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

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Abstract

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

Résumé

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

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

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

Introduction

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

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

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

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

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

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

Materials & Methods

Determination of original northern European bumblebee fauna

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

Detection of expanding species

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

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

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

Results

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

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

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

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

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

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

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

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

Discussion

Toward a new Arctic bumblebee fauna?

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

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

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

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

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

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

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

Consequences for Arctic species conservation

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

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

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