The influence of mature oak stands and spruce plantations on soil-dwelling click beetles in lowland plantation forests

Tereza Loskotová, Jakub Horak

Most European forests have been converted into forest plantations that are managed for timber production. The main goal of this paper was to determine the difference between mature native sessile oak (*Quercus petraea*) stands and non-indigenous Norway spruce (*Picea abies*) plantations with respect to communities of *Athous* click beetles in approximately 6,500 ha of lowland plantation forest area in the Czech Republic. *Athous subfuscus* was the most abundant and widespread species, followed by *A. zebei* and *A. haemorrhoidalis*, while *A. vittatus* was considered rare. Spatial analysis of environmental variables inside studied patches showed that the species composition of *Athous* beetles best responded to a 20 m radius surrounding traps. Species' responses to the environment showed that *A. vittatus* and *A. haemorrhoidalis* preferred oak stands, while *A. zebei* and *A. subfuscus* were associated with spruce plantations. In addition, oak stands showed higher diversity of beetle communities. The studied species are important for their ecosystem services (e.g. predation on pests or bioturbation) and seems to tolerate certain degrees of human disturbances, which is beneficial especially for forest plantations managed for timber production.

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3

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10

11 **Running title**

12 Click beetles in plantation forests

13

14 **Abstract**

15 Most European forests have been converted into forest plantations that are managed for

16 timber production. The main goal of this paper was to determine the difference between

17 mature native sessile oak (*Quercus petraea*) stands and non-indigenous Norway spruce (*Picea*

18 *abies*) plantations with respect to communities of *Athous* click beetles in approximately 6,500

19 ha of lowland plantation forest area in the Czech Republic. *Athous subfuscus* was the most

20   abundant and widespread species, followed by *A. zebei* and *A. haemorrhoidalis*, while *A.*

21   *vittatus* was considered rare. Spatial analysis of environmental variables inside studied patches

22   showed that the species composition of *Athous* beetles best responded to a 20 m radius

23   surrounding traps. Species' responses to the environment showed that *A. vittatus* and *A.*

24   *haemorrhoidalis* preferred oak stands, while *A. zebei* and *A. subfuscus* were associated with

25   spruce plantations. In addition, oak stands showed higher diversity of beetle communities. The

26   studied species are important for their ecosystem services (e.g. predation on pests or

27   bioturbation) and seems to tolerate certain degrees of human disturbances. This is important

28   information especially for forest plantations managed for timber production.

29

30   **Introduction**

31   Forests are biologically diverse ecosystems, representing some of the richest biological

32   areas on Earth (Lindenmayer et al. 2002; Wesolowski 2005). While many species thrive, some

33   forest organisms are threatened as a result of deforestation, fragmentation, change in tree

34   species composition, climate change and other stressors like fire suppression (Carnus et al.

35   2006).

36   Semi-natural forests are rare in Europe (Wesolowski 2005). Most forests have been

37   cleared and converted into agricultural land or into regularly cut forest plantations (Horak et al.

38   2012). Many of the broadleaved forests of lowland Europe were replaced by coniferous stands

39   (Carnus et al. 2006). Large-scale intensive forestry has led to a shift in the quality of forest

40   habitats, which has influenced the diversity of forest organisms (Brockerhoff et al. 2008).

41   However, managed forests can still have a high ecological value (Bauhus et al. 2010) particularly

42   compared to intensively managed agriculture land.

43   The distribution of forest organisms in fragmented landscapes is influenced by structural

44   characteristics of the forest, such as patch quality, configuration or history (Collinge 2009;

45   Horak and Rebl 2013). While quality and the spatial aspects of forest fragmentation (i.e.

46   isolation) have received much attention recently (e.g. Mason and Zapponi 2015), the temporal

47   dimension of habitat fragmentation (Brunet 1993; Horak et al. 2012) – e.g. through the long-

48   term dominance of native tree species (Carnus et al. 2006) – has been the focus less often.

