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Research Article

Possible bivoltine development of several bumblebee species in Europe

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Abstract

This article is devoted to an analysis of possible bivoltine development of several bumblebee species in Europe. This study is based on materials collected by the authors in European countries (Slovakia, France and Greece) and in the European North of Russia (Solovetsky Archipelago). Four bumblebee species were studied. They are *Bombus hortorum*, *B. terrestris*, *B. pratorum* and *B. jonellus*. *Bombus hortorum* was collected from south-eastern Slovakia and southern France, *B. terrestris* was additionally from the Isle of Crete, *B. pratorum* was from southern France and the Solovetsky Archipelago, and *B. jonellus* was collected only on the Solovetsky Archipelago. Our records reveal that several bumblebee species may have two generations per season. *Bombus hortorum* and *B. pratorum* in south-eastern Slovakia and southern France had males present in late May. Both these species have a short life cycle, so they are potentially able to produce two generations in a season. *Bombus terrestis* was found in January on southern France and in Late November in the Isle of Crete. Because this species has no obligate diapause, this fact may indicate bivoltine development for *B. terrestris* in the studied territories. The potential ability of *B. jonellus* to produce two generations per season was revealed during long-term research on the Solovetsky Archipelago.

Keywords

Bumblebees, two generations, Europe, climatic conditions

The study of the life cycles of different bumblebee species is an important topic in modern research into bumblebees (Stelzer et al. 2010). The study of their phenology on a global scale reveals general patterns of bumblebee life cycles in different landscape-zonal conditions.

The number of papers dedicated to this subject is relatively small. The majority of these describe the

life cycle of one or two species typical for the study region (Meidell 1968, Rasmont 1985, Prŷs-Jones et al. Corbet 1987). Only a few papers summarise information on the life cycles of bumblebees. One of them is a book by Radchenko and Pesenko (1994). This work is dedicated to the biology of bees and, in one section, contains descriptions of examples of bumblebee life cycles in various climatic conditions. Also worth noting is a review by Sakagami (Sakagami 1967) describing the life cycles of bumblebees in different climatic zones.

The aim of this study was to analyse our field observations of bumblebees from different areas of Europe with a special focus on the possibility of bivoltine development of bumblebee families in certain taxa.

Materials and methods

Bumblebees from European North of Russia were studied on the Solovetsky Archipelago during long-term research 2001–2010 (Kolosova and Podbolotskaya 2010, Bolotov et al. 2013). 119 individuals were studied for the present research.

Bumblebees from European countries were collected in 2011. These came from south-eastern Slovakia, southern France and the Isle of Crete. Bumblebees were caught with an entomological net. In summary, from Europe, 55 individuals were collected and 3 were observed.

Bumblebees were identified following Løken (1973), Rasmont and Terzo (2010). In this paper, we use the taxonomic status of species according to Williams (2017). Three females of *Bombus terrestris* (L., 1758) from the Isle of Crete were dissected using a micro-scalpel for investigation of their crops (Alford 1975). The specimens of bumblebees are deposited in the Russian Museum of the Biodiversity Hotspots (RMBH), Federal Centre for Integrated Arctic Research, Arkhangelsk, Russia.

Results

During the field research, four bumblebees were studied. They are *B. hortorum*, *B. terrestris*, *B. pratorum* and *B. jonellus*. *Bombus hortorum* was collected from south-eastern Slovakia and southern France, *B. terrestris* was additionally from the Isle of Crete, *B. pratorum* was from southern France and the Solovetsky Archipelago, and *B. jonellus* was collected only on the Solovetsky Archipelago.

The full description of the studied localities and records of bumblebees are presented in Table 1.

