Evaluation of window flight traps for effectiveness at monitoring dead wood associated beetles: the effect of ethanol lure under contrasting environmental conditions

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5 Evaluation of window flight traps for effectiveness at monitoring dead wood
6 associated beetles: the effect of ethanol lure under contrasting environmental
7 conditions

8

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27

28 **Abstract**

- 29 1. Since the species-rich group of saproxylic beetles has been proposed to be used as
30 a factor in forest management, more explicit knowledge about the efficiency and
31 selective properties of beetle sampling methods is needed.
- 32 2. We compared saproxylic beetle assemblages caught by alcohol-baited or unbaited
33 window traps in different forest contexts. Considering that trap attractiveness
34 depends on kairomone concentrations, we appraised whether the trap efficiency was
35 influenced by trap environment (openness and local supply of fresh dead wood).
- 36 3. Saproxylic beetles were sampled using 48 cross-vane window flight traps,
37 arranged in paired designs (alcohol-baited/unbaited), in 8 ancient and 8 recent gaps
38 (open stands), and 8 closed-canopy control stands in an upland beech forest in the
39 French Pyrenees.
- 40 4. Baited traps were more efficient than unbaited devices in terms of abundance and
41 richness in our deciduous forests. The ethanol lure did not have any repellent effect
42 on the individual response of saproxylic taxa.
- 43 5. The influence of local environmental conditions on trap attractiveness was
44 observed. The effects of variations in openness were actually moderate, whereas trap
45 attractiveness appeared to be reduced in the alcohol-saturated environment of recent
46 gaps due to a disruption by local fresh dead-wood concentrations of the kairomonal
47 response of saproxylic beetles to baited traps ('alcohol disruption').
- 48 6. Since the ethanol lure globally enhances species detection probability (no repellent
49 effect, many individual attractive effects), it may be extensively used in programs of
50 early-warning surveillance, monitoring and control of wood borers. We recommend
51 to account for the slight influences of local conditions on baited trap efficiency while
52 using them for beetle biodiversity monitoring.

53 Introduction

54 Forest management practices currently include many nature conservation measures
55 in favour of fauna and flora. Nonetheless, in managed forest ecosystems, the dead
56 wood component has been severely reduced by intensive forestry and still is under-
57 represented (Siitonen, 2001).

58 Since considerable effort is devoted to preserving dead wood and the associated
59 fungi and fauna involved in the wood decaying process, we need an explicit
60 ecological assessment of the performance of forestry measures designed to increase
61 deadwood.

62 Saproxylic beetles have been widely studied over the past 20 years, especially in
63 northern and central Europe, and have been proposed as indicator species of forest
64 integrity (Speight, 1989 ; Nilsson et al., 2001) because they are highly dependent on
65 dead wood and have been particularly affected by forest management practices (e.g.
66 Siitonen, 2001 and references therein). They make up one of the largest groups of
67 red-listed species, and they represent many different functional groups (Siitonen,
68 2001).

69 As saproxylic beetles are diverse, and mainly small and cryptic, their study is very
70 challenging. If we want to use saproxylic beetles as a management tool in forestry
71 (evaluation of practices, biodiversity monitoring schemes), we need much more
72 explicit knowledge about the efficiency and selective properties of sampling
73 methods.

74

75 Several different methods are generally used to collect saproxylic beetles. These are
76 (i) direct active hand-collecting techniques, including peeling, sifting the bark of
77 dead trees and beating dead wood, (ii) rearing techniques (log emergence traps,

78 Owen traps, eclectors, extraction cylinders) and (iii) trapping methods such as
79 interception or attractive (coloured, silhouette, chemo-attractive) traps (Leather,
80 2005). Window-flight trapping (WFT), also called Flight-Intercept Trapping (FIT),
81 window/ barrier trapping or collision trapping), developed by Chapman & Kinghorn
82 Peck & Davies, 1980), is currently the most frequently used technique for catching
83 active flying saproxylic beetles (Økland, 1996 ; Wikars et al., 2005 ; Alinvi et al.,
84 2007). Window flight traps consist of a vertical barrier to insect flight that is
85 considered invisible to the insect. On hitting the barrier, most beetles drop down and
86 fall into a collection container with liquid preservatives.

87 Although interception traps do not give accurate information about the local habitat,
88 they have proved to be satisfactory in many respects. Compared with extraction
89 methods they offer reliable means of replication and standardization, and give a
90 representative picture of saproxylic beetle fauna (Siitonen, 1994).

91

92 From the original simple model of flight-interception trap, modifications have been
93 proposed concerning the dimensions, colour, shape, bait... For instance, window-
94 flight traps may be fitted with an attractant dispenser to increase catches of dead
95 wood associated beetles (Brustel, 2004).

96 Dead wood associated species have evolved behavioral responses to volatile host-
97 plant chemicals that indicate the presence of a suitable host (i.e. kairomones). It is
98 well known that ethanol, a volatile compound released by micro-organisms in
99 decaying woody tissue (mainly in fresh tissues ; Cade et al., 1970) and stressed
100 plants (Kimmerer & Kozlowski, 1982), acts as a foraging kairomone (used in the
101 context of food location ; Döring, 1955; Ruther et al., 2002). It is therefore attractive
102 to a wide variety of species of dead wood associated beetles (Montgomery & Wargo,

103 1983 ; Lindelöw et al., 1992), including early- (Nordlander et al., 1986 ; Byers,
104 1989) and late-successional saproxylic species (Jonsell et al., 2003), and beetles
105 associated with dead wood from deciduous (Roling & Kearby, 1975) or conifer trees
106 (Magama et al., 1982 ; Chénier & Philogène, 1989).

