

The Bumblebees Scarcity Syndrome: Are heat waves leading to local extinctions of bumblebees (Hymenoptera: Apidae: *Bombus*)?

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Abstract. It is now well known that many bumblebee species are threatened in Europe and in N. America. Various hypotheses have been proposed to explain this regression. Some of the hypothetical factors act at a continental level, as the general restructuration of the agriculture toward the use of synthetic nitrogen fertilisation, in place of leguminous crops. The landscape fragmentation is typically a local factor the fusion of which also leads to large-scale effects. Since 2002, we observed a great number of situations where local droughts and heat waves occurred in France, UK, Scandinavia, Turkey, leading to very strong local reductions of the bumblebee's fauna. We observed so many local cases in 2007–2009 that we could hypothesise that a merger of these local effects could lead to a new general threat. As they are the most exposed to heat waves, the species with a late (summer) phenology should be the most sensitive to this risk.

Résumé. Le Syndrome de Rareté Anormale des Bourdons : les canicules conduisent-elles à des extinctions locales des bourdons (Hymenoptera : Apidae : *Bombus*) ? Il est maintenant bien connu que beaucoup d'espèces de bourdons sont menacées en Europe et en Amérique du Nord. Diverses hypothèses ont été proposées pour expliquer ces régressions. Certains facteurs hypothétiques agissent à l'échelle continentale, par exemple la restructuration générale de l'agriculture. La fragmentation du paysage est typiquement un facteur local dont la fusion spatiale a des effets sur de vastes territoires. Depuis 2002, nous avons observé un parallélisme entre des sécheresses locales ou des canicules et une très forte dépression de la faune de bourdons. Nous avons observé tellement de cas locaux de 2007 à 2009 (en France, au Royaume-Uni, en Scandinavie et en Turquie) que nous émettons l'hypothèse qu'une confluence de ces effets locaux pourrait mener à une nouvelle menace à l'échelle continentale. Parce qu'elles sont les plus exposées aux canicules, les espèces estivales sont celles qui pourraient être les plus sensibles à ce risque.

Keywords: Global warming, climate, pollinators, drought, regression.

It is now well known that many bumblebees species are threatened in Europe and in N. America (see e.g. Biesmeijer *et al.* 2006; Kosior *et al.* 2007; Williams *et al.* 2009; Cameron *et al.* 2011). Various hypotheses have been proposed to explain this regression. Some of the hypothetical factors act at a continental level, as the general restructuration of the agriculture thanks to the use of synthetic nitrogen fertilisation in place of leguminous crops. The landscape fragmentation is typically a local factor where the spatial merger could affect wide areas. More obscure is the role that climatic events could play in the fate of the bumblebee's species. Recently, we observed an abnormally low number of bumblebees in several situations. We will discuss here the potential role played by heat waves to explain these situations.

For the World Meteorological Organisation a heat wave occurs when during more than five consecutive

days the daily maximum temperature exceeds the average maximum temperature by 5 °C (Robinson 2001).

The IPCC (2007) observed a “quite slow” global warming (0.74 °C for the passed century). This increase of the temperature is only a mean and does not take into account events occurring at local or regional scales. As an example, from the year 2000 to 2010, the meteorological station of Le Luc (France, Var) recorded a mean temperature increase of +0.9 °C, and a mean decrease of 32% of the yearly precipitations. However, the generalised use of means to figure the climatic variations blurs the impact of the extreme meteorological events of short duration like storms, drought, and heat waves. Is it possible that such events that are not accounted for by global statistics act on the fate of the bumblebee's faunas?

Observations

Since 2002, we observed many situations that we never met before (1979–2001) during our field trips and samplings. Until the first decade of the 21st

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century, in most places, it was very common to collect scores or even hundreds of bumblebees in a day. Since 2002, we sampled several times in regions or places where the vegetation was obviously overheated. In such places, we recorded bumblebee densities that were very abnormally low. In some places where we had observed or collected lots of bumblebees some years before, after heat waves, we observed no or very sparse individuals.

