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1 **Forward to the North: two Euro-Mediterranean bumblebee species**
2 **now cross the Arctic Circle**

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14 **Abstract**

15 **In recent decades, several animal and plant species have been in regression**
16 **(population size decrease and geographical distribution shrinking). This loss of**
17 **biodiversity can be due to various factors such as the destruction and**
18 **fragmentation of habitat, urban development, pesticides or climate change.**
19 **However, some species benefit from these changes and expand their distribution.**
20 **Here we report observations of two Euro-Mediterranean bumblebee species:**
21 ***Bombus terrestris* for the first time and *Bombus lapidarius*, north of the Arctic**
22 **Circle in Fennoscandia.**

23 **Résumé**

24 Ces dernières décennies, de nombreuses espèces animales et végétales sont en
25 régression autant d'un point de vue de leur distribution qu'au niveau de leur effectif

26 de population. Cette perte de biodiversité peut être due à différents facteurs comme la
27 destruction et la fragmentation de l'habitat, le développement urbain, les pesticides ou
28 encore le changement climatique. Néanmoins, certaines espèces profitent de ces
29 perturbations pour étendre leur distribution. C'est ainsi que pour la première fois,
30 deux espèces Euro-Méditerranéennes de bourdons (*B. terrestris* et *B. lapidarius*) ont
31 été observées en 2013 et 2014 en Fennoscandie au-delà du Cercle Arctique.

32 **Keywords:** *Bombus terrestris*, biogeography, climate change, Fennoscandia, heat
33 wave

34

35 **Introduction**

36 Although bumblebees (genus *Bombus* Latreille) are distributed from Arctic tundra to
37 lowland tropical forest, they are clearly most abundant (relative abundance) in alpine
38 grassland habitats and cold and temperate regions of the Northern Hemisphere
39 (Williams 1998). Indeed, these robust hairy bees have thermoregulatory adaptations
40 involving facultative endothermy (Heinrich 1979), that enable them to live in the
41 coldest areas inhabited by insects such as the Himalayas (Williams 1991), the Andes
42 (Gonzalez *et al.* 2005) or north Greenland (Skorikov 1937), the Alps (Pradervand *et*
43 *al.* 2011) and the Pyrenees (Iserbyt & Rasmont 2012). They also reach a high
44 diversity in Arctic regions (e.g. Fennoscandia: Skorikov 1937; Løken 1973 or Alaska:
45 Williams 2014). In these high altitudes and latitudes, bumblebees are the only
46 remaining bee pollinators, supporting a large part of the pollination ecosystem service
47 (Shamurin *et al.* 1966; Kevan 1973). In recent decades, several animal and plant
48 species have been in regression (population size decrease and geographical
49 distribution shrinking). This loss of biodiversity can be due to various factors such as

50 the destruction and fragmentation of habitat, urban development, pesticides or climate
51 change.

52 However, their hotspot diversity areas (mountains, Arctic, Subarctic and Boreal
53 regions) are also regions most severely affected by global warming (IPCC 2007;
54 Franzén & Ockinger 2011; Franzén & Molander 2012), a phenomenon that will most
55 likely increase during the next decades (Berger 1991; Settele *et al.* 2005; Spangenberg
56 2012). Climate change poses a major threat to many bumblebee species (Rasmont *et*
57 *al.*, 2015), however, some are able to benefit and expand their ranges.

58

59 Current and expected global warming consequences are the focus of many research
60 projects (e.g. Parmesan & Yohe 2003). One of the major consequences of global
61 warming is species range displacement because organisms track their climatic niches
62 as observed in several organisms (Parmesan & Yohe 2003; Chen *et al.* 2011;
63 Kuhlmann *et al.* 2012). However, since thermo-tolerance is species specific, species
64 distribution shifts happen at different strength and speed (Klok & Chown 2003;
65 Franzén & Ockinger 2011) resulting in new species communities and new
66 interspecific interactions (Franzén & Molander 2012). For native species, the
67 interaction with climatic refugee species can lead to consequences similar to those
68 fostered by invasive species (Inoue *et al.* 2008; Kanbe *et al.* 2008; Yoon *et al.* 2009;
69 Nagamitsu *et al.* 2010; Meeus *et al.* 2011; Aizen *et al.* 2011; Thomas 2011; Arbetman
70 *et al.* 2013a; Murray *et al.* 2013; Arbetman *et al.* 2013b). Therefore, an early
71 detection of climatic refugee species through efficient faunistic surveys is important.

