

1 **The effect of forest management on endangered insects assessed by**  
2 **radio-tracking: the case of the ground beetle *Carabus olympiae* in**  
3 **European beech *Fagus sylvatica* stands**

4  
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20 **Abstract**

21

22 Beech forests are important for biodiversity conservation in Europe and studies to identify  
23 sustainable forest management practices are therefore required. ~~Several ground beetle species~~  
24 ~~inhabiting European beech forests are endangered and potentially threatened by logging~~  
25 ~~interventions.~~The ground beetle *Carabus olympiae* Sella, 1855, is a large steno-endemic  
26 endangered alpine species with very restricted ranges. Its known range is only delimited in two  
27 beech forests in the western Italian Alps where beech wood is still harvested. Forty individuals were  
28 collected and radio-tracked in 2014-2015 in order to assess the effects of forest management on  
29 microclimatic conditions, microhabitat use and movements.  
30 All management interventions changed microhabitat availability, with an increase of deadwood and  
31 bare ground. Thermo/hygro button loggers showed that temperature was higher and humidity lower  
32 in managed than in unmanaged stands, suggesting logging interventions may be detrimental to *C.*  
33 *olympiae*, either directly (inducing suboptimal climatic conditions) or indirectly (decreasing the  
34 availability of prey). Microhabitat selection analyses showed that in all scenarios, deadwood and  
35 tree bases were preferred, and were used as refuges during the daytime. Bare ground was never  
36 used. The length of the path travelled by individual insects was more variable and the tortuosity  
37 lower in managed than in unmanaged stands, suggesting that management induced more uncertain  
38 and constrained trajectories.  
39 We concluded that logging may exert short-term negative effects on *C. olympiae* ground beetles (as  
40 suggested by the increase in bare ground, and changes in climatic conditions and movements).  
41 However, the preference for tree bases and deadwood suggests that forest management,  
42 concurrently, may also be beneficial, on the condition that: *i*) the coppice,  
43 which provides more suitable microhabitats, prevails over conversion to high forest, and *ii*)  
44 deadwood originating from cutting (branches and treetops) is properly accumulated.

**Commento [EC1]:** Abstract is way too long. Delete "several ground beetle..." sentence on L 23-25; clarify if the global distribution of *C. olympiae* is indeed the two forests in Italy (L 27); results should focus on beetles not logging techniques; delete "suggesting logging... (...)" ...analyses showed that" (unnecessary text); "scenarios" (L 34) is misleading as it usually refers to modeling so rather say "Regarding microhabitat selection, deadwood..."; "never" (L 35) is too dramatic, say "not"; "more uncertain" (L 37) is unclear, rather clarify if you refer to movement directions and/or distances; L 39-40 delete the text in parentheses (unnecessary); L 45-47 while I do not disagree with this it is out of scope and should be omitted. It is better to end Abstract with a sentence about the importance of results concerning beetles themselves.

45 In methodological terms, this study indicates that radio-tracking may be successfully used as a tool  
46 to assess the effect of forest management on endangered and/or rare ground dwelling insects, and to  
47 identify forest management practices that are most compatible with their conservation.

48

49

50 **Introduction**

51

52 European beech (*Fagus sylvatica* L.) forests represent a unique ecosystem, stretching from the  
53 Mediterranean regions and southeastern Europe to the British Isles and Scandinavia, comprising  
54 vast areas in the Alps, Balkans and the Carpathians as well as in the northern European lowlands.

55 The special history and ongoing ecological processes related to beech forests has been  
56 acknowledged by the establishment of the transnational UNESCO World Heritage site "Primeval  
57 Beech Forests of the Carpathians and the Ancient Beech Forests of Germany", instigated in 2007  
58 and 2011. Apart from old-growth remnants, even secondary or managed beech forests harbour  
59 relevant ecosystem processes, animal and plant species of conservation interest, and provide an  
60 immense array of ecosystem services to man. For these reasons, they feature prominently in the  
61 Habitats Directive of the European Commission, Annex I (EU Council 1992), which lists five

62 different beech forest types that deserve conservation at the EU level - ~~(9110 Luzulo-Fagetum beech~~  
63 ~~forests, 9120 Atlantic acidophilous beech forests, 9130 Asperulo-Fagetum beech forests, 9140~~  
64 ~~Medio-European subalpine beech woods, 9150 Medio-European limestone beech forests of the~~  
65 ~~Cephalanthero-Fagion).~~ Beech (*Fagus sylvatica* L.) forests are important for many autotrophic and

66 heterotrophic organisms like soil macrofungi, ground dwelling arthropods, land snails, saproxylic  
67 fungi, hole nesting birds, saproxylic insects, epiphytic lichens and bryophytes and epixylic  
68 bryophytes (Brunet et al. 2010, Larrieu et al. 2014a; Larrieu et al. 2014b). European conservation

69 policy also takes into account beech forests. The Annex 1 of the "Habitats Directive" (92/43/EEC),  
70 ~~which aims to preserve biodiversity through the conservation of the environment,~~ lists eight beech

71 habitat types as worthy of conservation. Current threats to these ecosystems comprise climate  
72 change (Gessler et al., 2007; Di Filippo et al., 2012), increased possibility of fire and drought  
73 damage (Piovesan et al., 2008; Ascoli et al., 2013), habitat loss and fragmentation (Kunstler et al.,  
74 2007), species invasion (Krumm and Vítková 2016) and grazing by domestic or wild ungulates  
75 (Vandenberghé et al., 2007; Olesen and Madsen, 2008). Forestry practices can also affect

Commento [EC2]: L 61-65, irrelevant lists, delete

Commento [EC3]: L70, irrelevant description of directive aim, delete

76 biodiversity both positively and negatively, and studies focused on the impacts of beech forest  
77 management on animal diversity (e.g. Laiolo et al. 2004; Kappes 2005 and 2006; Müller et al. 2007;  
78 Moning and Müller, 2009; Floren et al. 2014; Chumak et al., 2015) are necessary to identify the  
79 practices which are compatible with animal conservation. A case in point are the beech forests of  
80 many mountain areas in Italy (Nocentini, 2009). Most of them were traditionally managed as  
81 coppice, i.e., by repeatedly cutting back sprouts to ground level to stimulate vegetative growth and  
82 provide firewood on a short rotation basis (20 to 40 years). High forests , i.e., stands where trees  
83 regenerate by seed, are rare. However, many coppices are now transitioning to a high-forest  
84 structure, due to either abandonment of regular management, or silvicultural conversion by thinning  
85 (Nocentini, 2009), yet the impacts of such management changes on animal biodiversity are not fully  
86 understood.

87 Ground beetles (Coleoptera: Carabidae) are typical inhabitants of European beech forests. Carabids  
88 show a wide range of life history traits and microhabitat requirements, and therefore they have been  
89 widely used as biological model of forest management (Rainio and Niemelä, 2003). They are  
90 relatively easy and cost-efficient to sample with standardized methods (i.e., pitfall trapping), and are  
91 sensitive to environmental factors such as temperature, humidity and vegetation structure (Stork,  
92 1990; Butterfield, 1996; Lövei and Sunderland, 1996). Most studies on carabids in different forest  
93 habitats have focused on habitat fragmentation (Davies and Margules, 1998; Niemelä, 2001;  
94 Koivula and Vermeulen, 2005) and edge effects (Heliölä et al., 2001; Koivula et al., 2004; Negro et  
95 al., 2009). The consequences of forestry practices on ground beetle diversity have also been  
96 extensively studied in non-beech forests (Werner and Raffa, 2000; du Bus de Warnaffe and Lebrun,  
97 2004; Pearce and Venier, 2006; Taboada et al., 2006, Baker et al., 2009; Lange et al., 2014;  
98 Skłodowski 2014; Macko, 2016). Habitat modification and destruction may be responsible for  
99 species decline, which affects particularly large-sized and brachypterous (short or reduced wings)  
100 ground beetles, because of their limited dispersal capacity (Kotze and O'Hara, 2003). A common  
101 trend in carabids is that populations of large, poorly dispersing species decrease with increasing

**Commento [EC4]:** L 87, only species and genus names are italicized

**Formattato:** Tipo di carattere: Non Corsivo

**Commento [EC5]:** L 96, the statement on "non-beech forests" appears strange as most of the other listed studies are non-beech studies too.

102 disturbance and forest management intensity (Raino and Niemela 2003, Kotze and O’Hara, 2003,  
103 Paillet et al. 2010). Since *C. olympiae* is a large, brachypterous species, we expected that forest  
104 management could exert some negative effect on individual microhabitat use and movements.  
105 Several ground beetle species are threatened (Assmann and Janssen 1999; Kotze and O’Hara, 2003,  
106 Brockerhoff et al., 2005; Matern et al. 2007; Pokluda et al., 2012), despite that, for most species, the  
107 status of populations is not known, and therefore field studies are needed in order to develop the  
108 most appropriate conservation measures.

**Commento [EC6]:** L 104, why would you expect only negative effects? Besides, I don't think there is much basis for linking these to management because of lack of replication.

