Eptesicus serotinus*. *Landsc. Ecol.* 12,
650 117–125. doi:10.1007/bf02698211
- 651 Vesk, P.A., Nolan, R., Thomson, J.R., Dorrough, J.W., Nally, R. Mac, 2008. Time lags in
652 provision of habitat resources through revegetation. *Biol. Conserv.* 141, 174–186.
653 doi:10.1016/j.biocon.2007.09.010
- 654 Vonhof, M.J., Gwilliam, J.C., 2007. Intra- and interspecific patterns of day roost selection by
655 three species of forest-dwelling bats in Southern British Columbia. *For. Ecol. Manage.* 252,
656 165–175. doi:DOI: 10.1016/j.foreco.2007.06.046
- 657 Webala, P.W., Craig, M.D., Law, B.S., Wayne, A.F., Bradley, J.S., 2010. Roost site selection by
658 southern forest bat *Vespadelus regulus* and Gould’s long-eared bat *Nyctophilus gouldi* in

- 659 logged jarrah forests; south-western Australia. *For. Ecol. Manage.* 260, 1780–1790.
660 doi:DOI: 10.1016/j.foreco.2010.08.022
- 661 Whitford, K.R., 2002. Hollows in jarrah (*Eucalyptus marginata*) and marri (*Corymbia*
662 *calophylla*) trees: I. Hollow sizes, tree attributes and ages. *For. Ecol. Manage.* 160, 201–
663 214. doi:Doi: 10.1016/s0378-1127(01)00446-7
- 664 Young, T.P., 2000. Restoration ecology and conservation biology. *Biol. Conserv.* 92, 73–83.
665 doi:http://dx.doi.org/10.1016/S0006-3207(99)00057-9
- 666
- 667

668 **Figure Captions**

669 Figure 1: a) The location of 5 bat trapping sites (diamonds), adjacent to waterholes within Huntly
670 minesite. Restored forest is denoted by grey while unmined forest is white. Black lines denote
671 roads while grey lines denote streams. Roost trees selected by *N. gouldi* females (black stars), *N.*
672 *gouldi* males (grey stars), *V. regulus* females (black circles) and *V. regulus* males (grey circles)
673 are shown for b) Sites 1 and 5; c) Sites 2 and 3; and d) Site 4.

674

675 Figure 2: Boxplots showing significant ($P \leq 0.01$) roost scale preferences by sex, season and
676 available roosts for *N. gouldi* (DBH, snag class, dead branch order and crown senescence) and *V.*
677 *regulus* (snag class, dead branch order and crown senescence).

678

679 Figure 3: Boxplot showing the significant ($P \leq 0.01$) site scale preference by sex, season and
680 available roosts for *N. gouldi* (log cover) and *V. regulus* (shrub and log cover).

681

682 Figure 4: Boxplots showing significant ($P \leq 0.01$) landscape scale preferences for *N. gouldi* by
683 sex, season and available roosts (elevation, slope, distance to stream, distance to track and the
684 amount of unmined forest within 3000 m).

685

686 Figure 5: Boxplots showing significant ($P \leq 0.01$) landscape scale preferences for *V. regulus* by
687 sex, season and available roosts (elevation, time since fire, the amount of unmined forest within
688 250 m, 1000 m, and 3000 m, and the length of restored forest edge perimeter within 250 m, 1000
689 m and 3000 m).

690

691 Figure A.1: Vegetation structure across the restored landscape in south-western Australia. We
692 compared vegetation structure between roost sites (n=36) and each age group of restored forest
693 sites (0-4 n=8, 5-9 n=16, R 10-14 n=16, R >15 n= 16) using linear models; * indicates a
694 significant difference at $P < 0.05$. All linear models were significant at the $P < 0.05$.