107 Previous studies have already demonstrated the general effects of ethanol as a lure in
108 attractive window flight traps (Berti & Flechtmann, 1986; Shibata et al., 1996). In
109 this study comparing two sampling techniques in paired designs, we first intended to
110 confirm and detail the differences in catches between alcohol-baited and unbaited
111 traps under field conditions.

112 Secondly, we wanted to assess whether the catches of dead wood associated beetles
113 in alcohol-baited or unbaited traps are influenced by local environmental conditions.
114 Indeed, we need standardized unbiased methods to study the effects of forest
115 management practices and compare open (e.g. felling areas) and closed-canopy
116 stands; ideally saproxylic beetle detectability should not change with habitat
117 structure. We thus asked the two following questions.

118 (i) Did the difference between the two methods (alcohol-baited and unbaited traps)
119 remain constant in open gaps or closed-canopy stands? From Schroeder and
120 Lindelöw (1989), release rates of chemicals are known to affect the attraction. We
121 may assume that kairomone volatility, and therefore trap attractiveness, increases
122 with stand openness. In this perspective, the difference between baited and unbaited
123 traps would be expected to be higher in open areas than in closed-canopy stands.
124 This bias variation between stands would call into question the between-stand
125 comparison using alcohol-baited traps.

126

127 (ii) Did the difference between the two methods remain constant whether or not the
128 close trap surroundings were poor or rich in naturally emitted ethanol from fresh or
129 decaying dead wood?

130 We may assume that trap attractiveness is influenced by the alcohol concentration in
131 the atmosphere surrounding the trap. In recent sun-exposed gaps, the high volumes
132 of fresh dead wood release a large amount of ethanol, which may lead to a saturated
133 olfactory landscape and therefore to a reduction in the capture efficiency of the trap
134 attractant. Due to an alcohol disruption, we hypothesize that the differences between
135 paired baited and unbaited traps would be lower in recent gaps than in both old gaps
136 and forest controls where the local atmosphere is not alcohol-saturated.

137

138 **Material and methods**

139 **Study areas and sampling designs**

140 Our investigations were carried out in an upland beech forest in the central French
141 Pyrenees, in the National Orlu Reserve, about 150 km south of Toulouse. Altitude
142 ranged from 1600 m to 1750 m. The selected plots were 100 to 140 year-old beech
143 stands, and had previously been exploited for charcoal by coppicing.

144 The balanced sampling design included three types of stands: 8 ancient gaps, 8 recent
145 gaps (open stands) and 8 forest controls (closed-canopy stands). The 16 gaps were
146 originally dedicated to the monitoring of conservation measures in favour of the
147 Western capercaillie (*Tetrao urogallus*, L. 1758). Ancient and recent gaps were
148 created in 1999 and 2004 respectively; they were circular in shape and ca 0.05 ha in
149 area. Distance between gaps varied from 80 m to 1000 m. Cut trees were left in all
150 gaps but only recent gaps had high amounts of recent (freshly-cut) dead wood. In
151 parallel, a transect of 8 forest control plots was set up in closed-canopy beech stands,

152 where the cover was quite dense (basal area = 23 m²/ha, stem density = 300 stems/ha,
153 mean dbh = 25cm, mean height=15m) and the understory very poor.

154 **Beetle sampling**

155 Beetles were sampled with a multidirectional PolytrapTM (Brustel, 2004), a cross-
156 vane window flight trap with a cumulative panel area of 1 m² ((Fig. 1). For the

Fig. 1

157 preservation of insects, containers were half-filled with a salt mixture. A detergent
158 was added to reduce surface tension. Two traps were set in each plot, one baited with
159 an alcohol lure (1:10 ethanol released from a dispenser) and one unbaited trap.
160 Alcohol lure is known to attract hardwood-feeding species (Mongomery & Wargo,
161 1983).

162 Overall, 24 pairs of PolytrapsTM were set up in 2004, from May 15 to August 30 in
163 recent and ancient gaps and closed-canopy beech stands. The traps were emptied
164 every two weeks.

165 Collected specimens were stored in alcohol and we identified them to species level.
166 Several amateur entomologists helped with the identification on the following
167 families: Anobiidae, Curculionidae, Dasytidae, Melyridae, Mordellidae, Pselaphidae,
168 Scolytinae, Scraptiidae, Staphylinidae. The nomenclature follows the online
169 FaunaEuropaea database (www.faunaeur.org). We pooled the data for the entire
170 sampling period.

171

172 **Data processing**

173 The two sampling methods were compared in terms of total saproxylic beetle
174 abundance, cumulative species number per trap, family and species abundance per
175 trap (cumulated over the trapping periods).

176 Linear mixed-model ANOVA tests (Pinheiro & Bates, 2000) were carried out to
177 check for differences in abundance and species richness between the two trap types
178 in each paired comparison. The plot variable was classified as a spatial random effect
179 to take the pairing pattern of the sampling design into account. Some differences
180 were exceptionally tested by Wilcoxon signed-rank tests. Species and families
181 represented by fewer than 30 individuals were not tested.

182 The effects of the interaction between bait and two factors on total abundance and
183 abundance of alcohol-attracted taxa (in our data), species richness were assessed. The
184 three stand types of the study were clustered using two different grouping factors.
185 First, to study the influence of stand openness on trap attractiveness, we compared
186 the difference between paired baited and unbaited traps in open (recent and ancient
187 gaps) or closed-canopy stands. We analysed this difference through the interaction
188 effect in linear mixed-model ANOVAs (bait*openness). Second, to study the
189 influence of local fresh dead wood concentrations on trap attractiveness, we
190 examined the difference (baited - unbaited) in fresh dead-wood rich (recent gaps) or
191 poor (ancient gaps and forest controls) stands. The F-test of the interaction effect
192 (bait*stand type) in linear mixed-model ANOVAs was followed by a multiple
193 comparison post hoc Tukey test of the mean value of this difference.