109 The species *Carabus olympiae* Sella, 1855, is an endangered alpine species with a very restricted  
110 range, given that it inhabits only two neighboring beech forests (a few hectares each) in the western  
111 Italian Alps. After the alarming population decline suffered in the years 1930-42 (Malausa et al.,  
112 1983), *C. olympiae* has been declared a *priority species* (i.e. a species for the conservation of which  
113 the European Community has a particular responsibility) and included in Annexes II and IV of the  
114 EU Habitats Directive. It is listed in international agreements such as the Bern Convention, and is  
115 considered Vulnerable according to the IUCN red list of Threatened species  
116 (<http://www.iucnredlist.org/>). Despite this protection framework, *C. olympiae* still faces threats due  
117 to the construction of downhill skiing facilities (Negro et al. 2009, 2010, 2013) and to forestry  
118 practices. In addition to removing trees, logging usually alters the shrub, herbaceous, and litter  
119 layers. The period immediately after logging may therefore be dangerous for forest ground beetles,  
120 which are deprived of protection by the canopy and understory layers. Previous research focused on  
121 local ground beetle diversity, and tentatively indicated that the best option to protect this species  
122 was low-intensity or no management (Negro et al. 2007, 2013), particularly avoiding homogenous  
123 thinning in over-mature coppices (Negro et al., 2014).

**Commento [EC7]:** L 109, please clarify if these two forests are the whole population in this planet

124 ~~Here we tested different forest management techniques to identify those interventions that are~~  
125 ~~compatible with and, possibly favourable to, the conservation of *C. olympiae*.~~

**Commento [EC8]:** L 122, please clarify "homogeneous" – I suppose you refer to thinning that aims at rather even distribution of even-sized trees?

126 We radio tracked *C. olympiae* individuals in multiple stands that differed in terms of forest  
127 management and certain structural elements of forests in order to evaluate their effects on

**Formattato:** Tipo di carattere: Corsivo

128 ~~microhabitat use and movements of these beetles to identify those interventions that are compatible~~  
129 ~~with and, possibly favourable to, the conservation of *C. olympiae*.~~  
130 ~~After logging, we collected and translocated tagged individuals into the managed stands and started~~  
131 ~~to radio track them to assess individual ecological choices under different forest management~~  
132 ~~scenarios. We hypothesized that logging would increase temperature and decrease humidity, change~~  
133 ~~microhabitat use and affect movement parameters of the radio-tagged individuals. In particular we~~  
134 ~~expected that bare soil should be avoided by this species, and many other studies provide more~~  
135 ~~predictions regarding dead wood, dense field vegetation.~~  
136 We assessed the short-term effects of different types of logging practices on: i) local microclimatic  
137 conditions, ii) habitat use and iii) movements of radio-tagged individuals. ~~In methodological terms,~~  
138 ~~we aimed to test the effectiveness of the radio tracking technique as a tool to assess the effect of~~  
139 ~~forest management on endangered insects.~~

## 141 Study area

142  
143 The study area was the upper Sessera Valley, in the North-western Italian Alps (45°40' N; 8°16'E).  
144 The area is classified as Site of Community Importance (SCI, IT113002, Val Sessera) with the  
145 purpose of ~~protecting this ground beetle species~~ *C. olympiae*. It includes the upper part of the River  
146 Sessera basin, a mountainous catchment, from the valley bottom up to an elevation of 2556 m a.s.l.  
147 (average elevation: 1350 m). Annual rainfall is 1700 mm with two equinoctial maxima, and mean  
148 annual temperature is 7°C. Snow cover lasts about 5 months (November to March). The most  
149 common land cover classes are pasture, shrubland (Alpine rose *Rhododendron ferrugineum* L. and  
150 bilberry *Vaccinium myrtillus* L.), secondary forest on former pastures, coniferous plantation, and  
151 beech forest (belonging to the association *Luzulo-Fagetum*). In the study area, Alpine rose  
152 shrubland is characterized by sparse isolated patches as the result of historical forest cutting and

**Commento [EC9]:** Inserire citazioni

**Commento [EC10]:** 1. The study questions have been improved, but they are far from satisfactory. Microhabitat conditions per se should not be included here, as the focus was on beetles not on forest structures. These measurements and tests should definitely be presented in Results but they are used to explain some of beetle observations and are thus not in the focus. Delete. The same concerns the ending topic, the efficiency of your method, which cannot be assessed without comparing it with other methods (such as the use of radioactive powder in M.A. Baars' studies in the 1970s, etc.). Delete that too. Also, there is no need to describe in such detail what you did in this part: it suffices to say that "We radio tracked *C. olympiae* individuals in multiple stands that differed in terms of forest management and certain structural elements of forests in order to evaluate their effects on microhabitat use and movements of these beetles" and then specify what you expected concerning microhabitats, based on earlier studies (your own research, for example, shows that bare soil should be avoided by this species, and many other studies provide more predictions regarding dead wood, dense field vegetation, etc.). These changes are necessary to put your study into a context of previous research.

**Commento [EC11]:** L 139, "this ground beetle species" => *Carabus olympiae*

**Formattato:** Tipo di carattere: Corsivo

153 pastoral practices. Beech was traditionally managed as coppice-with-standards (i.e., trees retained to  
154 provide a seed source for stump replacement over time) to produce firewood and charcoal. Over  
155 recent decades, forest management has been progressively reduced. The last harvest in privately  
156 owned coppice stands was carried out in 1960; the density of standards is on average 100 trees per  
157 hectare, and they are now about 80 years old. On the other hand, most coppices on public properties  
158 have been actively converted to high forest in the 1980s. Conversion has been carried out by  
159 progressive thinning (3-4- entries) of sprouts (Giannini and Piussi, 1976), before reaching the final  
160 step of “temporary high forest”, i.e., a forest that has the structure of a mono-layered high forest,  
161 but which originated from sprouting, to which the seeding cut will be eventually applied. Most of  
162 the coppices in conversion are currently between the second and the third thinning, and the trees are  
163 70–75 years old, with some ~~standards~~ trees > 100 years old.

Commento [EC12]: L 157,  
“Standards” => trees

## 166 Methods

### 168 **Experimental forest management**

169 Experimental forest management was carried out in 2014 and 2015 in seven different stands, with  
170 the aim of reproducing “business as usual” as well as alternative management options for beech  
171 coppices and high forests (Fig. 1). Forest structure and ground cover were measured before and  
172 after logging across 30 sampling plots (details in Negro et al., 2014). In all logging practices  
173 adopted (interventions *ii*, *iii* and *iv*) the retention of coarse woody debris was prescribed and the  
174 following four treatments were applied:

- 176 *i*) no logging (control, C), only in over-mature coppices (two stands, one in 2014 and one in  
177 2015, 3 hectares each). These had an average stem density of 2029 trees ha<sup>-1</sup>, mean canopy



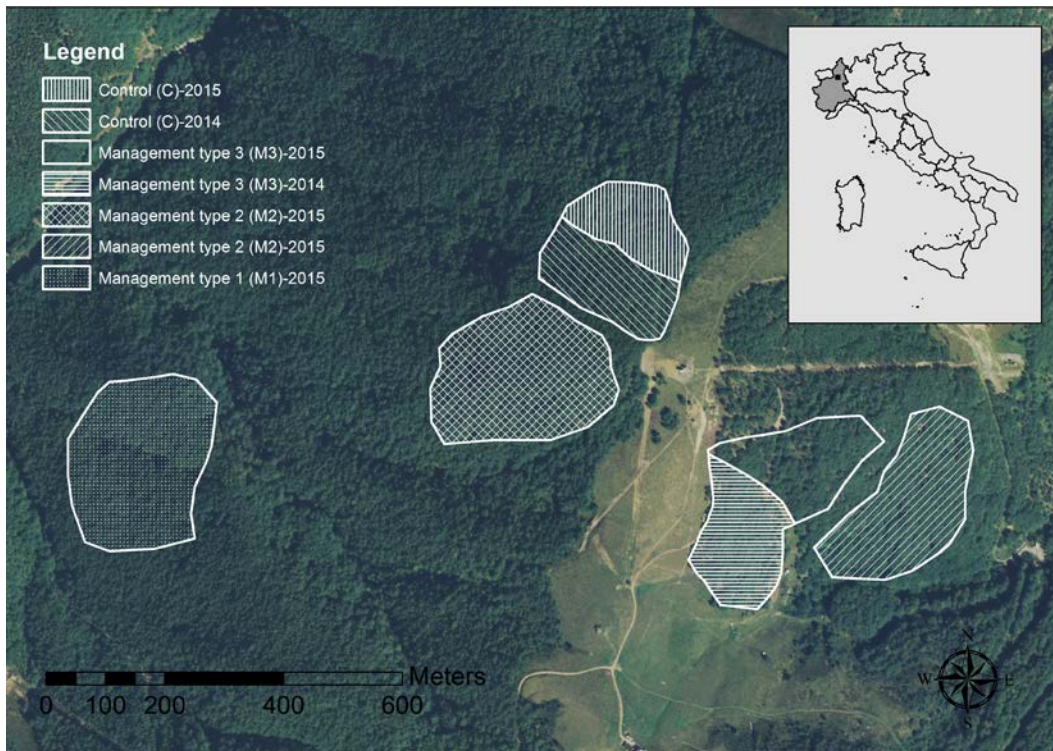
178 cover of 89%, and mean living aboveground tree volume of 207 m<sup>3</sup> ha<sup>-1</sup>. Ground cover by  
179 deadwood (downed logs and branches, either sparse or piled) was in the range of 0% to 10%  
180 (Negro et al., 2014);  
181

**Commento [EC13]:** L173, please clarify "sparse or piled" – do you mean that the same amounts were distributed evenly all over the stands versus stacked in (how large?) piles?

