Climatic Risk and Distribution Atlas of European Bumblebees

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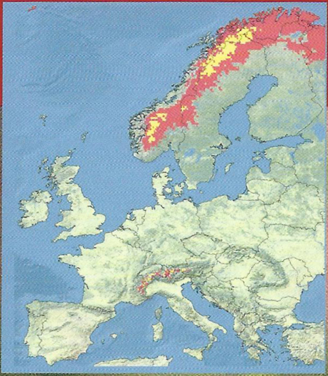

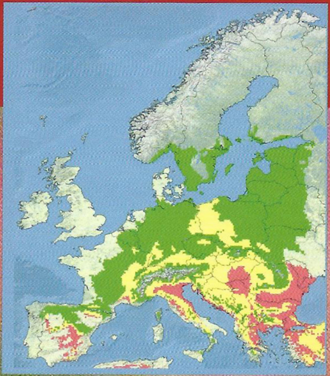

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Dedicated to
Astrid Løken, Bruno Pittioni, William F. Reinig & Anton S. Skorikov
who pioneered bumblebee biogeography

John Heath & Jean Leclercq
founders of the European Invertebrate Survey -
Cartographie des Invertébrés Européens - Erfassung der Europäischen Wirbellosen

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by

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3. Foreword

Pollinators are increasingly recognised as providing a vital ecosystem service, not least for feeding people, and bumblebees are among the most important pollinators in north temperate regions like Europe. Like most animals, bumblebees are sensitive to climate, in part through their geographically varying interactions with other pressures, such as land use and pesticide use. Climate change, for which the evidence is now unequivocal, is therefore expected to affect bumblebee distributions across Europe. For relatively cool-adapted animals like bumblebees, many of the already evident and likely future climate changes are unlikely to be good news. This may be especially challenging if constraints on the ability of bumblebees to spread to keep up with climate changes will make it difficult for them to compensate in terms of distribution extent by moving into new areas of Europe. This atlas, considering the likely effects of climate change on bumblebees in Europe, is therefore a timely and vital work. It is an important complement to the earlier Red List of Threatened Species for the IUCN Bumblebee Specialist Group, in which the BBSG Regional Coordinators Pierre Rasmont and Stuart Roberts also took leading roles.

The challenge is one of dealing with very complex systems. Even if we know which service or function is needed in a changing world, we may not always be able to predict precisely which species will best be able to carry out that role as the system changes. Therefore while we can try to target efforts on the currently most critical species, it is also important to conserve the diversity of species, as an insurance against unpredictable outcomes from complex systems in which unexpected species prove to become the most important in the future.

This atlas breaks new ground in assessing the most likely consequences of climate change for these important pollinators in Europe. The prognosis is shown to be dire. But it should be an inspiration and a stimulus to encourage people to look urgently at similar model projections in other, often less well studied, parts of the world. The clock is ticking and we need to see progress in all regions, before it becomes too late for some species.

Paul Williams
Chair, IUCN Bumblebee Specialist Group

4. Context

4.1. An overview of the bumblebees

Bumblebees are amongst the most familiar insects inhabiting meadows, gardens, and grasslands of the temperate regions of the World. They have long been popular with field biologists and naturalists thanks to their bright colours, large body size, and abundance. Bumblebees (genus *Bombus*) are insects closely related to honey bees, stingless bees, cuckoo bees, carpenter bees and orchid bees which together constitute the family Apidae within the order Hymenoptera (Michener, 2000). Today, approximately 250 species assigned to 15 subgenera are recognized world-wide (Williams, 1998; Williams *et al.*, 2008). Most of the bumblebees are eusocial species while few of them are socially parasitic bees (i.e. inquiline species; the 27 species included in the subgenus *Psithyrus* and two other species). Like other Apidae, the bumblebees are recognised as pollinator species (Neff & Simpson, 1993). Among animal pollinators of the Northern Hemisphere, only few achieve such a numerical dominance as flower visitors as bumblebees. This makes bumblebees a critically important functional group providing ecosystem services for natural environments and for agricultural crops (e.g. Free, 1993; Klein *et al.*, 2007).

Although the distribution of bumblebees encompasses a wide geographic range from Arctic tundra to lowland tropical forest, they are clearly most abundant in mountain 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. Thanks to these adaptations, bumblebees have been able to recolonise areas depopulated by Ice Ages in the last three million years (Hines, 2008). However these adaptations to cold climate raise the question of what will be the fate of bumblebees under current global warming. Investigating this question requires large biogeographic databases which, until recently, have been unavailable.

4.2. Advances in the study of bumblebee biogeography

The late 19th century and the first half of the 20th century brought the first modern biogeographical studies based on species mapping (for bumblebees see e.g. Reinig, 1937, 1939; Pittioni, 1938, 1942, 1943). However, these first studies were based on highly uncertain geographic locations which strongly limited the potential usefulness of these first biogeographic data. Advances in geographic localisation methods and instruments in the second half of the 20th century have tremendously increased the quality of distribution data and led to the development of the first biogeographic databases. In the early 1970's, the foundation of the European Invertebrate Survey - *Cartographie des Invertébrés Européens - Erfassung der Europäischen Wirbellosen* launched the mapping of insects from Europe (Heath & Leclercq, 1969). However, the technological limitations of the 1970's allowed only few pioneer results at the continental level (Heath & Leclercq, 1981). Once again, technological advances, especially in micro-computing, database management and geographical information systems allowed further progress by gathering huge amounts of data. The rapid increase in the accessibility of the modern technology has allowed collecting an unprecedented number of biogeographical data by numerous professional and citizen scientists in many countries.

This has led to many high level studies in several groups of organisms (e.g. Tutin *et al.*, 2001; Settele *et al.*, 2008; Kudrna *et al.*, 2011). In contrast, for bees, despite the great interest of biologists and the wider society, the complexity of the taxonomy considerably delayed the establishment of a database. In this context, the European Union FP7 "STEP" project ("Status and Trends of European Pollinators"; www.step-project.net; Potts *et al.*, 2011) appeared as one of the first occasions (but see also ALARM project; www.alarmproject.net) to make a significant advance in the knowledge of bees from the whole European region. The outcome of this European collaboration has exceeded the initial expectations. After four years of survey, more than 2.5 million species observations have been joined together to map the distributions of the majority of European bee species. In August 2014, more than 1200 European bee species have been mapped. This extensive mapping has been made available to both the scientific and public audiences on the Atlas Hymenoptera website (www.atlashymenoptera.net; Rasmont & Haubruge, 2014). A joint effort produced the first comprehensive checklist of European bees (Kuhlmann *et al.*, 2014). Further, a collaboration with the IUCN resulted in a first Red List of European bees (Rasmont *et al.*, 2013).

Most of the STEP data concerns bumblebees (more than one million bumblebee data from all West-Palearctic countries). Thanks to the STEP project, the mapping and the IUCN assessments of all European bumblebee species have been published (Rasmont *et al.*, 2013; Rasmont & Iserbyt, 2014). This large database can now allow investigation of the recent history of bumblebee species.

4.3. Bumblebee decline and the tomorrow's bumblebee fauna

As long ago as the early 1970's, many entomologists pointed out the decline of bumblebee species in Europe (Peters, 1972; Williams, 1982; Rasmont & Mersch, 1988; Williams *et al.*, 1991, 2007, 2013; Goulson *et al.*, 2005, 2008b; Rasmont *et al.*, 2005; Biesmeijer *et al.*, 2006; Kosior *et al.*, 2007; Williams & Osborne, 2009; Carvalheiro *et al.*, 2013). Thank to the advances in the study of bumblebee biogeography, and to the sharing of long-term datasets, the comparison of the past and current European bumblebee fauna has revealed the scale of the problem (Rasmont & Iserbyt, 2014). Moreover this decline is a global phenomenon (e.g. North America, Cameron *et al.*, 2011; South America, Arbetman *et al.*, 2013; China, Xie *et al.*, 2008).

Several hypotheses have been proposed to explain this global decline such as (i) habitat fragmentation (Williams, 1982; Williams & Osborne, 2009; Darvill *et al.*, 2010; Mayer *et al.*, 2012; Hatten *et al.*, 2013), (ii) shortage of flower resources (Peters, 1972; Williams, 1989; Rasmont & Mersch, 1988; Rasmont *et al.*, 1993, 2005; Goulson *et al.*, 2005, 2008a), (iii) killing by car traffic (Donath, 1986), (iv) overgrazing of bumblebee habitat by cattle (Özbek, 1995; Xie *et al.*, 2008), (vi) parasites and pathogens resulting from spillover from domesticated species (Cameron *et al.*, 2011; Arbetman *et al.*, 2013), (vii) urbanization (Ahrné *et al.*, 2009; Martins *et al.*, 2013), or (viii) vegetation displacement due to nitrogen deposition (Rasmont, 2008). Pesticides have most likely also played a role because of their extreme toxicity for some bumblebee species (e.g. Whitehorn *et al.*, 2012; Zarevúcka, 2013) or to the closely related species *Apis mellifera* (e.g. Johnson *et al.*, 2010, 2013). But their impact remains still largely unevaluated for most of the bumblebees. Several alternative factors such as herbicides or helminthicides impacting other organism groups could also be a factor in bumblebee decline (Lumaret, 1986; Madsen *et al.*, 1990; Colin & Belzunces, 1992; Vandame & Belzunces, 1998; Hayes *et al.*, 2002; Mussen *et al.*, 2004; Simon-Delso *et al.*, 2014). At least one other factor is regarded as strongly affecting the bumblebee fauna: the changing climate (Iserbyt & Rasmont, 2012; Rasmont & Iserbyt, 2012; Ploquin *et al.*, 2013; Herrera *et al.*, 2014). However, throughout the present work, it should be kept in mind that it is very likely that none of the factors potentially explaining bumblebee decline is the unique or even the main trigger of current bumblebee regression. As Jeremy Kerr (Toronto, pers. comm.) recently wrote "there is no silver bullet that killed the bumblebees".

Besides explaining the current decline of bumblebees, their importance in ecosystem service provision places a premium on predicting the future of the bumblebee fauna. Even if all above cited factors do shape the fate of bumblebees, only the evolution of climate change has been assessed thanks to the work of the Intergovernmental Panel on Climate Change (www.ipcc.ch). In the present work, we investigate the future for the European bumblebee fauna in the light of these climatic change projections.

5. Introduction

5.1. Effects of climate change

Climate is one of the most important determinants of large-scale species distributions (Thuiller *et al.*, 2004). Climate and its changes have shaped the current wild bee distribution and biodiversity (e.g. Groom *et al.*, 2014; for bumblebees see Lecocq *et al.*, 2013). Likewise, several studies have shown that the current bumblebee decline can be attributed to climate change (e.g. Williams *et al.*, 2007; Bartomeus *et al.*, 2013), which can either act via an increasing frequency of extreme events or via gradual changes in average conditions.

Ranta & Vepsäläinen (1981) pointed out that a large number of individuals could be killed by "*catastrophic environmental vicissitudes*" prior to a fast population recovery. This random cycle of "*sudden extermination - fast recovery*" is considered as a key process of local species diversity, by maintaining all species under a competition level (Pekkarinen, 1984; Rasmont, 1989). Recent contributions noticed that bumblebees are indeed sensitive to extreme climatic events (Iserbyt & Rasmont, 2012; Ploquin *et al.*, 2013; Herrera *et al.*, 2014; Rasmont & Iserbyt, 2014). Year after year, the local bumblebee fauna can change (including local species extinctions) due to variations in local climatic factors such as heat waves and droughts (Iserbyt & Rasmont, 2012; Rasmont & Iserbyt, 2012). However, this seems to drive the species not only along a random climatic hazard as proposed by Ranta & Vepsäläinen (1981) but also to a temporal and spatial gradient of changes (Ploquin *et al.*, 2013; Herrera *et al.*, 2014).

Beside extreme climatic events, gradually changing conditions can also seriously impact species (e.g. Parmesan & Yohe, 2003). On the one hand, gradually changing climatic conditions can lead to shifts in species ranges which has been observed for many species (e.g. Parmesan & Yohe, 2003; Chen *et al.*, 2011) including bees (e.g. Kuhlmann *et al.*, 2012). On the other hand, the gradual changes can lead to modification of species' phenology (Polgar *et al.*, 2013; Kharouba *et al.*, 2014; for wild bees see Bartomeus *et al.*, 2011). Indeed, in both cases, species can respond to gradual climate change by tracking spatially or temporally their climatic niche (e.g. Tingley *et al.*, 2009; Moo-Llanes *et al.*, 2013).

5.2. Toward a new pollinator community

There is strong evidence that variations in climatic conditions deeply affect the bumblebee fauna (e.g. Williams *et al.*, 2007; Bartomeus *et al.*, 2013a; Pradervand *et al.*, 2014), and recent projections of expected changes in climatic conditions for the 21st century give rise to particular concerns. For instance, the Intergovernmental Panel on Climate Change (IPCC) states in its 5th Assessment Report that "*a large* *fraction of terrestrial and freshwater species face increased extinction risk under projected climate change during and beyond the 21st century, especially as climate change interacts with other pressures, such as habitat modification, over-exploitation, pollution and invasive species* (high confidence; IPCC 2014)". Indeed, bumblebee populations seem to be more sensitive to other threats when they reach their climatic limits (Williams & Osborne, 2009). Further, there is some indication that future climate change could have severe impacts on wild bee faunas (Kuhlmann *et al.*, 2012) including bumblebees (Kirilenko & Hanley, 2007; Herrera *et al.*, 2014).

Species-specific responses to future climate change can lead to the generation of new communities (e.g. Schweiger *et al.*, 2010; Lurgi *et al.*, 2012; Pradervand *et al.*, 2014) with changed functional structures. Indeed, changes in the spatial/temporal occurrence of pollinators can lead to spatial gaps/asynchrony between the pollinators and insect pollinated plants (Kudo, 2013; Kudo & Ida, 2013; Pradervand *et al.*, 2014). The resulting effects could be dramatic for both plants and pollinators (e.g. Kudo & Ida, 2013; Petanidou *et al.*, 2014), even if several empirical studies suggest that the large plant and insect biodiversity could mitigate the expected dramatic consequences (e.g. Bartomeus *et al.*, 2011, 2013b; Forrest & Thomson, 2011; Iler *et al.*, 2013). Such changes in pollinator communities may not only affect wild plants but can also impact important agricultural crops (e.g. Free, 1993; Klein *et al.*, 2007). In a study in Britain, Polce *et al.* (2014) found that future climate change can lead to spatial mismatches between orchards and their pollinators. This may in turn increase the risks to human society of suffering from pollination deficits of economically important crops.

The impacts of future climate change on the fate of single species, the functioning of ecosystems and the sustainable provision of ecosystem services highlights the need for efficient assessments of potential future climatic risks for pollinators. So far there is no comprehensive assessment of such risks available for Europe or any other continent on the world. With this atlas we take the first step for a prominent and important group of pollinators – the bumblebees.

5.3. Objectives of the climatic risk atlas

The general aims of this atlas are:

- to inform the broader public about the potential risks of climate change for the future fate of European bumblebees;
- to aid biodiversity conservation managers and policy makers;
- to provide background knowledge for critical discussions about the sustainable provision of pollination services in the light of food security.

6. Methodology

6.1. General approach

The general approach used in this atlas was to assess the climatic niche of each bumblebee species according to its European distribution (from 1970 to 2000) and the corresponding climatic conditions. The species-specific climatic requirements were then used to project the climatically suitable areas and the corresponding changes of these areas under potential future climatic conditions. These future conditions were taken from scenarios of climate change which incorporate different potential pathways of political, socio-economic and technological development. The projected changes in suitable climatic conditions for each species were illustrated on a map and assigned to six climate risk categories (see chapter 8). Finally, summary statistics about the projected changes and the risk categories were used to provide a comprehensive overview about the future climatic risks of the majority of European bumblebees (Chapter 10, Appendix 2).

6.2 Species distribution data

Species distribution data used for this atlas were collated within the EU FP7 project STEP (Potts *et al.*, 2011; http://www.step-project.net) and were published in an aggregated way on the website Atlas Hymenoptera (Rasmont & Iserbyt, 2014; http://www.atlashymenoptera.net/). Original data were kindly provided by a vast number of professional and citizen scientists (Tab. 6.1). By 28.12.2014 this database had 988,187 observation records for all 69 European bumblebees (for a list of species see chapter 7). From this extensive database all records (300,435) between 1970 and 2000 within a defined geographical frame (latitude from 35° to 72°N; longitude from -12°W to 32°E) were extracted and used in the species distribution models.

6.3 Geographic extent and resolution

Although the original geographic coverage of the Atlas Hymenoptera data is much wider, we restricted the geographic extent of the distribution data to avoid including areas with low sampling intensities and thus a likely high proportion of areas where a species is falsely assumed to be absent just because it has not been observed. Since such false absence data tend to increase with increasingly finer spatial resolutions and thus could lead to wrong or biased assessments of the species' climatic requirements, we aggregated the distributional data at a 50 km x 50 km UTM grid to increase the reliability of our models (Fig. 6.1).

Table 6.1. Major data providers (more than 99.9% data).

Provider	Country/Region	Number of records
P. Rasmont & E. Haubruge (BDFGM)	Europe	426,559
S.P.M. Roberts (BWARS)	UK	112,313
B. Cederberg (SSIC)	Sweden	97,448
J. Neumayer	Austria	90,053
M. Reemer (EISN)	The Netherlands	76,427
F. Odegaard (NSIC)	Norway	52,713
Y. Gonseth (CSCF)	Switzerland	40,810
T. Pawlikowski	Poland	21,734
U. Fitzpatrick (NBDC)	Ireland	15,358
J. Paukkunen (FMNH)	Finland	14,367
J. Straka & L. Dvorak	Czech Republic	9,671
J. D'Haeseler (WID)	Belgium	9,857
G. Mahé	France	9,156
A. Manino	Italy	2,551
L. Castro	Spain	1,962
L. Baliteau	France	1,538
K. Mandery (BUWB; website)	Germany	1,070
M. Cornalba	Italy	945
D. Laget (UGent)	Belgium	422
N. Filipov	Russia	104
X. Lair	France	280
A. Gogala	Slovenia	268
A. Jenic	Slovenia	241
A. Chorein	France	199
A. Bertsch (website)	Germany	196
D. Baldock	Portugal	249
S. Bailey	France	122
M. Quaranta	Italy	117
EU FP6 project ALARM	Europe	98
D. Roustide	France	59
P. Sima	Slovakia	58
E. Budrys	Lithuania	27
R.Barbattini	Italy	26
T. Petanidou	Greece	13
F. Burger	Germany	7
Others		1169
Total		**988,187**

The geographic extent of the considered area ranged from -12° W to 32° E longitude and from 35° to 72° N latitude (Fig. 6.1) and included the whole of Europe and the northern parts of Morocco, Algeria and Tunisia in Africa.

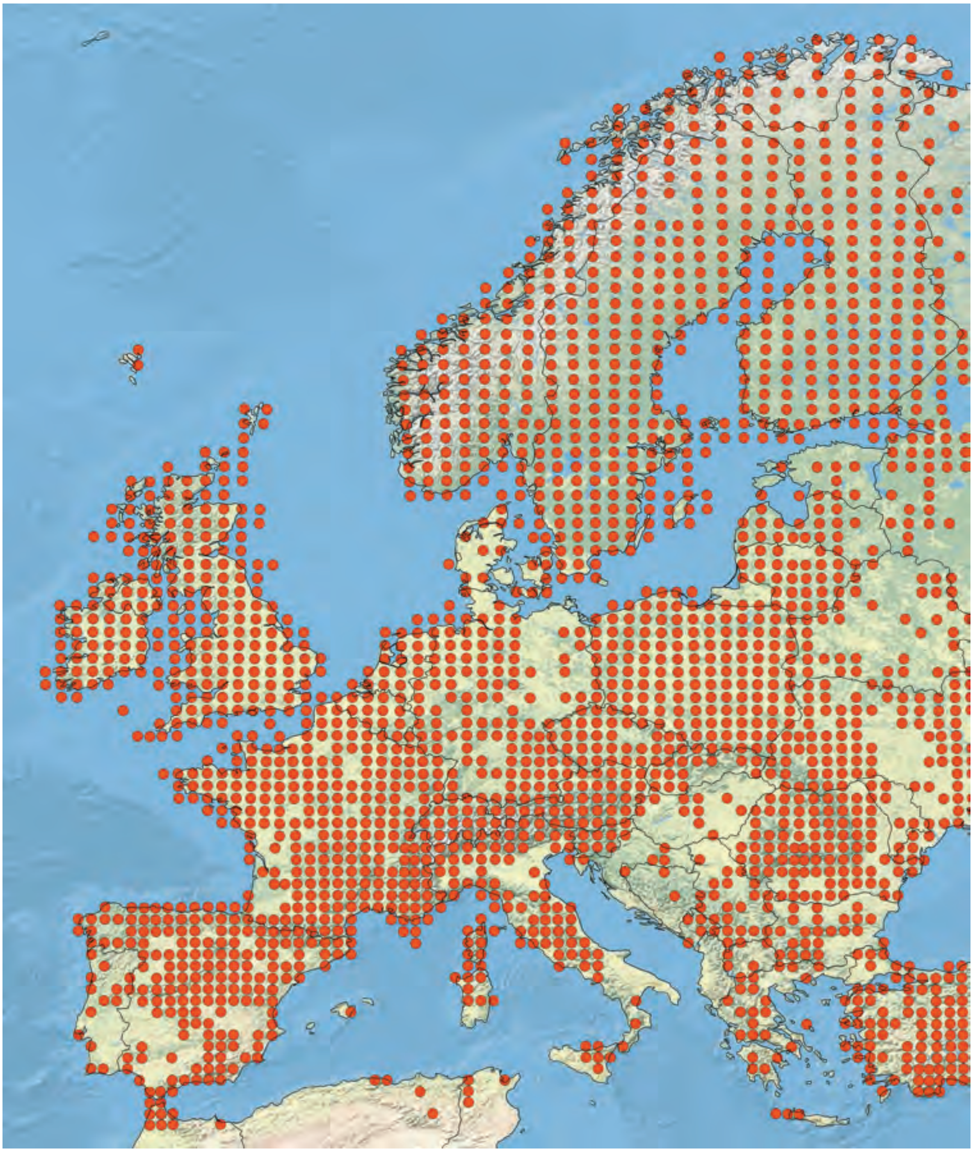


Figure 6.1. The study area and all 50 km x 50 km UTM grids used in the species distribution modelling represented by a dot.

6.4 Current climate data

The climatic niches of bumblebees were modelled using monthly interpolated climate data (New *et al.*, 2000; Mitchell *et al.*, 2004) aggregated to the same 50 km x 50 km UTM grid as was used for the species distribution data. Mean values of the following 27 climate variables (absolute values and annual variations) for the period 1971-2000 were considered for the analysis of the climatic requirements of the bumblebees:

- annual temperature (°C);
- temperature seasonality (calculated as the range between hottest and coldest month; °C);
- quarterly temperature (e.g. March - May = spring; °C);
- quarterly temperature seasonality (°C);
- diurnal temperature range per year (°C);
- diurnal temperature range per quarter (°C);
- annual precipitation sum (mm);
- precipitation seasonality (calculated as the range between wettest and driest month; mm);
- quarterly summed precipitation (mm);
- quarterly precipitation seasonality (mm);
- annual cloudiness (%);
- quarterly cloudiness (%).

Climatic variables, especially those measuring similar entities such as for instance mean annual temperature and mean summer temperature, are often highly correlated and their information content is thus highly redundant. Such collinearities among environmental variables can cause problems for the assessment of the climatic requirements of single species (Dormann *et al.*, 2013). To avoid such biases we selected ecological relevant and least correlated variables by means of cluster analysis. The threshold for variable selection was a Pearson correlation coefficient lower than 0.3 (Graham, 2003).

The selected variables to assess the climatic requirements of each bumblebee species were:

- mean annual temperature (Fig. 6.2);
- annual precipitation sum (Fig. 6.3);
- temperature seasonality (reflecting continentality ; Fig. 6.4);
- precipitation seasonality (reflecting oceanity; Fig. 6.5).

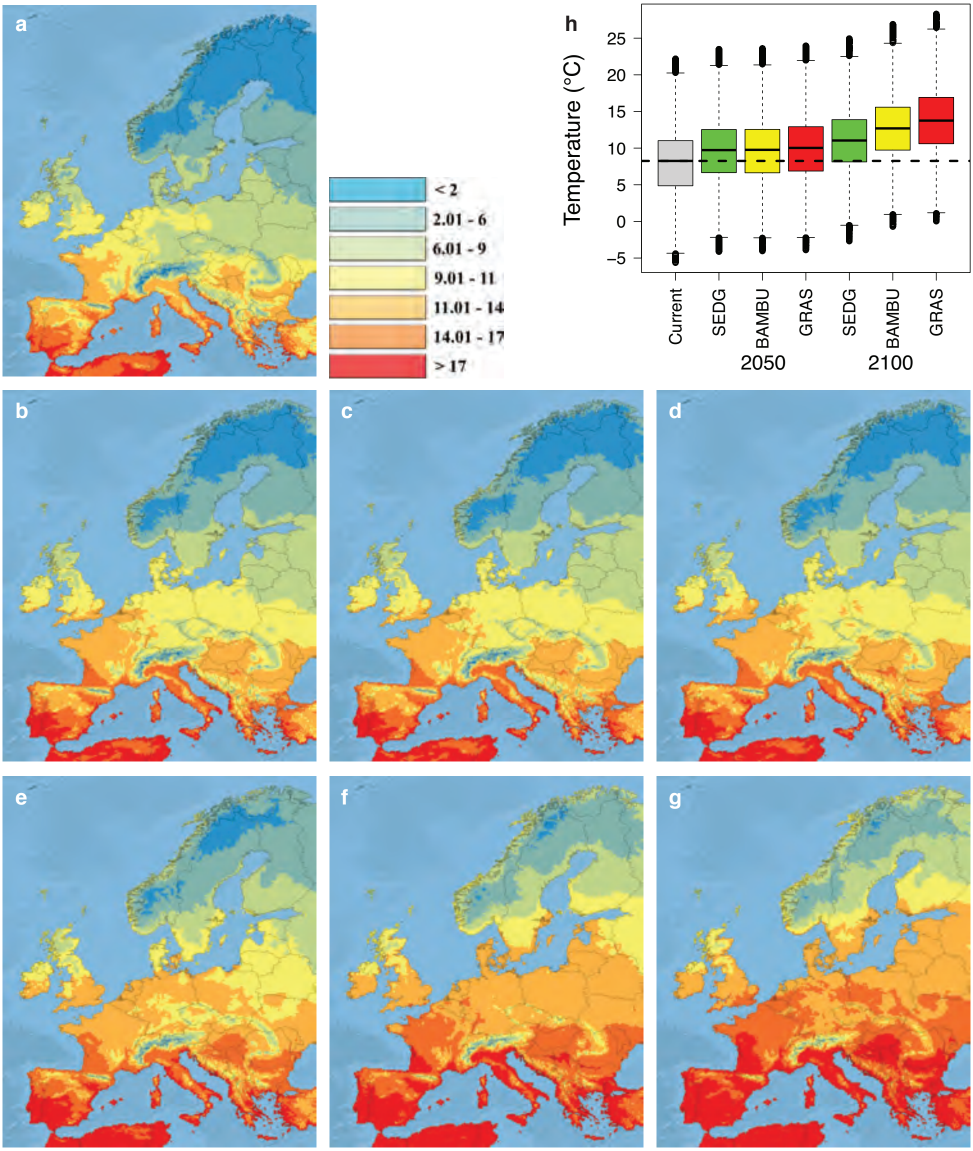


Figure 6.2. Mean annual temperature. (a) Current conditions (1971-2000); (b, c, d) future conditions for 2050; (e, f, g) future conditions for 2100; (b, e) moderate change scenario (SEDG); (c, f) intermediate change scenario (BAMBU); (d, g) severe change scenario (GRAS); (h) Boxplot of temperature conditions and projected changes across all 10 min x 10 min grid cells of the selected geographic window for 2050 and 2100 under three climate change scenarios. The black bar within the box represents the median value; box boundaries show the interquartile range. Whiskers show data points that are no more than 1.5 times the interquartile range on both sides. Open circles identify outliers. Horizontal dashed line shows the median value for current conditions.

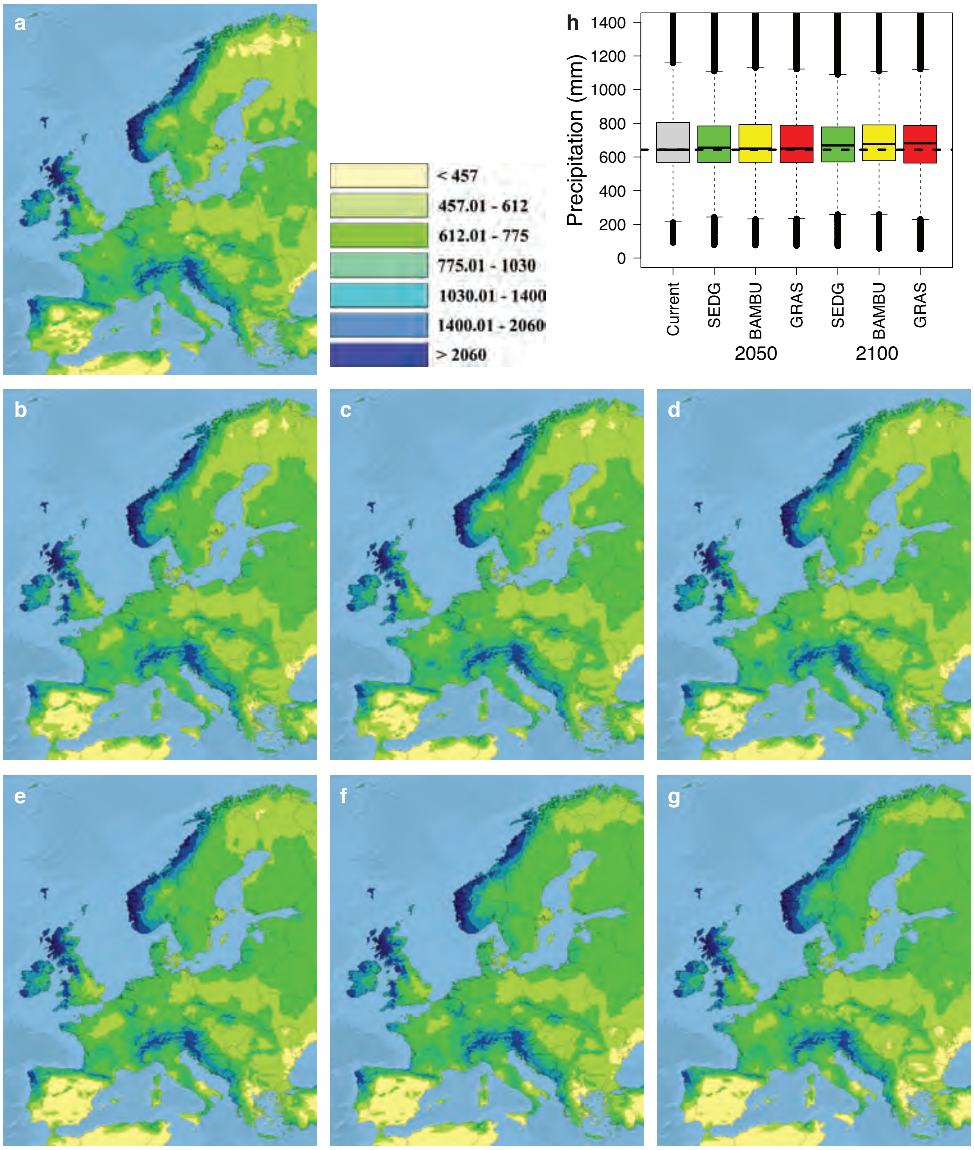


Figure 6.3. Annual precipitation sum. (a) Current conditions (1971-2000); (b, c, d) future conditions for 2050; (e, f, g) future conditions for 2100; (b, e) moderate change scenario (SEDG); (c, f) intermediate change scenario (BAMBU); (d, g) severe change scenario (GRAS); (h) Boxplot of precipitation conditions and projected changes across all 10 min x 10 min grid cells of the selected geographic window for 2050 and 2100 under three climate change scenarios. The black bar within the box represents the median value; box boundaries show the interquartile range. Whiskers show data points that are no more than 1.5 times the interquartile range on both sides. Open circles identify outliers, note that extreme outliers have been cutt off for means of better visualisation. Horizontal dashed line shows the median value for current conditions.

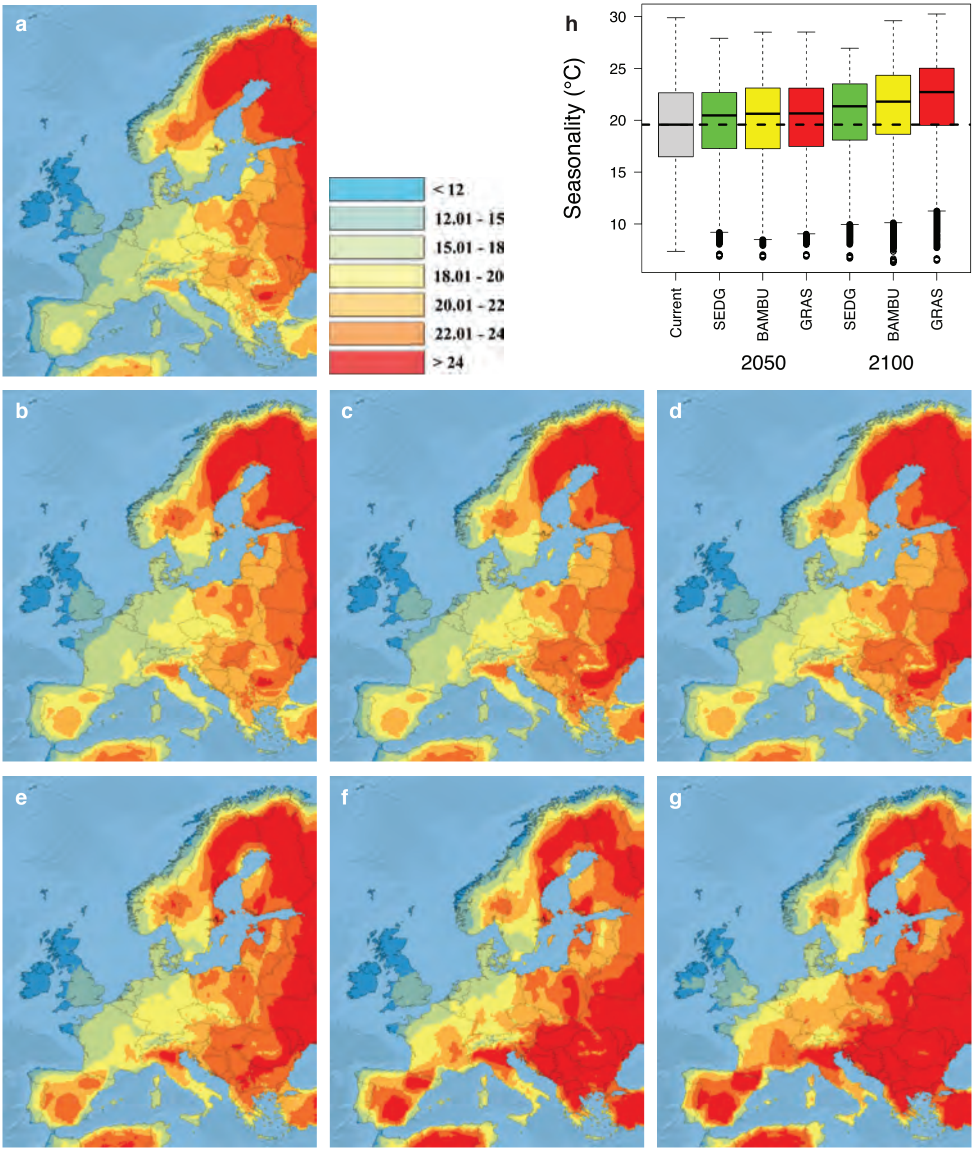


Figure 6.4. Temperature seasonality. (a) Current conditions (1971-2000); (b, c, d) future conditions for 2050; (e, f, g) future conditions for 2100; (b, e) moderate change scenario (SEDG); (c, f) intermediate change scenario (BAMBU); (d, g) severe change scenario (GRAS); (h) Boxplot of temperature seasonality and projected changes across all 10 min x 10 min grid cells of the selected geographic window for 2050 and 2100 under three climate change scenarios. The black bar within the box represents the median value; box boundaries show the interquartile range. Whiskers show data points that are no more than 1.5 times the interquartile range on both sides. Open circles identify outliers. Horizontal dashed line shows the median value for current conditions.

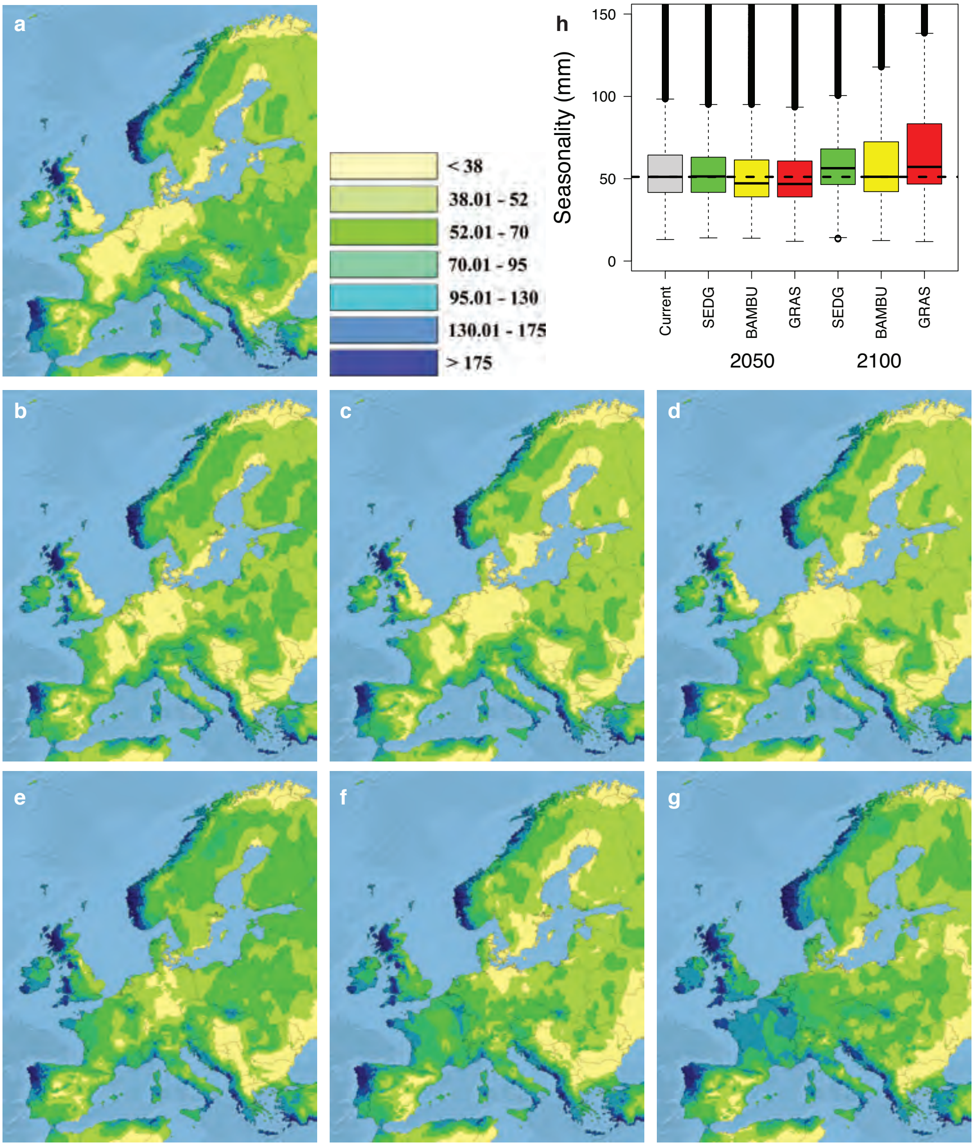


Figure 6.5. Precipitation seasonality. (a) Current conditions (1971-2000); (b, c, d) future conditions for 2050; (e, f, g) future conditions for 2100; (b, e) moderate change scenario (SEDG); (c, f) intermediate change scenario (BAMBU); (d, g) severe change scenario (GRAS); (h) Boxplot of precipitation seasonality and projected changes across all 10 min x 10 min grid cells of the selected geographic window for 2050 and 2100 under three climate change scenarios. The black bar within the box represents the median value; box boundaries show the interquartile range. Whiskers show data points that are no more than 1.5 times the interquartile range on both sides. Open circles identify outliers, note that extreme outliers have been cutt off for means of better visualisation. Horizontal dashed line shows the median value for current conditions.

6.5 Scenarios of climate change

Current and future climatic conditions are predominantly determined by anthropogenic activities which affect the concentrations of greenhouse gases in the atmosphere (IPCC, 2013). To assess the effects of future climate change on biodiversity, we need to rely on scenarios. Since future changes in greenhouse gas emissions depend on a large variety of factors such as political decisions, demographic change and sociological, economic and technical developments, nobody can actually foresee future conditions. In this context scenarios can be a strong tool but they must not be mistaken. They are not predictions but they can help to illustrate possible future developments (European Environment Agency, 2009) following a "what – if" approach. For instance, what will happen if we continue like we do now, or establish successful mitigation actions, or follow a path of even higher greenhouse gas emissions? By applying such different scenarios of different potential future human developments and corresponding effects on the climate, we can get an idea on the range of resulting risks for biodiversity but also on the scope and need of action in many fields starting from local conservation management to EU-level policies.

During the production process of the atlas it was not possible to integrate the most recent global change scenarios (Representative Concentration Pathways, RCPs) as they have been used in the 5th Assessment Report of the IPCC, but we used three scenarios which are based on storylines developed within the EU FP6 project ALARM (Settele *et al.*, 2005; Spangenberg *et al.*, 2012). These scenarios integrated the IPCC (2001) Special Report on Emission Scenarios (SRES). These future climate scenarios were developed on the basis of a coupled Atmosphere-Ocean General Circulation Model (HadCM3; New *et al.*, 2000).

The three scenarios were:

1. SEDG, **S**ustainable **E**uropean **D**evelopment **G**oal scenario – a storyline for moderate change. A policy primacy scenario focused on the achievement of a socially, environmentally and economically sustainable development. It includes attempts to enhance the sustainability of societal developments by integrating economic, social and environment policies. Aims actively pursued include a competitive economy, a healthy environment, social justice, gender equity and international cooperation. As a normative back-casting scenario, policies are derived from the imperative of stabilising atmospheric greenhouse gas concentrations and ending biodiversity loss. This scenario approximates the IPCC B1 climate change scenario. Mean expected temperature increase in Europe until 2100 is 3.0°C.

2. BAMBU, **B**usiness-**A**s-**M**ight-**B**e-**U**sual scenario – a storyline for intermediate change. A continuation into the future of currently known and foreseeable socio-economic and policy trajectories. Policy decisions already made are implemented and enforced. At the national level, deregulation and privatisation continue except in "strategic areas". Internationally, there is free trade. Environmental policy is perceived as another technological challenge, tackled by innovation, market incentives and some legal regulation. The result is a rather mixed bag of market liberalism and socio-environmental sustainability policy. This scenario approximates the IPCC A2 climate change scenario. Mean expected increase in temperature until 2100 is 4.7°C.

3. GRAS, **GR**owth **A**pplied **S**trategy scenario – a storyline for maximum change. A future world based on economic imperatives like primacy of the market, free trade, and globalisation. Deregulation (with certain limits) is a key means, and economic growth a key objective of politics actively pursued by governments. Environmental policy will focus on damage repair (supported by liability legislation) and some preventive action. The latter are designed based on cost-benefit calculations and thus limited in scale and scope. This scenario approximates the IPCC A1FI climate change scenario. Mean expected increase in temperature until 2100 is 5.6°C.

Projections of future climatic changes resulting from each scenario were developed on a 10 min x 10 min grid and intersected with the geographic window used in this atlas. Relevant monthly projected climate data were averaged for the two periods 2021-2050 and 2071-2100.

6.6 Species distribution models

To assess the climatic niche of the bumblebee species, we related the presences and absences of the species, aggregated to the 50 km x 50 km UTM grid, to the respective climatic conditions per grid cell by means of statistical species distribution models (SDMs). SDMs were developed with generalised linear models (GLMs) with a binomial error distribution and a logit link function. Since GLMs can be sensitive to false absence data, where a species has not been observed although it is actually present in a grid cell, we excluded grids without any bumblebee observation and an additional 51 grids with observations of one species. In total we used 2160 grid cells (Fig. 6.1). For the development of the SDMs we used species records from 1970 to 2000 to match the temporal resolution of the current climate data. For the parameterisation of the SDMs we allowed for additive and curvilinear effects by incorporating second order polynomials. Models were checked for spatial autocorrelation with Moran's I correlograms of model residuals, but none was detected. Initial models were simplified by stepwise regression, while minimizing Akaike's information criterion. Models were calibrated on an 80% random sample of the initial data set and model accuracy was evaluated on the remaining 20%. Agreements between observed presences and projected distributions were evaluated by true skill statistic (TSS) and the area und the curve (AUC) of the receiver operating characteristic. TSS is a simple and intuitive measure for the performance of species distribution models when predictions are expressed as presence-absence maps and handle shortcomings of other measures such as kappa (Allouche *et al.*, 2006). Thresholds for calculating presence-absences and projections were obtained by maximizing TSS. To allow comparability with Settele *et al.* (2008) we also calculated AUC which is a threshold-independent measure of model performance. While the climatic niche models were developed at the 50 km × 50 km UTM grid, the current climatic niche and future climatic niche were projected to 10 min × 10 min grid cells. According to the projected future conditions of climatically suitable areas in comparison with the predictions for current conditions, we mapped the resulting changes indicating areas of potential loss, potential gain and remaining suitable conditions. These changes were mapped within the geographical window across Europe used for this atlas. SDMs were developed in the statistical environment R (R Development Core Team, 2013). All maps were based on the WGS1984 coordinate system with a Miller cylindrical projection using ArcGIS software (ESRI, 2013).

6.7 Change categories

To assess the projected changes in climatically suitable areas, we provide tables with the net changes in numbers of grid cells and percentage changes. To ease the interpretation of these values, we also provide a colour code where we aggregated the projected changes into groups ranging from strong expansion to strong regression (Tab. 6.2).

Table 6.2. Colour codes to assess the severity of projected changes in climatically suitable areas.

Change intensity	**Percentage change colour code**
Strong expansion	> +80%
Expansion	20 to 80%
No or low changes	-20 to +20%
Moderate regression	-20 to -50%
Strong regression	-50 to -80%
Very strong regression, with extinction risks	-80 to -100%

6.8 Dispersal abilities

The severity of geographical changes in the areas of suitable climatic conditions critically depends on the ability of the species to keep track with these changes. However, detailed data on the dispersal ability do not exist for most of the species. Thus, it is not possible to explicitly include dispersal in the assessments of potential future distributions of the bumblebees. Consequently, we provide information on the severity of the effects of climate change based on two extreme assumptions:

- Unlimited dispersal, in which the entire projected future climatically suitable area can be colonised in principle.
- No dispersal, in which the future climatically suitable area results from the overlap of current and future suitable area and the species can only lose areas with suitable conditions.

However, based on ecological behaviour of each species, it is possible to provide a rough indication about the potential dispersal abilities of each species. Based on the criteria below two authors (PR and TL) performed expert classifications of each species into either low or high dispersal ability (Tab. 7.1). This classification can be used as an aid to decide which of the both assumptions in the future projections is more likely – full or no dispersal abilities.

Low dispersal ability was assigned for species exhibiting the following characteristics:
- Species restricted to high altitudes or high latitudes in mountain areas
- Insular species
- Species with a highly fragmented distribution with obvious subspecific differentiation
- Habitat specialist species
- Dietary specialist species
- Parasites of species with low dispersal abilities
- Species that have been unable to colonise islands

High dispersal ability was assigned for species exhibiting the following characteristics:
- Species living in low altitude areas
- Continental species
- Species with low subspecific differentiation
- Species with apparently continuous distribution
- Habitat generalists
- Dietary generalists
- Parasites of species with high dispersal abilities
- Species with recent range expansions

6.9 Definitions of climate change risk categories for European bumblebees

We also adapted the system of Settele *et al.* (2008) and placed each bumblebee species assessed in a risk category according to the loss of grid cells with suitable climatic conditions in each climate change scenario. Categories were only assigned for species whose distributions were modelled reasonably accurately (AUC > 0.75). Species whose distributions were not modelled reasonably accurately were assigned to the category "PR – Potential climate change risk". The categories of model quality are as follows:

AUC > 0.95: Present distribution can be very well explained by climatic variables
AUC > 0.85 – 0.95: Present distribution can be well explained by climatic variables
AUC > 0.75 – 0.85: Present distribution can be explained by climatic variables to a moderate extent
AUC ≤ 0.75: Present distribution can be explained by climatic variables to only a limited extent

The climate risk categories which have been defined based on from the analysis and which are used throughout the atlas are as follows:

Category	Risk	% loss of grid cells	AUC
HHHR	extremely high climate change risk	> 95	> 0.75
HHR	very high climate change risk	> 85 – 95	> 0.75
HR	high climate change risk	> 70 – 85	> 0.75
R	climate change risk	> 50 – 70	> 0.75
LR	lower climate change risk	≤ 50	> 0.75
PR	potential climate change risk	0 - 100	≤ 0.75

The overall risk categories are integrated across all scenarios and time steps and are defined as follows:

HHHR (extremely high climate change risk): Climate change poses a very high risk to the species because more than 95% of the grids with currently suitable climate may no longer be suitable in 2100 under at least one scenario (under the “no dispersal” assumption). Present distribution can be explained by climatic variables at least to a moderate extent (AUC > 0.75).

HHR (very high climate change risk): Climate change poses a very high risk to the species because more than 85% of the grids with currently suitable climate may no longer be suitable in 2100 under at least one scenario (under the “no dispersal” assumption). Present distribution can be explained by climatic variables at least to a moderate extent (AUC > 0.75).

HR (high climate change risk): Climate change poses a high risk to the species because more than 70% of the grids with currently suitable climate may no longer be suitable in 2100 under at least one scenario (under the “no dispersal” assumption). Present distribution can be explained by climatic variables at least to a moderate extent (AUC > 0.75).

R (climate change risk): Climate change poses a risk to the species because more than 50% of the grids with currently suitable climate may no longer be suitable in 2100 under at least one scenario (under the "no dispersal" assumption). Present distribution can be explained by climatic variables at least to a moderate extent (AUC > 0.75).

LR (lower climate change risk): Climate change poses a lower risk to the species because 50% or less of the grids with currently suitable climate may no longer be suitable in 2100 under at least one scenario (under the "no dispersal" assumption). Present distribution can be explained by climatic variables at least to a moderate extent (AUC > 0.75).

PR (potential climate change risk): At the moment, climate change can only be regarded as a potential risk for the species' long-term survival in Europe. All species whose present distribution can be explained by climatic variables to only a limited extent (AUC: ≤ 0.75) have been categorised as PR, independent of the rate of decline of their climatic niche distribution.

Bombus polaris. This species currently has a restricted range in the Scandinavian mountains and Arctic tundra. Even the most optimistic scenario projects that the species will lose the largest part of its climatically suitable area. It is at risk of extinction in Europe as soon as 2050. Photo G. Holmström.

7. Checklist of the European bumblebee species

According to current taxonomic knowledge we recognise 79 West-Palaearctic bumblebee species (Tab. 7.1). Detailed, and up-to-date, distribution maps are provided at the end of this atlas and can also be found online (Rasmont & Iserbyt, 2014).

Eleven West-Palaearctic species do not occur in our defined European window. From the remaining 69 species we could not model a further 13 species either because their range is too small (five species), their distribution cannot be modelled reliably with climate data only (four species) or because of taxonomic issues (four species; Tab. 7.1). Range maps of all 13 non-modelled species are presented and discussed in chapter 9. In total we modelled 56 species.

There is presently no general key to allow the identification of all European bumblebee species. However several regional keys or keys specific to some subgenera are available (Pittioni, 1938; Løken, 1973, 1984; Alford, 1975; Rasmont & Adamski, 1995; Amiet, 1996; Ornosa & Ortiz-Sánchez, 2004; Edwards & Jenner, 2009; Intoppa *et al.*, 2009; Williams *et al.*, 2011, 2012; Prys-Jones & Corbet, 2011).

Table 7.1. West-Palaearctic bumblebees. Subgeneric taxonomy follows Williams *et al.* (2008). Species are sorted alphabetically.

Scientific name	**Modelled species page**	**Not modelled**	**Distribution outside modelling frame**	**Taxonomically problematic species**	**Inquiline species**	**Distribution map page**
Bombus (Melanobombus) alagesianus Reinig, 1930			177			213
Bombus (Alpinobombus) alpinus (L., 1758)	32					213
Bombus (Megabombus) argillaceus (Scopoli, 1763)	34					213
Bombus (Thoracobombus) armeniacus Radoszkowski, 1877		148				213
Bombus (Alpinobombus) balteatus Dahlbom, 1832	36					214
Bombus (Psithyrus) barbutellus (Kirby, 1802)	38			●	●	214

Bombus (Psithyrus) bohemicus Seidl, 1838	40				●	214
Bombus (Rhodobombus) brodmanni Skorikov, 1911		145				213
Bombus (Pyrobombus) brodmannicus Vogt, 1909		146				215
Bombus (Psithyrus) campestris (Panzer, 1801)	42				●	215
Bombus (Melanobombus) caucasicus Radoszkowski, 1859			212	●		218
Bombus (Pyrobombus) cingulatus Wahlberg, 1854	44					215
Bombus (Bombias) confusus Schenck, 1861	46			●		215
Bombus (Megabombus) consobrinus Dahlbom, 1832	48					216
Bombus (Bombus) cryptarum (Fabricius, 1775)	50			●		216
Bombus (Cullumanobombus) cullumanus (Kirby, 1802)	52			●		216
Bombus (Thoracobombus) deuteronymus Schulz, 1879		148		●		217
Bombus (Subterraneobombus) distinguendus Morawitz, 1869	54					217
Bombus (Psithyrus) flavidus Eversmann, 1852	56				●	217
Bombus (Subterraneobombus) fragrans (Pallas, 1771)	58					218
Bombus (Megabombus) gerstaeckeri Morawitz, 1881	60					218
Bombus (Pyrobombus) glacialis Friese, 1902			153	●		218
Bombus (Pyrobombus) haematurus Kriechbaumer, 1870	62					218
Bombus (Mendacibombus) handlirschianus Vogt, 1909			212	●		218
Bombus (Megabombus) hortorum (L., 1761)	64			●		219
Bombus (Thoracobombus) humilis Illiger, 1806	66					219
Bombus (Alpinobombus) hyperboreus Schönherr, 1809	68				●	219
Bombus (Pyrobombus) hypnorum (L., 1758)	70					220
Bombus (Melanobombus) incertus Morawitz, 1881	72					218
Bombus (Thoracobombus) inexspectatus (Tkalců, 1963)	74				●	218
Bombus (Pyrobombus) jonellus (Kirby, 1802)	76					220
Bombus (Thoracobombus) laesus Morawitz, 1875		149		●		220
Bombus (Melanobombus) lapidarius (L., 1758)	78			●		221
Bombus (Pyrobombus) lapponicus (Fabricius, 1793)	80			●		221
Bombus (Bombus) lucorum (L., 1761)	82			●		221
Bombus (Bombus) magnus Vogt, 1911	84			●		222
Bombus (Subterraneobombus) melanurus Lepeletier, 1836			212			222
Bombus (Mendacibombus) mendax Gerstäcker, 1869	86					222
Bombus (Thoracobombus) mesomelas Gerstäcker, 1869	88					222
Bombus (Thoracobombus) mlokosievitzii Radoszkowski, 1877		146				222
Bombus (Thoracobombus) mocsaryi Kriechbaumer,1877		149		●		223
Bombus (Pyrobombus) modestus Eversmann, 1852			178			222
Bombus (Pyrobombus) monticola Smith, 1849	90			●		223

Bombus (Thoracobombus) mucidus Gerstäcker, 1869	92					223
Bombus (Thoracobombus) muscorum (L., 1758)	94			●		224
Bombus (Sibiricobombus) niveatus Kriechbaumer, 1870	96			●		223
Bombus (Psithyrus) norvegicus (Sparre-Schneider, 1918)	98				●	224
Bombus (Thoracobombus) pascuorum (Scopoli, 1763)	100					225
Bombus (Bombus) patagiatus Nylander, 1848		146				224
Bombus (Psithyrus) perezi (Schulthess-Rechberg, 1886)				●	●	232
Bombus (Thoracobombus) pereziellus (Skorikov, 1922)				●		225
Bombus (Thoracobombus) persicus Radoszkowski, 1881			212			224
Bombus (Alpinobombus) polaris Curtis, 1835	102					225
Bombus (Thoracobombus) pomorum (Panzer, 1805)	104					226
Bombus (Megabombus) portschinsky Radoszkowski, 1883			211			225
Bombus (Pyrobombus) pratorum (L., 1761)	106					226
Bombus (Pyrobombus) pyrenaeus Pérez, 1879	108					225
Bombus (Psithyrus) quadricolor (Lepeletier, 1832)	110				●	226
Bombus (Megabombus) reinigiellus (Rasmont, 1983)		147		●		227
Bombus (Bombus) renardi Radoszkowski, 1881		151		●		227
Bombus (Thoracobombus) ruderarius (Müller, 1776)	112					227
Bombus (Megabombus) ruderatus (Fabricius, 1775)	114			●		227
Bombus (Psithyrus) rupestris (Fabricius, 1793)	116				●	228
Bombus (Megabombus) saltuarius (Skorikov, 1931)			211			229
Bombus (Thoracobombus) schrencki Morawitz, 1881	118					228
Bombus (Cullumanobombus) semenoviellus Skorikov, 1910	120					228
Bombus (Melanobombus) sichelii Radoszkowski, 1859	122			●		229
Bombus (Kallobombus) soroeensis (Fabricius, 1776)	124					229
Bombus (Bombus) sporadicus Nylander, 1848	126					230
Bombus (subterraneobombus) subterraneus (L., 1758)	128					230
Bombus (Sibiricobombus) sulfureus Friese, 1905			212			229
Bombus (Thoracobombus) sylvarum (L., 1761)	130					230
Bombus (Psithyrus) sylvestris (Lepeletier, 1832)	132				●	231
Bombus (Bombus) terrestris (L., 1758)	134			●		231
Bombus (Thoracobombus) velox (Skorikov, 1914)			212			232
Bombus (Psithyrus) vestalis (Geoffroy, 1785)	136			●		232
Bombus (Thoracobombus) veteranus (Fabricius, 1793)	138					232
Bombus (Alpigenobombus) wurflenii Radoszkowski, 1859	140					233
Bombus (Bombus) xanthopus Kriechbaumer, 1873		151		●		232
Bombus (Thoracobombus) zonatus Smith, 1854	142					233

8. Climatic risks of European bumblebees

8.1 Colour codes

Scenario tables
From 80% gained area
Between 20% and 80% gained area
Between -20% and +20% area change
Between -20% and -50% lost area
Between -50% and -80% lost area
From -80% lost area

8.2 Risk categories

Category	Risk	% loss of grid cells	AUC
HHHR	extremely high climate change risk	> 95	> 0.75
HHR	very high climate change risk	> 85 – 95	> 0.75
HR	high climate change risk	> 70 – 85	> 0.75
R	climate change risk	> 50 – 70	> 0.75
LR	lower climate change risk	≤ 50	> 0.75
PR	potential climate change risk	0 - 100	≤ 0.75

Bombus alpinus. The global distribution of this species is presently restricted to high levels of the Alps, the Carpathian and Scandinavian mountains and to Arctic tundra of northern Fennoscandia. The species is expected to lose a substantial part of its climatic suitable area already in 2050 and could be driven to the verge of extinction in 2100. Photo G. Holmström.

Bombus niveatus. The global distribution of this species includes presently the Balkan Peninsula and Near Orient. Its climatically suitable area is expected to increase dramatically already by 2050 and still further by 2100. Depending to its seemingly high dispersal abilities, it is expected to expand its distribution in a large part of Europe. Photo P. Rasmont.

Bombus alpinus (L., 1758)

= *Bombus (Alpinobombus) alpinus*

© Photo: P. Rasmont

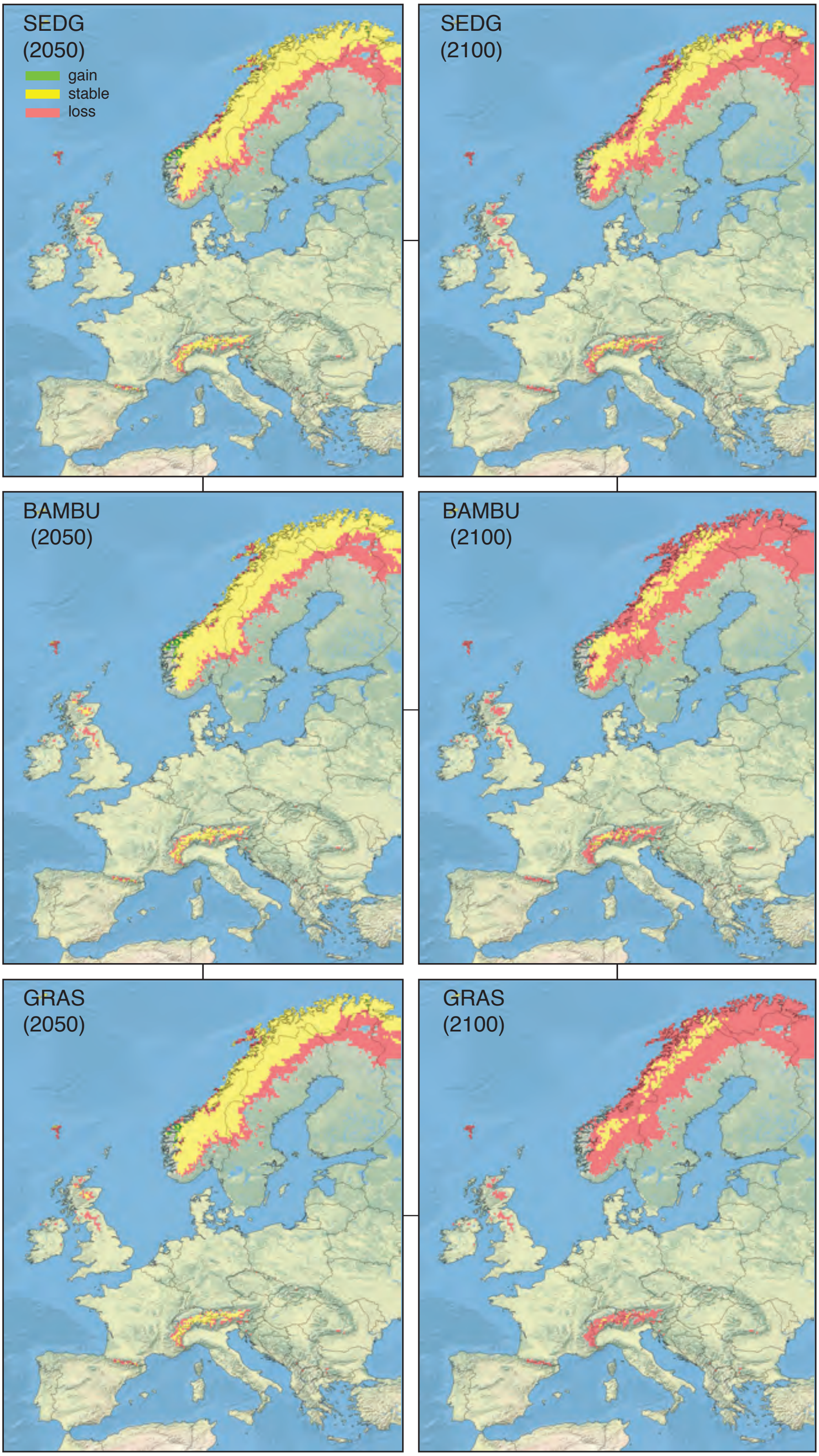
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus alpinus is a large bumblebee, present only in the Arctic tundra and high alpine grasslands. Its coat colour is quite invariable, with a black thorax and a largely reddish abdomen. It lives in small colonies and is a generalist forager. *Bombus alpinus* occurs at the highest elevations in the Alps and in the Scandinavian Mountains. It can also be found at the sea level along the northern coast of Norway. The modelled distribution shows that its climatic niche would be larger than its actual distribution. Indeed, despite the presence of available climatic conditions, it is absent from Pyrenees, British Isles and Iceland. All scenarios project that suitable areas will disappear from its southernmost locations in the Carpathians. The GRAS scenario projects a strong reduction of suitable climate space in the Alps and in the Scandinavian mountains, resulting in an increasingly fragmented distribution. Currently, the species seems to be in decline especially in the Alps and in the Carpathians and it is assessed as Vulnerable in the IUCN Red List of European Bees. The dispersal ability is unknown, but might be low as the species is associated with cold temperatures and occurs in small populations. It is projected to suffer considerably from global warming in all scenarios. It is projected to be at the verge of extinction by the year 2100.

