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

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Summary. 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 (in 2013 and 2014) 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 (Bombus terrestris et Bombus lapidarius) ont été observées en 2013 et 2014 en Fennoscandie au-delà du Cercle Arctique.

Keywords: Bombus terrestris; biogeography; climate change; Fennoscandia; heat wave

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), 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; Loken 1973; or Alaska: Williams et al. 2014). In these high altitudes and latitudes, bumblebees are the only remaining bee pollinators, supporting a large part of the pollination ecosystem service (Shamurin 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 (mountainous, arctic, subarctic and boreal regions) are also regions most severely affected by global warming (Core Writing Team et al. 2007; Franzén & Molander 2012; Franzén & Ockinger 2012), a phenomenon that will most likely increase during the next decades (Berger & Loture 1991; Settele et al. 2005; Spangenberg et al. 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 2012), 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; Aizen et al. 2011; Meeus et al. 2011; Thomas 2011; Murray et al. 2013; Arbetman et al. 2013a,

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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 and 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 (MZIH), Finland) and P. Rasmont & E. Haubruege (Banque de Données Faunique de Gembloux et de Mons (BDFGM), Belgium). These occurrence datasets were mapped using Data Fauna Flora software (Barbier et al. 2014).

Detection of expanding species

In order to assess potential changes in the northern European bumblebee fauna, we collected samples north of the Arctic Circle (see sampling map Figure 1) in 2013 and 2014 using entomological sweep nets. All specimens were individually 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 & Kaarnamaki 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 were verified by comparing the GC-FID chromatograms of cephalic labial gland 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, Kvisle 15.VIII.2008, 63°16’N 13°56’E; PRAS0323 from Scotland, Wick, Wireless 12.VIII.2009, 58°28’N 3°13’W, see Figure 1) and with the list of compounds given by Bertsch and Schweer (2012a, 2012b). The cephalic labial gland secretions are commonly used as diagnostic characters (Bertsch & Schweer 2012a). We followed the preparation and analysis methods of De Meulemeester et al. (2011), Lecocq et al. (2011, 2015a, 2015b) and Brasero et al. (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 unexpected species 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** (Figure 2A): Abisko (Sweden), 68°21'10.3" N 18°48'53.7" E, altitude 388 m asl, 22.VII.2013, 1 ♀ (queen) on *Trifolium pratense*, leg. Martinet.

**B. terrestris** (Figure 2B): Kiruna (Sweden), 67°49'38.6" N 20°20'26.9" E, 446 m asl, 15.VII.2013, 1 ♂ (male) (BMAR0235) on *Epilobium angustifolium*, leg. Martinet; Björkliden (Sweden), 68°24'36.9" N 18°48'53.7" E, altitude 388 m, 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) (Figure 1B) on *Epilobium angustifolium*, leg. Rasmont & Martinet.

**B. wurflenii** (Figure 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 *B. lapidarius* and *B. terrestris* from north of the Arctic Circle (Figures 2A and B) are of dubious provenance or unverified (see Discussion).

**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. 2005; Cameron et al. 2011) while a few species are expanding their distribution (e.g. *B. semenoviellus*: van der Smissen & Rasmont 2000; Šima & Smetana 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 north of 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 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 Scotland (60° N) (Roberts 2012 and Rasmont pers. obs.) and Shetland (Macdonald 2014). In Russia, Panfilov (1957) observed only few specimens of B. terrestris in only one location in the Moscow region, while recently Lekvenchon (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. wurbelli beyond the Arctic Circle could most likely be explained by the cold adaptations of these species (Loken 1973; Reinig & Rasmont 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). However, 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, 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. Higher temperature and successful reproduction probably also stimulate dispersal of queens. 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 (Rasmont et al. 2001; Teräväinen 1985; Rasmont 1988; Tepfer 2004). On the other hand, Arctic bumblebee species only establish small colonies with a low number of offspring (Loken 1973; Richards 1973; Berezin 1994, 1995). Therefore, Arctic bumblebee species already impacted by climatic stress (Franzén & Målander 2012; Franzén & Ockinger 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 colonization of these species, it is, as yet, difficult to project the future situation.

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