182 *ii*) strip cuts in the high forest (one stand in 2015, 10 hectares) (management type 1, M1). This  
183 had an average stem density of 915 trees ha<sup>-1</sup>, mean canopy cover of 89%, and mean living  
184 aboveground tree volume of 273 m<sup>3</sup> ha<sup>-1</sup> before treatment. After the cut, which was carried  
185 out by removing all trees in 10 elongated openings (350-1250 m<sup>2</sup> each) and leaving a total of  
186 30 m<sup>3</sup> of cut timber on the ground in the form of whole trees, ground cover by deadwood  
187 had increased on average from 2% to 6%;  
188

189 *iii*) single-tree selection in over-mature coppices (two stands in 2015, 14 and 6 hectares  
190 respectively) (management type 2, M2). This was carried out by harvesting individual  
191 sprouts, trees, or small groups (tree diameter <25 cm) with the aim to promote the growth of  
192 better-quality beech stems, while retaining all other tree species and leaving all branches on  
193 the ground. Stem density and living tree volume were reduced on average by 26% and 30%  
194 respectively, while ground cover by deadwood increased on average from 2% to 8%;  
195

196 *iv*) uniform thinning to convert over-mature coppices to high forest (two stands, one in 2014  
197 and one in 2015, 3 hectares each) (management type 3, M3). This represents the "business  
198 as usual" scenario for beech coppices in the region, and was carried out by harvesting all but  
199 the best-quality sprouts from each stool, and leaving branches in small piles uniformly  
200 scattered on the ground. Stem density and living tree volume were reduced on average by  
201 85% and 60%, respectively, while ground cover by deadwood increased on average from  
202 2% to 5%.  
203



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Figure 1. Experimental design. Seven different stands underwent four different forest management interventions: i) absence of management in over-mature coppices (control, C); ii) strip cuts in the temporary high forest (management type 1, M1); iii) single-tree selection in over-mature coppices (management type 2, M2); iv) uniform thinning to convert over-mature coppices to high forest (management type 3, M3).

## 212 Microclimate monitoring

213 Five *Thermo/Hygro Button* loggers (Maxim Integrated Products, Inc., Sunnyvale, CA, U.S.A.) were  
214 used to record temperature and relative humidity every 1 h in each stand in 2015. The data loggers,

215 ~~fixed~~ attached to wooden poles (2 cm above the soil surface) and sheltered from rain by means of a  
216 plastic roof, were located in areas that were representative of the treatment applied in that stand.

217 Recorded data were used to compute daily mean, minimum, and maximum temperature and relative  
218 humidity.

219

## 220 Pitfall trapping

**Commento [EC14]:** L 209, "fixed"  
=> attached

**Commento [EC15]:** L 201,  
werelocated => were located

221 We captured ground beetles by pitfall trapping in un-managed areas. In each sampling area, five  
222 baited pitfall traps were arranged according to a Latin square design, i.e., at the four vertices and at  
223 the center of a 20 m-wide square. Each trap (7.5 cm diameter and 9 cm deep), filled with 150 ml of  
224 vinegar as an attractant (van den Berghe, 1992), was assembled with a double bottom in order to  
225 keep animals alive. A flat stone was placed above each trap to prevent flooding. The exact location  
226 of traps was determined by means of a Global Positioning System (GPS) Garmin eTrexR  
227 Navigator. A total of 23 sampling areas in 2014 (early July-mid August) and 24 in 2015 (mid June-  
228 early August) were set and traps emptied at three-day intervals.

**Commento [EC16]:** L 220, what are these "areas"? Do you refer to traps?

229

### 230 **Radio-tracking**

231 Individuals were radio tagged with Micro-Pip radio-tag transmitters (about 0.3 g, 15 × 5 × 4 mm)  
232 developed by Biotrack Ltd, (Wareham, England, [www.biotrack.co.uk](http://www.biotrack.co.uk)). Transmitters were attached  
233 with cyanoacrylate on top of the elytrae, with the short antenna (2.5 cm) directed backwards, in  
234 keeping with Negro et al. (2008). After radio-tagging, individuals were kept for some hours in a  
235 dark terrarium before releasing them back to the wild. In the field, radio-signals could be detected  
236 from about 300 m, with a battery life span of about three weeks. Tagged carabids were relocated  
237 once a day, in the morning, using a receiver and a hand-held Yagi directional antenna. The exact  
238 radio-telemetry location (fix) was determined in the field by a GPS, where a coloured peg was also  
239 driven into the soil. At the end of the experiment period, radio tagged individuals were caught to  
240 retrieve transmitters before being released.

241

242 *C. olympiae* are more active at night than by day. During the day, they do not move or move only  
243 very short distances (typically < 2.5 m) up to few meters, whilst long distance movements of several  
244 tens of meters (the maximum linear dispersal range was 77.7 m) were almost exclusively at night  
245 (Negro et al. 2008). The fixes collected in the present study reflect therefore the microhabitat used  
246 by individuals as a refuge or shelter during the day time.

**Commento [EC17]:** L 236-237, too precise values for any practical use. Rather say "up to a few meters" and "of several tens of meters"

247

#### 248 **Microhabitat assessment**

249 Microhabitat availability for ground beetles was assessed in October 2015 by transect sampling. We  
250 set six linear transects (60 m long) per stand in the same areas used by radio-tracked individuals (a  
251 total of 42 transects, i.e. 6 transects x 7 stands). Quadrats (60 x 60 cm) along transects were set at  
252 two metres one from another (i.e. 30 quadrats for each transect) for a total of 1260 quadrats (30  
253 quadrats x 42 transects). We took a picture of ground cover in each quadrat and the dominant  
254 microhabitat was later classified into one of the following categories: shrubs (SH), tree bases (ST),  
255 deadwood (DW, i.e. coarse woody debris such as pieces of branches or trunks), grass (G), bare  
256 ground (BG), rocks (R) and litter (L).

257 Individual microhabitat use was assessed by recording the microhabitat used by radio-tagged  
258 individuals as shelter during the day (i.e. the dominant microhabitat category at the fix).

259

#### 260 **Data analysis**

261

#### 262 **Microhabitat use**

263 We used a binomial Generalized Linear Mixed Model to model microhabitat use (i.e. 1 used, 0  
264 unused) as a function of management (i.e. C, M1, M2 and M3), year of study (2014 and 2015), sex,  
265 and microclimate (average humidity and temperature), specifying the identity of radio tagged  
266 individuals as a random effect. We modelled the use of three microhabitat types, i.e. litter,  
267 deadwood and tree bases, for which the sample size was statistically adequate not to have  
268 convergence problems of the model.

269 In our study design, microhabitat use was measured for each individual, whilst microhabitat  
270 availability was measured at the population scale (i.e. inside each managed stand), assuming that  
271 microhabitat types were equally available to all monitored animals (Thomas & Taylor 1990). To

272 compare use and availability in this kind of study design (i.e. to study microhabitat selection), we  
273 used Compositional Analysis, calculating the significance of Wilk's  $\Lambda$  and t statistics by  
274 randomization tests (Aebischer et al. 1993). Analyses were performed using the function *compa*  
275 in the package *adehabitatHS* for R (Calenge, 2011; R Core team, 2016). We also calculated the  
276 selection ratio:  $w_j = u_j/a_j$  where  $u_j$  is the proportion of use of the habitat class j and  $a_j$  is the  
277 proportion of availability (relative frequency) of habitat class j (Manly et al., 2002). If individuals  
278 use all habitats in relation to their availability, the ratio is 1, if they use a certain habitat  
279 proportionally less than its availability, the ratio is a value between 1 and 0, while if they use the  
280 habitat proportionally more than its availability, the ratio is  $> 1$  (i.e., the higher the value, the higher  
281 the preference for that habitat).

282 Since the selection ratio showed that microhabitat selection was different from one animal to  
283 another, we investigated these differences by means of eigenanalysis of selection ratios (Calenge,  
284 2006). If W is the table containing the selection ratios for each animal (rows) and each microhabitat  
285 type (columns), the eigenanalysis consists of a non-centred and non-scaled principal component  
286 analysis of the table  $W - 1$ , using the proportion of availability of each microhabitat type as column  
287 weights and the number of relocations of each animal as row weights. This analysis partitions the  
288 statistics:

289

$$S = \sum_{i=1}^P \sum_{j=1}^K \frac{(u_{ij} - p_i u_j)^2}{p_i u_j}$$

291

292 where  $u_{ij}$  is the number of relocations of animal j in microhabitat i,  $p_i$  is the proportion of available  
293 resource units in microhabitat i, and  $u_j$  is the total number of relocations of animal j. This statistic  
294 was proposed by White and Garrott (1990) to test microhabitat selection. ~~What is interesting is that~~

295 ~~this analysis connects two widely used approaches for microhabitat selection studies into a unified~~  
296 ~~framework [selection ratios and the White and Garrott (1990) statistic].~~

**Commento [EC18]:** L 283, the journal may want you to number this formula

**Commento [EC19]:** L 287, delete the unnecessary "What is interesting is that"

**Commento [EC20]:** L 288-289, please clarify (rewrite) this sentence; also, (connects => combines

297

## 298 **Movements**

299 Movements were studied by measuring the linear distances (with a telemeter) and the turning angles  
300 between consecutive fixes (Cain, 1989). Vagility indices were computed for each individual,  
301 consistent with Negro et al., 2008. Independence among successive angles was tested by the non-  
302 parametric Runs Test above and below the median, which is used to test the randomness of a  
303 sequence of a series of observations (turning angles, in our case) (Sokal & Rohlf, 1995). To  
304 approach normality (checked by using normal probability plots), distance data were square-root  
305 transformed (Sokal & Rohlf, 1995).