Present distribution can be well explained by climatic variables (AUC = 0.95)
Climate risk category: HHR
IUCN Red List status: Vulnerable

	Scenario	Full dispersal	No dispersal
2050	SEDG	-1223 (-31%)	-1249 (-32%)
	BAMBU	-1155 (-29%)	-1198 (-31%)
	GRAS	-1370 (-35%)	-1392 (-36%)
2100	SEDG	-2241 (-57%)	-2246 (-57%)
	BAMBU	-3036 (-77%)	-3038 (-78%)
	GRAS	-3450 (-88%)	-3450 (-88%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
🟩 gain
🟨 stable
🟥 loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus argillaceus (SCOPOLI, 1763)

= *Bombus (Megabombus) argillaceus*

© Photo: G. Holmström

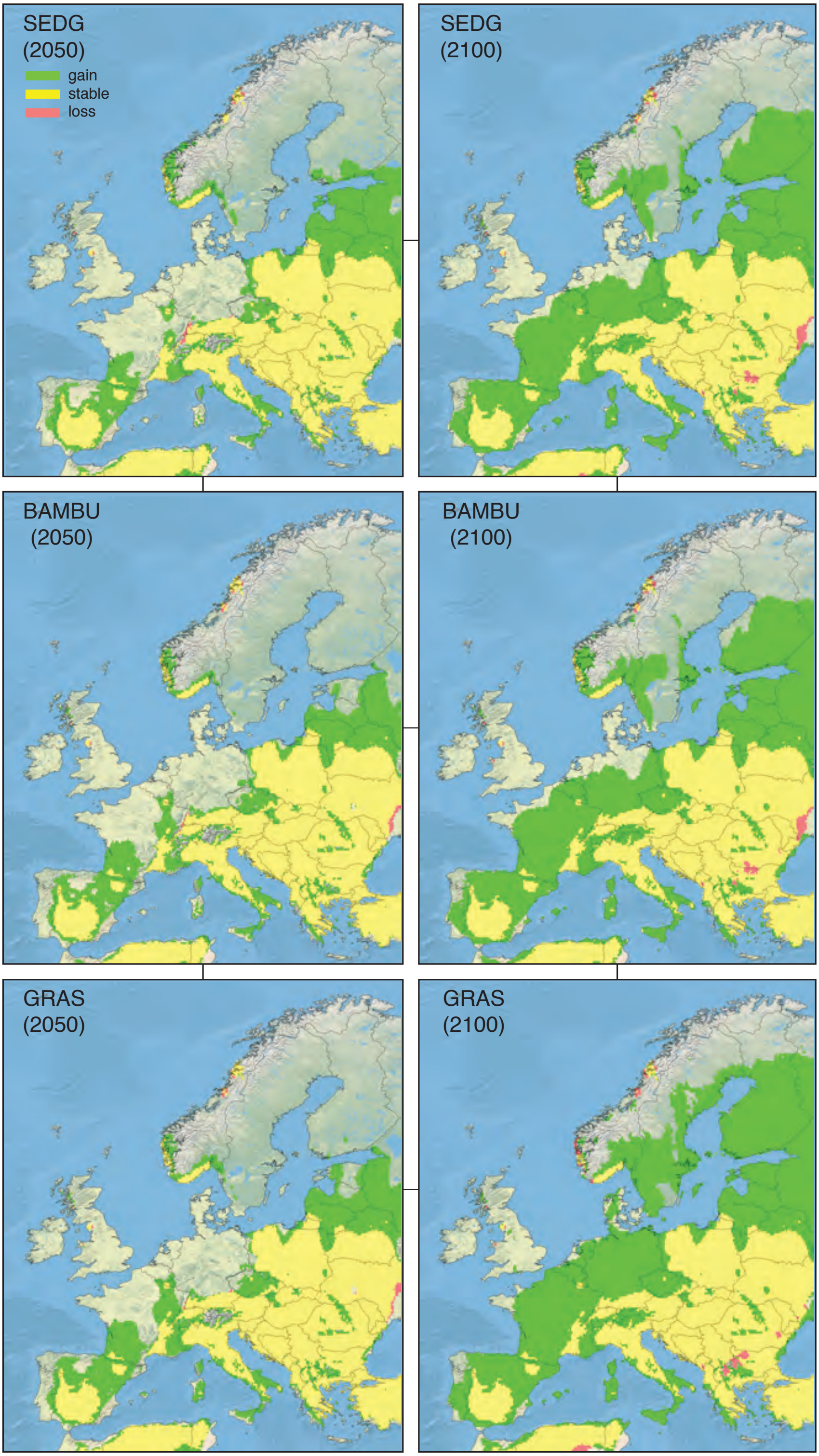
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus argillaceus is a very large bumblebee. The large queens show a unique colour pattern, being the only European species with a completely black abdomen. Males and workers show the same yellow bands but the tail is white. It is considered to be a generalist species but it prefers to forage from flowers with a long corolla which are best suited for its long tongue. It is abundant south of latitude 45° N; from south-east France to Ukraine and Turkey in the west to Iran in the east. It mainly lives in Mediterranean and sub-Mediterranean habitats where it produces large colonies. It is generally absent from high mountains. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. The modelled distribution shows that its climatic niche would include a wider area in eastern Europe, the Iberian peninsula and even in southern Scandinavia, from where it is absent at the moment. All scenarios project a large expansion. SEDG and GRAS project that its suitable areas could even reach as far north as the Arctic Circle by 2100. The GRAS scenario indicates that suitable areas could include all central Europe and a large part of western Europe and subarctic Scandinavia. The British Isles and Brittany seem to remain out of reach in all scenarios. As it is an unspecialised lowland species, we could assume that it would have a good dispersal capacity. The species is expected to benefit from climate change and will most likely expand its distribution range dramatically.

Present distribution can be well explained by climatic variables (AUC = 0.86)
Climate risk category: LR
IUCN Red List status: Least Concern

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	5462 (52%)	-44 (0%)
	BAMBU	4822 (46%)	-62 (-1%)
	GRAS	5359 (51%)	-64 (-1%)
2100	**SEDG**	9724 (92%)	-22 (0%)
	BAMBU	10980 (104%)	-184 (-2%)
	GRAS	13428 (127%)	-193 (-2%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus balteatus (Dahlbom, 1832)

= *Bombus (Alpinobombus) balteatus*

© Photo: P. Rasmont

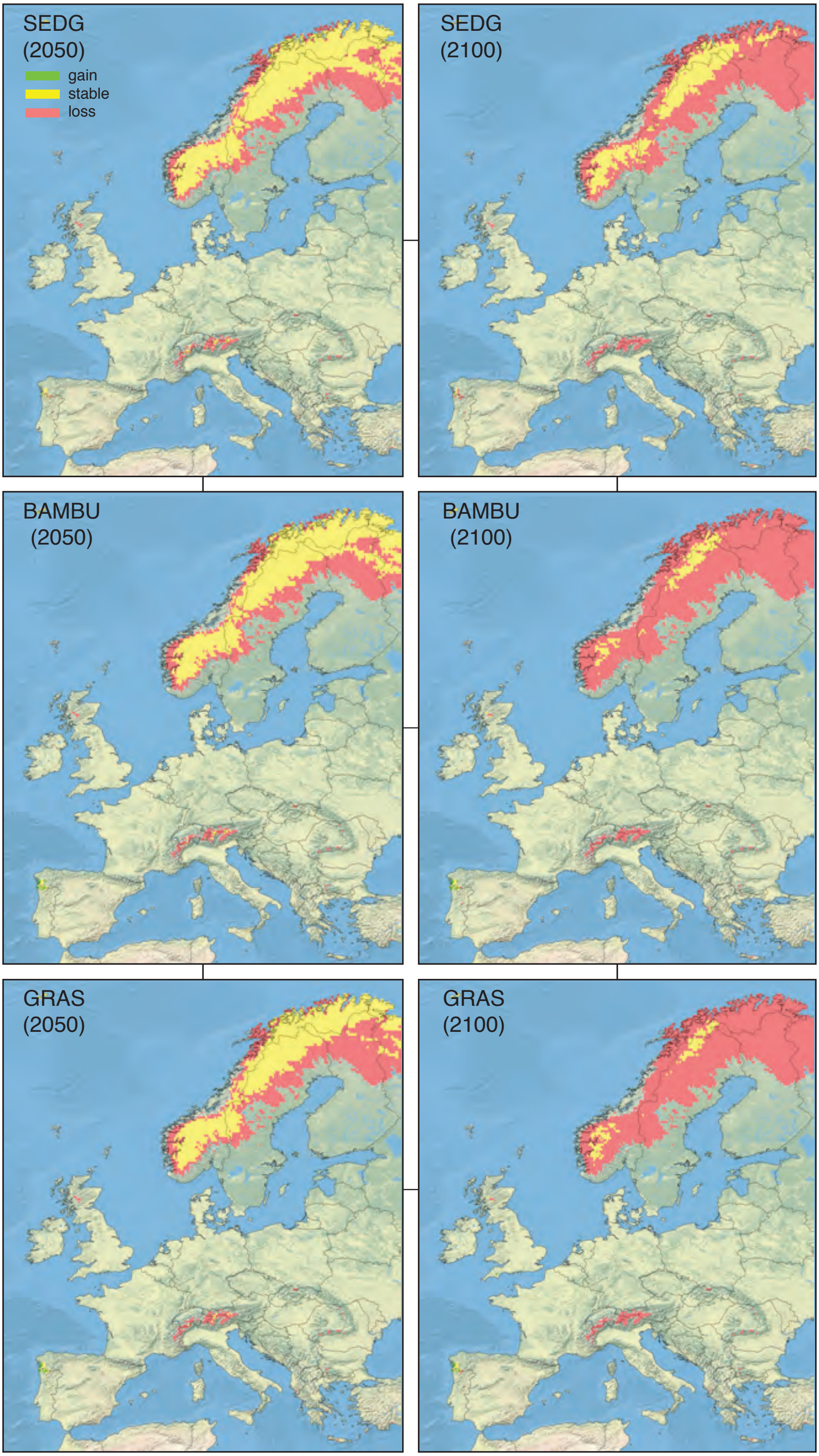
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus balteatus is a large bumblebee, with several colour forms, with or without yellow bands and with a white or red tail. It is a generalist forager. It is found only in alpine and subalpine areas of Scandinavia, northern Finland and northern Russia, with a circum-boreal distribution. *Bombus balteatus* mainly lives in the taiga and tundra where it produces medium-sized colonies. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. The modelled distribution shows that its climatic niche presently includes most of the southern European mountains, from where it is absent. All scenarios project a reduction of suitable areas. By 2100, it would be restricted to alpine areas, disappearing from lower altitudes even at northern latitudes along the Barents Sea shore. Regardless of its dispersal ability, as it is adapted to cold temperatures, *B. balteatus* is projected to suffer considerably from global warming.

Present distribution can be very well explained by climatic variables (AUC = 0.99)
Climate risk category: HHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-1730 (-41%)	-1731 (-41%)
	BAMBU	-1785 (-42%)	-1795 (-42%)
	GRAS	-2061 (-49%)	-2070 (-49%)
2100	SEDG	-3169 (-75%)	-3170 (-75%)
	BAMBU	-3915 (-92%)	-3926 (-92%)
	GRAS	-3973 (-94%)	-3982 (-94%)

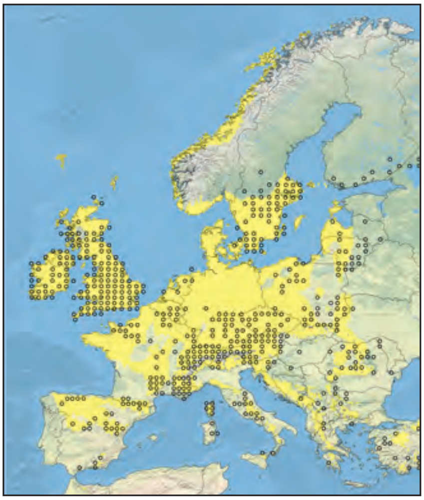
Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus barbutellus (Kirby, 1802)

= *Bombus (Psithyrus) barbutellus; Psithyrus barbutellus; Psithyrus maxillosus*

© Photo: P. Rasmont



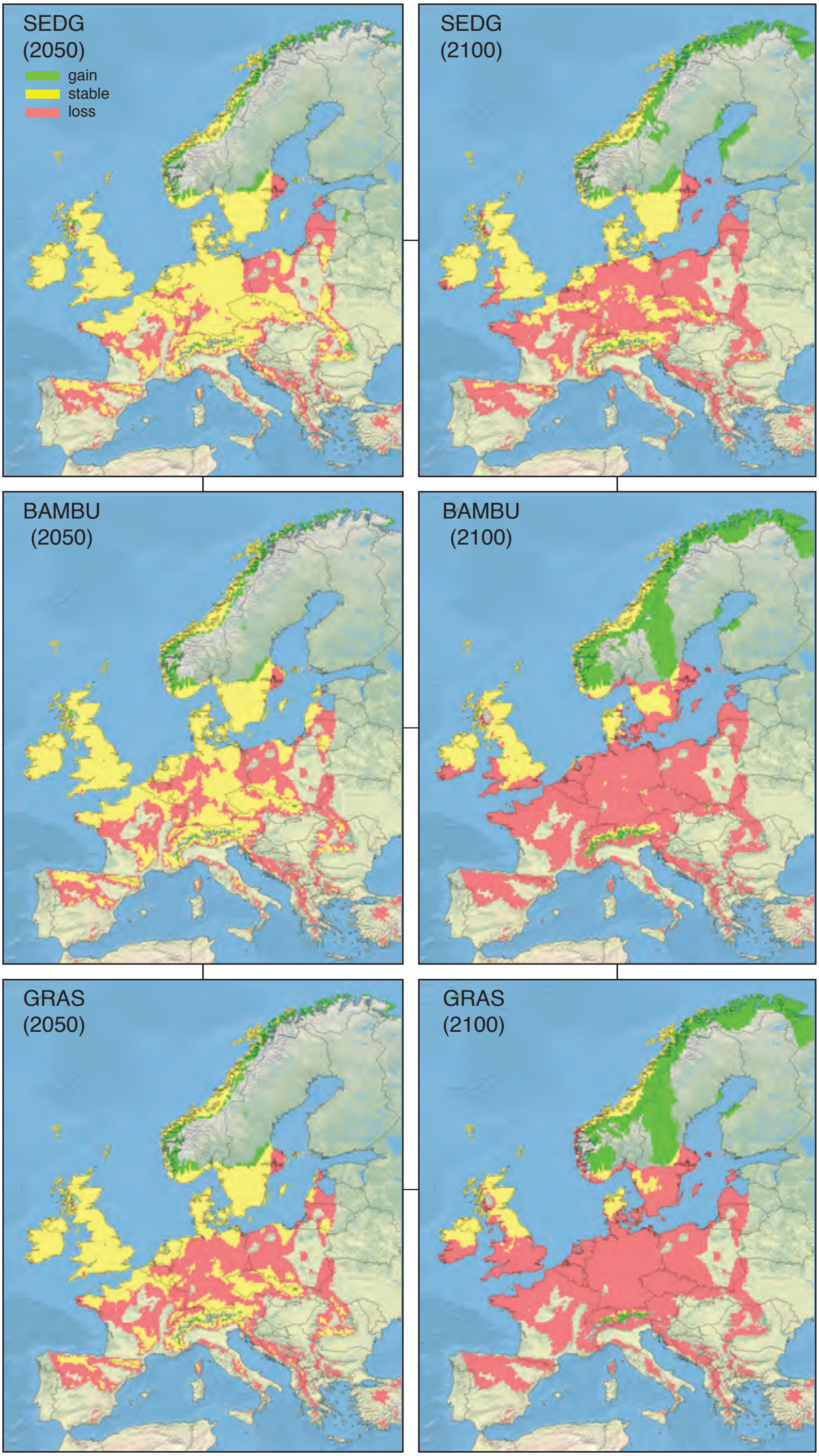
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus barbutellus is a medium-sized bumblebee. While populations close to its northern range margin have a coat colour with 3 yellow bands and a white tail, some southern populations can be nearly all black with very dark wings (ssp. maxillosus). It is a social parasite species (cuckoo-bumblebee) invading the nests primarily of *B. argillaceus*, *B. hortorum* and *B. ruderatus*. The species occurs across a large area from Spain in the south to Stockholm and Helsinki in the north and from Ireland in the west as far as to the Pacific coast in the east. It is however never abundant. The species has disappeared from most of its historic locations in the west- and central European lowlands. Despite this regional regression, the species is not considered to be threatened at a continental scale: Least Concern in the IUCN Red List of European Bees. The modelled distribution shows that its climatic niche includes a wider area along the Atlantic coast of west Norway from where it is absent. All scenarios project a fragmentation of the climatic space in central and south Europe and an expansion of its suitable areas into the Arctic Circle to the north. The GRAS scenario projects that suitable areas could completely disappear from all lowlands south of 55° N by 2100. As it is a cuckoo-bumblebee associated with only a few host species and has a scattered distribution, its dispersal ability is expected to be low and *B. barbutellus* would suffer considerably from climatic warming.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.76)
Climate risk category: HHR
IUCN Red List status: Least Concern

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	-2840 (-26%)	-3398 (-31%)
	BAMBU	-3700 (-33%)	-4237 (-38%)
	GRAS	-4797 (-43%)	-5378 (-48%)
2100	**SEDG**	-5475 (-49%)	-6665 (-60%)
	BAMBU	-6645 (-60%)	-8710 (-78%)
	GRAS	-7445 (-67%)	-9617 (-87%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus bohemicus SEIDL, 1837

= *Bombus (Psithyrus) bohemicus; Psithyrus bohemicus; Psithyrus distinctus*

© Photo: P. Rasmont

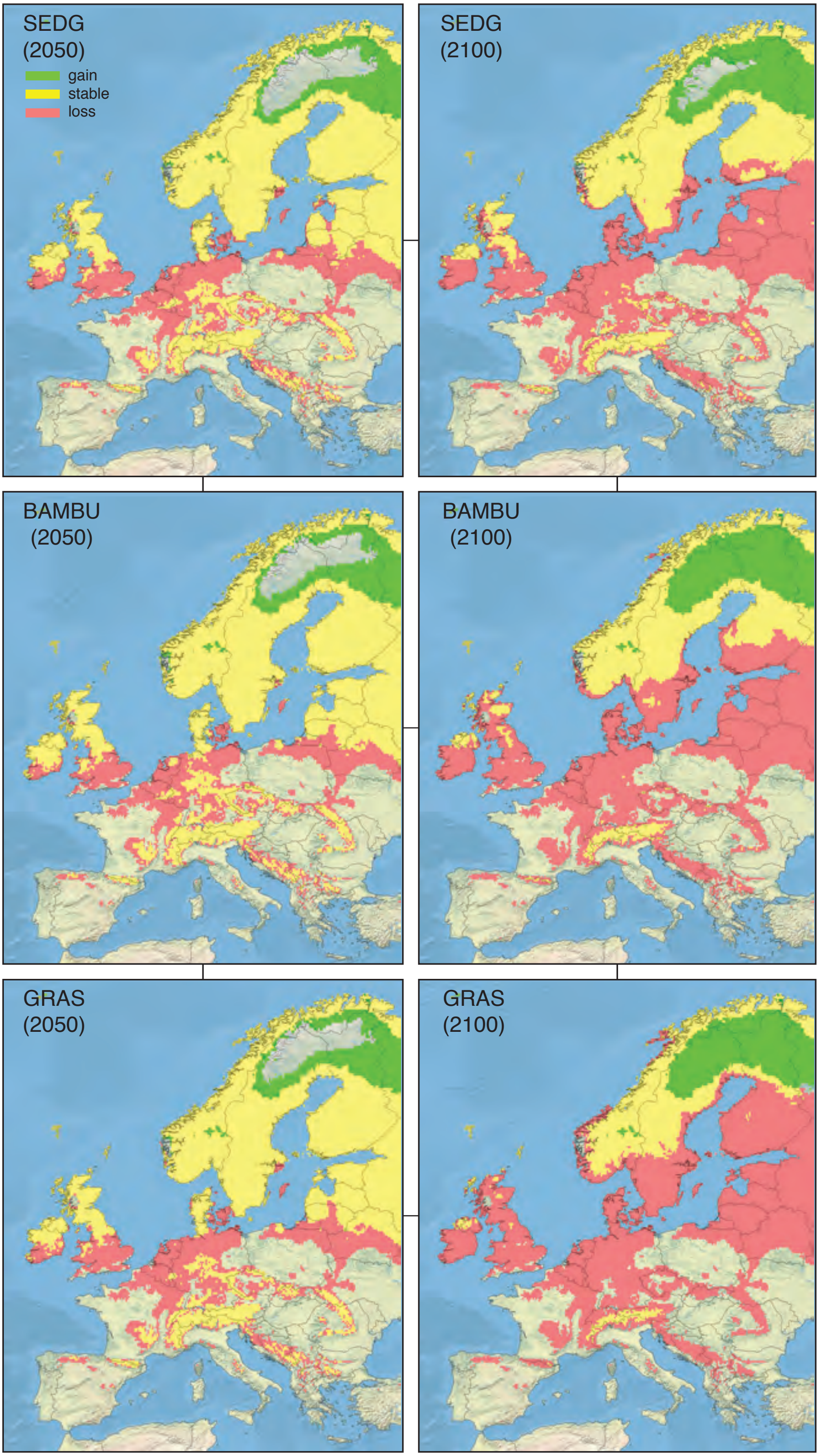
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus bohemicus is a medium-sized bumblebee. Its coat colour is rather constant, generally with one large yellow band and a white tail. It is a social parasite species (cuckoo-bumblebee) specialising primarily on *B. lucorum* and probably also *B. magnus*, *B. cryptarum* and *B. terrestris*. Its southernmost location is in the southern Italian mountains. All locations south of latitude 45° N are in the mountains. In the lowlands, *B. bohemicus* occurs from this latitude northwards to 70° N. It is distributed from Ireland in the west to the Pacific coasts in the east. It is also the most common cuckoo-bumblebee. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. The modelled distribution corresponds very well to the actual one. All scenarios project a fragmentation of the range in central and southern Europe and an expansion of its suitable areas to the Barents Sea coast and to the highest altitudes of the Scandinavian mountains. The GRAS scenario projects that suitable areas could completely disappear from the lowlands south of latitude 60° N by 2100. Regardless of its dispersal ability, as it is a cuckoo-bumblebee, specialised to few host species with a seemingly low dispersal ability, *B. bohemicus* would suffer significantly from global warming.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.81)
Climate risk category: HHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	**SEDG**	-3428 (-22%)	-4738 (-30%)
	BAMBU	-2978 (-19%)	-4378 (-28%)
	GRAS	-3477 (-22%)	-4921 (-32%)
2100	**SEDG**	-7068 (-45%)	-8947 (-57%)
	BAMBU	-8245 (-53%)	-10482 (-67%)
	GRAS	-10053 (-65%)	-12262 (-79%)

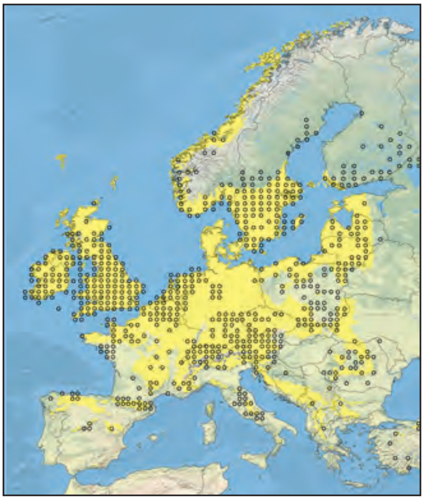
Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus campestris (Panzer, 1801)

= *Bombus (Psithyrus) campestris; Psithyrus campestris*

© Photo: P. Rasmont



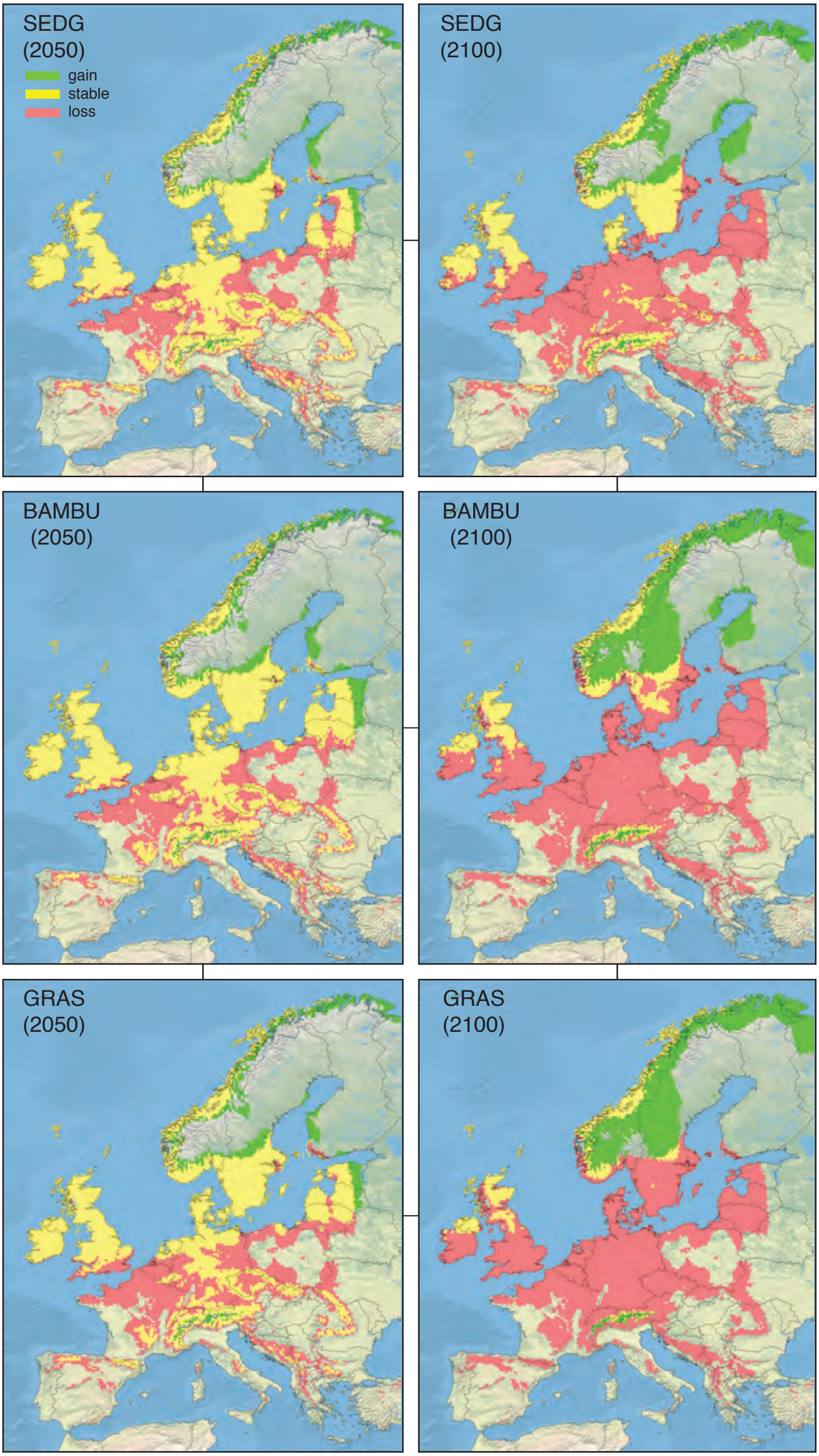
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus campestris is a medium-sized bumblebee. Its coat colour is very variable, generally with yellow bands and a yellow tail. The tail can also be reddish. Some specimens are completely black. It is a social parasite species (cuckoo-bumblebee) mostly of *B. pascuorum*, *B. humilis*, *B. ruderarius*, B. *sylvarum*, *B. muscorum* and *B. subterraneus*. Most locations south latitude 45° N are in the mountains. In the lowlands, it occurs from this latitude in the south up to 65° N, near the Arctic Circle. It is distributed from Ireland in the west to the Pacific coasts in the east. It is also one of the most abundant and widespread cuckoo-bumblebees. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. The modelled distribution corresponds very well to the actual one. All scenarios project a fragmentation of the range in central and southern Europe and an expansion of its suitable areas to the Barents Sea coast without reaching the highest levels of Scandinavian mountains. The GRAS scenario projects that suitable areas could completely disappear from all lowlands south of latitude 60° N by 2100. As it is a cuckoo-bumblebee specialised on a few host species, with a scattered distribution, and with a seemingly low dispersal ability, *B. campestris* would suffer significantly from global warming.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.77)
Climate risk category: HHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-3086 (-28%)	-3971 (-36%)
	BAMBU	-2829 (-26%)	-3884 (-35%)
	GRAS	-3664 (-33%)	-4695 (-42%)
2100	SEDG	-5989 (-54%)	-7633 (-69%)
	BAMBU	-6475 (-59%)	-9191 (-83%)
	GRAS	-7420 (-67%)	-9879 (-89%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus cingulatus Wahlberg, 1854

= *Bombus (Pyrobombus) cingulatus*

© Photo: P. Rasmont

Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus cingulatus is a medium-sized bumblebee. Its coat colour is quite constant, with a brownish thorax with a more or less wide black thoracic band and with a white tail. It is a species restricted to the boreal taiga where it prefers to forage from Ericaceae and *Epilobium angustifolium* flowers. It occurs in Europe from the latitude of Stockholm in the south close to the Barents Sea coast in the north. In the west from Norway to the Pacific coasts in the east. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. The modelled distribution corresponds very well to the actual one, bearing in mind that the species does not occur in the southern mountains. All scenarios project shrinkage of suitable areas by 2050. By 2100 suitable conditions for this species would be restricted to mountain areas, this tendency being the most extreme with the GRAS scenario. Regardless of its dispersal capability, as it is a species linked to boreal conditions, *B. cingulatus* would suffer considerably from global warming.

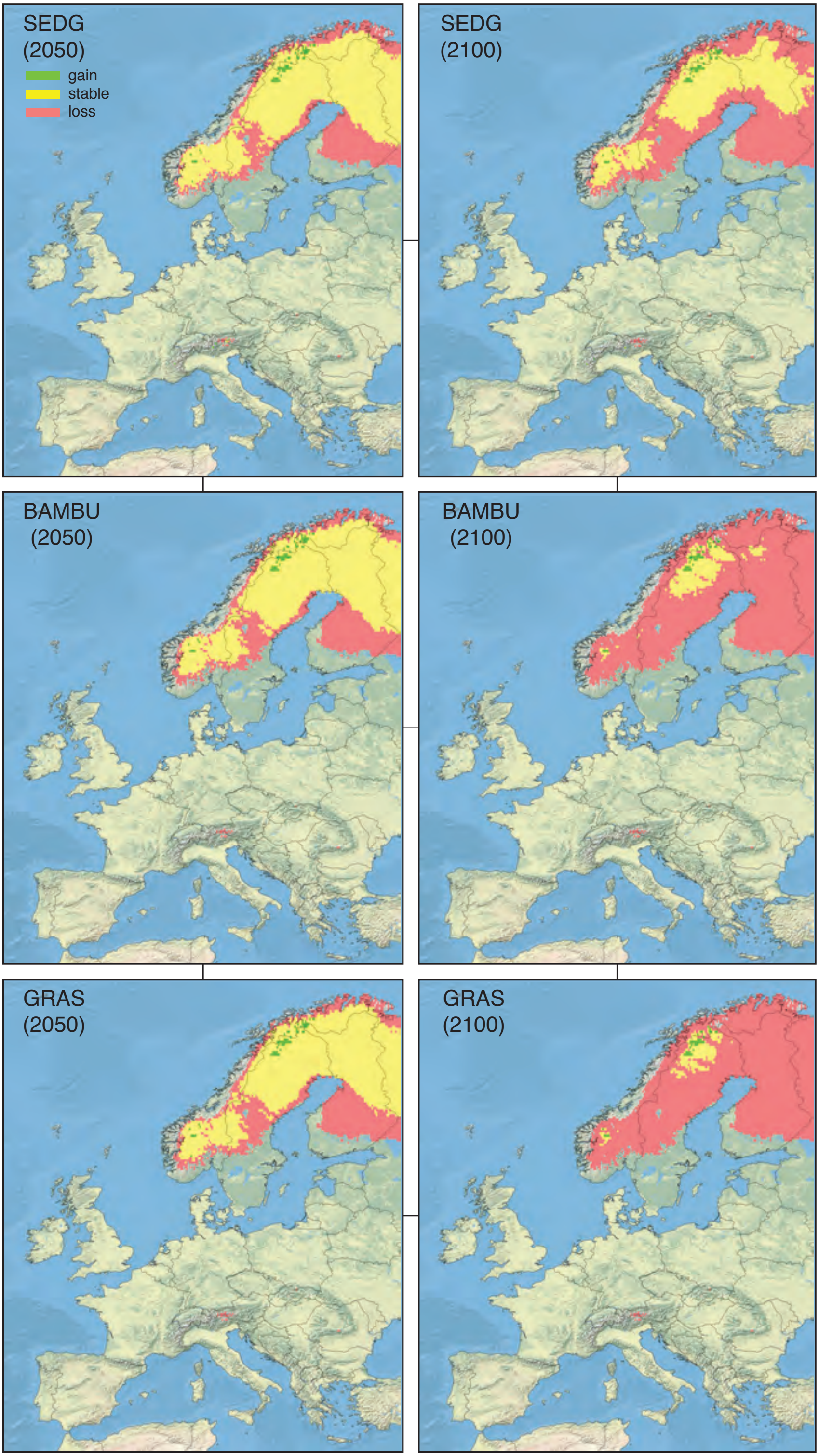
Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.97)

Climate risk category: HHHR

IUCN Red List status: Least Concern

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	-1703 (-30%)	-1770 (-31%)
	BAMBU	-1774 (-31%)	-1835 (-32%)
	GRAS	-1891 (-33%)	-1953 (-34%)
2100	**SEDG**	-3246 (-57%)	-3307 (-58%)
	BAMBU	-5093 (-89%)	-5141 (-90%)
	GRAS	-5328 (-94%)	-5372 (-94%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus confusus Schenck, 1859

= *Bombus (Bombias) confusus; Bombus (Confusibombus) confusus; Bombus paradoxus*

© Photo: P. Rasmont

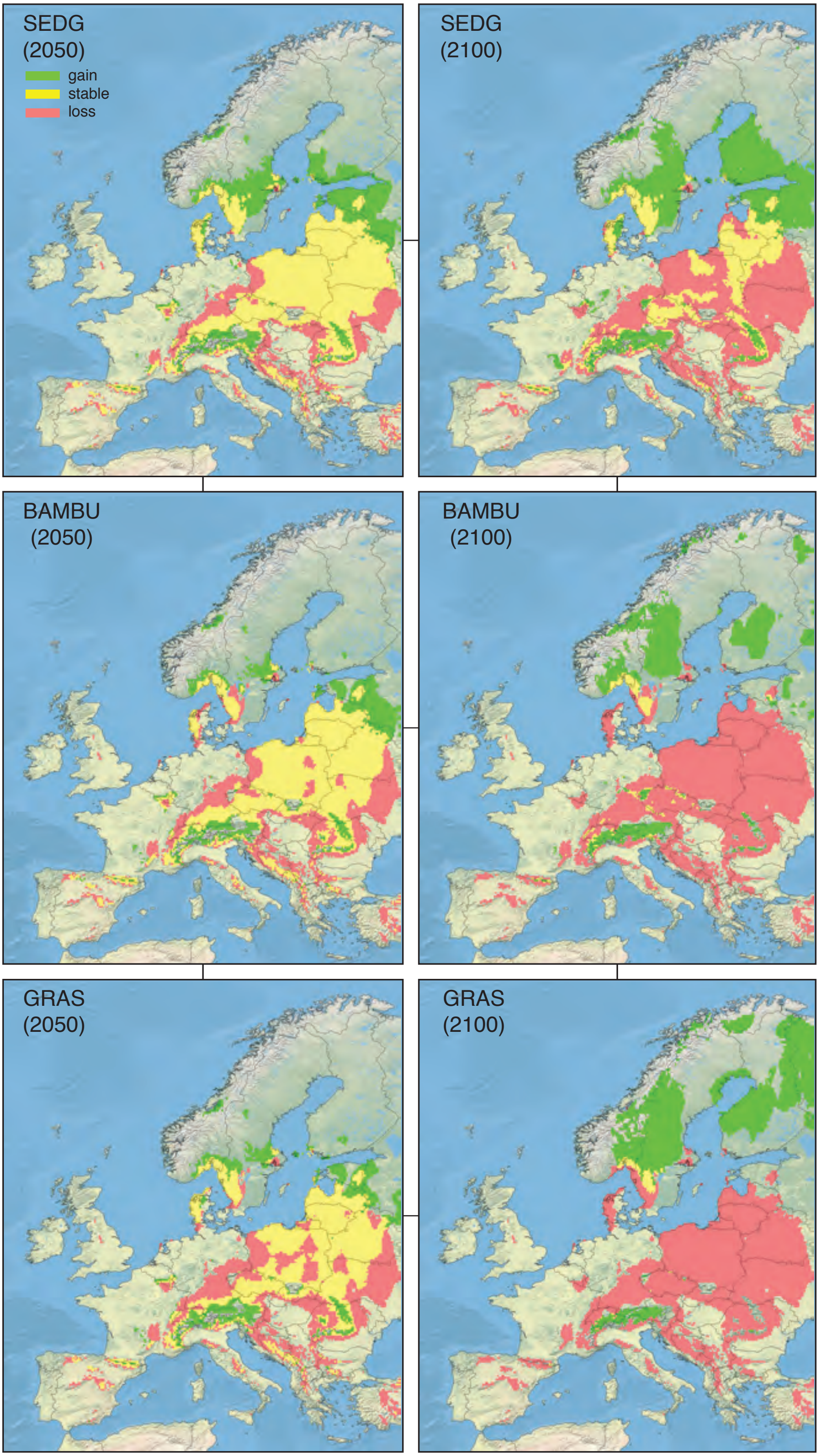
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus confusus is a medium-sized bumblebee. It includes two very conspicuously different colour forms: the nominal subspecies, black with a red tail, and the ssp. *paradoxus*, with 3 yellow bands and a white tail. The coat also shows a very typical velvet-like aspect. This species is mostly present in steppes or dry grasslands with scattered trees and shrubs. The queens and workers forage mainly on Fabaceae while males forage for nectar on thistles (Asteraceae). *B. confusus* occurs from the Pyrenees and northern Balkans in the south to Estonia in the north. It is absent from the British Isles and Fennoscandia. Its westernmost location is in south-east France while it reaches Novosibirsk in the east. The modelled distribution does not perfectly fit with its actual one. The species is one of the most threatened European bumblebees, and is assessed as Vulnerable in the IUCN Red List of European Bees. All scenarios project a reduction of areas with suitable conditions by 2050, with an expansion toward the north. By 2100, the suitable areas of the species would reach the Arctic Circle with only a fragmented distribution in the south. The GRAS scenario projects an almost complete shift of suitable areas, disappearing from the lowlands of Europe, with the exception of Fennoscandia. The dispersal ability of *B. confusus* is likely to be low. It would therefore considerably suffer from global warming, which could eventually lead to its extinction.

Present distribution can be well explained by climatic variables (AUC = 0.87)
Climate risk category: HHHR
IUCN Red List status: Vulnerable

	Scenario	Full dispersal	No dispersal
2050	SEDG	-96 (-1%)	-2351 (-30%)
	BAMBU	-1553 (-20%)	-2981 (-38%)
	GRAS	-2378 (-30%)	-3729 (-47%)
2100	SEDG	-1909 (-24%)	-5438 (-68%)
	BAMBU	-5375 (-68%)	-7618 (-96%)
	GRAS	-4501 (-57%)	-7807 (-98%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus consobrinus Schenck, 1859

= *Bombus (Megabombus) consobrinus*

© Photo: P. Rasmont

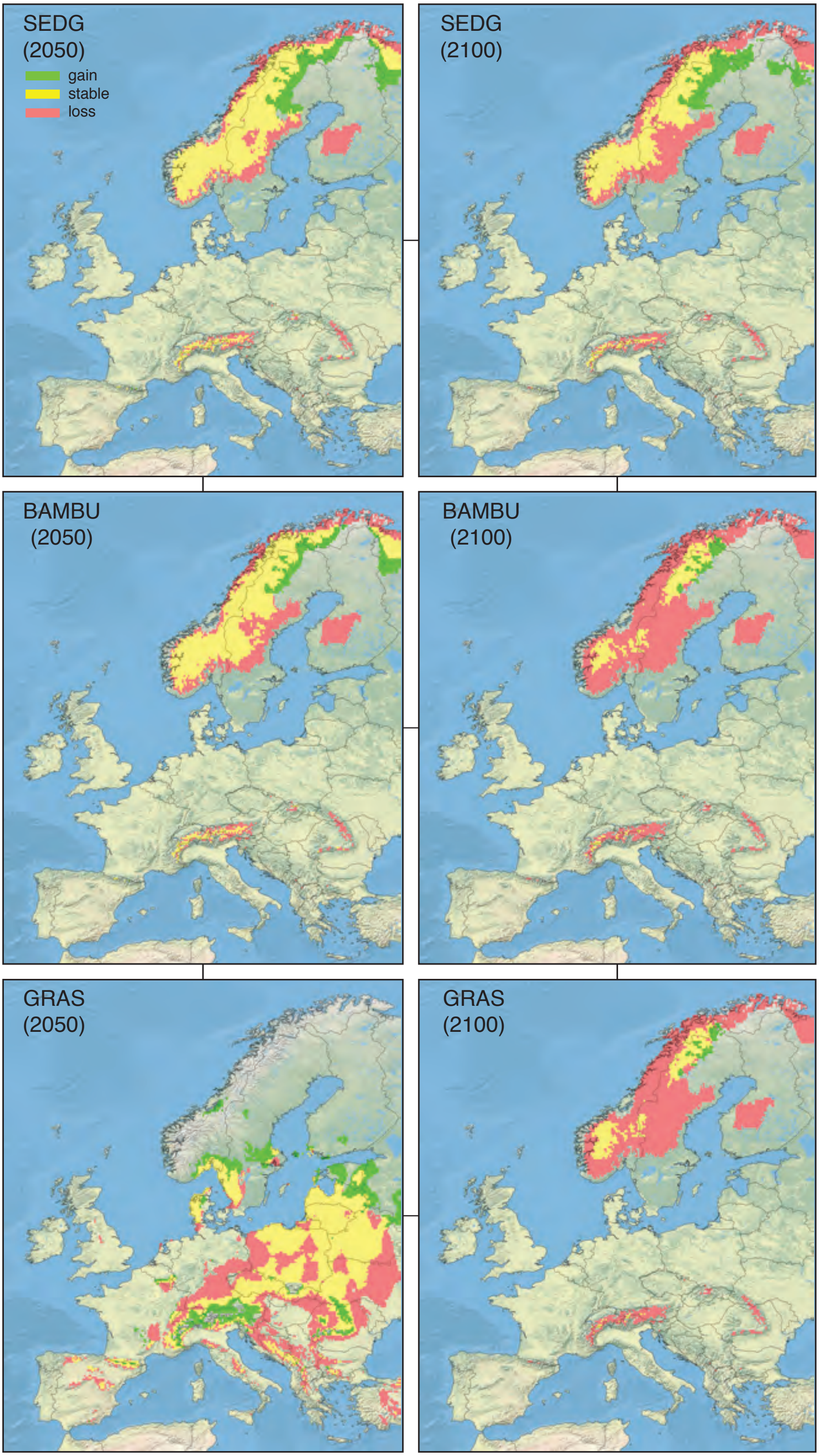
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus consobrinus is a large bumblebee. Its coloration is quite constant, being brown on thorax and the basal part of abdomen, the mid part is black gradually becoming whitish grey towards the tip. In Europe, this species exclusively inhabits the boreal taiga where it is highly specialised in flower choices: it forages almost exclusively on *Aconitum* spp., even though it occasionally forages for nectar on other flowers. It occurs from Norway in the west to the Pacific coasts in the east. Its modelled distribution indicates that climatic conditions would be well suited in most of the southern European mountains, even though the species is absent there. The species is not threatened: Least Concern in the IUCN Red List of European Bees. All scenarios project a reduction of suitable areas by 2050. This tendency is projected to continue, and by 2100 the GRAS scenario indicates that suitable climatic conditions would persist only in the high Scandinavian mountains. Movement of this species to southern European mountains is very unlikely. As it is adapted to rather cold climates and is highly specialised in its habitat and food choices, the dispersal ability of this species is likely to be low. Thus, *B. consobrinus* would suffer considerably from global warming.

Present distribution can be very well explained by climatic variables (AUC = 0.97)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-748 (-21%)	-1297 (-37%)
	BAMBU	-1102 (-31%)	-1463 (-41%)
	GRAS	-1169 (-33%)	-1534 (-43%)
2100	SEDG	-1463 (-41%)	-2030 (-57%)
	BAMBU	-2843 (-80%)	-2970 (-84%)
	GRAS	-2898 (-82%)	-2999 (-85%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus cryptarum (Fabricius, 1885)

= *Bombus (Bombus) cryptarum; Bombus lucocryptarum*

© Photo: P. Rasmont

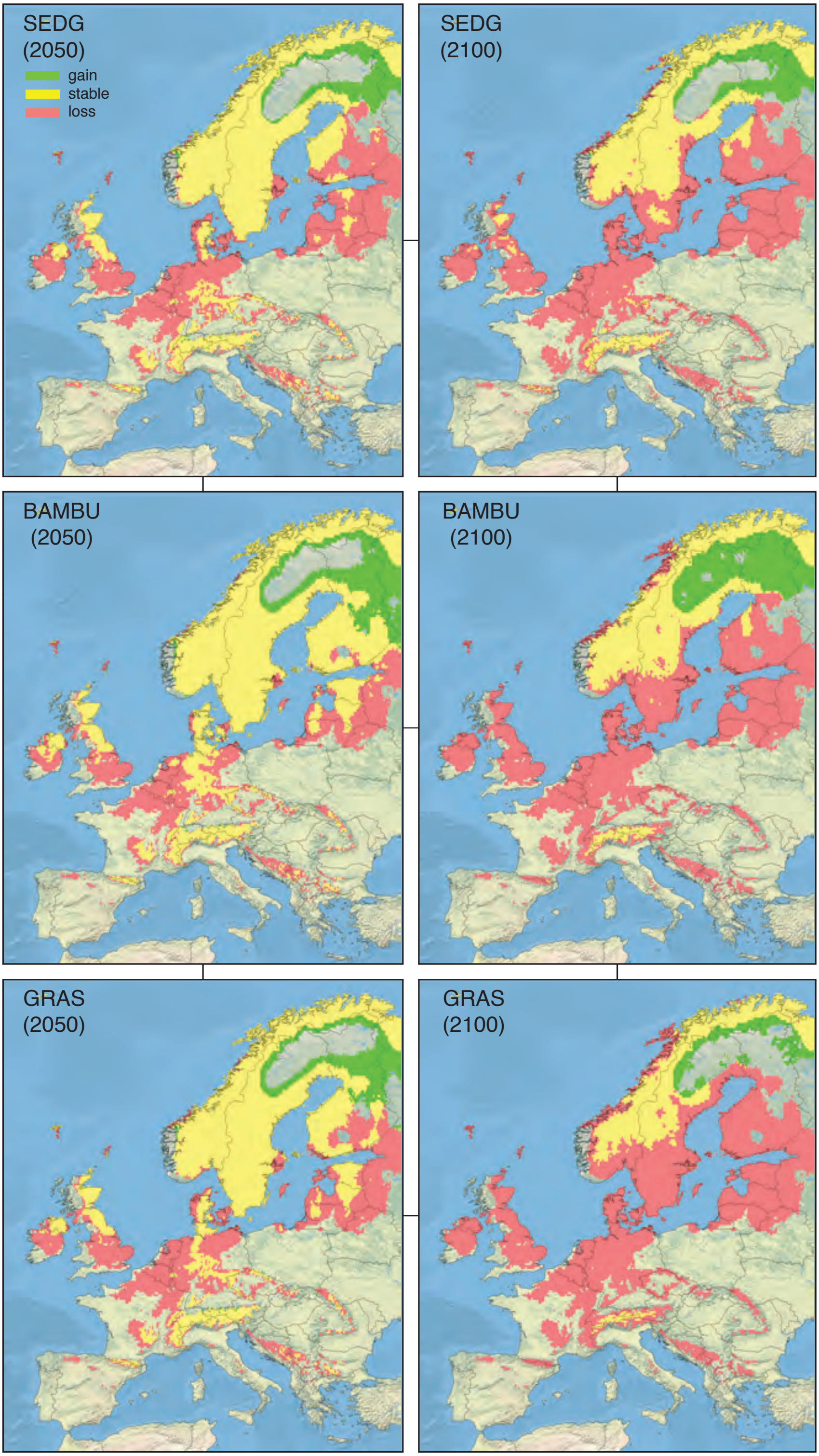
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus cryptarum is quite a small species of bumblebee. With some variations, the coat colour always shows two yellow bands and a white tip to the abdomen. The more or less developed prothoracic yellow band usually has a black "comma" at the height of the tegulae. The identification can be very difficult and confusions could occur with *B. magnus* and *B. lucorum*. In Europe, this species generally inhabits heaths and moors with abundant Ericaceae flowers which are its main food resource (e.g. *Vaccinium* spp., *Erica* spp., *Rhododendron* spp.). It occurs from the northern Balkan, the Alps and Massif Central in the south to the Barents Sea shore in the north and from Ireland in the west to the Pacific coast in the east. The actual and modelled distribution might be potentially blurred by numerous identification mistakes. The species is not threatened: Least Concern in the IUCN Red List of European Bees. All scenarios project a reduction of suitable areas already in 2050, especially in the lowlands of west and central Europe. In 2100 all scenarios project that the suitable climatic conditions would persist only in mountains of South Europe, Fennoscandia, Ireland and Scotland (not even in these latter areas following GRAS). As *B. cryptarum* is quite specialised in its habitat and food preferences, it could suffer from global warming if these resources are altered, regardless of its dispersion capability.

Present distribution can be explained by climatic variables to only a limited extent (AUC = 0.72)
Climate risk category: PR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	**SEDG**	-4901 (-40%)	-5753 (-47%)
	BAMBU	-2649 (-22%)	-4134 (-34%)
	GRAS	-4019 (-33%)	-5125 (-42%)
2100	**SEDG**	-7183 (-58%)	-8112 (-66%)
	BAMBU	-7133 (-58%)	-8818 (-72%)
	GRAS	-9260 (-75%)	-9880 (-80%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus cullumanus (Kirby, 1802)

= *Bombus (Cullumanobombus) cullumanus*

© Photo: P. Rasmont

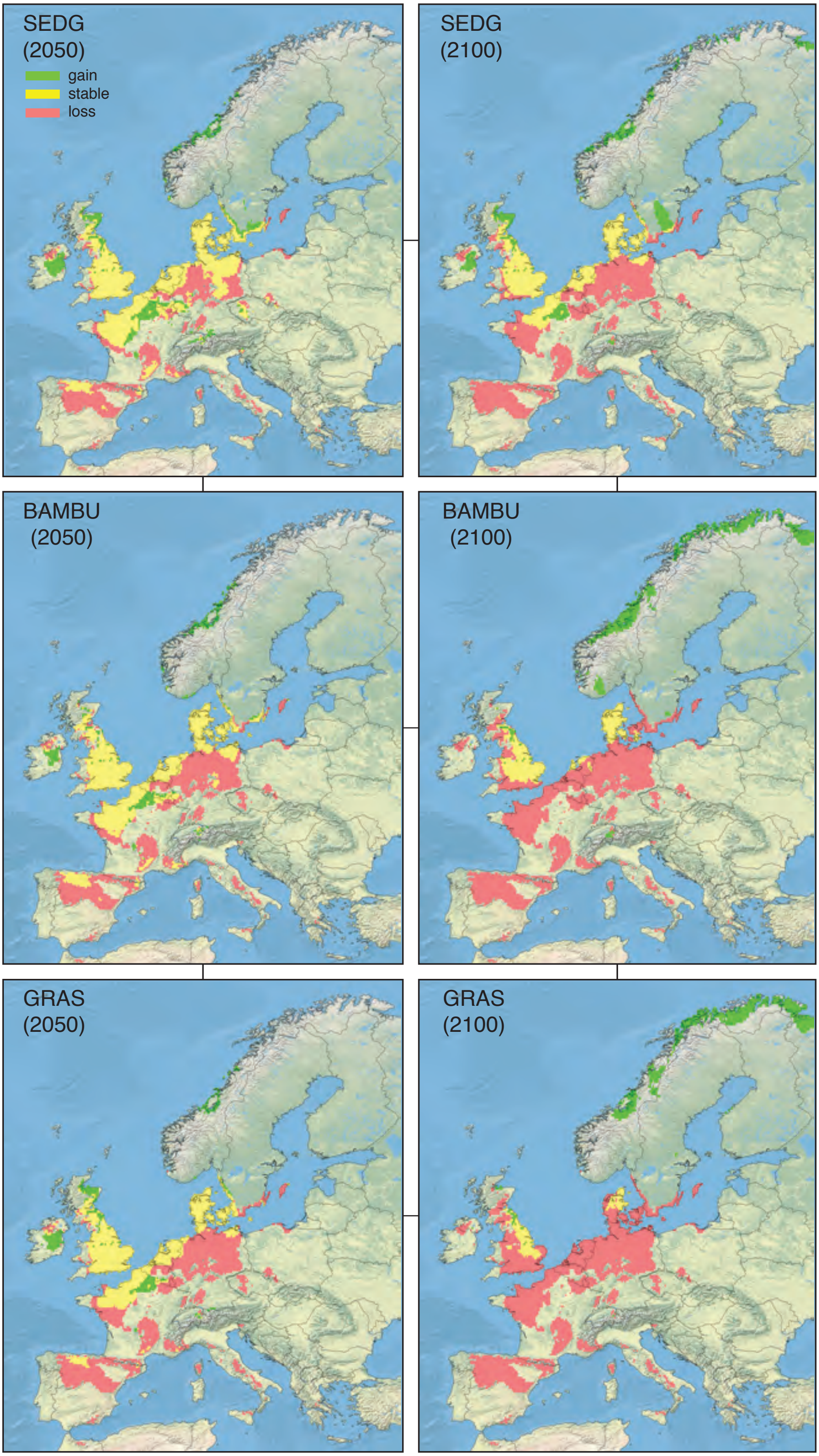
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus cullumanus is a medium-sized bumblebee. The coat colour can show three different regional patterns: all black with a red tail (ssp. *cullumanus*), with three yellowish bands and a red tail (ssp. *serrisquama* Morawitz), with three white bands and a red tail (ssp. *apollineus* Skorikov). The ssp. cullumanus once occurred in chalky grasslands across the more Atlantic parts of the continent from the Pyrenees in the south to the Isle of Öland (Baltic sea) in the north. This ssp. seems to be completely extinct, with the last specimen being seen in 2004 in the Massif Central. Ssp. *serrisquama* was once found in steppe areas of Spain, central and eastern Europe, the Caucasus, southern Siberia and Mongolia. For Europe, this ssp. only persists still in a few locations in central Spain and the Volga valley, while it can be abundant in some parts of eastern Turkey, Siberia and Mongolia. The ssp. *apollineus* is restricted to eastern Turkey, Georgia, Azerbaijan and Iran where it remains abundant in some locations. The identification can be difficult and confusions could occur with *B. lapidarius*. The queens and workers of *B. cullumanus* forage mainly on *Trifolium* spp. while males visit thistles (Asteraceae). The species is highly threatened: Critically Endangered in the IUCN Red List of European Bees. All scenarios project a reduction of suitable areas by 2050. By 2100 all scenarios project that the suitable climatic conditions would persist only in northern Europe from where this species has already vanished. As this species is highly specialised, has a scattered distribution, has already become extinct from most of its original range, and is likely to have a very low dispersal capability, *B. cullumanus* would seriously suffer from global warming likely leading to its extinction by 2050.

Present distribution can be well explained by climatic variables (AUC = 0.91)
Climate risk category: HHR
IUCN Red List status: Critically Endangered

	Scenario	Full dispersal	No dispersal
2050	SEDG	-1164 (-28%)	-1742 (-41%)
	BAMBU	-1813 (-43%)	-2139 (-51%)
	GRAS	-2115 (-50%)	-2480 (-59%)
2100	SEDG	-2264 (-54%)	-2833 (-67%)
	BAMBU	-2885 (-68%)	-3543 (-84%)
	GRAS	-3284 (-78%)	-3942 (-94%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus distinguendus Morawitz, 1869

= *Bombus (Subterraneobombus) distinguendus*

© Photo: P. Rasmont

Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus distinguendus is a large bumblebee. The coat colour is very constant: gold-yellow with a black thoracic band. The species occurs from a latitude of 45°N in the south to the Arctic Circle in the north and from Ireland in the west to Kamchatka and even to the Aleutian Islands in the east. It forages mainly on *Trifolium* spp. (queens and workers) and thistles (males). This species is scarce throughout Europe and it seems threatened: Vulnerable in the IUCN Red List of European Bees. The distribution model shows that its climatic niche includes southern mountains such as the Cantabrian mountains, Pyrenees, Apennines, and the Balkans from where it is not known to occur. Most of its original distribution from a century ago is now out of its modelled range, possibly meaning that suitable climatic conditions have already moved significantly. All scenarios project a reduction of suitable areas by 2050, where all lowland locations south of 55° N become unsuitable. By 2100 all scenarios project that suitable climatic conditions would only persist in northern Europe and in the mountains of central and eastern Europe. The GRAS scenario indicates that the suitable areas would remain in only a very restricted area of the Alps, in scattered locations in Scotland and north of 60° N in Scandinavia, reaching the highest altitudes in the Scandinavian mountains. As *B. distinguendus* is quite specialised in its food preference and its range in the central and western European lowlands is already scattered, low dispersal abilities may be assumed (even if it the species is able to forage on coastal islands). Thus, *B. distinguendus* would suffer considerably from global warming.