194 Graphs include multipanel boxplots displaying the distribution of data according to
195 the two factors bait*environment, or simple boxplots showing the numerical
196 difference (baited-unbaited) for different environment types.

197 Non-Metric Multidimensional Scaling (NMDS) based on the Bray-Curtis
198 dissimilarity was used for pattern recognition in species composition and the
199 ANOSIM procedure was carried out to test for differences in assemblage
200 composition between trap types (Clarke, 1993). Before calculation of the Bray-Curtis

201 distance matrix, species represented by only 1 individual were discarded and
202 abundance data were (ln+1) transformed.

203 ANOVA, NMDS and ANOSIM were performed using S.Plus 7.0.

204

205 **RESULTS**

206 When baited with alcohol, window flight traps were more selective: the ratio
207 (number of saproxylic beetles/number of beetles) reached 85.8% in baited traps but
208 was only 69.4% in unbaited traps. A total of 12,211 saproxylic beetles were
209 identified during the study, including 196 species.

210

211 **Comparison of effectiveness between alcohol-baited and unbaited traps**

212 Alcohol-baited or unbaited traps significantly differed in effectiveness. The catches
213 of saproxylic beetles were significantly affected by the alcohol lure (mixed-model
214 ANOVA $F_{(1,23)} = 66.48$, $p < 0.0001$; Table 1). Overall, more than twice as many
215 saproxylic beetle individuals were captured in alcohol-baited traps as in unbaited
216 traps (Table 1).

Tab. 1

Similarly, significantly more saproxylic species were caught in alcohol-lured traps
218 than in unbaited (ANOVA $F_{(1,23)} = 68.65$, $p < 0.0001$; Table 1). The richness per trap

Fig. 2

219 was 40% higher in baited traps than in unbaited traps (Table 1). From the ordination
220 plot of the Bray-Curtis distance matrix between samples (Fig. 2), the species
221 composition of saproxylic beetle assemblages caught with or without an alcohol lure
222 clearly differed. Samples from baited or unbaited traps were obviously separated in
223 ordination space. This distinction was consistent with the results of the ANOSIM test
224 (10 000 permutations, $R = 0.65$, $p < 0.0001$). The average Bray-Curtis dissimilarity
225 between baited and unbaited traps reached a value of 44%.

226 In accordance with this global dissimilarity, important specific differences were
 227 noticed. For several families and species (Cryptophagidae (*Cryptophagus* spp.),
 228 Staphylinidae (*Paraphloeostiba gayndahensis*, *Aleochara sparsa*), Salpingidae
 229 (*Rhinosimus ruficollis*, *R. planirostris*, *Rabocerus foveolatus*)), significantly more
 230 individuals were caught in baited traps than in unbaited traps (mixed-model
 231 ANOVA; Table 2). *Rhizophagus* spp. (Monotomidae) was more abundant in baited
 232 traps compared with unbaited traps, whereas Cleridae were not affected by trap bait.
 233 Amongst xylophagous taxa, Scolytidae (*Ernoporicus fagi*, *Xyloterus signatus*, *X.*
 234 *domesticus*, *Xyleborus saxesenii*) and Lymexylidae (*Hylecoetus dermestoides*) were
 235 more abundantly caught in baited traps, whereas Cerambycidae, Anobiidae,
 236 Melyridae were not sensitive to alcohol bait.

Tab. 2

No species or family was significantly more abundant in unbaited traps.

238

239 **Comparison of effectiveness between alcohol-baited and unbaited traps in open**
 240 **or closed-canopy stands**

241 The difference between alcohol-baited and unbaited traps in open (gaps) or closed-
 242 canopy stands may be interpreted first in terms of abundance or species richness. As

Fig. 3

shown in figure 3, saproxylic beetle abundance in both baited and unbaited traps was
 244 higher in open sites than in closed-canopy controls. The difference in abundance
 245 between baited and unbaited devices was only slightly higher in open plots; in other
 246 words, the bait-openness interaction effect was quite moderate (mixed-model
 247 ANOVA test $F_{2,21} = 5.17$, $p = 0.015$).

248 The difference in species richness between baited and unbaited traps was not
 249 significantly influenced by the openness of trap environment (Fig. 3: mixed-model
 250 ANOVA test of the bait-openness interaction effect: $F_{2,21} = 3.23$, $p = 0.060$).

251

252 For several taxa noticed to be sensitive to the alcohol attractant (see above), i.e.
253 Monotomidae, Scolytidae and Lymexylidae as a whole, the difference baited-
254 unbaited was not affected by the environment closure. Two families
255 (Cryptophagidae, i.e. *Cryptophagus* spp., and Salpingidae), and 4 species (*Rabocerus*

Fig. 4

256 *foveolatus*, *Rhinosimus ruficollis*, *Rhinosimus planirostris*, *Aleochara sparsa*)
257 showed a significant difference baited-unbaited, but not in compliance with the
258 hypothesis of a bait-openness interaction. The difference was indeed lower in open
259 stands than in closed-canopy plots (fig. 4). Only the bark beetle species *Xyloterus*
260 *domesticus* showed a significant and higher difference baited-unbaited in open
261 stands.

262 In conclusion, the difference between alcohol-baited and unbaited traps was not
263 increased greatly by the openness of trap environment.

264

265 **Comparison of effectiveness between alcohol-baited and unbaited traps in fresh**
266 **dead wood poor or rich stands**

267 Regarding this potential bait-environment interaction effect, the difference between
268 alcohol-baited and unbaited traps was only slightly influenced by the local volume of
269 fresh woody debris releasing alcohol kairomones. The baited-unbaited difference in
270 fresh dead wood poor (ancient gaps and controls) or rich stands (recent gaps) was
271 examined in terms of total abundance, species richness, family and species
272 abundances.