49   The occurrence of many forest organisms is assumed to be exclusively or largely

50   restricted to forests with geographic habitat continuity – e.g. the presence of matured and

51   over-matured native broadleaved tree stands in lowlands (Peterken 1974; Brunet 1993), while

52   some other species have good dispersal abilities and are able to spread together within forests

53   of suitable tree composition (e.g. Norway spruce associates) when they are planting or

54   spreading (Roder et al. 2010).

55   The click beetles, Elateridae, comprise one of the most ecologically diverse families of

56   beetles (Leseigneur 1972; Laibner 2000; Johnson 2002). Adults are active in the afternoon and

57   evening and some can be effectively collected using window traps (Horak and Rebl 2013). Click

58   beetles from the genus *Athous* Eschscholtz are known for their beneficial function of

59   bioturbation and predation on the larvae of Hymenopteran and Lepidopteron pests (Laibner

60   2000). The adults occasionally feed on buds, leaves and below-ground parts of crop (Douglas

61   2011), although the damage is insignificant in central Europe (Laibner 2000). Most observation

62   records of adults are from herbs, shrubs or lower branches, and the development of larvae

63   takes years (Laibner 2000; Johnson 2002).

64   Recently, five *Athous* species have been reported from the Czech Republic (Dusanek and

65   Mertlik 2012) – namely, *Athous haemorrhoidalis* (Fabricius 1801), *A. subfuscus* (Müller 1767), *A.*

66   *vittatus* (Fabricius 1792), *A. zebei* (Bach 1854) and *A. bicolor* (Goeze 1777). *Athous*

67   *haemorrhoidalis* is widely distributed from lowlands to mountains, preferring open park

68   landscapes, abandoned agricultural and urban areas, and grasslands (Laibner 2000). *Athous*

69   *subfuscus* is widely distributed in all types of forests, especially in clear-cuts and adjacent sites

70   (Laibner 2000). *Athous vittatus* and *A. bicolor* are indicated to prefer close to natural open

71   canopy broadleaved woodlands with lower altitudes and *A. zebei* is indicated to prefer

72   coniferous woodlands at higher altitudes (Laibner 2000). *Athous haemorrhoidalis* and *A.*

73   *vittatus* both have larvae that dwell in the sun-warmed soils and feed on dead invertebrates.

74   *Athous subfuscus* and *A. zebei* larvae are predaceous (Laibner, 2000). They dwell in the soils and

75   litter of shaded woodlands, especially under mosses. The fifth species distributed in the Czech

76   Republic, *A. bicolor*, is indicated to be relatively widespread (Laibner 2000), although to our

77   knowledge, the trapping success of this species is very low, with the species only having been

78   trapped in semi-natural woodlands (Horak and Rebl 2013). Its ecological requirements are quite

79   similar to those of *A. vittatus* (Laibner 2000).

80

81   **Aims**

82   Our prediction was that stands with planted non-indigenous trees influence the *Athous*

83   click beetles in lowland plantation forest areas due to their known habitat requirements. Thus,

84   the general goal of this study was to explore the influence of mature native sessile oak (*Quercus*

85   *petraea*) stands and non-indigenous Norway spruce (*Picea abies*) plantations on studied click

86   beetles. More specifically, we explored: (i) the response of the studied community to the forest

87   environment at the most suitable patch level through spatial partitioning and (ii) the individual

88   *Athous* species' responses to the environment.

89

90   **Material and methods**

91   **Study group**

92   The genus *Athous* is poorly studied group of click beetles (Roberts 1919; Wolters 1989).

93   In spite of this fact, they are mentioned as both potential pests (feeding on buds and leaves)

94   and as beneficial organisms (predation and bioturbation) (Laibner 2000). They, furthermore,

95   could be the dominant part of the community of soil-dwelling organisms in forests. Their study

96   could bring us important information on how forest organisms could be affected by alteration

97   of tree species composition – mainly due to changes in vegetation structure caused by different

98   litter decomposition effects of conifer vs. broadleaved and native vs. non-indigenous trees.

99   Regarding their response to the forest environment, the species composition and individual

100   species population densities of genus *Athous* were studied as dependent variables.