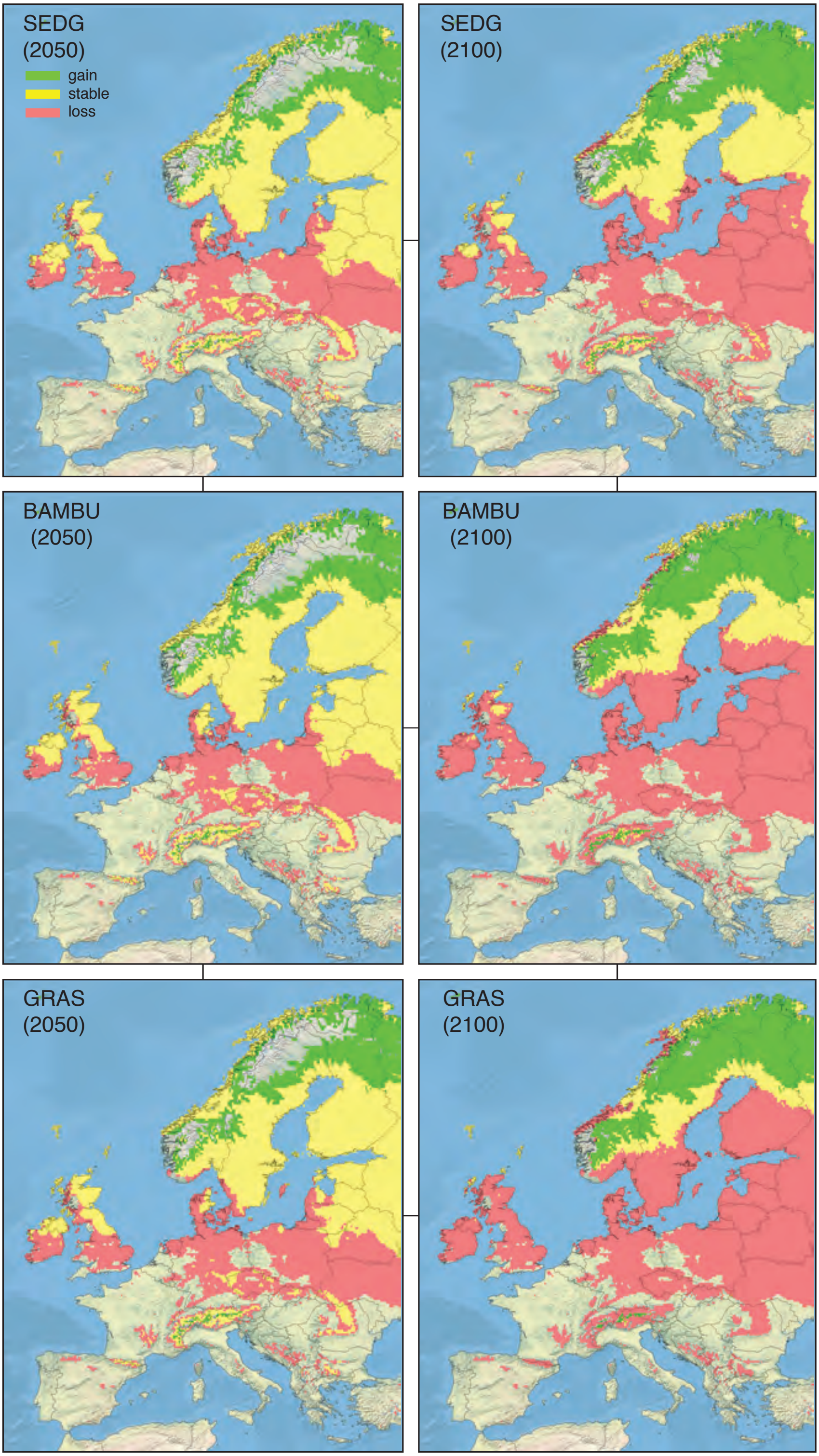
Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.81)

Climate risk category: HHR

IUCN Red List status: Vulnerable

	Scenario	Full dispersal	No dispersal
2050	SEDG	-3944 (-27%)	-6096 (-42%)
	BAMBU	-3580 (-25%)	-5813 (-40%)
	GRAS	-4122 (-28%)	-6530 (-45%)
2100	SEDG	-6589 (-46%)	-9656 (-67%)
	BAMBU	-8038 (-56%)	-11484 (-79%)
	GRAS	-9252 (-64%)	-12608 (-87%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus flavidus Eversmann, 1852

= *Bombus (Psithyrus) flavidus; Psithyrus flavidus*

© Photo: P. Rasmont

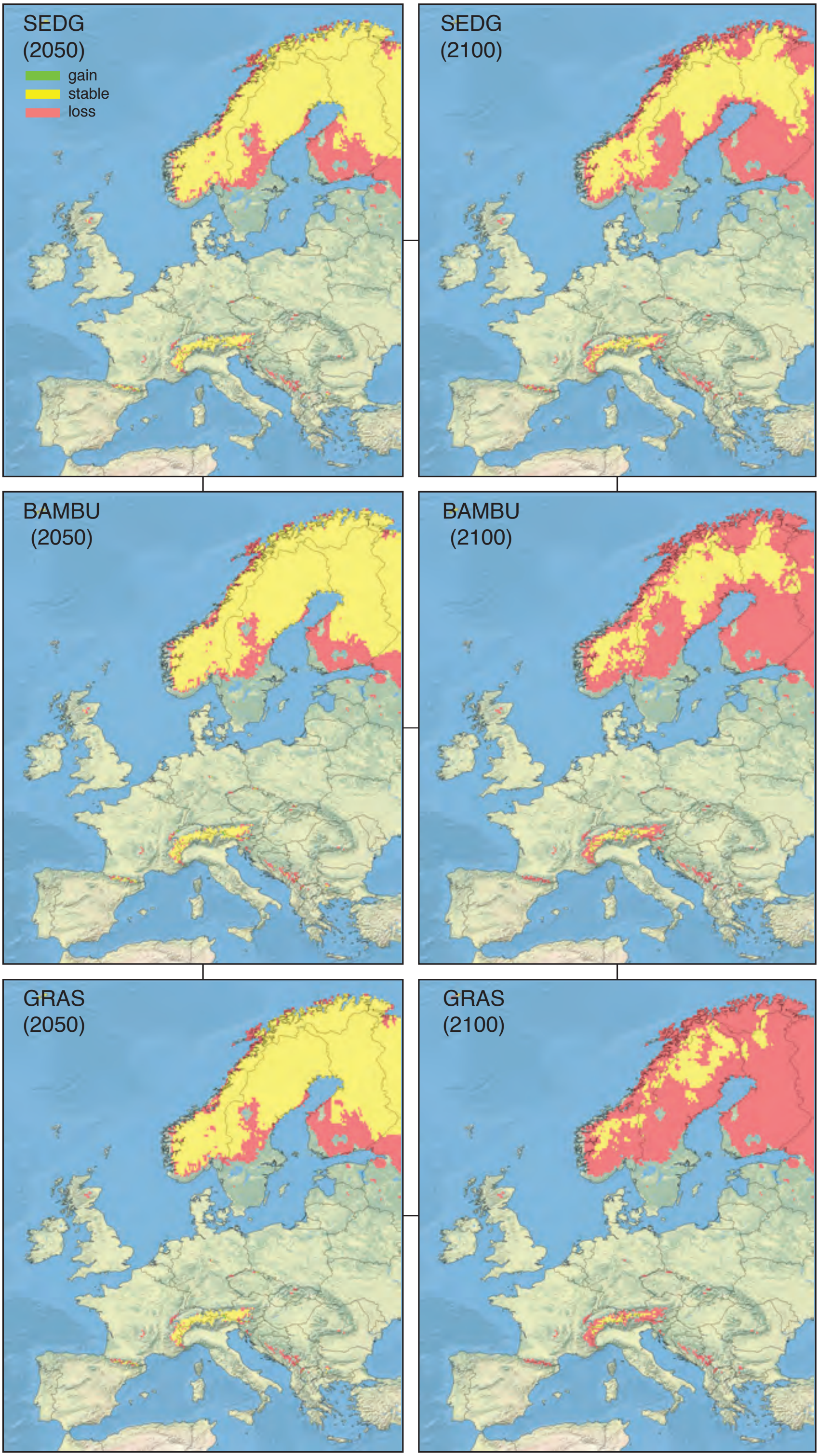
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus flavidus is a small- to medium-sized bumblebee. The coat colour generally shows a yellow prothoracic band and a whitish to yellowish tail. The rest of the body is black more or less intermixed with yellowish hairs. It is a social parasite species (cuckoo-bumblebee) most likely of *B. monticola*, *B. lapponicus*, *B. jonellus*, *B. cingulatus* and *B. pyrenaeus*. The species occurs in the alpine and subalpine zones in the Pyrenees and the Alps, the Scandinavian mountains, the boreal taiga and the arctic tundra. To the east, its distribution reaches the Pacific coast. It is locally numerous and in some places, it can even be the most abundant cuckoo-bumblebee. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. The modelled distribution shows that its climatic niche would include Durmitor, the Balkans mountains, Carpathians, Tatra, Massif Central and even Scotland, (from where the species has never been observed). All scenarios project a small shift of suitable climatic conditions by 2050 while by 2100 the suitable areas of the species would be much more restricted in the Scandinavian mountains, Alps and Pyrenees. GRAS projects that unsuitable climatic conditions will exclude *B. flavidus* from the Pyrenees. Regardless of its dispersal ability, as it is a cuckoo-bumblebee specialised to few host species, with scattered distribution, *B. flavidus* would suffer greatly from global warming.

Present distribution can be well explained by climatic variables (AUC = 0.94)
Climate risk category: HHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	**SEDG**	-1814 (-24%)	-1814 (-24%)
	BAMBU	-1470 (-20%)	-1473 (-20%)
	GRAS	-1682 (-22%)	-1684 (-22%)
2100	**SEDG**	-3730 (-50%)	-3730 (-50%)
	BAMBU	-5189 (-69%)	-5189 (-69%)
	GRAS	-6354 (-85%)	-6354 (-85%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus fragrans (Pallas, 1771)

= *Bombus (Subterraneobombus) fragrans*

© Photo: G. Holmström

Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus fragrans is a very large bumblebee, the largest in Europe. The coat colour is yellowish with a black interalar band. It occurs only in true steppes where it is a generalist forager. It nests mainly in suslik burrows (steppic colonial rodents of the genus *Spermophilus*). The species occurs in the steppes of central and eastern Europe and the Anatolian plateau, where it is generally rare. To the east, it reaches Mongolia. As the species has not been observed recently in most of its former central European locations, it is considered to be threatened: Endangered in the IUCN Red List of European Bees. The modelled distribution shows that suitable climatic conditions include the areas of central Europe from which the species had already disappeared. All scenarios project a small shift of its climatic niche space by 2050 with no significant gains or losses in area. By 2100, all scenarios project a clear fragmentation of the species' range south of latitude 45°N , while GRAS projects a complete shift of suitable climatic conditions to the north of latitude 55°N,where the species does not live presently. To cope with such a major shift would require high mobility of the species, which would be quite unlikely as it only lives in habitats that are generally suffering considerably from agricultural intensification. As it is a species that is restricted to true steppes (a habitat that is not expected to expand) and is already very localised or absent from much of its former range, the dispersal ability of the species can be assumed to be low. Therefore, *B. fragrans* would suffer considerably from global warming, the worst scenario leading to the extinction of the species in Europe.

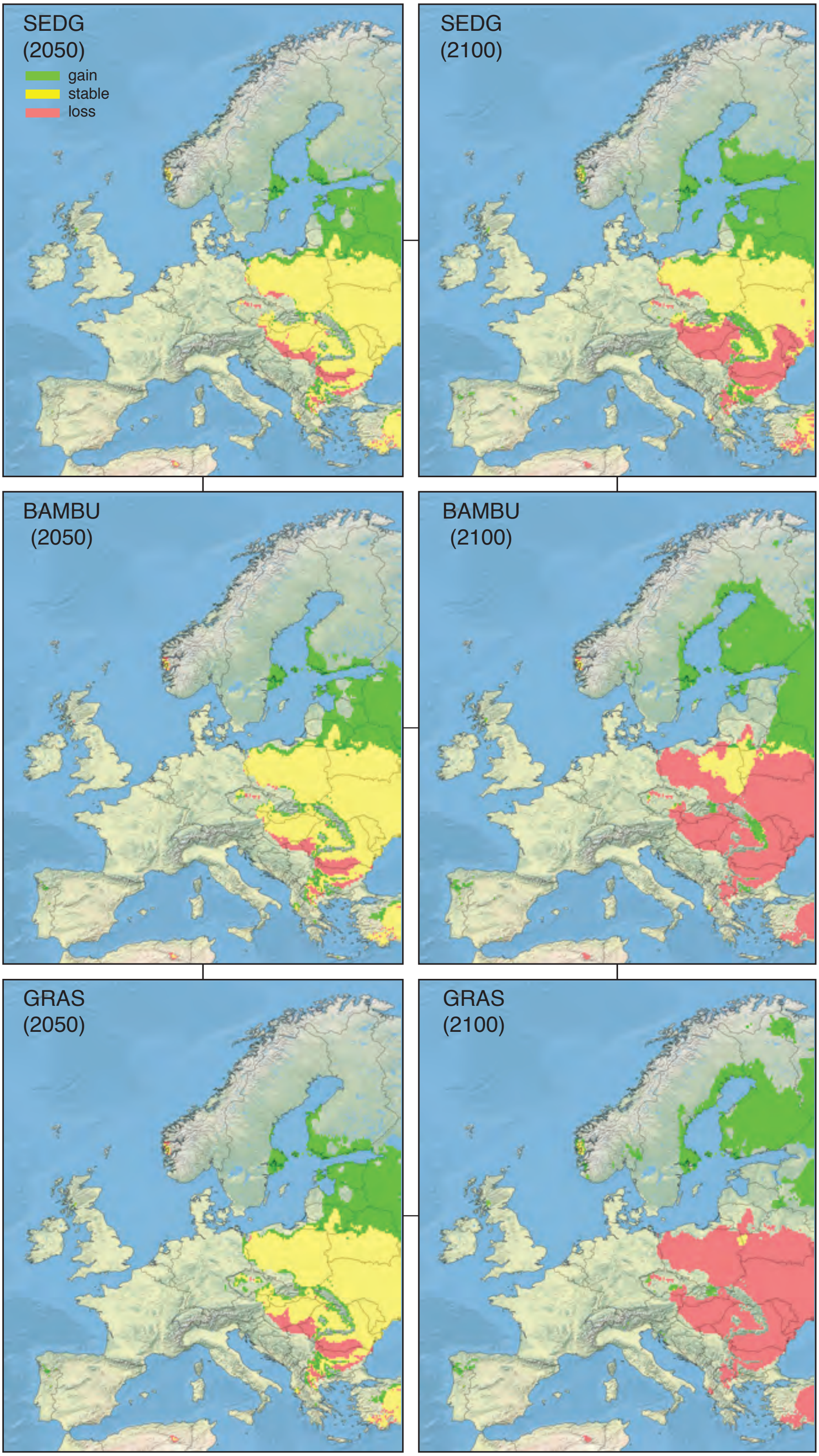
Present distribution can be well explained by climatic variables (AUC = 0.94)

Climate risk category: HHHR

IUCN Red List status: Endangered

	Scenario	Full dispersal	No dispersal
2050	SEDG	1690 (31%)	-510 (-9%)
	BAMBU	1807 (33%)	-526 (-10%)
	GRAS	1966 (36%)	-670 (-12%)
2100	SEDG	1365 (25%)	-1900 (-34%)
	BAMBU	-1572 (-28%)	-4791 (-87%)
	GRAS	-2777 (-50%)	-5446 (-98%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus gerstaeckeri Morawitz, 1875

= *Bombus (Megabombus) gerstaeckeri*

© Photo: P. Rasmont

Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus gerstaeckeri is a large bumblebee. The coat colour is brownish on both the thorax and the base of the abdomen. The abdomen has a whitish tail. It is a highly specialist forager, visiting almost exclusively monkshood (*Aconitum* spp.). Often, each colony is small, including only a few workers and a very low number of new queens and males are produced in a year. *Bombus gerstaeckeri* is a very rare species, endemic to the high mountains of southern Europe: The Pyrenees, Alps, Carpathians, and the Caucasus. As it is a very conspicuous species, it is usually regarded as more abundant than it actually is. The species is considered to be threatened: Vulnerable in the IUCN Red List of European Bees. The modelled distribution includes most of the mountainous areas of Europe but its actual distribution is much more restricted. All scenarios project smaller shifts of its climatic niche space by 2050 with little change in climatically suitable area. By 2100, the BAMBU and SEDG scenarios also project smaller shifts of the climatic niche space but GRAS projects more drastic range contractions leading to extinction in both the Pyrenees and Carpathians. As this highly specialised species shows low dispersal abilities, a move to new suitable areas in Scandinavia is very unlikely. Thus, *B. gerstaeckeri* would suffer considerably from global warming, with the worst scenario leading to the extinction of the species in the Pyrenees and Carpathians.

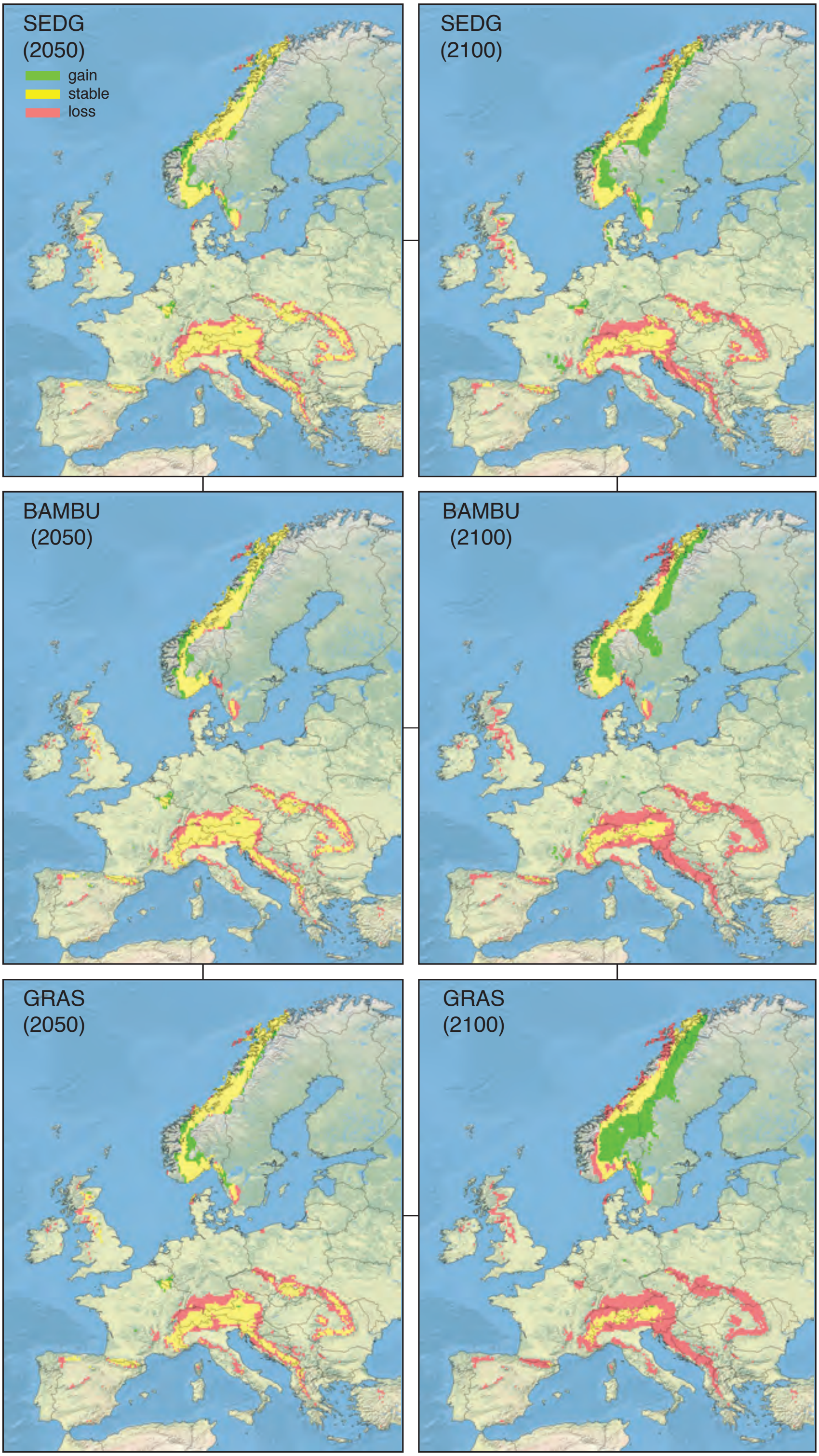
Present distribution can be well explained by climatic variables (AUC = 0.95)

Climate risk category: HR

IUCN Red List status: Vulnerable

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	-696 (-21%)	-938 (-28%)
	BAMBU	-871 (-26%)	-1085 (-33%)
	GRAS	-1028 (-31%)	-1277 (-38%)
2100	**SEDG**	-1048 (-32%)	-1661 (-50%)
	BAMBU	-1511 (-45%)	-2134 (-64%)
	GRAS	-1518 (-46%)	-2448 (-74%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus haematurus Kriechbaumer, 1870

= *Bombus (Pyrobombus) haematurus*

© Photo: P. Rasmont

Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus haematurus is a small bumblebee. The coat colour shows a large yellow prothoracic band. The abdomen has a large basal yellow band and a small red tail. It is a generalist species occurring in forests, orchards and park-like landscapes of Turkey and south-east Europe. It reaches Slovenia in the west and Iran in the esast, southern Greece to the south, and Slovakia and Romania to the north. *Bombus haematurus* has recently expanded its range by about 1000 km westwards. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. Its modelled distribution includes a much larger area than its actual distribution. All scenarios except GRAS project an expansion of its climatic niche space by 2050 and 2100. GRAS projects fragmentation of areas with suitable climatic conditions in the lowlands south of latitude 48° N and also an expansion to the north-west, reaching Belgium, the Netherlands and Scandinavia.Its recent expansion across the Balkans shows that the species is a good disperser. Thus, *B. haematurus* could take advantage from global warming leading to its expansion towards western and northern Europe.

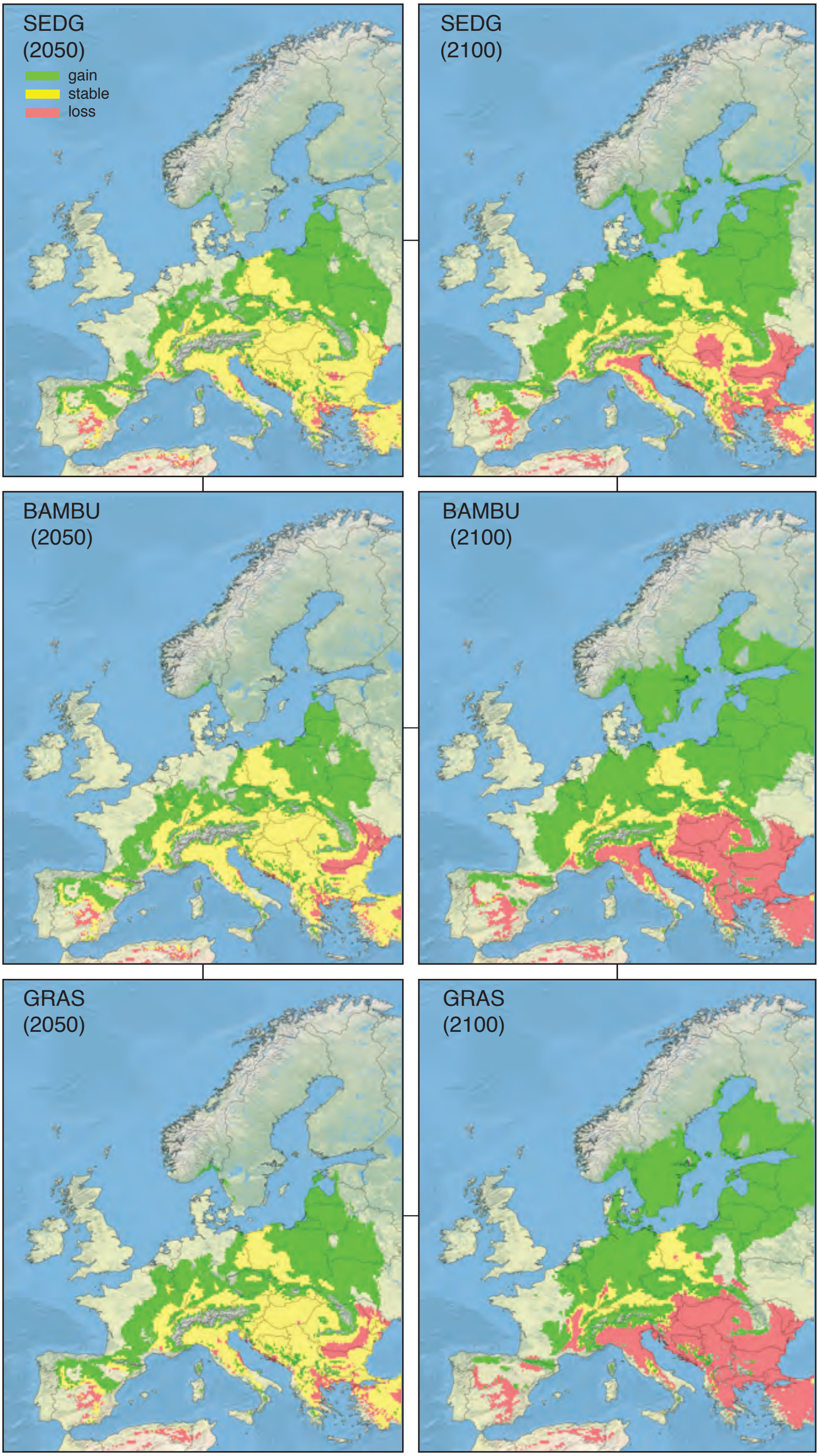
Present distribution can be well explained by climatic variables (AUC = 0.93)

Climate risk category: HR

IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	**SEDG**	4869 (77%)	-554 (-9%)
	BAMBU	4074 (64%)	-947 (-15%)
	GRAS	4826 (76%)	-1096 (-17%)
2100	**SEDG**	5935 (94%)	-2396 (-38%)
	BAMBU	5095 (80%)	-4404 (-69%)
	GRAS	3527 (56%)	-5110 (-81%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus hortorum (L. 1761)

= *Bombus (Megabombus) hortorum*

© Photo: P. Rasmont

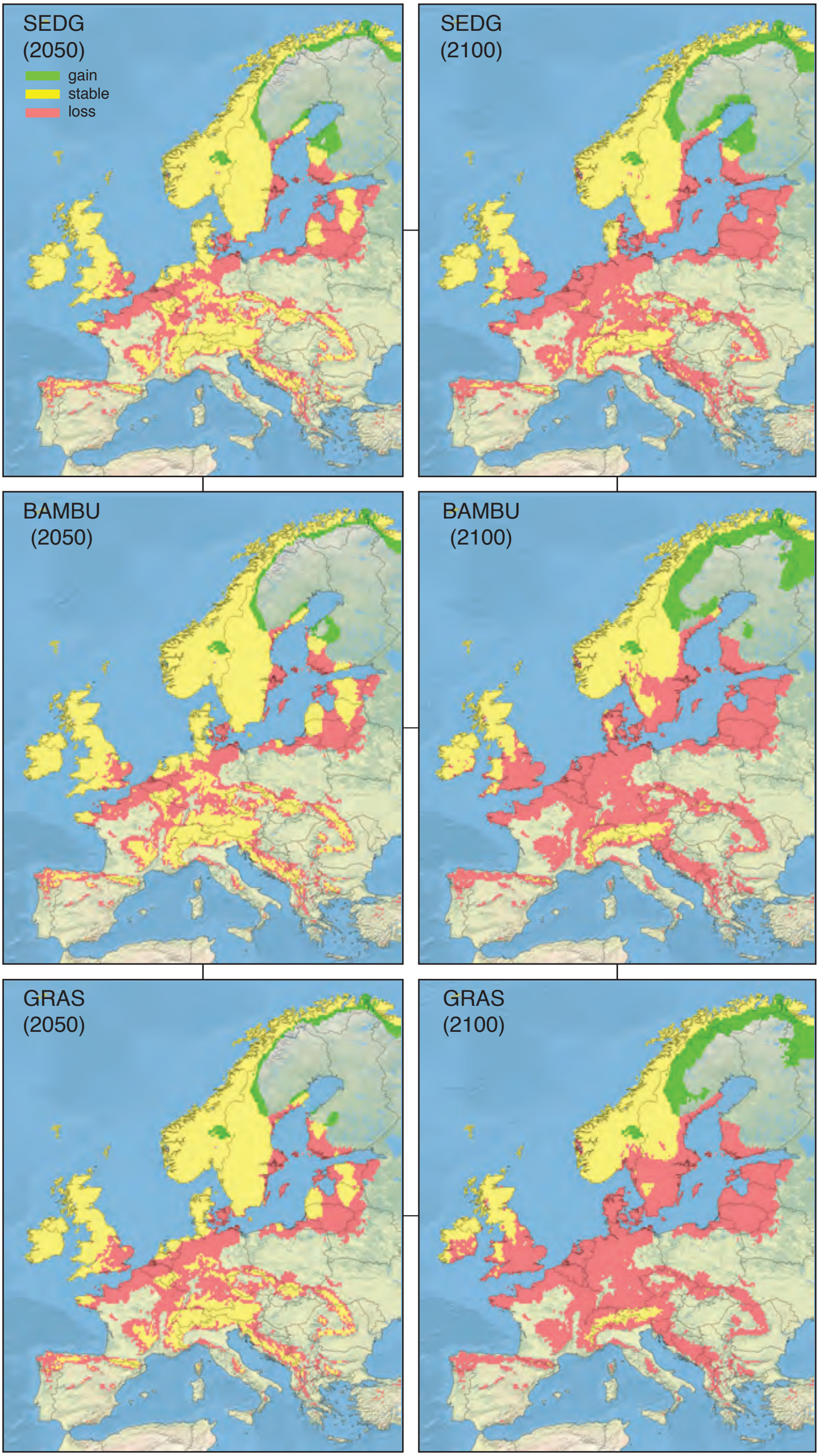
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus hortorum is a medium-sized bumblebee. The coat colour shows three large yellow bands and a white tail. Other coloration patterns can be seen in Corsica (black with a red tail) and here and there as a melanic form which is all black but with white tail. It is a generalist species even if it forages mainly on flowers with long corollas which are well suited to its very long proboscis. It is widely distributed across Europe, from Sicily and southern Spain in the south (where it occurs only in the mountains) to the extreme north, occurring in the coldest tundra along the Barents Sea coasts. To the east, it reaches the Pacific coast. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. Its modelled distribution includes an area somewhat more restricted than its actual one. All scenarios project a reduction of the climatic niche space of the species in the south. By 2100, the GRAS scenario would make all lowland areas in the European mainland unsuitable. Suitable conditions would only remain in the Alps, Wales, Ireland, Scotland, Scandinavia and northern Finland. Even though *B. hortorum* is quite abundant, and a generalist species, with high dispersal capability, it would lose a considerable amount of climatically suitable area under warming conditions.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.77)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-3837 (-30%)	-4439 (-34%)
	BAMBU	-3873 (-30%)	-4378 (-34%)
	GRAS	-4822 (-37%)	-5269 (-41%)
2100	SEDG	-6009 (-46%)	-7072 (-55%)
	BAMBU	-7078 (-55%)	-8391 (-65%)
	GRAS	-7997 (-62%)	-9146 (-71%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus humilis Illiger, 1806

= *Bombus (Thoracobombus) humilis; Bombus variabilis*

© Photo: P. Rasmont

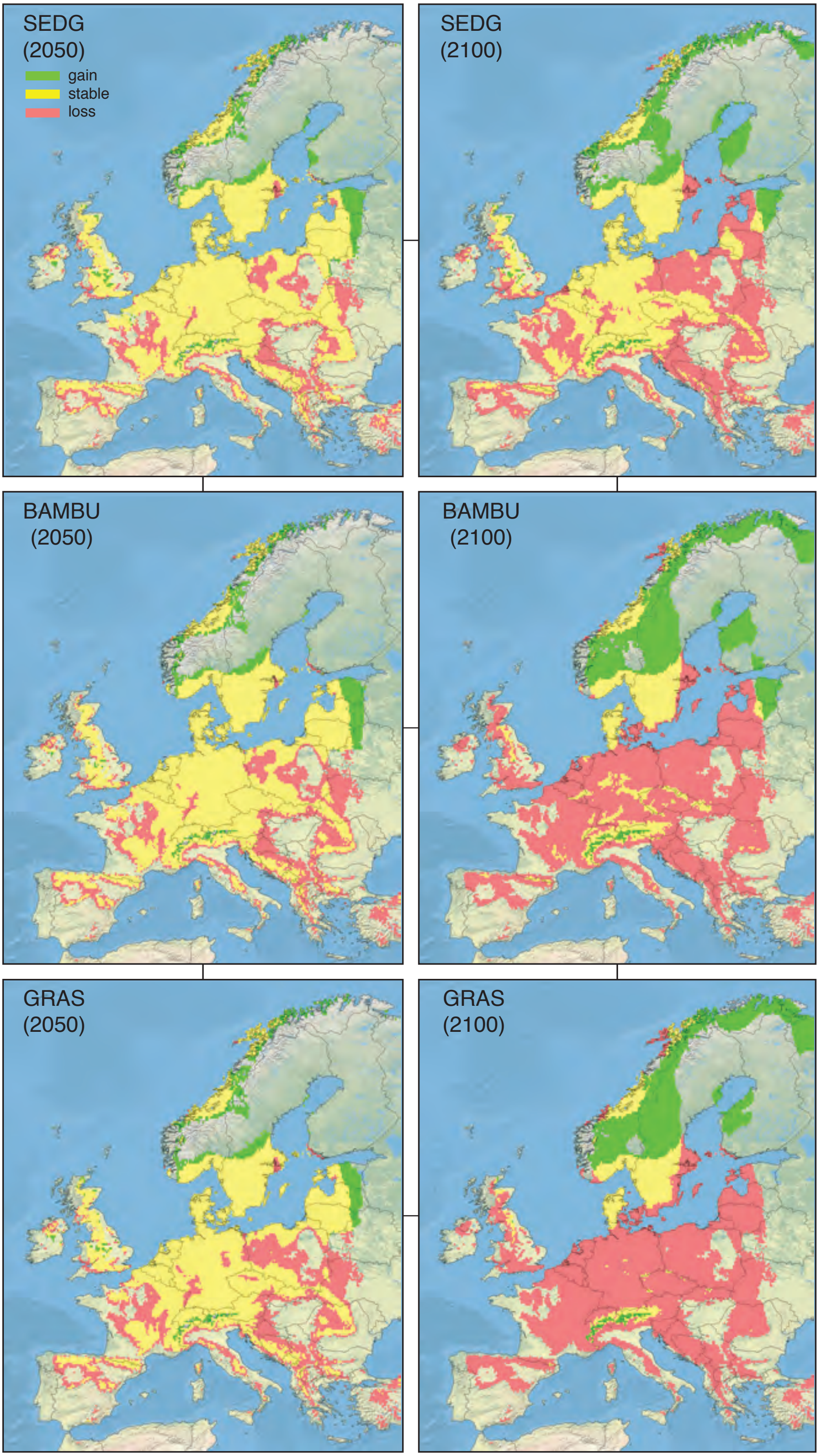
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus humilis is a medium-sized bumblebee. The coat colour is extremely variable depending on region (often classified as different subspecies), but also populations more close to each other show considerable variation. Frequent colour patterns are brownish, or black with a red tail, the most typical colour character being the brown hairs on the 2nd tergum. It is a generalist species although it forages mainly on Lamiaceae and Fabaceae flowers. In Europe, it can be found from southern Spain, Greece and Turkey in the south, (where it lives in mountains only), to a latitude of 65° N in Scandinavia and Russia in the north. To the west, it reaches Scotland and north-west Spain (not Ireland) and the Pacific coast to the east. The species is absent from all the Mediterranean islands. It has become scarce in most lowland areas of west and central Europe. Despite this regional regression, at a continental scale the species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. Its modelled distribution includes some areas in which the species does not occur, such as Morocco, Ireland, Corsica, Sardinia, Sicily and western Norway. All scenarios project a moderate reduction of suitable areas in the south and some extension to the north, depending on its dispersion capability. By 2100, the GRAS scenario would make all lowland areas in the European mainland unsuitable. Suitable conditions would only remain in the Alps, Wales, Ireland, Scotland, Scandinavia and northern Finland. As *B. humilis* seems to have quite a low dispersal ability (being unable to reach islands), and as it is already becoming scarce in most lowland areas, it would lose a noticeable suitable area because of global warming.

Present distribution can be explained by climatic variables only to a limited extent (AUC = 0.75)
Climate risk category: HHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-1972 (-16%)	-2957 (-24%)
	BAMBU	-2576 (-21%)	-3545 (-29%)
	GRAS	-3132 (-26%)	-4100 (-34%)
2100	SEDG	-4350 (-36%)	-6223 (-51%)
	BAMBU	-6893 (-57%)	-9741 (-80%)
	GRAS	-7980 (-66%)	-10623 (-87%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus hyperboreus Schönherr, 1809

= *Bombus (Alpinobombus) hyperboreus*

© Photo: P. Rasmont

Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus hyperboreus is a very large bumblebee. The coat colour is constant and very typical: with 3 yellow bands and a black tail. It is a social parasite of *B. polaris, B. jonellus* and probably other *Bombus* species. It is a generalist forager. It lives in the Scandinavian mountains and along the northern tundra, reaching the Novaya Zemlya in Russia towards the north. It is a circumpolar species, present also in Russia, Alaska, Canada and even the north coast of Greenland where it reaches 84° N. The species is considered to be threatened: Vulnerable in the IUCN Red List of European Bees. Its modelled distribution includes the Alps where the species has never been observed. All scenarios project a strong reduction of suitable areas in the lowlands. Only the coldest areas of the Scandinavian mountains would remain suitable. All three scenarios project severe losses of areas with suitable conditions by 2100. Since *Bombus hyperboreus* shows a specialised way of life and as it is already rare, has a patchy distribution and is restricted to cold areas, it would lose a considerable amount of suitable area which could lead to its extinction in Europe.

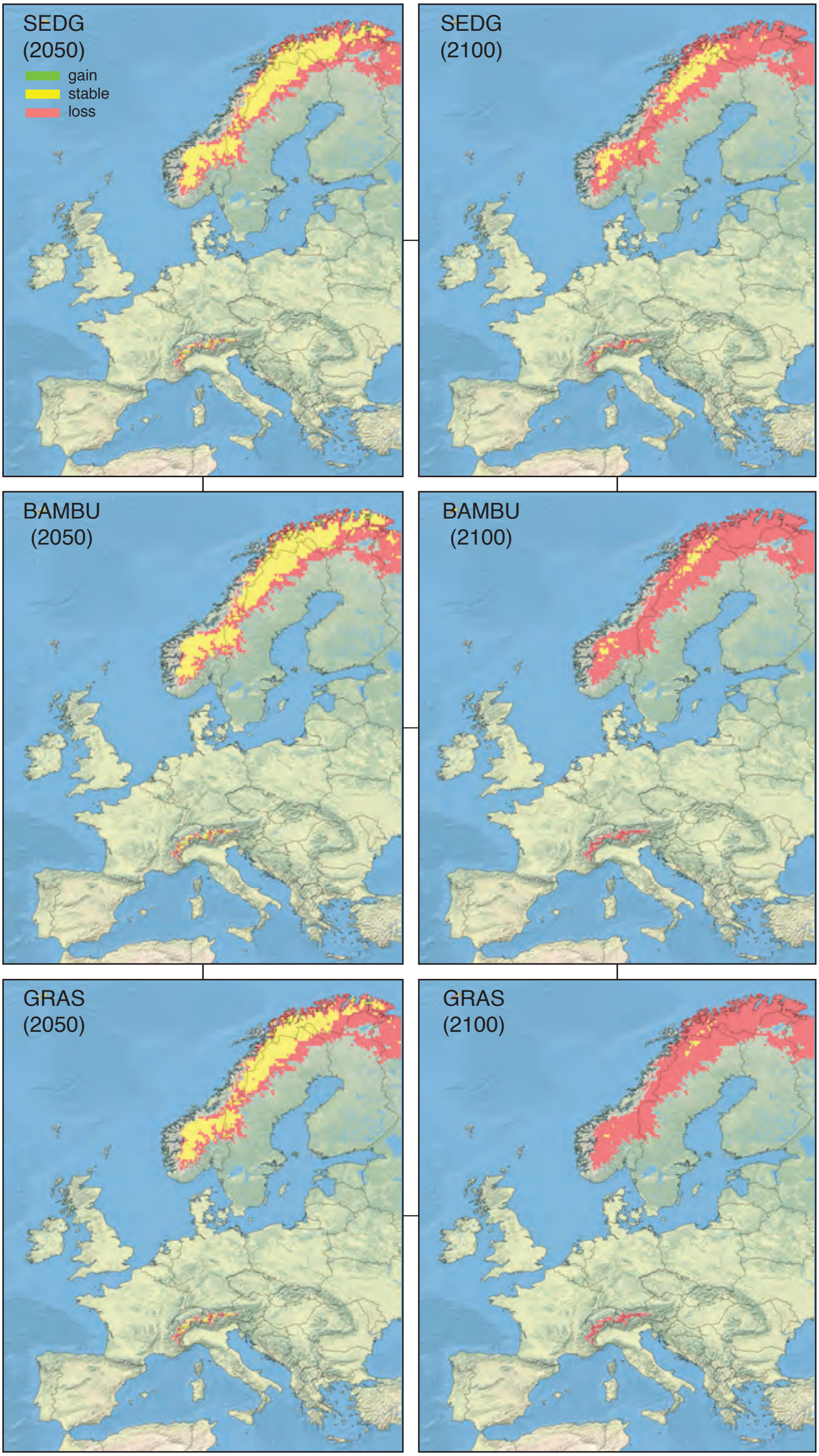
Present distribution can be very well explained by climatic variables (AUC = 0.99)

Climate risk category: HHHR

IUCN Red List status: Vulnerable

	Scenario	Full dispersal	No dispersal
2050	**SEDG**	-1382 (-51%)	-1384 (-51%)
	BAMBU	-1311 (-48%)	-1313 (-48%)
	GRAS	-1496 (-55%)	-1496 (-55%)
2100	**SEDG**	-2217 (-81%)	-2217 (-81%)
	BAMBU	-2584 (-94%	-2584 (-94%)
	GRAS	-2688 (-98%)	-2688 (-98%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus hypnorum (L., 1758)

= *Bombus (Pyrobombus) hypnorum*

© Photo: P. Rasmont

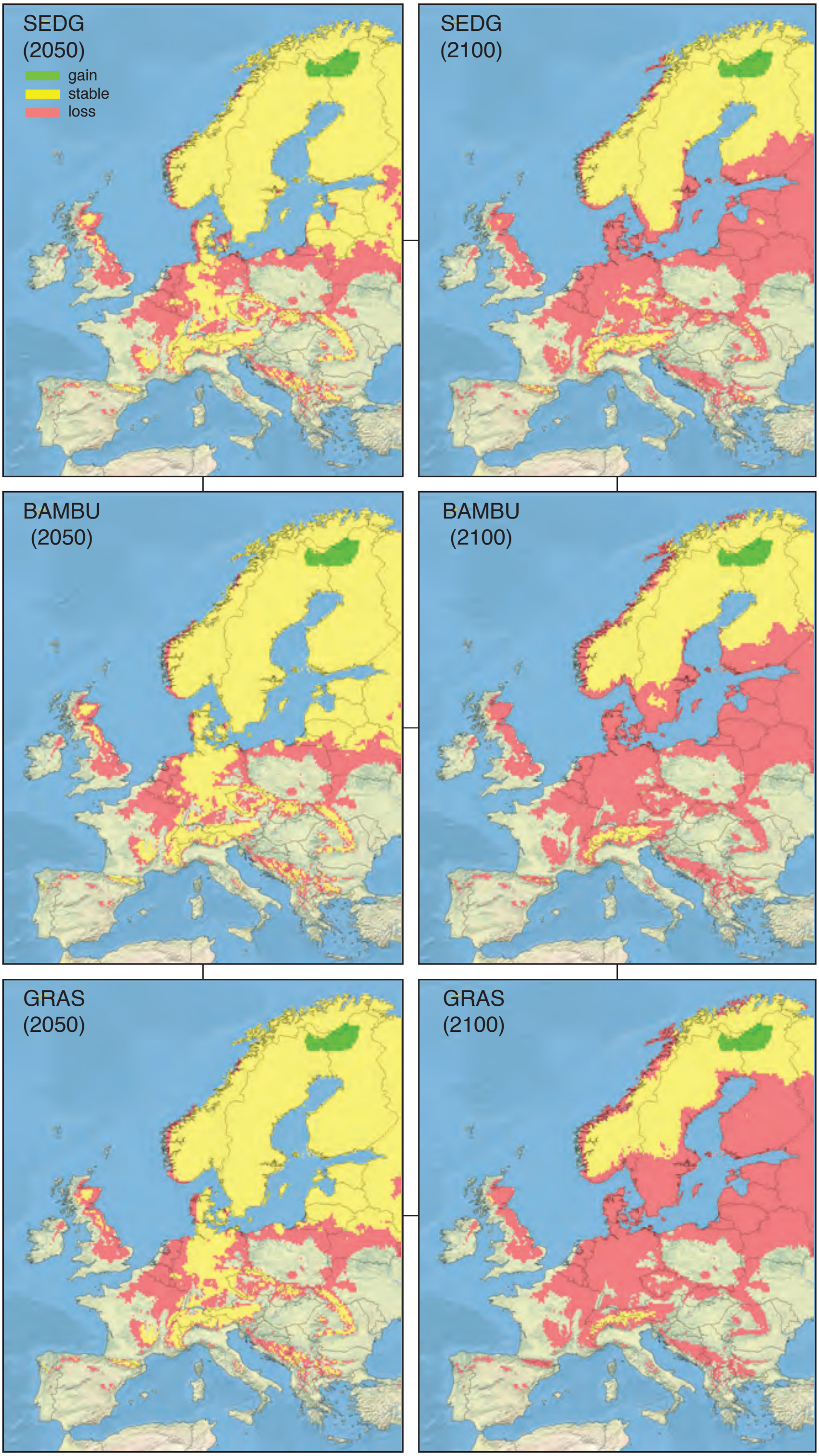
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus hypnorum is a medium-sized bumblebee. The coat colour typically shows a brown thorax, intermixed (to a greater or lesser extent) with an admixture of black hairs. The abdomen has a white tail. It builds large colonies, and nests in tree cavities, buildings, and bird-nest boxes. It is a generalist forager often associated with habitats strongly influenced by human activities. To the south, it reaches the Pyrenees and Balkan mountains and to the north, it reaches the Barents Sea coast. Eastwards, its range extends to the Pacific coast and to the west it has expanded its distribution considerably in recent times. Thirty years ago, it was absent from the coast of Brittany and from the British Isles. It arrived in England in 2001 and expanded its range very quickly, reaching Scotland in 2012. Since 2010, it has also been found in Iceland. The species is not threatened: Least Concern in the IUCN Red List of European Bees. Its modelled distribution includes the mountains of central Spain, the Apennines and Ireland. All scenarios project a significant reduction of suitable areas in the lowlands. By 2100, the scenarios project a near extinction of the species in all lowlands of Europe south of latitude 55° N. As *B. hypnorum* shows a clear and recent expansion of its distribution area and as it is more or less synanthropic, it seems not threatened by global warming. However, even if this species presents clearly a high mobility, all scenarios project a noticeable future reduction of its suitable area.

Present distribution can be well explained by climatic variables (AUC = 0.80)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	**SEDG**	-4461 (-27%)	-4719 (-28%)
	BAMBU	-3815 (-23%)	-4073 (-24%)
	GRAS	-4179 (-25%)	-4435 (-27%)
2100	**SEDG**	-9007 (-54%)	-9265 (-56%)
	BAMBU	-10118 (-61%)	-10374 (-62%)
	GRAS	-11766 (-71%)	-12022 (-72%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
🟩 gain
🟨 stable
🟥 loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus incertus Morawitz, 1882

= *Bombus (Melanobombus) incertus*

© Photo: P. Rasmont

Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus incertus is a medium-sized bumblebee. The coat colour shows 3 white bands and a red tipped abdomen. It is a generalist forager recorded from Armenia, Iran and Turkey, where it is one of the most abundant and ubiquitous bumblebees, but does not reach the Caucasus. It is not a threatened species but, as it is not a sensu stricto European species, it has not been assessed in the IUCN Red List of European Bees. Its modelled distribution shows that limited areas in Europe are climatically suitable for the species. Some scenarios project an expansion of its climatic niche space in Europe or, alternatively, a strong regression, depending on the dispersal ability which remains unsettled, even if its small distribution area suggests low. As *B. incertus* is an abundant and ubiquitous species in Turkey (but that never colonized Great Caucasus), it looks unlikely that the species would go extinct but global warming could in the same time lead to a possible expansion of its range in parts of Europe while it is vanishing in west Turkey.

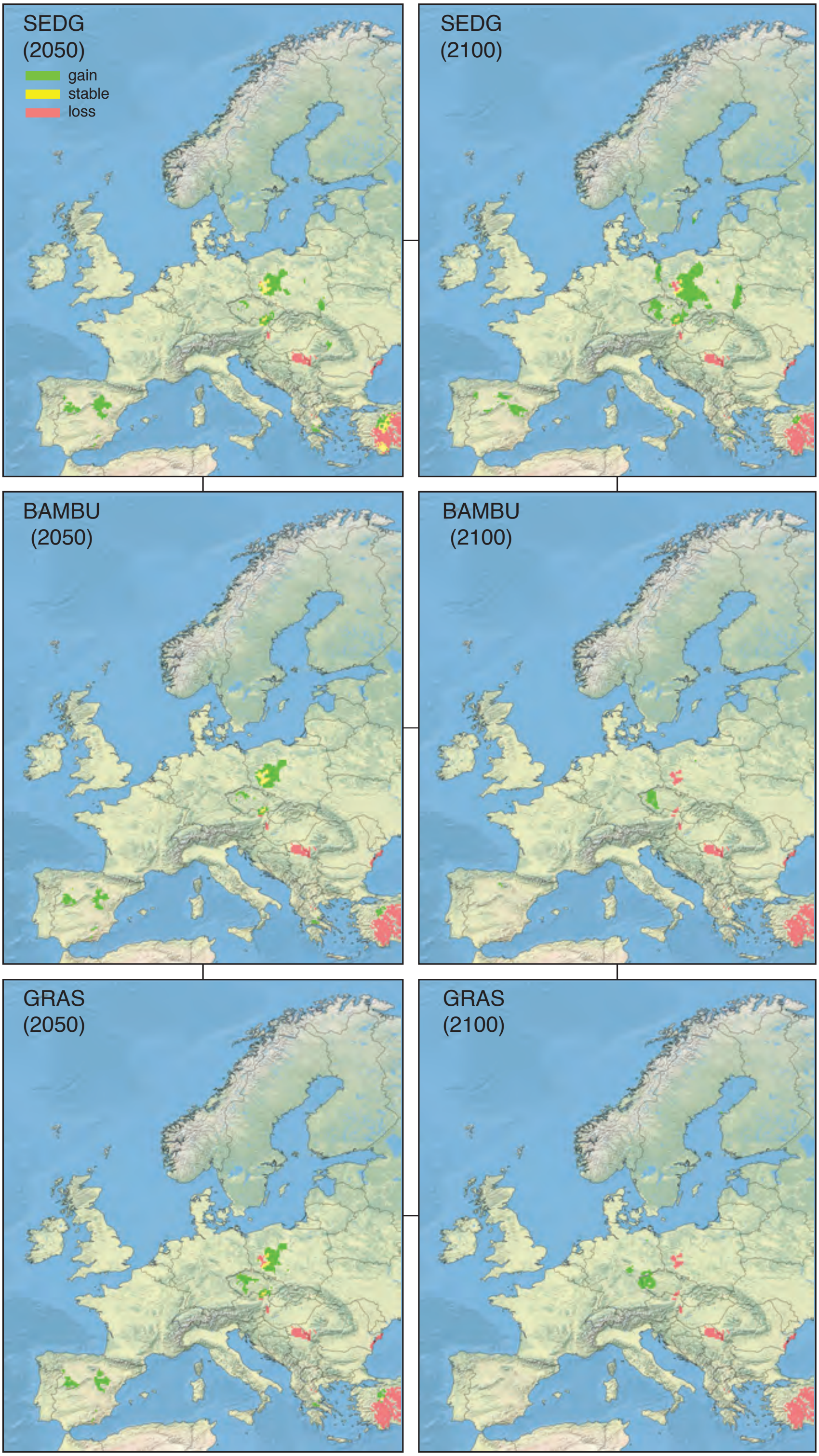
Present distribution can be very well explained by climatic variables (AUC = 1.00)

Climate risk category: HHHR

IUCN Red List status: Not Evaluated

	Scenario	Full dispersal	No dispersal
2050	**SEDG**	79 (20%)	-294 (-74%)
	BAMBU	-68 (-17%)	-359 (-90%)
	GRAS	-65 (-16%)	-372 (-93%)
2100	**SEDG**	195 (49%)	-373 (-93%)
	BAMBU	-346 (-87%)	-399 (-100%)
	GRAS	-314 (-79%)	-399 (-100%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus inexspectatus (Tkalců, 1963)

= *Bombus (Thoracobombus) inexspectatus*

© Photo: G. Mahé

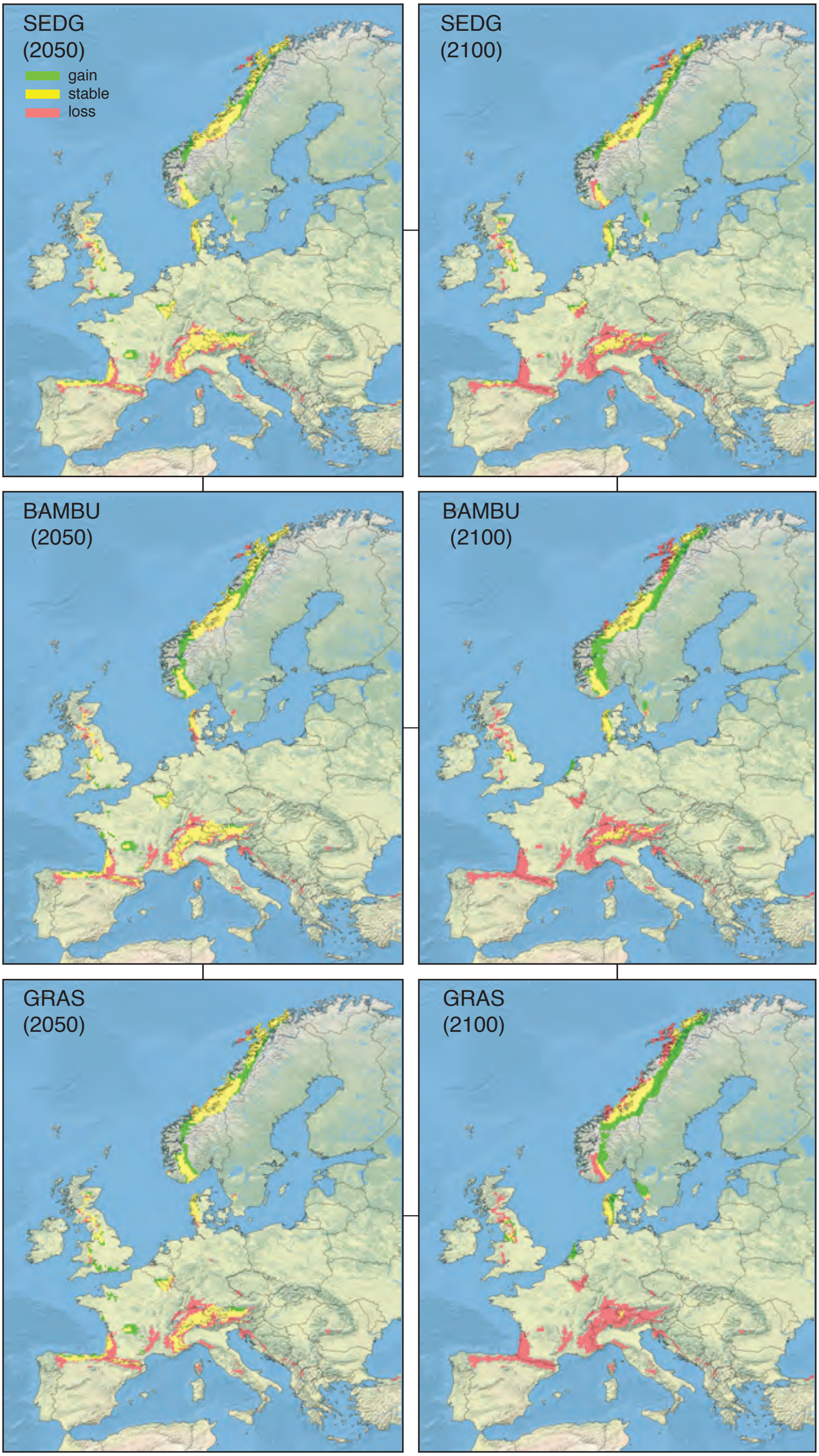
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus inexspectatus is a medium-sized bumblebee. Its coat colour generally shows three greyish bands and a reddish tail. It is a cuckoo bumblebee which is hosted by *B. ruderarius* and maybe also by other closely related species. It occurs only in the Cantabrian Mountains and the Alps where it is extremely rare. Because of its low abundance and restricted distribution, it is listed as Endangered in the IUCN Red List of European Bees. Its modelled distribution includes most of the mountain massifs of Europe where it does not actually occur. All scenarios project a significant reduction of suitable areas by 2050. By 2100, areas with suitable climatic conditions are projected to decrease drastically. As *B. inexspectatus* is a rare and highly specialised species, with a restricted distribution, and apparently a low dispersal capability, the considerable reduction of suitable conditions by global warming could drive it to total extinction.

Present distribution can be very well explained by climatic variables (AUC = 0.98)
Climate risk category: HR
IUCN Red List status: Endangered

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	-258 (-14%)	-568 (-32%)
	BAMBU	-266 (-15%)	-615 (-34%)
	GRAS	-329 (-18%)	-703 (-39%)
2100	**SEDG**	-766 (-43%)	-1070 (-60%)
	BAMBU	-745 (-42%)	-1215 (-68%)
	GRAS	-918 (-51%)	-1417 (-79%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus jonellus (Kirby, 1802)

= *Bombus (Pyrobombus) jonellus*

© Photo: P. Rasmont

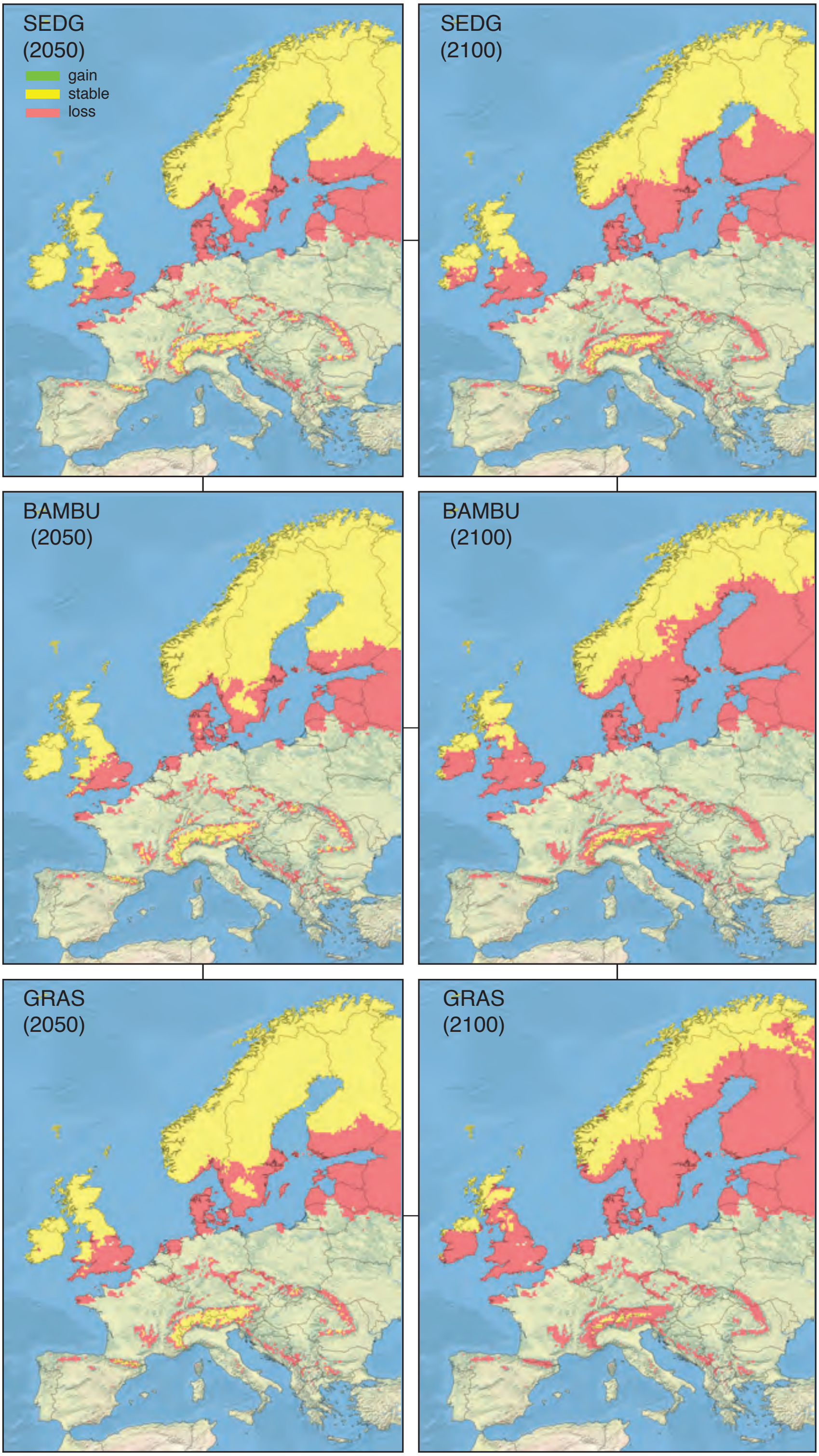
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus jonellus is a small bumblebee. The coat colour is quite constant with 3 yellow bands and a white tail. It can be found in moors and heathlands in small colonies. Together with with *B. terrestris*, it is one of the only two European bumblebees that are bivoltine. It forages on numerous flower species but when possible it prefers Ericaceae (*Vaccinium* spp., *Erica* spp., *Rhododendron* spp.). Its southernmost populations occur in the Pyrenees and Cantabrian mountains, while it reaches the Barents Sea coast to the north. It reaches Iceland in the west and Kamchatka in the east. In Europe, it lives in the lowlands north of latitude 50° N and in mountains and hills north of latitude 41° N. It can be very abundant in the northern parts of its range while it is very rare in the southern range margins such as in the Pyrenees. The species is not considered to be threatened at the continental scale: Least Concern in the IUCN Red List of European Bees. Its modelled distribution includes some mountains in the south (Balkan, Carpathians) where it has never been observed. However, it is inconspicuous with a high chance of remaining unrecorded as has been the case in Pyrenees for a long time. Regardless of its dispersal capability, all scenarios project a reduction of suitable areas space mainly in the lowlands. In the worst case, GRAS projects a considerable reduction of the suitable area mainly in the Alps, Scotland and Scandinavia. As *B. jonellus* can be very abundant, bivoltine and able to forage over such a long period of the year, it would be not directly threatened by global warming even if the area of its suitable areas could considerably be reduced. Moreover, heathlands and moors are habitats that could suffer a lot from warming.

Present distribution can be well explained by climatic variables (AUC = 0.90)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-4648 (-34%)	-4650 (-34%)
	BAMBU	-4523 (-33%)	-4525 (-33%)
	GRAS	-4991 (-37%)	-4991 (-37%)
2100	SEDG	-6509 (-48%)	-6509 (-48%)
	BAMBU	-8131 (-60%)	-8131 (-60%)
	GRAS	-9463 (-70%)	-9463 (-70%)

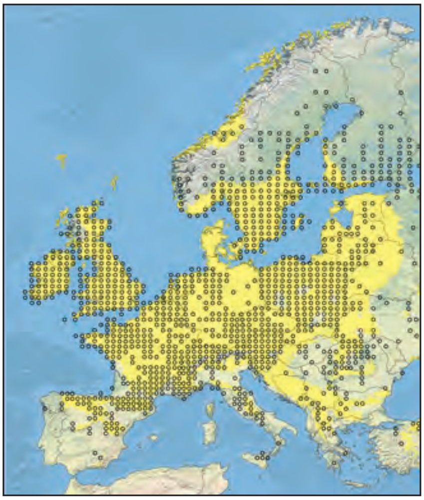
Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus lapidarius (L., 1758)

= *Bombus (Melanobombus) lapidarius*

© Photo: A. Pauly



Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus lapidarius is a medium-sized bumblebee. Its coat colour is quite constant in most parts of Europe: all black with a red tail (female) the head and thorax being more or less intermixed with yellow hairs in males. In Spain and Italy, the females can show three greyish yellow bands and a red tail (ssp. *decipiens* Pérez). It lives in large underground colonies in nearly all habitats. It is also a generalist forager. Its distribution extends from north Morocco, southern Spain, Sicily and southern Greece in the south to northern Sweden in the north. It occurs from Ireland in the west to the Ural Mountains in the east. It is generally abundant, and is not considered to be threatened at the continental scale: Least Concern in the IUCN Red List of European Bees. Its modelled distribution more or less fits with its actual one except in north Scandinavia. All scenarios project a reduction of suitable areas, mainly in the lowlands. This reduction would still be inconspicuous in 2050 but more drastic by 2100. In the worst case, GRAS projects that by 2100 there will be a considerable reduction of the suitable area in the Alps, Scotland and Scandinavia and in some areas of the Pyrenees and central European mountains and hills. Even if *B. lapidarius* is a ubiquitous species, generally abundant, with a potentially high dispersal capability, the area of its suitable areas would be considerably reduced.