Discussion

Our novel records reveal that several bumblebee species may have at least two generations per season. In summary, we found evidence of possible bivoltine development for the following species: *B. hortorum* (Slovakia and France), *B. terrestris* (Slovakia, France and Isle of Crete), *B. pratorum* (France

Table 1. New records of bumblebees indicating possible bivoltine development

Species	Locality	Date	Records	Collectors
B. hortorum (L., 1761)	SE Slovakia, Vihorlatské Vrchy Region, slope of the Marečková Mountain [48°49'40"N, 21°59'19"E, 350-400 m alt.], oak-maple forest with herb-celandine plant cover (fig. 1A)	19–20.05.2011	4 males and 41 workers collected	Bolotov & Kolosova
	S France, close to La Carole Village [42°54'35"N, 1°49'8"E, approx. 600 m alt.], beech forest, near travertine terraces	25.05.2011	3 males collected	Bolotov & Kolosova

Species	Locality	Date	Records	Collectors
B. terrestris (L., 1758)	SE Slovakia, Vihorlatské Vrchy Region, slope of the Marečková Mountain [48°49'40"N, 21°59'19"E, 350-400 m alt.], oak-maple forest with herb-celandine plant cover (fig. 1A)	20.05.2011	A female with specific searching behaviour was recorded. The female was looking around a mouse hole and seems to be a new generation, with brilliant, bright hair cover (fig. 1B)	Bolotov & Kolosova
	SE Slovakia, Vihorlatské Vrchy Region, forest road near Vinné village [48°48'36"N, 21°58'46"E, 195 m alt.], mixed broadleaf forest with herb plant cover	21.05.2011	2 females with specific searching behaviour were recorded*. The females are probably looking for nesting sites and they appear to be a new generation, with brilliant, bright hair cover	Bolotov & Kolosova
	S France, near Toulouse, garden	15.01.2011	A worker collected	Pokrovsky & Shirokova
	Greece, Isle of Crete, entrance to the Imbras Gorge, near café [35°14'53" N, 24°10'3" E, alt. 770 m], on the flowerbed	23.10.2011	A male collected	Bolotov & Kolosova
	Greece, Isle of Crete, the Imbras Gorge, mountain valley [35°14'36" N, 24°10'2" E, alt. 700 m], on flowers of the common ivy (*Hedera helix* L.)	23.10.2011	2 live and 1 dead females were collected and a worker was observed (fig. 1C). The females were very sluggish, with empty crops (dissected), most likely because ivy provides an imperfect nectar source, but other flowering plants were lacking along the valley on that date (fig. 1D)	Bolotov & Kolosova
B. pratorum (L., 1761)	S France, Pyrenees, foothills of the Neouville Mountain, near the boundary of Pyrenees National Park [42°48'05"N, 00°13'50"E, 1330 m alt.], sparse mixed fir-beech forest with juniper-grass-herb plant cover on a mountain slope in a river valley (fig. 1E). The early-summer phenological aspect was recorded there, with flowering of *Anemone* sp.	26.05.2011	A male collected	Bolotov & Kolosova
	European North of Russia, Solovetsky Archipelago, Isakovo Village [65°05'42"N, 35°36'57" E, approx. 11 m alt.], grass-herb meadow near pine-birch forest (fig. 1F).	29.06.2009	A male collected	Kolosova & Podbolotskaya

Species	Locality	Date	Records	Collectors
B. jonellus (Kirby, 1802)	European North of Russia, Solovetsky Archipelago, Savvatyevo Village [65°07'03"N, 35°36'20" E, approx. 5 m alt.], grass-herb meadow near pine-birch forest.	26.06.2003	12 males collected	Kolosova & Podbolotskaya
	European North of Russia, Solovetsky Archipelago, Bolshoy Zayatskiy Island [64°58'05"N, 35°39'42" E, approx. 2 m alt.], grass community near coast (fig. 1G).	20.06.2009	20 males collected	Kolosova & Podbolotskaya
	European North of Russia, Solovetsky Archipelago, Isakovo and Savvatyevo Villages.	29.06.2009	86 males collected	Kolosova & Podbolotskaya

*Visually identified as *B.* cf. *terrestris*.

and European North of Russia), and *B. jonellus* (European North of Russia).