101

102   **Study area**

103   The study woodland area of nearly 6,500 ha was situated in a spatially continuous area

104   of the east-Bohemian woodlands, between the towns of Choceň and Holice (Pardubice Region,

105   Czech Republic; Fig. 1). According to Neuhaslova (2001), a potential vegetation of forests in the

106   area consists of oak-hornbeam forests mixed with European beech (*Fagus sylvatica*) forests

107   with a scattered distribution of silver fir (*Abies alba*) and some oak forests with Scots pine

108   (*Pinus sylvestris*). The historical distribution and abundance of Scots pine is unclear, although it

109   has been recently found to dominate the area due to its commercial value (e.g. Cienciala et al.

110   2006). The former natural distribution of European beech in the area is uncertain and today,

111   this tree is restricted to the slopes close to the Tichá Orlice River in the east. The European

112   hornbeam (*Carpinus betulus*) is presently the only admixed tree species. Of the broadleaved

113   trees, only sessile oak (*Quercus petraea*) now covers relatively large areas. A large number of

114   forest stands have been planted over more than two centuries using non-indigenous Norway

115   spruce (*Picea abies*).

116

117   Figure 1.

118

119   **Site selection**

120   Mature stands (i.e. more than 80 years old) dominated by sessile oak or Norway spruce

121   that had more than 1 ha in total area were studied over the whole study area. Sessile oak and

122   Norway spruce dominated stands were chosen as they best reflect the recent environmental

123   condition of the forest with respect to its tree species composition in the past. In our study, oak

124   stands represented former continuous vegetation and spruce plantations indicated spatial and

125   temporal discontinuity. Due to possible significant influence of spatial autocorrelation and the

126   effect of tourist beetles from non-forest and highly disturbed areas, their choice was limited to

127   the two another parameters: (i) the minimal distance between sampling points in oak and

128   spruce dominated stands, which was set to 50 m, (ii) as well as the distance to the woodland

129   edge and/or to clear cut, which was also set to 50 m. This selection enabled us to sample in the

130   30 sites – i.e. 15 pairs of oak and spruce stands.

131

132   **Trap description**

133   Crossed-panel window traps were used for this study. We installed one trap per site.

134   Each trap consisted of three transparent plastic panes (one pane 0.4 × 0.5 m and two panes 0.2

135   × 0.5 m), a protective top cover (diameter 0.45 m), and a funnel leading down into a container

136   holding a solution of water and salt with a small amount of detergent to reduce the surface

137   tension of the liquid. This solution preserved the insects but did not attract them (Horak 2011).

138   The height of the center of the trap was approximately 1.3 meters. Traps were fixed using two

139   iron sticks on two opposite sides and they were positioned at the centers of the stands. All of

140   the traps were activated at the beginning of March and deactivated at the end of September

141   2011, resulting in eight sampling efforts (25.3., 25.4., 20.5., 10.6., 5.7., 30.7., 25.8. and 20.9.).

142   Thus, each trap was working for a period of 179 days (i.e., 5,370 days for our trapping design).

143   We assumed that every individual had an equal probability of being captured.

144

145   Figure 2.

146

147   **Environmental variables**

148   The main focus was on environmental variables (as independent variables) at the

149   circular patch scales surrounding each trap, which potentially best described requirements of

150   the studied group within the studied plantation forests (Table 1). All of the studied variables,

151   except for canopy openness (measured in the viewing angle of 180°), were measured as a

152   percentage of coverage of a circle with a radius of 10 meters (314 m^2) and then in those with

153   twice the radius of the previous samples – i.e. 20 (1,256 m^2) and 40 (5,024 m^2) meters (Table 1).

154   Canopy openness, as an expression of the light conditions of the study site was

155   measured using a Nikon COOLPIX 995 camera with a Nikon FC-E8 Fish Eye converter. Each

156   photograph was taken at the top of the trap, approximately in 1.55 m above ground. All

157   photographs were then evaluated using Gap Light Analyzer 2.0.