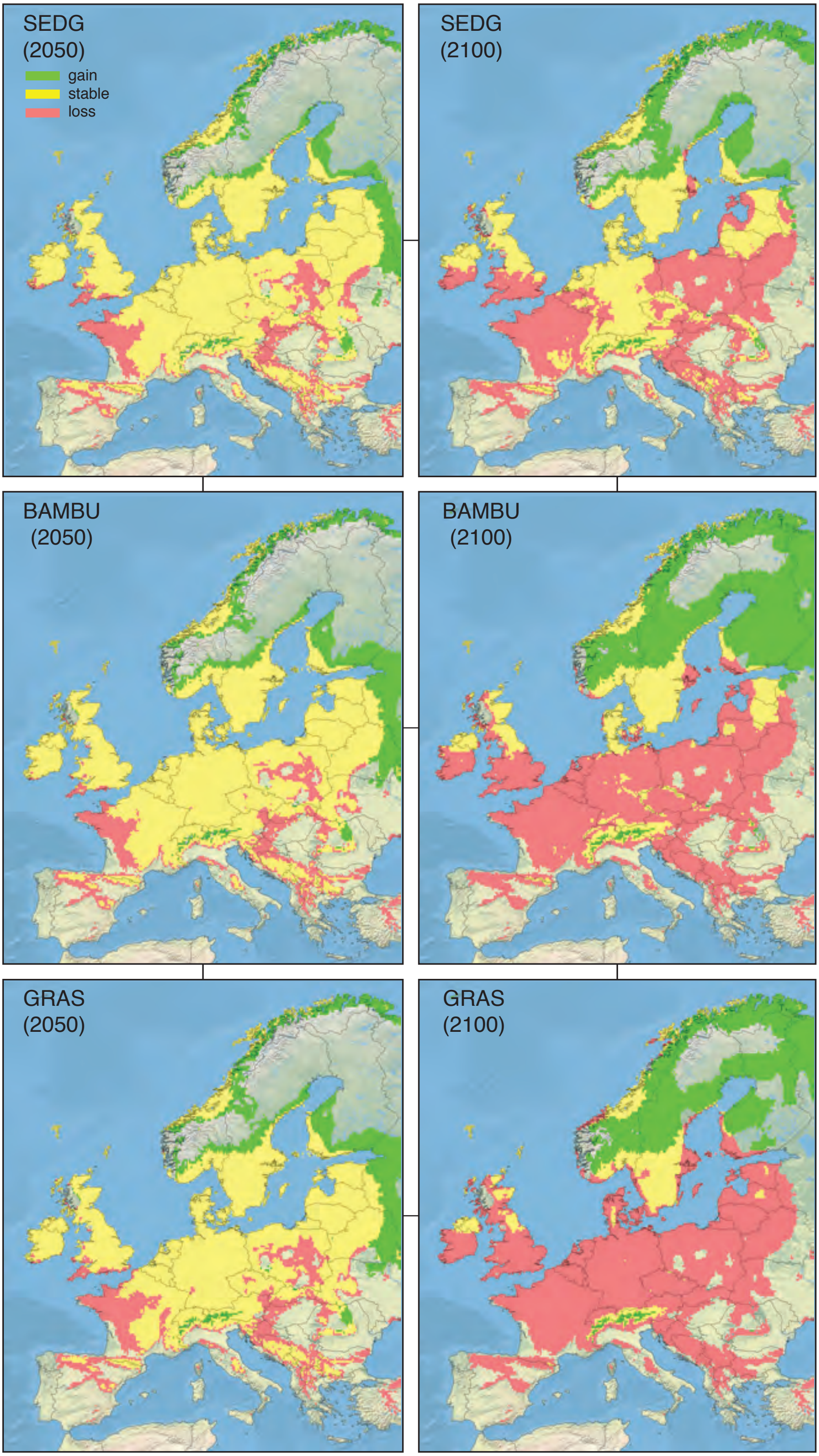
Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.79)

Climate risk category: HHR

IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-961 (-7%)	-2927 (-20%)
	BAMBU	-217 (-1%)	-2794 (-19%)
	GRAS	-665 (-5%)	-3388 (-23%)
2100	SEDG	-5632 (-38%)	-7924 (-54%)
	BAMBU	-5793 (-40%)	-11052 (-75%)
	GRAS	-8604 (-59%)	-12780 (-87%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus lapponicus (Fabricius, 1793)

= *Bombus (Pyrobombus) lapponicus*

© Photo P. Rasmont

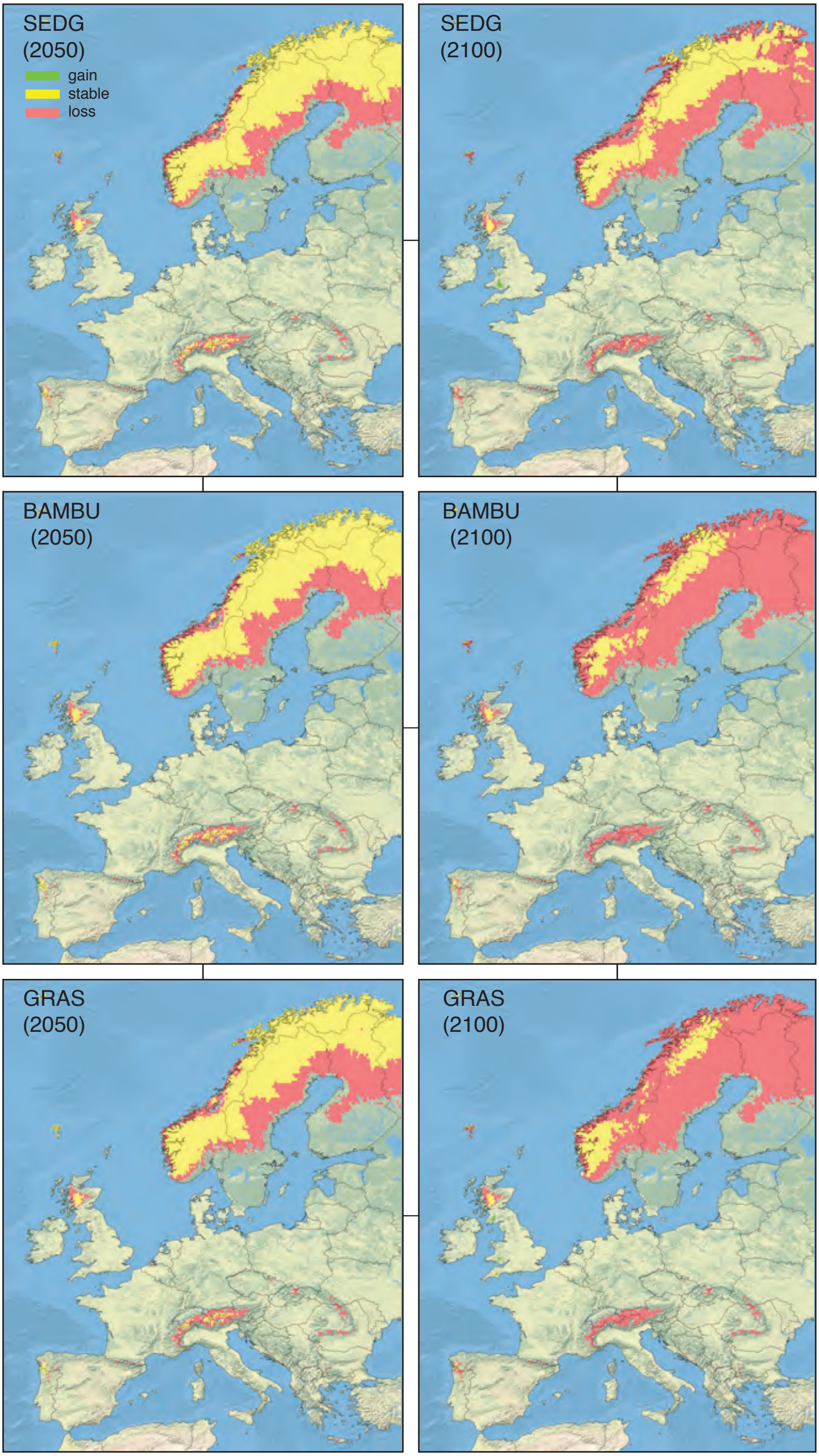
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus lapponicus is a small bumblebee. Its coat colour is quite variable but always shows greyish hairs on the thorax and a largely red abdomen. It is very difficult to separate from *B. monticola* with which it coexists in most areas. It has small colonies in the Fennoscandian and Russian taiga and tundra where it can be abundant. It extends to the east all along the north-Siberian lowlands to the Pacific coast. It is a generalist forager. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. Its modelled distribution more or less fits with its actual one in northern Europe. However, the species has never been observed in the British Isles or any European mountains south of latitude 60° N. All scenarios project a conspicuous reduction of suitable areas by 2050 which becomes even more accentuated by 2100. In the worst case scenario, GRAS projects that by 2100 the climatically suitable area will be restricted to the Scandinavian mountains and will exclude all lowland areas. Regardless of its dispersal capability, as *B. lapponicus* is a typical northern species, closely linked with boreal taiga and arctic tundra, the area of its suitable climatic areas would be significantly reduced.

Present distribution can be very well explained by climatic variables (AUC = 0.98)
Climate risk category: HHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-1977 (-33%)	-1978 (-33%)
	BAMBU	-2146 (-36%)	-2148 (-36%)
	GRAS	-2299 (-38%)	-2301 (-39%)
2100	SEDG	-3544 (-59%)	-3555 (-59%)
	BAMBU	-5051 (-85%)	-5052 (-85%)
	GRAS	-5177 (-87%)	-5184 (-87%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus lucorum (L., 1761)

= *Bombus (Bombus) lucorum*

© Photo P. Rasmont

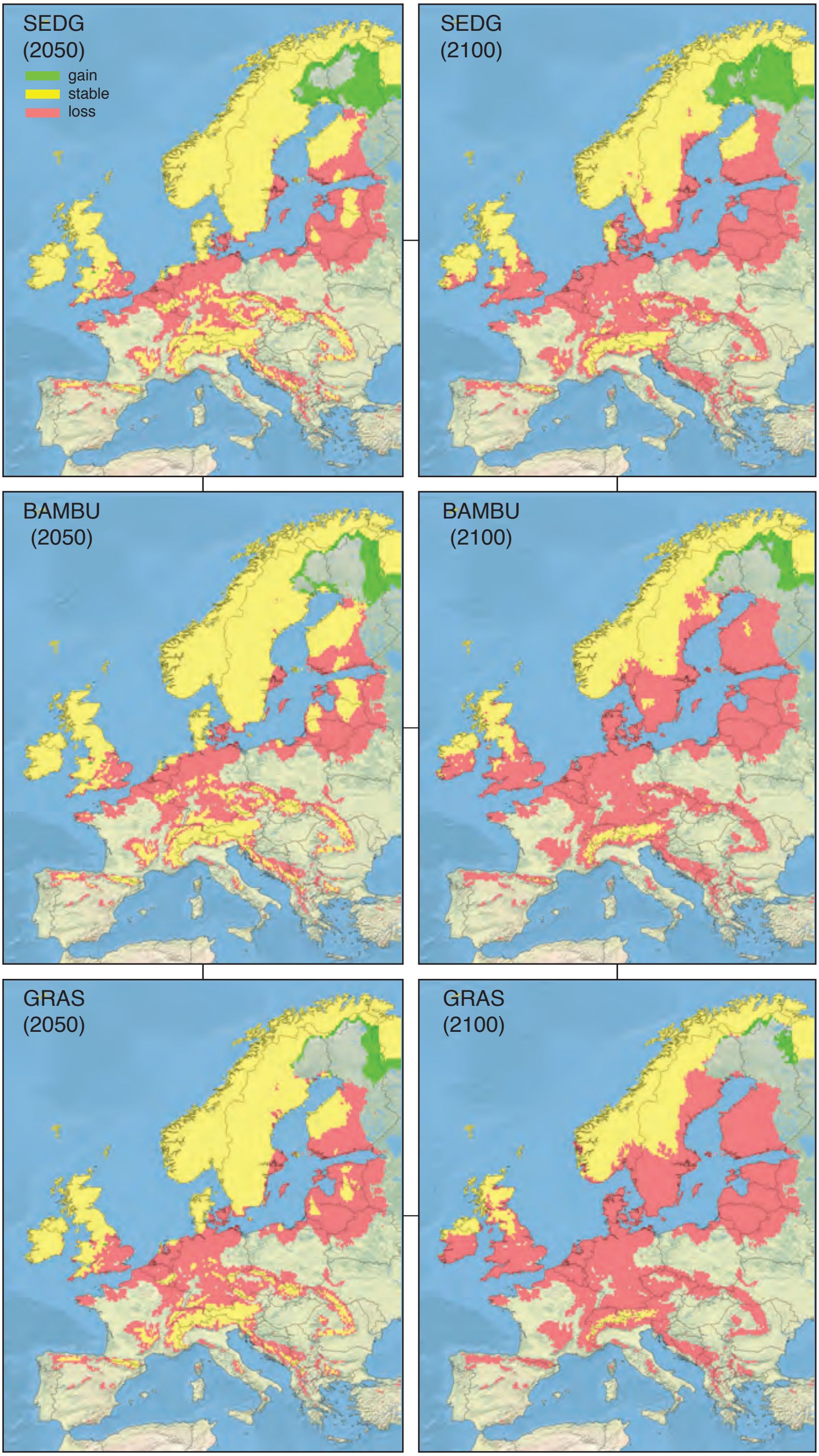
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus lucorum is a medium-sized bumblebee. Its coat colour generally shows two yellow bands and a white tip to the abdomen. The head and thorax of the males are very typically intermixed with numerous yellow and greyish hairs. Some specimens are extremely difficult to separate from *B. magnus, B. cryptarum* and *B. terrestris*. It lives in small- to medium-sized underground colonies in all habitats with a clear preference for forests and forest-edges. It is a generalist forager occurring from southern Europe north to the Barents Sea coast. To the west, it reaches Iceland and to the east, it occurs across northern Asia to the Pacific coast. It can be very abundant, especially towards the north of its range. However, since 2000, it becomes obviously much less abundant in Belgium and western France. Despite this regional regression, the species is not considered to be threatened at the continental scale: Least Concern in the IUCN Red List of European Bees. Its modelled distribution more or less fits with its actual one. All scenarios project a reduction of suitable areas which will already be significant by 2050, especially in the south of England, France, Belgium, the Netherlands and across the central European lowlands. This reduction is projected to be more drastic still by 2100. In the worst case, GRAS projects that by 2100 a reduction of the suitable area will leave only the north of British Isles, the Scandinavian mountains and the Alps, and exclude all European lowlands south of latitude 60° N. As *B. lucorum* is a ubiquitous species that can be very abundant, possibly with a high dispersal capability, it is unlikely that it would become extinct in Europe. However, the area of suitable climatic conditions would be considerably reduced, leading to a substantial decrease in most European countries.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.82)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-4788 (-32%)	-5700 (-38%)
	BAMBU	-5127 (-34%)	-5672 (-38%)
	GRAS	-6237 (-41%)	-6618 (-44%)
2100	SEDG	-7065 (-47%)	-8143 (-54%)
	BAMBU	-9468 (-63%)	-9913 (-66%)
	GRAS	-10491 (-70%)	-10652 (-71%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
🟩 gain
🟨 stable
🟥 loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus magnus VOGT, 1911

= *Bombus (Bombus) magnus*

© Photo P. Rasmont

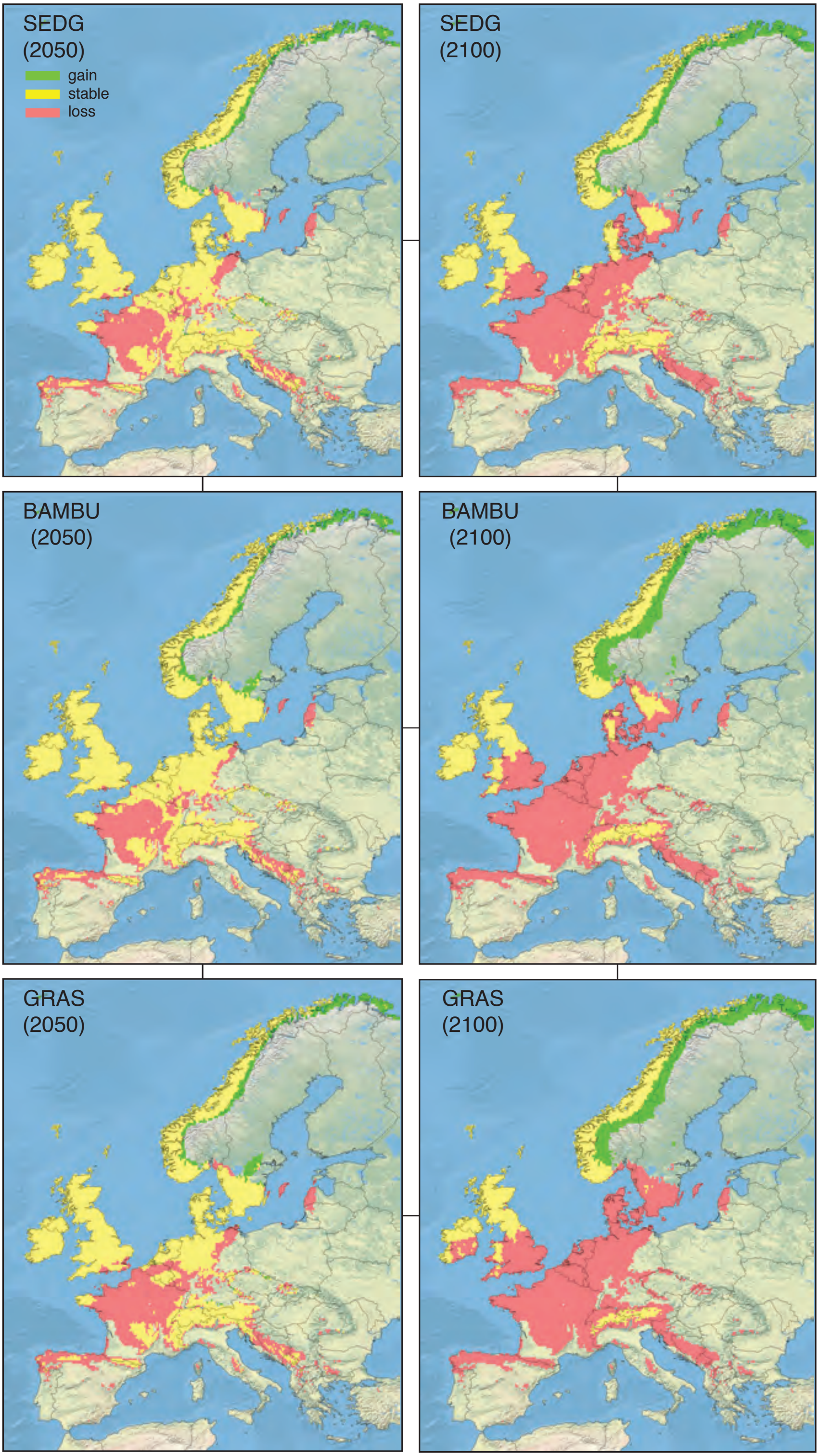
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus magnus is a medium- to large-sized bumblebee. Its coat colour generally shows two yellow bands, extending low on the side of the thorax, and a white tail. The head and thorax of the males are always intermixed with numerous yellow (but no greyish) hairs. Some individuals are difficult to separate from *B. lucorum* and *B. cryptarum* and this taxonomic uncertainty certainly explains why there are relatively few verified records for this species. It makes small- to medium-sized underground colonies in heath lands and moorlands. It is clearly most common in the region with oceanic influences. As it is a quite difficult species to identify with certainty, its distribution is not completely known. As far as we know, it occurs from north Portugal in the south to the north of the Arctic Circle along the west Norwegian coast. It reaches Ireland to the west, where it is abundant, to isolated locations around Moscow to the east, where it is very rare. It is a generalist forager but has a preference for Ericaceae (e.g. *Vaccinium* spp., *Erica* spp., *Rhododendron* spp.). The species is not considered to be threatened at the continental scale: Least Concern in the IUCN Red List of European Bees. Its modelled distribution more or less fits with its actual one, even if it is absent from Corsica, the Apennine mountains and probably from Durmitor and the Balkans. All scenarios project a reduction of suitable areas that is already significant by 2050, especially in the French lowlands. This reduction is projected to be more drastic by 2100. In the worst case, GRAS projects that by 2100 a reduction of the climatically suitable area will confine the species to the north of the British Isles and Scandinavia. Reductions are also projected for the Alps but here the species is already extremely rare. Regardless of its dispersal capability, as *B. magnus* is a bumblebee with quite narrowly defined habitat preferences, clear flower preferences and climatic preferences linked with oceanic climates, it would be strongly affected by a significant reduction of suitable areas. It is unlikely that this species would become extinct but it could disappear from most European countries.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.85)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	-2072 (-24%)	-2468 (-29%)
	BAMBU	-1811 (-21%)	-2263 (-26%)
	GRAS	-2508 (-29%)	-2986 (-35%)
2100	**SEDG**	-4401 (-51%)	-5029 (-59%)
	BAMBU	-4658 (-54%)	-5682 (-66%)
	GRAS	-5312 (-62%)	-6321 (-74%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus mendax Gerstaecker, 1869

= *Bombus (Mendacibombus) mendax*

© Photo P. Rasmont

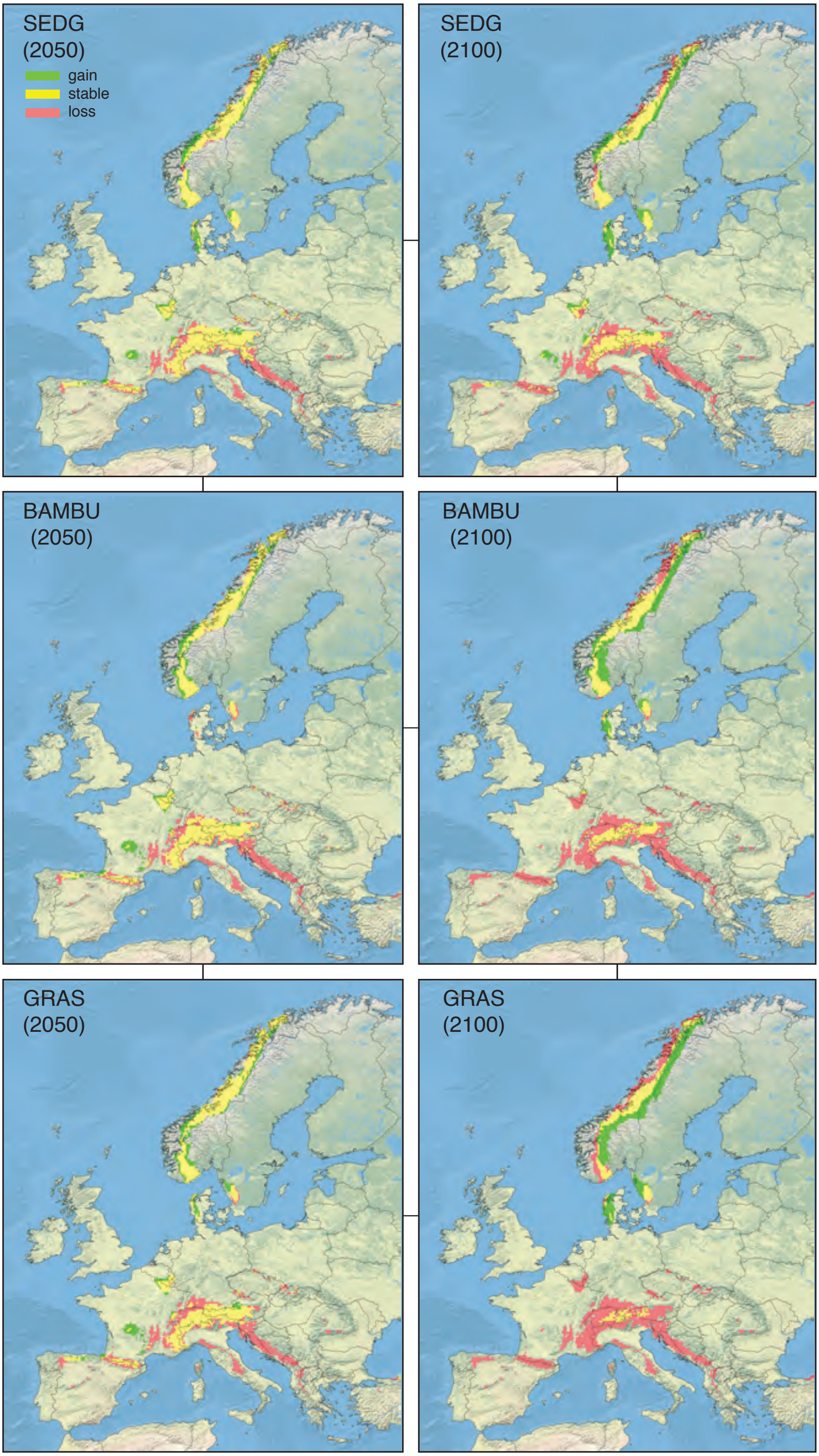
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus mendax is a medium-sized bumblebee. Its coat colour generally shows three greyish bands and a reddish tail. The male has conspicuously enlarged eyes. *Bombus mendax* lives in small underground colonies restricted to high alpine and subalpine areas. It is a generalist forager but prefers flowers with long corollas such as *Trifolium* spp. or *Aconitum* spp. It occurs only in the Cantabrian Mountains (where it is very rare), Pyrenees and Alps. Because of its restricted distribution, the species is considered to be Near Threatened in the IUCN Red List of European Bees. Its modelled distribution includes the Apennines and Scandinavian mountains where the species has never been observed. All scenarios project a reduction of its climatic niche that will already be significant by 2050. In the worst case, the GRAS scenario projects reduction of the suitable climatic conditions to a restricted area in the Alps and an even smaller area in the Pyrenees by 2100. Such a situation could lead it close to extinction. As *B. mendax* is a bumblebee that is restricted to the highest alpine and subalpine levels of the Cantabrian Mountains, Pyrenees and Alps, is likely to have a low dispersal capability, global warming is projected to reduce the area of suitable climatic conditions considerably, leaving the species on the verge of extinction by 2100.

Present distribution can be very well explained by climatic variables (AUC = 0.97)
Climate risk category: HR
IUCN Red List status: Nearly Threatened

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	-376 (-18%)	-673 (-32%)
	BAMBU	-466 (-22%)	-760 (-36%)
	GRAS	-533 (-25%)	-855 (-40%)
2100	**SEDG**	-751 (-35%)	-1158 (-55%)
	BAMBU	-975 (-46%)	-1403 (-66%)
	GRAS	-1162 (-55%)	-1676 (-79%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus mesomelas GERSTAECKER, 1869

= Bombus (Thoracobombus) mesomelas; Bombus (Rhodobombus) mesomelas; Bombus elegans (partim)

© Photo P. Rasmont

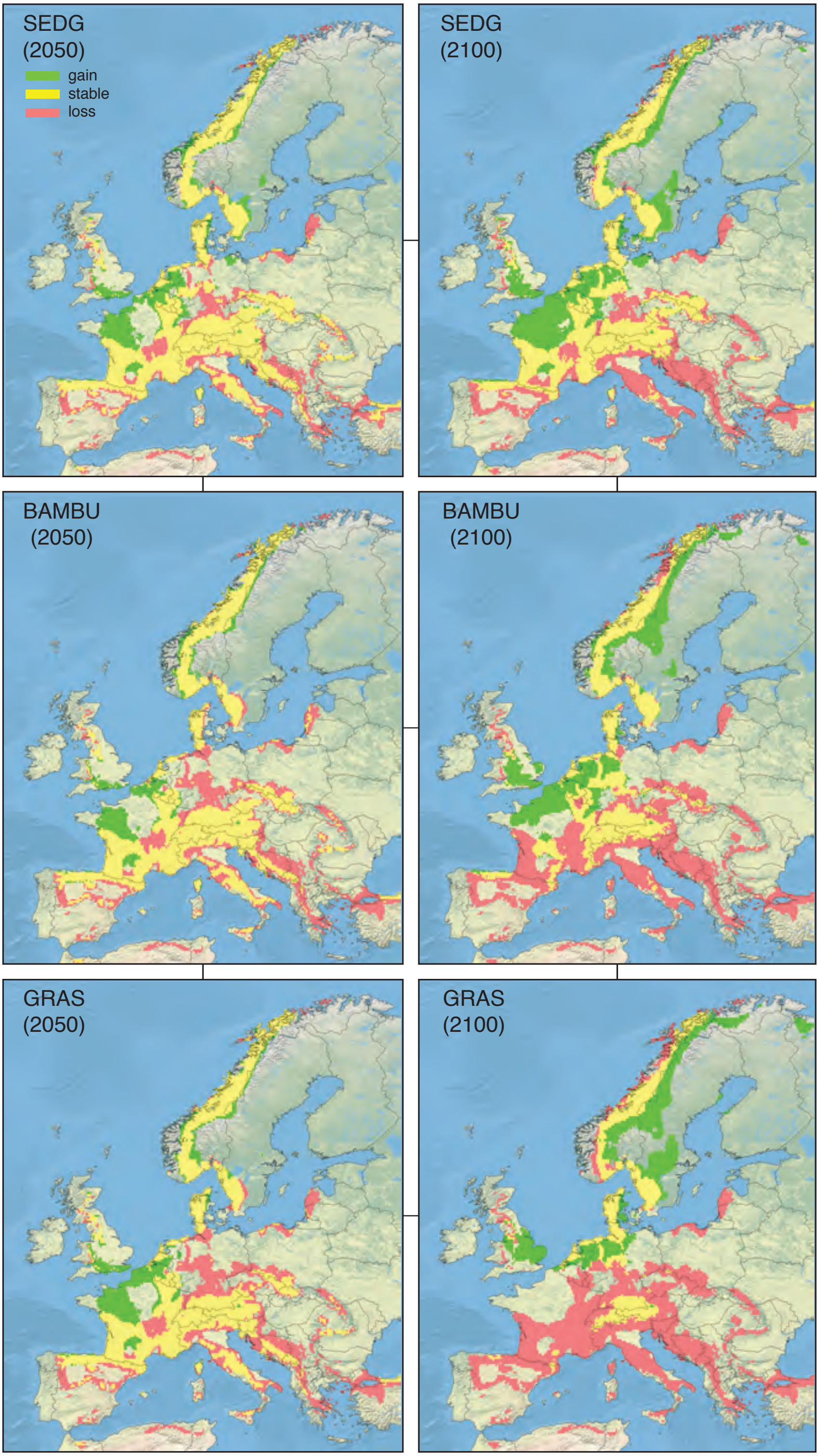
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus mesomelas is a medium- to large-sized bumblebee. Its coat colour is grey with a black thoracic band. In the Balkan peninsula and Turkey, the abdomen shows a conspicuous reddish tinge (ssp. *alboluteus*). *Bombus mesomelas* lives in large underground colonies and is restricted to mountain meadows. It is a generalist forager but it clearly prefers flowers with long corollas such as *Trifolium* spp. (Fabaceae). It occurs in the Cantabrian Mountains, Pyrenees, Alps, Apennines, Balkans, and Carpathians. It has disappeared from lower montane regions of central Europe, such as Harz mountains and Krkonose were it was living one century ago. Despite this regression, the species is not considered to be threatened at the continental scale: Least Concern in the IUCN Red List of European Bees. Its modelled distribution includes large areas of European mountains and hills where the species has never been observed. All scenarios project a significant reduction of suitable areas by 2050, especially in the low mountains of central Europe (from where it already disappeared). The expansion area in Scandinavia that could appear as a counterbalance is nevertheless out of reach. This reduction is even more pronounced by 2100. As *B. mesomelas* is a bumblebee restricted to mountain meadows, and is likely to have a low dispersal capability, global warming would lead to considerable reductions of its suitable areas, especially in the central European mountains, then in the Balkans and Carpathians, and even in the Cantabrian mountains and Pyrenees. However, it is quite unlikely that global warming would lead to extinction of the species.

Present distribution can be well explained by climatic variables (AUC = 0.91)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	-1095 (-14%)	-2343 (-30%)
	BAMBU	-2049 (-26%)	-2902 (-37%)
	GRAS	-1994 (-26%)	-3145 (-40%)
2100	**SEDG**	-1268 (-16%)	-3540 (-45%)
	BAMBU	-2782 (-36%)	-4745 (-61%)
	GRAS	-4136 (-53%)	-5983 (-77%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus monticola Smith, 1851

= *Bombus (Pyrobombus) monticola*

© Photo P. Rasmont

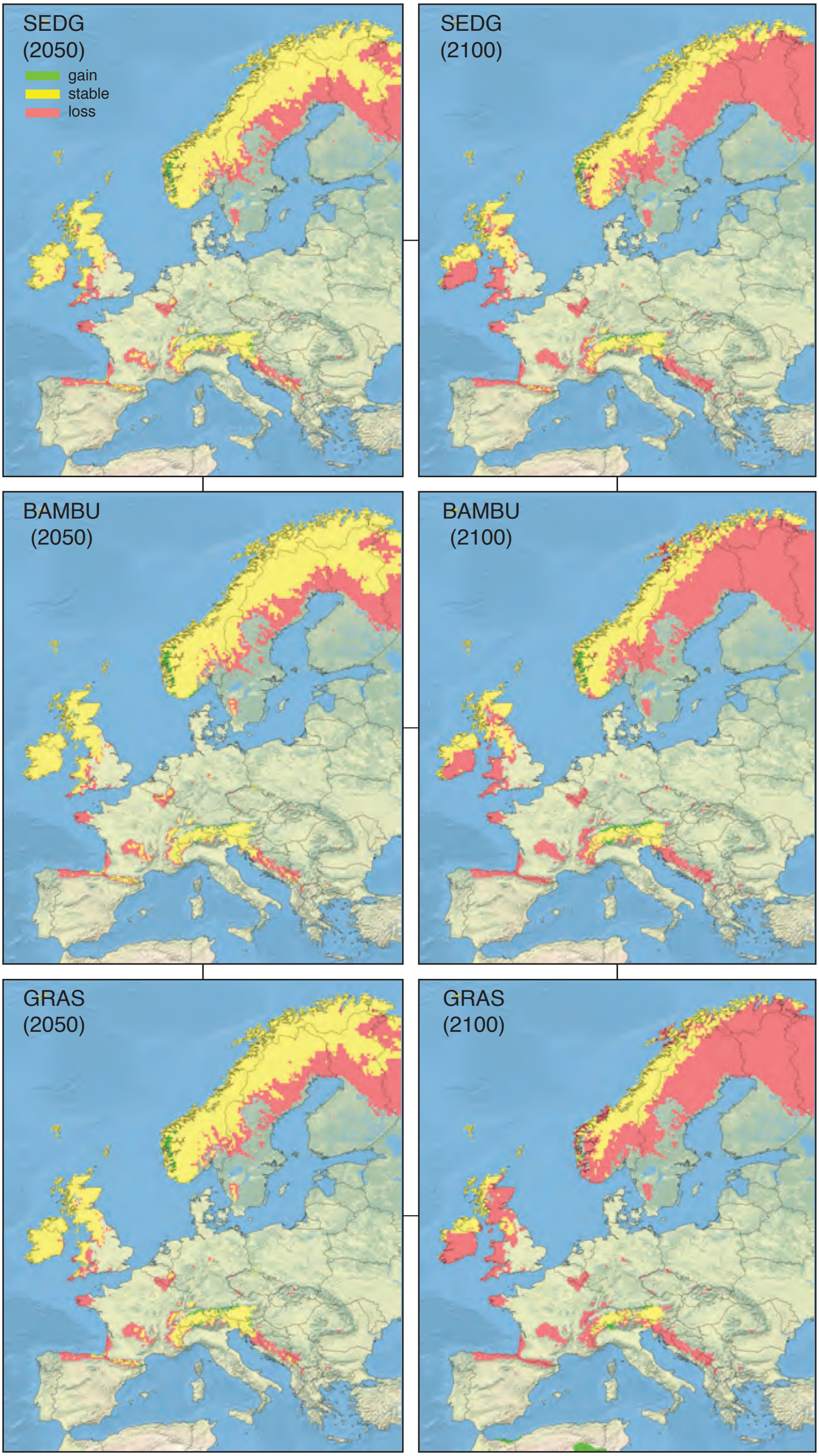
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus monticola is a small bumblebee. Its coat colour is quite variable but always with an abdomen that is largely red and with more or less greyish hairs intermixed with black on thorax and head. It is difficult to separate from *B. lapponicus* with which it coexists in Fennoscandia. It lives in small colonies in Fennoscandian taiga and tundra and in alpine and subalpine meadows in Wales, Scotland, the Cantabrian mountains, Pyrenees, Alps, Apennines, Balkans and the Olympus range (Greece). It seems to recently have colonised Ireland in the late 1970'. *Bombus monticola* can be locally abundant across its range and does not occur outside Europe. It is a generalist forager. The species is not considered to be threatened at the continental scale: Least Concern in the IUCN Red List of European Bees. Its modelled distribution more or less fits with its actual one but it is clear that the species does not occur in highly isolated mountains and hills. It is noticeable that the modelled distribution does not include either the Olympus range or the Apennines, where the species has experienced a significant and recent reduction in abundance. All scenarios project a significant reduction of suitable areas by 2050 and an even more drastic reduction by 2100. In the worst scenario, GRAS projects a reduction by 2100 of the suitable area which will exclude this species from Mt Olympus, the Apennines, Cantabrian mountains and even the Pyrenees. Regardless of its dispersal capacity, as *B. monticola* is a typical mountain species, linked with cold areas, the area of suitable climatic conditions would be significantly reduced.

Present distribution can be well explained by climatic variables (AUC = 0.88)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-2525 (-32%)	-2607 (-33%)
	BAMBU	-2143 (-27%)	-2228 (-28%)
	GRAS	-2508 (-31%)	-2602 (-33%)
2100	SEDG	-4556 (-57%)	-4616 (-58%)
	BAMBU	-4916 (-62%)	-5019 (-63%)
	GRAS	-5777 (-72%)	-5915 (-74%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
🟩 gain
🟨 stable
🟥 loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus mucidus Gerstaecker 1869

= *Bombus (Thoracobombus) mucidus; Bombus (Mucidobombus) mucidus*

© Photo P. Rasmont

Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus mucidus is a small bumblebee. Its coat colour is generally greyish with a black thoracic band; the thoracic and abdominal hairs can be more or less intermixed with black and some specimens from the Alps are mainly black with a greyish tail. It lives in small colonies in subalpine and alpine meadows and forages mainly on Fabaceae (queens, workers) or thistles (males). The species occurs only in the Cantabrian Mountains, Alps, Apennines, Carpathians and Balkans. It is generally a rare species, and is endemic to Europe. The species is considered as Near Threatened in the IUCN Red List of European Bees. Its modelled distribution covers more mountainous areas in which the species does not occur, perhaps due to a lack of sufficient dispersal ability. All scenarios project a substantial reduction of suitable areas by 2050 and a more drastic reduction by 2100. In the worst case, GRAS projects that by 2100 the reduction of the suitable area would exclude the species from the Balkan, Carpathians, and Cantabrian mountains and probably the Pyrenees. *Bombus mucidus* is already considered as a rare species. It is associated with high mountains and is assumed to have a low dispersal ability. A significant reduction in the area of its suitable climatic space could lead to extinction in the Cantabrian mountains, Pyrenees, Appenines, Balkan mountains and the Carpathians.

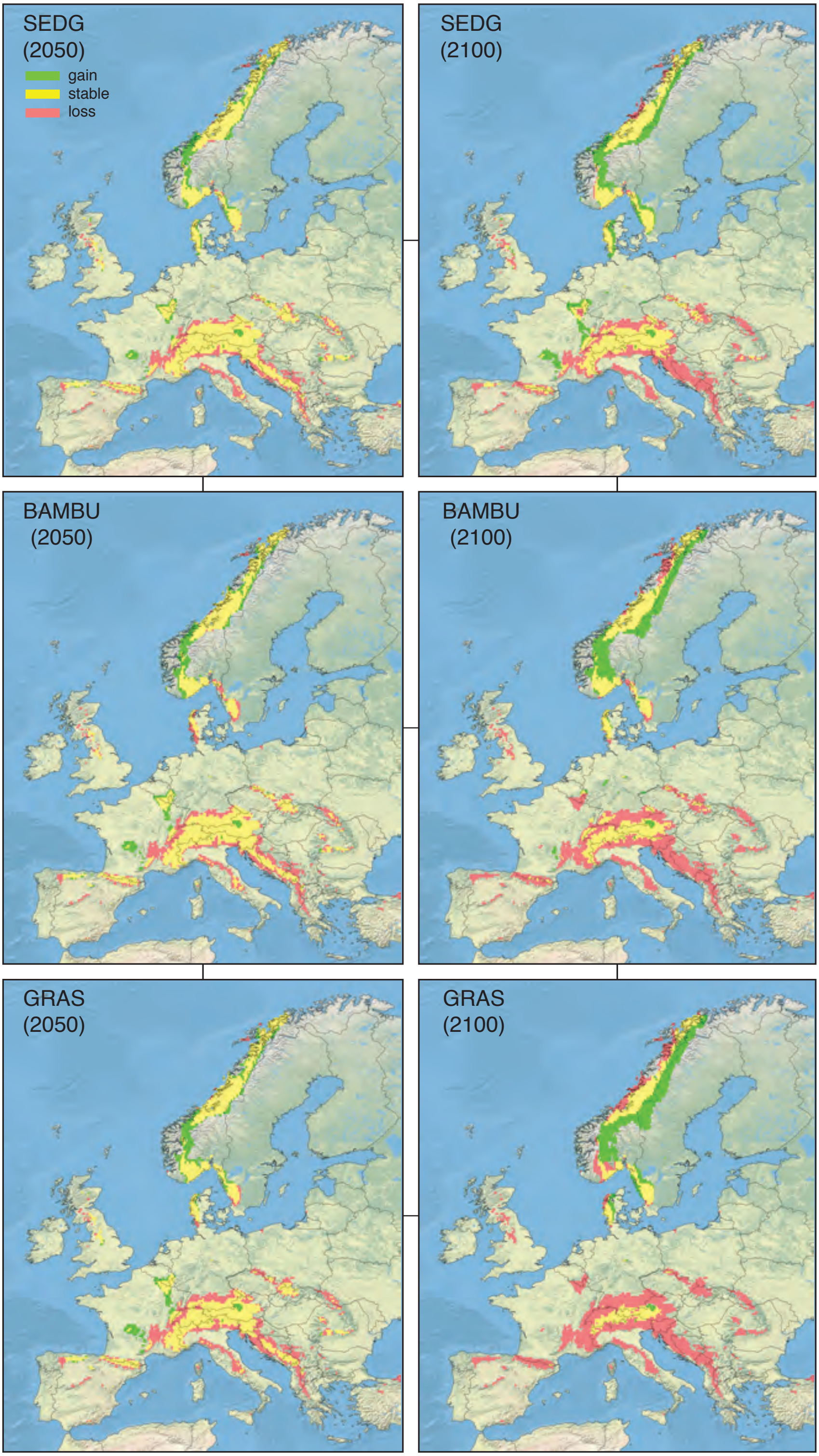
Present distribution can be well explained by climatic variables (AUC = 0.95)

Climate risk category: HR

IUCN Red List status: Least Concern

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	-543 (-17%)	-898 (-28%)
	BAMBU	-687 (-21%)	-1063 (-33%)
	GRAS	-737 (-23%)	-1165 (-36%)
2100	**SEDG**	-928 (-29%)	-1583 (-49%)
	BAMBU	-1423 (-44%)	-2013 (-62%)
	GRAS	-1730 (-53%)	-2435 (-75%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus muscorum (L., 1758)

= *Bombus (Thoracobombus) muscorum*

© Photo P. Rasmont

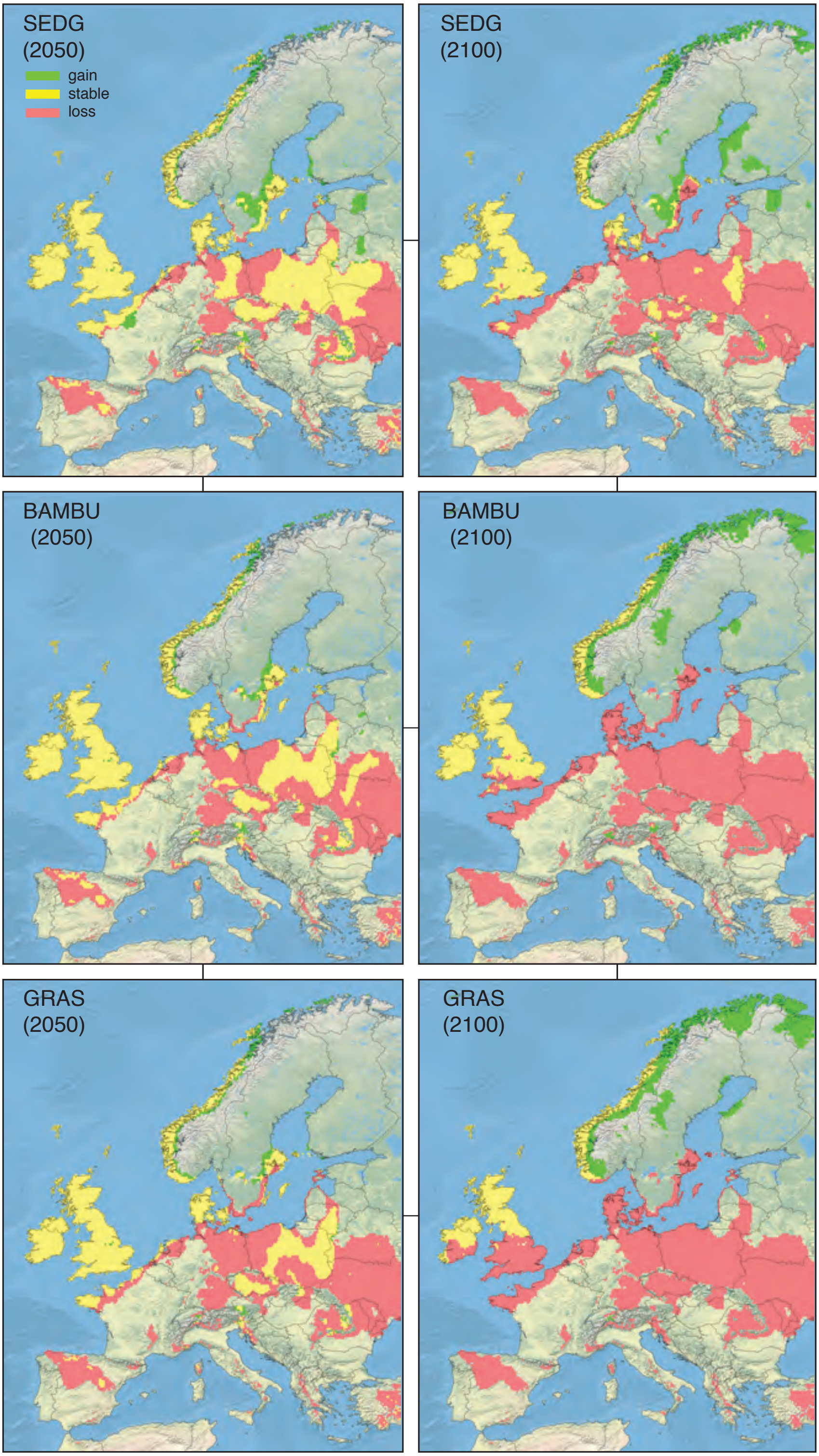
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus muscorum is a medium-sized bumblebee. Its coat colour is generally completely orange. Most populations of western islands, northern Scandinavia and northern Russia have black hairs on the legs (ssp. *bannitus*) while the Corsican ssp. is very dark, with the thorax almost entirely black (ssp. *pereziellus*). It lives in large colonies in grass-tussocks in various landscapes but with a clear preference for areas close to the sea coasts. It prefers to forage on Fabaceae flowers. The species occurs in most parts of Europe but it is very rare south of latitude 40° N. It has not been observed in many of the locations of west, central and south-east Europe where it occurred one century ago. Outside Europe, it reaches Mongolia in the east. The species is considered to be threatened: Vulnerable in the IUCN Red List of European Bees. Its modelled distribution fits with its present distribution but excludes large areas of former occurrence. All scenarios project a significant reduction of suitable areas by 2050 and an even more drastic reduction by 2100. Most of the areas from which the species has already disappeared, but were modelled as suitable under current conditions, are areas that are projected to become unsuitable in the future. Suitable climatic conditions remain only in Ireland, north of the British Isles (where it is already scarce) and in Scandinavia north of latitude 60° N (where it is not very abundant). *Bombus muscorum* is currently declining where its extinction is projected for the future. It is assumed to have a low dispersal capability. The area of its suitable climatic niche would be considerably reduced leading to local extinctions across large parts of Europe. The potential of the species to persist in the remaining, much smaller area is questionable.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.83)
Climate risk category: HHR
IUCN Red List status: Vulnerable

	Scenario	Full dispersal	No dispersal
2050	SEDG	-3358 (-34%)	-4076 (-41%)
	BAMBU	-4701 (-48%)	-5058 (-51%)
	GRAS	-5536 (-56%)	-5851 (-59%)
2100	SEDG	-5816 (-59%)	-6990 (-71%)
	BAMBU	-6775 (-69%)	-7926 (-80%)
	GRAS	-7080 (-72%)	-8470 (-86%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus niveatus KRIECHBAUMER, 1870

Bombus (Sibiricobombus) niveatus; Bombus vorticosus

© Photo G. Pisanty

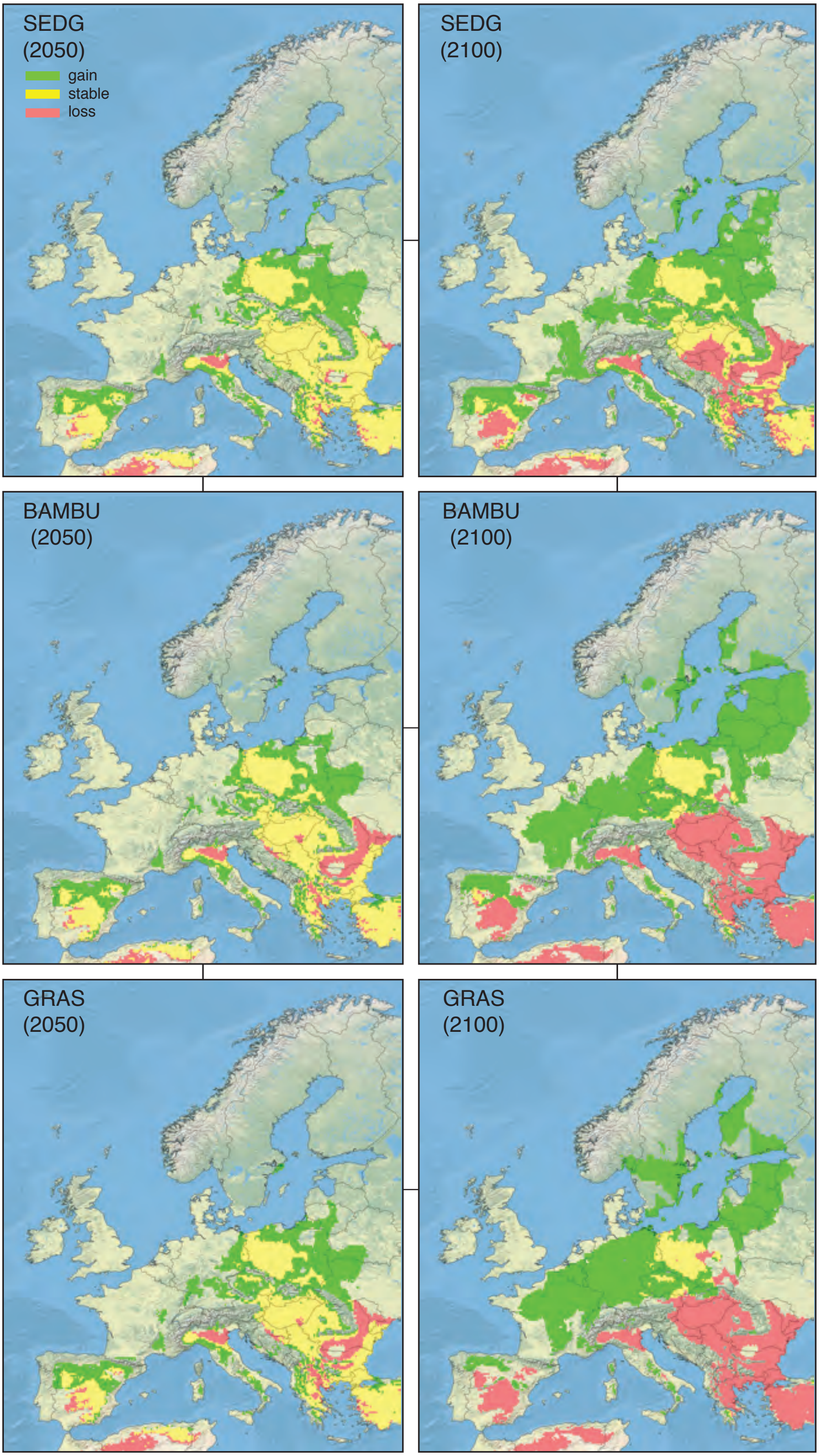
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus niveatus is a large bumblebee. On the European continent, its coat colour is very constant with three yellowish bands and a red tail (ssp. *vorticosus* Gerstaecker). In Turkey, Armenia, Georgia, Azerbaijan, the Caucasus and Iran, a form occurs where the yellowish bands are replaced by white ones (ssp. *niveatus* s.s.). The males have large eyes and fly very fast. It lives in sizeable colonies that are often established in cavities, sometimes after ousting the bird that was occupying the nest site. It's a generalist forager even if (as a long-tongued species) it prefers flowers with deep corollas. In Europe, the species occurs in the Balkans only. Elsewhere it is found in Turkey, Georgia, the Caucasus, Azerbaijan and Iran. It is abundant throughout most of its range. The species is not considered to be threatened at the continental scale: Least Concern in the IUCN Red List of European Bees. Its modelled distribution is much larger than its actual one. All scenarios project a considerable enlargement of its suitable area by 2050. This tendency would be even more pronounced by 2100, with suitable area even extending to western Europe and Scandinavia. However, if the species is limited by dispersal, it would be at risk, as its original area could become unsuitable (under the GRAS scenario). As it is an abundant species, with an assumed high dispersal capability, and adapted to warm and dry climatic conditions, *B. niveatus* could benefit from global warming as its climatic suitable area would expand considerably.

Present distribution can be well explained by climatic variables (AUC = 0.95)
Climate risk category: HHR
IUCN Red List status: Least Concern

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	2788 (53%)	-523 (-10%)
	BAMBU	1732 (33%)	-1107 (-21%)
	GRAS	2136 (41%)	-1226 (-23%)
2100	**SEDG**	2999 (57%)	-2442 (-47%)
	BAMBU	2198 (42%)	-4381 (-84%)
	GRAS	1544 (29%)	-4586 (-87%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus norvegicus Sparre Schneider, 1918

= *Bombus (Psithyrus) norvegicus; Psithyrus norvegicus*

© Photo P. Rasmont

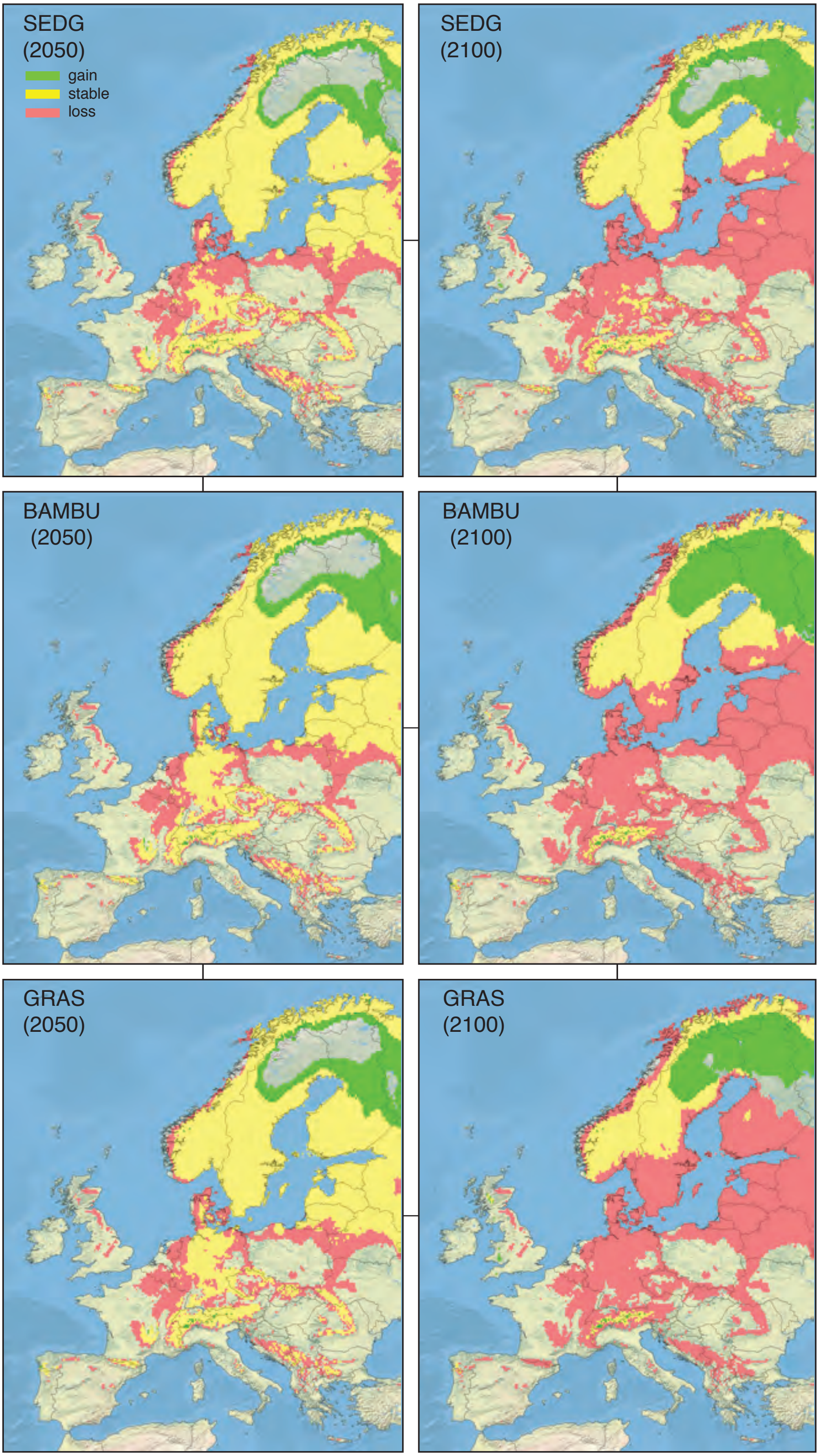
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus norvegicus is a small- to medium-sized bumblebee. Its coat colour generally shows a large prothoracic band and a white tail. Confusions are frequent with the closely related species *B. sylvestris.* It is a specialised social parasite species (cuckoo-bumblebee) mostly of *B. hypnorum*. Its southernmost populations are in the Cantabrian mountains and Pyrenees. It occurs as far north as the Arctic Circle, but is not known from the British Isles or in the Balkan peninsula. To the east, it reaches the Pacific coast. It is everywhere a rare species. The species is not considered to be threatened at a continental scale: Least Concern in the IUCN Red List of European Bees. The modelled distribution is much wider than its actual one, extending to central Spain, the Apennines, British Isles and the Balkans, where the species has never been observed. All scenarios project a substantial decline in suitable climatic area in central and southern Europe by 2050. By 2100, no suitable area would remain in the lowlands of west, central and eastern Europe. The only climatically suitable areas would remain in the Alps and in Scandinavia. *Bombus norvegicus* is a cuckoo-bumblebee specialised on a single host-species, and is believed to have a low dispersal capability. It already occurs in a much more restricted area than climate conditions would allow. One could expect a considerable reduction of its distribution caused by global warming.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.81)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-2916 (-22%)	-4101 (-31%)
	BAMBU	-1855 (-14%)	-3401 (-26%)
	GRAS	-2194 (-17%)	-3692 (-28%)
2100	SEDG	-6528 (-49%)	-8345 (-63%)
	BAMBU	-6761 (-51%)	-9412 (-71%)
	GRAS	-8510 (-64%)	-10611 (-80%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus pascuorum (Scopoli, 1763)

= *Bombus (Thoracobombus) pascuorum; Bombus agrorum auctt.*

© Photo P. Rasmont

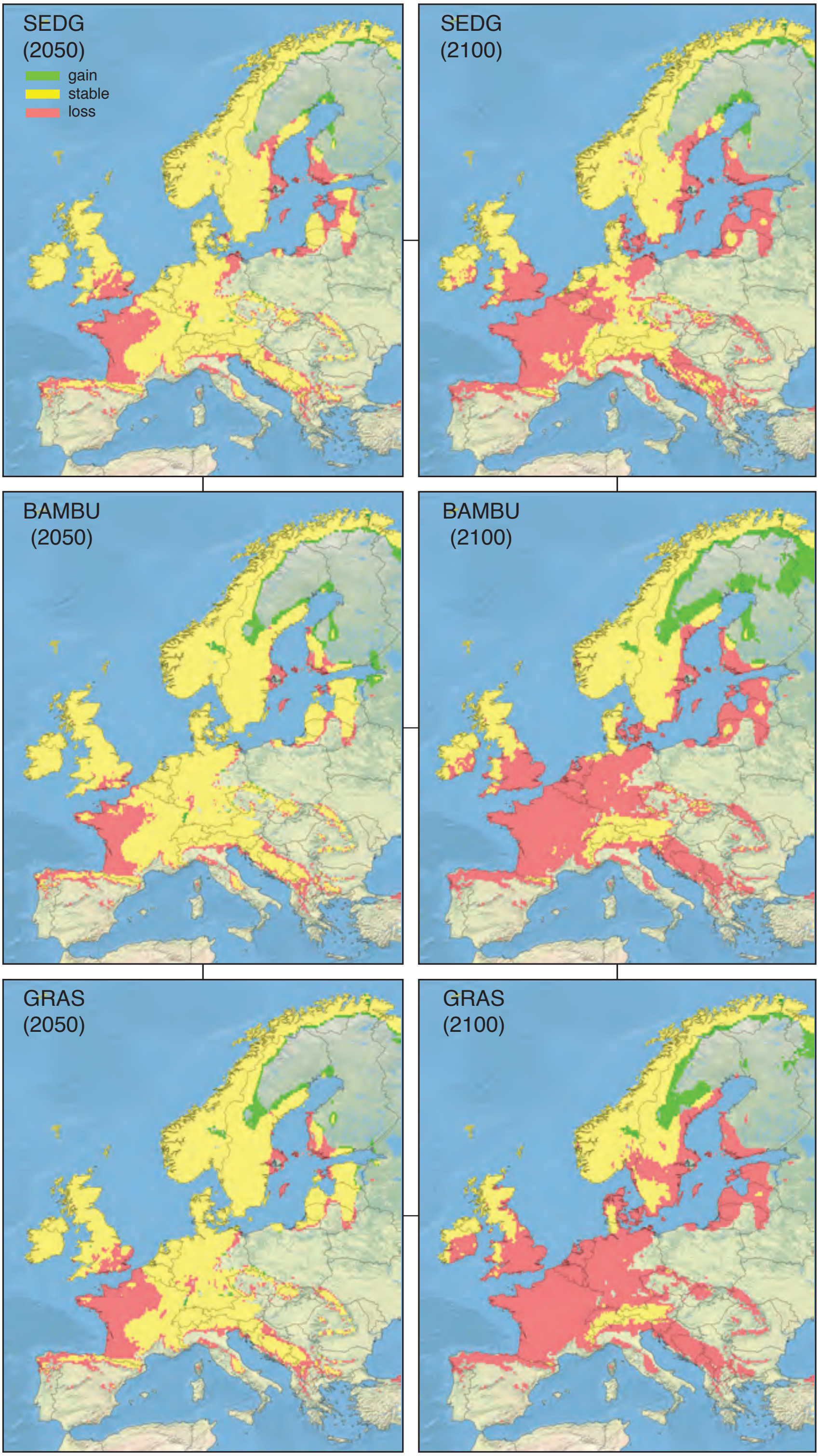
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus pascuorum is a medium-sized bumblebee. The coat colour is extremely variable from region to region (as different subspecies), making *B. pascuorum* the most polytypic of the European bumblebees. Colour schemes are typically brownish, with a greater or lesser amount of black and grey hairs intermixed. It is a generalist forager that visits all available flowers. In Europe, it can be found from southern Spain, Greece and Turkey in the south, where it can reach the Mediterranean coast (even if it is mainly confined to hills and mountains), to the Barents Sea coast in the north. To the west, it reaches Ireland and the Pacific coast in the east. It has recently colonised Iceland. The species is present on some Mediterranean islands, such as Corsica and Sicily. It occurs in any kind of habitats, but it prefers woody landscapes. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. It is, by far, the most widespread and the most abundant European bumblebee and even in heavily human-influenced landscapes, where other bumblebee species are scarce, *B. pascuorum* remains abundant. The species distribution model underestimated the current range to some extent and was not able to reproduce occurrences in parts of Finland, Sweden, Poland, southern Spain, southern Italy and Sicily. All scenarios project a moderate reduction of suitable areas especially in western France. By 2100, in the worst case, the GRAS scenario would lead to unsuitable conditions in all lowland regions of the European mainland. Suitable conditions would remain only in the Alps, Wales, Ireland, Scotland, Scandinavia and northern Finland. However, *B. pascuorum* is highly polytypic (one potential reason for the just moderate model performance) and it can be expected that the plasticity of the regional populations would allow the species to adapt to local climatic variation. *Bombus pascuorum* seems to have a high dispersal capability, as it is very abundant. However, it could lose significant parts of its climatically suitable area because of global warming.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.75)
Climate risk category: R
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-2887 (-21%)	-3135 (-23%)
	BAMBU	-1713 (-13%)	-2283 (-17%)
	GRAS	-2443 (-18%)	-2898 (-21%)
2100	SEDG	-5916 (-44%)	-6230 (-46%)
	BAMBU	-6228 (-46%)	-7477 (-55%)
	GRAS	-8253 (-61%)	-8912 (-66%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus polaris Curtis, 1835

= *Bombus (Alpinobombus) polaris, Bombus arcticus*

© Photo P. Rasmont

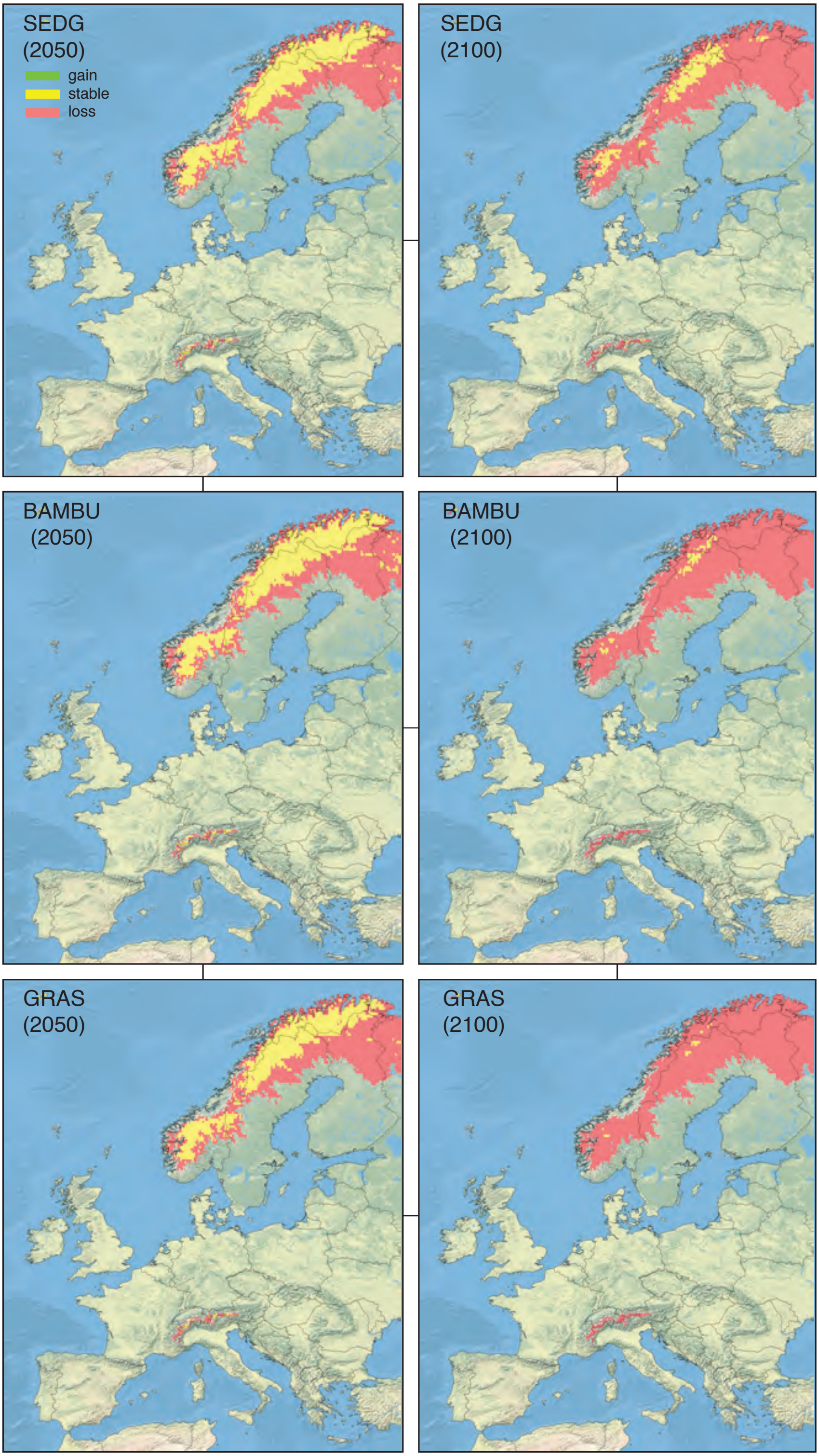
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus polaris is a large bumblebee occurring in the Arctic tundra and alpine grasslands in Scandinavia. Its colour coat is quite invariable: it has a black thorax and an abdomen that is largely covered in faded reddish hairs. It lives in very small colonies and it is a generalist forager. It can be found at the sea level in Arctic tundra along the northern coast of Norway and Russia and in Novaya Zemlya, North America and Greenland. The species is currently declining: assessed as Vulnerable in the IUCN Red List of European Bees. Its modelled distribution shows that its climatic niche space might be larger than its actual distribution, and includes the higher elevations of the Alps and also Iceland, where it has never been found. Even in Scandinavia, the total area of its presently suitable area is larger than its actual distribution. All scenarios project that its suitable areas will be considerably reduced by 2050 (more than 50% of the current area). By 2100, the reduction of suitable area would reach 90% or even more. As the species is rare and linked to cold climates in high Alpine and Arctic habitats, there is little chance that the populations will remain numerous enough to allow for the survival of the species in Europe, regardless of its dispersal capability.