306 To test the agreement among turning angles, we computed an index of angular concordance, or  
307 angular concentration (Zar, 1999; Fortin & Dale, 2005), converting angles in a circular system  
308 using Batschelet's (1981) protocol. For any sets of data the angles ( $\theta_i$ ) are represented in a circular  
309 system by vectors of unit length and coordinates ( $x_i, y_i$ ) by means of the following equations:  $x_i =$   
310  $\cos(\theta_i)$  and  $y_i = \sin(\theta_i)$ . The coordinates of the mean vector are  $(\bar{x}, \bar{y})$ , while its length is equal to  $r_a =$   
311  $\sqrt{\bar{x}^2 + \bar{y}^2}$ . The circular equivalent of the standard deviation is  $s = \sqrt{2(1 - r_a)}$ , which can be  
312 converted to degrees by multiplying by  $180^\circ/\pi$  (Batschelet, 1981). The mean vector length ( $r_a$ ) takes  
313 a value of 1 when all the angles are the same and a value of 0 when the vectors cancel each other  
314 out (Upton & Fingleton, 1989; Fortin & Dale, 2005).

315 To check the compactness of the paths travelled by each radio-tagged individual, we calculated the  
316 Index of Tortuosity (T) that considers both distances and angles. This index is based on the convex  
317 hull, which is the smallest convex polygon that fully contains the path. T is equal to the L/M ratio,  
318 where L is the total distance covered and M is the major diameter of the convex hull (Claussen et  
319 al., 1997). The coefficient of variation (CV = standard deviation/mean  $\times$  100) of distance was used  
320 to test the variability of daily distance between fixes among different forest management types.

**Commento [EC21]:** L 300-304, unnecessary jargon; just say that you used Batschelet's (1981) protocol for these

321 Movement data were merged with those of 21 individuals radio-tracked in Alpine rose shrubberies  
 322 and over-mature beech coppices in years 2005 and 2006 (Negro et al., 2008). This merger  
 323 significantly increased the size of the data set and gave us the opportunity to study movements in a  
 324 gradient of increasing human impact (from undisturbed forest to managed forest to shrubs resulting  
 325 from past forest harvesting).

326 All vagility parameters (i.e. tortuosity index, angular concordance and CV of distance) were  
 327 modelled by means of GLMs, in relation to the sex of the individual and forest management.

328

## 329 **Results**

330 A total of 40 *C. olympiae* individuals were collected and radio-tracked within stands: 15 in 2014 (in  
 331 two stands i.e. C and M3) and 25 in 2015 (in four stands i.e. C, M1, M2 and M3) (Table 1). Forest  
 332 management increased deadwood (M1: from 2 to 6%; M2: from 2 to 8%; M3: from 2 to 5%) and  
 333 bare ground cover (M1: from 4 to 9%, M2: from 3 to 9%; M3: from 3 to 29%) in all managed  
 334 stands. Cover by litter decreased greatly (M1: from 80 to 60%, M2: from 75 to 63%; M3: from 75  
 335 to 32%), while grass cover exhibited only little change (M1: from 0 to 3%, M2: from 5 to 1%; M3:  
 336 from 5 to 4%). The harvest did not affect ground cover by tree bases, shrubs and rocks.

337 Table 1. Number of fixes, daily mean  $\pm$  SE and total distances covered by radio-tagged ground beetles in  
 338 2014-2015.

339

No.	Management	Sex	Year	Fix No.	Total distances (m)	Mean (m) $\pm$ SE
1	Control	F	2014	31	151.10	5.04 $\pm$ 0.76
2	Control	M	2014	6	12.91	2.58 $\pm$ 1.25
3	Control	M	2014	14	130.05	10.00 $\pm$ 2.65
4	Control	M	2014	4	97.10	32.37 $\pm$ 6.93
5	Control	F	2014	20	88.90	5.56 $\pm$ 0.84
6	Control	F	2014	9	134.80	19.26 $\pm$ 4.44
7	Control	M	2014	3	8.65	4.33 $\pm$ 2.98
8	M3	F	2014	6	76.91	15.38 $\pm$ 11.78
9	M3	M	2014	6	57.99	11.60 $\pm$ 6.74
10	M3	M	2014	6	130.47	26.09 $\pm$ 11.05
11	M3	M	2014	31	310.72	11.10 $\pm$ 3.23
12	M3	F	2014	11	125.00	15.63 $\pm$ 6.03

13	M3	M	2014	11	195.30	19.53 ± 5.65
14	M3	F	2014	4	3.40	1.13 ± 0.34
15	M3	F	2014	22	319.40	15.21 ± 3.54
16	M3	M	2014	16	73.40	4.89 ± 1.36
17	Control	M	2015	37	806.50	22.40 ± 3.09
18	Control	M	2015	38	388.60	10.50 ± 1.40
19	Control	M	2015	6	7.00	1.40 ± 0.44
20	Control	F	2015	13	67.65	5.64 ± 1.91
21	Control	M	2015	29	654.15	23.36 ± 3.79
22	Control	F	2015	4	71.80	23.93 ± 3.14
23	Control	F	2015	15	95.80	6.84 ± 2.50
24	M2	F	2015	24	259.00	11.26 ± 2.73
25	M2	F	2015	24	27.28	1.19 ± 0.55
26	M2	M	2015	19	135.50	7.53 ± 2.65
27	M2	M	2015	24	63.30	2.75 ± 1.27
28	M1	M	2015	14	91.20	7.02 ± 2.16
29	M1	M	2015	11	66.80	6.68 ± 3.35
30	M1	M	2015	6	110.00	22 ± 11.49
31	M1	M	2015	6	155.10	15.51 ± 4.74
32	M1	F	2015	26	306.85	12.27 ± 2.38
33	M1	F	2015	15	102.73	7.34 ± 2.98
34	M2	M	2015	11	201.85	20.19 ± 4.77
35	M2	F	2015	17	289.35	18.08 ± 4.75
36	M2	F	2015	15	109.13	7.80 ± 2.48
37	M2	M	2015	14	54.75	4.21 ± 1.74
38	M3	F	2015	20	343.30	18.07 ± 5.10
39	M3	F	2015	13	162.20	13.52 ± 4.66
40	M3	M	2015	7	88.50	14.75 ± 6.68
41	M3	M	2015	26	453.55	17.44 ± 6.28

340

341

342 ***Microclimatic conditions***

343 A complete series of climate data was only available for C and M3 stands in 2015, where data  
344 loggers ran without interruption from 18 June to 5 August. Microclimatic conditions in these  
345 control and managed stands were significantly different. No significance differences were found  
346 between control and M1 and M2 stands, likely because the incompleteness of the data collected; the  
347 maximum temperature was on average significantly higher in M3 than in C (Gaussian GLM: beta  
348 5.0297, SE 0.4861, t value 10.35, p <2e-16), whilst the minimum and average humidity were lower



349 (minimum humidity: Gaussian GLM: beta -3.27, SE 0.86, t value -3.77,  $p < 0.000185$ ; average  
350 humidity: Gaussian GLM: beta -18.74, SE 1.53, t value -12.2,  $p < 0.000185$ ).

351

### 352 ***Microhabitat use***

353 Five microhabitats were available for radio-tagged ground beetles in all managed and control areas.

354 The most available microhabitat was litter (min= 48% of quadrats in M1, max= 63% in C),

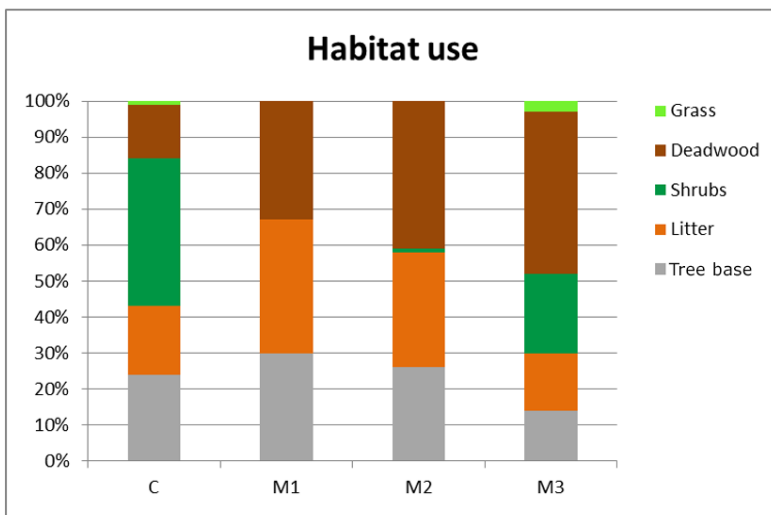
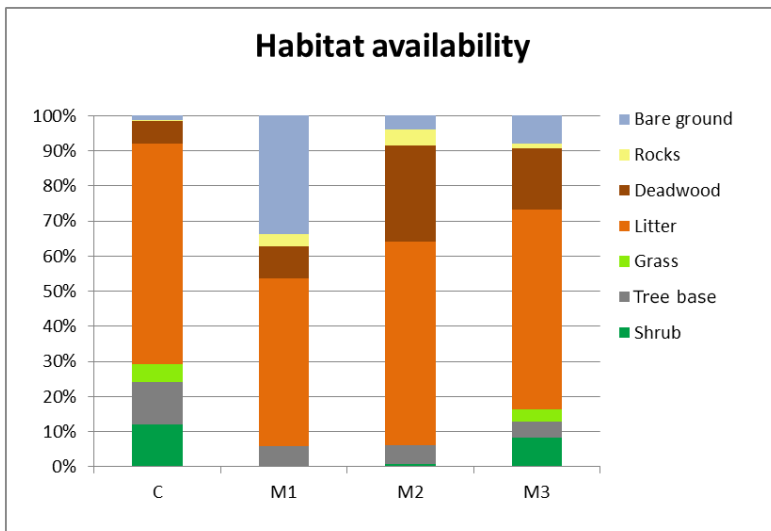
355 followed by deadwood (min = 6% in C, max=27% in M2), bare soil (min = 1% in C, max=34% in

356 M1), tree bases (min = 4% in M3, max=12% in C) and rocks (min= 1% in M3, max=5% in M2).

357 Shrubs were absent from M1 and grass cover from M1 and M2. Overall, control areas used by

358 radio-tagged individuals had more litter, shrubs and tree bases, while managed areas had more

359 deadwood and bare soil (Fig. 2, on top).