158   Total representation (i.e., % of tree species in the patch) of mature sessile oak in the

159   tree species composition of the overstory was measured as a reflection of the maintenance of

160   the former vegetation. The representation of mature Norway spruce was measured as a

161   reflection of the historical anthropogenic disturbance of the stand. The representation of other

162   deciduous and coniferous trees was also measured. The conditions in the understory were

163   measured, with focus placed on the total coverage of shrubby vegetation, vascular plants, bare

164   soil and mosses (Table 1).

165

166   Table 1.

167

168   **Statistical analyses**

169   Due to limited number of traps used (based on criteria mentioned in the Site selection

170   section), sufficiency of number of traps used for statistical power to detect an effect (i.e.

171   trapping success) was assessed using EstimateS 8.2 (Colwell 2006). Sample-based rarefaction

172   (Mao Tau function with 95% confidence intervals) and the Chao estimation functions were

173   computed (Colwell 2006), with the number of randomizations set at 1,000.

174   Principal components analysis (PCA) of species composition of the study group of *Athous*

175   click beetles regarding the site character was computed in CANOCO 4.5 (ter Braak and Smilauer

176   2002) for the analysis of discrimination between the samples, and then was visualized in

177   CanoDraw 4.14 (ter Braak and Smilauer 2002).

178   Redundancy analysis (RDA) of species composition, as a dependent variable, was

179   computed with 9,999 unrestricted permutations under the full model in CANOCO. All

180   environmental variables with a variance inflation factor (VIF) higher than ten were first

181   excluded from the final analyses due to multi-collinearity (Table 1). Control for possible

182   influence of spatial autocorrelation was included as the co-variable – i.e. coordinates and their

183   crossed and square products (x, y, xy, x^2, y^2; e.g. Horak 2013). Spatial partitioning of the studied

184   patches helped with the selection of the best spatial extent (i.e. radii of 10, 20 or 40 m) of the

185   analyses of response of the species composition of *Athous* click beetles to the studied

186   environmental variables (Horak et al. 2013). The final choice of patch space for analyses was

187   based on the highest variance explained by canonical axes, as derived from RDA.

188   Individual species' response to the environmental variables at the previously selected

189   most suitable patch area was computed in the same way, as previously described with regards

190   to RDA and was visualized in CanoDraw using species-environmental and Shannon diversity

191   based data attribute-environmental biplots. The variance explained by the studied

192   environmental variables and its significance was computed in CANOCO with 9,999 unrestricted

193   permutations under the full model.

194   Generalized linear models (GLM) were computed in CanoDraw, with model selection

195   based on Akaike information criterion (AIC) statistics and with Gaussian distribution for

196   response of total species composition to individual environmental variables, while Poisson

197   distribution was used for individual species data in the same way.

198

199   **Results**

200   Four of the five *Athous* species reported from the Czech Republic (Dusanek and Mertlik

201   2012) were trapped. *Athous subfuscus* was the most abundant and widespread species,

202   followed by *A. zebei* and *A. haemorrhoidalis*, while *A. vittatus* was collected rarely, at only five

203   sites (Table 2).

204

205   Table 2.

206

207   The use of thirty traps in our study was enough, and the use of twenty traps was found

208 to be sufficient in similar studies – namely, observed species richness reached the asymptote at

209 19 traps (± 1 C.I. 95%). Chao 1 and Chao 2 estimators indicated sufficiency at 17 traps.

210   There was a difference between the beetle communities of oak- and spruce-dominated

211 stands. It explained nearly 82% of variance of the data in PCA, with only three sites overlapping

212 on the first axis (Fig. 3).

213

214 Figure 3.

215

216   The response of species composition to the environmental variables was the best at a 20

217 meters radius (1,256 m^2 area) of the surrounding forest patch (Fig. 4). All axes for the 20 m

218 radius together explained nearly 65% of the data variance. The worst response was at the

219 longest radius of 40 meters, which did not exceed 60% of the explained variance. This also

220 indicated that a selected distance of 50 meters (see the Materials and methods section) for

221 possible overlapping among traps was sufficient.

222

223 Figure 4.

224

225   Species responses to the environmental variables at a 20-meter radius (Fig. 5a) showed

226   that there were two species groups that were clearly discriminated on the first axis of RDA.