273 In figure 5, the difference between baited and unbaited lures in terms of abundance
274 and species richness seems to be slightly lower in gaps rich in recent fresh dead
275 wood. Nevertheless, this bait-environment interaction effect was only slightly

Fig. 5

276 significant on saproxylic beetle abundance (mixed-model ANOVA, $F_{2,35} = 4.84$, $p =$
277 0.014). The only significant pairwise difference was observed between ancient and
278 recent gaps (Multiple comparison Tukey test), the difference being larger in ancient
279 gaps. This bait-environment interaction did not significantly affect species richness
280 in traps (mixed-model ANOVA, $F_{2,35} = 1.66$, $p = 0.204$).

Fig. 6

281 A bait-environment interaction effect was observed on the abundance of several
282 families and species known to be sensitive to the ethanol attractant (fig. 6). The
283 baited-unbaited differences were lower in recent gaps than in ancient gaps and forest
284 controls for the abundance of Salpingidae (and the species *Rhinosimus ruficollis* in
285 particular) (multiple comparison Tukey test). Similarly, we observed a smaller yet
286 still significant baited-unbaited difference for the abundance of Cryptophagidae and
287 *Rhinosimus planirostris* in recent gaps compared with closed-canopy stands. For
288 *Rabocerus foveolatus*, *Aleochara sparsa*, *Xyloterus signatus*, the difference was less
289 in recent gaps than in closed-canopy controls (but the difference between ancient or
290 recent gaps was not significant). No difference was measured for Scolytidae as a
291 whole (and *Xyloterus domesticus*, *Ernoporicus caucasicus*, *Xyleborus saxesenii* in
292 particular), Lymexylonidae, Staphylinidae (peculiarly *Paraphloeostiba gayndahense*)
293 and Monotomidae (*Rhizophagus* spp. in particular).

294

295 Discussion

296

297 Alcohol lure effect

298 The results from our study confirm that ethyl alcohol, acting as a kairomone released
299 from decaying woody tissues, strongly attracts some beetles associated with dead
300 hardwood (Montgomery & Wargo, 1983) and suggests that an ethanol lure

301 strengthens the effectiveness of window-flight traps in deciduous forests. Indeed,
302 more than twice as many saproxylic beetles, representing a 40% higher species
303 richness, were captured in alcohol-baited traps as in unbaited traps. Assemblages
304 were globally dissimilar between baited and unbaited devices, mainly because more
305 species were caught in baited traps. It is very important to stress that we did not
306 detect any species or family significantly more abundant in unbaited traps. We may
307 therefore infer that the ethanol lure did not have any inhibiting or repellent effect.

308

309 In our methodological approach in beech forests, the individual responses of dead-
310 wood taxa to alcohol lure were actually heterogeneous. As previously demonstrated
311 by Byers (1992), significantly more individuals of *Rhizophagus* spp. (Monotomidae)
312 were caught in baited traps than in unbaited traps. Host tree chemicals are known to
313 be important to *Rhizophagus* species in finding their habitat (scolytid galleries).
314 Conversely, natural enemies such as Cleridae were not affected by trap bait in our
315 study. Likewise, Schroeder (2003) pointed out that two *Thanasimus* clerid species
316 preying on several bark beetle species differ in their response to α -pinene and
317 ethanol. Our results showed that the abundance of ambrosia and bark beetles was
318 about 4 times as high in alcohol-baited traps, in agreement with previous findings
319 (Magama et al., 1982 ; Berti & Flechtmann, 1986 ; Poland et al. 2004). Amongst the
320 other wood-feeding taxa, Cerambycidae were not sensitive to alcohol bait, which had
321 been shown previously by Sweeney et al. (2004). Conversely, Döring (1955)
322 demonstrated that ethanol acts as a kairomone for the longhorned beetle *Cerambyx*
323 *cerdo*. Among the fungus feeders, unlike Tetratomidae, Melandryidae and Ciidae,
324 only Cryptophagidae were significantly attracted by the alcohol lure, as was the
325 tenebrionid studied by Jonsell et al. (2003).

326

327 Interaction effects between trap attractant and trap environment

328 Some results did not comply with the hypothesized bait-openness interaction. Five
329 species showed a significant lower baited-unbaited difference in open areas.
330 Moreover, the baited-unbaited difference in species richness and in abundance of the
331 other alcohol-attracted taxa was not significantly influenced by the openness of trap
332 environment. Only the total saproxylic beetle abundance and the abundance of the
333 bark beetle *Xyloterus domesticus* were in accordance with the hypothesis of an
334 increased baited-unbaited difference in open areas compared with closed-canopy
335 stands. In other words, trap attractiveness appeared to increase only slightly, but not
336 significantly, with stand openness, even though canopy cover may strongly influence
337 kairomone volatility. However, such an interaction effect was reported by Honek
338 (1988), between crop density and an attractant in pitfall traps, on catches of epigaeic
339 arthropods.