In N. Finland in July 2003, we observed an absolute record of 33 °C at the meteorological station of Utsjoki. In Ankara (Turkey), we recorded extreme high temperature and drought in July 2007 (38 °C as maximum at 959 m elevation). In East-Pyrenees, the meteo-station of Ste-Léocadie (1320 m) recorded the record temperatures of 33 °C in August 2001 and 2007. In these regions, we had made abundant sampling some years before (see e.g. Iserbyt *et al.* 2008; Rasmont *et al.* 2009). After these heat waves, we observed no or very scarce bumblebees. We could roughly evaluate that the apparent bumblebee's density decreased from one to

two orders of magnitude. We repeated such experience (fig. 1) in East-Turkey (2002, 2011), in the Pyrenees (2003, 2006, 2007, 2008, 2012), in Middle Norway (2008), in Central Sweden (2008), and in Scotland (2009) (fig. 2). The most extreme cases were in the Pyrenees (fig. 2E), in Arctic Finland in 2003 (fig. 2D), and in Central Anatolia in 2007 (fig. 2A).

We propose to name these situations the **Bumblebee Scarcity Syndrome (BSS)**. This syndrome became so common during the last years that it considerably disturbs (or prevents) many field bumblebee experimentations.

Discussion

The correlation between the number of several bumblebee species and climatic parameters in a mountain biome is presented by Iserbyt & Rasmont (2012). It shows that most of the studied species are sensitive to variations of climatic monthly means. To take into account extreme meteorological events is the

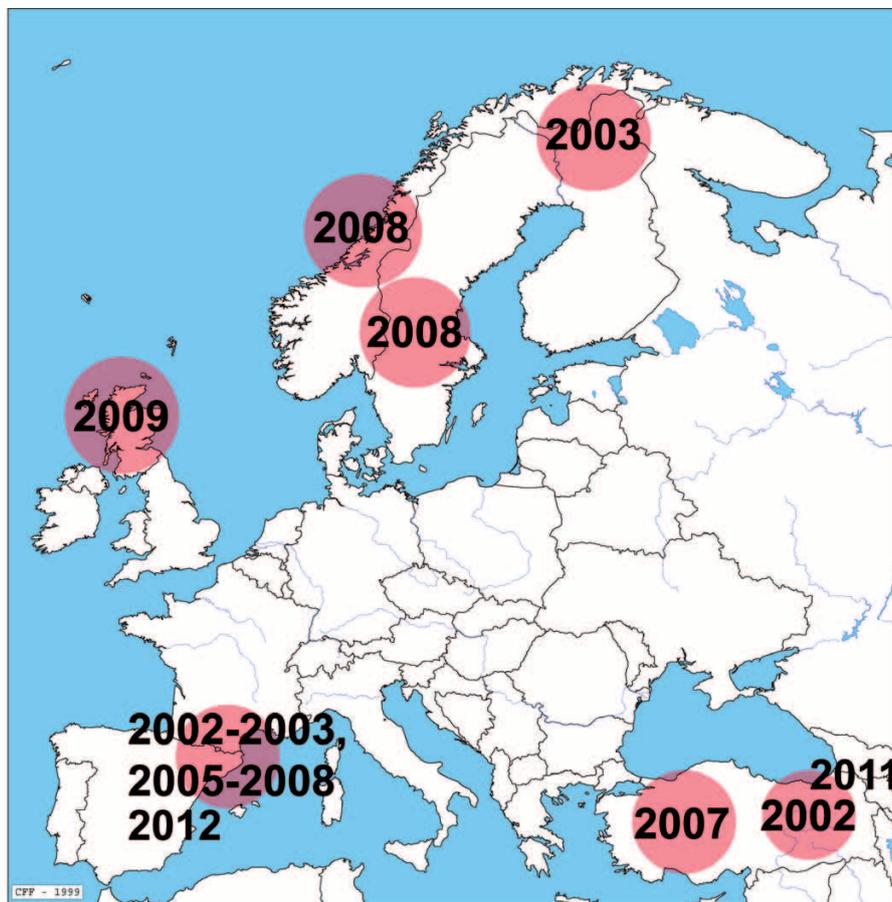


Figure 1
Map of the collecting trips of the authors where they experience the Bumblebees Scarcity Syndrome following a heat wave.

more difficult, that very frequently, these events barely modify the climatic means.