360

361 Fig 2. Available (top) vs used (bottom) microhabitat types in managed and control areas used by  
 362 radio-tracked individuals.

363

364 Radio-tagged individuals used five microhabitat types, i.e. litter, tree bases, deadwood, shrubs and

365 grass (Fig. 2, on bottom). Bare ground and rocks were ~~never~~ not used. Microhabitat use modelling

366 did not show any significant differences in the use of litter, deadwood or tree bases due to year of

367 sampling, sex, mean temperature or humidity. The use of these microhabitat types significantly

368 changed according to management type only. In particular, litter was used more frequently in M1

Commento [EC22]: L 357, "never"  
=> not

369 than in control stands, and deadwood was used more frequently in all managed than in control  
 370 stands (Table 2).

371 Table 2. Binomial Generalized Linear Mixed Models of the frequency of the use of Litter, Tree  
 372 bases and Deadwood diurnal shelter in the different forest management stands. Control was set as  
 373 reference category. Significance codes: '\*\*\*' p < 0.001; '\*\*' p<0.01; '\*' p<0.05; '.' p<0.1.

**Commento [EC23]:** L 364, "diurnal shelter" is an interpretation and should be omitted

Litter				
	Estimate	St. Error	z values	Code
(Intercept)	-1.61	0.28	-5.75	***
M1	1.02	0.48	2.13	*
M2	0.69	0.43	1.61	NS
M3	-0.06	0.40	-0.14	NS
Deadwood				
	Estimate	St. Error	z values	
(Intercept)	-1.83	0.27	-6.87	***
M1	1.10	0.45	2.45	*
M2	1.49	0.39	3.78	***
M3	1.67	0.35	4.76	***
Tree bases				
	Estimate	St. Error	z values	
(Intercept)	-1.15	0.22	-5.14	***
M1	0.26	0.42	0.63	NS
M2	0.03	0.37	0.09	NS
M3	-0.68	0.35	-1.95	.

374  
 375

376 The ranking of microhabitats obtained through Compositional Analysis showed that deadwood and  
 377 tree bases were the most preferred microhabitats both in managed and control stands, whilst litter  
 378 and grass were the least preferred ones. Shrubs was a high ranking microhabitat in control stands,  
 379 but a low ranking one in M2 and M3 stands (Table 3 and Appendix I).

380

381 Table 3. Microhabitat selection as revealed by Compositional Analysis. Microhabitats are ranked in  
 382 ascending order of preference.

383

	C	M1	M2	M3
Shrub	5	-	2	2
Tree base	6	4	4	5

Grass	2	-	-	384 <sup>4</sup>
Litter	3	2	3	385 <sup>3</sup>
Deadwood	4	3	5	386 <sup>6</sup>
Rocks	0	1	0	387 <sup>1</sup>
Bare ground	1	0	1	388 <sup>0</sup>
Lambda	0.068	0.088	0.021	0.134 <sup>4</sup>
p-value	0.002	0.040	0.018	0.002 <sup>390</sup>

391

392

393

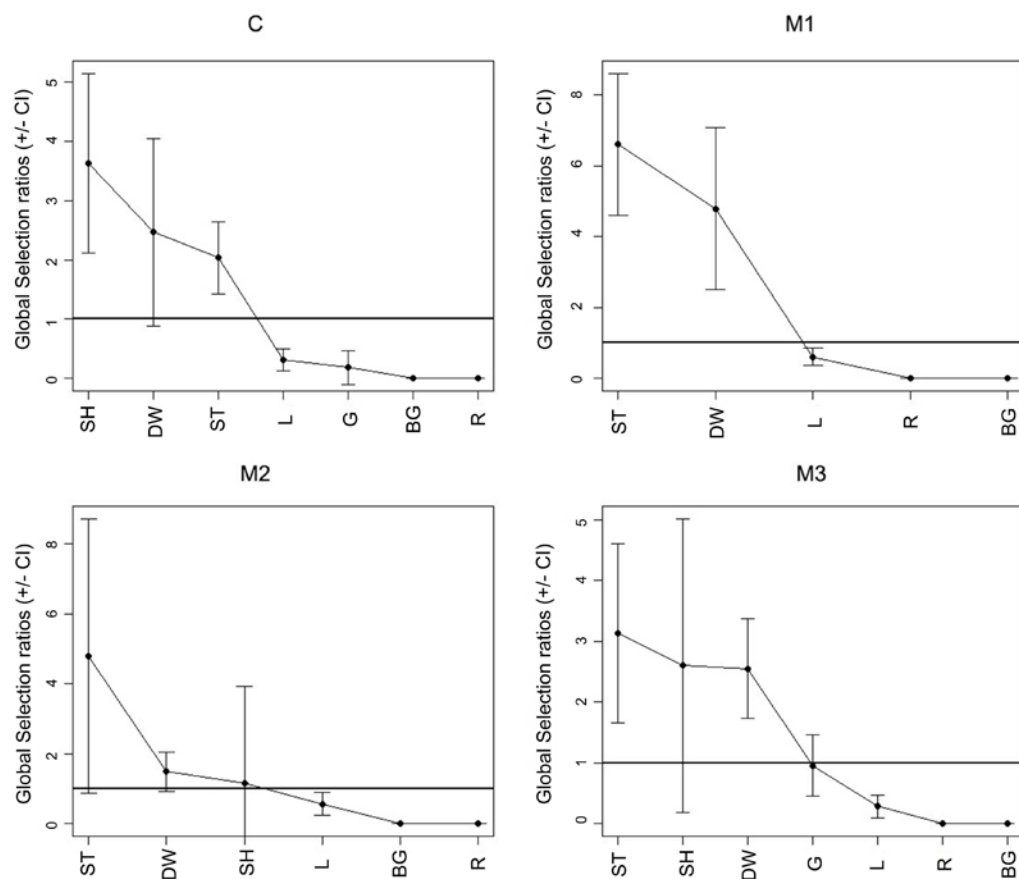
394

395 Manly's selection ratio  $W_i$  for deadwood, tree bases and shrubs was higher than 1 (i.e. positive  
396 selection) and ranged between 0 and 1 for litter and grass (negative selection) both in the managed  
397 and control stands. The selection ratio for tree bases was higher in M1 and M2 stands (4.74 and  
398 4.40, respectively), suggesting a high preference for that microhabitat, and close to 1 for shrubs in  
399 M2 stand (1.06), suggesting a weak positive selection or a random use for that microhabitat (Fig. 3).

400

401

### Manly selectivity measure



402

403 Figure 3. Microhabitat selection in control (C), and managed stands t (M1, M2 and M3) as revealed  
 404 by Manly selection ratio  $W_i (\pm SE)$ . Microhabitat codes as follows: shrubs (SH), tree bases (ST),  
 405 deadwood (DW), grass (G), bare ground (BG), rocks (R) and litter (L).

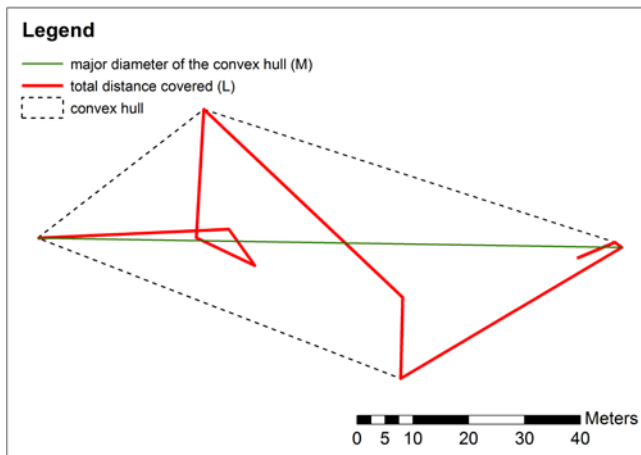
406

407 The eigenanalysis of selection ratios (Calenge and Dufour, 2006) graphically showed that all  
 408 individuals avoided bare ground, grass and rocks and showed variable preference in the use of tree  
 409 bases, shrubs and deadwood (Appendix II). The radiotracked individuals selected shrubs, deadwood  
 410 and tree bases in C, in M1 they selected deadwood and tree bases, in M2 some individuals selected  
 411 shrubs and deadwood and some selected tree bases, while in M3 most individuals selected tree  
 412 bases and deadwood.

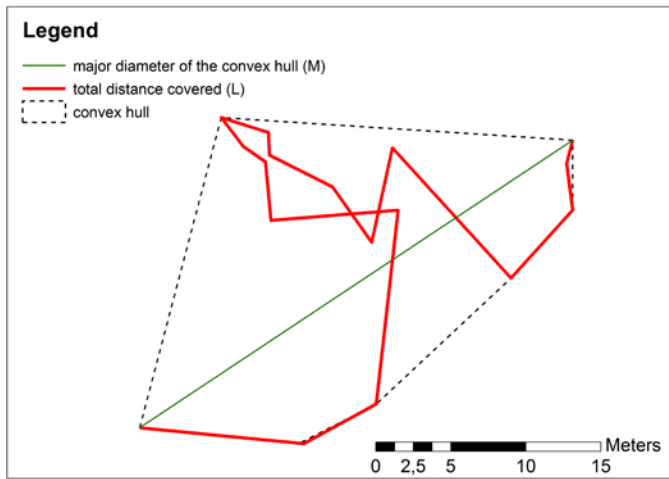
413 **Movements**

414 By pooling old (2005 and 2006) and new (2014 and 2015) fixes together, a four-year integrated data  
415 set of 1161 fixes (527 + 634) relative to 61 (21 + 40) ground beetles was obtained. All individuals  
416 displayed zig-zag trajectories (Fig 4).