Present distribution can be very well explained by climatic variables (AUC = 0.99)
Climate risk category: HHHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-2038 (-57%)	-2038 (-57%)
	BAMBU	-1955 (-55%)	-1955 (-55%)
	GRAS	-2184 (-61%)	-2184 (-61%)
2100	SEDG	-3115 (-87%)	-3115 (-87%)
	BAMBU	-3459 (-97%)	-3459 (-97%)
	GRAS	-3524 (-99%)	-3524 (-99%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus pomorum (Panzer, 1805)

= *Bombus (Thoracobombus) pomorum; Bombus (Rhodobombus) pomorum*

© Photo D. Genoud

Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus pomorum is a medium- to large-sized bumblebee. In Europe, its coat colour is black with a reddish hind part of the abdomen. In males, the black coat can be more or less intermixed with grey. *Bombus pomorum* lives in large underground colonies generally in dry bushy grasslands. It is a generalist forager but it clearly prefers flowers with long corollas like *Trifolium* spp. (Fabaceae). It occurs from latitude 42° in the Balkan to 55° N in southern Scandinavia and from north-west France and the Massif Central in the west to the Ural and Caucasus mountains in the east. It is absent from the Pyrenees, and the Iberian and Italian peninsulas. It is considered to be extinct in England, Sweden, Denmark, The Netherlands, Belgium and Luxembourg. Its modelled distribution already integrates this actual reduction of its distribution area. This modelled distribution also shows that its suitable climatic area includes the Pyrenees, Iberian and Italian peninsula and southern Turkey, too, despite that, it has never been found there. The species is considered to be threatened: Vulnerable in the IUCN Red List of European Bees. It never reached some parts of its potential area, meaning that its dispersion capability is likely to be quite low. All dispersal scenarios project a considerable reduction of the climatically suitable area by 2050, and further reductions by 2100. Because of its present scarcity in its already declining range, allied with the seemingly low dispersal capability of *B. pomorum*, the considerable reduction of its suitable area could drive the species to extinction.

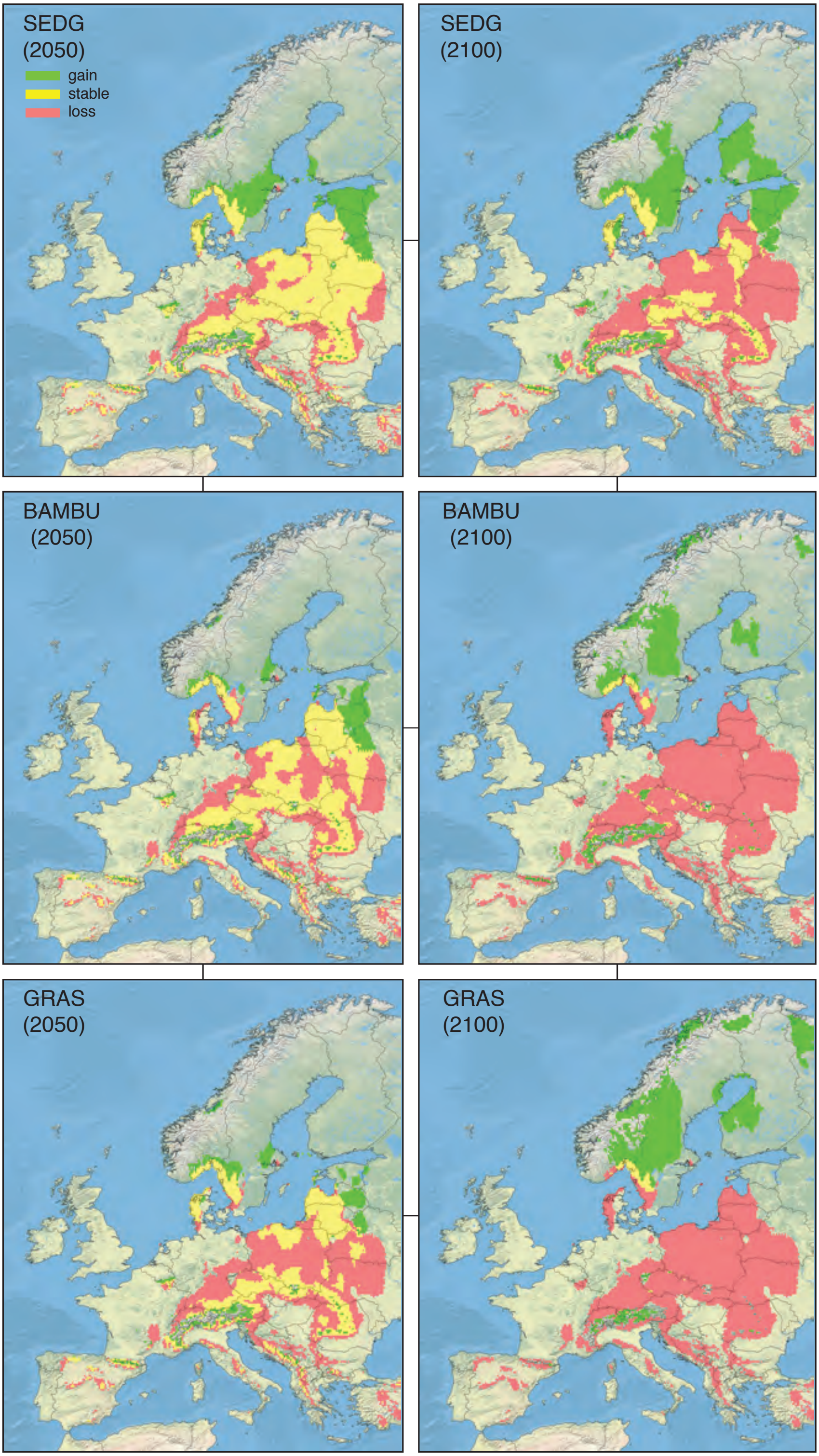
Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.85)

Climate risk category: HHHR

IUCN Red List status: Vulnerable

	Scenario	Full dispersal	No dispersal
2050	SEDG	-725 (-10%)	-2315 (-33%)
	BAMBU	-2474 (-35%)	-3374 (-48%)
	GRAS	-3591 (-51%)	-4387 (-62%)
2100	SEDG	-2711 (-38%)	-5304 (-75%)
	BAMBU	-5335 (-75%)	-6856 (-97%)
	GRAS	-4716 (-67%)	-6952 (-98%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus pratorum (L., 1756)

= *Bombus (Pyrobombus) pratorum*

© Photo P. Rasmont

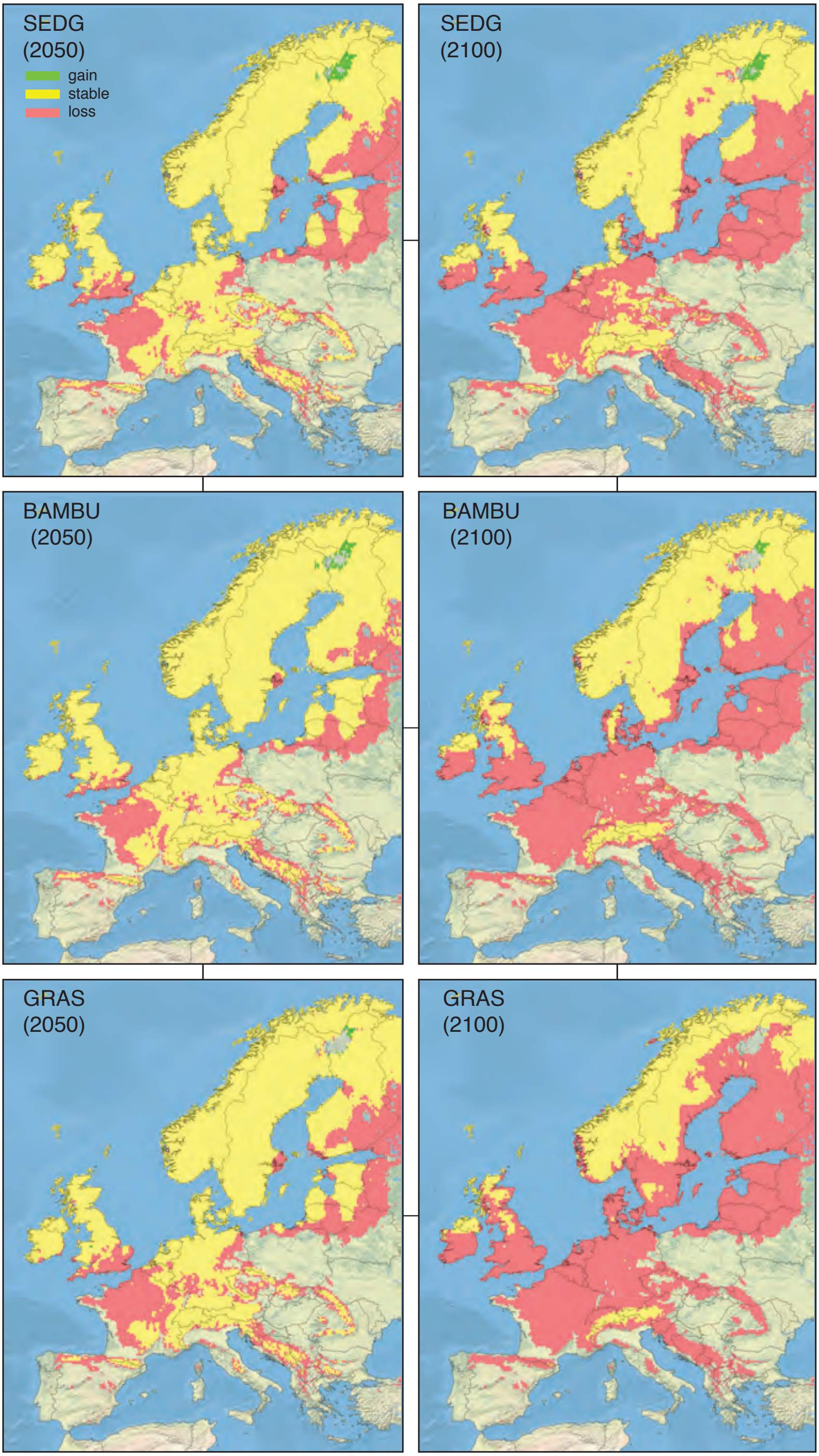
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus pratorum is a small bumblebee. Its coat colour is quite variable but always black with a red tail and with or without one to three yellow bands. *B. pratorum* has small colonies which are often established in grass tussocks in forests or forest edges. It is a generalist forager. It occurs from southern Spain and southern Italy (where it is found only in the mountains) northwards to the Barents Sea coasts and from Ireland in the west to the Pacific coast in the east. Its modelled distribution fits with the current distribution. The species is one of the most widespread and abundant of the European bumblebees. Like *Bombus pascuorum*, it can survive in urban and surburban areas where other bumblebees are scarce. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. All scenarios project a reduction of its climatically suitable area. As it often occurs in high abundances, it is a generalist forager, and can occupy most habitats, a high dispersal capability is expected. *Bombus pratorum* would not be threatened by global warming, despite a possible significant reduction of its suitable climatic area.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.80)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	**SEDG**	-4998 (-28%)	-5105 (-28%)
	BAMBU	-4056 (-22%)	-4134 (-23%)
	GRAS	-5418 (-30%)	-5445 (-30%)
2100	**SEDG**	-9377 (-52%)	-9472 (-52%)
	BAMBU	-10864 (-60%)	-10896 (-60%)
	GRAS	-13243 (-73%)	-13244 (-73%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus pyrenaeus PÉREZ, 1879

= *Bombus (Pyrobombus) pyrenaeus*

© Photo P. Rasmont

Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus pyrenaeus is a small bumblebee. Its coat colour is quite variable but generally with a large greyish thorax with a black thoracic band, with a grey base of the abdomen and with a large part of the remaining abdomen being reddish. *B. pyrenaeus* lives in small colonies in grass tussocks or under rocks in subalpine and alpine meadows. It is a generalist forager with some preferences for Ericaceae (*Vaccinium* spp., *Rhododendron* spp.). It occurs in the Pyrenees, Alps, Tatra, Carpathians, Durmitor and Balkan mountains, with quite conspicuously different subspecies. Its modelled distribution includes much more mountain areas than its actual distribution (e.g. in UK where it never occurred). The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. As the species seems strongly differentiated from mountain to mountain and as larger parts of suitable climatic areas are currently not populated, its dispersal ability is assumed to be low. Therefore, the no dispersal scenarios seem to be the most likely. Both BAMBU and GRAS scenarios show considerable reductions in the Balkan and Carpathian mountains. Despite such reduction of climatically suitable area, *B. pyrenaeus* would not be threatened to the point of extinction by global warming.

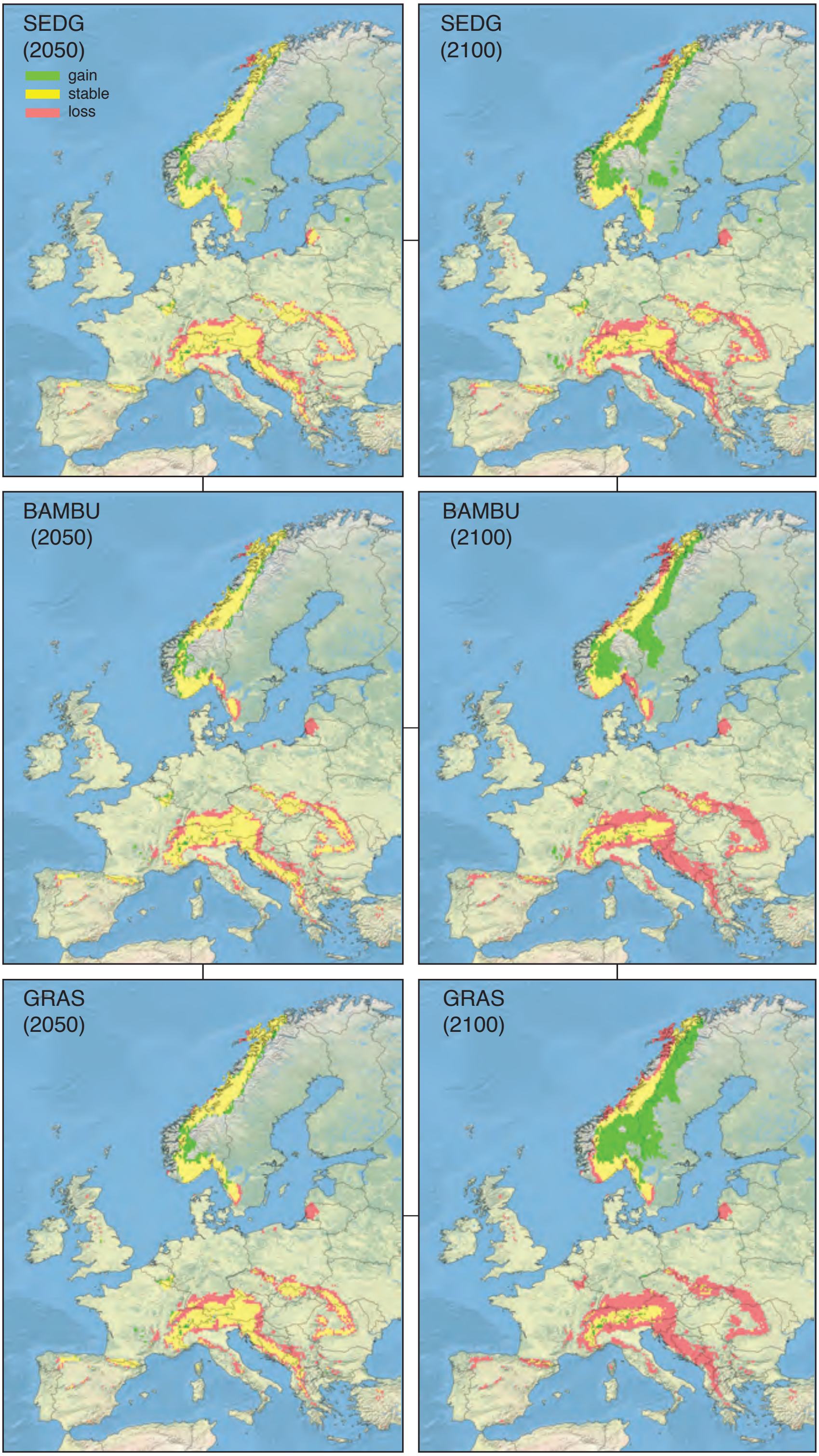
Present distribution can be well explained by climatic variables (AUC = 0.93)

Climate risk category: HR

IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-633 (-18%)	-911 (-26%)
	BAMBU	-826 (-23%)	-1048 (-30%)
	GRAS	-934 (-26%)	-1208 (-34%)
2100	SEDG	-862 (-24%)	-1582 (-45%)
	BAMBU	-1457 (-41%)	-2239 (-63%)
	GRAS	-1335 (-38%)	-2512 (-71%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus quadricolor (LEPELETIER, 1832)

= *Bombus (Psithyrus) quadricolor; Psithyrus quadricolor*

© Photo P. Rasmont

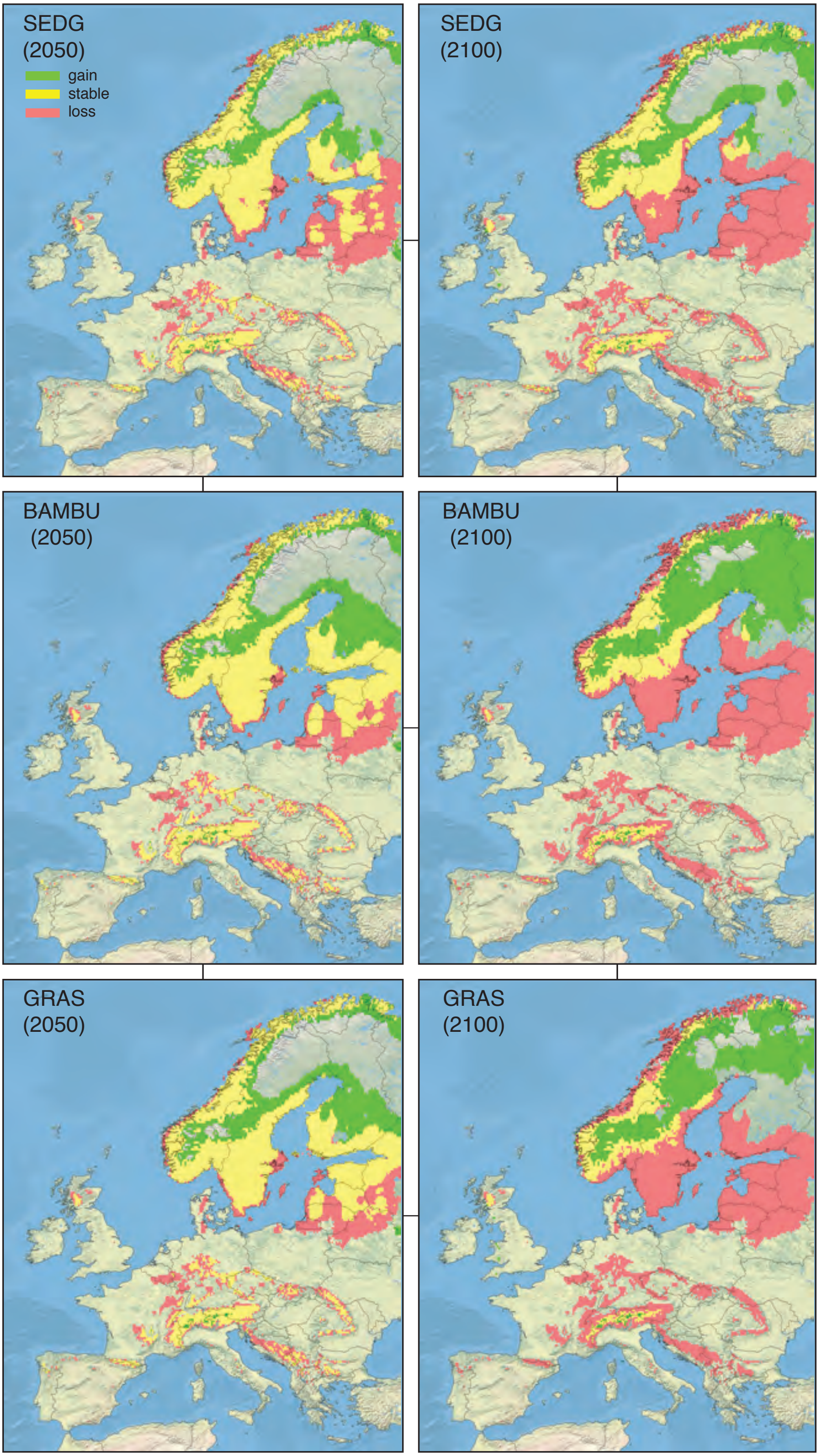
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus quadricolor is a medium-sized bumblebee. Its colour is quite variable: with or without a large yellow prothoracic band, with or without yellow band at the base of the abdomen, with a red or a white and red tail. It is a specialised social parasite species (cuckoo-bumblebee) mainly of *B. soroeensis*. Its southernmost populations occur in the Cantabrian mountains, Pyrenees and Balkan mountains and it reaches a latitude of 65° N. To the east, it reaches the Altai mountains. The species is rare and recently declined in most areas. This decline is probably associated with the decline of its main host *B. soroeensis*. Despite this regression, the species is not considered to be threatened at the continental scale: Least Concern in the IUCN Red List of European Bees. The modelled distribution is somewhat wider than the actual one. All scenarios project fragmentation of suitable climatic space in the lowlands of central and southern Europe and an expansion of its climatic niche space to the Barents Sea coast and to the Scandinavian mountains. By 2100, all scenarios project that its suitable areas would completely disappear from all lowlands south of latitude 60° N. As it is a species which is likely to have a low dispersal capability, is specialised on only one main host species, is currently declining and as its climatically suitable area would be considerably reduced, *B. quadricolor* would suffer considerably from global warming.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.85)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	-1720 (-21%)	-3178 (-39%)
	BAMBU	-226 (-3%)	-2354 (-29%)
	GRAS	-437 (-5%)	-2501 (-31%)
2100	**SEDG**	-3503 (-44%)	-5388 (-67%)
	BAMBU	-2654 (-33%)	-6245 (-78%)
	GRAS	-4116 (-51%)	-6773 (-84%)

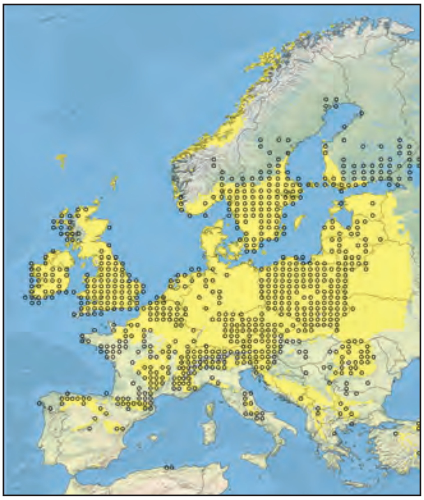
Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus ruderarius (Müller, 1776)

= *Bombus (Thoracobombus) ruderarius*

© Photo P. Rasmont



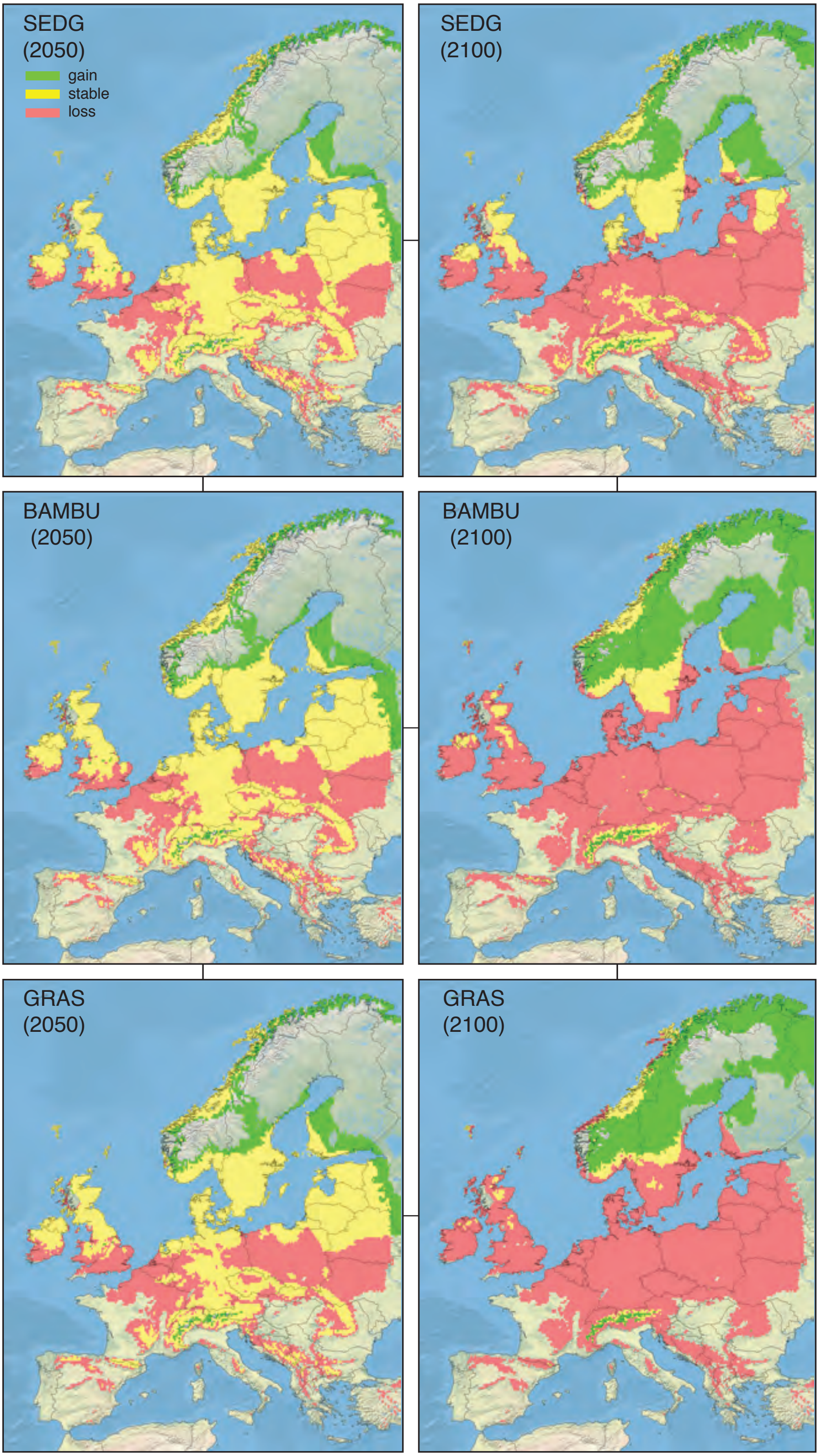
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus ruderarius is a medium-sized bumblebee. The coat colour is generally black with a reddish tail with more or less greyish hairs intermixed on both thorax and abdomen (f. *montanus* Lepeletier). North African populations have three yellow bands and a white tail (ssp. *tunensis* (Tkalců)). It is a generalist species even if it prefers to forage on Lamiaceae, Fabaceae and Asteraceae flowers. In Europe, it can be found from central Spain, southern Italy and northern Greece in the south, (where it is restricted to the mountains), to the Arctic Circle in the north. To the west, it reaches Ireland and north-west Spain and in the east it occurs to the Altai. There is an isolated population in Tunisia and north-east Algeria. It has declined in lowland areas of western and central Europe. Despite this regional regression the species is not considered to be threatened at a continental scale: Least Concern in the IUCN Red List of European Bees. Its modelled distribution includes some areas which the species does not reach, such as northern Scandinavia, but it excludes north Africa. By 2050, all scenarios project a moderate reduction of the suitable areas in the south and some extension to the north, depending on its dispersion capability. By 2100, all scenarios project a significant reduction of suitable areas in the lowlands of Europe. In the worst case, the GRAS scenario would lead to unsuitable conditions in all lowland regions of the European mainland and even in most of the mountains, depending on its dispersal ability. *Bombus ruderarius* is already becoming scarce in most lowland locations, the projected losses of suitable climatic conditions can be assumed to have severe consequences for this species and might lead to extinction from most of the temperate lowland areas and southern mountains of Europe.

Present distribution can be explained by climatic variables only to a limited extent (AUC = 0.75)
Climate risk category: HHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-3198 (-23%)	-4853 (-35%)
	BAMBU	-3278 (-23%)	-5194 (-37%)
	GRAS	-4244 (-30%)	-6095 (-43%)
2100	SEDG	-7605 (-54%)	-10123 (-72%)
	BAMBU	-7976 (-57%)	-12331 (-88%)
	GRAS	-9443 (-67%)	-13187 (-94%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus ruderatus (Fabricius, 1775)

= *Bombus (Megabombus) ruderatus*

© Photo P. Rasmont

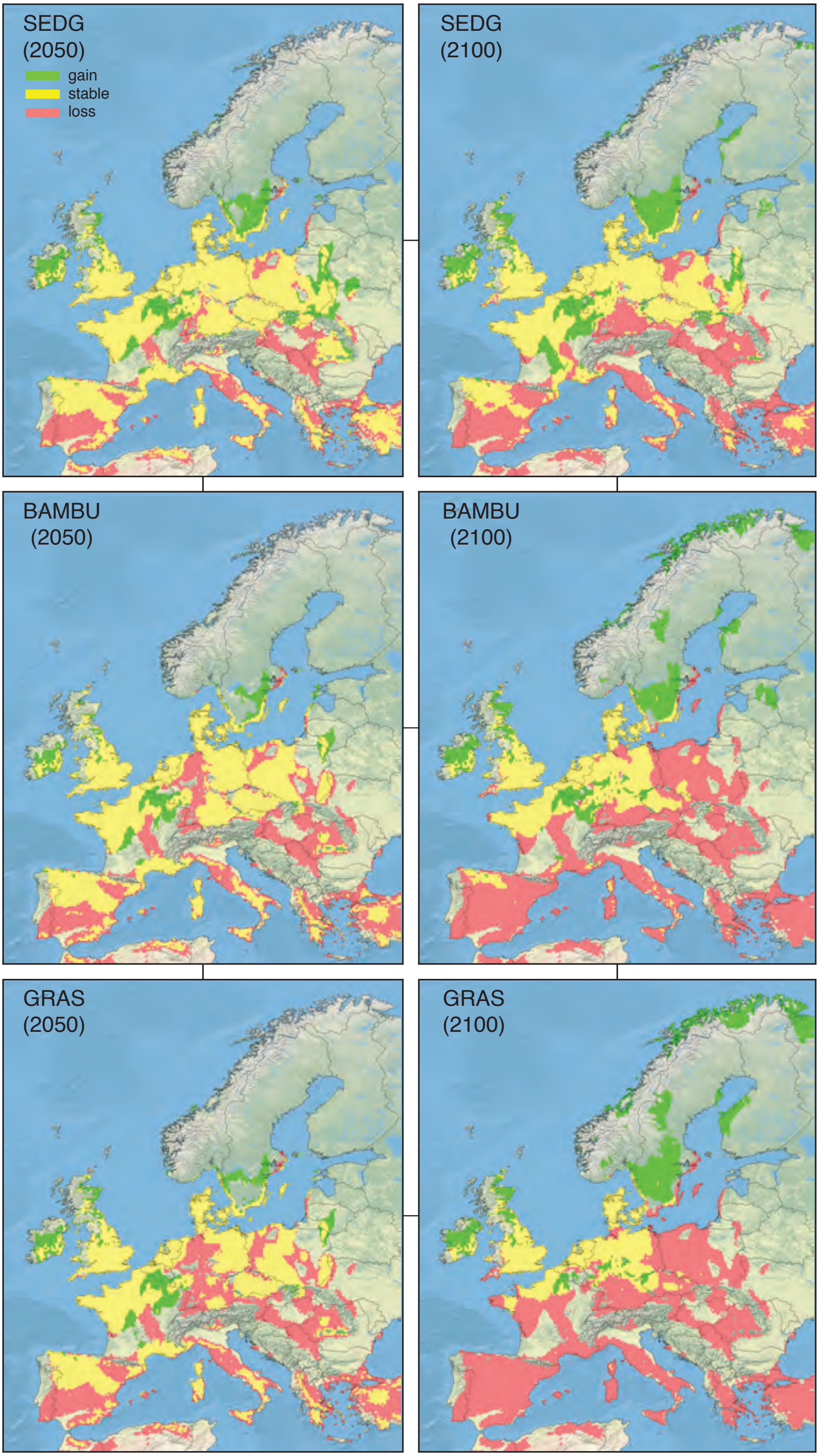
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus ruderatus is a large bumblebee with a variable coat colour. In the main part of Europe and north Africa, it shows three yellow bands and a white tail, however, it can also be all black, as in some English populations (ssp. *perniger* (Harris)), all black with a red tail, as in Corsica (ssp. *corsicola* Strand) or with mixed black and reddish hairs and with a white tail as in Sardinia (ssp. *sardiniensis* Tournier). It is a generalist species even if it prefers to forage on flowers with deep corollas which it can access thanks to its very long tongue. It has been recorded from the Azores, north Africa, and the Iberian and Italian peninsulas in the south, reaching northern England and southern Scandinavia in the north. To the east, it reaches Ukraine but it does not occur at all in south-eastern Europe where it is replaced by its sibling species *B. argillaceus*. It has become very rare in most parts of its range. Despite this regression, the species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. Its modelled distribution includes some areas where the species does not occur, such as Romania, the Balkans and Turkey. By 2050, all scenarios project a moderate reduction of suitable areas of the species in the south and some extension to the north, depending on its dispersal capability. In 2100, all scenarios project a significant regression of suitable areas in the lowlands of Europe, with some expansion towards the east. However, in most of the locations where suitable climatic conditions are projected to persist the species already suffers presently from strong declines, meaning that other parameters are affecting the population dynamics. In the worst case, the GRAS scenario projects unsuitable conditions for all lowlands south of latitude 48° N, and its extinction in all the Mediterranean countries where it presently thrives. As *B. ruderatus* is already becoming rare in most lowland locations, it is projected to lose a noticeable amount of suitable area because of global warming, regardless of its dispersal ability. Additionally, some other ecological or anthropogenic factors seem to play a role in its present regression, thus adding threatening risk in a quite unpredictable but negative way.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.78)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	-1753 (-15%)	-3339 (-29%)
	BAMBU	-3780 (-33%)	-4647 (-40%)
	GRAS	-4390 (-38%)	-5409 (-47%)
2100	**SEDG**	-3739 (-32%)	-5636 (-49%)
	BAMBU	-6148 (-53%)	-8045 (-69%)
	GRAS	-6912 (-60%)	-9029 (-78%)

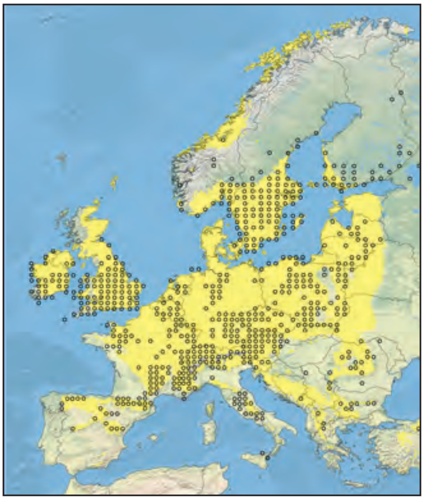
Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus rupestris (Fabricius, 1793)

= *Bombus (Psithyrus) rupestris; Psithyrus rupestris*

© Photo P. Rasmont



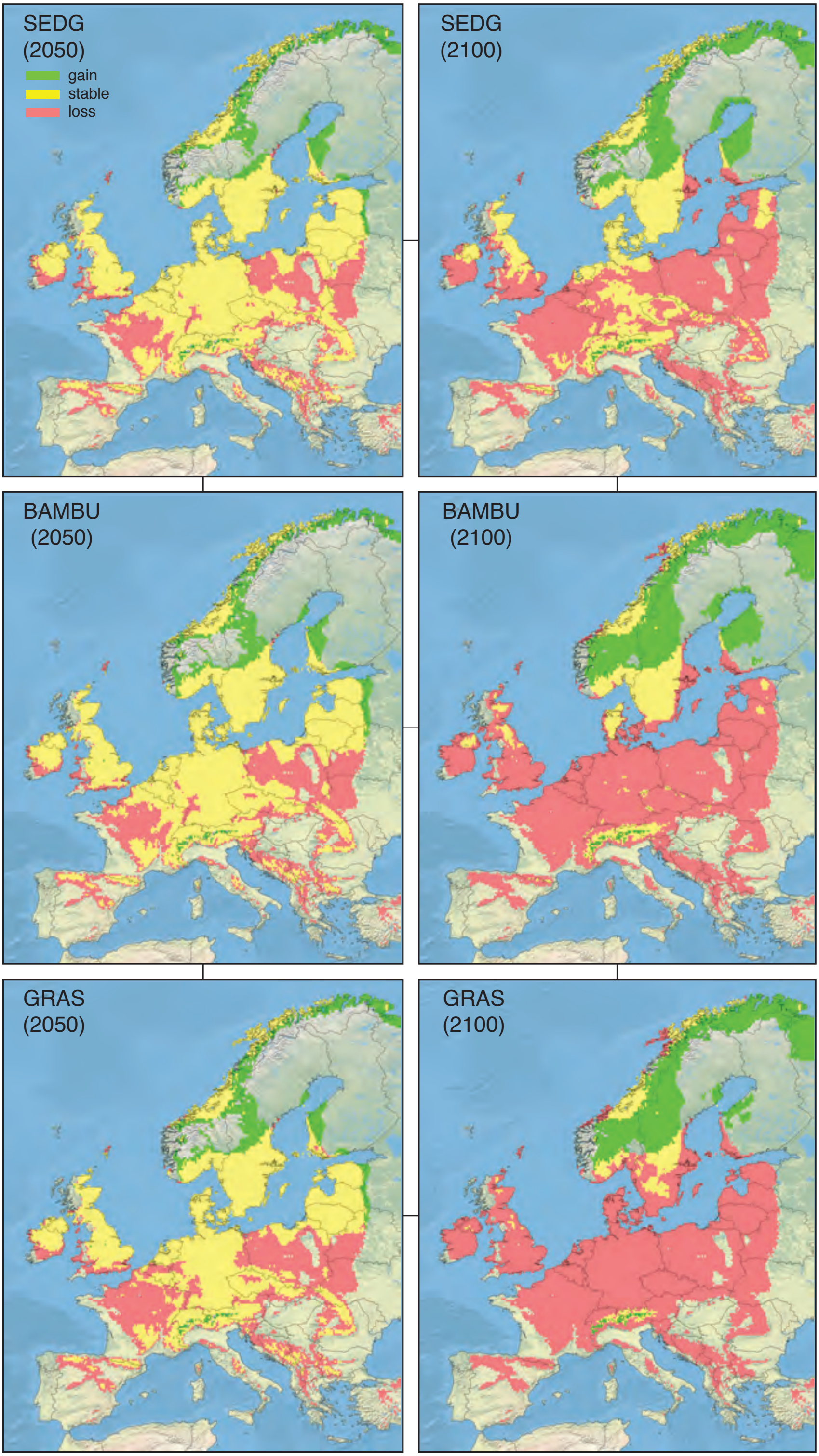
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus rupestris is a medium- to large-sized bumblebee. Its colour coat is mainly black with a red tail. The thorax could be more or less intermixed with grey. The wings are conspicuously darkened. It is a specialised social parasite species (cuckoo-bumblebee) mainly on *B. lapidarius* and *B. sichelii.* It can be found from central Spain, Sicily and the northern Balkans in the south up to latitude 65° N in Scandinavia, remaining absent from Scotland and also from all Mediterranean islands, except Sicily. To the east, it reaches the Pacific coast. It might be one of the most common cuckoo-bumblebees, but it seems to become rarer in some locations, especially in The Netherlands, Belgium and Germany. Despite this regional regression, the species is not considered to be threatened at a continental scale: Least Concern in the IUCN Red List of European Bees. The modelled distribution corresponds quite well to the actual one, with some discrepancies along the Norwegian coasts, central Spain and Turkey. All scenarios project fragmentation in central and southern Europe and expansion of its climatic niche space to the Barents Sea coast. By 2100, this tendency would lead to considerable reduction of suitable climatic conditions in the lowlands of western Europe. The GRAS scenario projects that its suitable areas would completely disappear from all lowlands south of latitude 60° N by 2100. As it is a cuckoo-bumblebee and is restricted to just 2 host-species and as it seems already regressing in temperate European lowlands, *B. rupestris* would suffer significantly from global warming, regardless of its dispersal abilities.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.78)
Climate risk category: HHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-2660 (-20%)	-3886 (-29%)
	BAMBU	-2813 (-21%)	-4221 (-32%)
	GRAS	-3760 (-28%)	-5122 (-39%)
2100	SEDG	-6702 (-51%)	-8699 (-66%)
	BAMBU	-8170 (-62%)	-11149 (-84%)
	GRAS	-9631 (-73%)	-12224 (-92%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus schrencki (MORAWITZ, 1881)

= *Bombus (Thoracobombus) schrencki*

© Photo O. Korsun

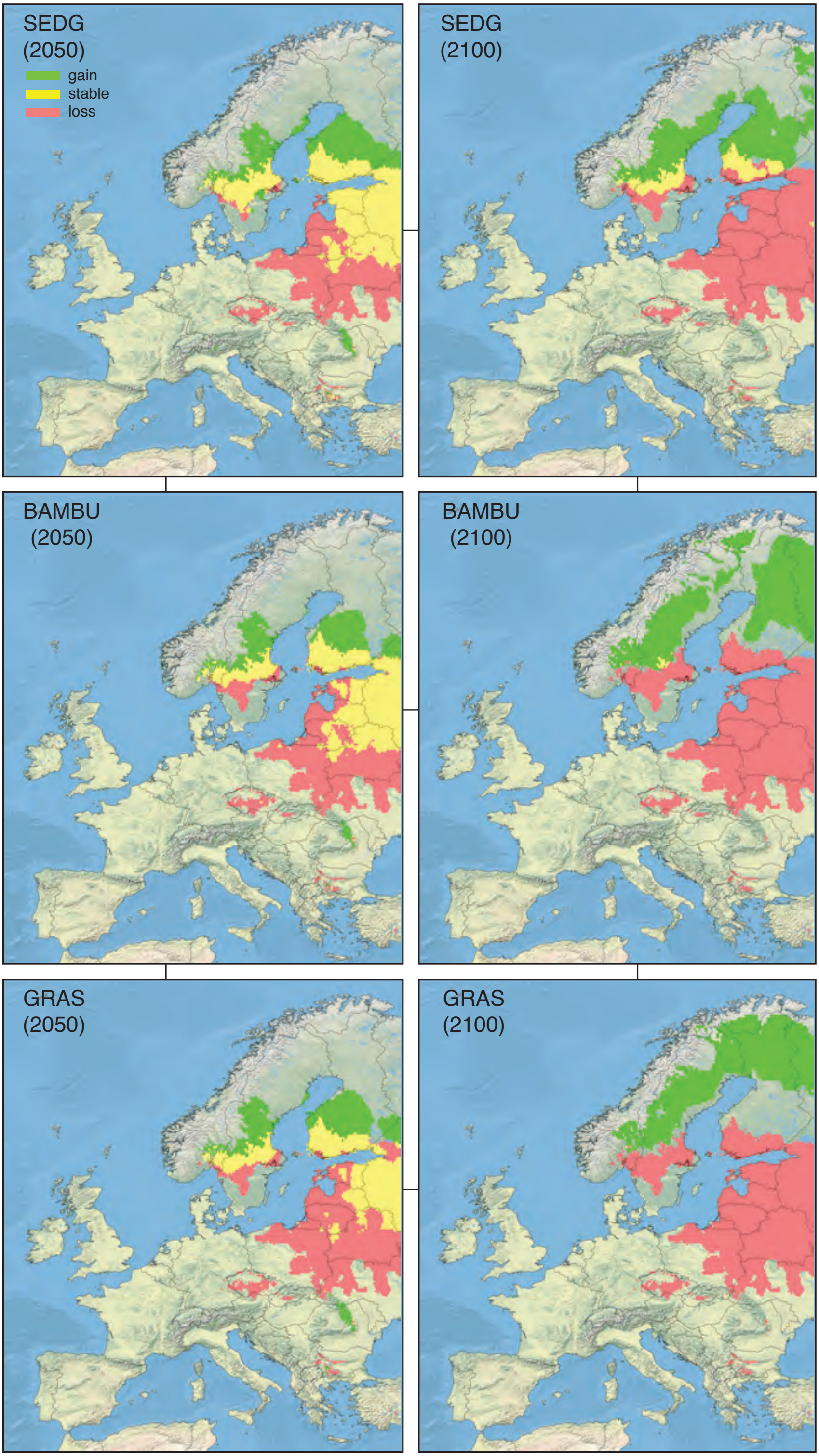
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus schrencki is a medium-sized bumblebee. The coat colour is brown on the thorax and on the base of the abdomen and black with thin grey bands on the rest of the abdomen. It occurs in north-eastern Europe, from latitude 55° N in the south to 70° N in the north and from eastern Poland in the west eastwards to the Pacific coasts.The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. It seems to have expanded recently towards the west, now reaching Poland and Finland. Its modelled distribution includes some areas which the species does not reach, especially in Scandinavia and Finland. By 2050, all scenarios project an extension of its suitable climatic niche space towards the north, in Scandinavia and Finland (to where the species expanded recently) and a noticeable reduction of suitable areas in the south. These tendencies would continue by 2100, leading to an almost total extinction if the species cannot disperse sufficiently. The recent and quite rapid expansion of the species suggests a high dispersal ability. However, even with the best expansion capability, the remaining suitable climatic area of *B. schrencki* would become much smaller than its present range. Even if it is not threatened, the species would considerably suffer from the global warming.

Present distribution can be very well explained by climatic variables (AUC = 0.96)
Climate risk category: HHHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-1266 (-23%)	-2674 (-49%)
	BAMBU	-1908 (-35%)	-3001 (-55%)
	GRAS	-2244 (-41%)	-3528 (-65%)
2100	SEDG	-2674 (-49%)	-4814 (-88%)
	BAMBU	-2611 (-48%)	-5357 (-98%)
	GRAS	-2729 (-50%)	-5381 (-99%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus semenoviellus SKORIKOV, 1910

= *Bombus (Cullumanobombus) semenoviellus*

© Photo W. Kornmilch

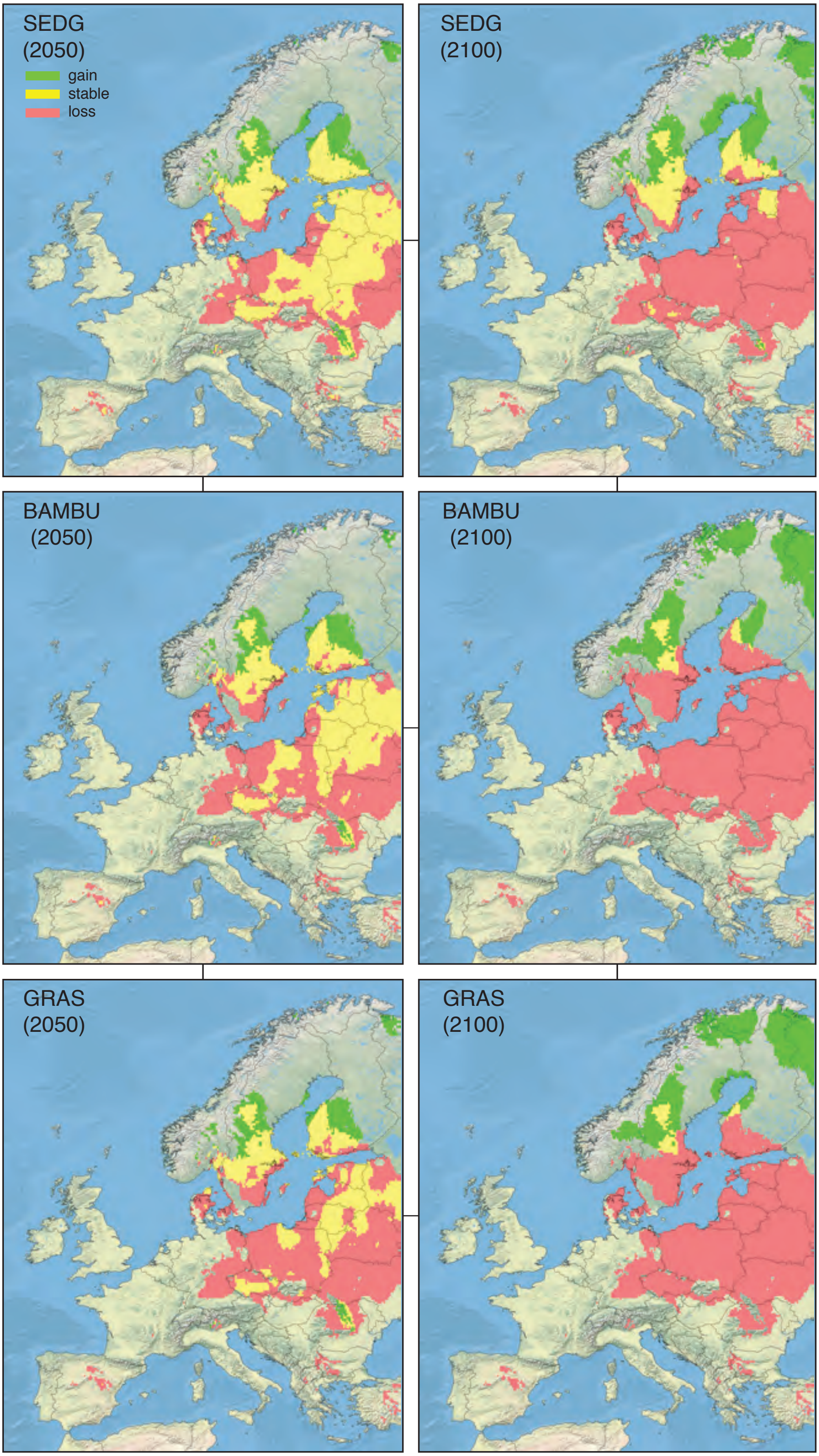
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus semenoviellus is a medium-sized bumblebee. The coat colour shows three yellow bands and a white tail. It occurs in central and eastern Europe, from a latitude of 48° N (in the south) to 64° N (in the north) and from Central Germany in the west to Central Siberia in the east. It is a generalist forager. It has expanded recently towards the west, reaching Germany and the Czech Republic. Recently also found in Norway (2013). The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. Its modelled distribution includes areas which the species does currently occupy, especially in Scandinavia and Finland, but also in south-eastern Europe, Turkey and the Iberian peninsula, regions that are presently out of reach for the species. By 2050, all scenarios project an expansion of its suitable climatic areas towards the north in Scandinavia and Finland (to where the species expanded recently) and in northern Russia. The climatically suitable area would severely contract in central Europe. These tendencies would continue to 2100, leading to an almost total extinction if the species cannot disperse sufficiently. However, the recent, considerable and rapid expansion of the species to the west indicates good dispersal abilities. Even with high dispersal capability, the remaining suitable climatic area of *B. semenoviellus* would become much smaller compared to its present range. The species would suffer considerably from global warming

Present distribution can be well explained by climatic variables (AUC = 0.90)
Climate risk category: HHHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	**SEDG**	-2546 (-30%)	-3461 (-41%)
	BAMBU	-3839 (-46%)	-4571 (-55%)
	GRAS	-4893 (-58%)	-5675 (-68%)
2100	**SEDG**	-5467 (-65%)	-7066 (-84%)
	BAMBU	-6230 (-74%)	-8060 (-96%)
	GRAS	-6236 (-75%)	-8112 (-97%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus sichelii Radoszkowski, 1859

= *Bombus (Melanobombus) sichelii*

© Photo P. Rasmont

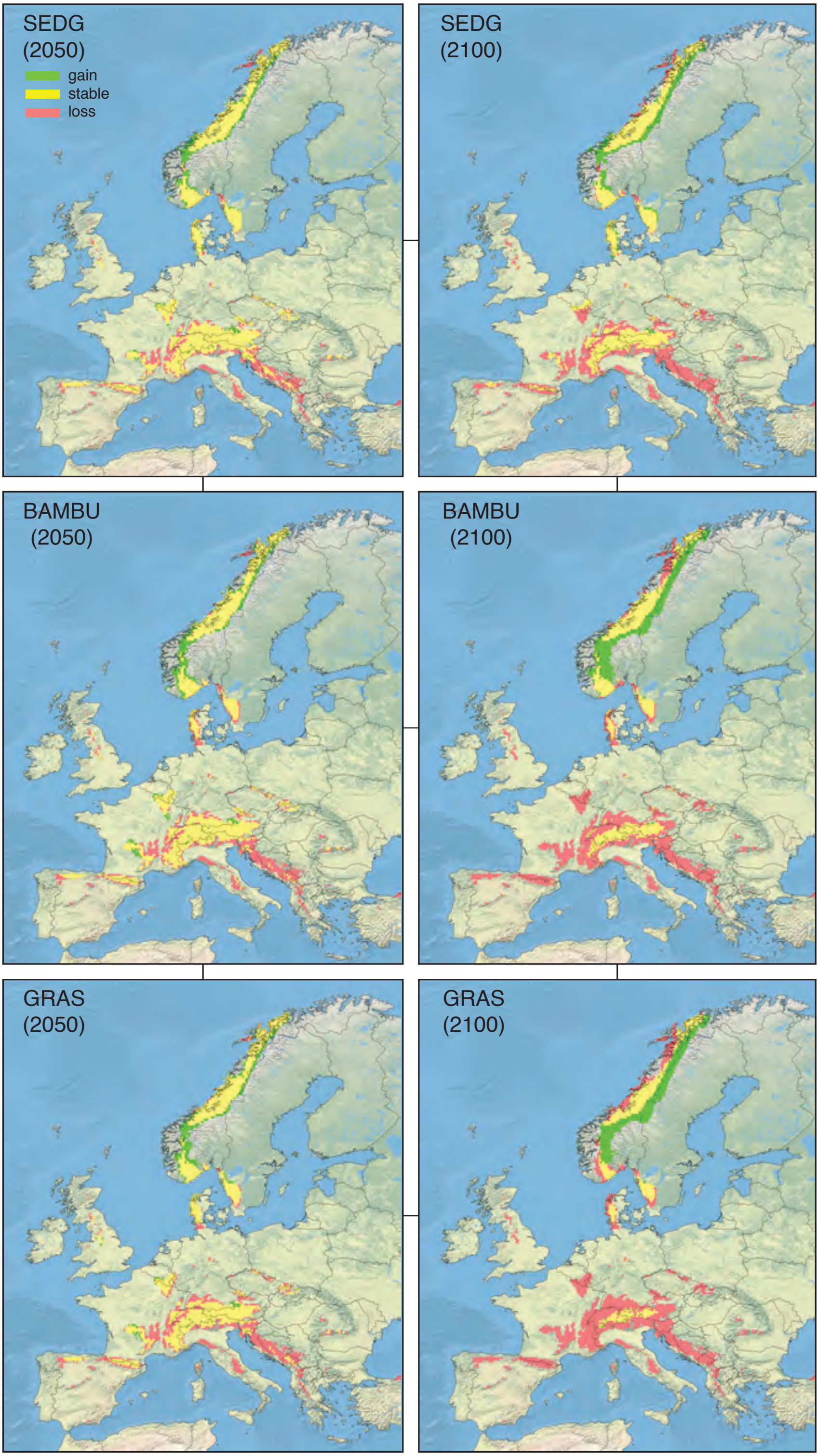
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus sichelii is a medium-sized bumblebee. Its colour coat shows three more or less extended greyish bands and a reddish tail. It is a species with a disjunct distribution: one part is in north-eastern European boreal taiga in Russia (not mapped); the other part in the highest elevations of the Pyrenees, Alps and Balkan mountains. To the east, it occurs in north-eastern Turkey, Iran and the Caucasus and eastwards across Siberia to the Pacific coast. It is a generalist forager. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. The modelled distribution appears somewhat larger than its actual one, including the Apennines, Scandinavia and the British isles. All scenarios project a moderate reduction of its suitable areas by 2050. By 2100, the climatic niche space would be even more restricted, especially in the BAMBU and GRAS scenario where the Pyrenees would become unsuitable. With low dispersal capability and as *B. sichelii* is a species linked to cold boreal and alpine-subalpine conditions, it would suffer significantly from global warming.