In temperate latitudes, a bumblebee family typically exists only one season (Alford 1975, Goulson 2010). Bumblebee families live from spring to autumn, on average 3 to 6 months, the duration of their life depending on the different species (Goulson 2010). One reproductive generation emerged by the end of summer. From the beginning of autumn, the bumblebees from nests die, except young females of the new generation (Goulson 2010). Hence, the majority of bumblebees in temperate latitudes are characterised by an annual life cycle (Sakagami 1967). However, some species of bumblebee in temperate latitudes can transform their life cycles and are capable of producing two generation in a season (Radchenko and Pesenko 1994).

B. terrestris has no obligate diapause. In laboratory conditions, this species can breed throughout the year (Radchenko and Pesenko 1994). According to Rasmont et al. (2008), "In N. Europe, the phenology of *Bombus terrestris* is similar to that of other bumblebee species; the same is not true in Mediterranean regions, where colony foundation may occur in autumn and winter". Examples of two generations in a season for this species are known from S France, S England, Corsica and Sardinia (Stelzer et al. 2010, Rasmont 1985, Rasmont et al. 2008). According to our materials, at least bivoltine development of *B. terrestris* is possible in S France, near Toulouse, where a single worker of this species was collected in January. On the Isle of Crete, a male and females of *B. terrestris* were recorded in late November, which might also indicate two generations per season. Based on the observations of flowering plants and the study of bumblebee crops, we suggest that winter activity of *B. terrestris* on the Isle of Crete is not a common phenomenon, probably because limited food sources might lead to their mortality.

Both *B. hortorum* and *B. pratorum* have a short life cycle (Prŷs-Jones and Corbet), which explains the presence of males of these species in SE Slovakia and S France in late May. According to Prŷs-Jones and Corbet (1987), *B. hortorum* and *B. pratorum* may produce two generations per season in Britain, because the short life cycle allows these species "to complete a second nesting cycle in some years". Hence, it can be assumed for SE Slovakia and S France.

The ability of *B. jonellus* to produce two generations per season is well-known (Meidell 1968, Prŷs-Jones and Corbet 1987, Alford 1975, Alfken 1913, Douglas 1973). The two-generation ability of *B. jonellus* and also *B. pratorum* during the summer months is possible on the Solovetsky Islands. Entomological research on the Solovetsky Archipelago was carried out annually in the summer months 2001-2010 (re-