The heat wave could affect the bumblebee's fauna in various ways:

1. The bumblebees could be killed by the heat when the temperature rises above a lethal threshold. The upper fatal limit of temperature is generally very high in most insects (Uvarov, 1931: 17) and it is

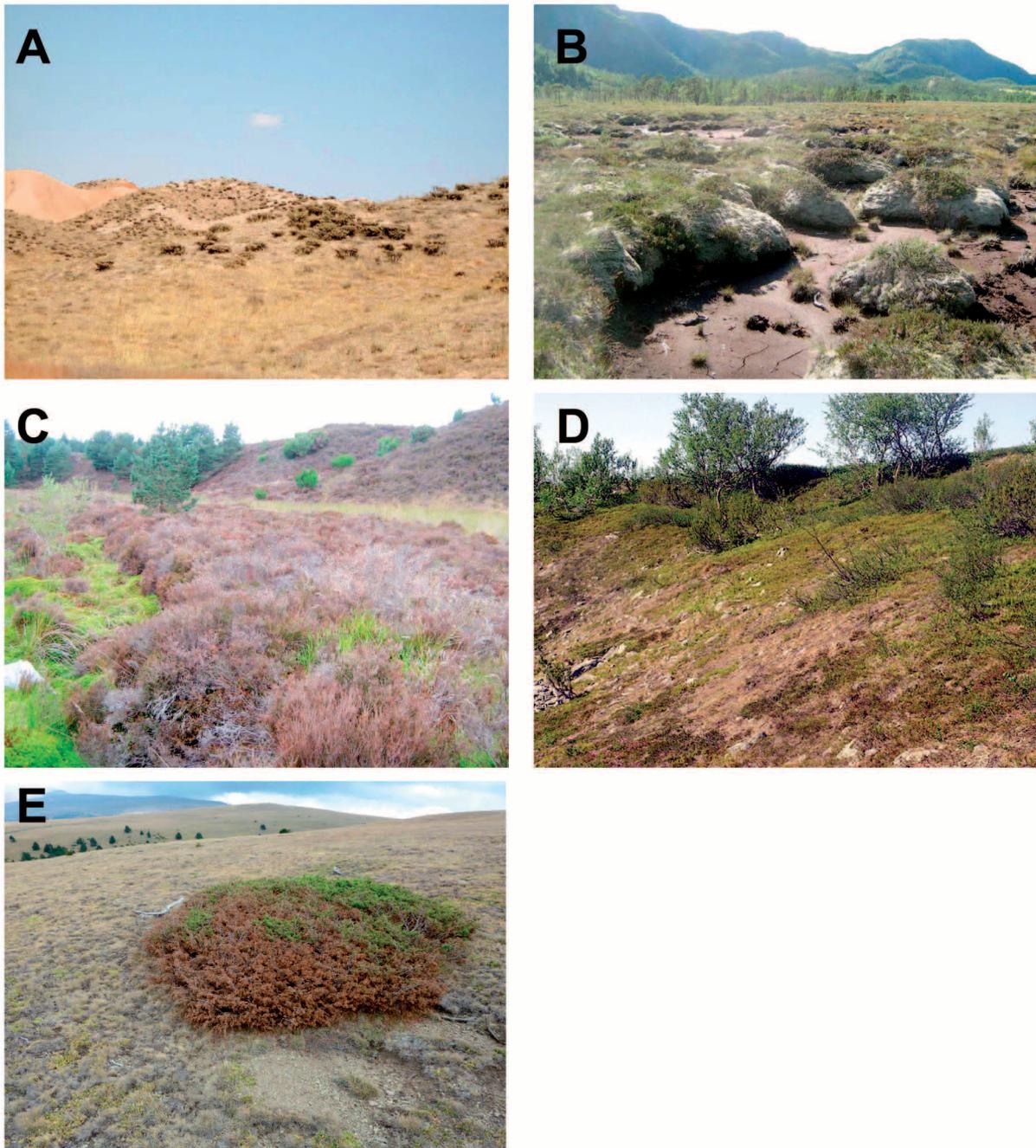


Figure 2

Landscapes with overheated vegetation, with the BSS. **A**, Dried and overheated *Astragalus* - steppe in Yozgat (Turkey) in 2007; **B**, Dried and overheated *Sphagnum* bog in Flatanger (Norway) in 2008; **C**, Overheated heath in Brora (Scotland) in 2009; **D**, Overheated lesser tundra vegetation in Utsjoki, (N-Finland) in 2003; **E**, Dried and overheated alpine vegetation with dying *Juniperus sibirica* Lodd. ex Burgsd. (= *J. nana* Willd.) in Osséja (France, Pyrénées-Orientales) in 2012.

very unlikely that it could be overtaken, even in the strongest heat waves. However, the bumblebees are now known to be endothermic animals (Heinrich 1979, 1993). Several mechanisms of thermoregulation (e.g. active nest ventilation) may cause a considerable energy cost (Heinrich 1979, 1993). Most bumblebees being cold climate animals, their preferendum (sensu Uvarov, 1931: 54), or “tolerance zone” (sensu Hallman & Denlinger 1998), spreads over low temperature intervals. When they undergo temperatures higher than their preferendum, their energy need for thermoregulation could pass over their foraging intake. For Uvarov (1931: 56), “the preferendum is probably one of the most potent factors influencing the ecological distribution of insects and their movements”.

2. It is very important to notice that not only the extreme temperatures during the heat wave are of importance but also its **total duration**. Following Hallman & Denlinger (1998), “the insect is capable of surviving a series of non-lethal lesions, but at certain point, the lesions accumulate to a critical level and cause death.” Denlinger & Yocum (1998) show that “survival curves which plot survival against duration of high temperature exposure characteristically have a broad shoulder (little mortality initially), followed by a high rate of death”. That means that heat waves could kill with sublethal temperatures (without trespassing any lethal threshold), if such high but sublethal temperature persists during a long time. This effect is well known for human (see e.g. Argaud *et al.* 2007; INED 2008).