Present distribution can be very well explained by climatic variables (AUC = 0.96)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-530 (-19%)	-788 (-28%)
	BAMBU	-649 (-23%)	-936 (-33%)
	GRAS	-734 (-26%)	-1026 (-36%)
2100	SEDG	-1060 (-37%)	-1401 (-49%)
	BAMBU	-1373 (-48%)	-1871 (-66%)
	GRAS	-1693 (-60%)	-2189 (-77%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus soroeensis (FABRICIUS, 1776)

= *Bombus (Kallobombus) soroeensis*

© Photo P. Rasmont

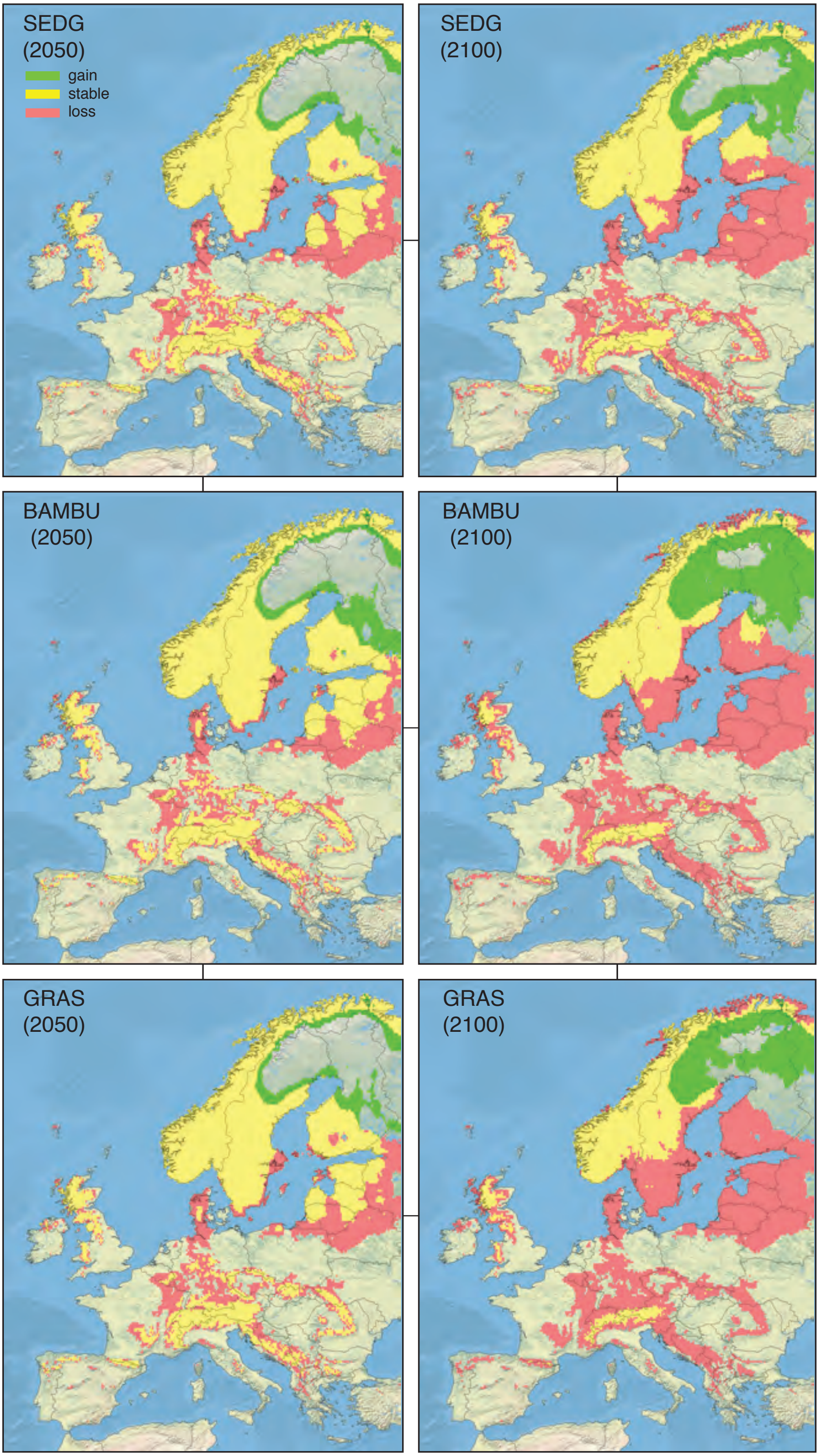
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus soroeensis is a small- to medium-sized bumblebee. Its colour coat is highly variable. Most colour patterns show one, two or three more or less extended yellow bands and a white to red tail. This species occurs from northern Spain, southern Italy and the Balkans in the south to beyond the Arctic Circle in the north and from north-west Spain, (but not in Ireland), in the west eastwards to the Altai and Sajan mountains in Central Siberia. It is restricted to the highest elevations of the mountains in the south while it lives also in the lowlands of the north. It is a generalist forager with a preference for Campanulaceae. The modelled distribution appears somewhat smaller than its actual one, especially in England, Belgium, The Netherlands, Poland and southern Italy. However, the species is becoming increasingly rare in these regions. Despite this regional regression, the species is not considered to be threatened at a continental scale: Least Concern in the IUCN Red List of European Bees. All scenarios project a moderate reduction of suitable areas by 2050, accentuating the present tendencies. By 2100, its suitable areas would exclude all lowlands south of latitude 60° N. In the GRAS scenario, the species would only remain in the Pyrenees and Alps, with the remaining areas in the Tatra and Carpathians becoming too small to allow the survival of the species. Even though *B. soroeensis* is a species which currently has a large distribution range, and is likely to have a high dispersal ability, it is already becoming scarce in some regions which are projected to become unsuitable. Its climatically suitable area would decrease considerably under warming conditions.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.82)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-3124 (-26%)	-3842 (-32%)
	BAMBU	-2469 (-21%)	-3557 (-30%)
	GRAS	-3263 (-27%)	-4080 (-34%)
2100	SEDG	-4843 (-41%)	-6530 (-55%)
	BAMBU	-5480 (-46%)	-7942 (-67%)
	GRAS	-6786 (-57%)	-8639 (-73%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus sporadicus Nylander, 1848

= *Bombus (Bombus) sporadicus*

© Photo P. Rasmont

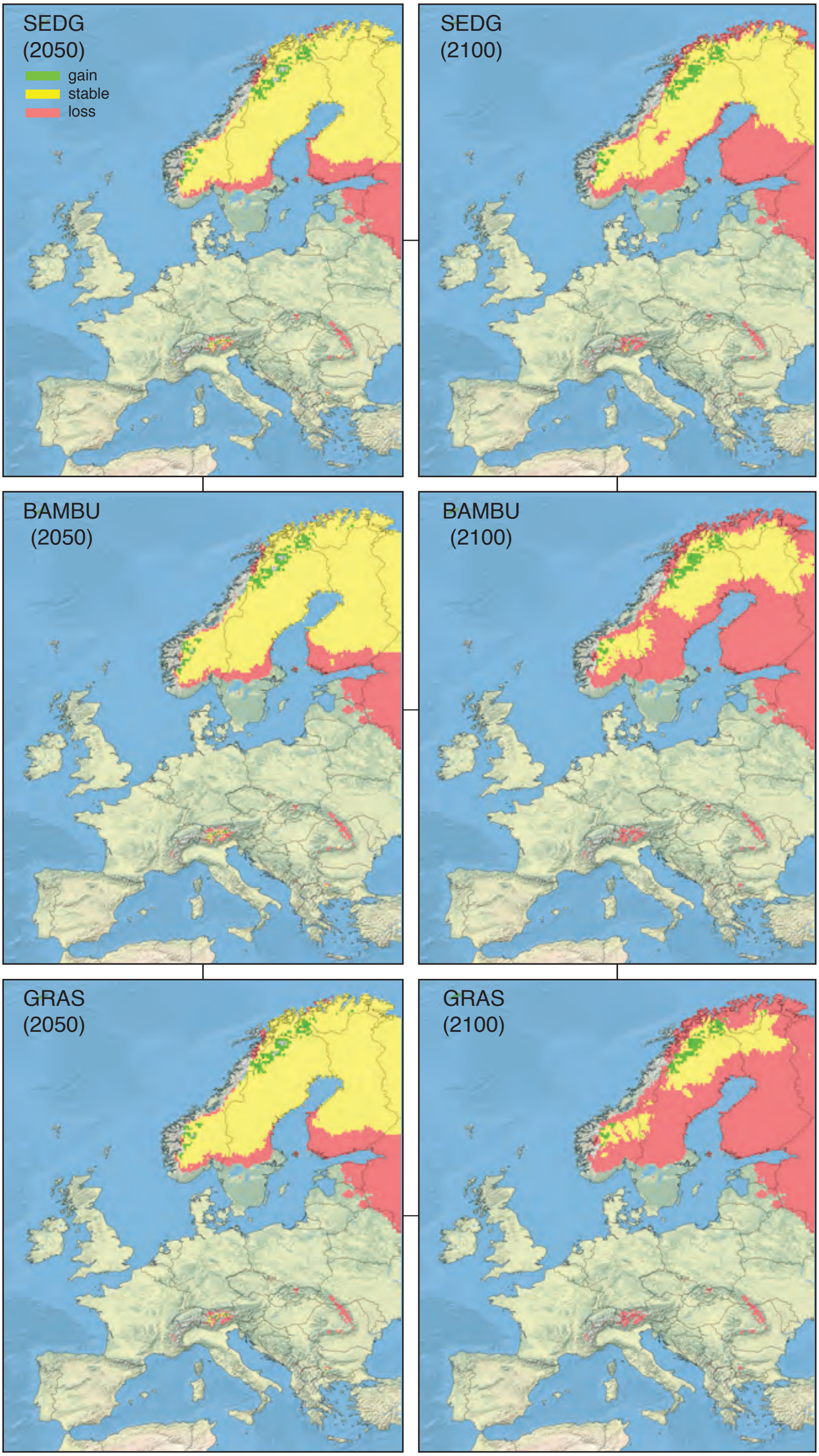
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus sporadicus is a large bumblebee. Its coat colour is constant, with three yellow bands and a white tail. Its wings are clearly darkened. It is a species restricted to the boreal taiga where it forages on the most abundant flowers, mainly Ericaceae and *Epilobium angustifolium* (Onagraceae). It occurs in Europe from the latitude of Stockholm in the south northwards towards the Barents Sea coast in the north and from western Norway eastwards to the Pacific coasts. The species is not considered to be threatened at a continental scale: Least Concern in the IUCN Red List of European Bees. The modelled distribution corresponds very well to the actual one, except that the species does not occur in southern mountains. All scenarios project a reduction of suitable areas by 2050. By 2100, the climatic niche space of the species would be restricted to mountain areas, this tendency being the most extreme under the GRAS scenario. Since this species is linked to boreal conditions, *B. sporadicus* would suffer considerably from global warming, regardless of its dispersal abilities.

Present distribution can be very well explained by climatic variables (AUC = 0.97)
Climate risk category: HR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-1755 (-23%)	-1959 (-25%)
	BAMBU	-1717 (-22%)	-1925 (-25%)
	GRAS	-1905 (-25%)	-2108 (-27%)
2100	SEDG	-3177 (-41%)	-3390 (-44%)
	BAMBU	-5039 (-65%)	-5230 (-68%)
	GRAS	-6115 (-79%)	-6297 (-82%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus subterraneus (L., 1758)

= *Bombus (Subterraneobombus) subterraneus*

© Photo P. Rasmont

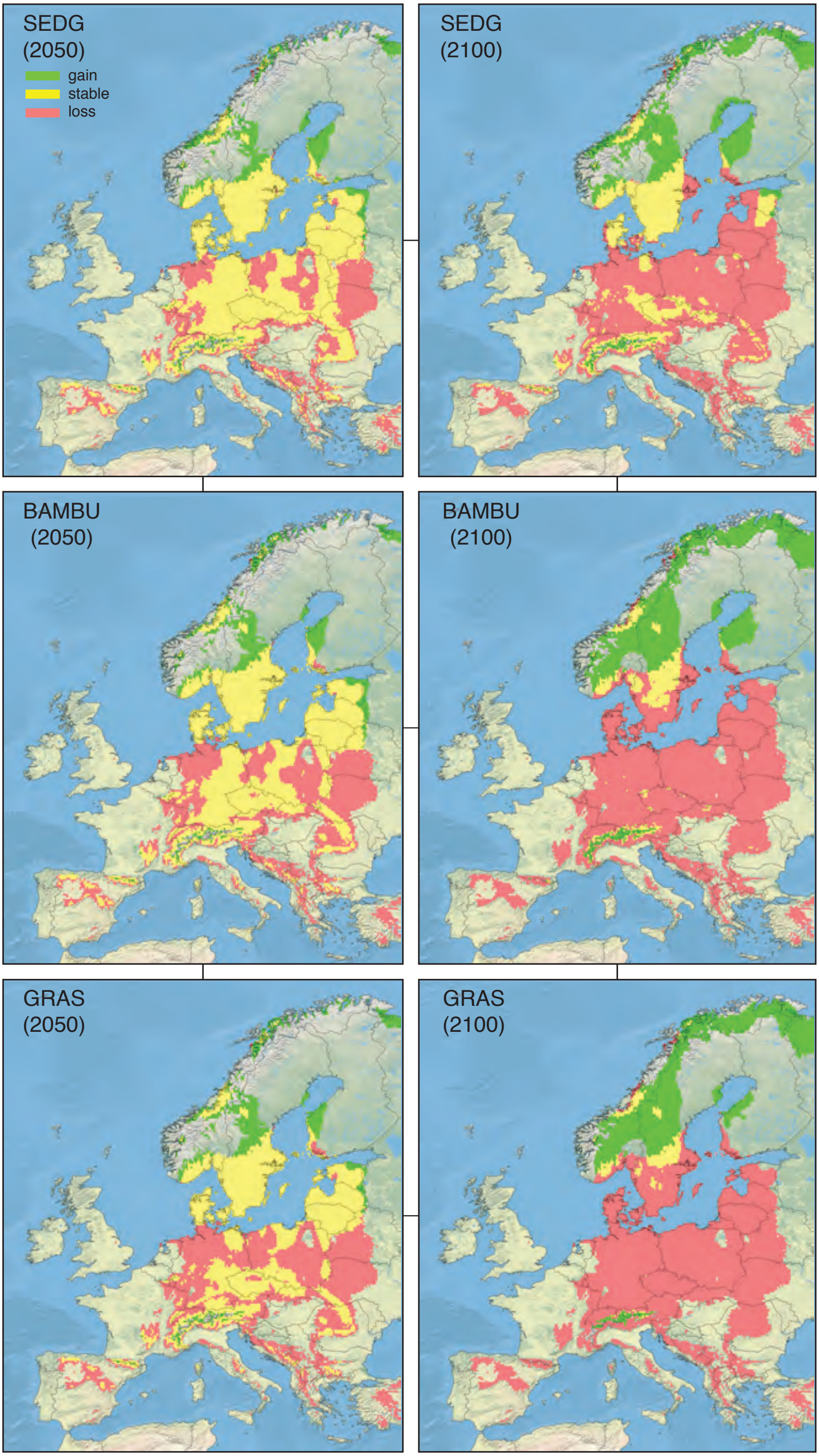
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus subterraneus is a large bumblebee. The coat colour shows two very different forms. In most of Europe it has three yellow bands and thin grey abdominal bands and a white tail (ssp. *latreillellus* (Kirby)). In Sweden and northern Italy it is all black with or without an admixture of dark brown hairs on the thorax and with or without a brownish tail (ssp. *subterraneus*); it can even be all-black. The coat also appears to be conspicuously short and velvet-like. It is a generalist species although it forages especially on Fabaceae and other flowers with long corollas. In Europe, it can be found from central Spain, southern Italy, Greece and Turkey in the south, (where it is restricted to the mountains) to latitude 62° N in Fennoscandia and Russia in the north. In the west, it used to reach Wales and north-western Spain (not Ireland) and to the east it reaches Mongolia. The species is absent from all Mediterranean islands. It has become rare in most lowland locations of western and central Europe. It is now considered extinct in the British Isles and it has not been seen for a long time in Belgium, The Netherlands and in most parts of Germany. Despite this strong regional regression, the species is not considered to be threatened at a continental scale: Least Concern in the IUCN Red List of European Bees. Its modelled distribution includes precisely some of these areas from where the species has vanished recently. All scenarios project a moderate reduction of the climatic niche space in the south and some extension to the north, depending on its dispersion capability. In 2100, in the worst case, the GRAS scenario projects unsuitable conditions for all lowlands and most of the mountains in the European mainland. Suitable conditions would only remain in the Alps and Scandinavia and Finland. As *B. subterraneus* seems to have a low dispersal capability (being unable to reach islands), and as it is already becoming rare or has even vanished in most lowland locations, it would lose a considerable amount of climatically suitable area under global warming likely leading to extinction in Europe under the most severe scenario (GRAS).

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.82)
Climate risk category: HHHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	**SEDG**	-2525 (-25%)	-3581 (-35%)
	BAMBU	-3325 (-32%)	-4361 (-43%)
	GRAS	-4143 (-40%)	-5176 (-51%)
2100	**SEDG**	-5580 (-55%)	-7568 (-74%)
	BAMBU	-6813 (-67%)	-9423 (-92%)
	GRAS	-7375 (-72%)	-9829 (-96%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus sylvarum (L., 1758)

= *Bombus (Thoracobombus) sylvarum*

© Photo J. Carteron

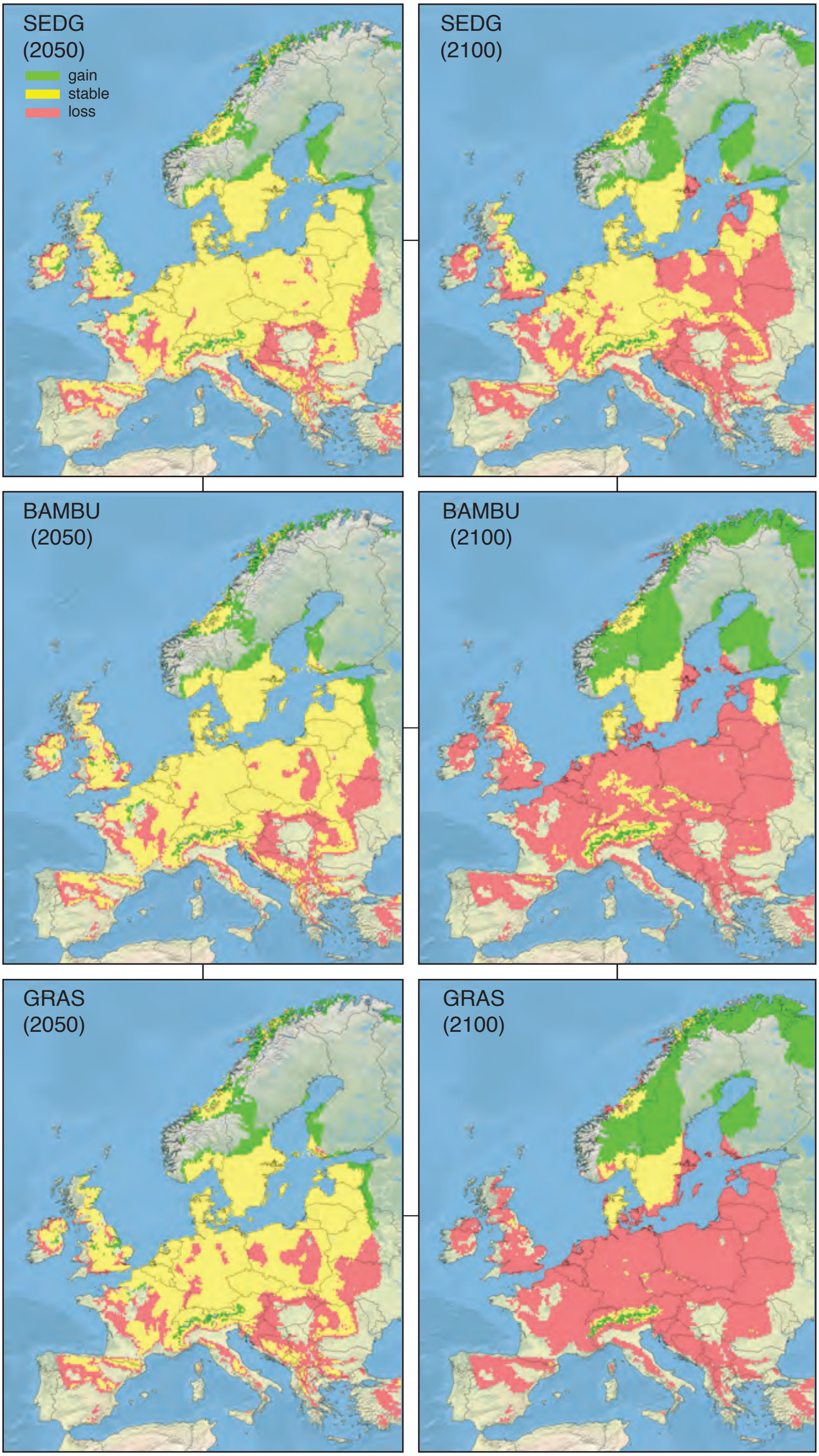
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus sylvarum is a small- to medium-sized bumblebee. The coat colour shows two different forms: with three very large greyish bands and with thin grey bands and a reddish tail intermixed with grey (f. *sylvarum*); or alternatively all black with or without grey intermixed hairs on the thorax and with a reddish tail (f. *nigrescens* Pérez). It is a generalist species but it forages principally on Fabaceae and other flowers with long corollas, e.g. Lamiaceae and Boraginaceae. In Europe, it can be found from central Spain, Sicily, southern Italy, Greece and Turkey in the south, (where it is restricted to the mountains), to the Arctic Circle in Scandinavia in the north. To the west, it reaches Ireland and northern Portugal and to the east it reaches Mongolia. The species is absent from all Mediterranean islands except from Sicily. It expanded recently in Sweden, with a progression of 5° latitude northwards, now nearly reaching the Arctic Circle. At the same time, it has become rare in most lowland locations of western and central Europe. Despite this regional regression, the species is not considered to be threatened at a continental scale: Least Concern in the IUCN Red List of European Bees. Its modelled distribution fits moderately to its actual one. All scenarios project a moderate reduction of suitable areas in the south and some extension to the north, depending on its dispersal ability. In 2100, in the worst case, the BAMBU and GRAS scenario project unsuitable conditions for most lowlands (including the British Isles). Suitable conditions would only remain in the Alps, Scandinavia and Finland. As *B. sylvarum* seems to have a quite good dispersal ability (as it is present in Sicily and as it expanded recently toward the north), it would not be threatened much by global warming, even if its already precarious situation in the lowlands would become worse. Nevertheless, the most severe scenario projects a considerable reduction of its climatically suitable area.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.77)
Climate risk category: HHHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-1516 (-11%)	-2939 (-21%)
	BAMBU	-2491 (-18%)	-3809 (-27%)
	GRAS	-3142 (-22%)	-4487 (-32%)
2100	SEDG	-4674 (-33%)	-7026 (-50%)
	BAMBU	-8115 (-57%)	-11430 (-81%)
	GRAS	-9627 (-68%)	-12672 (-90%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus sylvestris (Lepeletier, 1832)

= *Bombus (Psithyrus) sylvestris; Psithyrus sylvestris*

© Photo P. Rasmont

Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus sylvestris is a small- to medium-sized bumblebee. Its colour is not very variable, generally with one large yellow band and a white and black tail intermixed with red. It is a specialised social parasite species (cuckoo-bumblebee) mostly of *B. pratorum* and probably also *B. jonellus*. Its southernmost populations are in southern Spain, southern Italy and Greece, (where it is restricted to the mountains). To the north it reaches the coast of Barents Sea and it is distributed from Ireland in the west eastwards across Siberia to the Pacific coasts. It is also the second most common cuckoo-bumblebee. The species is not considered to be threatened at a continental scale: Least Concern in the IUCN Red List of European Bees. The modelled distribution corresponds quite well to the actual one. All scenarios project fragmentation in the lowlands of central and southern Europe and expansion of its climatic niche space in Fennoscandia up to the highest elevations of Scandinavian mountains. The GRAS scenario projects that suitable areas could completely disappear from all lowlands south of latitude 60° N by 2100 and from southern mountain areas (except for the Alps). As it is a cuckoo-bumblebee specialised on only one (possibly two) host-species and despite that it is presently one of the most abundant cuckoo-bumblebees, *B. sylvestris* might suffer substantially from global warming, regardless of its dispersal capability.

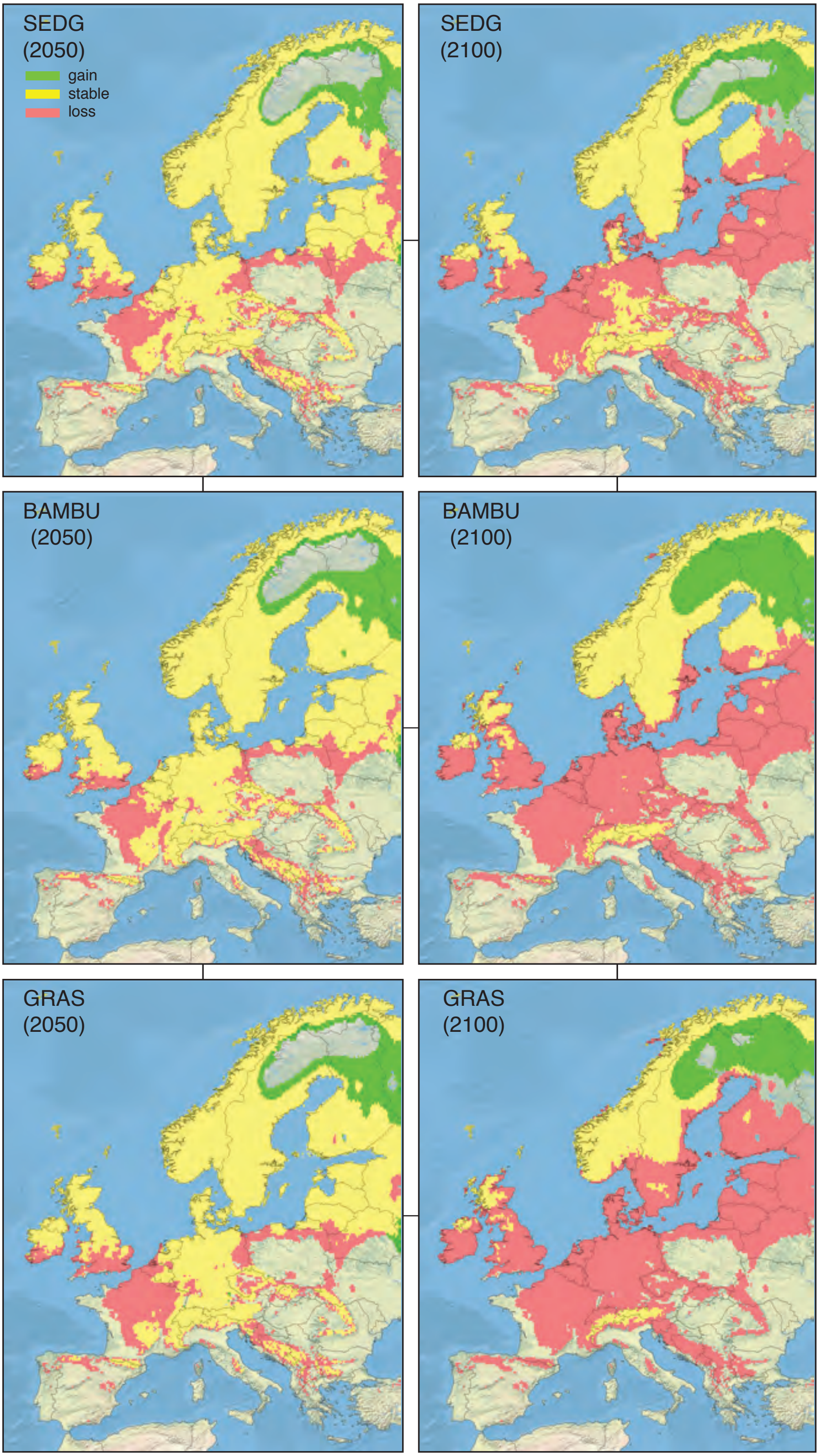
Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.78)

Climate risk category: HR

IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-2987 (-18%)	-4056 (-24%)
	BAMBU	-1806 (-11%)	-3326 (-20%)
	GRAS	-2495 (-15%)	-3972 (-24%)
2100	SEDG	-8233 (-49%)	-9527 (-57%)
	BAMBU	-8279 (-50%)	-10659 (-64%)
	GRAS	-10840 (-65%)	-12613 (-76%)

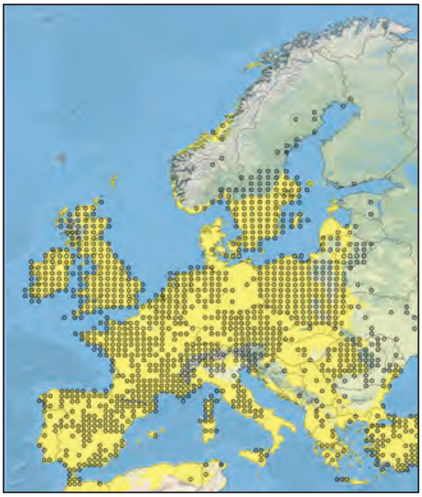
Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus terrestris (L., 1758)

= *Bombus (Bombus) terrestris*

© Photo P. Rasmont



Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus terrestris is a medium- to large-sized bumblebee. Its most widespread coat colour pattern shows two yellow bands and a white tail, or a faded orange tail in the British isles (ssp. *audax* (Kirby)). It is all black with a white tail in the Canary Islands (ssp. *canariensis* Pérez). There are still other conspicuous colour patterns in the Iberian Peninsula (ssp. *lusitanicus* Krüger) and Sardinia (ssp. *sassaricus* Tournier). It lives in very large underground colonies in all habitats. It is also a generalist forager. *B. terrestris* is the only European bumblebee able to change its phenology completely according to the seasonal conditions, being able to produce one to three generations per year in any of the four seasons, with or without hibernation or aestivation. Its distribution extends from the Azores, Madeira, Canary Islands, southern Spain, Morocco, Sicily, north Libya, Crete, Cyprus, Israel and central Iran in the south northwards to north Sweden. It has recently made a dramatic advance towards the north, crossing the Arctic Circle in Sweden and Norway. It reaches the Altai Mountains to the east. It is abundant or even dominant in most of its locations and it is even considered as invasive where it has been introduced (e.g. in Argentina, Chile, Japan, Tasmania). The species is not considered to be threatened by IUCN. Its modelled distribution fits well with its actual one. All scenarios project a reduction of suitable areas together with an expansion towards the north. This reduction could be inconspicuous by 2050 but more dramatic by 2100. In the worst case, the GRAS scenario projects by 2100 a considerable reduction of the suitable area in southern Europe and North Africa. As *B. terrestris* is a very ubiquitous and generalist species, highly polymorphic, very abundant, with conspicuous and dramatic dispersal abilities, it would not be threatened by global warming but, nevertheless, in some scenarios, its climatic suitable areas would be noticeably or even considerably reduced in the south.

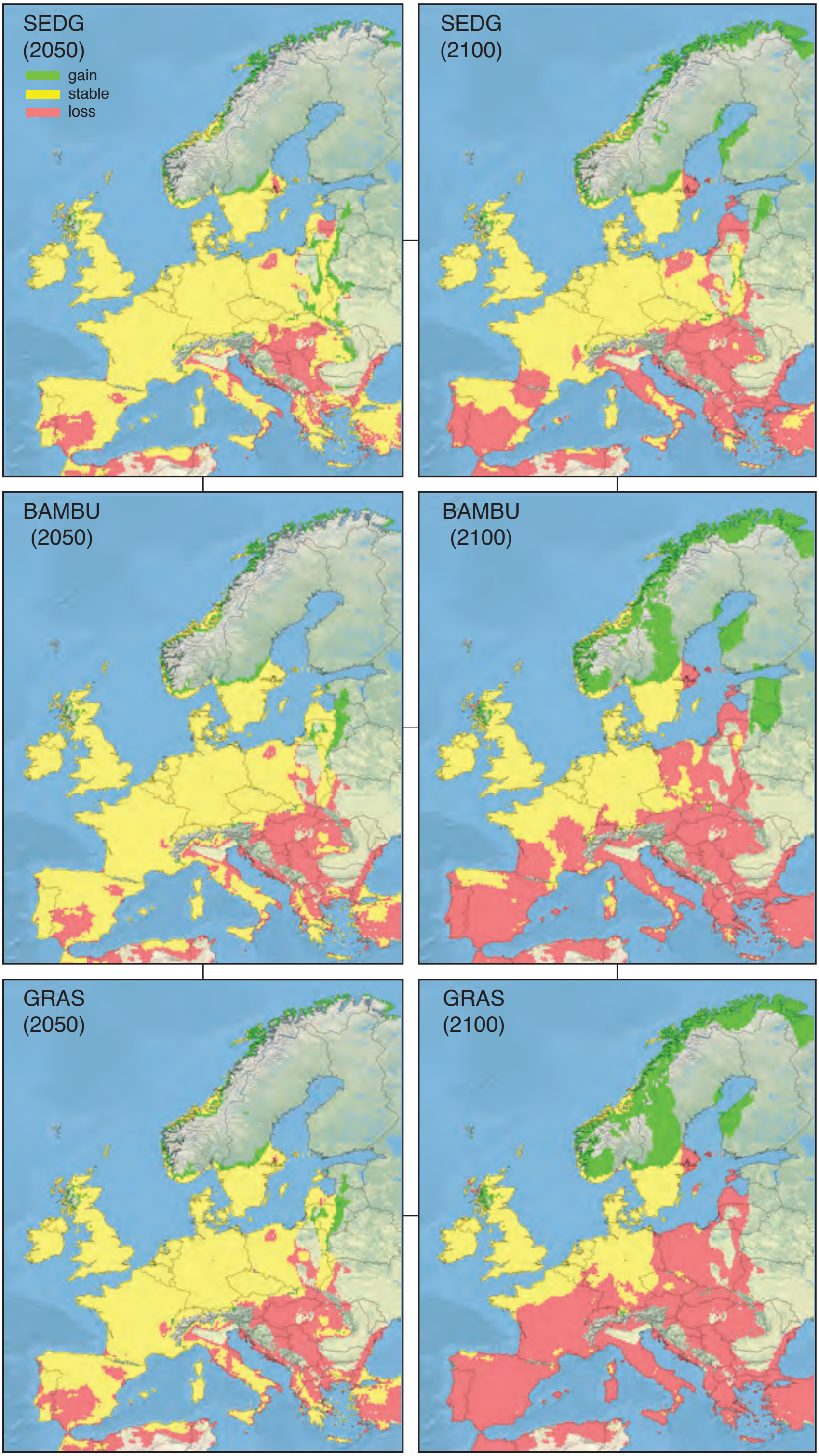
Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.82)

Climate risk category: HR

IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-2478 (-14%)	-3367 (-19%)
	BAMBU	-3701 (-21%)	-4390 (-25%)
	GRAS	-4286 (-25%)	-4985 (-29%)
2100	SEDG	-5851 (-34%)	-7192 (-41%)
	BAMBU	-7609 (-44%)	-10351 (-60%)
	GRAS	-9711 (-56%)	-12309 (-71%)

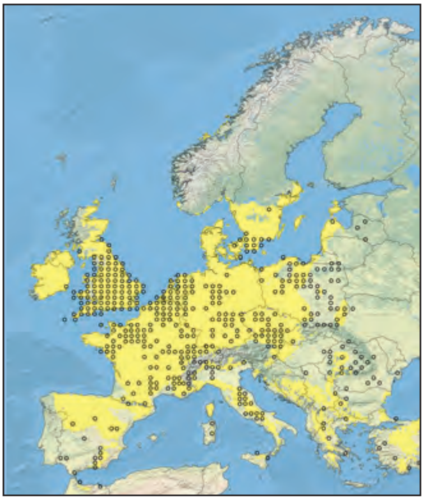
Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus vestalis (Geoffroy, 1785)

= *Bombus (Psithyrus) vestalis; Psithyrus vestalis*

© Photo J. Michailowski



Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus vestalis is a large bumblebee. The specimens from the European mainland generally have a colour pattern with one large yellow prothoracic band and a white tail intermixed with some yellow hairs (ssp. *vestalis*). There are some conspicuous subspecies in southern areas, as in Sardinia, where there is no yellow band on the thorax (ssp. *sorgonis* (Strand)) or in Corsica, where specimens have generally an all-black coat with a red tail (ssp. *perezi* (Schulthess-Rechberg), which is often considered to be a good endemic species). It is a social parasite species (cuckoo-bumblebee) specialised primarily on *B. terrestris*. The species occurs from north Morocco northwards to southern Sweden (where it recently expanded its distribution) and Latvia in the north and from Ireland and Portugal eastwards to the Urals. As a cuckoo-bumblebee it is clearly much scarcer than its host *Bombus terrestris* but it can be locally abundant. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. The modelled distribution shows that its climatic niche space includes a wider area along all margins of the species' actual range. All scenarios project fragmentation in southern Europe and expansion of suitable conditions northwards to the Arctic Circle and the Barents Sea coast by 2100. The GRAS scenario projects that its suitable areas could completely disappear from all lowlands south of latitude 52° N by 2100. As it is a social parasite specialised on a single host-species and despite that it is a common cuckoo-bumblebee, it would suffer noticeably from global warming, depending on its dispersal capability (which we assume to be high).

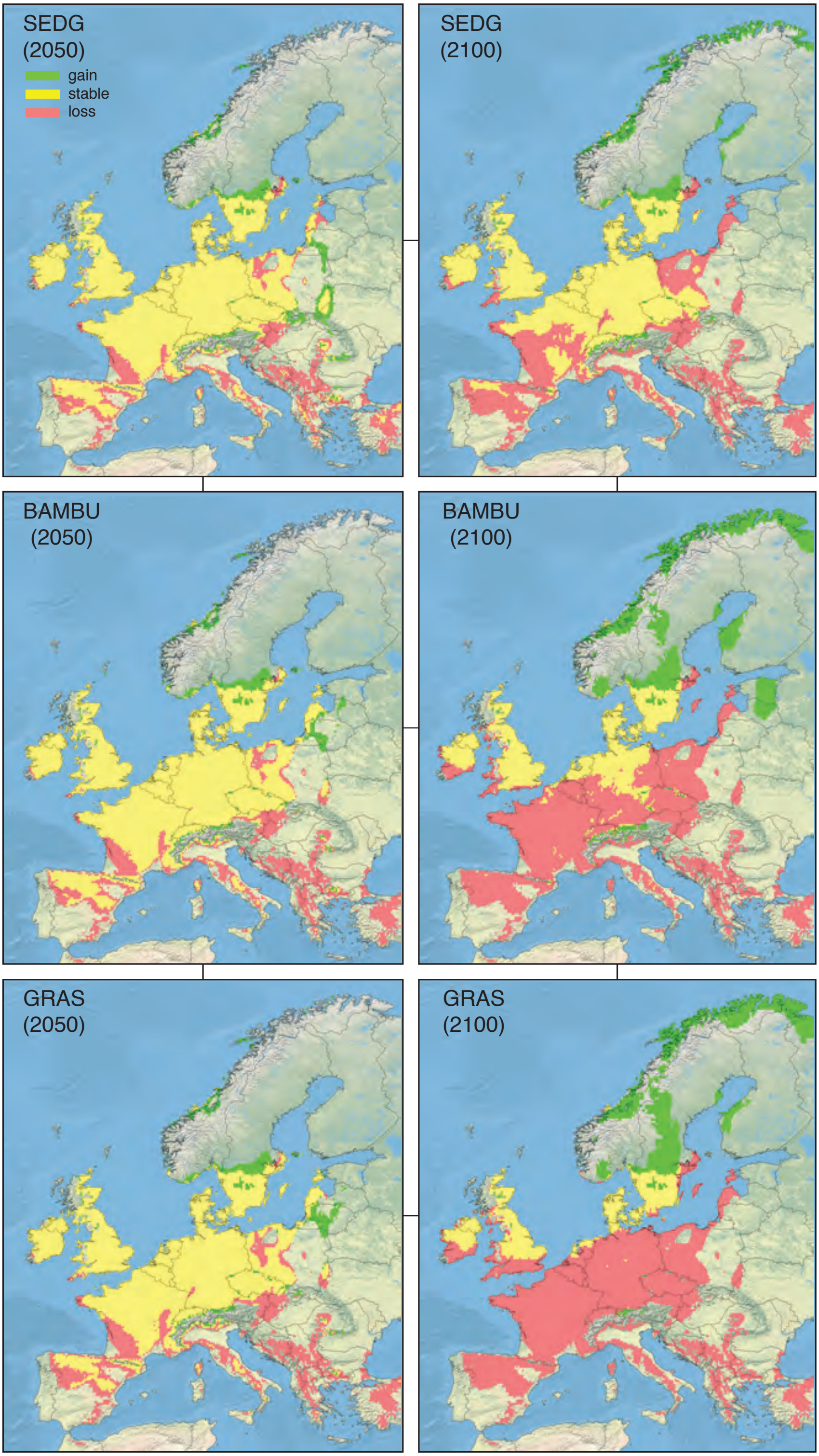
Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.79)

Climate risk category: HR

IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-1785 (-17%)	-2542 (-24%)
	BAMBU	-2114 (-20%)	-2715 (-26%)
	GRAS	-2386 (-23%)	-3061 (-29%)
2100	SEDG	-3824 (-36%)	-4744 (-45%)
	BAMBU	-5663 (-53%)	-7681 (-73%)
	GRAS	-7026 (-66%)	-8897 (-84%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG (2050)
gain
stable
loss
SEDG (2100)
BAMBU (2050)
BAMBU (2100)
GRAS (2050)
GRAS (2100)

Bombus veteranus (Fabricius, 1793)

= *Bombus (Thoracobombus) veteranus*, =*Bombus arenicola.*

© Photo P. Rasmont

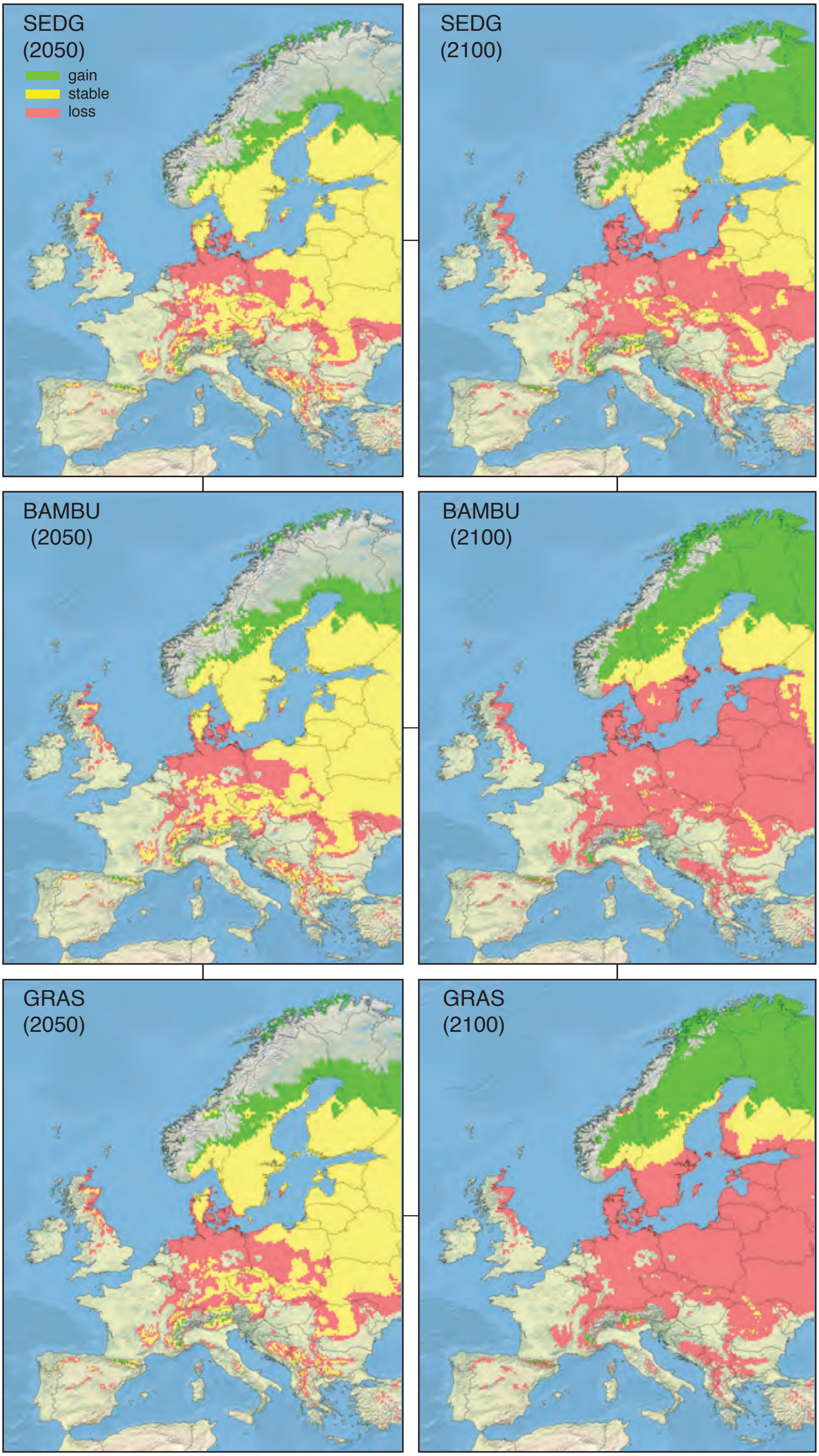
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus veteranus is a medium-sized bumblebee. The coat colour is very constant: all grey with a black thoracic band. The species occurs from the Massif Central (44° N) northwards to beyond the Arctic Circle in Finland and northern Russia. To the west, it reaches Britanny (western France) and to the east, it is found across Siberia to the Pacific coast. It does not occur in any of the large European islands or in the major peninsulas (Iberian, Italian, Balkan). It prefers to forage mainly on flowers with long corollas, especially Fabaceae or Lamiaceae (queens and workers) or Asteraceae (males). It is known to be a facultative social parasite of *B. sylvarum* and *B. humilis*. It has recently expanded its range towards the north and it recolonised Sweden via Finland. It has clearly become rare in most of the western and central European parts of its range. Surprisingly, it can also be very abundant during some years in some locations (e.g. in The Netherlands). Despite its increasing scarcity the species is not considered to be threatened at a continental scale: Least Concern in the IUCN Red List. The distribution model shows that its climatic niche space includes large European islands and peninsulas. Most of the places where it occurred a century ago, are now out of its modelled distribution, i.e. areas of suitable climatic conditions have already shifted significantly. All scenarios project a reduction of suitable areas by 2050. By 2100, all scenarios project that suitable climatic conditions would persist only in northern Europe and in the mountains of central and eastern Europe. The BAMBU and GRAS scenarios indicate that suitable areas of the species would only remain in a very restricted area of the southern mountains and north of latitude 60° N in Fennoscandia, reaching the Scandinavian mountains. As this species is already scattered in most of its lowland locations in west and central Europe, indicating a low dispersal capability, *B. veteranus* would suffer considerably from global warming.

Present distribution can be explained by climatic variables to a moderate extent (AUC = 0.80)
Climate risk category: HHR
IUCN Red List status: Least Concern

	Scenario	Full dispersal	No dispersal
2050	SEDG	-2014 (-15%)	-3666 (-28%)
	BAMBU	-1978 (-15%)	-3606 (-27%)
	GRAS	-2504 (-19%)	-4345 (-33%)
2100	SEDG	-3567 (-27%)	-6973 (-53%)
	BAMBU	-6070 (-46%)	-10474 (-80%)
	GRAS	-7006 (-53%)	-11487 (-87%)

Changes in climatic niche distribution (in 10’ x 10’ grid cells)


SEDG
(2050)
🟩 gain
🟨 stable
🟥 loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus wurflenii Radoszkowski, 1859

= *Bombus (Alpigenobombus) wurflenii; Bombus wurfleini*

© Photo P. Rasmont

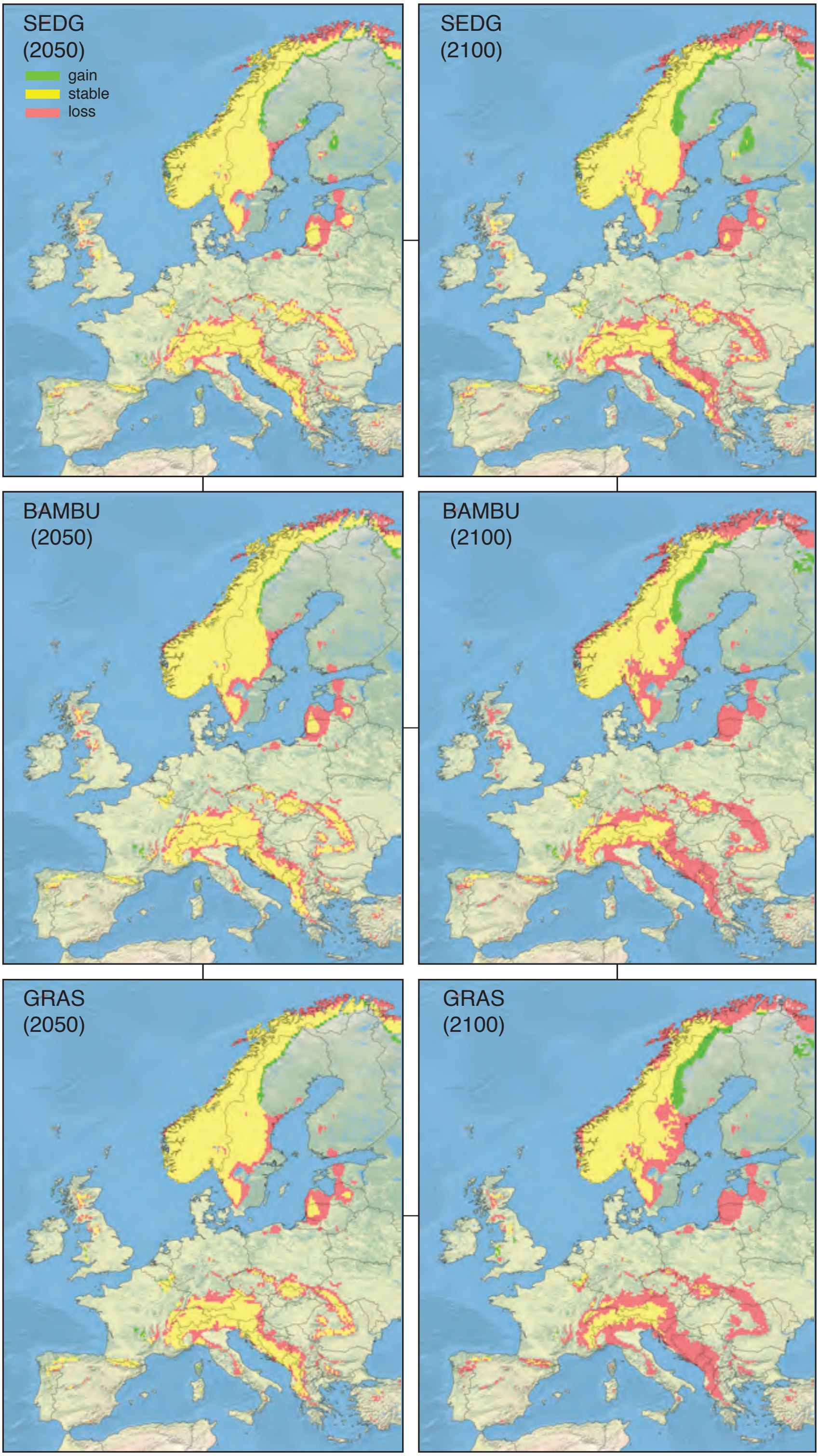
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus wurflenii is a medium-sized bumblebee. Its coat colour is mainly black with a reddish tail. More or less grey hairs can be intermixed with the black ones on the thorax and abdomen, and the amount of grey is characteristic for different isolated subspecies. It is a species with a disjunct distribution: (i) Scandinavian mountains, Ural, Cantabrian Mountains, Pyrenees, Alps, Apennines; and (ii) Carpathians, Balkans, Little and Great Caucasus. This species is highly adapted for "nectar robbing", i.e. perforating holes at the base of long corollas to reach the nectar, and to do this it uses its modified mandibles. The species is not considered to be threatened: Least Concern in the IUCN Red List of European Bees. The modelled distribution appears somewhat larger than its actual one, including parts of central Spain, the British Isles and eastern Baltic countries. All scenarios project a moderate reduction of suitable areas by 2050. By 2100, the climatic niche space of the species would be even more restricted, especially in the GRAS scenario where the Balkan would become unsuitable. With low dispersal capability and since *B. wurflenii* is a specialised species linked to cold boreal and alpine-subalpine conditions, it would suffer substantially from global warming.

Present distribution can be well explained by climatic variables (AUC = 0.89)
Climate risk category: R
IUCN Red List status: Least Concern

	Scenario	**Full dispersal**	**No dispersal**
2050	**SEDG**	-1470 (-20%)	-1685 (-23%)
	BAMBU	-1712 (-24%)	-1850 (-26%)
	GRAS	-1893 (-26%)	-2031 (-28%)
2100	**SEDG**	-2263 (-31%)	-2669 (-37%)
	BAMBU	-3428 (-48%)	-3731 (-52%)
	GRAS	-3809 (-53%)	-4123 (-57%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
gain
stable
loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

Bombus zonatus Smith, 1854

= *Bombus (Thoracobombus) zonatus*

© Photo G. Holmstrom

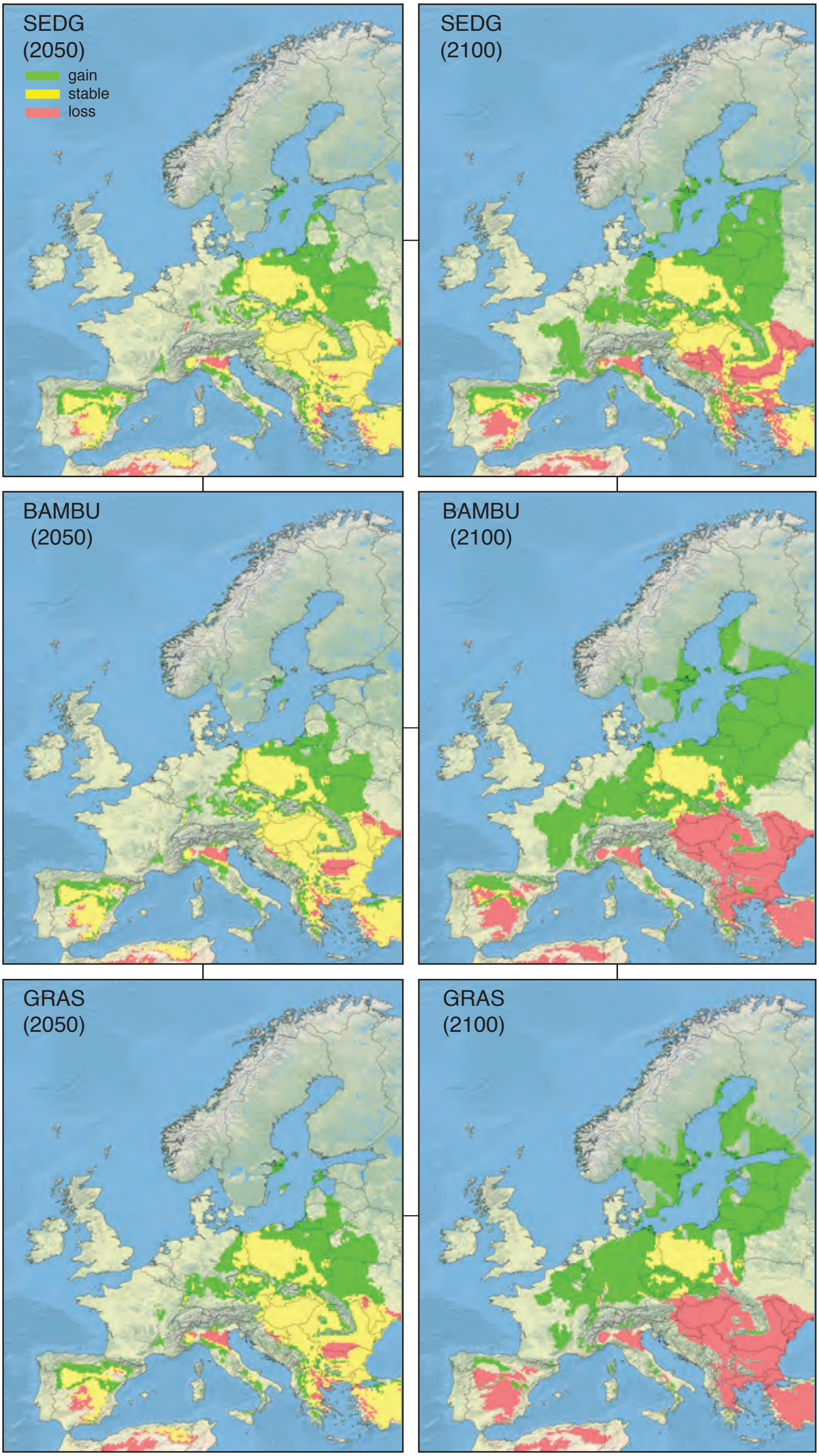
Dots: actual distribution 1970-2000; yellow areas: modelled suitable climatic conditions in 2000

Bombus zonatus is a medium-sized bumblebee. Its coat colour presents one or two broad yellow bands on the thorax and a largely yellow abdomen with a black tail. The species occurs in the Balkans, Romania, Moldova, Ukraine, southern Russia, Turkey, Caucasian countries and Iran. It is a generalist forager most often found on thistles (Asteraceae). The species is considered to be threatened at the European scale: Endangered in the IUCN Red List of European Bees. The modelled distribution appears much larger than its actual one, including Spain, Italy, and central Europe. This restricted actual range compared to its potential area, and the recent fragmentation along the Black Sea coast might indicate low dispersal ability and/or additional hostile conditions other than the climatic ones. Depending on its dispersal capability (that remains unsettled because we have too few European data at hand to assess it), the scenarios display considerably different results. If *B. zonatus* has a high dispersal ability, it could considerably expand its distribution. If the species would not be able to use this opportunity, it could suffer considerably from reductions in the area of climatically suitable space, especially under the most severe scenario (GRAS).

Present distribution can be well explained by climatic variables (AUC = 0.93)
Climate risk category: HR
IUCN Red List status: Endangered

	Scenario	Full dispersal	No dispersal
2050	SEDG	2940 (52%)	-525 (-9%)
	BAMBU	2155 (38%)	-856 (-15%)
	GRAS	2696 (48%)	-965 (-17%)
2100	SEDG	3457 (61%)	-2324 (-41%)
	BAMBU	2334 (41%)	-4520 (-80%)
	GRAS	1347 (24%)	-4756 (-84%)

Changes in climatic niche distribution (in 10' x 10' grid cells)


SEDG
(2050)
🟩 gain
🟨 stable
🟥 loss
SEDG
(2100)
BAMBU
(2050)
BAMBU
(2100)
GRAS
(2050)
GRAS
(2100)

9. Non-modelled European bumblebee species

Given the methodological restrictions of statistical species distribution modelling, we were not able to model 13 species. These were (i) rare species with a very narrow distributional range (too few data points) or (ii) species for which additional environmental or anthropogenic factors seem to override the climatic limitations or (iii) species with some taxonomic uncertainties or with recently modified status. Since most of the species included in the two first categories are either rare, endemic or habitat specialists with assumed low ability to disperse and thus low ability to follow the changing climates, many of them are very likely to be highly vulnerable to climate change. However, warm-adapted species might also profit from climate change and an assessment of the actual climatic risk of such data-insufficient species remains speculative. For such species better data would be needed with a much higher spatial resolution for rare and endemic species or from the entire range for species that occur only marginally in Europe.

9.1. Rare species and/or species with narrow distributional range

Some European bumblebee species are extremely rare and occur only in small geographic areas with few records. Trying to model such species is often not possible because of too little information content provided by the very few data points at the coarse resolution we used for modelling and consequent overfitting of the SDMs. Further, some species have the centre of their distribution in Central Asia and occur only occasionally or on the margins of the considered geographic window. For such species we do not cover either the whole distributional range or the likely relevant range boundaries (most importantly the north and south) necessary for the development of realistic niche models. For these reasons the following species were not modelled.

Bombus reinigiellus is the rarest bumblebee species in Europe. It also shows the most restricted distribution range, living only at the highest level of the Sierra Nevada, in south-east Spain. Pictures of this species are exceptional. Photo A.G. Maldonado

Bombus brodmanni Skorikov, 1911

=Bombus (Thoracobombus) brodmanni, =Bombus (Rhodobombus) brodmanni

Distribution of *B. brodmanni* in the chosen geographic window (red dot in Turkey).

© Photo P. Rasmont

This species is extremely rare and endemic to the mountains of north Turkey and west Caucasus. It occurs only marginally in the south-east of the considered area (Fig. 9.1). The species is poorly known and was not assessed by the IUCN Red List of European Bees.

Bombus brodmannicus Vogt, 1909

=Bombus (Pyrobombus) brodmannicus

Distribution of *B. brodmannicus* in the chosen geographic window (red dots in France).

© Photo P. Rasmont

This species lives in two well separated areas. In the Caucasian region the species can be locally very abundant. In the south west Alps (France) it is restricted to very few locations (Fig. 9.2). The Caucasian population forages on many different plant species while the population from the Alps seems to be specialised on *Cerinthe* flowers (Boraginaceae). The restricted distribution and food specialisation led to an assessment as Endangered in the IUCN Red List of European Bees. Because of this highly specialised foraging requirements and its already localised distribution in a small area of the Alps, the western population seems extremely vulnerable to warming. On the other hand, the eastern population is rather widespread in the Caucasian region with no apparent food specialisation. It is likely much less vulnerable to climate change.

Bombus mlokosievitzii Radoszkowski, 1877

=Bombus (Thoracobombus) mlokosievitzii

© Photo P. Rasmont

Distribution of *B. mlokosievitzii* in the chosen geographic window (red dots in Turkey and the Balkans).

This species mainly occurs in forests of northern Turkey, the Caucasus and northern Iran. In Europe, it occurs only in some scattered locations in the Balkans, where it is locally quite rare. The present rarity of the species in the Balkans might make it vulnerable to climate change. It has not been assessed (Data Deficient) in IUCN Red List of European Bees.

Bombus patagiatus Nylander, 1848

=Bombus (Bombus) patagiatus

© Photo P. Rasmont

Distribution of *B. patagiatus* in the chosen geographic window (red dot in Finland).

This species is abundant in the boreal taiga from the Ural to the Pacific coast of Russia. It occurs also west of the Ural, reaching the Finnish border near Lake Ladoga. Only very few individuals have been found in the area studied here. It has not been assessed (Data Deficient) in IUCN Red List of European Bees.