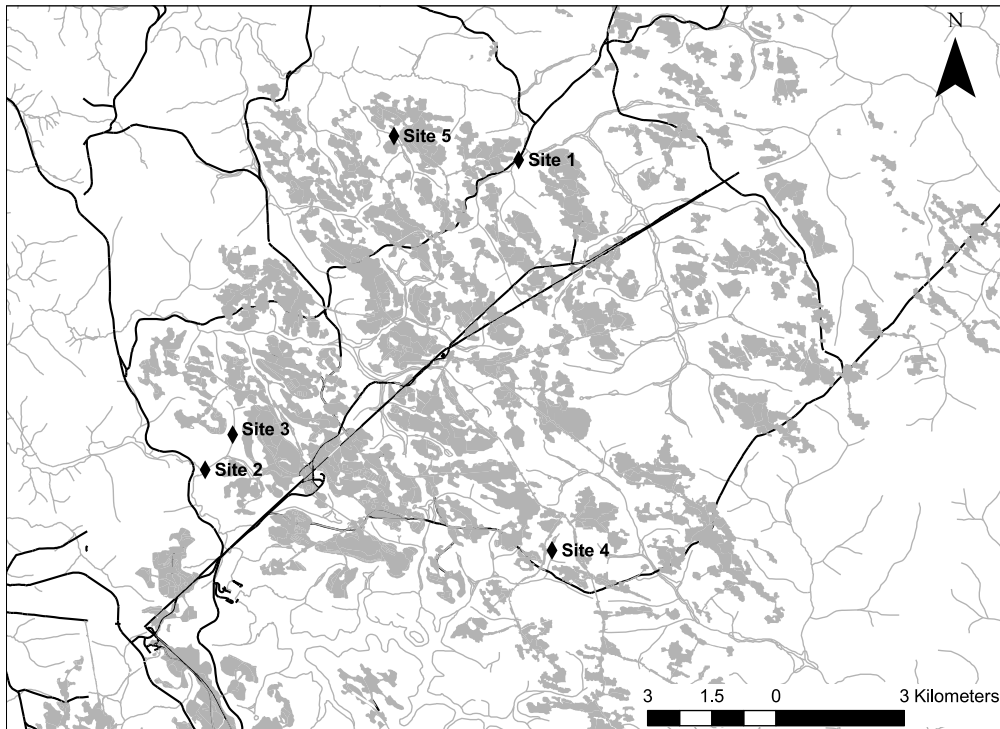
Tables

Table 1: Radio-tracking results for *N. gouldi* and *V. regulus*, by season and sex, tracked between October 2011 and March 2012. Roost tree species are jarrah (J), marri (M) and other (O), comprising sheoak and bull banksia for *N. gouldi* and bullich for *V. regulus*.

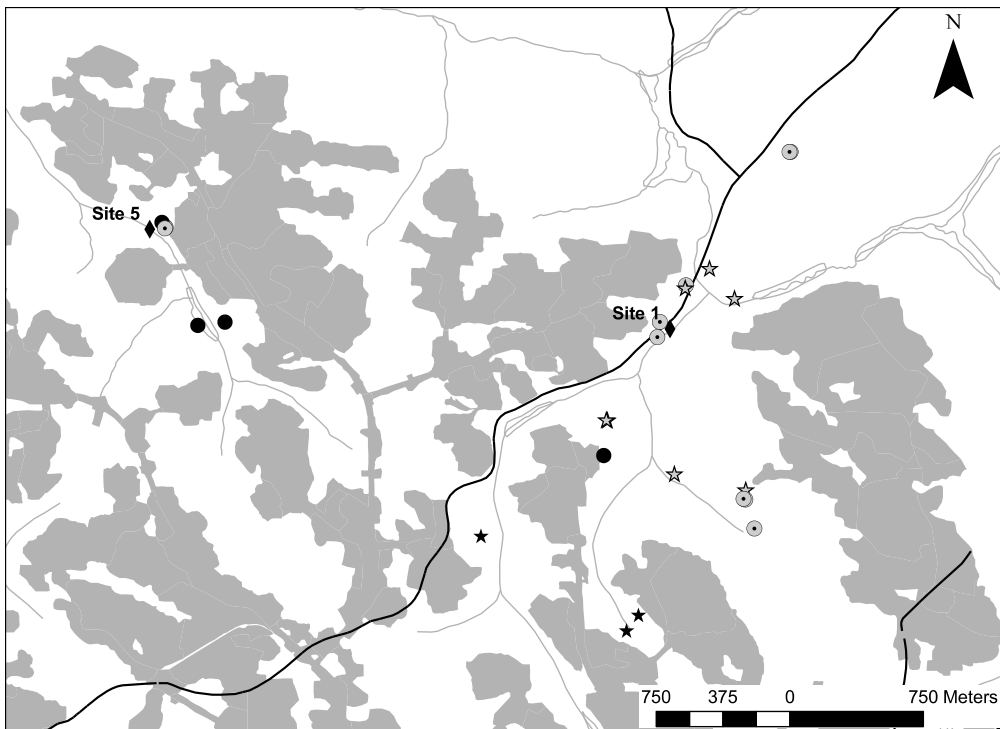
Species	Season	Sex	No. fitted	No. never located	Total No. of roosts located	Dist. to first roost (m) \pm SE	Dist. btwn roosts (m) \pm SE	Roost tree species		
								J	M	O
<i>N. gouldi</i>	Maternity	Female	5	1	7	931 \pm 182	341 \pm 86	7		
		Male	3	0	3	1232 \pm 138	--*	3		
	Mating	Female	7	1	11	1831 \pm 290	200 \pm 77	8	1	2
		Male	6	1	9	705 \pm 135	83 \pm 59	8		1
<i>V. regulus</i>	Maternity	Female	6	1	8	526 \pm 115	83 \pm 25	5	1	2
		Male	4	1	4	198 \pm 55	6*		2	2
	Mating	Female	5	1	6	628 \pm 91	113 \pm 80	5		1
		Male	7	1	11	685 \pm 225	100 \pm 42	7	2	2