340

341 Apart from openness, another environmental factor separated the plots into groups.
342 Indeed, recent gaps, ancient gaps and forest controls differed in terms of local
343 volume of fresh dead wood. We hypothesized that the high volume of fresh dead
344 wood in recent sun-exposed gaps would release a large amount of ethanol, which
345 could saturate the beetle's olfactory landscape around the traps and therefore reduce
346 trap attractiveness. In accordance with this hypothesis, the baited-unbaited difference
347 was lower in recent and fresh dead wood rich gaps for some assemblage parameters.
348 Though this bait-environment interaction was slight, it significantly affected the total
349 abundance of saproxylic beetles, the abundance of several families and species
350 known to be sensitive to the ethanol attractant (Salpingidae, *Rhinosimus ruficollis*

351 and *Rhinosimus planirostris* in particular, Cryptophagidae). Conversely, the response
352 of species richness and abundance of the other families (such as Scolytidae) to traps
353 was not influenced by the local volume of fresh dead wood.
354 The alternative hypothesis of a “mass effect”, i.e. a stronger attractiveness of baited
355 traps in the alcohol-rich atmosphere of recent gaps, was thus invalidated. These
356 results may be related to a phenomenon that could be called ‘alcohol disruption’ (in
357 the spirit of the ‘mating disruption’; Ruther et al., 2002), i.e. the disruption by local
358 fresh dead-wood concentrations of the kairomonal response of saproxylic beetles to
359 baited traps. Nonetheless, even though trap attractiveness appeared to be reduced in
360 an alcohol-saturated environment, baited traps remain more efficient than unbaited
361 devices in terms of abundances and richness. They have the capacity to sample the
362 pool of saproxylic beetles in recent gaps.

363

364 **Conclusion - Implications for saproxylic beetle sampling**

365 Even though the extrapolation of our findings from upland forests to other climatic
366 contexts should be done with care, their interpretation may help with the
367 optimization of the two types of forest beetle monitoring.

368 The first type, i.e. monitoring and control of forest pest populations and early-
369 warning surveillance programs to detect invasive wood borers, aim at maximizing
370 detection probability. We demonstrated that the ethanol lure does not have any
371 repellent effect but significantly attracts several wood feeders. Like the New Zealand
372 monitoring programme for invasive wood-feeders (Brockerhoff et al., 2006),
373 effective sampling designs may use the large spectrum of ethanol attractiveness.

374 The second type, i.e. biodiversity surveys of saproxylic beetle diversity in monitoring
375 networks or evaluation studies of forest management practices, implies distinct

376 constraints. To compare the biodiversity between stands or to assess trends in
377 saproxylic beetle diversity over broader landscapes, ideally saproxylic beetle
378 detectability should not change with habitat structure. A variation in trap efficiency
379 as a function of any stand environmental parameter would call into question an inter-
380 site comparison. For instance, a relation between trap efficacy and stand openness
381 would prevent the comparison of open (e.g. felling areas) and closed-canopy stands
382 with alcohol-baited traps, or studies on the influence of shading for the attractiveness
383 of dead wood (Hjältèn et al., 2007). Our results show slight interaction effects
384 between trap attractant and trap environment. A very moderate bait-openness
385 interaction effect was measured, whereas trap attractiveness appeared to be reduced
386 in an alcohol-saturated environment, through a disruption by local fresh dead-wood
387 concentrations of the kairomonal response of saproxylic beetles to baited traps
388 ('alcohol disruption').

389 In accordance with these results and although alcohol-baited traps appeared to be
390 more efficient than unbaited devices, we recommend to take care to use baited
391 brine or glycol solution used as a preservative fluid does not vary with forest stands.
392 Beside the attractant, other trap parameters, such as colour and shape, should be
393 assessed for optimization and standardization and have been partly examined in
394 another study (Bouget et al., in press).

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396

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404

405 References

- 406 Alinvi, O., Ball, J., Danell, K., Hjältén, J. & Pettersson, R. (2007) Sampling the
407 saproxylic beetle community in dead wood logs: comparing window and eclector
408 traps to traditional bark sieving and a refinement. *Journal of Insect Conservation*, 11,
409 99-112.
- 410 Berti, F. & Flechtmann, C. (1986) A model of ethanol trap to collect Scolytidae and
411 Platypodidae (Insecta, Coleoptera). *Revista Instituto de Pesquisas e Estudos*
412 *Florestais*, 34, 53-56.
- 413 Bouget, C., Brustel, H., Brin, A. & Noblecourt, T. (in press) Sampling saproxylic
414 beetles with window flight traps: methodological insights. *Terre et Vie, Revue*
415 *d'écologie*
- 416 Brockhoff, E., Jones, D., Kimberley, M., Suckling, D. & Donaldson, T. (2006)
417 Nationwide survey for invasive wood-boring and bark beetles (Coleoptera) using
418 traps baited with pheromones and kairomones. *Forest Ecology and Management*,
419 228, 234-240.
- 420 Brustel, H. (2004) "Polytrap™" a window flight trap for saproxylic beetles. *3rd*
421 *Symposium and Workshop on the Conservation of Saproxylic Beetles*, Riga (Latvia),
422 7th-11th July, 2004. Poster
- 423 Byers, JA. (1992) Attraction of bark beetles, *Tomicus piniperda*, *Hylurgops*
424 *palliatu*s, and *Trypodendron domesticum* and other insects to short chain alcohols
425 and monoterpenes. *Journal of Chemical Ecology*, 18, 2385-2402.
- 426 Byers, J.A. (1989) Chemical ecology of bark beetles. *Experientia*, 45, 271-283
- 427 Cade, S., Hrutfiord, B. & Gara, R. (1970) *Gnathotrichus sulcatus* (Coleoptera:
428 Scolytidae): identification of a primary attractant. *Journal of Economic Entomology*,
429 63, 1014-1015.