227   *Athous vittatus* and *A. haemorrhoidalis* were on the left side of the diagram, preferring oak

228   stands, while *A. zebei* and *A. subfuscus* were distributed on the right side of the biplot, with

229   association to the spruce plantations. Samples in oak-dominated stands showed higher

230   diversity (Fig. 5b). This is also illustrated by the negative *t* value of the first axis (t = -0.41),

231   derived from significant GLM (F = 7.06; P < 0.01).

232

233   Figure 5.

234

235   In relation to the studied beetle species composition, the percentage of spruce and oak

236   in tree species composition at a radius of 20 meters surrounding the traps was significant and

237   revealed the highest shared variance. From the variables at the understory level, coverage of

238   mosses, together with shrubs, influenced the composition of studied beetles much more than

239   did the coverage of plants, which showed an effect that was the lowest regarding the shared

240   explained variance (Table 3). The shared variance explained by canopy openness with respect

241   to the species composition of *Athous* click beetles was significant and was close to 25% (Table

242   3).

243

244   Table 3.

245

246   Individual species' responses (Table 4) showed that *A. haemorrhoidalis* and *A. vittatus*

247   were positively related to the higher percentage of oak in the tree species composition and

248   were negatively related to spruce, while the response of *A. subfuscus* and *A. zebei* was the

249   opposite. Both *A. subfuscus* and *A. vittatus* showed the peak in preference for the tree species

250   composition, with approximately 70% of spruce and oak, respectively. With respect to canopy

251   openness, *A. subfuscus* preferred sun-exposed sites, while *A. vittatus* showed an increase in

252   abundance with the shading of habitats. *Athous subfuscus* responded significantly to the

253   coverage of mosses with the peak occurrence of around 40%, while also responding to the

254   increasing coverage of shrubs. *Athous subfuscus* and *A. zebei* were negatively affected by the

255   increasing coverage of the herb layer and the response of *A. vittatus* was slightly positive.

256

257   Table 4.

258

259   **Discussion**

260   Our results can be summarized that the studied click beetles best responded to the

261   environment at the middle selected patch area – i.e. with a 20 meters radius, and that

262   dominant tree species in the patch were the most important with regards to the in

263   discrimination of studied beetle communities.

264   Studied click beetles best responded to the environment at the middle selected distance

265   of a 20-meter radius surrounding the sampling site. This indicates the scales at which beetles

266   with similar requirements are searching for suitable habitats. Even though the adults of most

267   *Athous* species are known to be good dispersers comparing to other beetles (Laibner 2000;

268   Johnson 2002), the studies on beetle dispersal abilities have indicated that most beetle flight

269   events are over shorter distances than previously predicted (Drag et al. 2011), even in pest

270   species (Mercader et al. 2009) – i.e., on average, to one hundred meters. Nevertheless,

271   populations of several insect taxa are known to release macropterous or highly dispersive

272   individuals during times of high population densities (Kocarek et al. 2013). Thus, this,

273   surprisingly and most probably, illustrates a relatively sedentary response to the environment

274   of *Athous* beetles regarding the response to the patch of 20 m radius.

275   The study species were relatively clearly discriminated with respect to their relationships

276   with the dominant tree species. Two necrophagous species (*Athous haemorrhoidalis* and *A.*

277   *vittatus*) preferred oak stands and avoided spruce plantations, while two predators (*A.*

278   *subfuscus* and *A. zebei*) showed the opposite response. The presence of two predaceous

279   species in Norway spruce plantations is thus important and beneficial from the management

280   point of view because of the higher vulnerability to environmental disturbances and potentially

281   higher pest densities in soil of plantation forests of non-indigenous trees. The results also

282   indicate that Norway spruce, as an autochthonous tree for the mountainous areas of the

283   Central Europe, is also able to promote its habitat associates in areas of lower altitudes, which

284   has been recently indicated (Roder et al. 2010).