3. The heat wave could also kill by water loss, as heat waves are very generally associated with drought.

4. It could kill by starvation if overheating or drought affects the availability of foraged vegetation.

5. Winter heat waves could also die in waking up the hibernating queens when no flower resources are available. Without to wake up the queens, winter heat waves could also increase the soil humidity, resulting in higher mortality from diseases (fungi, viruses).

When the bumblebees are in the solitary phase of their life cycle, they could be affected by any of these causes. When the bumblebees are living in colonies, they benefit from the underground or at least protected nest and its relative homeostasis. At this time, they probably suffer mainly from the low energy intake that could be caused by lowered plant productivity. Taking these hypotheses into consideration, the young sexuals are at higher risk during their solitary phase.

As the heat waves mainly occur during the months of July and August, the species that are able to complete their life cycle and to enter diapause before July could be saved (e.g. *B. hypnorum* (L.), *B. lucorum* (L.), *B. pratorum* (L.) or *B. terrestris* (L.)). The species with a late phenology could be much more affected by heat waves, while they mainly increase their colonies in July and their sexual behaviour takes place during August. As examples of very late species, we could give *B. confusus* Schenck, *B. cullumanus* (Kirby), *B. distinguendus* Morawitz, *B. humilis* (Illiger), *B. magnus* Vogt (fig. 3A), *B. muscorum* (L.) (fig. 3B), *B. subterraneus* (L.), *B. sylvarum* (L.), *B. veteranus* (Fabricius), (for phenology, see e.g. Løken 1973; Peeters *et al.* 1999). As most of these late species are strongly regressing everywhere in Europe (see e.g. Kosior *et al.* 2007; Rasmont & Iserbyt 2010–2012), we could hypothesise that the heat waves play a role in this regression and that the late species are the species most sensitive to the Bumblebee Scarcity Syndrome.