- 430 Chapman, J. A. & Kinghorn, J. M. (1955) Window flight traps for insects. *Canadian*
431 *Entomologist*, 87, 46-47.
- 432 Chénier, J.V.R. & Philogène, B.J.R. (1989) Field responses of certain forest
433 Coleoptera to conifer monoterpenes and ethanol. *Journal of Chemical Ecology*, 15,
434 1729–1745
- 435 Clarke, K.R. (1993) Non-parametric multivariate analyses of changes in community
436 structure. *Australian Journal of Ecology*, 18, 117-143.
- 437 Döring, E. (1955) Zur Biologie des grossen Eichenbockkäfers (*Cerambyx cerdo* L.)
438 unter besonderer Berücksichtigung der Populationsbewegungen im Areal. *Zeitschrift*
439 *Angewandte Zoologie*, 42, 251-373.
- 440 Hjältén, J., Johansson, T., Alinvi, O., Ball, J., Danell, K., Pettersson, R., Gibb, H. &
441 Hilszczanski, J. (2007) The importance of substrate type, shading and scorching for
442 the attractiveness of dead wood to saproxylic beetles. *Basic and Applied Ecology*, 8,
443 364-376.
- 444 Honek, A. (1988) The effect of crop density and microclimate on pitfall trap catches
445 of Carabidae, Staphylinidae (Coleoptera) and Lycosidae (Araneae) in cereal fields.
446 *Pedobiologia*, 32, 233-242.
- 447 Jonsell, M., Schroeder, M. & Larsson, T. (2003) The saproxylic beetle *Bolitophagus*
448 *reticulatus*: its frequency in managed forests, attraction to volatiles and flight period.
449 *Ecography*, 26, 421-428.
- 450 Kimmerer, T. & Kozlowski, T. (1982) Ethylene, ethane, acetaldehyde and ethanol
451 production by plants under stress. *Plant Physiology*, 69, 840-847.
- 452 Leather, S. (2005) *Insect Sampling in Forest Ecosystems*. Blackwell Science, 320 p.

453 Lindelöw, Å., Risberg, B. & Sjödin, K. (1992) Attraction during flight of scolytids
454 and other bark- and wood-dwelling beetles to volatiles from fresh and stored spruce
455 wood. *Canadian Journal of Forest Research*, 22, 224–228.

456 Magema, N, Gaspar, C. & Séverin, T. (1982) Efficacité de l'éthanol dans le piégeage
457 du scolyte *Trypodendron lineatum* (Olivier, 1795)(Coleoptera, Scolytidae) et rôle des
458 constituants terpéniques de l'épicéa. *Annales de la Société Royale de Zoologie de*
459 *Belgique*, 112, 49-60.

460 McIntosh, R. L., Katinic, P. J., Allison, J. D., Borden, J. H. & Downey, D. L. (2001)
461 Comparative efficacy of five types of trap for woodborers in the Cerambycidae,
462 Buprestidae and Siricidae. *Agricultural and Forest Entomology*, 3, 113-120.

463 Montgomery, M.E., & Wargo, P.M. (1983) Ethanol and other host-derived volatiles
464 as attractants to beetles that bore into hardwoods. *Journal of Chemical Ecology*,
465 9:181-190.

466 Nilsson, S.G., Hedin, J. & Niklasson, M. (2001) Biodiversity and its assessment in
467 boreal and nemoral forests. *Scandinavian Journal of Forest Research*, Suppl. 3, 10-
468 26.

469 Nordlander, G., Eidmann, H. H., Jacobsson, U., Nordenhem, H. & Sjödin, K. (1986)
470 Orientation of the pine weevil *Hylobius abietis* to underground sources of host
471 volatiles. *Entomologia Experimentalis Applicata*, 41, 91-100.

472 Økland, B. (1996) A comparison of three methods of trapping saproxylic beetles.
473 *European Journal of Entomology*, 93, 195-209.

474 Peck, S. B. & Davies, A. E. (1980) Collecting small beetles with large area window
475 traps. *The Coleopterists Bulletin*, 34, 237-239.

476 Pinheiro, J.C. & Bates, D.M. (2000) *Mixed-effects models in S and S-PLUS*.
477 Springer, New York.

478 Poland, T.M., Haack, R.A. & Petrice, T.R. (2004) Evaluation of three trap types and
479 five lures for monitoring *Hylurgus ligniperda* (Coleoptera: Scolytidae) and other
480 local scolytids in New York. *Great Lakes Entomologist*, 37 (No. 1/2), 1-9

481 Roling, M. P. & Kearby, W. H. (1975) Seasonal flight and vertical distribution of
482 Scolytidae attracted to ethanol in an oak-hickory forest in Missouri. *Canadian*
483 *Entomologist*, 107, 1315-1320

484 Ruther, J., Meiners, T. & Steidle, J. (2002) Rich in phenomena-lacking in terms. A
485 classification of kairomones. *Chemoecology*, 12, 161-167.

486 Schroeder, L. & Lindelöw, A. (1989) Attraction of scolytids and associated beetles
487 by different amounts and proportions of alpha pinene and ethanol. *Journal of*
488 *Chemical Ecology*, 15, 807-817.

489 Schroeder, L.M. (2003) Differences in responses to α -pinene and ethanol, and flight
490 periods between the bark beetle predators *Thanasimus femoralis* and *T. formicarius*
491 (Col.: Cleridae). *Forest Ecology and Management*, 177, 1-3, 7, 301-311

492 Shibata, E., Sato, S., Sakuratani, Y., Sugimoto, T., Kimura F. & Ito F. (1996)
493 Cerambycid beetles (Coleoptera) lured to chemicals in forests of Nara prefecture,
494 Central Japan. *Ecology and Population Biology*, 89, 6, 835-842.

495 Siitonen, J. (2001) Forest management, coarse woody debris and saproxylic
496 organisms : Fennoscandian boreal forests as an example. *Ecological Bulletins*, 49,
497 11-41.

498 Siitonen, J. (1994) Decaying wood and saproxylic Coleoptera in two old spruce
499 forests: a comparison based on two sampling methods. *Annales Zoologici Fennici*,
500 31, 89-95.