417  
418



419  
420



421

422 Fig 4. Trajectories of two randomly selected *Carabus olympiae* individuals (i.e. male No. 13, top  
423 and female No. 5, bottom) radio-tracked in 2014. The individual's path (red line) and the major  
424 diagonal of the Minimum Convex Polygon (green line) that includes the entire path are shown.  
425

426

427 The total distances covered by radio-tracked individuals varied between 3.40 and 806.50 metres,  
 428 with mean daily distances ranging from 1.13 to 32.37 metres (Table 1). Angles were evenly  
 429 distributed in all stands (shrubberies, control and in managed stands), indicating the lack of a  
 430 prevailing walking direction (Appendix III).  
 431 GLMs showed that the coefficient of variation of the distances and the tortuosity index varied  
 432 according to the management; the length of the paths of individuals in M2 and M3 stands was more  
 433 variable than in control stands and the tortuosity index was significantly lower in shrubbery and in  
 434 M2 stands than in control, and significantly higher in males than in females (Table 4 and Fig. 5).

435

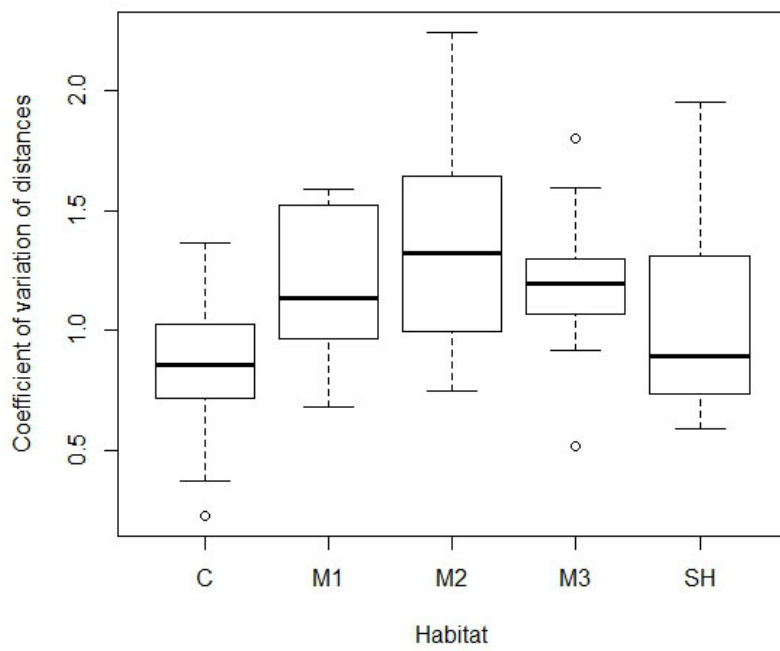
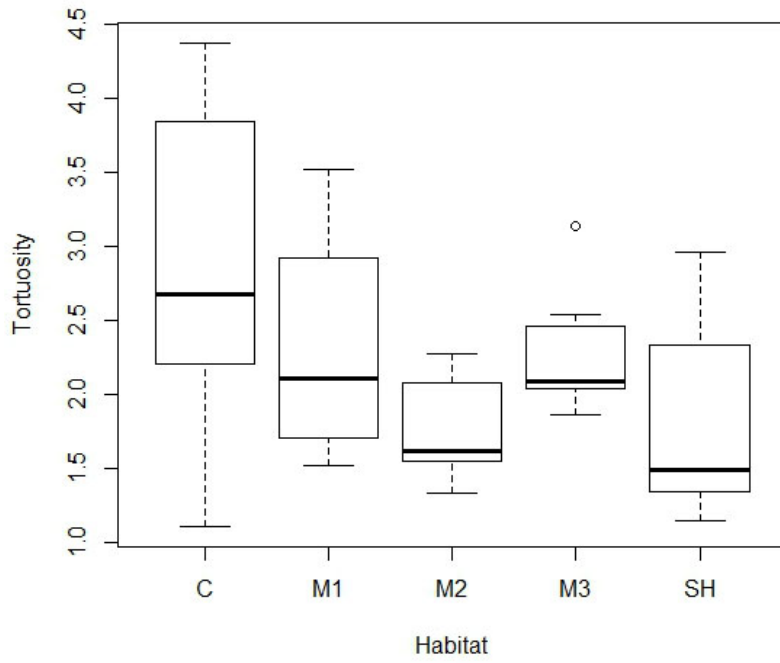
CV Distance				
	Estimate	St..Error	t values	P
(Intercept)	0.86	0.07	11.88	<2E-16
M1	0.31	0.16	1.93	5.80E-02
M2	0.50	0.14	3.49	9.52E-04
M3	0.33	0.12	2.70	9.25E-03
Shrubbery	0.18	0.13	1.41	0.16
Tortuosity				
	Estimate	St..Error	t values	P
(Intercept)	0.83	0.08	9.76	<2.96E-12
M1	-0.18	0.16	-1.11	0.27
M2	-0.39	0.15	-2.60	0.01
M3	-0.16	0.13	-1.30	0.20
Shrubbery	-0.47	0.11	-4.22	1.31E-04
Sex	0.29	0.09	3.34	1.80E-03

436

437 Table 4. Generalized Linear Mixed Models of CV of distances and tortuosity in the different forest  
 438 management and shrubland stands. Control was set as reference category.

439

440



441  
 442 Fig.5 Box plots of the tortuosity index (top) and of the coefficient of variation of the distances  
 443 (bottom) between management types (Control C, Management M1, Management M2, Management  
 444 M3 and Shrubs SH)  
 445



446 **Discussion**

447 Logging may ~~have negative impacts~~ ~~faffects~~ or forest wildlife and insect fauna because of the  
448 induced changes in microclimatic conditions and microhabitat availability. Ground beetles strongly  
449 depend on particular humidity and temperature requirements (Sklodowski 2014). Data loggers  
450 showed that temperature was higher and humidity lower in M3 than in control stands, suggesting  
451 that uniform logging may induce significant short term climatic changes. Warmer and drier  
452 microclimates may negatively affect *C. olympiae* both directly (this species likes fresh and humid  
453 beech forests, Negro et al. 2014) and indirectly, reducing the local availability of snails and slugs  
454 (*Arianta arbustorum*, *Arion* and *Limas* spp.), which are the preferred prey (Negro ~~et al., 2008~~pers.  
455 comm.). Canopy and shrub cover usually take several years to recover after a cut, depending on the  
456 intensity of the removal. Montagnoli et al. (2012) compared canopy cover and soil temperature  
457 between May and October at 5 cm depth in over-mature beech coppices (not cut for 40 years)  
458 against those following uniform conversion to high forest (75% of trees removed). Even 14 years  
459 after the cut, canopy cover was on average 22% lower and soil temperature 1 °C warmer than in the  
460 uncut forest.

462 ~~The low-intensity interventions (M1 and M2) may have resulted in only negligible changes in~~  
463 ~~micro-climate, shadiness and shrub cover~~ ~~M1 and M2 forest management interventions, conversely,~~  
464 ~~might have produced negligible climatic changes. Such lower intensity cuts may mitigate the~~  
465 ~~changes in shading, shrub cover, and soil microclimate~~ by preserving patches or corridors of trees  
466 throughout the stands. Small canopy gaps (20 to 30 m diameter) ~~were found~~ ~~have been found~~ to  
467 increase maximum soil temperature by +0.2 - +1.9 °C relative to an uncut control, but the effect  
468 was already cancelled out at the edge of the gap (Prévost and Raymond, 2012). Gap cutting may be  
469 even more conservative in terms of soil moisture, which has been found to be unchanged, or even  
470 increased, in small (300-400 m<sup>2</sup>) and large (500-700 m<sup>2</sup>) gaps compared to below fully closed  
471 canopy (Bilek et al., 2014).

**Commento [EC24]:** 9. Discussion is exhaustingly long. It would benefit from 2-3 subtitles which would bring about clearer structure, for example based on your research questions.

**Commento [EC25]:** 8. Discussion begins rather weakly by stating general logging impacts, but it should begin with one of your results (concretely, the sentence on lines 441-443). The rest of the paragraph would then clarify and present other studies. Also, logging has also positive effects so L 439 should perhaps say "logging may affect forest wildlife...".

**Commento [EC26]:** L 446, the cited study does not present data on prey so this "preferred prey" is unwarranted or at least the reference is incorrect. There may not be any study that would show this for this species, but generally slugs and snails are used as part of the diet of many large carabids. Cite, for example, Rob Hengeveld's studies from 1980s, or some general papers about carabids (Thiele's 1977 book, or more recent papers such as Kotze et al. 2011/ZooKeys or Lövei & Sunderland 1996/Annu.Rev. Ent.).

MATTEO

**Commento [EC27]:** L 453-456, very wordy text, compress, for example "The low-intensity interventions (M1 and M2) may have resulted in only negligible changes in micro-climate, shadiness and shrub cover."

**Commento [EC28]:** L 456, you did not show anything about canopy gaps. If you intend to refer to Prévost et al., then rather say "have been found"

472 Compared to other broadleaves, beech has a strong ability to fill canopy gaps by crown extension  
473 (Brunet et al. 2010). If the regeneration strategy is successful, a new beech layer will establish in  
474 recently opened gaps within a few years, resulting in moderate microclimatic changes with a new  
475 canopy (Dovciak and Brown, 2014). Finally, the release of deadwood on the ground may provide  
476 shadier microsites that mitigate the absence of a more uniform canopy or shrub cover as a  
477 consequence of the cut (Marzano et al., 2013) and contribute to preserving soil moisture (Ritter and  
478 Vesterdal, 2006).