72 We here report the observations of two Euro-Mediterranean bumblebee species (*sensu*
73 de Lattin 1967) north of the Arctic Circle, a region hosting many bumblebee species

74 with restricted areas. Specifically, we hypothesize the potential trigger factors and the
75 potential consequences of the range shift to the North for Arctic biodiversity.

76 **Materials & Methods**

77 **Determination of original northern European bumblebee fauna**

78 We focused on the region north of the Arctic Circle in Fennoscandia. We determined
79 the original Arctic European bumblebee fauna (i.e. baseline dataset) according to (i)
80 literature (Løken 1973) and (ii) occurrence observations before 1973. The occurrence
81 observations were hosted by databases managed by B. Cederberg (Swedish Species
82 Information Centre (SSIC), Sweden); F. Ødegaard (Norwegian Biodiversity
83 Information Centre (NBIC) Norway); J. Paukkunen (Finnish Museum of Natural
84 History (MZH), Finland) and P. Rasmont & E. Haubruge (*Banque de Données*
85 *Faunique de Gembloux et de Mons* (BDFGM), Belgium). These occurrence datasets
86 were mapped using *Data Fauna Flora* software (Barbier *et al.* 2013)

87 **Detection of expanding species**

88 In order to assess potential changes in the northern European bumblebee fauna, we
89 collected samples beyond the Arctic Circle (see sampling map Fig. 1) in 2013 and
90 2014 using entomological sweep nets. All individuals were killed by freezing. Males
91 were prepared for chemotaxonomic analyses following De Meulemeester *et al.*
92 (2011).

93 The specific identification was verified by checking different morphological
94 diagnostic characters (Løken 1973, 1984; Rasmont 1984; Rasmont *et al.* 1986;
95 Pekkarinen & Kaarnama 1994). For the species belonging to the subgenus *Bombus*
96 *sensu stricto* (Cameron *et al.* 2007), a group with low morphological differentiation,
97 the morphological characters based on identification was assessed by comparing the
98 GC-FID chromatograms of cephalic gland labial secretions (Lecocq *et al.* 2011) with

99 reference specimens (*Bombus terrestris*: PRAS0006 from France, Var, Gonfaron
100 3.VII.2008, 43°18'N 06°18'E; *Bombus cryptarum*: PRAS0148 from Sweden,
101 Jämtland, Kvissle 15.VIII.2008, 63°16'N 13°56'E; PRAS0323 from Scotland, Wick,
102 Wireless 12.VIII.2009, 58°28'N 3°13'W, see Fig. 1) and with the list of compounds
103 given by Bertsch & Schweer (2012a,b). The cephalic gland labial secretions are
104 commonly used as diagnostic characters (Bertsch & Schweer 2012a). We followed
105 the preparation and analysis methods of De Meulemeester *et al.* (2011) and Lecocq *et*
106 *al.* (2011, 2014, 2015).

107 **Results**

108 A total of 756 specimens (17 species) were collected in the vicinity of Abisko
109 (Sweden), and Narvik (Norway) in 2013, 1159 specimens (20 species) from Abisko
110 (Sweden), Tarfala (Sweden) and Narvik (Norway) areas in 2014.

111 Among these specimens, we found two species previously unknown (unexpected)
112 north of the Arctic Circle: *B. lapidarius* and *B. terrestris*. Another species *B. wurflenii*
113 was observed far north of its baseline distribution (Løken 1973).