Bombus renigiellus (Rasmont, 1983)

=Bombus (Megabombus) renigiellus

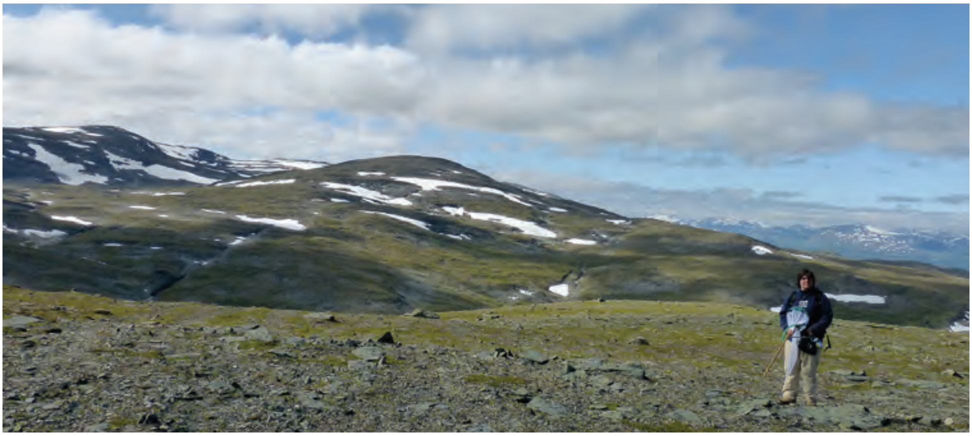
© Photo P. Rasmont

Distribution of *B. renigiellus* in the chosen geographic window (red dots in Spain).

This species is endemic to high altitudes of the Sierra Nevada (southern Spain), where it is rare and restricted to a few locations above 1800 m asl. *Bombus renigiellus* has the smallest distribution of any *Bombus* species in Europe. As the species is already restricted to the cooler areas in the highest regions of the Sierra Nevada, it seems very likely that any further warming could drive the species to extinction. It is assessed as Endangered by IUCN Red List of European Bees.

9.2. Species with a distribution poorly explained by climatic variables

The impact of climatic variables on the distributions of some species can sometimes be overridden by other environmental factors. This is the case when a species is, for instance, highly bound to a particular habitat type that occurs only occasionally and most often only with small patches compared to the size of our grid cells and is highly scattered across Europe such as steppic grasslands or moors. For these species we were not able to develop reliable SDMs indicated by poor model performance.



The Scandinavian mountain tundra is inhabited by several bumblebee species threatened by global warming (N. Sweden, Abisko, 2013. Photo P. Rasmont).

Bombus armeniacus Radoszkowski, 1877

= Bombus (Thoracobombus) armeniacus; Bombus (Rhodobombus) armeniacus

© Photo P. Rasmont

Distribution of *B. armeniacus* in the chosen geographic window (red dots).

Bombus armeniacus lives in steppic areas in Hungary, Romania, the Balkan peninsula, Moldova, Ukraine, southern Russia and Turkey. Its range extends into Central Asia. It is a generalist forager with a marked preference for flowers with long corollas that can be accessed by its long tongue. This species is clearly declining and it was classified as Endangered in IUCN Red List of European Bees.

Bombus deuteronymus Schulz, 1906

Bombus (Thoracobombus) deuteronymus; Bombus bureschi; Bombus superequester

© Photo P. Rasmont

Distribution of *B. deuteronymus* in the chosen geographic window (red dots).

Bombus deuteronymus occurs in dry woods and forest edges in the Balkans and in Russia where it is a very rare species. To the east, its distribution reaches the Pacific coasts and Japan. Its floral resources are unknown. Because of its scarcity, the IUCN Red List of European Bees does not provide an assessment (Data Deficient).

Bombus laesus Morawitz, 1875

= Bombus (Thoracobombus) laesus; Bombus (Laesobombus) laesus

Distribution of *B. laesus* in the chosen geographic window (red dots).

© Photo P. Rasmont

Bombus laesus is a steppic species of Hungary, Romania, Moldova, Ukraine, southern Russia and Turkey. To the east, its distribution includes the steppes of central Asia. Its floral resources principally include flowers with long corollas which it can access easily with its medium-sized tongue. This species was quite abundant in true steppes of Europe, especially in Hungary and Ukraine. However, it has recently declined considerably and it is now only present in a small fraction of its former distribution area. It is assessed as Near Threatened in the IUCN Red List of European Bees.

Bombus mocsaryi Kriechbaumer, 1877

= Bombus (Thoracobombus) mocsaryi; Bombus (Laesobombus) mocsaryi; Bombus laesus mocsaryi; Bombus maculidorsis

Distribution of *B. mocsaryi* in the chosen geographic window (red dots).

© Photo P. Rasmont

Bombus mocsaryi lives in wooded-steppes and dry grasslands on the Iberian peninsula, south of France, Hungary, Serbia, Romania, Poland, Belarus, Moldova, Ukraine, central Russia. To the east, its distribution includes the extensive grasslands in central Asia. This species forages mainly on flowers with long corolla which it can access easily with its medium-sized tongue. *Bombus mocsaryi* was formerly quite abundant in many dry grasslands. However, it recently declined considerably, remaining only in few locations in Spain, Hungary, Balkans, and Ukraine. It is assessed as Endangered by the IUCN Red List of European Bees.

9.3. Taxonomically problematic species

For the following species from Corsica and adjacent islands, there are some taxonomic issues that could potentially affect the modelling. These issues are discussed in chapter 12.

Bombus perezi Schulthess-Rechberg, 1886

=Bombus (Psithyrus) perezi; Psithyrus vestalis perezi

Distribution of *B. perezi* in the chosen geographic window (red dots).

© Photo M. McGlinchey

This species is endemic to Corsica and few other islands of the Tuscan archipelago. It is abundant within its restricted range where it is a cuckoo-bumblebee of *B. xanthopus* and, possibly, also of *B. renardi*. Its distribution is too restricted to allow the development of reliable species distribution models. It is assessed as Least Concern in the IUCN Red List of European Bees.

Bombus pereziellus (Skorikov, 1922)

=Bombus (Thoracobombus) pereziellus; Bombus muscorum pereziellus

Distribution of *B. pereziellus* in the chosen geographic window (red dots).

© Photo P. Rasmont

This species is endemic to Corsica, where it is quite rare. Its distribution is too restricted to allow the development of reliable species distribution models. It is assessed as Least Concern by IUCN Red List of European Bees.

Bombus renardi Radoszkowski, 1881

=Bombus (Bombus) renardi; Bombus lucorum renardi

Distribution of *B. renardi* in the chosen geographic window (red dots).

© Photo P. Rasmont

This species is strictly endemic to Corsica. Its distribution is too restricted to allow the development of reliable species distribution models. It has not been assessed by the IUCN Red List of European Bees as it has been only recently restored to species status.

Bombus xanthopus Kriechbaumer, 1877

= Bombus (Bombus) xanthopus; Bombus terrestris xanthopus

Distribution of *B. xanthopus* in the chosen geographic window (red dots).

© Photo P. Rasmont

This species is endemic to Corsica and few other islands of Tuscan archipelago where it is very abundant. Its distribution is too restricted to allow the development of reliable species distribution models. It has not been assessed by the IUCN Red List of European Bees as it has been only recently been restored to species status.

10. General patterns of future risk

10.1. General overview

A common trend across all scenarios is that for the majority of species their climatically suitable areas are projected to shrink moderately to strongly, while the suitable areas for only few species are projected to expand (Table 10.1). Out of the 56 modelled species five species may expand their ranges by 2050 and four to six species, depending on the scenario, may expand by 2100 under the assumption of full dispersal. Four to 17 species, depending on the scenario and the dispersal assumptions, are projected to maintain more or less their status quo up to 2050 and zero to one up to 2100. Suitable climatic conditions are projected to decrease for 34 to 52 species up to 2050 and for 49 to 55 species up to 2100. The 13 non-modelled species are all very rare and localised and their area can be expected to shrink considerably in any situations and potential extinction of many of these species seems most likely in any cases of climate warming.

Table 10.1 Projected changes in climatically suitable areas for European bumblebee species by the years 2050 and 2100. The values represent the number of species in each change category. Thirteen species were too rare to be modelled.

<table>
<tr><th rowspan="3">Change categories</th><th rowspan="3">Percentage change</th><th colspan="6">Full dispersal</th><th colspan="6">No dispersal</th></tr>
<tr><th colspan="3">2050</th><th colspan="3">2100</th><th colspan="3">2050</th><th colspan="3">2100</th></tr>
<tr><th>SEDG</th><th>BAMBU</th><th>GRAS</th><th>SEDG</th><th>BAMBU</th><th>GRAS</th><th>SEDG</th><th>BAMBU</th><th>GRAS</th><th>SEDG</th><th>BAMBU</th><th>GRAS</th></tr>
<tr><td>Non-modelled</td><td></td><td>13</td><td>13</td><td>13</td><td>13</td><td>13</td><td>13</td><td>13</td><td>13</td><td>13</td><td>13</td><td>13</td><td>13</td></tr>
<tr><td>Strong expansion</td><td>>+80%</td><td>0</td><td>0</td><td>0</td><td>2</td><td>2</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Moderate expansion</td><td>+20 to +80%</td><td>5</td><td>5</td><td>5</td><td>4</td><td>2</td><td>3</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Status quo</td><td>-20 to +20%</td><td>17</td><td>13</td><td>8</td><td>1</td><td>0</td><td>0</td><td>7</td><td>8</td><td>4</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Moderate regression</td><td>-20 to -50%</td><td>32</td><td>37</td><td>37</td><td>31</td><td>17</td><td>2</td><td>46</td><td>42</td><td>43</td><td>18</td><td>0</td><td>0</td></tr>
<tr><td>Strong regression</td><td>-50 to -80%</td><td>2</td><td>1</td><td>6</td><td>16</td><td>28</td><td>42</td><td>3</td><td>5</td><td>8</td><td>32</td><td>35</td><td>21</td></tr>
<tr><td>Very strong regression to extinction</td><td>-80 to 100%</td><td>0</td><td>0</td><td>0</td><td>2</td><td>7</td><td>8</td><td>0</td><td>1</td><td>1</td><td>5</td><td>20</td><td>34</td></tr>
<tr><td>TOTAL</td><td></td><td colspan="6">69 69 69 69 69 69 69</td><td colspan="6">69 69 69 69 69 69 69</td></tr>
</table>

10.2. No dispersal vs full dispersal

Under the assumption of no dispersal, which is actually the assumption of negligible dispersal ability within the next 40 or 90 years respectively, no range expansion is possible per definition. Thus, large differences between both assumptions are visible for the assessment of potential future reductions of suitable areas. The number of species which might retain their status quo in terms of range size, but not necessarily according to their current distribution, ranges between zero and 17, when full dispersal ability is assumed. But only between one and seven species will not change under the assumption of no dispersal, which means they could more or less sustain their current ranges. The number of species potentially losing suitable areas is higher with no dispersal (between 48 and 55), compared to full dispersal (between 34 and 52). Dispersal plays a particular role with respect to potential extinction at the European level. While only between two and eight species are at a particularly high risk of extinction when full dispersal is assumed, between five and 34 species are at risk of extinction under the assumption of no dispersal by the year 2100.

Based on the assumed dispersal ability for each species (as described in chapters 6-7), we used the likely more realistic assumption for each species (full or no dispersal if assumed dispersal ability is high or low) and assessed the overall effects of projected climate change on the potential future range changes for the European bumblebees (Table 10.2).

Considering the assumed dispersal abilities, three species can potentially expand their ranges by 2050 and also by 2100. Five to eight species could keep their status quo up to 2050 and none by 2100. Forty-five to 48 species are projected to lose suitable areas by 2050 and 53 by 2100 (see also Fig. 13.2, p. 174).

Bombus glacialis is large species that could be found only in two distant locations in Arctic ocean: Novaya Zemlya and Wrangel islands. Its coat colour strongly recalls the near species *Bombus lapponicus*, greyish on the back of the pro- and metathorax and tergite 1, nearly all the remaining abdomen reddish. It differs by the admixture of numerous black hairs in the middle of tergite 4 and 5. This species only lives in cold arctic tundra with permafrost where it nests in lemming's abandoned burrows. Photo P. Rasmont.

Table 10.2 Projected changes in climatically suitable areas for European bumblebee species in 2050 and 2100 considering rough assessments of species-specific dispersal abilities. The values represent the number of species in each change category. Dispersal ability has been assessed for each species according to ecological characteristics (see chapters 6-7). Dispersal abilities for two species (*B. incertus* and *B. zonatus*) were unknown. We therefore assume these two species to have full dispersal abilities (providing optimistic results for potential range shifts).

Change categories	Percentage change	2050			2100		
		SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS
Non-modelled		13	13	13	13	13	13
Strong expansion	>+80%	0	0	0	2	2	1
Moderate expansion	+20 to +80%	3	3	3	1	1	2
Status quo	-20 to +20%	8	9	5	0	0	0
Moderate regression	-20 to -50%	42	40	40	23	6	0
Strong regression	-50 to -80%	3	3	7	27	33	28
Very strong regression to extinction	-80 to 100%	0	1	1	3	14	25
Total		69	69	69	69	69	69

10. 3. Climate change scenarios

As expected, the three scenarios do not show strong divergence for 2050. However, under the most severe change scenario (GRAS) eight species are projected to suffer from strong or very strong reductions of suitable areas compared to four species in the intermediate change scenario (BAMBU) or three species for the moderate change scenario (SEDG; Table 10.2).

For 2100, the three models diverge considerably, even if they all project reduction of climatically suitable area for the majority of the species. Especially under the GRAS scenario a large fraction of European bumblebee species (25 species) are pre projected to lose nearly their entire suitable area, leaving them to the verge of extinction. In comparison, the BAMBU and SEDG scenarios project such drastic reductions for only 14 and 3 species respectively.

10. 4. Effects on subregional scales

To assess the effects of climate change on the bumblebees and their potential variability at subregional scales, we also examined the number of species that could find suitable climatic conditions within the surrounding (50 km radius) of 30 selected European cities (Table 10.3). The actual observed number of species and the number of species that could find suitable climatic conditions increases with latitude (Pearson R=0.43 and 0.31). In most of the cases more species are predicted to find climatically suitable conditions in the selected areas than are actually present. For instance, the median number of actually present species across the selected areas is 21.5. In contrast, the median of the modelled number of species that could find suitable climatic conditions is 26 (Table 10.3). This indicates the presence of other limiting factors apart from climatic conditions. One other major factor might be dispersal limitation for a number of species, either as a consequence of species-specific movement abilities, or caused by the presence of hard dispersal barriers. Other factors such as limited amounts of other essential resources such as the availability of pollen and nesting or hibernation sites might play a role, too (see chapter 11 for a more detailed discussion about the principal limitations of species distribution modelling).

For 2050, the median modelled number of species finding suitable climatic conditions varies from 17.5 to 19.5, depending on the scenario, meaning a remaining median diversity of 64 to 76% compared to the modelled situation in 2000.

For 2100, the median modelled number of species finding suitable climatic conditions varies only between 1.5 and 10. At this time, irrespective of the scenario, the diversity reduction will be considerable with a remaining median diversity ranging from 10 to 46% (Table 10.3).

Most worryingly, the projected loss of suitable climatic conditions is not evenly distributed across Europe. Clearly, southern Europe, which already harbours a poor bumblebee fauna, will be most strongly affected by potential further species losses (Fig. 10.1). For instance, in areas around Granada, Seville, Athens and Lisbon the present number of bumblebee species is already very low. For these regions, severe regressions are projected for almost all scenarios. For Lisbon and Seville, most of the scenarios project that only one bumblebee species may remain by 2050. In the worst case, it could lead to complete extinction of the native bumblebee fauna, as it is projected in 2100 by the GRAS scenario. The remaining species will be *Bombus terrestris* or alternatively *Bombus argillaceus*, as it is likely to be the case already in the warmer regions of southern Greece and Turkey.

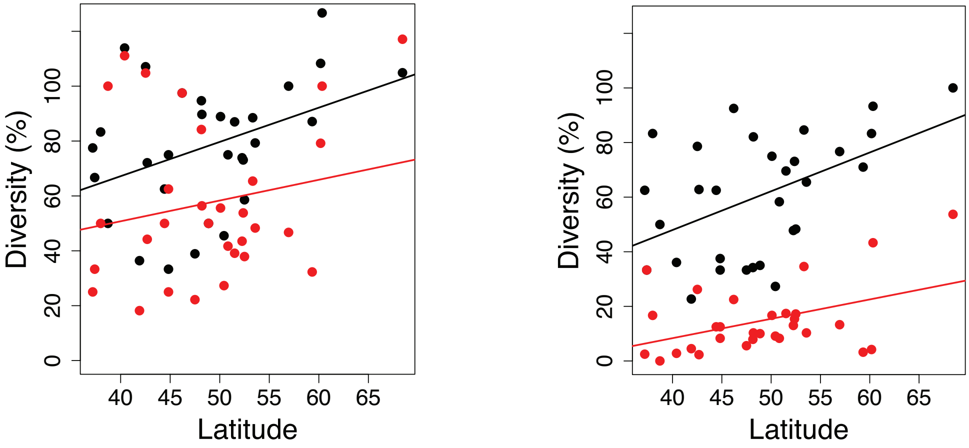


Figure 10.1 Projected changes of bumblebee diversity in selected areas across a latitudinal gradient. Projected changes were calculated relative to the number of species that would find suitable climatic conditions in the respective areas (100%). Selected areas represent the surroundings of larger cities in Europe (50 km radius). Black dots and regression lines represent changes in 2050. Red dots and regression lines represent changes in 2100. (a) Projected changes in the best case according to scenario and dispersal assumptions (see Table 10.3). Linear regression model for 2050 (black): $P = 0.004$, $R^2 = 0.23$ and for 2100 (red): $P = 0.06$, $R^2 = 0.09$). (b) Projected changes in the worst case according to scenario and dispersal assumptions (see Table 10.3). Linear regression model for 2050 (black): $P = 0.02$, $R^2 = 0.17$ and for 2100 (red): $P = 0.03$, $R^2 = 0.13$).

Table 10.3 Number of bumblebee species that could find suitable climatic conditions in several representative areas across Europe. Actual sp. Nb indicates the number of species that have been actually observed in the region between 1970 and 2000. Projected nb of sp provides the modelled numbers of species that could find suitable climates in the year 2000. The two first 2050 and 2100 categories display the modelled number of species that could find suitable climatic conditions in 2050 or 2100 under 3 climate change scenarios for the assumptions of either full or no dispersal abilities. The two last 2050 and 2100 categories provide the percentage of remaining species numbers in 2050 or 2100 for the best or worst cases, according to scenarios and dispersal abilities, relative to the model predictions for 2000. Green background indicates an increased number of species (remaining number of species > 120%); white background indicates an approximate *status quo* (remaining number of species < 120% and > 80%); yellow background indicates a moderate decrease (remaining number of species < 80% and > 49.9%); indicates a strong to very strong diversity decrease (remaining number of species < 50% and >19.9%); shows a considerable loss in diversity (remaining number of species < 20%).In the regions around Madrid, Rome, Bucharest, Belgrade, Bordeaux, Budapest and Kiev, the present number of species could be somewhat higher than it actually is according to climatic suitability, but there again the diversity loss is projected to be severe, depending on the scenario. Also in these regions, only one species is projected to remain in most case or even none as it is projected in Bordeaux.

City	Latitude	Longitude	Present		2050						2100						2050		2100	
			Actual nb. of species	Projected nb of sp	Full Dispersal			No Dispersal			Full Dispersal			No Dispersal			% remaining		% remaining	
					SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	Best	Worst	Best	Worst
Narvik	68.44	17.44	23	41	43	42	42	41	41	41	48	48	48	41	41	41	104.9	100.0	117.1	100.0
Bergen	60.33	5.33	20	30	32	38	32	28	28	28	30	37	23	26	22	21	126.7	93.3	123.3	70.0
Helsinki	60.18	24.93	25	24	26	24	22	21	22	20	19	15	7	12	5	1	108.3	83.3	79.2	4.2
Stockholm	59.33	18.05	26	31	27	26	25	22	24	22	9	5	5	5	1	1	87.1	71.0	29.0	3.2
Riga	56.95	24.10	28	30	27	30	29	23	26	23	11	7	4	6	2	0	100.0	76.7	36.7	0.0
Hamburg	53.58	10.00	23	29	23	21	19	23	21	19	14	7	7	13	6	3	79.3	65.5	48.3	10.3
Dublin	53.33	-6.25	19	26	23	23	23	22	22	22	17	12	9	16	12	9	88.5	84.6	65.4	34.6
Berlin	52.50	13.42	16	29	17	15	15	17	15	14	11	7	6	9	6	5	58.6	48.3	37.9	17.2
Amsterdam	52.37	4.88	24	26	19	19	19	19	19	19	14	8	7	14	7	4	73.1	73.1	53.8	15.4
Warsaw	52.25	21.00	27	23	17	16	12	15	15	11	10	5	4	8	4	3	73.9	47.8	43.5	13.0
London	51.50	-0.13	25	23	20	19	18	18	18	16	9	7	5	8	6	4	87.0	69.6	39.1	17.4
Brussels	50.83	4.33	29	24	18	16	15	17	15	14	10	7	7	7	3	2	75.0	58.3	41.7	8.3
Kiev	50.43	30.52	12	11	5	3	4	3	3	3	2	1	1	2	1	1	45.5	27.3	18.2	9.1
Praha	50.08	14.47	23	36	32	30	28	31	29	27	20	11	7	19	10	6	88.9	75.0	55.6	16.7
Paris	48.87	2.33	18	20	10	10	7	9	10	7	10	7	5	5	2	2	50.0	35.0	50.0	10.0
Wien	48.20	16.37	34	39	35	35	33	35	34	32	22	4	4	22	4	4	89.7	82.1	56.4	10.3
Munich	48.15	11.58	35	38	36	36	35	34	34	33	32	14	8	30	12	6	94.7	86.8	84.2	15.8
Budapest	47.50	19.08	13	18	7	6	6	7	6	6	4	1	1	4	1	1	38.9	33.3	22.2	5.6
Geneva	46.20	6.17	36	40	38	39	38	38	38	37	39	36	11	37	33	9	97.5	92.5	97.5	22.5
Belgrade	44.83	20.50	6	12	4	4	4	4	4	4	3	1	1	3	1	1	33.3	33.3	25.0	8.3
Bordeaux	44.83	-0.83	5	8	5	6	4	4	4	3	3	1	1	2	0	0	75.0	37.5	37.5	0.0
Bucharest	44.43	26.10	19	8	5	5	5	5	5	5	4	1	1	4	1	1	62.5	62.5	50.0	12.5
Sofia	42.68	23.32	27	43	31	29	28	30	28	27	19	3	1	18	2	1	72.1	62.8	44.2	2.3
Mont-Louis	42.52	2.12	35	42	44	43	45	41	41	40	44	42	36	40	38	31	107.1	95.2	104.8	73.8
Rome	41.90	12.48	18	22	6	8	6	5	7	5	4	2	1	2	2	1	36.4	22.7	18.2	4.5
Madrid	40.40	-3.68	16	36	17	18	13	17	18	13	7	5	4	7	2	1	50.0	36.1	19.4	2.8
Lisbon	38.72	-9.13	4	2	1	1	1	1	1	1	2	1	1	1	0	0	50.0	50.0	100.0	0.0
Athens	37.98	23.73	6	6	5	5	5	5	5	5	3	1	1	3	1	1	83.3	83.3	50.0	16.7
Seville	37.38	-5.99	2	3	1	2	1	1	2	1	1	1	1	1	1	1	66.7	33.3	33.3	33.3
Granada	37.18	-3.60	9	40	31	26	26	31	26	25	10	5	2	8	2	1	77.5	62.5	25.0	**2.5**
Median			21.5	26	19.5	19	18.5	18.5	18.5	17.5	10	6	4.5	8	2.5	1.5	76.25	64.15	46.23	**10.3**

In most of the regions around Sofia in the south to around Helsinki in the north quite a large number of bumblebee species can be observed currently. However, a considerable loss of species is projected here under all scenarios. In most of the cases, a reduction of bumblebee richness by 40% is projected by 2050. For 2100, already the moderate change scenarios project a reduction by 50% while under the most severe change scenario only one or two remaining species are projected in the areas around Paris, Brussels, Stockholm and Helsinki. Some places like Vienna, London, Amsterdam, Warsaw, Hamburg and Riga may suffer from similarly drastic reductions with only 3 to 4 remaining species by 2100 or even none in the worst case in Riga. Areas around Prague, Dublin and Berlin would also suffer from considerably high diversity reduction with 5 to 9 remaining species at worst.

In the northernmost localities around Narvik and Bergen, the number of species is already very high and in most of the scenarios this diversity could be maintained or even increased by 2050 and 2100. Of course some of the most sensitive species are at risk in these regions but there could be a gain thanks to colonisation from the south.

The species richnesss of bumblebees in mountainous areas (Mont-Louis, Sofia, Geneva, Munich and Vienna) is currently very high (34 to 36 species). It is noticeable that these high species numbers are very well reflected by the modelled potential number of species according to climatic suitability for 2000 (38 to 43 species). Iserbyt *et al.* (2010) showed that such a high diversity can be found in very restricted mountain areas (e.g. 33 species in a small valley in the Pyrenees). Pradervand *et al.* (2011) also found such a high diversity in the Valais (26 species). The projected future of these areas could be quite different: a strong reduction of the diversity in areas around Sofia, Munich and Vienna but a higher number of surviving species in Geneva and Mont-Louis. The two northernmost areas considered here (around Narvik and Bergen) are characterised by mountains, which could explain the sustainability of their diversity in all scenarios. On the contrary, most of the areas that are located in the lowlands are projected to suffer the most, even if they are far to the north, such as the Riga, Stockholm and Helsinki areas.

In conclusion, a reduction in bumblebee diversity could already be noticeable in most of the considered areas as soon as 2050, and this reduction will become more drastic under all scenarios by 2100. Only few areas which include mountains would be able to conserve a substantial part of their present diversity.

11. Methodological limitations

Species distribution models (SDMs; Guisan & Zimmermann, 2000; Guisan & Thuiller, 2005) are increasingly used in studies of biogeography, conservation biology, ecology and palaeoecology. One way to develop such SDMs, as utilised in this atlas, is to assess statistically the relationship of species occurrences and absences to environmental conditions. Although such models are purely correlative, compared to more process-driven dynamic population models (Morin & Thuiller, 2009), they can be a powerful tool, especially when a large number of species is modelled for which detailed mechanistic understanding of the actual processes that determine occurrence are lacking. However, several limitations of the statistical SDM approach remain (Araújo & Guisan, 2006); and knowledge of these limitations is crucial for the level of certainty and interpretation of the results. These limitations can be basically grouped in relation to (i) the conceptual approach, (ii) data issues, (iii) modelling techniques and (iv) the interpretations of the results.

11. 1. Conceptual background of SDMs

SDMs rely on the concept of the ecological niche (Hutchinson, 1957) but there is still some discussion about which aspect of the ecological niche, fundamental or realised, is assessed by SDMs. Since observed species distributions, which are used for the development of the SDMs, can be constrained by non-climatic factors, many scientists consider the outcomes of SDMs as an approximation of the realised niche (Guisan & Zimmermann, 2000; Pearson & Dawson, 2003). But in a recent example Soberon & Peterson (2005) concluded that niche models can also provide an approximation of the fundamental niche. However, Araújo & Guisan (2006) ask "… *whether the distinction between fundamental and realized niches is useful* .." and suggest accepting that "… *any characterization of the niche is an incomplete description of the abiotic and biotic factors allowing species to satisfy their minimum ecological requirements*." In terms of climatic niche modelling, we thus have to accept the possibility that other biotic or abiotic factors may limit the distribution of the focal species in addition to climate. However, this could only turn into a problem for the assessment of the climatic niche and the consequences of future change when these additional limiting factors are also related to climatic conditions and thus would introduce a systematic bias in the assessment of the climatic niche.

In the case of the bumblebees, biotic interactions such as nest and resource availability could limit large-scale distributions especially of specialised bumblebees and thus bias the assessment of the respective climatic niches. While studies on butterflies have shown that limitations by biotic interactions are possible (Schweiger *et al.*, 2008; Hanspach *et al.*, 2014) it has also been shown that in most cases distributions are determined by climatic conditions rather than by biotic interactions (Schweiger *et al.*, 2012).

Another assumption of SDMs is that species are in equilibrium with their current environment (Pearson & Dawson, 2003). However, there is evidence that some species groups actually are in disequilibrium with current climate. It seems that, for instance trees suffer from postglacial dispersal limitation and currently do not fill their areas of suitable climatic condition (Svenning & Skov, 2007). Such climatic disequilibrium could have severe consequences for the reliability of the SDMs since in this case they would systematically underestimate the climatic niche space of the species. However, it was also suggested that the ability to fill the potential ranges, defined by suitable climates, depends on the dispersal abilities of the species (Araújo & Pearson, 2005). For bumblebees we assume either low or high dispersal abilities (see also Kraus *et al.*, 2009; Lepais *et al.*, 2010), but even bumblebees considered as low dispersers might have had enough time since the last glacial period to fill their ranges (Hines, 2008). Recent phylogeographic studies suggest that *Bombus lapidarius* expanded its distribution from its Ice-Age refugia to the whole of Europe (e.g. Lecocq *et al.*, 2013a) while other species have remained rather stable since the 20th century (Rasmont & Iserbyt, 2014). This allows us to expect a climatic equilibrium for bumblebees. However, for a small number of species which have recently expanded their ranges into Europe from the East, such as *B. hypnorum,* we might underestimate the climatic requirements, since it is most likely that they have not yet filled their potential climatic range. Thus, future projections for these species need to be interpreted with great caution.

Table 11.1. Sampled countries sorted by decreasing order of sampling effort (all periods). Data: number of entries in the database; Nspec; number of specimens; D/10kmSQ: number of data by 10 km square; N/10kmSQ: number of specimens by 10 km square.

Code	Country	Area (km²)	Data	Nspec	D/10kmSQ	N/10kmSQ
BE	Belgium	30528	34806	81528	114.0	267.1
NL	The Netherlands	41530	18626	82532	44.9	198.7
SZ	Switzerland	41285	12936	56429	31.3	136.7
AT	Austria	83879	57082	96589	68.1	115.2
UK	United Kingdom	242900	115970	127558	47.7	52.5
IE	Ireland	70273	17242	17372	24.5	24.7
SE	Sweden	449965	41329	102257	9.2	22.7
FR	France	551695	48109	106709	8.7	19.3
NO	Norway	385199	52599	72921	13.7	18.9

Code	Country	Area (km²)	Data	Nspec	D/10kmSQ	N/10kmSQ
LT	Lithuania	65303	791	11383	1.2	17.4
PL	Poland	312679	25660	47785	8.2	15.3
FI	Finland	338144	7186	37676	2.1	11.1
IT	Italy	301336	11314	32885	3.8	10.9
CZ	Czech Republic	78870	3986	6850	5.1	8.7
DE	Germany	357026	6605	29140	1.9	8.2
EE	Estonia	43698	135	3228	0.3	7.4
ME	Montenegro	13812	157	868	1.1	6.3
SI	Slovenia	20273	718	1123	3.5	5.5
LU	Luxembourg	2586	113	141	4.4	5.5
BG	Bulgaria	110944	2867	4221	2.6	3.8
MK	FYROM	25713	217	770	0.8	3.0
ES	Spain	505911	8291	13944	1.6	2.8
SK	Slovakia	49035	416	1297	0.8	2.6
GR	Greece	131957	716	3175	0.5	2.4
RS	Serbia	88361	414	1630	0.5	1.8
DK	Denmark	43100	148	648	0.3	1.5
RO	Romania	238391	1656	2872	0.7	1.2
HR	Croatia	31067	202	266	0.7	0.9
LV	Latvia	64597	498	515	0.8	0.8
TR	Turkey (whole country)	783562	6959	20914	0.9	2.7
HU	Hungary	93029	293	434	0.3	0.5
BA	Bosnia Herzegovina	51197	71	229	0.1	0.4
PT	Portugal	92201	129	272	0.1	0.3
AL	Albania	28748	36	56	0.1	0.2
MD	Moldova	33843	12	14	0.04	0.04
RU	Russia (Europe)	3960000	1253	1525	0.03	0.04
UA	Ukraine	603549	213	214	0.04	0.04
BY	Belarus	207600	58	58	0.03	0.03
TN	Tunisia (partim)	163610	12	34	0.01	0.02
DZ	Algeria (partim)	2381741	31	210	0.00	0.01

11. 2. Data issues

11. 2.1. Data quality

The quality of SDMs largely depends on the quality of the environmental and species data. While climatic data are of high quality, the quality of large-scale species distribution data usually varies considerably in space and time. While species presence data are usually more accurate, although they can suffer from misidentifications, species absence data are generally less reliable, e.g. because of low accessibility of some regions, generally poor knowledge of certain areas, inconspicuousness of the species or unavailability of data. Similar to the potential effects of other biotic or abiotic factors on the assessment of the climatic niche, variability in sampling effort can lead to biased SDMs, especially when sampling effort correlates with climate.

For the bumblebees analysed in this atlas, misidentifications (false presences) can be considered as negligible. The species distribution data used in this atlas was extracted from a database (Atlas Hymenoptera) which is thoroughly cross-checked by the leading experts in bumblebee ecology. However, the sampling effort has differed considerably across Europe (Tab. 11.1) but we did not use grids with no data in the species distribution models (Lobo *et al.*, 2010), thus the influence of false absences are expected to be rather low for most species even if some species that are difficult to identify or recently separated taxonomicly will have a less well known distribution and thus more false absences present in our data such as *B. magnus*. Further uncertainties in the development of SDMs may arise from imprecise information on the sampling date. However, for the considered time period (1970-2000) most data in the Atlas Hymenoptera database include precise dates (day, month, and year). In some cases, only an interval is given. In these cases only the most recent data were considered as sampling data. In cases when no sampling date was provided but the information was extracted from a publication, the year before the publication occurred was taken as sampling date. Museum data with no sampling dates were not considered.

11.2.2. Polytypic species

Many European bumblebee species display a large geographic intraspecific variation (i.e. polytypic species) (Reinig, 1935; Pittioni, 1938; Rasmont, 1983a; Lecocq *et al.*, 2014) most probably fostered by historical biogeographic events (Reinig, 1937, 1939; Lecocq *et al.*, 2013a,b). These geographic variations have been used by several authors to define many subspecies mainly based on variation in colour patterns (Vogt, 1909, 1911; Pittioni, 1938; Krüger, 1951, 1958; Rasmont, 1983a; Rasmont *et al.*, 2008). For example, B. pascuorum includes 23 different subspecies in Europe (Rasmont, 1983a,b). In several European bumblebee species, this polytypism is related to local eco-climatic and behavioural adaptations (Rasmont & Adamski, 1995; Chittka *et al.*, 2004; Velthuis & van Doorn, 2006; Rasmont *et al.*, 2008; Lecocq *et al.*, 2013a,b, 2014). Therefore conspecific populations/subspecies could have different climatic requirements, while our modelling approach is based on the assessment of the climatic niche at the species level. This homogenisation of the climatic requirements across the species could underestimate the resistance to climate change of some populations, especially populations at species range margins. For example, a projected range contraction at the southern range margin according to species-level distribution models must not necessarily affect southern populations when these are genetically distinct from their northern conspecifics and moreover are better adapted to warmer conditions. The integration of this intraspecific variation in predictive models requires an a priori definition of genetically distinct sub-units based on phylogeographic lineages (Lecocq *et al.*, 2013a) or on evolutionary significant units (Lecocq *et al.*, 2014) with specific climatic requirements. However, since the necessary data for defining these sub-units are not available in most of the case, we developed our SDMs at the species level and thus some level of uncertainty about potential effects of local adaptations remain.

11.3. Modelling techniques

There are now many different methodological approaches available to develop SDMs and all have their strengths and weaknesses (Elith *et al.*, 2006; Heikkinen *et al.*, 2006). Since model performance and predictive ability have been shown to differ among these techniques (Thuiller *et al.*, 2003; Thuiller, 2004; Araujo *et al.*, 2005a; Elith & Graham, 2009), using ensembles of different models to reach consensus among the different models has been suggested (Thuiller, 2004; Araujo *et al.*, 2005a). However, building a consensus across a large variety of models bears the danger that models providing the most realistic future projections are in a minority and would contribute only little to the consensus. Thus, the challenge to develop and discriminate better models still remains. In the vast amount of literature comparing different modelling techniques, generalised linear models (GLMs) often appear, together with other approaches, such as generalised additive models (GAMs), boosted regression trees (BRTs) or MAXENT, as the most powerful approaches.

In this atlas, we used GLMs despite the fact that they did not always provide the best model performance compared to general GAMs or BRTs (Heikkinen *et al.*, 2006). However, GLMs had the overall best performance and their clear and simple mathematical formulation allows highly accurate extrapolations into new environmental space (Elith *et al.*, 2006; Heikkinen *et al.*, 2012).

An elegant model should also have a low level of complexity (i.e. number and complexity of terms used to explain the variability in the response variable) while maintaining a high level of performance (i.e. decreasing the residual variance). Thus the number of terms (including linear, second or higher order terms and interactions) must be reduced to a reasonable number (Harrell *et al.*, 1996).

To reduce the complexity of our SDMs, we pre-selected ecological relevant and least correlated variables by means of cluster analysis. The threshold for variable selection was a Pearson correlation coefficient lower than 0.3 (Graham 2003). In this way we avoided statistical problems due to high levels of collinearity between climate variables. Further reduction of cemplexity was then undertaken by removing less important variables when their removement minimised the AIC. The final model must be evaluated in terms of its prediction ability to assess model credibility. At best, the model predictions should be evaluated against an independent data set. However, assessing predictive ability of a model for future conditions is not possible, but transferring models from historical conditions to current conditions and vice versa could be a solution (Dobrowski *et al.*, 2011). However, in many cases, which apply also to the bumblebee data, historical data often suffer from lower sampling intensities, at least in some regions. Consequently, false absence data are likely increased in historic data sets, which make the interpretation of such back-casting evaluations difficult. Thus, splitting the data by random resampling the original dataset into a training and an evaluation dataset is a commonly applied alternative approach (Fielding & Bell, 1997; Olden & Jackson, 2000; Araujo *et al.*, 2005a). However, such a procedure can only be used to assess the ability of the model to predict current conditions, but this does not necessarily imply that these models are also able to accurately transfer their predictions in space (Heikkinen *et al.*, 2012) or time (Randin *et al.*, 2006). Since no proper independent dataset was available for the evaluations of our SDMs for European bumblebees, we calibrated our models on an 80% random sample of the initial data set and model accuracy was evaluated on the remaining 20%.

Many measures are available for model evaluation (Fielding & Bell, 1997). Most widely used are Cohen's Kappa (Cohen, 1960) and the Area Under the Receiver Characteristic Curve (AUC; Hanley & McNeil, 1982). However, it was shown that values of Cohen's Kappa and AUC should be interpreted with caution, since they depend on species prevalences (the fraction of occurrences relative to all data points) which makes model evaluations unreliable for species with very high or low prevalences (Allouche *et al.*, 2006; Lobo *et al.*, 2008, 2010). However, the True Skill Statistic (Peirce, 1884; Allouche *et al.*, 2006) is independent of prevalence and represents a powerful measure of predictive ability.

To maintain consistency with the Climatic Risk Atlas of European Butterflies (Settele *et al.*, 2008), we nevertheless keep the AUC values in the species pages and for the assignment of species to the risk categories. In addition, we also provide TSS and Kappa values together with values for specificity (proportion of correctly predicted occurrences) and specificity (proportion of correctly predicted absences; Appendix 1).

11.4. Interpretation of the results

11.4.1. General remarks

Projections of species distribution models to future climatic conditions are often mistaken as predictions of future species ranges. However, this is not what SDMs can provide. Moreover, they rely on scenarios of potential ways how environmental conditions might change in the future (see chapter 6). Under the assumptions of the different scenarios the SDMs project assessments of current suitable climatic conditions to the future, thus they only indicate areas where a species could in principle occur according to its climatic requirements. However, these projections do not allow drawing conclusions whether the species will actually be able to colonise the new areas or necessarily have to vanish at once in areas of increasingly unsuitable climatic conditions. Thus, the resulting projected changes in suitable climatic conditions cannot be translated one-to-one into actual range changes but they can be used to assess potential risks of climate change. To obtain a more realistic assessment of actual changes in species ranges two main processes might be discriminated (i) potential colonisation of new areas with suitable climates (leading edge) and (ii) extinction in the areas which are projected to become unsuitable (trailing edge).

11.4.2. Processes at the leading edge

The ability of a species to colonise new areas with suitable climatic conditions first of all depends on the likelihood that it can reach these areas, which basically is determined by the dispersal ability of the species but also on the frequency of anthropogenic displacement.

In contrast to the assumed high levels of range filling during the long time period since the last glacial maximum, bumblebees, especially those with low dispersal capacity, might be assumed to lag considerably behind changing climatic conditions. Birds and butterflies have been shown to be unable to follow changing climatic conditions sufficiently during the last twenty years (1990-2008) (Devictor *et al.*, 2012). Moreover, the observed climatic debts of birds and butterflies correspond to a 212 and 135 km lag behind climate (Devictor *et al.*, 2012). Thus, it might be assumed that climate change velocities are also much higher than colonisation rates of many bumblebees. Further, natural barriers might additionally hamper the colonisation of new areas. For instance, some bumblebee species which are restricted to southern mountains and have not yet colonised suitable areas in Scandinavia (e.g. *B. pyrenaeus*). Thus, it is highly unlikely that such bumblebee species profit from gains in suitable climatic conditions there.

Intentional anthropogenic displacements, on the other hand have the potential to lead to quick and massive species translocations. For instance, the current bumblebee international trade leads to the importation of nests by over 50 countries for pollination services to agriculture (Velthuis & van Doorn, 2006), an industry now worth billions of dollars annually (Goulson, 2003; Winter *et al.*, 2006). More than two million *B. terrestris* colonies (the main bumblebee species used in crop pollination) produced each year are shipped throughout the world (Goka *et al.*, 2001; Velthuis & van Doorn, 2006). Such commercial translocation has resulted in several introductions around the world (Buttermore *et al.*, 1998; Goulson & Hanley, 2004; Torretta *et al.*, 2006; Nukatsuka & Yokoyama, 2010; Williams *et al.*, 2012). Beside the potential low efficiency of translocations for the bumblebee conservation (see chapter 14), only one European species is currently traded making quite unlikely the translocation of e.g. threatened species by the international trade. Moreover, international trade appears more as a major threat for the bumblebee fauna rather than a hope for their conservation (Inoue *et al.*, 2008; Kanbe *et al.*, 2008; Yoon *et al.*, 2009; Nagamitsu *et al.*, 2010; Aizen *et al.*, 2011; Meeus *et al.*, 2011; Arbetman *et al.*, 2013a,b; Murray *et al.*, 2013).

Non-intentional anthropogenic translocations of species could also improve the likelihood of moving them into novel suitable areas. This is usually seen as a problem when alien species are concerned, especially when they are causing problems within ecosystems or for human health or economy (Richardson *et al.*, 2000; Jeschke *et al.*, 2014), but might be beneficial for European species which would otherwise seriously suffer from range contractions.

Once a species has reached a new area, survival will depend on the successful establishment and growth of populations. However, a large range of preconditions have to be met in terms of abiotic and biotic requirements of a species in addition to climatic suitability (Davis *et al.*, 1998; Heikkinen *et al.*, 2004; Schweiger *et al.*, 2008, 2010, 2012).

Key resources for bumblebees are pollen and nesting or hibernation sites. However, the most specialised species (e.g. *B. gerstaeckeri*) may not find relevant resources in the otherwise climatically suitable novel areas. We also cannot expect that the relevant resources move simultaneously with the respective species. For instance, it has been shown for butterflies and their larval host plants, that their climatic niches could overlap only to some extent (Hanspach *et al.*, 2014) and due to these differences in the climatic niches, future climate changes could lead to drastic spatial mismatches between areas suitable for butterflies or host plants (Schweiger *et al.*, 2008). Further, even if the climatic niche spaces of bumblebees and their pollen plants would change similarly, other constraints can restrict the pollen sources to colonise the novel areas successfully. Dispersal limitations might be one limiting factor, hostile soil conditions another. For instance, deciduous forests which usually grow on brown soils will shift towards the current taiga and podzol soil. Steppes which are associated with sierozem or chernozem soils will move towards brown soils and podzols. Of course, these soils themselves will change their chemistry as a response to the new climatic conditions but this is a very slow process, taking typically not centuries but thousands of years. Thus, it will most likely not be entire vegetation complexes or plant communities which shift their ranges, but single species will move individualistically. This also means that finding proper pollen resources might get increasingly difficult the farther the range has to be shifted, usually towards the north or upwards in altitude, to keep track with climate change. Thus, many species are likely to considerably lag behind future climate change due to a lack of proper pollen resources in the novel areas.

The potential problem of spatial mismatch between interacting species will even be more pronounced when one species entirely depends on one or few others (Schweiger *et al.*, 2008). This is the case for many parasitic (inquiline) bumblebee species. Here the same principle of individualistic responses of the host and the social parasite to changing climates because of differences in the climatic niche, dispersal ability or colonisation success could lead to a decreased, or impeded, ability to colonise new climatically suitable areas for *Psithyrus* species.

11.4.3. Processes at the trailing edge

There are also several reasons why a species might not become extinct immediately from areas where climatic conditions are projected to become unsuitable. Extinction of these populations can be avoided if they move to favourable refugia (Stewart & Lister, 2001) or if the individuals overcome the climatic stress through plastic changes (see below) or evolutionary adaptation (Williams *et al.*, 2008). Far from spread over several million years, evolutionary change can be rapid in a number of taxa (West-Eberhard, 1983), especially in fragmented populations (Blondel, 2000; Millien, 2006) or in populations under anthropogenic pressure (Hendry *et al.*, 2008). Many studies show that species can display rapid evolutionary adaptations that help them to counter stressful conditions or realise ecological opportunities arising from climate change (review in Hoffmann & Sgrò 2011).

The adaptive capacity of bumblebee species has not been integrated into our models. This could probably bias our projections and lead to a more pessimistic picture of the future fate of European bumblebees. This limitation can be overruled by using the approaches developed for predicting and describing evolutionary responses to recent climate change in natural populations (review in Hoffmann & Sgrò 2011). However all of these methods have their own limitations (Hoffmann & Sgrò, 2011) and cannot be easily applied to a large number of species. Thus, when interpreting our results, one has to bear in mind that there is the possibility of rapid adaptation and that the actual losses at the trailing edge might be lower than projected for some species. So far, we can neither estimate the adaptive potential of the bumblebees nor potential differences therein among the species, but it is more likely that evolutionary adaptation potentially occurs under moderate change scenarios than under severe change scenarios.

Another reason why species might persist even when climates are projected to become hostile are time lag effects. For some species it can take a considerable amount of time before declining populations disappear (Tilman *et al.*, 1994). These extinction debts have been observed in the course of habitat loss and fragmentation (Krauss *et al.*, 2010) but can in principle also occur under climate change (Jackson & Sax, 2010). Changing climatic conditions must not necessarily lead to instant extinction but can lead to unsustainable populations due to reduced fitness or competitive success. As a consequence, even moderate projections of range losses can ultimately lead to severe but delayed declines of species ranges (Dullinger *et al.*, 2012). It has also been shown that extinction debts depend on the longevity of the organisms (Krauss *et al.*, 2010) and that short-lived animals respond more rapidly to climate change (Thomas *et al.*, 2004; Morris *et al.*, 2008; Devictor *et al.*, 2012). Thus, for bumblebees we could expect a minor impact of extinction debts at the trailing edge of distribution.

A further reason for potentially sustaining populations under projected unsuitable conditions is a more trivial one and concerns the resolution of our spatial data and the model output. For reasons of model reliability, we used a rather coarse grid of 50 km x 50 km. To increase the information content for our projections we downscaled the models to a 10 min x 10 min grid. Downscaling to a certain extent is justifiable (Araujo *et al.*, 2005b) but there are obvious limits to how far downscaling can go. Thus a resolution of 10 min x 10 min is still coarse enough not be overly precise but also to ignore climatic variability within the grid cells. As a consequence, there might still be smaller areas within a grid cell where suitable climatic conditions remain, e.g. by shifting such conditions from a south-facing side of a hill to the north-exposed side. Such micro-refuges could ensure the persistence of a species within a grid cell in which the average conditions are projected to turn hostile (Austin & Van Niel, 2011; Lawson *et al.*, 2014). With the current resolution of our projections we cannot assess the importance of such micro-refuges for the future fate of bumblebees at their trailing edges. However, since such small-scale beneficial conditions are more likely to occur in more heterogeneous areas, the likelihood of bumblebee populations surviving is higher in mountainous areas and areas with a larger number of different types of habitats.

11.5. Conclusions on SDM limitations

Here we highlighted the major limitations of SDMs and future projections. Given all these limitations it is obvious that SDMs cannot represent the entire complexity of real-world systems. Moreover SDMs depend on and are only valid under simplifying assumptions. These limitations might question the usefulness of such an approach. However, if the simplifications are accepted and the limitations considered as good as possible, such simplified assessments can even help to gain a better understanding of the basic patterns and underlying natural processes, while not getting lost in all the species- and context dependencies. Thus, SDMs cannot predict the future fate of bumblebees, but they are a strong tool to assess their climatic risks in terms of potential changes in climatically suitable areas. They can help to identify areas of particular conservation concern, e.g. areas with an increased risk of species loss or areas with an increased level of colonisation credits, i.e. areas that species could colonise and thus maintain large enough ranges or even ensure survival but are unlikely to reach them in time on their own.

12. Taxonomic issues

For the following species, there are some taxonomic issues that could potentially affect the interpretation of the results. Prior to computation, we had to make some assumptions and simplifications according to taxonomic knowledge and data availability.

12.1. *Bombus confusus* and *B. paradoxus*

Bombus confusus includes two well differentiated taxa (Reinig, 1939): (i) *B. confusus confusus* Schenck 1859, with an all-black coat and a red tail; (ii) *B. confusus paradoxus* Dalla Torre 1882, with three yellow bands and a white tail. Some authors assumed that *B. confusus confusus* and *B. confusus paradoxus* were different species (e.g. Pittioni, 1938). Following most authors (Rasmont, 1983; Williams, 1998) and due to limited data availability at subspecies level, we assumed here that *B. confusus confusus* and *B. confusus paradoxus* are conspecific. However, we should keep in mind that these two taxa are conspicuously different and that their conspecificity is poorly grounded. These two taxa seem also to have a quite distinctly different fates during the 20th century. While both taxa were widespread across the entire mainland of Europe at the beginning of the 20th century, *B. confusus paradoxus* disappeared quite early in most parts of western and central Europe. In the Volga basin and in Siberia, on the other hand, *B. confusus paradoxus* remains by far the more abundant subspecies. We cannot exclude that these taxa could be two separate species and that they could have quite different eco-climatic requirements. If this is the case, then their climatic risk should be assessed separately.

12.2. *Bombus cryptarum*, *B. lucorum*, *B. magnus*, and *B. terrestris*

In the majority of their ranges, these four taxa constitute a group of cryptic species (see e.g. Williams *et al.*, 2012). Until recently, several confusions in species identification between these four species occurred (Rasmont, 1983; Rasmont *et al.*, 1986; Bertsch, 1997; Williams *et al.*, 2012). This means that most of the historical data could be based on misidentifications: old observations of one of these species could include observations of other species. As a result, we cannot exclude that the distribution and abundance of *B. lucorum* are defined with the same accuracy (i.e. overestimation of the species distribution) as it could be for easily identified species.

12.3. *Bombus lucorum* and *B. renardi*, *B. terrestris*, and *B. xanthopus*

Bombus renardi and *B. xanthopus* are closely related to *B. lucorum* and *B. terrestris,* respectively (Rasmont & Adamski, 1995; Lecocq *et al.*, 2013, 2014). In contrast to other taxa from the group of cryptic species including *B. lucorum* and *B. terrestris* (see above), *B. renardi* and *B. xanthopus* are phenotypically well differentiated from their sibling species (Rasmont & Adamski, 1995). Both species have been described as distinct species (Kriechbaumer, 1870; Radoszkowski, 1884) but later included in *B. lucorum* and *B. terrestris,* respectively (Vogt, 1909; Krüger, 1951; Rasmont & Adamski, 1995). However, Lecocq *et al.* (2013, 2014) recently demonstrated their species status according to their differentiation in genetics, morphology and species specific male secretions from *B. lucorum* and *B. terrestris*. Even if we recognise that *B. renardi* and *B. xanthopus* are two distinct species, we considered them together with *B. lucorum* and *B. terrestris* respectively for means of data reliability. This could marginally affect the *B. lucorum* and *B. terrestris* modelling.

12.4. *Bombus cullumanus*

Until recently, the specific status of *B. cullumanus* (Kirby 1802), *B. serrisquama* Morawitz 1888, and *B. apollineus* Skorikov 1910 remained doubtful. Recent evidence from COI barcodes and male species identification secretions is consistent with the three taxa being part of a single species (Rasmont *et al.*, 2012; Williams *et al.*, 2013). We used this new lumped taxonomic status in our analyses.

12.5. *Bombus laesus* and *B. mocsaryi*

Bombus laesus has been until recently considered as conspecific with *B. mocsaryi* (= *maculidorsis* Panfilov). Brasero *et al.* (2012) recently showed that these taxa diverge not only in their conspicuously different colour patterns but also by their morphology, their genetics and the composition of their species recognition male secretions. Reinig (1939) already showed that these two taxa also occupy quite distinctive biogeographical areas. *B. laesus* seems to be associated with true steppes, while *B. mocsaryi* lives in woody-steppes and in grasslands, reaching almost to the Arctic Circle in north Russia. Both species seem to have regressed considerably during the last decades. However, since this split has occurred very recently, we do not have reliable data to model these two species separately and thus we consider and model them as a single species.

12.6. *Bombus muscorum* and *B. pereziellus*

Bombus muscorum is a polytypic species with quite numerous distinct allopatric subspecies. Some authors (e.g. Kruseman, 1964) have lumped all the subspecies with black-haired legs in a distinct species for which the priority name would be *B. bannitus*

Skorikov (= *smithianus* auct.). All the taxa associated with *bannitus* are mainly insular, living on the Atlantic littoral from La Coruna, in Spain to Namsos in Norway and in most of the small British islands (but not on the mainland). All taxa associated with *muscorum s.s.* are living on the mainland, more often along the sea coast but also on the continent, and even in central Asia, reaching eastward to Mongolia.

Bombus pereziellus has been described as an endemic Corsican subspecies of *B. muscorum* (under the name *B. cognatus nigripes* Pérez 1909). Later it was considered as a distinct species (Skorikov, 1922), while in the following it was considered to be a subspecies of *B. muscorum* again (Delmas, 1976; Rasmont, 1983). More recently Rasmont & Adamski (1996) considered *pereziellus* as a distinct species. A recent study nevertheless suggested that *pereziellus* is an insular subspecies of *B. muscorum* (Lecocq *et al.* 2014).

Here we assumed that they are conspecific since most of studies considered them as a single species (Løken, 1973; Alford, 1975; Rasmont, 1983; Williams, 1998).

12.7. *Bombus niveatus and B. vorticosus*

Bombus niveatus includes two taxa: *niveatus* Kriechbaumer 1870 and *vorticosus* Gerstaecker, 1872. In Europe (the Balkans, Romania, Ukraine), only the ssp. *vorticosus* occurs. In Turkey, the Caucasian region and Iran, both subspecies *niveatus* and *vorticosus* can be present together. However, while *vorticosus* occurs from sea level in Greece, ssp. *niveatus* only occurs in mountains. Numerous authors considered *vorticosus* to be a distinct species (e.g. Pittioni, 1938). However, these taxa have been more recently considered to be conspecific (Williams, 1998; Rasmont *et al.*, 2005). Following this recent status revision, we assumed here that *vorticosus* is a subspecies of *B. niveatus*.

12.8. *Bombus perezi* and *B. vestalis*

Lecocq *et al.* (2013, 2014) recently considered that *B. perezi* is conspecific with *B. vestalis*. However, several authors have considered *B. perezi* as a distinct species (review in Rasmont & Adamski, 1995). We assumed here that it is a good species. Therefore the distribution of *B. perezi* is not included in our *B. vestalis* modelling.

12.9. *Bombus reinigiellus*

Bombus reinigiellus has been described as a distinct species endemic to the Sierra Nevada (south-east Spain). However, Castro (1987) synonymised it with *B. hortorum* until more material showed that *B. reinigiellus* is a separate species (Castro, 1988). We assumed here that *B. reinigiellus* is a good species.

12.10. *Bombus sichelii* and *B. erzurumensis*

Bombus erzurumensis and *B. sichelii* are two closely related taxa considered as conspecific (Williams 1998) or as distinct species (Rasmont *et al.* 2000). Nevertheless, recent taxonomic revision based on genetic, morphology, and species-specific attractive compounds suggest that the two taxa are conspecific (Lecocq *et al.* in press). We here followed these recent statuses.

12.11. *Bombus handlirschianus* and *B. shaposhnikovi*

These two taxa should be better considered as conspecific (Cameron *et al.* 2007; De Meulemeester *et al.* 2011).

12.12. *Bombus lapponicus, B. monticola* and *B. glacialis*

Bombus lapponicus was considered as a species distinct from *B. monticola* by Svensson (1979) while *B. glacialis* was also regarded as a different species from the two other species by Berezin (1990). We follow these authors and separate these species.

12.13. *Bombus lapidarius* and *B. caucasicus*

Bombus lapidarius included five subspecies (Rasmont 1983; Reinig 1935, 1970; Tkalců 1960): (i) *lapidarius* (L.) in the European plains, Balkans and West Anatolia, (ii) *decipiens* Pérez 1890 in the Iberian Peninsula and in Southern Italy, (iii) *caucasicus* Radoszkowski 1859 in the North East Anatolia and Caucasus, (iv) *eriophorus* Klug 1807 in Caucasus, and (v) *B. lapidarius atlanticus* Benoist 1928 in the Moroccan Atlas. However, recent genetic and eco-chemical studies showed that *caucasicus* is a different species from *B. lapidarius* (Lecocq *et al.* 2013a, *in press*). Nevertheless, *eriophorus* (not studied by Lecocq *et al.* 2013a) and *B. caucasicus* have been considered as two forms of the same taxon by Reinig (1935) while Rasmont (1983) regarded them as two different taxa. If *eriophorus* and *B. caucasicus* are to be considered conspecific, *B. eriophorus* (Klug, 1807) would be the oldest available name for the species. Further analyses on *B. lapidarius eriophorus* and *B. caucasicus* are needed to assess their conspecificity.

12.14. *Bombus barbutellus* and *B. maxillosus*

Bombus barbutellus and *B. maxillosus* were previously considered by most authors as two closely related species (review in Lecocq *et al.* 2011). However, the two taxa have been shown to be conspecific by Lecocq *et al.* (2011). We follow these authors and considered the taxa as conspecific, *Bombus barbutellus* being their senior name.

13. Climate change and bumblebee conservation

13.1 Climatic risks of European bumblebees

Bumblebees are clearly cold-adapted species (Fig. 13.1; Heinrich, 1979). While the mean annual temperature ranges between -3.6°C and 22.1°C with a median value of 9.2°C for the analysed geographic window (Fig. 13.1A), the average temperature requirements of all bumblebee species did not reflect this broad range but are concentrated at intermediate to cold conditions (Fig. 13.1B). Average temperature requirements of the bumblebees were calculated as the mean of the mean annual temperature values across the grid cells in which a particular species occurred. This value is also known as species temperature index (STI; Devictor *et al.*, 2008) and has successfully been used for the assessment of community changes in response to recent climate change (Devictor *et al.*, 2012). The STI values for the European bumblebees range between -1.6°C (*Bombus hyperboreus*) and 10.4°C (*B. ruderatus*) with a median of 7.0°C. The species with the lowest STI values (<5°C) formed a separate group (Fig. 13.1B) and were dominated by boreal and Arctic species with particularly small distributions (Appendix 3). Given these climatic preferences, European bumblebees can be considerably affected by climate warming.

Taking into account their most likely dispersal abilities, we can project the severity of suitable area changes for 2100 (see Appendix 3 for species values). 13 species have not been modelled. In all three scenarios, only 3 species are expected to expand their suitable climatic area. With the less severe scenario (SEDG), 3 species (4%) are expected to loose more than 80% of their suitable area (meaning severe risk of extinction); 27 species (39%) from 50 to 80% of their suitable area and 23 (33%) species from 20 to 50% suitable area lost. With the intermediate scenario (BAMBU), 14 species (20%) should loose more than 80% of suitable area; 33 species (48%) from 50 to 80% of suitable area and 6 species from 20 to 50% lost. For the most extreme scenario (GRAS), as much as 25 species (36%) should loose more than 80% of their suitable area while 28 species (41%) would loose from 50 to 80% of suitable area. This last case means that a total of 77% of the bumblebee species would lose the largest part of their suitable climatic area, with more than a third of the total number of species driven at the verge of extinction.

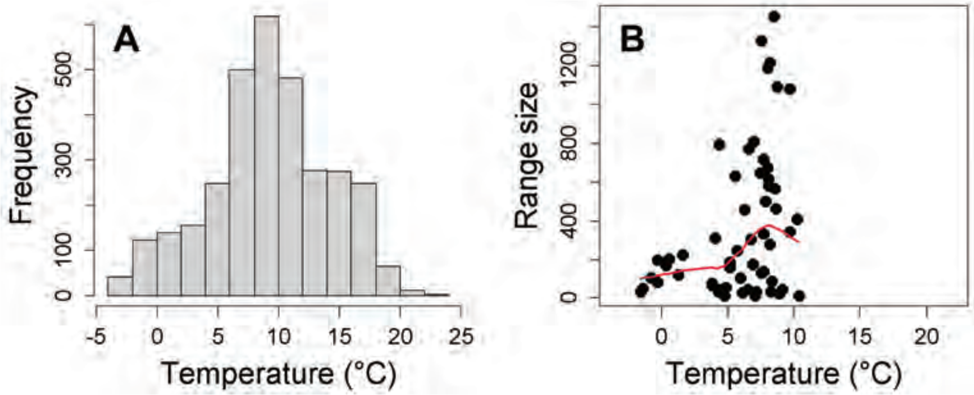


Figure 13.1 Temperature conditions across Europe and climatic requirements of the European bumblebees. (A) Frequency distribution of mean annual temperature at a grid resolution of 50 km x 50 km. (B) Species temperature index (STI) of all modelled bumblebee species and their respective range size in numbers of UTM 50 km grid cells. The species with the lowest STI are Arctic and Boreal species that are the most sensitive to climate warming (see Appendix 3).

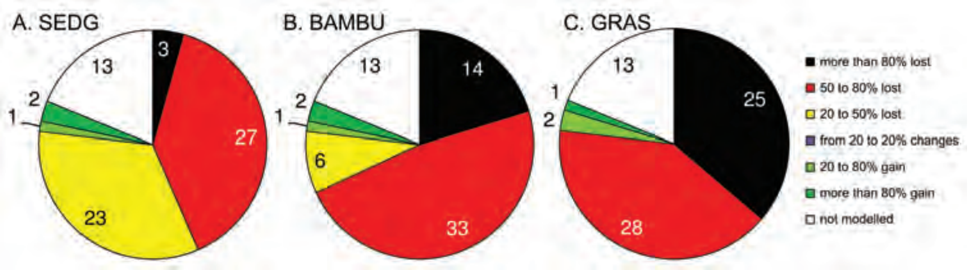


Figure 13.2 Severity of projected changes in 2100 for the 69 studied European bumblebee species. For 21 species we assumed full dispersal, for the remaining no dispersal (see Appendix 3). Thirteen species have not been assessed (white background). Dark green background indicates a large expansion (more than 80% gain in suitable area); light green indicate expansion (between 20 and 80% gain in suitable area); yellow background indicates regression (between 20 and 50% loss of suitable area); red background indicates strong regression (from 50 to 80% loss of suitable area); dark background indicates very strong regression with extinction risk (more than 80% loss of suitable area). A. SEDGE scenario; B. BAMBU scenario; C. GRAS scenario.