479  
480 In addition to microclimatic conditions, forest management may change ground cover and  
481 understory, and induce a different microhabitat use. Even though we were able to consider only 1-2  
482 stands per management, we nonetheless described in details and by means of several sampling  
483 points the variance within each treatments. This allowed us to identify that the use of microhabitat  
484 types by radio-tagged *C. olympiae* individuals indeed changed significantly according to the  
485 management. The increase in bare ground after logging is obviously a negative effect, given that  
486 individuals cannot hide in such a microhabitat ~~(which was never used)~~ (Niemelä et al., 1996,  
487 Skłodowski 2008). This finding is consistent with previous analyses that showed that *C. olympiae*  
488 abundance was negatively related to bare ground cover (Negro et al., 2014). However, the increase  
489 in deadwood availability may be beneficial. Microhabitat selection analyses (i.e. Compositional  
490 Analysis and Manly ratio) showed that deadwood and tree bases were ~~positively selected~~ preferred  
491 and litter ~~negatively selected~~ ~~(i.e. was avoided avoided)~~ in all managed and control stands,  
492 suggesting that microhabitat preferences did not significantly change with forest interventions. At  
493 the same time, univariate models showed that deadwood was used more frequently in all managed  
494 stands than in control stands. This major use, given the consistency of microhabitat preferences,  
495 may be easily explained by the greater deadwood availability in managed stands. The abundance of  
496 deadwood in managed stands was a consequence of experimental logging that aimed at a high level  
497 of retention of coarse woody debris (Negro et al. 2014).

**Commento [EC29]:** L 471-472, this is what you did indeed, but it brings pseudoreplication regarding the treatments. Much caution must be added. Besides, the less intense (M1, M2) were not that different from the more intensive (M3) management, and results comparing these were often not systematic (Tables).

**Commento [EC30]:** L 475, delete "(which was never used)" (unnecessary text)

**Commento [EC31]:** L 479-480, use biological terms: were preferred, were avoided

**Commento [EC32]:** L 485, what is "high level of retention"? Retention should also be clarified in Mat & Met: how much dead wood per hectare, were it all dead before logging, etc.

498 ~~It should be emphasised that d~~Deadwood is crucial for hundreds of rare and threatened species in  
499 Europe alone (cit?!)  
500  
501 ~~decomposition plays a key role in the recycling of nutrients and organic matter, as well as in~~  
502 ~~providing a wide variety of microhabitats for plants and invertebrates, particularly insect species~~  
503 ~~and other organisms (Stevens 1997, Floren et al. 2014, Chumak et al. 2015). Insects, in turn, may be~~  
504 ~~beneficial to forest bird specialists, whose diversity increases with increasing amounts of deadwood,~~  
505 ~~both in breeding and in wintering seasons (Laiolo et al. 2004; Caprio et al. 2009).~~

506 The quantity of deadwood in Europe's forests has decreased significantly since the middle of the  
507 19<sup>th</sup> century due to intense forest exploitation. Since 2000, however, a small overall increase in  
508 deadwood has been observed (Forest Europe 2011). This may be due to management practices that  
509 deliberately increase the amount of woody debris in managed forests (as in our case), either thanks  
510 to legal or policy prescriptions, or as a measure to comply with forest certification requirements  
511 (European Environment Agency 2015). The increases in forest cover and stem density in  
512 many European forests, following extensification of forest use, have also led to a increased natural  
513 disturbance levels (Seidl et al. 2014). Wind storms and bark beetle disturbance events may have  
514 influenced the production of dead wood in some areas (Kulakowski et al. 2017), although this  
515 should not be relevant for the area studied here (no evidence for large disturbances in the managed  
516 beech forest was found). Finally, climate change may also contribute to increased disturbance  
517 frequency and severity, and increased deadwood input (Seidl et al. 2017).

518 All the above confirms that the retention of deadwood is thus crucial in conservation of forest  
519 organisms, and specific attention should be paid for securing its spatio-temporal continuity in  
520 managed forests a method that produces results that are superior to those achieved by other means  
521 and should therefore be recommended as best practice in forest management devoted to animal  
522 diversity conservation.

**Commento [EC33]:** L 487-492, too wordy text. The message is that deadwood is crucial for hundreds of rare and threatened species in Europe alone (add references). Then, this simple statement could/should be added as a beginning sentence for the next paragraph, discussing deadwood role.

Lassaue, A., Paillet, Y., Jactel, H., Bouget, C., 2011. Deadwood as a surrogate for forest biodiversity: Meta-analysis of correlations between deadwood volume and species richness of saproxylic organisms. *Ecological Indicators* 11, 1027–1039. doi:10.1016/j.ecolind.2011.02.004

Gossner, M.M., Wende, B., Levick, S., Schall, P., Floren, A., Linsenmair, K.E., Steffan-Dewenter, I., Schulze, E.-D., Weisser, W.W., 2016. Deadwood enrichment in European forests – Which tree species should be used to promote saproxylic beetle diversity? *Biological Conservation* 201, 92–102. doi:10.1016/j.biocon.2016.06.032

**Commento [EC34]:** L 505-507 Add caution by just saying, for example, that "Retention of deadwood is thus crucial in conservation of forest organisms, and specific attention should be paid for securing its spatio-temporal continuity in managed forests." It is dangerous to say that deadwood would be superior: it is one important thing, but there will not be much dead wood if e.g. all large trees are harvested as it would interrupt the continuity of this resource.

**Formattato:** Colore carattere: Automatico

523 Very large bases of living and dead trees were clearly preferred by *C. olympiae* individuals that  
524 probably used this resource as shelter for daytime rest or against micro-climatic variation ~~Enlarged~~  
525 ~~tree bases, especially those with decaying wood, were also greatly appreciated by radio tagged *C.*~~  
526 ~~*olympiae* (Manly ratio was well above 1 and scored the highest values in M1 and M2 stands), which~~  
527 ~~took advantages of splits and cavities as shelters.~~ Coppices may provide more of this habitat than  
528 high forests, since the tree base tends to expand if it must support a larger number of sprouts.  
529 Interventions aimed at maintaining over mature coppices are therefore preferable to those aimed at  
530 converting over-mature coppices to high forest, consistent with previous analyses (Negro et al.,  
531 2014, Seidle et al. 2017).  
532 The eigenanalysis of selection ratios showed that microhabitat preferences changed from one  
533 individual to another.  
534  
535 The present research also indicates that forest management may affect *C. olympiae* movements.  
536 Both the coefficient of variation of the distances and the tortuosity index varied according to the  
537 management. The length of the paths of individuals in managed stands was more variable than in  
538 control stands, suggesting that movements of individuals ~~were more uncertain and~~  
539 ~~unpredictable~~ ~~random in terms of direction and length~~ ~~(sometimes they moved a lot, sometimes they~~  
540 ~~did not move)~~ when relocated in forest stands subjected to logging. Trajectories were rather  
541 tortuous, ~~fitting the requirements hunting behaviour~~ of a typical “olfactory-tactile” predator that  
542 looks for prey by systematically exploring its territory. The high tortuosity is also in keeping with  
543 the use of decaying fruits and vegetables (as shown by multiple choice tests carried out in the lab by  
544 Negro and Palestrini, unpublished). We did not track individuals in between two successive  
545 telemetric locations. This means that true paths were likely longer and trajectories more tortuous  
546 than those measured. The tortuosity index was significantly lower in Alpine rose shrubland and in  
547 M2 stands than in control. Negro et al. (2008) found that most individuals located in shrubland were  
548 hidden under Alpine rose shrubs, which probably were used as shelter from extreme temperatures

**Commento [EC35]:** L 508-510, rewrite as “Very large bases of living and dead trees were clearly preferred by *C. olympiae* individuals that probably used this resource as shelter for daytime rest or against micro-climatic variation.”

**Commento [EC36]:** L 521, “uncertain and unpredictable” sounds strange, perhaps say “random in terms of direction and length”

**Commento [EC37]:** L 522-523, delete the text in parentheses (not needed)

**Commento [EC38]:** L 523, “requirements” is not the correct word here, perhaps say behavior?

549 and protection from predators. We believe the low availability of shrubs (which were isolated and  
550 sparse) may have constrained trajectories (individuals were compelled to move from shrub to shrub)  
551 and reduced their tortuosity. Analogously, changes in microhabitat and/or resource availability in  
552 some managed forest stands may have significantly reduced tortuosity in comparison with controls.  
553 Tortuosity index was significantly higher in males than in females. Males of insects are able to  
554 detect pheromones produced and emitted by females (Gullan & Cranston 1994). We therefore  
555 hypothesize the paths of males were more tortuous in order to diminish the time allocated for the  
556 searching for females (in keeping with Negro et al. 2008).

557

558 We assumed that microhabitat use and movements of radio-tracked individuals were unaffected by  
559 radio-tags. Although their weight and dimensional impediment were low, concerns about the effects  
560 of tagging on animal behaviour may arise and a reduction in dispersal ability cannot be excluded. In  
561 fact, the weight of the tag (0.3 g) is about 40% of the average weight of individuals, and the tag  
562 fixed on top of the elytra may be a hindrance to the movements across narrow passages (leaf-litter,  
563 thick grass, etc.). In a previous paper on movements of the common ground beetle species *C.*  
564 *coriaceus*, Riecken & Rath (1996) stated that foraging success was not substantially reduced by  
565 radiotags. During the present research, radio-tagged individuals were observed on many occasions  
566 to feed on molluscs and to copulate with untagged individuals (in keeping with Negro et al., 2008),  
567 suggesting radio-tagging did not significantly affect feeding and mating behaviour. If a reduction in  
568 dispersal existed, however, this would have affected both individuals in control and in managed  
569 stands to the same degree. Our results, focused on the comparative analyses between managed and  
570 un-managed forest patches are therefore highly reliable.