*During the maternity season no male *N. gouldi* and only one male *V. regulus* were tracked to multiple roosts

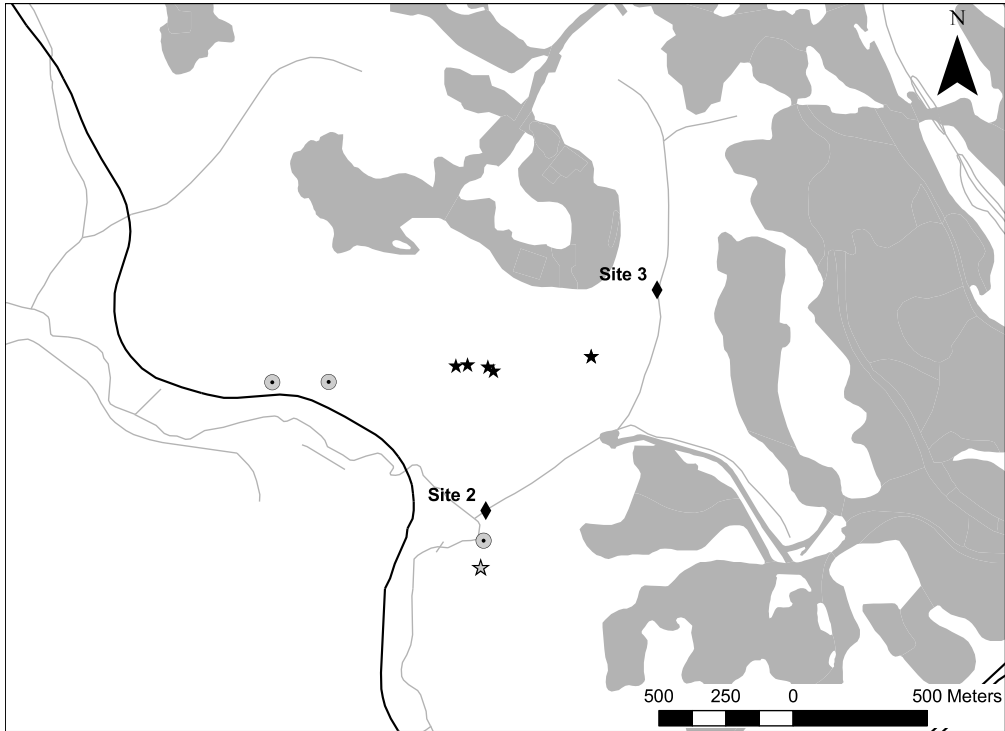
Figures



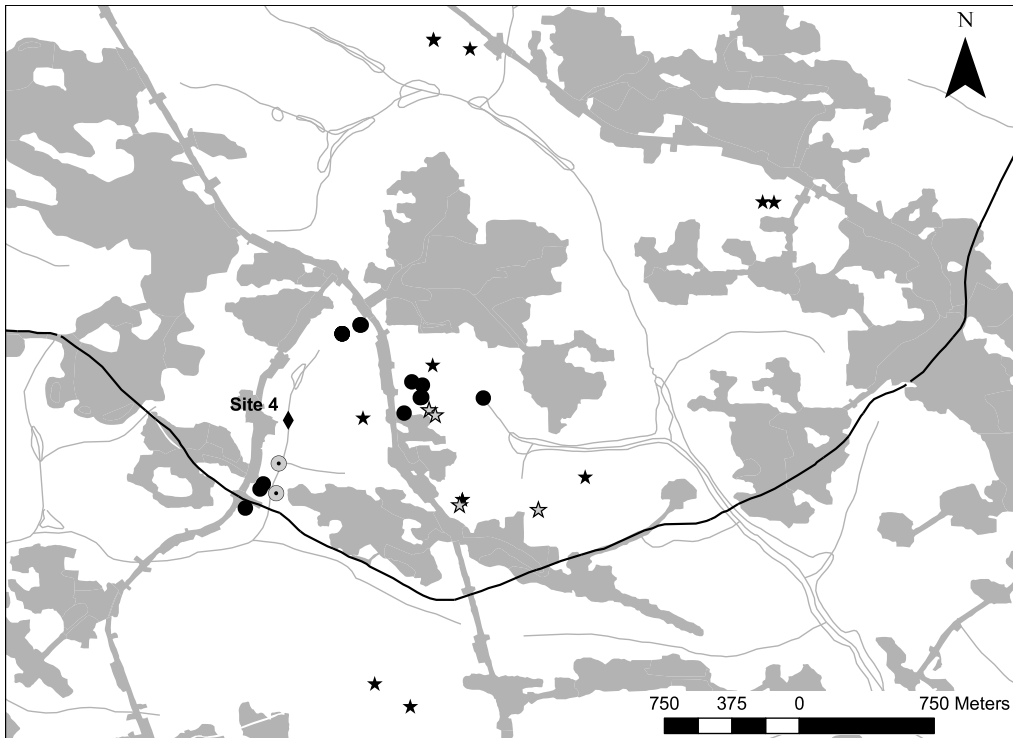
a)



b)



c)



d)