285   The results also showed that most of the studied species are able to reach high levels of

286   abundance in mature stands within the plantation forests. Only *A. vittatus* was rather rare and

287   was most abundant in relatively artificially undisturbed and mostly over-matured oak-

288   dominated stands (based on our observation). This species preferred stands where oak

289   accounted for between 60 and 80% of the tree species composition and with higher coverage

290   of the herb layer in the understory. *Athous vittatus* is also known to be associated with sun-

291   exposed woodlands (Laibner 2000), although the results showed a relatively surprising

292   association with closed canopy stands.

293   A relatively high abundance of *A. zebei* may be considered surprising because this

294   species is indicated as being to be associated with mountainous and partly sub-mountainous

295   woodland areas of central Europe (Laibner 2000). Its non-response to canopy openness is also

296   surprising because *A. zebei* is known for its preference for shaded coniferous woodlands. On

297   the other hand, it showed a negative relationship with plant cover at the understory, which

298   could be the result of more opened canopy cover.

299   *Athous subfuscus* seemed to prefer sun-exposed sites in spruce dominated stands with

300   mosses and shrubs at the understory level. Its high level of abundance and preference for

301   spruce dominated stands correspond with recent data (Laibner 2000; Kula 2010).

302   *Athous haemorrhoidalis* was not associated with any patch parameter other than the

303   main tree species in species composition. This may be considered surprising, however, since it

304   can also be frequently found in agricultural landscapes (Laibner 2000).

305

306   **Conclusions**

307   To the best of our knowledge, this is the first statistical evidence of the soil click beetle

308   requirements within plantation forests, which provides some new or contrasting results with

309   respect to the published evidence of distribution of these soil-dwelling taxa.

310   Some species from the genus *Athous* may reach relatively high levels of abundance in

311   mature commercial stands and also those with a high proportion of non-indigenous Norway

312   spruce plantations. Even though they are good dispersers, their response to the environment

313   was over a relatively short patch radius and rapidly decreased with increasing study patch area.

314   Most of the studied species are rather beneficial organisms. Some of their larvae are

315   predaceous on pests, which may contribute to the higher stability of Norway spruce

316   plantations. Necrophagous larvae may contribute to the process of bioturbation, which is

317   beneficial for nutrition availability or seed regeneration of the mature stands studied (e.g.

318   Scheu 1987). Thus, their levels of high abundance, and probable higher resistance to

319   anthropogenic forest alterations, seem to be beneficial for commercially harvested woodland

320   landscapes.

321

331

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401

402   **Figure 1** Location map of study area (black) near Choceň town in the Czech Republic.

403

404   **Figure 2** A window trap used to capture *Athous* click beetles (Elateridae) in lowland plantation

405   forest area.

406

407   **Figure 3** Sample based scatter-plot of species composition of soil-dwelling click beetles as

408   derived from principal components analysis (PCA) illustrating the discrimination between the

409   samples in stands dominated by sessile oak (grey dots) and Norway spruce plantations (black

410   dots) in the lowland plantation forest area.

411

412   **Figure 4** Results of spatial partitioning using variance explained by all canonical axes as derived

413   from redundancy analyses (RDA). Species composition of *Athous* click beetles was dependent

414   variable and environmental independent variables were analyzed in a particular radius of

415   surrounding patch in the lowland plantation forest area. Spatial terms (x, y, xy, x^2 and y^2) were

416   included as co-predictors (*** is for P < 0.001).

417

418   **Figure 5** (a) Species-environmental biplot at 20 meters radius as derived from redundancy

419   analyses (RDA) on species composition of soil-dwelling click beetles showing the response of

420   species to environmental variables of the forest patch in the lowland plantation forest area. (b)

421   Shannon diversity based data attribute-environmental biplot showing the diversity of samples.

422   Note that in (a), the response of the species corresponded to the right angle projection of the

423   end of the species arrow to the arrow of the particular studied predictor. The variance

424   explained by each environmental variable and its *P* values is in Table 3. The size of the bubbles