501 Speight, M.C.D. (1989) *Les invertébrés saproxyliques et leur protection*. Conseil de
502 l'Europe, Strasbourg.

503 Sweeney, J., De Groot, P., MacDonald, L., Smith, S., Cocquempot, C., Kenis, M. &
504 Gutowski, J.M. (2004) Host volatile attractants and traps for detection of *Tetropium*
505 *fuscum* (F.), *Tetropium castaneum* L., and other longhorned Beetles (Coleoptera :
506 Cerambycidae). *Environmental Entomology*, 33, 4, 844-854

507 Wikars, L.O., Sahlin, E. & Ranius, T. (2005) A comparison of three methods to
508 estimate species richness of saproxylic beetles (Coleoptera) in logs and high stumps
509 of Norway spruce. *Canadian Entomologist*, 137, 304-324.

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511 Figure legends

512

513 Figure 1

514 Design of the cross-vane window flight trap used during the study

515

516 Figure 2

517 NMDS ordination plot of the Bray-Curtis dissimilarity matrix of baited (AL) and
518 unbaited (NAL) samples. The two axes with highest correlation to bait factor are
519 represented. 4-dimension stress = 0.153. ANOSIM test (10 000 permutations)
520 confirmed the difference of assemblages ($R=0.65$, $p<0.0001$).

521

522 Figure 3

523 Mean abundance (a) and species richness (b) per trap of saproxylic beetles in baited
524 (AL) and unbaited (NAL) traps in open (MO) or closed-canopy (MF) stands. Linear
525 mixed-model ANOVA F-test significance of the interaction effect between bait and
526 openness: ** $p<0.01$, * $0.01<p<0.05$, ns $p>0.05$.

527

528 Figure 4

529 Mean difference in abundance per trap of saproxylic beetle families (a) and species
530 (b) between baited (AL) and unbaited (NAL) traps in open (MO) or closed-canopy
531 (MF) stands. Mann-Whitney test significance: ** $p<0.01$, * $0.01<p<0.05$, ns $p>0.05$.
532 Only species and families including more than 30 individuals were tested.

533

534 Figure 5

535 Mean species richness (a) and abundance (b) per trap of saproxylic beetles in baited
536 (AL) and unbaited (NAL) traps in fresh dead wood poor stands [forest controls (F)
537 and ancient gaps (TA)] and fresh dead wood rich stands [recent gaps (TR)]. Linear
538 mixed-model ANOVA test significance: ** $p < 0.01$, * $0.01 < p < 0.05$, ns $p > 0.05$.
539 Mean difference in richness (c) and abundance (d) between baited and unbaited traps
540 in fresh dead wood poor stands [F, TA] and fresh dead wood rich stands [TR].
541 Different letters indicate significant differences between means after a post-hoc
542 Tukey test ($p = 0.01$).

543

544 Figure 6

545 Mean difference in abundance per trap of saproxylic beetle families (a) and species
546 or genera (b) between baited and unbaited traps in fresh dead wood poor stands
547 [forest controls (F) and ancient gaps (TA)] and fresh dead wood rich stands [recent
548 gaps (TR)]. Linear mixed-model ANOVA test significance: ** $p < 0.01$, *
549 $0.01 < p < 0.05$, ns $p > 0.05$. Different letters indicate significant differences between
550 means after a post-hoc Tukey test ($p = 0.01$). Only species and families including
551 more than 30 individuals were tested.

552

553 Tables

554

555 Table 1

556

557 Differences between baited (AL) and unbaited (NAL) traps, in terms of saproxylic
558 beetle abundance, species richness. Test significance: ** $p < 0.01$, * $0.01 < p < 0.05$, ns
559 $p > 0.05$. Differences were tested by linear mixed-model ANOVA F-tests. Mean
560 values are expressed +/- Standard Deviation.

561

Taxa	Alcohol-baited traps	Unbaited traps	
Abundance	331,417 +/- 156,330	143,750 +/- 55,155	$F_{(1,23)}=66,482$ **
Species richness	43,125 +/- 9,768	31,458 +/- 8,827	$F_{(1,23)}=68,649$ **

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Table 2

Mean abundance per trap of saproxylic beetle species and families in baited (AL) and unbaited (NAL) traps. Linear mixed-model ANOVA test significance: ** $p < 0.01$, * $0.01 < p < 0.05$, ns $p > 0.05$. Mean values are expressed +/- Standard Deviation.