114 ***B. lapidarius* (Fig. 2A):** Abisko (Sweden), 68°21'10.3" N 18°48'53.7" E, altitude 388
115 m asl, 22 VII 2013, 1 ♂ on *Trifolium pratense*, leg. Martinet.

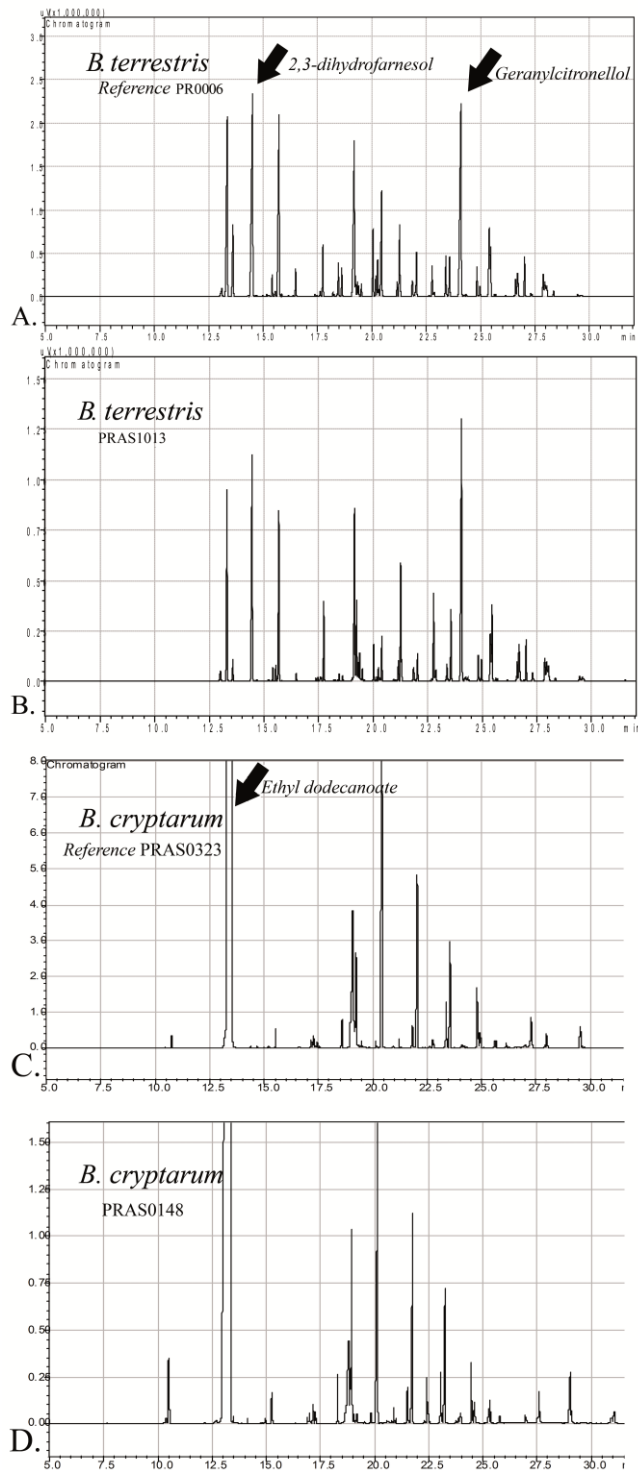
116 ***B. terrestris* (Fig. 2B):** Kiruna (Sweden), 67°49'38.6" N 20°20'26.9" E, 446 m asl, 15
117 VII 2013, 1 ♀ (BMAR0235) (Fig. 2B) on *Epilobium angustifolium*, leg. Martinet;
118 Björkliden (Sweden), 68°24'36.9" N 18°39'16.9"E, 565 m asl, 21 VII 2014, 1 worker
119 on *Astragalus alpinus*, leg. Rasmont; Narvik (Norway), Iptojávri, 68°06'23.8" N
120 17°29'20.4" E, 620 m asl, 27 VII 2014, 1 ♀ (PRAS1013) on *Epilobium angustifolium*,
121 leg. Rasmont & Martinet.