425   in (b) corresponds to the diversity of particular sample.
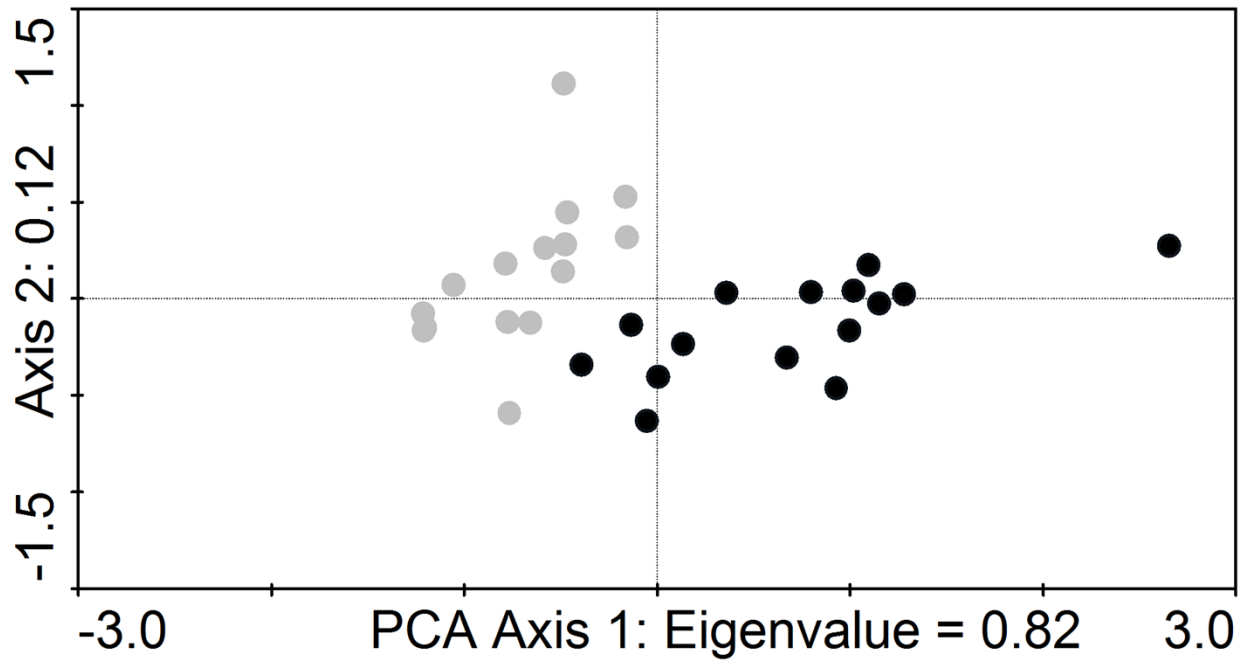
427   Figures:

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429   **Figure 1**

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431 **Figure 2**

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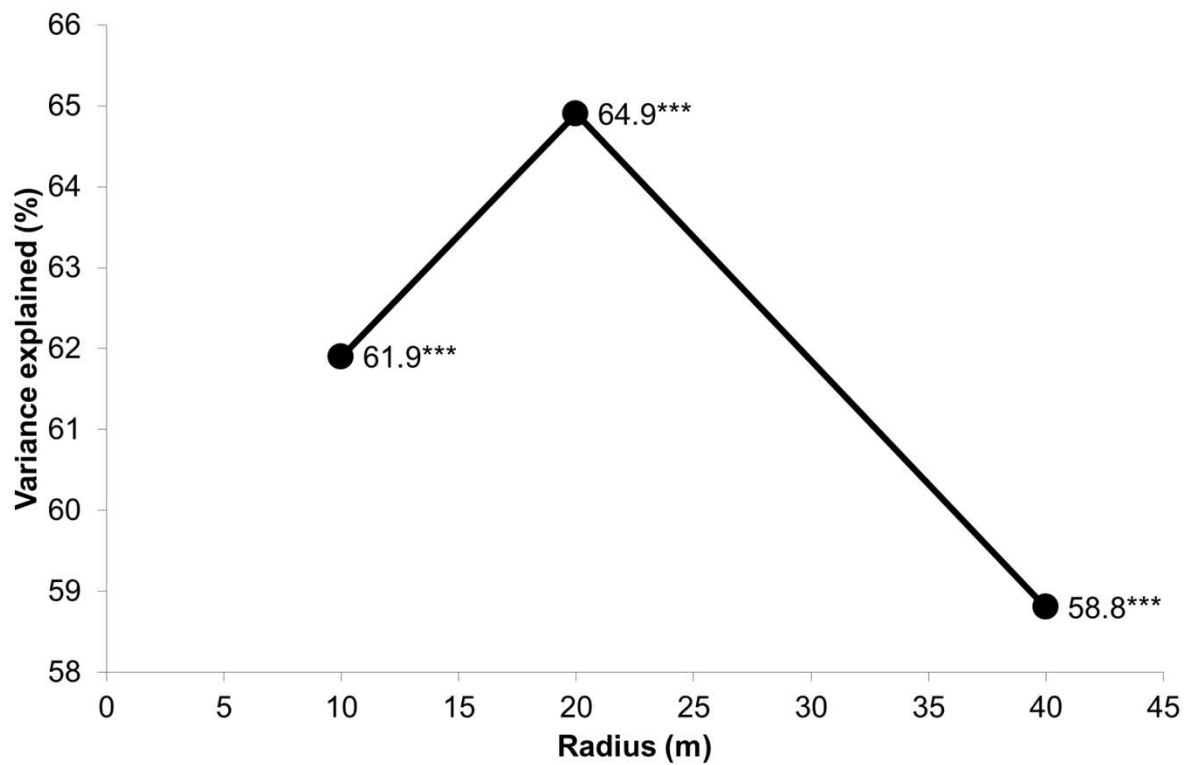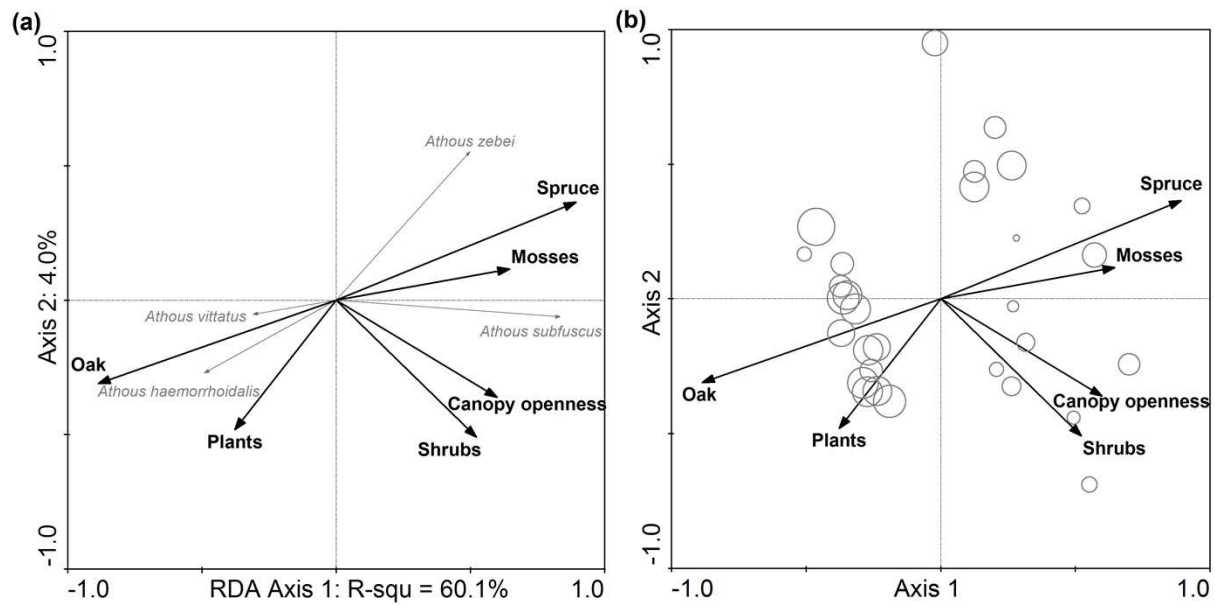434 **Figure 3**

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438   **Figure 4**

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441 **Figure 5**