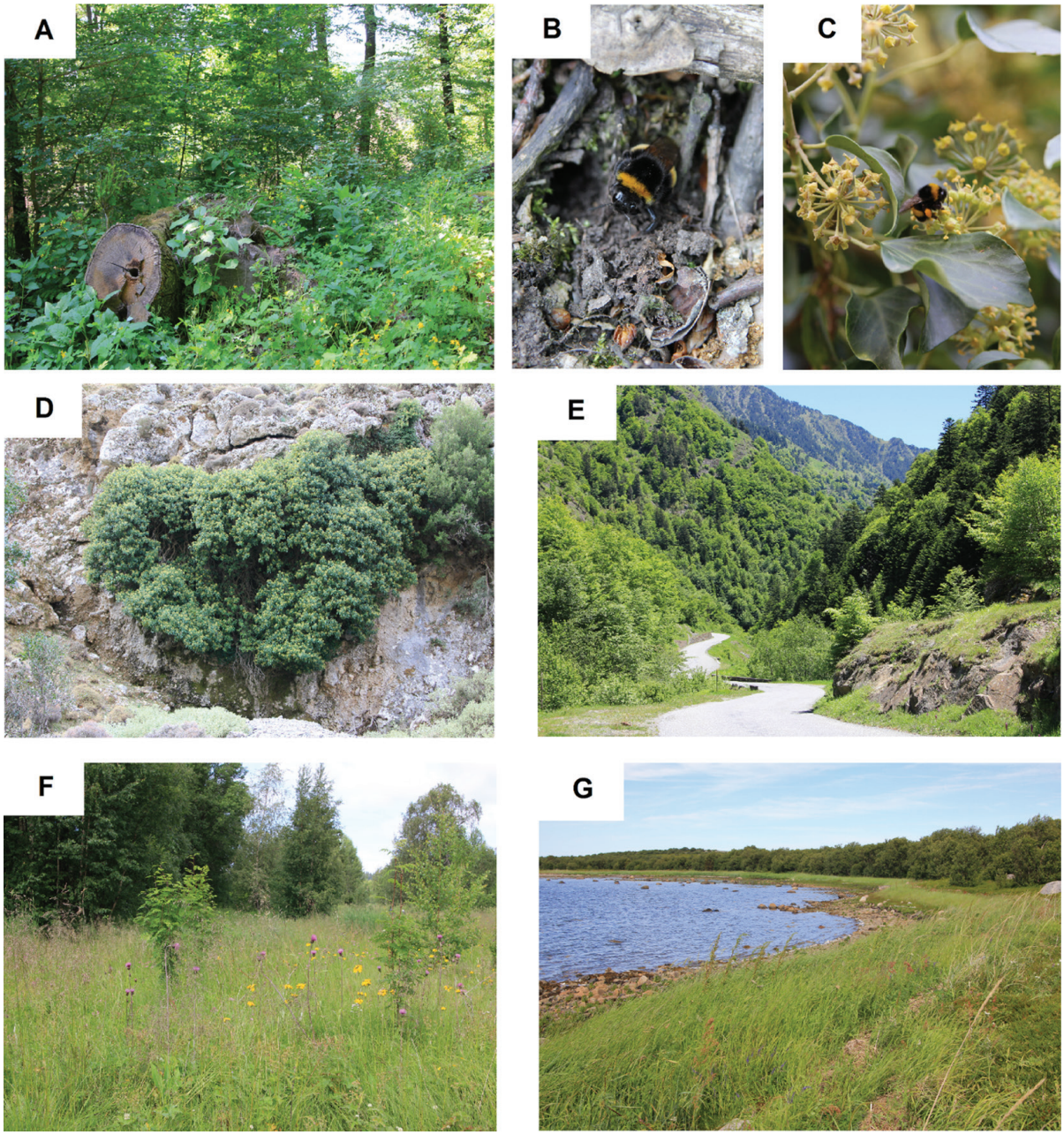

Fig. 1. Habitats and bumblebees. (A) Oak-maple forest with herb-celandine plant cover on a slope of the Marečková Mountain, 20.05.2011, Slovakia. (B) Female of *B. terrestris* with specific searching behaviour on a slope of the Marečková Mountain, 20.05.2011, Slovakia. (C) Worker of *B. terrestris* on flowers of common ivy in the Imbras Gorge, 23.10.2011, Isle of Crete. (D) Common ivy thickets on a rocky outcrop, the single available nectar source in the Imbras Gorge, 23.10.2011, Isle of Crete. (E) Sparse mixed fir-beech forest with juniper-grass-herb plant cover on the foothills of the Neouville Mountain, 26.05.2011, Pyrenees, France. (F) Grass-herb meadow near pine-birch forest in the village of Isakovo, Solovetsky Archipelago of Russia. (G) Grass community near the coast on Bolshoy Zayatskiy Island, Solovetsky Archipelago. Photos: Yu.S. Kolosova

peated twice, for 7-10 days, each summer season: late June – early July and late July – early August) (Kolosova and Podbolotskaya 2010, Bolotov et al. 2013). The location of the Solovetsky Islands in the south-west of the White Sea leads to cool summers that are shorter than on the mainland (Shvartsman and Bolotov 2007). Overwintered females emerge here in mid-June; workers have been recorded since the end of June and reach maximum abundance by mid-July; young females and males come closer to the end of July – early August. However, in years 2003 and 2009, we observed males of *B. jonellus* and *B. pratorum* in late June – early July, so two generations per season can be assumed for these species on the Solovetsky Archipelago.

Finally, the problem of studying bivoltine development for bumblebee species is promising for the further research. Climate warming, which has had a global impact on bumblebees with multiple consequences (Kerr et al. 2015), can also lead to rapid shifts in the number of possible generations per season, which might have a negative influence on agricultural crops across Eurasia.

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