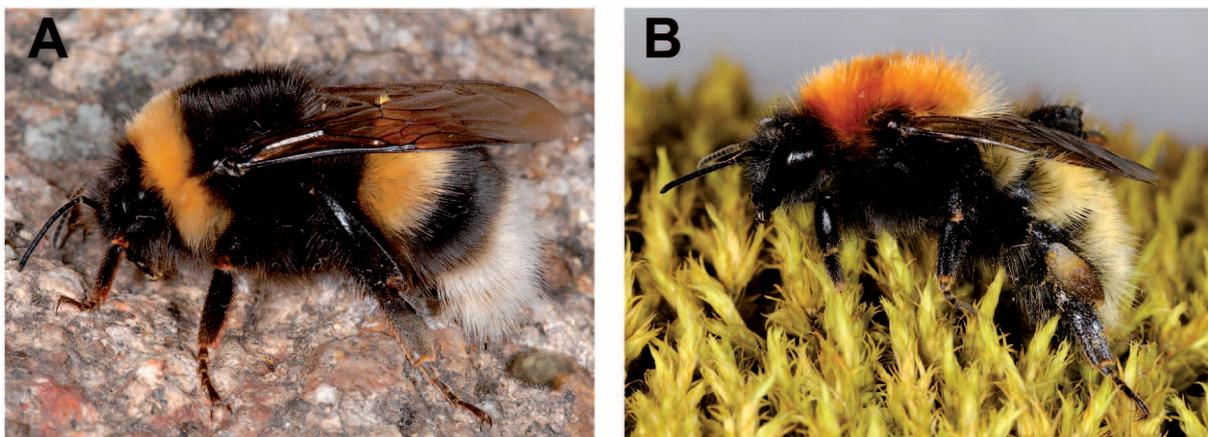


Figure 3
Some species with late phenology, likely the most sensible to the BSS. **A**, *Bombus magnus* Vogt; **B**, *Bombus muscorum* (L.) ssp. *liepeterseni* Løken.

Edwards & Williams (2004) and Williams *et al.* (2009) hypothesise that the food shortage is a main cause of bumblebee depletion. However, these authors also pointed out that the bumblebees that experience the worst regression across Great Britain, China and Canada are 1) species with narrow climatic specialisation, 2) species along their climatic edges and 3) species with queens that begin their activity late in the year. On the contrary, following these authors, the species that remain the most successful “tend to be those bumblebee species with broad climatic ranges that occur away from the edges of their climatic ranges and that become active early in the season.”

Our opinion is that the heat waves play an obvious role in the local and temporary extinction of bumblebees. We hypothesise that the geographical coalescence and the repetition year after year of the Bumblebee Scarcity Syndrome caused by increasingly frequent heat waves could be a major factor in the regression of bumblebee species. This factor could strongly affect other insects as already reported long ago by Chaîne (1912, 1919, reported by Uvarov 1931). It also concerns other animals, e.g. McKechnie & Wolf (2010) found that heat waves induce catastrophic avian mortality while Welbergen *et al.* (2008) found the same about flying foxes.

As the frequency of the heat waves is expected to increase dramatically during the 21st century (Meehl & Tebaldi 2004; Ganguly *et al.* 2009), a large number of bumblebee species could be endangered. It urgently needs to understand how the bumblebees are able to withstand to high temperatures. Their physiological limits need to be clearly determined by experimental studies.

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