Taxa	Alcohol-baited traps	Unbaited traps	$F_{(1,23)}^p$
LEIODIDAE	1,125 +/- 1,424	1,625 +/- 2,123	$F=1,274^{ns}$
STAPHYLINIDAE	49,458 +/- 28,290	34,667 +/- 19,325	$F=15,243^{**}$
<i>Aleochara sparsa</i>	1,833 +/- 1,711	0,167 +/- 0,637	$F=27,688^{**}$
<i>Eusphalerum angustum</i>	29,542 +/- 26,132	30,500 +/- 19,638	$F=1,908^{ns}$
<i>Paraphloeostiba gayndahense</i>	9,958 +/- 8,175	0,375 +/- 0,576	$F=198,854^{**}$
<i>Leptusa pulchella</i>	0,958 +/- 1,301	0,500 +/- 0,780	$F=1,929^{ns}$
LUCANIDAE	0,625 +/- 0,824	0,833 +/- 1,007	$F=0,512^{ns}$
<i>Sinodendron cylindricum</i>	0,542 +/- 0,658	0,750 +/- 0,847	$F=0,682^{ns}$
EUCNEMIDAE	1,250 +/- 2,345	0,667 +/- 1,049	$F=0,414^{ns}$
<i>Melasis buprestoides</i>	1,250 +/- 2,345	0,667 +/- 1,049	$F=0,467^{ns}$
ELATERIDAE	1,667 +/- 1,903	2,292 +/- 1,944	$F=1,422^{ns}$
<i>Idolus picipennis</i>	0,917 +/- 1,501	1,375 +/- 1,610	$F=2,293^{ns}$
ANOBIIDAE	26,500 +/- 22,043	24,042 +/- 22,160	$F=0,141^{ns}$
<i>Grynobius planus</i>	0,917 +/- 1,558	1,167 +/- 2,160	$F=0,012^{ns}$
<i>Hemicoelus costatus</i>	7,292 +/- 8,961	7,250 +/- 7,731	$F=0,000^{ns}$
<i>Ptilinus pectinicornis</i>	16,500 +/- 20,061	12,458 +/- 15,704	$F=0,280^{ns}$
<i>Ptinomorphus imperialis</i>	0,458 +/- 0,932	0,958 +/- 3,458	$F=0,043^{ns}$
<i>Xestobium plumbeum</i>	1,333 +/- 1,494	2,083 +/- 5,579	$F=0,209^{ns}$
LYMEXYLIDAE	6,333 +/- 10,639	0,375 +/- 1,279	$F=38,526^{**}$
<i>Hylecoetus dermestoides</i>	6,333 +/- 10,639	0,375 +/- 1,279	$F=41,528^{**}$
CLERIDAE	0,917 +/- 1,283	1,042 +/- 1,459	$F=0,053^{ns}$
<i>Tillus elongatus</i>	0,917 +/- 1,283	1,042 +/- 1,459	$F=0,125^{ns}$
MELYRIDAE	12,792 +/- 12,646	8,875 +/- 8,295	$F=0,617^{ns}$
MALACHIIDAE	2,000 +/- 2,537	3,292 +/- 3,196	$F=3,651^{ns}$
MONOTOMIDAE	2,417 +/- 2,263	0,250 +/- 0,442	$F=60,460^{**}$
<i>Rhizophagus spp.</i>	2,375 +/- 2,281	0,167 +/- 0,381	$F=57,873^{**}$
CRYPTOPHAGIDAE	14,625 +/- 14,984	5,917 +/- 5,823	$F=17,544^{**}$
<i>Cryptophagus spp.</i>	14,125 +/- 15,103	5,833 +/- 5,880	$F=14,091^{**}$
LATRIDIIDAE	8,625 +/- 6,851	6,000 +/- 5,703	$F=3,009^{ns}$
MYCETOPHAGIDAE	1,750 +/- 1,539	1,042 +/- 1,083	$F=2,757^{ns}$
CIIDAE	5,667 +/- 5,346	5,208 +/- 5,073	$F=0,143^{ns}$
TETRATOMIDAE	3,583 +/- 3,202	2,625 +/- 3,609	$F=4,037^{ns}$
<i>Tetratoma ancora</i>	3,583 +/- 3,202	2,625 +/- 3,609	$F=4,037^{ns}$
MELANDRYIDAE	2,250 +/- 2,592	1,542 +/- 1,615	$F=1,850^{ns}$
<i>Melandrya caraboides</i>	0,958 +/- 1,398	0,792 +/- 1,285	$F=0,456^{ns}$
MORDELLIDAE	1,333 +/- 3,199	1,083 +/- 1,909	$F=0,337^{ns}$
<i>Tomoxia bucephala</i>	0,917 +/- 2,586	0,917 +/- 1,886	$F=0,316^{ns}$
SALPINGIDAE	89,417 +/- 44,071	3,417 +/- 2,165	$F=162,552^{**}$
<i>Rabocerus foveolatus</i>	4,750 +/- 3,650	0,208 +/- 0,588	$F=82,129^{**}$
<i>Rhinosimus planirostris</i>	53,167 +/- 25,426	1,583 +/- 1,248	$F=486,084^{**}$
<i>Rhinosimus ruficollis</i>	31,458 +/- 18,967	1,583 +/- 1,472	$F=201,812^{**}$
SCRAPTIIDAE	2,292 +/- 2,510	2,458 +/- 1,719	$F=1,540^{ns}$
<i>Anaspis rufilabris</i>	1,417 +/- 1,213	1,792 +/- 1,587	$F=0,428^{ns}$
CERAMBYCIDAE	10,375 +/- 7,471	9,792 +/- 7,396	$F=0,042^{ns}$
<i>Clytus arietis</i>	1,625 +/- 2,143	1,042 +/- 1,654	$F=2,878^{ns}$
<i>Oxymirus cursor</i>	1,625 +/- 2,018	1,542 +/- 1,250	$F=0,065^{ns}$
<i>Rhagium bifasciatum</i>	3,542 +/- 3,176	3,958 +/- 3,862	$F=0,007^{ns}$
<i>Rhagium mordax</i>	1,417 +/- 1,349	1,667 +/- 2,160	$F=0,005^{ns}$
SCOLYTIDAE	81,417 +/- 127,180	22,583 +/- 21,040	$F=23,698^{**}$
<i>Ernoporicus caucasicus</i>	18,667 +/- 37,632	4,417 +/- 4,452	$F=10,469^{**}$
<i>Taphrorychus bicolor</i>	53,083 +/- 125,971	17,208 +/- 20,121	$F=0,586^{ns}$
<i>Xyleborus saxesenii</i>	4,792 +/- 3,683	0,042 +/- 0,204	$F=107,812^{**}$
<i>Xyloterus domesticus</i>	2,000 +/- 2,284	0,125 +/- 0,448	$F=22,674^{**}$
<i>Xyloterus signatus</i>	1,792 +/- 2,021	0,000 +/- 0,000	$F=32,427^{**}$

570 Figures
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(a) Families

Difference in abundance

(b) Species

Difference in abundance

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587 Figure 5
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Figure 6

(a) Families

Differences in abundance

(b) Species

Differences in abundance

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