Figure 1

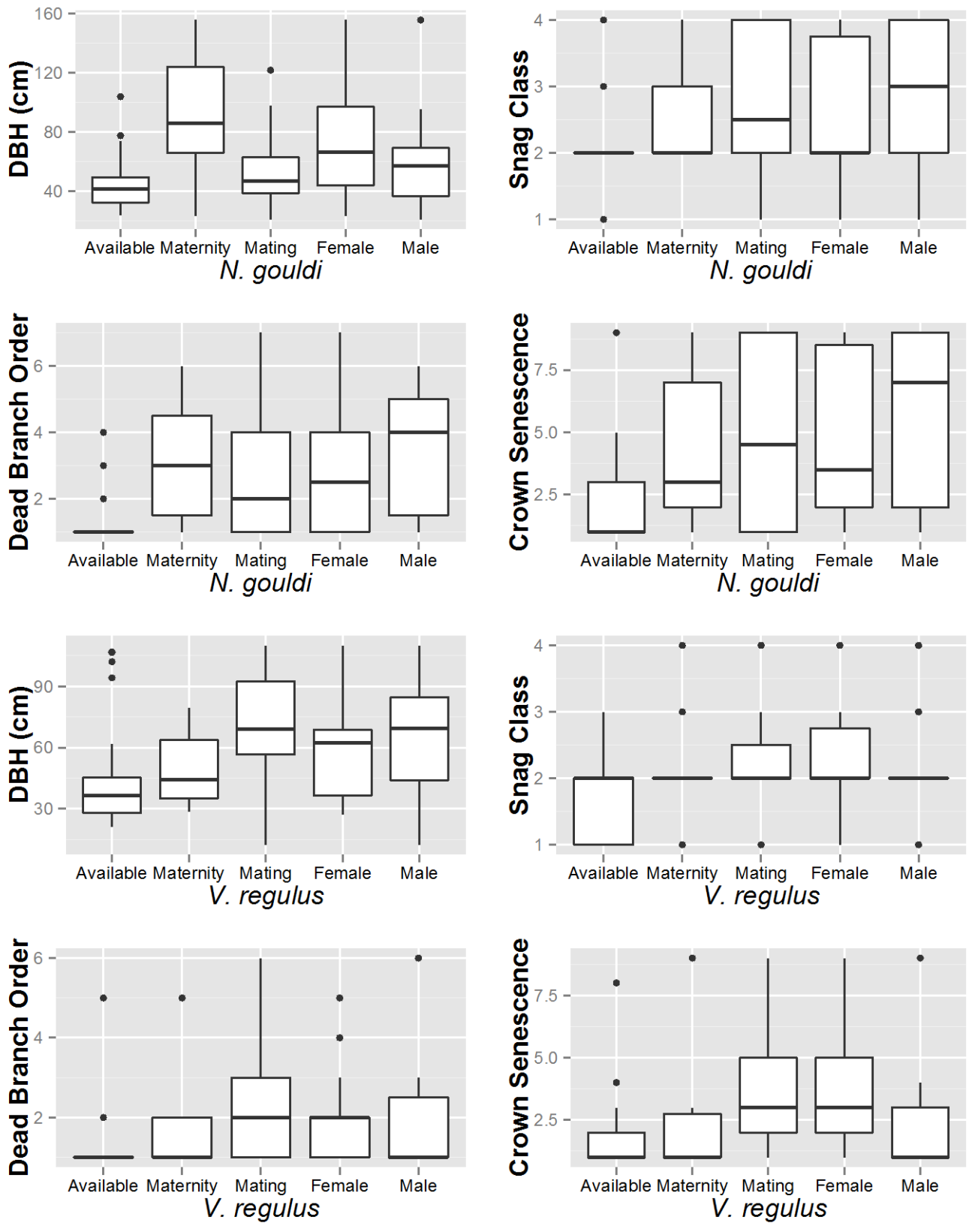


Figure 2

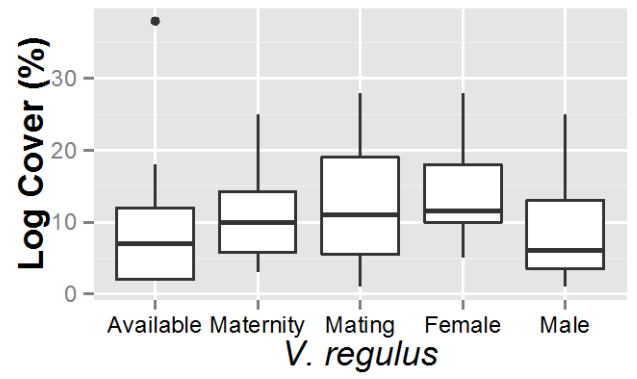