122 ***B. wurflenii* (Fig. 2C):** Tromsø (Norway), 69°38'02.0" N 18°59'57.2" E, 427 m asl,
123 10 VII 2014, 2 workers on *Vaccinium uliginosum*, leg. Martinet & Evrard.

124 The comparison between the distribution of these species in the baseline dataset
125 (Løken 1973) and our new occurrence observations shows that *B. lapidarius* occurs
126 now 400 km north of its 1973 limits; *B. terrestris* occurs 800 km north of its 1973
127 limits and *B. wurflenii* now occurs 200 km north of its 1973 limits. All previous
128 reports of *Bombus lapidarius* and *B. terrestris* from north of the Arctic Circle (Fig.
129 2A, Fig. 2B) are of dubious provenance and remain unverified (see discussion).

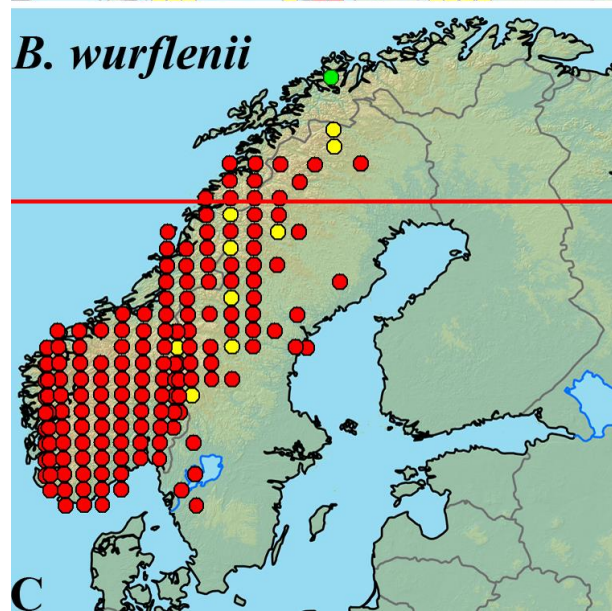
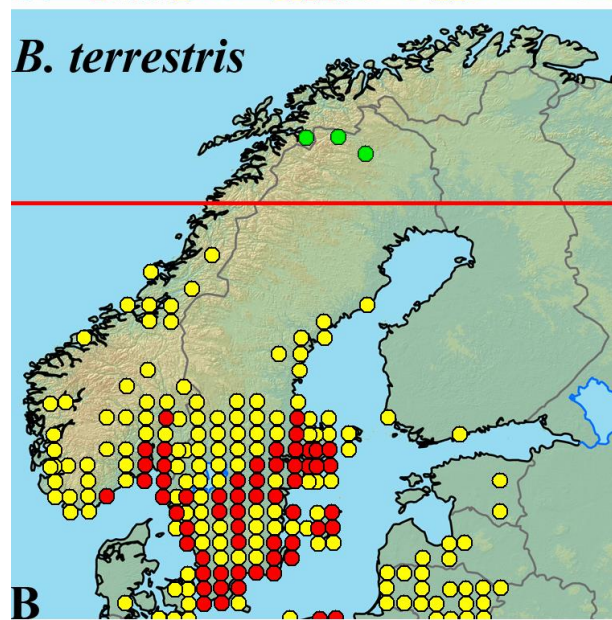
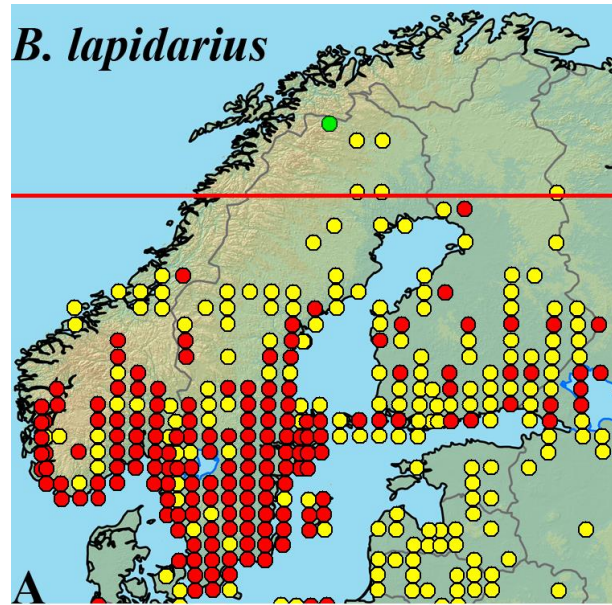
130