571

## 572 **Conclusions**

573 Our results support the evidence that logging may exert short-term negative effects on *C. olympiae*  
574 ground beetles (as suggested by the increase in bare ground, and changes in climatic conditions and

**Commento [EC39]:** Sono stati osservati anche durante questo studio? Quante volte?

**Commento [EC40]:** L 548-549, these are not from present data, plus unclear "many occasions", so delete.

**Commento [EC41]:** L 553, I disagree with this statement (poor replication) so delete "highly"

575 movements). However, the preference for tree bases and deadwood suggests that forest  
576 management, concurrently, may also be beneficial, on the condition that: *i*) the coppice,  
577 which provides more suitable microhabitats, prevails over conversion to high forest, and *ii*)  
578 deadwood originating from cutting (branches and treetops) is properly accumulated.

579 To our knowledge, this is the first time that radio-telemetry has been used as a tool to assess the  
580 effect of forest management on ground dwelling insects. In methodological terms, this study  
581 indicates therefore that radio-tracking may be successfully used as a tool to assess the effect of  
582 forest management on relatively large ground dwelling insects, and to identify the logging practices  
583 that are more compatible with their conservation.

**Commento [EC42]:** 10. Discussion ends with suspicious statements about logging being beneficial (L 558-561) and about an off-topic (and mostly unwarranted) statement about radio telemetry use (L 562-566). Regarding the former, clearly say that if these beetles are to be maintained in managed forests, deadwood continuity and high abundance must be secured while harvesting, and that very large clearings probably make the microclimate too warm and dry for this species, suggesting that only thinning or gap harvesting, if any, should be used in these habitats. Regarding the latter, this is a poor way to end a paper; rather end with a clear management statement, such as the one I suggest above. This is not a methodological paper, and the usefulness of telemetry has been shown over 20 years ago already (Riecken & Raths 1996/Ann.Zool. Fennici, etc.).

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588 permission to collect *Carabus olympiae* individuals. We are also indebted with Massimo Curtarello,  
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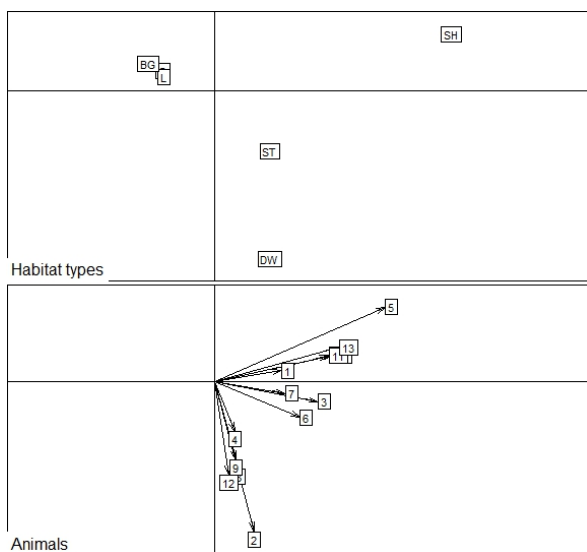
894 Appendix I. Ranking matrices of Compositional Analysis for ground beetles based on comparing  
 895 proportional microhabitat use of fixes with proportions of total available microhabitat types in  
 896 Control (C) and Managed (M1, M2, M3) stands. Microhabitat codes as follows: shrubs (SH),  
 897 stumps (ST), deadwood (DW), grass (G), bare ground (BG), rocks (R) and litter (L). Each mean  
 898 element in the matrix was replaced by its sign; a triple sign represents significant deviation from  
 899 random at  $P < 0.05$ .  
 900

Habitat type																	
C									M1								
	SH	ST	G	L	DW	R	BG			ST	L	DW	R	BG			
SH	0	-	+++	+++	+	+++	+++		ST	0	+++	+	+++	+++			
ST	+	0	+++	+++	+	+++	+++		L	---	0	---	+++	+++			
G	---	---	0	---	---	+++	+++		DW	-	+++	0	+++	+++			
L	---	---	+++	0	---	+++	+++		R	---	---	---	0	+++			
DW	-	-	+++	+++	0	+++	+++		BG	---	---	---	---	0			
R	---	---	---	---	---	0	---										
BG	---	---	---	---	---	+++	0										
M2									M3								
	SH	ST	L	DW	R	BG				SH	ST	G	L	DW	R	BG	
SH	0	-	-	---	+++	+++			A	0	---	-	-	---	+++	+++	
ST	+	0	+	-	+++	+++			C	+++	0	+++	+++	-	+++	+++	
L	+	-	0	---	+++	+++			E	+	---	0	+	---	+++	+++	
DW	+++	+	+++	0	+++	+++			L	+	---	-	0	---	+++	+++	
R	---	---	---	---	0	---			N	+++	+	+++	+++	0	+++	+++	
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905 Appendix II. Results of the eigenanalysis of selection ratio carried out to highlight microhabitat  
 906 selection by *Carabus olympiae* individuals radiotracked in Control (C) and Managed (M1, M2 and  
 907 M3) stands. Top panel: microhabitat type loadings on the first two factorial axes. Bottom panel:  
 908 animal scores on the first factorial plane (see Calenge & Dufour 2006 for further details).  
 909 Microhabitat codes as follows: shrubs (SH), stumps (ST), deadwood (DW), grass (G), bare soil  
 910 (BG), rocks (R) and litter (L). Numbers indicate animals in each treatment (i.e. 13 individuals in  
 911 controls, 6 in M1, 8 in M2 and 13 in M3). The distance of the label from the center of the graph in  
 912 the top panel indicates microhabitat preference (those close to the origin not being selected), the  
 913 length and direction of the arrows in the bottom panel indicates the preferred selection for each  
 914 individual.

915 Control

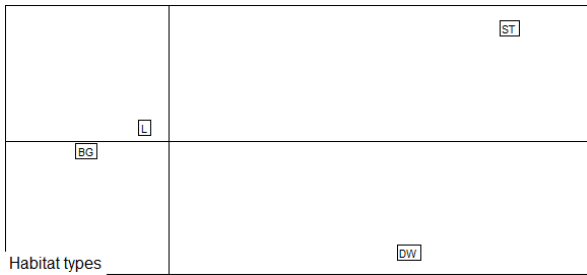


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918 M1





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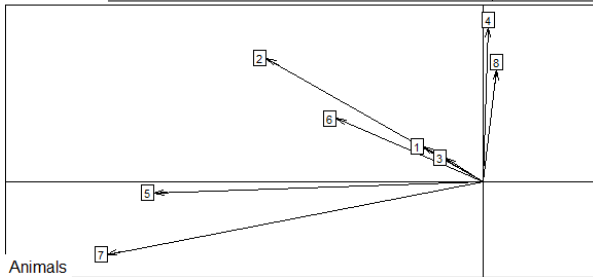
920 M2

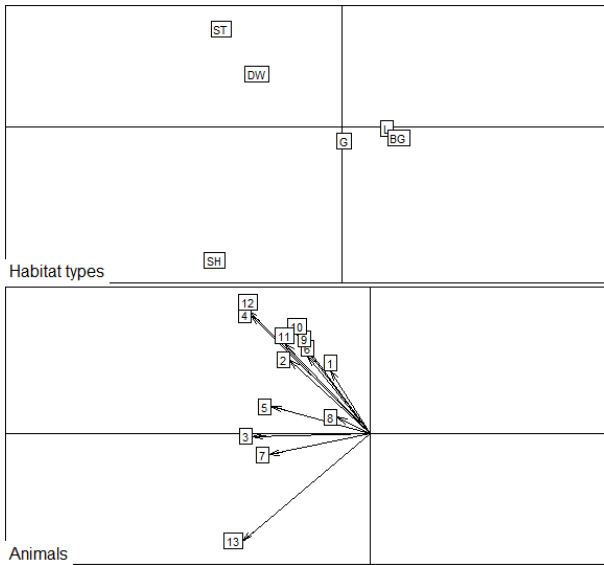


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923 M3





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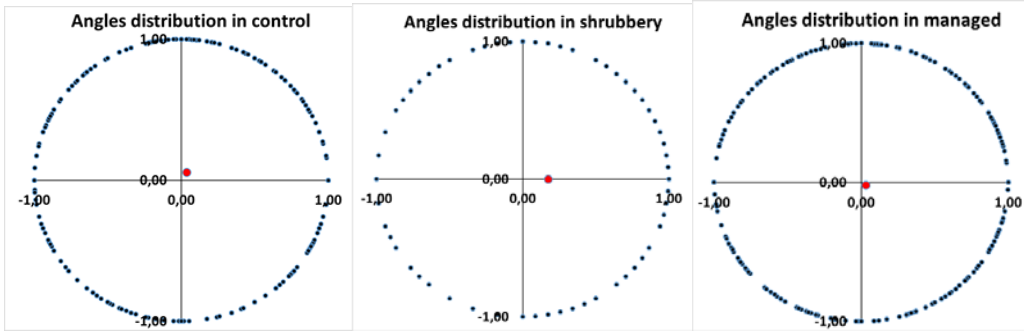
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956 Appendix III. Even distribution of angles in shrubbery, control and managed stands.  
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