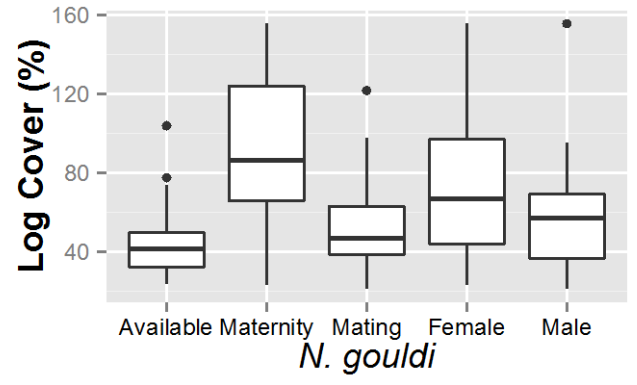
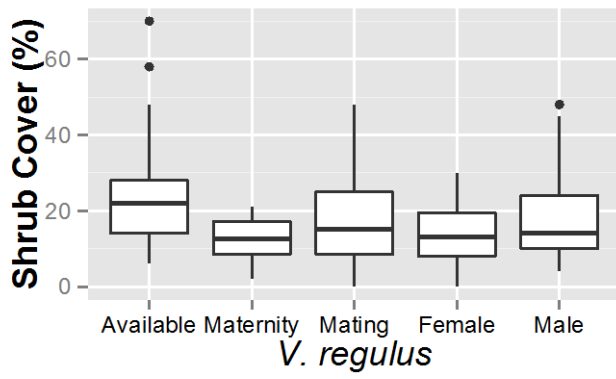