131



132

133 Figure 1. GC-FID chromatograms of *Bombus sensu stricto* males. (A) Reference
 134 specimen of *B. terrestris* (PRAS0006, Lecocq *et al.* 2013b). (B) *Bombus terrestris*
 135 male BMAR0235 (Kiruna). (C) Specimen of *B. cryptarum* male PRAS0323. (D) *B.*
 136 *cryptarum* male PRAS0148 (Jämtland, Sweden).



138 Figure 2. Maps summarizing the expansion toward the north of *B. lapidarius* (A), *B.*
139 *terrestris* (B) and *B. wurflenii* (C). Red dots represent the presence of the species
140 before 1974 (mainly Løken (1973) for Fennoscandia and Elfving (1968) for Finland)
141 and yellow dots represent records from new sites of the species since 1974, which
142 include data from BDFGM, MZH, NSIC, SSIC, Pekkarinen *et al.* (1981). Red dots
143 are also used, if records from both periods (>1974 and ≤ 1974) are known from the
144 same area (grid cell). Green dots represent our records of 2013 and 2014. The red line
145 represents the Arctic Circle.

146 **Discussion**

147 **Toward a new Arctic bumblebee fauna?**

148 The eco-climatic ranges (e.g. geographical distribution) of different species are
149 currently undergoing significant modifications. In bumblebees, many species are in
150 regression (e.g. Williams 1986; Rasmont *et al.* 2005a; Cameron *et al.* 2011) while few
151 species are expanding their distribution (e.g. *B. semenoviellus*: van der Smissen &
152 Rasmont, 2000; Sima & Šmetana 2012; *B. hypnorum*: Roberts 2012; *B. haematurus*:
153 Jenič *et al.* 2010; *B. moderatus*: Owen *et al.* 2012).

154 In Fennoscandia, our results show an obvious change in the northern European
155 bumblebee fauna since the 1970s. The main change is the expansion of two Euro-
156 Mediterranean species (*B. lapidarius* and *B. terrestris*) beyond the Arctic Circle. In
157 the 1970s, the northern limit of *B. terrestris* barely reached Uppsala (60° N) in
158 Sweden or Hamar (north Oslo, 60°50' N) in Norway, while *B. lapidarius* was
159 reaching higher latitudes, at the southernmost margin of the boreal taiga forest (Løken
160 1973). Our recent observations show that both species now reach the 68° N latitude,
161 whereby they have crossed the Arctic Circle. It is important to note that several
162 specimens of *B. lapidarius* have been collected in north Sweden before our sampling

163 in 1976 (Løken 1978). This year corresponds to the most extreme climatic event (heat
164 waves) of the last century in most of west Europe including the north of Fennoscandia
165 (Klein 2009). Our hypothesis is that *B. lapidarius* is probably rare with a patchy
166 distribution in the north of the Fennoscandia. However when the weather conditions
167 are favourable for this species (temperature increase) it becomes more visible, perhaps
168 more abundant or simply is more resistant to heat waves than the other species. So the
169 sampling likelihood of *B. lapidarius* is higher during a particularly hot summer such
170 as in 1976. The years 2013 and 2014 also provided heat waves in the north of
171 Fennoscandia (Finnish Meteorological Institute 2013, 2014).

172 The expansion of Euro-Mediterranean bumblebee taxa toward the north has already
173 been recorded in other regions. In Great Britain, *B. terrestris* was only recorded by
174 Alford (1975) at the maximum latitude of Aberdeen (57° N), while currently it
175 reaches the northern coast of the Scotland (60° N) (Roberts 2012 and Rasmont pers.
176 obs.) and the Shetland (Macdonald 2014). In Russia, Panfilov (1957) observed only
177 few specimens of *B. terrestris* in only one location in the Moscow region, while
178 recently Levchenko (2012) found a large number of specimens in nearly all surveyed
179 locations of this region. Such expansion has also been observed for *B. veteranus*
180 which now crosses the Arctic Circle in Finland, Russia (e.g. in the Murmansk Oblast,
181 Paukkunen & Kozlov 2015) and in Sweden (Cederberg 2013).

182 The expansion of *B. veteranus* and *B. wurflenii* beyond the Arctic Circle could most
183 likely be explained by the cold adaptations of these species (Løken 1973, Reinig
184 1988) and climate change. In contrast, *B. lapidarius* and *B. terrestris* are Euro-
185 Mediterranean bumblebees. Indeed, *B. terrestris* is abundant all around the
186 Mediterranean coast and reaches its southern limits on the edges of the Sahara
187 (Rasmont *et al.* 2008). *B. lapidarius* has not been found as far south and it does not

188 live on the Mediterranean coast, but it reaches the Atlas Mountains in Morocco
189 (Rasmont & Iserbyt 2014). Therefore, we suggest that the current global climate
190 warming in northern regions could be the trigger factor of the expansion of such a
191 species, as observed in other organisms (Rasmont *et al.* 2015).

192 An alternative hypothesis is that the Euro-Mediterranean species have not achieved
193 equilibrium with their current environment (Svenning & Skov 2007) and are still
194 continuing their post Ice-Age expansion (Lecocq *et al.* 2013a). Nevertheless the high
195 dispersal ability of several bumblebee species such as *B. lapidarius* and *B. terrestris*
196 (Kraus *et al.* 2009, Lepais *et al.* 2010), the long term occurrence of these species in
197 surrounding regions (Rasmont & Iserbyt 2014), as well as their phylogeographic
198 structure (i.e. endemic haplotypes and high genetic diversity in Fennoscandia at least
199 for *B.lapidarius*; Lecocq *et al.* 2013a; Lecocq *et al.* 2013b) make this hypothesis
200 unlikely. Further studies on bumblebee climatic niches are needed to assess the role of
201 climate change as a trigger factor of Euro-Mediterranean species expansion to cold
202 regions. And finally, since *B. terrestris* is widely used and internationally traded for
203 crop pollination, we cannot exclude that the collected *B. terrestris* individuals could
204 have escaped from greenhouses. However, we did not observe any greenhouses in the
205 surroundings of our study areas, the nearest ones being certainly more than 50 km
206 distant.

207 **Consequences for Arctic species conservation**

208 Besides the understanding of factors triggering expansion, the consequences of the
209 expansion of *B. terrestris* and *B. lapidarius* should be taken into account in local
210 bumblebee conservation management. It remains to assess how *B. lapidarius* and *B.*
211 *terrestris* could compete with the original high latitude bumblebee fauna where they
212 forage side-by-side. However, both species are known for their large colonies (Holm

213 1960; Velthuis & van Doorn 2006) and for their high opportunism in foraging plant
214 selection (Ruszkowski 1971; Teräs 1985; Rasmont 1988, Teper 2004). On the other
215 hand, Arctic bumblebee species only establish small colonies with a low number of
216 offspring (Løken 1973; Richards 1973; Berezin 1994, 1995). Therefore, Arctic
217 bumblebee species already impacted by climatic stress (Franzén & Ockinger 2011;
218 Franzén & Molander 2012; Martinet et al. 2015) could suffer from a drastic
219 competition from the new Euro-Mediterranean invaders. As we are at the very initial
220 stages of colonisation of these species, it is, as yet, difficult to project the future
221 situation.

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