Figure 3

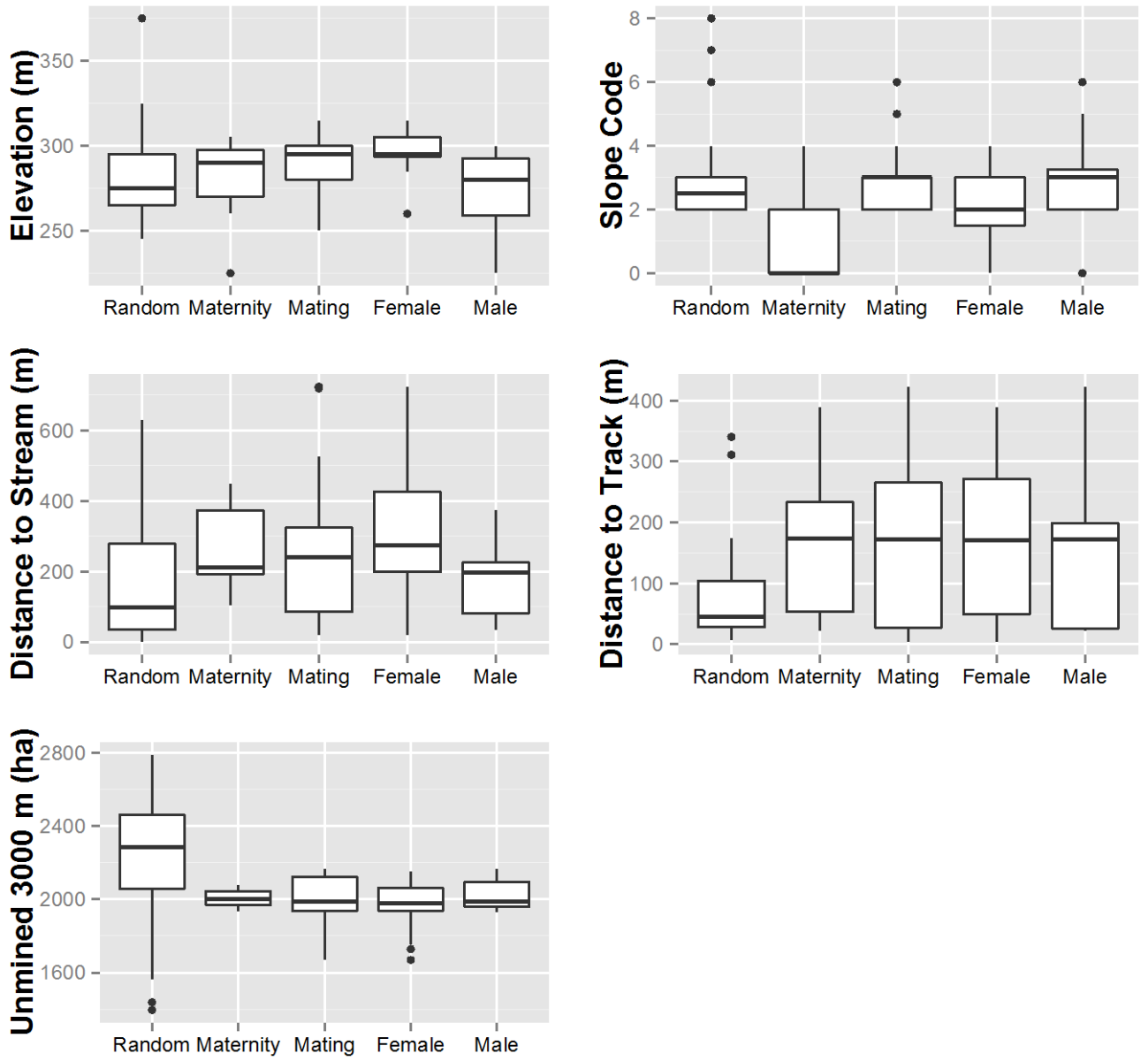


Figure 4

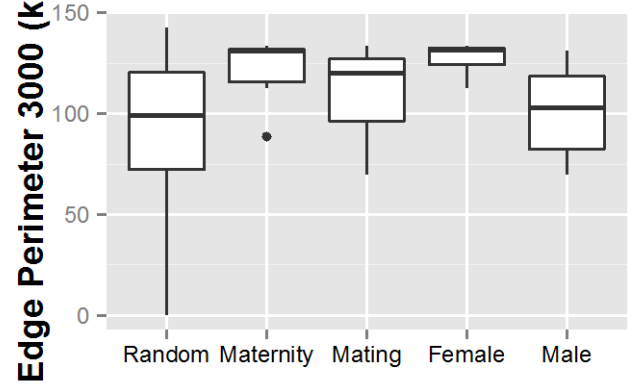
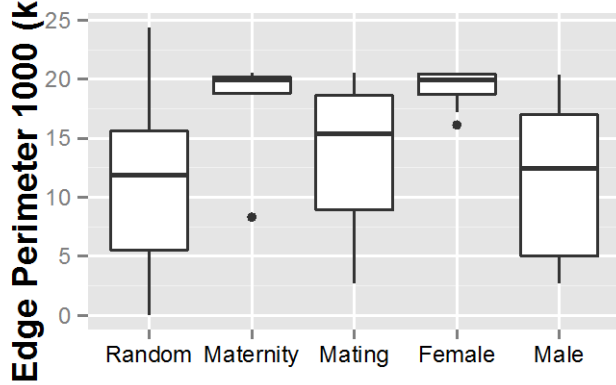
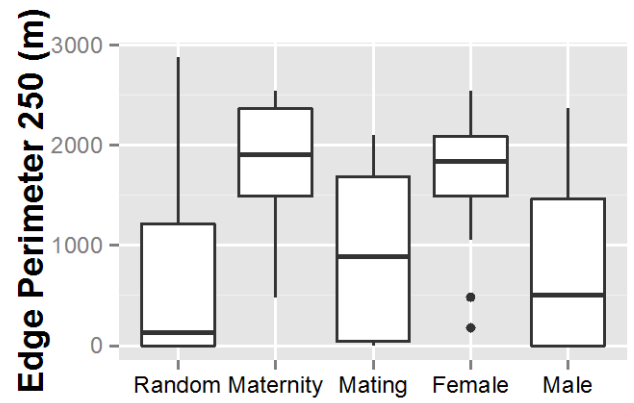
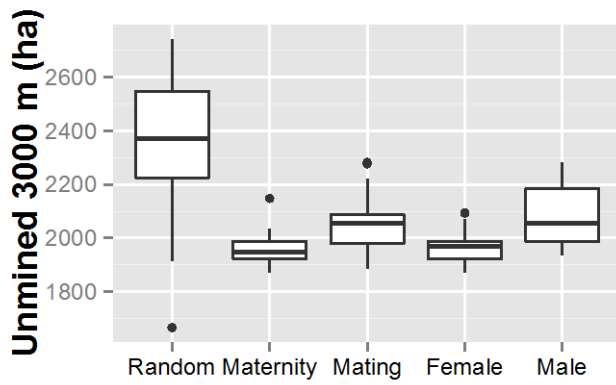
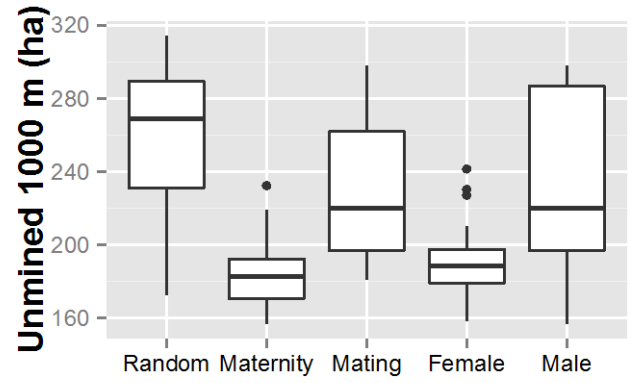
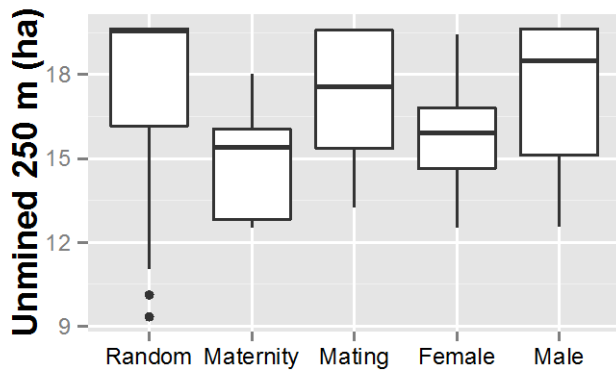
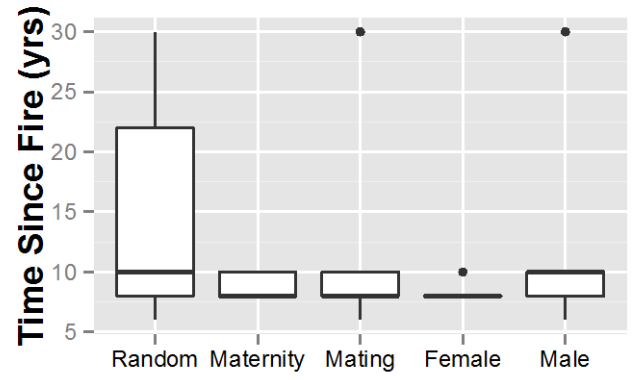
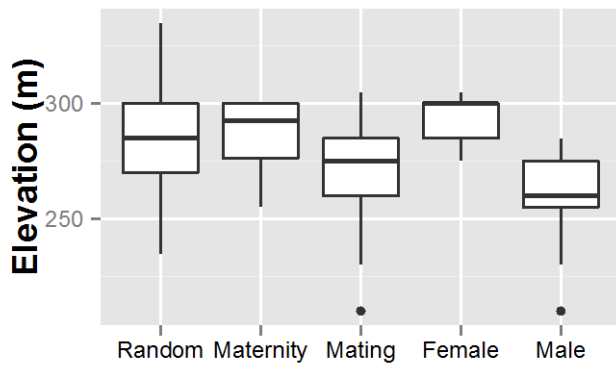


Figure 5

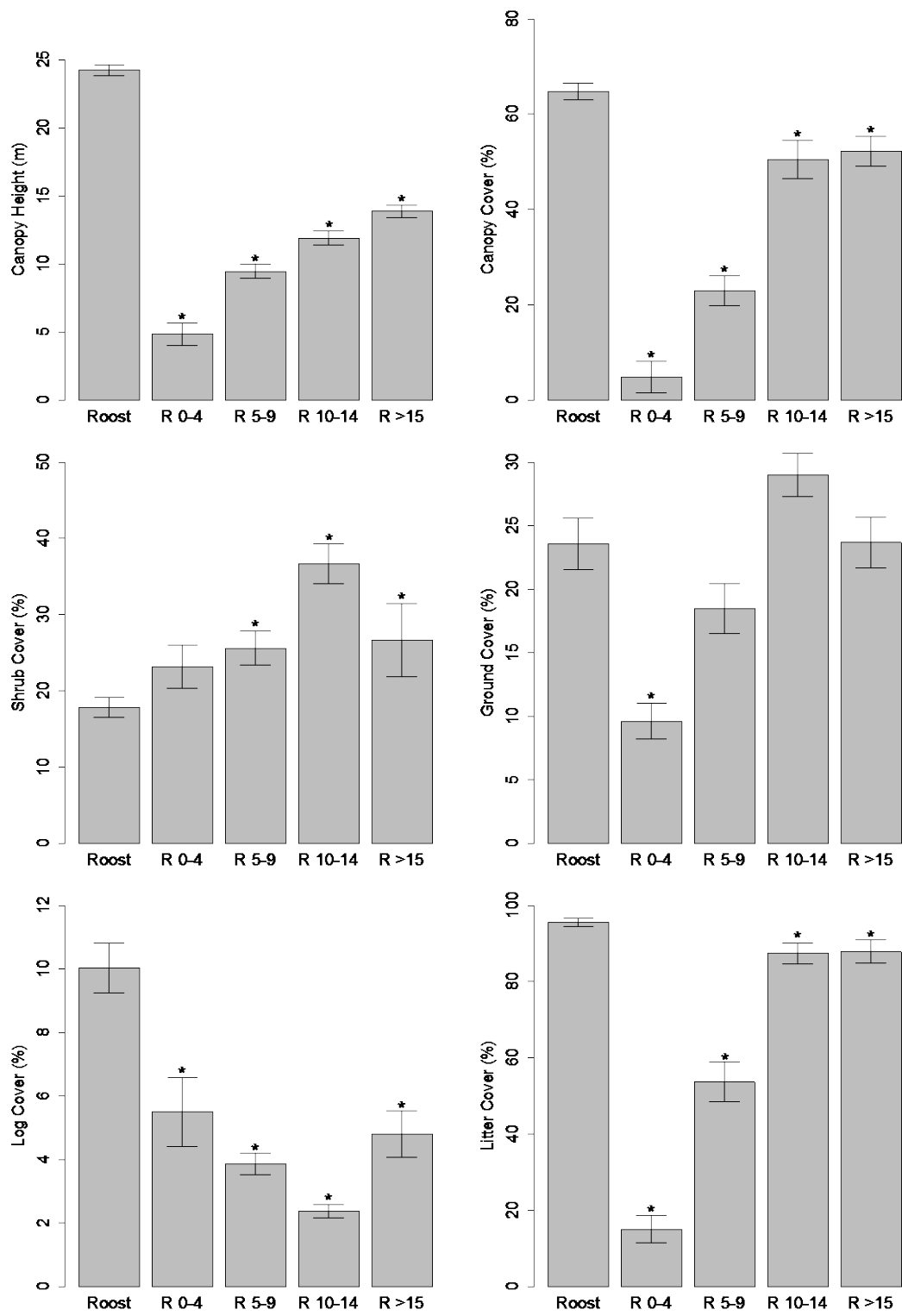


Figure A.1