13.2. Potential mitigation strategies

As mentioned in chapter 11, the actual response of species to changing climatic conditions depends on whether the species will be able to colonise new climatically suitable areas or can survive, at least for a while, in areas of increasingly unsuitable climatic conditions. These two ways of responding render different conservation actions possible. In principle they should aim at (i) guaranteeing the unrestricted, or even aid, movement of the species through the landscape to new areas, (ii) facilitate the colonisation success in the new areas, (iii) improve habitat conditions and microclimatic protection in the areas indicated to become unsuitable at average.

13.2.1 Are translocations of threatened species possible?

There is an ongoing debate about whether species threatened by climate change should be actively translocated to regions which are projected to become suitable in the near future (Thomas, 2011; Vilà & Hulme, 2011; Webber *et al.*, 2011; Müller & Eriksson, 2013). Thomas (2011) argues that the benefits of translocation will outweigh the associated risks. This point of view has received strong criticism, especially given the experiences from invasion ecology (Webber *et al.* 2011; Vila & Hulme 2011). A further argument concerns the dependency of translocation success on the level of specialisation. Webber *et al.* (2011) argue that the chances of successful translocations are highest for generalist species which do not depend largely on prey or mutualists. However these species are known to be likely to cause severe problems in recipient locations. On the other hand, Müller and Eriksson (2013) concluded in a recent study that translocation can prevent more global extinctions than it can cause and thus claim that translocation should be more widely accepted as a conservation tool.

For most of the threatened species in the Alps or in the Pyrenees, one solution might be to translocate them to the Scandinavian mountains, while for the most threatened arctic species (like *B. alpinus, B. balteatus, B. hyperboreus,* and *B. polaris*), the survival on the European mainland is unlikely. Three of these species nevertheless also occur outside Europe where they may survive in the extreme north of the Siberian Arctic (e.g. Taymir and Anadyr peninsulas), in Alaska, northern Canada or in Greenland. *Bombus alpinus*, on the other hand, is endemic to Europe. Thus disappearance from the European mainland would mean total extinction. To avoid the total extinction of this species, translocation to some northern Archipelagos, like Svalbard, Franz Josef Land or Novaya Zemlya might be a solution.

Undoubtedly, several bumblebee species have already been successfully translocated to different countries or even different continents. At the end of the 19thcentury, four species (*B. terrestris, B. hortorum, B. ruderatus,* and *B. subterraneus*) were moved from England to New Zealand, where they thrive (Buttermore *et al.*, 1998; Goulson *et al.*, 2002; Velthuis, 2002; Goulson & Hanley, 2004; Torretta *et al.*, 2006; Yokoyama & Inoue, 2010). From New Zealand, *B. ruderatus* has then been moved with success to Chile, where it is now more abundant than native species (Goulson & Hanley, 2004). From New Zealand again, some colonies of *B. terrestris* have been moved to Tasmania where the species settled and expanded very rapidly (Buttermore *et al.*, 1998; Goulson *et al.*, 2002). The domestication of *B. terrestris* has led to its translocation to numerous countries where it has successfully established, e.g. in Japan, Argentina and Chile (Torretta *et al.*, 2006; Yokoyama & Inoue, 2010). This species could be even considered as invasive and one could expect that sooner or later, all climatically suitable areas in the world will be colonised by *B. terrestris* (Peredo-Alvarez *et al.* 2014).

The extreme success of *B. terrestris* in invading new areas results from the extremely high number of translocated individuals (hundreds to thousands per event) but also from the high level of adaptability of this species (Rasmont *et al.*, 2008). *Bombus terrestris* is able to produce up to three generations per year, with a very adaptive phenology. It is also one of the most generalist foragers. Very few other bumblebee species share all these characteristics.

Nevertheless, in some cases, successful colonisation could not be supported even by the import of thousands of *B. terrestris* colonies, as has been the case for the Sardinian *B. terrestris sassaricus* which has been exported to areas in Southern France (Ings *et al.*, 2010).

Taking these experiences into account, we can assume that any successful translocation would require moving very large numbers of threatened species to the new targeted area. However, most of the species at high climatic risk are already rare and finding a sufficient number for translocation in the wild would be difficult if not impossible. For instance, for the most threatened *Alpinobombus* species, it would already be difficult to collect even one or two dozens of queens. Further, a recent attempt to reintroduce *B. subterraneus* from New Zealand to England, from where it disappeared, did not succeed (Gammans *et al.*, 2009) and also another try with Swedish strains has not yet proven successful (Sears, 2014).

If we, nevertheless, assume that such translocations can be done, several other problems arise. As the example of *B. terrestris* has shown, translocated species can cause severe disruption to existing ecosystems. Novel species can lead to the reduction of native species when they are better competitors (Stout & Morales, 2009; Nagamitsu *et al.*, 2010), worse pollinators (Kenta *et al.*, 2007) or introduce novel pathogens (Stout & Morales, 2009), and thus put additional pressures on the native bee and plant community which might already be suffering from climate change (Schweiger *et al.*, 2010). Even if the translocated species are readily integrated into the local communities, they may not find their required pollen and nectar plants or preferred nesting sites and material in the new areas. Thus, simple translocations can easily fail unless the ecology of the species with all their relevant resources, and important interactions with other species, are well known and their consequences can be assessed and evaluated.

13.2.2 Supporting species on the move

While species, whose climatically suitable conditions will just retract, such as Alpine species, might depend on active translocations by humans to overcome large areas of hostile climates, there are quite many species whose climatic conditions are projected to move continuously. Such species might be able move along with their suitable climates and thus expand their current ranges. There is evidence that some bumblebee species are able to spread fast and even cross narrow sea channels (Mikkola, 1978). In one of the most famous case, the rapid settlement and expansion of *B. hypnorum* in the UK indicates that this species was able to cross the channel between mainland Europe and the UK (Goulson *et al.*, 2011). However, the ability of species to successfully keep track with climate change depends on the general dispersal ability of the species and, moreover, on the landscape structures that have to be crossed (Hill *et al.*, 1999).

To support bumblebees in keeping track with changing climates the landscapes should be managed in a way that moving bumblebees can find enough and species-specific resources such as wild flowers and nesting sites. Unfortunately, there are large parts of Europe which are heavily dominated by intensive agriculture. In such cases, a shortage of food and additional pressures from pesticides might considerably hamper the ability of the species to move through the landscape and thus follow changing climates. Flower strips as part of European environmental schemes are very likely to support the moving species.

13.2.3 Supporting species at their trailing edge

As mentioned in chapter 12, the projected retractions at the southern and lower altitudinal edges of bumblebee distributions were done for average conditions within a grid cell of 10 min x 10 min. This ignores microclimatic variability due to habitat and topographic heterogeneity. Thus, the areas of loss might be better regarded as deteriorating average conditions which provide some space for successful conservation action. Management in a way that maximises microclimatic heterogeneity could allow some species to survive in micro-refugia, as has been observed with some vertebrate species (Willis & Bhagwat, 2009; Willis *et al.*, 2010; Morelli *et al.*, 2012) or suggested for butterflies (Lawson *et al.*, 2014).

Special attention should also be paid to natural features with major influence on the local microclimate. A very good example is the Forêt de la Sainte-Baume in south-eastern France (Fig. 13.6).Thanks to the shelter of a high cliff, a large beech (*Fagus sylvatica*) and yew (*Taxus baccata*) forest persists there since at least two thousand years (Chalvet 2013), while the surrounding area is characterized by a dry Mediterranean vegetation, deeply impacted by recent droughts (Villa *et al.* 2008). Here *Bombus pratorum* and other rare wild bees can survive (Terzo & Rasmont, 2003), whilst they do not occur in the surrounding area. Most hills and mountains include such areas of potential microrefugia and thus they should be of particular conservation concern and should be monitored with appropriate programmes.

Figure 13.6 The Forêt de la Sainte-Baume, near Marseille (Photo Georges Millet). On the right, the canopy of the beech forest sheltered by the cliff; on the left, the dry Mediterranean vegetation.

Species at their range margins can be particularly sensitive to additional threats apart from climatic limitations (Williams, 1988; Thomas *et al.*, 2001; Williams *et al.*, 2007; Oliver *et al.*, 2009). In such cases, management strategies should aim at reducing additional threats while providing as many micro-refugia as possible. Particularly important threats at the range margins could be malnutrition (due to reduced availability of floral resources) or increased stress (due to pathogens or pesticides). Again, proper management in agricultural areas could contribute enormously to the persistence of bumblebees in areas where the average climatic conditions are projected to get less suitable in the future. Conserving populations at the trailing edge of their distribution can be of particular importance because they can act as long-term stores of species genetic diversity and foci of speciation (Hampe & Petit, 2005).

Bombus alagesianus is a medium to large species that inhabits the steppes of alpine and subalpine levels in east Turkey, north Iran and Caucasian region. It also lives in high steppes of Central Asia. It is a rare species and few are known about its way of life. It presents a typical colour pattern, with yellowish bands and a reddish abdomen tip. Photo P. Rasmont.

Bombus modestus is a small species typical of Siberian taiga where it could be very abundant. In Europe, it only lives in few locations in boreal forest between Moscou and Ural. Its coat colour could be very variable but generally shows a largely yellow thorax and tergites 1 and 2 and with black and grey on the remaining of abdomen. Photo P. Rasmont.

14. Conclusions

Thanks to the EU FP7 project STEP (Potts *et al.* 2011), over one million bumblebee records from all over Europe have been collated. Based on data from 1970 to 2000 we modelled the current climatic niche for almost all European species (56 out of 69) and projected future climatically suitable conditions based on three climate change scenarios (SEDG, BAMBU and GRAS) for the years 2050 and 2100. Due to limited knowledge of actual bumblebee dispersal, we made two extreme assumptions: (i) the species has full dispersal abilities (meaning that the species is able to spread all over its suitable area) or (ii) the species is unable to disperse at all (i.e. that changes in climatic conditions can only lead to projected range retractions; see chapter 6). However, to aid the assessment as to which of these two extreme assumptions are more likely to meet reality, we also provide a rough indication of the species' potential dispersal ability based on the ecology of the different bumblebees.

Since bumblebees are mainly adapted to colder conditions, they appear as highly vulnerable to climate change. In 2100, depending on the scenario of climate change, up to 36% of the European bumblebees are projected to be at an high climatic risk (i.e. losing more than 80% of their current range), 41% will be at risk (loss between 50% and 80%). In addition to the projections of the modelled species, the 13 non-modelled species have a restricted distribution and their ranges are most likely to be shrinking considerably under all of the scenarios. Only three species are projected to benefit from climate change and can potentially enlarge their current distributions in Europe, *B. argillaceus*, *B. haematurus* and *B. niveatus*.

As expected, the three scenarios considered provide considerably different projections for 2100. While under the moderate change scenario (SEDG) only three species are projected to be at the verge of extinction by 2100. 14 species are at a particularly high risk under the intermediate change scenario (BAMBU). Under the most severe change scenario (GRAS) as many as 25 species are projected to lose almost all of their climatically suitable area.

Also the ability to keep track with climate change has a considerable impact of the projected changes. For instance, under the most severe climate change scenario (GRAS) eight species are at an extremely high climatic risk when full dispersal is assumed. However, under the assumption of no dispersal within the next 100 years, 34 species would fall into this category. When potential dispersal abilities, inferred from species traits and their autecologies, are considered to decide for which species no or full dispersal assumptions are more realistic, it seems that three to four species might expand their ranges by 2100, no species is likely to remain at the status quo, and 25 species would be at an extremely high climatic risk.

We also found that for many species (about 30%), especially the cold-adapted ones in Alpine and Arctic regions (e.g. *B. alpinus, B. balteatus, B. hyperboreus* and *B. polaris)* their dispersal abilities are actually irrelevant for the assessment of their future fate because climate change will only lead to reductions of areas with suitable climatic conditions while no extra suitable regions will emerge.

Given the great sensitivity of bumblebees to climate change and further considering the severe projected changes in the light of the great relevance of bumblebees as pollinators, designing management plans to sustain the highest level of pollination services on the one hand and to ensure the survival of as many bumblebee species on the other hand is of utmost importance. Given the different mechanisms leading to change, especially at the leading *versus* the trailing edge of species distributions and the geographical differences in the severity of climate change, management actions must be well and target-specific designed. One important issue would be to prioritise management actions across different geographic regions in Europe. We have seen that the expected species loss due to climate change increases with decreasing latitudes, i.e. that regions in the south of Europe will be most affected by the loss of important pollinators.

Important means to support European bumblebees would be to facilitate the movement of species trying to keep track with changing climates at the trailing edge and to prolong the persistence in regions where climatic conditions are deteriorating. Landscape management can be of particular help in this context. Increased connectivity and quality of bumblebee habitats can help colonising species, while habitat heterogeneity will generate heterogeneity in the microclimate and can thus increase population persistence at the trailing edge as a kind of "Noah's Ark". Areas with naturally high levels of microclimatic heterogeneity (such as mountainous areas) can be of particular importance and deserve special attention. Finally, the idea of assisted migration, i.e. purposeful anthropogenic translocations, seems appealing at first sight for species whose original distributional areas are projected to shrink tremendously and cannot move to suitable areas because of natural or anthropogenic barriers. However, the feasibility of such actions is still questionable.

To conclude, climatic risks for bumblebees can be extremely high, depending on the future development of human society, and the corresponding effects on the climate, strong mitigation strategies are needed to preserve this important species group and to ensure the sustainable provision of pollination services, to which they considerably contribute.

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16. Appendices

Appendix 1. Measures of model performance. AUC, area under the curve; TSS, true skill statistic. Empty cells for non-modelled species.

Species	Range size (50 km grid)	Modelled range size (10' grid)	AUC	Kappa	TSS	Sensitivity	Specificity
Bombus alpinus	86	3918	0.95	0.44	0.86	0.94	0.91
Bombus argillaceus	132	10590	0.86	0.20	0.57	0.83	0.73
Bombus armeniacus	11						
Bombus balteatus	120	4245	0.99	0.60	0.89	0.95	0.94
Bombus barbutellus	525	11104	0.76	0.31	0.41	0.79	0.62
Bombus bohemicus	933	15573	0.81	0.49	0.51	0.84	0.66
Bombus brodmanni	1						
Bombus brodmannicus	4						
Bombus campestris	670	11067	0.77	0.39	0.44	0.77	0.67
Bombus cingulatus	192	5694	0.97	0.70	0.90	0.97	0.93
Bombus confusus	157	7946	0.87	0.28	0.62	0.85	0.78
Bombus consobrinus	127	3536	0.97	0.60	0.80	0.86	0.94
Bombus cryptarum	326	12298	0.72	0.19	0.33	0.69	0.64
Bombus cullumanus	38	4215	0.91	0.14	0.73	0.89	0.84
Bombus deuteronymus	7						
Bombus distinguendus	502	14470	0.81	0.35	0.50	0.89	0.61
Bombus flavidus	221	7513	0.94	0.53	0.78	0.91	0.87
Bombus fragrans	36	5530	0.94	0.15	0.79	0.94	0.85
Bombus gerstaeckeri	52	3324	0.95	0.26	0.83	0.94	0.89
Bombus haematurus	34	6344	0.93	0.12	0.78	0.97	0.81
Bombus hortorum	1331	12958	0.77	0.38	0.40	0.67	0.73
Bombus humilis	707	12183	0.75	0.34	0.39	0.74	0.65
Bombus hyperboreus	33	2736	0.99	0.33	0.91	0.97	0.94
Bombus hypnorum	961	16632	0.80	0.45	0.46	0.80	0.67
Bombus incertus	16	399	1.00	0.58	0.99	1.00	0.99
Bombus inexspectatus	16	1791	0.98	0.15	0.87	0.94	0.93
Bombus jonellus	883	13547	0.90	0.64	0.65	0.85	0.80
Bombus laesus	17						
Bombus lapidarius	1233	14644	0.79	0.47	0.47	0.78	0.69
Bombus lapponicus	206	5976	0.98	0.66	0.88	0.96	0.92

Bombus lucorum	1403	15069	0.82	0.47	0.49	0.74	0.75
Bombus magnus	335	8585	0.85	0.32	0.52	0.82	0.70
Bombus mendax	54	2124	0.97	0.41	0.87	0.93	0.94
Bombus mesomelas	110	7816	0.91	0.20	0.66	0.93	0.73
Bombus mlokosievitzii	5						
Bombus mocsaryi	33						
Bombus monticola	260	7982	0.88	0.42	0.66	0.87	0.79
Bombus mucidus	75	3251	0.95	0.34	0.76	0.85	0.90
Bombus muscorum	625	9854	0.83	0.47	0.53	0.78	0.75
Bombus niveatus	51	5245	0.95	0.22	0.77	0.90	0.87
Bombus norvegicus	349	13218	0.81	0.30	0.49	0.84	0.65
Bombus pascuorum	1559	13543	0.75	0.32	0.38	0.64	0.74
Bombus patagiatus	1						
Bombus perezi	6						
Bombus pereziellus	6						
Bombus polaris	57	3571	0.99	0.44	0.94	1.00	0.94
Bombus pomorum	166	7077	0.85	0.29	0.59	0.80	0.79
Bombus pratorum	1313	18141	0.80	0.49	0.48	0.83	0.65
Bombus pyrenaeus	104	3540	0.93	0.41	0.77	0.88	0.90
Bombus quadricolor	204	8049	0.85	0.32	0.58	0.80	0.79
Bombus reinigiellus	2						
Bombus ruderarius	815	14025	0.75	0.39	0.42	0.79	0.63
Bombus ruderatus	437	11589	0.78	0.29	0.43	0.79	0.63
Bombus rupestris	630	13260	0.78	0.36	0.45	0.85	0.61
Bombus schrencki	37	5446	0.96	0.16	0.82	0.97	0.85
Bombus semenoviellus	61	8366	0.90	0.13	0.67	0.92	0.75
Bombus sichelii	72	2835	0.96	0.38	0.82	0.90	0.91
Bombus soroeensis	727	11912	0.82	0.48	0.50	0.74	0.77
Bombus sporadicus	252	7715	0.97	0.62	0.85	0.96	0.89
Bombus subterraneus	408	10234	0.82	0.38	0.51	0.78	0.73
Bombus sylvarum	793	14117	0.77	0.38	0.41	0.79	0.62
Bombus sylvestris	788	16661	0.78	0.38	0.44	0.88	0.56
Bombus terrestris	1269	17366	0.82	0.53	0.52	0.86	0.66
Bombus vestalis	435	10588	0.79	0.29	0.42	0.78	0.64
Bombus veteranus	346	13147	0.80	0.29	0.50	0.85	0.65
Bombus wurflenii	349	7204	0.89	0.54	0.64	0.77	0.87
Bombus zonatus	28	5669	0.93	0.11	0.74	0.89	0.84

Appendix 2. Projected changes in the number of grid cells with suitable climatic conditions under three climate change scenarios and full and no dispersal assumption for 2050 and 2100

	2050	**2050**	**2050**	**2050**	**2050**	**2050**	**2100**	**2100**	**2100**	**2100**	**2100**	**2100**
	full dispersal	**full dispersal**	**full dispersal**	**no dispersal**	**no dispersal**	**no dispersal**	**full dispersal**	**full dispersal**	**full dispersal**	**no dispersal**	**no dispersal**	**no dispersal**
Species	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**
Bombus alpinus	-1370 (-35%)	-1155 (-29%)	-1223 (-31%)	-1392 (-36%)	-1198 (-31%)	-1249 (-32%)	-3450 (-88%)	-3036 (-77%)	-2241 (-57%)	-3450 (-88%)	-3038 (-78%)	-2246 (-57%)
Bombus argillaceus	5359 (-51%)	4822 (-46%)	5462 (-52%)	-64 (-1%)	-62 (-1%)	-44 (0%)	13428 (-127%)	10980 (-104%)	9724 (-92%)	-193 (-2%)	-184 (-2%)	-22 (0%)
Bombus balteatus	-2061 (-49%)	-1785 (-42%)	-1730 (-41%)	-2070 (-49%)	-1795 (-42%)	-1731 (-41%)	-3973 (-94%)	-3915 (-92%)	-3169 (-75%)	-3982 (-94%)	-3926 (-92%)	-3170 (-75%)
Bombus barbutellus	-4797 (-43%)	-3700 (-33%)	-2840 (-26%)	-5378 (-48%)	-4237 (-38%)	-3398 (-31%)	-7445 (-67%)	-6645 (-60%)	-5475 (-49%)	-9617 (-87%)	-8710 (-78%)	-6665 (-60%)
Bombus bohemicus	-3477 (-22%)	-2978 (-19%)	-3428 (-22%)	-4921 (-32%)	-4378 (-28%)	-4738 (-30%)	-10053 (-65%)	-8245 (-53%)	-7068 (-45%)	-12262 (-79%)	-10482 (-67%)	-8947 (-57%)
Bombus campestris	-3664 (-33%)	-2829 (-26%)	-3086 (-28%)	-4695 (-42%)	-3884 (-35%)	-3971 (-36%)	-7420 (-67%)	-6475 (-59%)	-5989 (-54%)	-9879 (-89%)	-9191 (-83%)	-7633 (-69%)
Bombus cingulatus	-1891 (-33%)	-1774 (-31%)	-1703 (-30%)	-1953 (-34%)	-1835 (-32%)	-1770 (-31%)	-5328 (-94%)	-5093 (-89%)	-3246 (-57%)	-5372 (-94%)	-5141 (-90%)	-3307 (-58%)
Bombus confusus	-2378 (-30%)	-1553 (-20%)	-96 (-1%)	-3729 (-47%)	-2981 (-38%)	-2351 (-30%)	-4501 (-57%)	-5375 (-68%)	-1909 (-24%)	-7807 (-98%)	-7618 (-96%)	-5438 (-68%)
Bombus consobrinus	-1169 (-33%)	-1102 (-31%)	-748 (-21%)	-1534 (-43%)	-1463 (-41%)	-1297 (-37%)	-2898 (-82%)	-2843 (-80%)	-1463 (-41%)	-2999 (-85%)	-2970 (-84%)	-2030 (-57%)
Bombus cryptarum	-4019 (-33%)	-2649 (-22%)	-4901 (-40%)	-5125 (-42%)	-4134 (-34%)	-5753 (-47%)	-9260 (-75%)	-7133 (-58%)	-7183 (-58%)	-9880 (-80%)	-8818 (-72%)	-8112 (-66%)
Bombus cullumanus	-2115 (-50%)	-1813 (-43%)	-1164 (-28%)	-2480 (-59%)	-2139 (-51%)	-1742 (-41%)	-3284 (-78%)	-2885 (-68%)	-2264 (-54%)	-3942 (-94%)	-3543 (-84%)	-2833 (-67%)

	2050	2050	2050	2050	2050	2050	2100	2100	2100	2100	2100	2100
	full dispersal	**full dispersal**	**full dispersal**	**no dispersal**	**no dispersal**	**no dispersal**	**full dispersal**	**full dispersal**	**full dispersal**	**no dispersal**	**no dispersal**	**no dispersal**
Species	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**
Bombus distinguendus	-4122 (-28%)	-3580 (-25%)	-3944 (-27%)	-6530 (-45%)	-5813 (-40%)	-6096 (-42%)	-9252 (-64%)	-8038 (-56%)	-6589 (-46%)	-12608 (-87%)	-11484 (-79%)	-9656 (-67%)
Bombus flavidus	-1682 (-22%)	-1470 (-20%)	-1814 (-24%)	-1684 (-22%)	-1473 (-20%)	-1814 (-24%)	-6354 (-85%)	-5189 (-69%)	-3730 (-50%)	-6354 (-85%)	-5189 (-69%)	-3730 (-50%)
Bombus fragrans	1966 (-36%)	1807 (-33%)	1690 (-31%)	-670 (-12%)	-526 (-10%)	-510 (-9%)	-2777 (-50%)	-1572 (-28%)	1365 (-25%)	-5446 (-98%)	-4791 (-87%)	-1900 (-34%)
Bombus gerstaeckeri	-1028 (-31%)	-871 (-26%)	-696 (-21%)	-1277 (-38%)	-1085 (-33%)	-938 (-28%)	-1518 (-46%)	-1511 (-45%)	-1048 (-32%)	-2448 (-74%)	-2134 (-64%)	-1661 (-50%)
Bombus haematurus	4826 (-76%)	4074 (-64%)	4869 (-77%)	-1096 (-17%)	-947 (-15%)	-554 (-9%)	3527 (-56%)	5095 (-80%)	5935 (-94%)	-5110 (-81%)	-4404 (-69%)	-2396 (-38%)
Bombus hortorum	-4822 (-37%)	-3873 (-30%)	-3837 (-30%)	-5269 (-41%)	-4378 (-34%)	-4439 (-34%)	-7997 (-62%)	-7078 (-55%)	-6009 (-46%)	-9146 (-71%)	-8391 (-65%)	-7072 (-55%)
Bombus humilis	-3132 (-26%)	-2576 (-21%)	-1972 (-16%)	-4100 (-34%)	-3545 (-29%)	-2957 (-24%)	-7980 (-66%)	-6893 (-57%)	-4350 (-36%)	-10623 (-87%)	-9741 (-80%)	-6223 (-51%)
Bombus hyperboreus	-1496 (-55%)	-1311 (-48%)	-1382 (-51%)	-1496 (-55%)	-1313 (-48%)	-1384 (-51%)	-2688 (-98%)	-2584 (-94%)	-2217 (-81%)	-2688 (-98%)	-2584 (-94%)	-2217 (-81%)
Bombus hypnorum	-4179 (-25%)	-3815 (-23%)	-4461 (-27%)	-4435 (-27%)	-4073 (-24%)	-4719 (-28%)	-11766 (-71%)	-10118 (-61%)	-9007 (-54%)	-12022 (-72%)	-10374 (-62%)	-9265 (-56%)
Bombus incertus	-65 (-16%)	-68 (-17%)	79 (-20%)	-372 (-93%)	-359 (-90%)	-294 (-74%)	-314 (-79%)	-346 (-87%)	195 (-49%)	-399 (-100%)	-399 (-100%)	-373 (-93%)
Bombus inexspectatus	-329 (-18%)	-266 (-15%)	-258 (-14%)	-703 (-39%)	-615 (-34%)	-568 (-32%)	-918 (-51%)	-745 (-42%)	-766 (-43%)	-1417 (-79%)	-1215 (-68%)	-1070 (-60%)
Bombus jonellus	-4991 (-37%)	-4523 (-33%)	-4648 (-34%)	-4991 (-37%)	-4525 (-33%)	-4650 (-34%)	-9463 (-70%)	-8131 (-60%)	-6509 (-48%)	-9463 (-70%)	-8131 (-60%)	-6509 (-48%)

	2050	**2050**	**2050**	**2050**	**2050**	**2050**	**2100**	**2100**	**2100**	**2100**	**2100**	**2100**
	full dispersal	**full dispersal**	**full dispersal**	**no dispersal**	**no dispersal**	**no dispersal**	**full dispersal**	**full dispersal**	**full dispersal**	**no dispersal**	**no dispersal**	**no dispersal**
Species	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**
Bombus lapidarius	-665 (-5%)	-217 (-1%)	-961 (-7%)	-3388 (-23%)	-2794 (-19%)	-2927 (-20%)	-8604 (-59%)	-5793 (-40%)	-5632 (-38%)	-12780 (-87%)	-11052 (-75%)	-7924 (-54%)
Bombus lapponicus	-2299 (-38%)	-2146 (-36%)	-1977 (-33%)	-2301 (-39%)	-2148 (-36%)	-1978 (-33%)	-5177 (-87%)	-5051 (-85%)	-3544 (-59%)	-5184 (-87%)	-5052 (-85%)	-3555 (-59%)
Bombus lucorum	-6237 (-41%)	-5127 (-34%)	-4788 (-32%)	-6618 (-44%)	-5672 (-38%)	-5700 (-38%)	-10491 (-70%)	-9468 (-63%)	-7065 (-47%)	-10652 (-71%)	-9913 (-66%)	-8143 (-54%)
Bombus magnus	-2508 (-29%)	-1811 (-21%)	-2072 (-24%)	-2986 (-35%)	-2263 (-26%)	-2468 (-29%)	-5312 (-62%)	-4658 (-54%)	-4401 (-51%)	-6321 (-74%)	-5682 (-66%)	-5029 (-59%)
Bombus mendax	-533 (-25%)	-466 (-22%)	-376 (-18%)	-855 (-40%)	-760 (-36%)	-673 (-32%)	-1162 (-55%)	-975 (-46%)	-751 (-35%)	-1676 (-79%)	-1403 (-66%)	-1158 (-55%)
Bombus mesomelas	-1994 (-26%)	-2049 (-26%)	-1095 (-14%)	-3145 (-40%)	-2902 (-37%)	-2343 (-30%)	-4136 (-53%)	-2782 (-36%)	-1268 (-16%)	-5983 (-77%)	-4745 (-61%)	-3540 (-45%)
Bombus monticola	-2508 (-31%)	-2143 (-27%)	-2525 (-32%)	-2602 (-33%)	-2228 (-28%)	-2607 (-33%)	-5777 (-72%)	-4916 (-62%)	-4556 (-57%)	-5915 (-74%)	-5019 (-63%)	-4616 (-58%)
Bombus mucidus	-737 (-23%)	-687 (-21%)	-543 (-17%)	-1165 (-36%)	-1063 (-33%)	-898 (-28%)	-1730 (-53%)	-1423 (-44%)	-928 (-29%)	-2435 (-75%)	-2013 (-62%)	-1583 (-49%)
Bombus muscorum	-5536 (-56%)	-4701 (-48%)	-3358 (-34%)	-5851 (-59%)	-5058 (-51%)	-4076 (-41%)	-7080 (-72%)	-6775 (-69%)	-5816 (-59%)	-8470 (-86%)	-7926 (-80%)	-6990 (-71%)
Bombus niveatus	2136 (-41%)	1732 (-33%)	2788 (-53%)	-1226 (-23%)	-1107 (-21%)	-523 (-10%)	1544 (-29%)	2198 (-42%)	2999 (-57%)	-4586 (-87%)	-4381 (-84%)	-2442 (-47%)
Bombus norvegicus	-2194 (-17%)	-1855 (-14%)	-2916 (-22%)	-3692 (-28%)	-3401 (-26%)	-4101 (-31%)	-8510 (-64%)	-6761 (-51%)	-6528 (-49%)	-10611 (-80%)	-9412 (-71%)	-8345 (-63%)
Bombus pascuorum	-2443 (-18%)	-1713 (-13%)	-2887 (-21%)	-2898 (-21%)	-2283 (-17%)	-3135 (-23%)	-8253 (-61%)	-6228 (-46%)	-5916 (-44%)	-8912 (-66%)	-7477 (-55%)	-6230 (-46%)

	2050	2050	2050	2050	2050	2050	2100	2100	2100	2100	2100	2100
	full dispersal	**full dispersal**	**full dispersal**	**no dispersal**	**no dispersal**	**no dispersal**	**full dispersal**	**full dispersal**	**full dispersal**	**no dispersal**	**no dispersal**	**no dispersal**
Species	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**	**GRAS**	**BAMBU**	**SEDG**
Bombus polaris	-2184 (-61%)	-1955 (-55%)	-2038 (-57%)	-2184 (-61%)	-1955 (-55%)	-2038 (-57%)	-3524 (-99%)	-3459 (-97%)	-3115 (-87%)	-3524 (-99%)	-3459 (-97%)	-3115 (-87%)
Bombus pomorum	-3591 (-51%)	-2474 (-35%)	-725 (-10%)	-4387 (-62%)	-3374 (-48%)	-2315 (-33%)	-4716 (-67%)	-5335 (-75%)	-2711 (-38%)	-6952 (-98%)	-6856 (-97%)	-5304 (-75%)
Bombus pratorum	-5418 (-30%)	-4056 (-22%)	-4998 (-28%)	-5445 (-30%)	-4134 (-23%)	-5105 (-28%)	-13243 (-73%)	-10864 (-60%)	-9377 (-52%)	-13244 (-73%)	-10896 (-60%)	-9472 (-52%)
Bombus pyrenaeus	-934 (-26%)	-826 (-23%)	-633 (-18%)	-1208 (-34%)	-1048 (-30%)	-911 (-26%)	-1335 (-38%)	-1457 (-41%)	-862 (-24%)	-2512 (-71%)	-2239 (-63%)	-1582 (-45%)
Bombus quadricolor	-437 (-5%)	-226 (-3%)	-1720 (-21%)	-2501 (-31%)	-2354 (-29%)	-3178 (-39%)	-4116 (-51%)	-2654 (-33%)	-3503 (-44%)	-6773 (-84%)	-6245 (-78%)	-5388 (-67%)
Bombus ruderarius	-4244 (-30%)	-3278 (-23%)	-3198 (-23%)	-6095 (-43%)	-5194 (-37%)	-4853 (-35%)	-9443 (-67%)	-7976 (-57%)	-7605 (-54%)	-13187 (-94%)	-12331 (-88%)	-10123 (-72%)
Bombus ruderatus	-4390 (-38%)	-3780 (-33%)	-1753 (-15%)	-5409 (-47%)	-4647 (-40%)	-3339 (-29%)	-6912 (-60%)	-6148 (-53%)	-3739 (-32%)	-9029 (-78%)	-8045 (-69%)	-5636 (-49%)
Bombus rupestris	-3760 (-28%)	-2813 (-21%)	-2660 (-20%)	-5122 (-39%)	-4221 (-32%)	-3886 (-29%)	-9631 (-73%)	-8170 (-62%)	-6702 (-51%)	-12224 (-92%)	-11149 (-84%)	-8699 (-66%)
Bombus schrencki	-2244 (-41%)	-1908 (-35%)	-1266 (-23%)	-3528 (-65%)	-3001 (-55%)	-2674 (-49%)	-2729 (-50%)	-2611 (-48%)	-2674 (-49%)	-5381 (-99%)	-5357 (-98%)	-4814 (-88%)
Bombus semenoviellus	-4893 (-58%)	-3839 (-46%)	-2546 (-30%)	-5675 (-68%)	-4571 (-55%)	-3461 (-41%)	-6236 (-75%)	-6230 (-74%)	-5467 (-65%)	-8112 (-97%)	-8060 (-96%)	-7066 (-84%)
Bombus sichelii	-734 (-26%)	-649 (-23%)	-530 (-19%)	-1026 (-36%)	-936 (-33%)	-788 (-28%)	-1693 (-60%)	-1373 (-48%)	-1060 (-37%)	-2189 (-77%)	-1871 (-66%)	-1401 (-49%)

	2050	2050	2050	2050	2050	2050	2100	2100	2100	2100	2100	2100
	full dispersal	**full dispersal**	**full dispersal**	**no dispersal**	**no dispersal**	**no dispersal**	**full dispersal**	**full dispersal**	**full dispersal**	**no dispersal**	**no dispersal**	**no dispersal**
Species	**GRAS**	**BAM-BU**	**SEDG**	**GRAS**	**BAM-BU**	**SEDG**	**GRAS**	**BAM-BU**	**SEDG**	**GRAS**	**BAM-BU**	**SEDG**
Bombus soroeensis	-3263 (-27%)	-2469 (-21%)	-3124 (-26%)	-4080 (-34%)	-3557 (-30%)	-3842 (-32%)	-6786 (-57%)	-5480 (-46%)	-4843 (-41%)	-8639 (-73%)	-7942 (-67%)	-6530 (-55%)
Bombus sporadicus	-1905 (-25%)	-1717 (-22%)	-1755 (-23%)	-2108 (-27%)	-1925 (-25%)	-1959 (-25%)	-6115 (-79%)	-5039 (-65%)	-3177 (-41%)	-6297 (-82%)	-5230 (-68%)	-3390 (-44%)
Bombus subterraneus	-4143 (-40%)	-3325 (-32%)	-2525 (-25%)	-5176 (-51%)	-4361 (-43%)	-3581 (-35%)	-7375 (-72%)	-6813 (-67%)	-5580 (-55%)	-9829 (-96%)	-9423 (-92%)	-7568 (-74%)
Bombus sylvarum	-3142 (-22%)	-2491 (-18%)	-1516 (-11%)	-4487 (-32%)	-3809 (-27%)	-2939 (-21%)	-9627 (-68%)	-8115 (-57%)	-4674 (-33%)	-12672 (-90%)	-11430 (-81%)	-7026 (-50%)
Bombus sylvestris	-2495 (-15%)	-1806 (-11%)	-2987 (-18%)	-3972 (-24%)	-3326 (-20%)	-4056 (-24%)	-10840 (-65%)	-8279 (-50%)	-8233 (-49%)	-12613 (-76%)	-10659 (-64%)	-9527 (-57%)
Bombus terrestris	-4286 (-25%)	-3701 (-21%)	-2478 (-14%)	-4985 (-29%)	-4390 (-25%)	-3367 (-19%)	-9711 (-56%)	-7609 (-44%)	-5851 (-34%)	-12309 (-71%)	-10351 (-60%)	-7192 (-41%)
Bombus vestalis	-2386 (-23%)	-2114 (-20%)	-1785 (-17%)	-3061 (-29%)	-2715 (-26%)	-2542 (-24%)	-7026 (-66%)	-5663 (-53%)	-3824 (-36%)	-8897 (-84%)	-7681 (-73%)	-4744 (-45%)
Bombus veteranus	-2504 (-19%)	-1978 (-15%)	-2014 (-15%)	-4345 (-33%)	-3606 (-27%)	-3666 (-28%)	-7006 (-53%)	-6070 (-46%)	-3567 (-27%)	-11487 (-87%)	-10474 (-80%)	-6973 (-53%)
Bombus wurflenii	-1893 (-26%)	-1712 (-24%)	-1470 (-20%)	-2031 (-28%)	-1850 (-26%)	-1685 (-23%)	-3809 (-53%)	-3428 (-48%)	-2263 (-31%)	-4123 (-57%)	-3731 (-52%)	-2669 (-37%)
Bombus zonatus	2696 (-48%)	2155 (-38%)	2940 (-52%)	-965 (-17%)	-856 (-15%)	-525 (-9%)	1347 (-24%)	2334 (-41%)	3457 (-61%)	-4756 (-84%)	-4520 (-80%)	-2324 (-41%)

Appendix 3. Species characteristics and projected changes (in percent of modelled number of occupied 10 min grid cells) under three climate change scenarios and full and no dispersal assumption for 2050 and 2100.

Species	**Model**	**Taxonomical issues**	**IUCN status 2014**	**Traits**	**STI: Species Temperature Index (°C)**	**Number of records in the database across the study area**	**Number of records in the database for 1970 - 2000**	**Range size (number of 50km grid units)**	**Range size (number of 50km grid units) 1970 - 2000**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
B. alpinus	**Yes**		Vulnerable	**S**	-0.3	1212	311	110	86
B. argillaceus	**Yes**		Least Concern	**P**	8.3	2044	556	228	132
B. armeniacus	**No**		Endangered	**P**	7.6 *	442	37	41	11
B. balteatus	**Yes**		Least Concern	**S**	-0.8	1570	406	127	120
B. barbutellus	**Yes**		Least Concern	**I**	8.6	5873	2091	742	525
B. bohemicus	**Yes**		Least Concern	**I**	6.9	20064	5687	1064	933
B. brodmanni	**No**		Not Evaluated	**P**	6.2*	2	1	1	1
B. brodmannicus	**No**		Endangered	**S**	4.5*	391	201	8	4
B. campestris	**Yes**		Least Concern	**I**	8.5	10277	3219	900	670
B. cingulatus	**Yes**		Least Concern	**S**	0.3	959	539	197	192
B. confusus	**Yes**	**X**	Vulnerable	**U**	7.6	2656	331	456	157
B. consobrinus	**Yes**		Least Concern	**P**	1.2	1621	420	131	127
B. cryptarum	**Yes**	**X**	Least Concern	**S**	6.9	7746	2397	476	326
B. cullumanus	**Yes**	**X**	Critically Endangered	**S**	7.1	578	105	80	38
B. deuteronymus	**No**	**X**	Data Deficient	**P**	9.5*	97	5	21	7
B. distinguendus	**Yes**		Vulnerable	**P**	6.3	9275	2059	673	502
B. flavidus	**Yes**		Least Concern	**I**	0.6	1582	739	241	221
B. fragrans	**Yes**		Endangered	**P**	8.2	468	46	73	36
B. gerstaeckeri	**Yes**		Vulnerable	**P**	4.3	1781	526	72	52
B. haematurus	**Yes**		Least Concern	**S**	10.4	355	102	56	34
B. hortorum	**Yes**		Least Concern	**P**	8.2	50898	18785	1547	1331
B. humilis	**Yes**		Least Concern	**P**	8.1	20663	5600	951	707
B. hyperboreus	**Yes**		Vulnerable	**I**	-1.6	250	117	38	33
B. hypnorum	**Yes**		Least Concern	**S**	6.6	24224	5849	1121	961
B. incertus	**Yes**		Not Evaluated	**S**	7.1	48	46	18	16
B. inexspectatus	**Yes**		Endangered	**I**	4.7	275	59	28	16
B. jonellus	**Yes**		Least Concern	**S**	4.4	18666	5999	1024	883
B. laesus	**No**	**X**	Near Threatened	**P**	7.2*	472	14	52	17

Full dispersal						No dispersal						Most realistic dispersal assumption
2050			2100			2050			2100			
SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	
(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
-31.21	-29.48	-34.97	-57.2	-77.49	-88.06	-31.88	-30.58	-35.53	-57.33	-77.54	-88.06	No
51.58	45.53	50.6	91.82	103.68	126.8	-0.42	-0.59	-0.6	-0.21	-1.74	-1.82	Full
												No
-40.75	-42.05	-48.55	-74.65	-92.23	-93.59	-40.78	-42.29	-48.76	-74.68	-92.49	-93.8	No
-25.58	-33.32	-43.2	-49.31	-59.84	-67.05	-30.6	-38.16	-48.43	-60.02	-78.44	-86.61	No
-22.01	-19.12	-22.33	-45.39	-52.94	-64.55	-30.42	-28.11	-31.6	-57.45	-67.31	-78.74	Full
												No
												No
-27.88	-25.56	-33.11	-54.12	-58.51	-67.05	-35.88	-35.1	-42.42	-68.97	-83.05	-89.27	Full
-29.91	-31.16	-33.21	-57.01	-89.45	-93.57	-31.09	-32.23	-34.3	-58.08	-90.29	-94.34	No
-1.21	-19.54	-29.93	-24.02	-67.64	-56.64	-29.59	-37.52	-46.93	-68.44	-95.87	-98.25	No
-21.15	-31.17	-33.06	-41.37	-80.4	-81.96	-36.68	-41.37	-43.38	-57.41	-83.99	-84.81	No
-39.85	-21.54	-32.68	-58.41	-58	-75.3	-46.78	-33.62	-41.67	-65.96	-71.7	-80.34	No
-27.62	-43.01	-50.18	-53.71	-68.45	-77.91	-41.33	-50.75	-58.84	-67.21	-84.06	-93.52	No
												No
-27.26	-24.74	-28.49	-45.54	-55.55	-63.94	-42.13	-40.17	-45.13	-66.73	-79.36	-87.13	No
-24.14	-19.57	-22.39	-49.65	-69.07	-84.57	-24.14	-19.61	-22.41	-49.65	-69.07	-84.57	No
30.56	32.68	35.55	24.68	-28.43	-50.22	-9.22	-9.51	-12.12	-34.36	-86.64	-98.48	No
-20.94	-26.2	-30.93	-31.53	-45.46	-45.67	-28.22	-32.64	-38.42	-49.97	-64.2	-73.65	No
76.75	64.22	76.07	93.55	80.31	55.6	-8.73	-14.93	-17.28	-37.77	-69.42	-80.55	Full
-29.61	-29.89	-37.21	-46.37	-54.62	-61.71	-34.26	-33.79	-40.66	-54.58	-64.76	-70.58	Full
-16.19	-21.14	-25.71	-35.71	-56.58	-65.5	-24.27	-29.1	-33.65	-51.08	-79.96	-87.2	No
-50.51	-47.92	-54.68	-81.03	-94.44	-98.25	-50.58	-47.99	-54.68	-81.03	-94.44	-98.25	No
-26.82	-22.94	-25.13	-54.15	-60.83	-70.74	-28.37	-24.49	-26.67	-55.71	-62.37	-72.28	Full
19.8	-17.04	-16.29	48.87	-86.72	-78.7	-73.68	-89.97	-93.23	-93.48	-100	-100	Unset
-14.41	-14.85	-18.37	-42.77	-41.6	-51.26	-31.71	-34.34	-39.25	-59.74	-67.84	-79.12	No
-34.31	-33.39	-36.84	-48.05	-60.02	-69.85	-34.32	-33.4	-36.84	-48.05	-60.02	-69.85	Full
												No

Species	Model	Taxonomical issues	IUCN status 2014	Traits	STI: Species Temperature Index (°C)	Number of records in the database across the study area	Number of records in the database for 1970 - 2000	Range size (number of 50km grid units)	Range size (number of 50km grid units) 1970 - 2000
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
B. lapidarius	**Yes**		Least Concern	**S**	8.7	96599	31334	1471	1233
B. lapponicus	**Yes**		Least Concern	**S**	-0.3	6041	1012	203	206
B. lucorum	**Yes**	**X**	Least Concern	**S**	7.5	96089	38911	1596	1403
B. magnus	**Yes**	**X**	Least Concern	**S**	8.2	5223	1901	380	335
B. mendax	**Yes**		Near Threatened	**H**	4.2	5383	1075	88	54
B. mesomelas	**Yes**		Least Concern	**P**	6.0	5531	1649	203	110
B. mlokosievitzii	**No**		Data Deficient	**P**	6.8*	140	87	14	5
B. mocsaryi	**No**	**X**	Endangered	**P**	10.1*	443	127	111	33
B. monticola	**Yes**		Least Concern	**S**	5.2	10542	4479	331	260
B. mucidus	**Yes**		Near Threatened	**P**	4.8	2359	795	110	75
B. muscorum	**Yes**	**X**	Vulnerable	**P**	8.1	12681	4080	906	625
B. niveatus	**Yes**	**X**	Least Concern	**S**	9.1	1212	259	92	51
B. norvegicus	**Yes**		Least Concern	**I**	5.7	2303	670	405	349
B. pascuorum	**Yes**		Least Concern	**P**	8.5	161903	53907	1800	1559
B. patagiatus	**No**		Data Deficient	**S**	2.8*	1	1	1	1
B. perezi	**No**	**X**	Least Concern	**I**	12.6*	241	143	8	6
B. pereziellus	**No**	**X**	Least Concern	**P**	13.1*	215	81	7	6
B. polaris	**Yes**		Least Concern	**S**	-1.4	450	139	77	57
B. pomorum	**Yes**		Vulnerable	**P**	7.7	3628	642	375	166
B. pratorum	**Yes**		Least Concern	**S**	8.0	69762	22111	1498	1313
B. pyrenaeus	**Yes**		Least Concern	**S**	3.8	7176	2057	133	104
B. quadricolor	**Yes**		Least Concern	**I**	5.2	1806	365	303	204
B. reinigiellus	**No**	**X**	Endangered	**P**	13.1*	57	43	2	2
B. renardi	**No**	**X**	Not Evaluated	**S**	**	598	230	8	5
B. ruderarius	**Yes**		Least Concern	**P**	7.7	23146	9436	1021	815
B. ruderatus	**Yes**	**X**	Least Concern	**P**	10.2	9009	3828	673	437
B. rupestris	**Yes**		Least Concern	**I**	7.8	10731	2900	877	630
B. schrencki	**Yes**		Least Concern	**P**	6.1	2280	529	44	37
B. semenoviellus	**Yes**		Least Concern	**S**	6.5	310	99	65	61
B. sichelii	**Yes**		Least Concern	**S**	3.8	6905	2150	92	72
B. soroeensis	**Yes**		Least Concern	**S**	5.5	28820	7034	972	727
B. sporadicus	**Yes**		Least Concern	**S**	1.6	2366	581	268	252

Full dispersal						No dispersal						Most realistic dispersal assumption
2050			2100			2050			2100			
SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	
(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
-6.56	-1.48	-4.54	-38.46	-39.56	-58.75	-19.99	-19.08	-23.14	-54.11	-75.47	-87.27	Full
-33.08	-35.91	-38.47	-59.3	-84.52	-86.63	-33.1	-35.94	-38.5	-59.49	-84.54	-86.75	No
-31.77	-34.02	-41.39	-46.88	-62.83	-69.62	-37.83	-37.64	-43.92	-54.04	-65.78	-70.69	Full
-24.14	-21.09	-29.21	-51.26	-54.26	-61.88	-28.75	-26.36	-34.78	-58.58	-66.19	-73.63	No
-17.7	-21.94	-25.09	-35.36	-45.9	-54.71	-31.69	-35.78	-40.25	-54.52	-66.05	-78.91	No
-14.01	-26.22	-25.51	-16.22	-35.59	-52.92	-29.98	-37.13	-40.24	-45.29	-60.71	-76.55	No
												No
												No
-31.63	-26.85	-31.42	-57.08	-61.59	-72.38	-32.66	-27.91	-32.6	-57.83	-62.88	-74.1	No
-16.7	-21.13	-22.67	-28.55	-43.77	-53.21	-27.62	-32.7	-35.84	-48.69	-61.92	-74.9	No
-34.08	-47.71	-56.18	-59.02	-68.75	-71.85	-41.36	-51.33	-59.38	-70.94	-80.43	-85.95	No
53.16	33.02	40.72	57.18	41.91	29.44	-9.97	-21.11	-23.37	-46.56	-83.53	-87.44	Full
-22.06	-14.03	-16.6	-49.39	-51.15	-64.38	-31.03	-25.73	-27.93	-63.13	-71.21	-80.28	No
-21.32	-12.65	-18.04	-43.68	-45.99	-60.94	-23.15	-16.86	-21.4	-46	-55.21	-65.81	Full
												Unset
												No
												No
-57.07	-54.75	-61.16	-87.23	-96.86	-98.68	-57.07	-54.75	-61.16	-87.23	-96.86	-98.68	No
-10.24	-34.96	-50.74	-38.31	-75.39	-66.64	-32.71	-47.68	-61.99	-74.95	-96.88	-98.23	No
-27.55	-22.36	-29.87	-51.69	-59.89	-73	-28.14	-22.79	-30.01	-52.21	-60.06	-73.01	Full
-17.88	-23.33	-26.38	-24.35	-41.16	-37.71	-25.73	-29.6	-34.12	-44.69	-63.25	-70.96	No
-21.37	-2.81	-5.43	-43.52	-32.97	-51.14	-39.48	-29.25	-31.07	-66.94	-77.59	-84.15	No
												No
												No
-22.8	-23.37	-30.26	-54.22	-56.87	-67.33	-34.6	-37.03	-43.46	-72.18	-87.92	-94.02	Full
-15.13	-32.62	-37.88	-32.26	-53.05	-59.64	-28.81	-40.1	-46.67	-48.63	-69.42	-77.91	Full
-20.06	-21.21	-28.36	-50.54	-61.61	-72.63	-29.31	-31.83	-38.63	-65.6	-84.08	-92.19	Unset
-23.25	-35.03	-41.2	-49.1	-47.94	-50.11	-49.1	-55.1	-64.78	-88.4	-98.37	-98.81	Full
-30.43	-45.89	-58.49	-65.35	-74.47	-74.54	-41.37	-54.64	-67.83	-84.46	-96.34	-96.96	Full
-18.69	-22.89	-25.89	-37.39	-48.43	-59.72	-27.8	-33.02	-36.19	-49.42	-66	-77.21	No
-26.23	-20.73	-27.39	-40.66	-46	-56.97	-32.25	-29.86	-34.25	-54.82	-66.67	-72.52	Full
-22.75	-22.26	-24.69	-41.18	-65.31	-79.26	-25.39	-24.95	-27.32	-43.94	-67.79	-81.62	No

Species	Model	Taxonomical issues	IUCN status 2014	Traits	STI: Species Temperature Index (°C)	Number of records in the database across the study area	Number of records in the database for 1970 - 2000	Range size (number of 50km grid units)	Range size (number of 50km grid units) 1970 - 2000
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
B. subterraneus	**Yes**		Least Concern	**P**	7.7	7033	1434	634	408
B. sylvarum	**Yes**		Least Concern	**P**	8.0	21315	6954	1052	793
B. sylvestris	**Yes**		Least Concern	**I**	7.5	12950	4230	911	788
B. terrestris	**Yes**	**X**	Least Concern	**S**	9.7	101871	38048	1528	1269
B. vestalis	**Yes**		Least Concern	**I**	9.6	8044	3470	583	435
B. veteranus	**Yes**		Least Concern	**P**	6.7	7629	1868	487	346
B. wurflenii	**Yes**		Least Concern	**S**	4.1	25283	5610	504	349
B. xanthopus	**No**	**X**	Not Evaluated	**S**	**	2359	1457	13	10
B. zonatus	**Yes**		Endangered	**P**	8.9	290	104	67	28

(2) See chapter 7

(3) See chapter 12

(4) See Rasmont et al. (2014)

(5) H=Honey-comb maker, I=Inquiline, P=Pocket-maker, S=Pollen-storer, U=Unknown

(6) STI (Species Temperature Index, Devictor et al. 2008); *= indicative value to assess potential response of non-modelled species; **= not computed; STI under 5°C are in red; See chapter 13.

(7-8) Number of specimens in the modelling frame (latitude from 35° to 72°N; longitude from -12°W to 32°E), 30.XII.2014

(11) to (22) See chapter 6

(23) See chapter 8

Full dispersal						No dispersal						Most realistic dispersal assumption
2050			2100			2050			2100			
SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	SEDG	BAMBU	GRAS	
(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
-24.67	-32.49	-40.48	-54.52	-66.57	-72.06	-34.99	-42.61	-50.58	-73.95	-92.08	-96.04	No
-10.74	-17.65	-22.26	-33.11	-57.48	-68.19	-20.82	-26.98	-31.78	-49.77	-80.97	-89.76	Full
-17.93	-10.84	-14.98	-49.41	-49.69	-65.06	-24.34	-19.96	-23.84	-57.18	-63.98	-75.7	Full
-14.27	-21.31	-24.68	-33.69	-43.82	-55.92	-19.39	-25.28	-28.71	-41.41	-59.6	-70.88	Full
-16.86	-19.97	-22.53	-36.12	-53.49	-66.36	-24.01	-25.64	-28.91	-44.81	-72.54	-84.03	Full
-15.32	-15.05	-19.05	-27.13	-46.17	-53.29	-27.88	-27.43	-33.05	-53.04	-79.67	-87.37	No
-20.41	-23.76	-26.28	-31.41	-47.58	-52.87	-23.39	-25.68	-28.19	-37.05	-51.79	-57.23	No
												No
51.86	38.01	47.56	60.98	41.17	23.76	-9.26	-15.1	-17.02	-40.99	-79.73	-83.89	Unset

Bombus portschinsky is a large species endemic to east Turkey, north Iran and Caucasian region, where it lives mainly at forest-edges of subalpine level. It forages mainly flowers with long corolla, like *Aconitum* spp. or the endemic *Lallemantia canescens*. Its colour closely recalls the very common *Bombus hortorum* but here with greyish bands instead of yellow. Photo P. Rasmont.

Bombus saltuarius is a species that only lives in Europe in the north-east of Russia: the Pechora basin and the Ural mountains where it seems extremely rare. It could be found here and there in Siberia, Mongolia and north China. Nothing is known about its way of life. Photo P. Rasmont.

17. Distribution maps of West-Palaearctic bumblebees

Bombus caucasicus is a species endemic to mountain forests of Caucasian region. It has been very recently resurrected to the species status. Photo P. Rasmont.

Bombus melanurus is a very large high mountain species that occurs in the whole Central Asia. To the west, it reaches Caucasus and eastern Turkey. Photo P. Rasmont.

Bombus velox is a small species endemic to east Turkey and Caucasian region, where it is very rare, with a patchy distribution. Its thorax is grey with a large dorsal black band. Its abdomen is yellowish. Photo P. Rasmont.

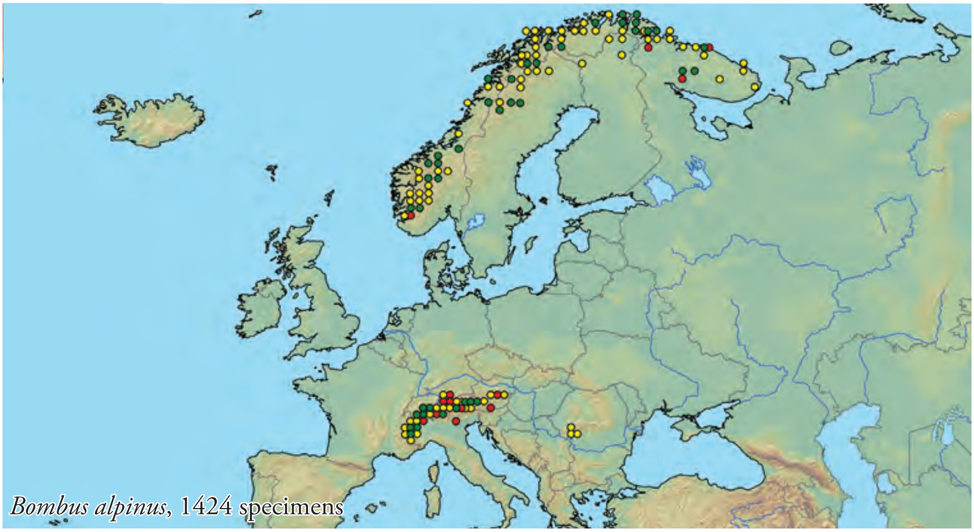
Bombus persicus is an endemic species of mountains steppes in east-Turkey, north Iran and Caucasian region. Photo P. Rasmont.

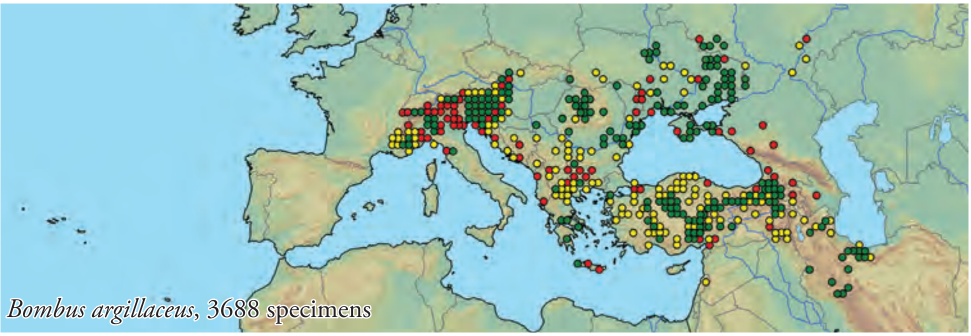
Bombus handlirschianus is a medium-sized species that lives in the highest mountain levels in east Turkey, north Iran and Caucasian region. Two different colour patterns could be found, with grey or yellowish bands and a reddish abdomen tip. Thanks to its long tongue, it forages mainly flowers with long corolla, like *Astragalus* spp. Photo P. Rasmont.

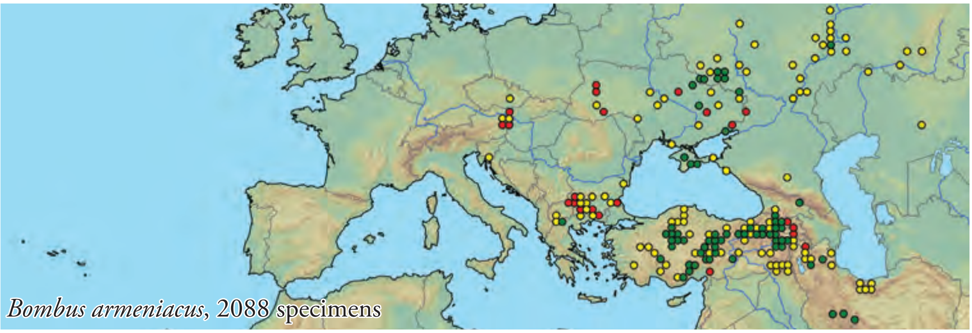
Bombus sulfureus is a large species endemic to mountain steppes in east Turkey and Iran. It shows a very conspicuous colour pattern, bright yellow with a black thoracic band and a reddish tergite 6. Beside that it is a very rare species, the males fly extremely fast and are therefore rarely observed. Photo P. Rasmont.

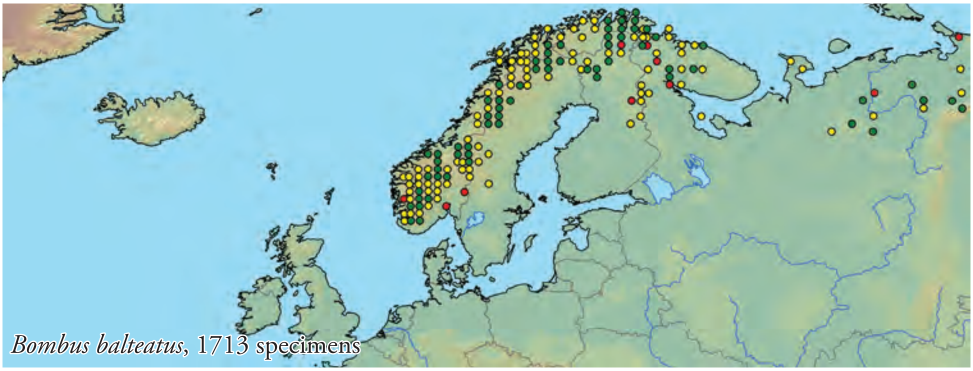

Bombus alagesianus, 231 specimens

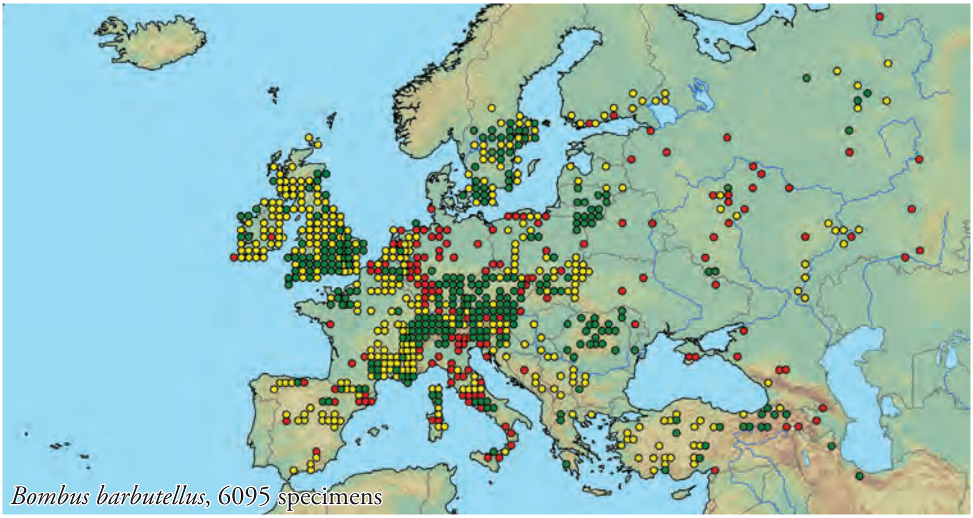

Bombus brodmanni, 45 specimens

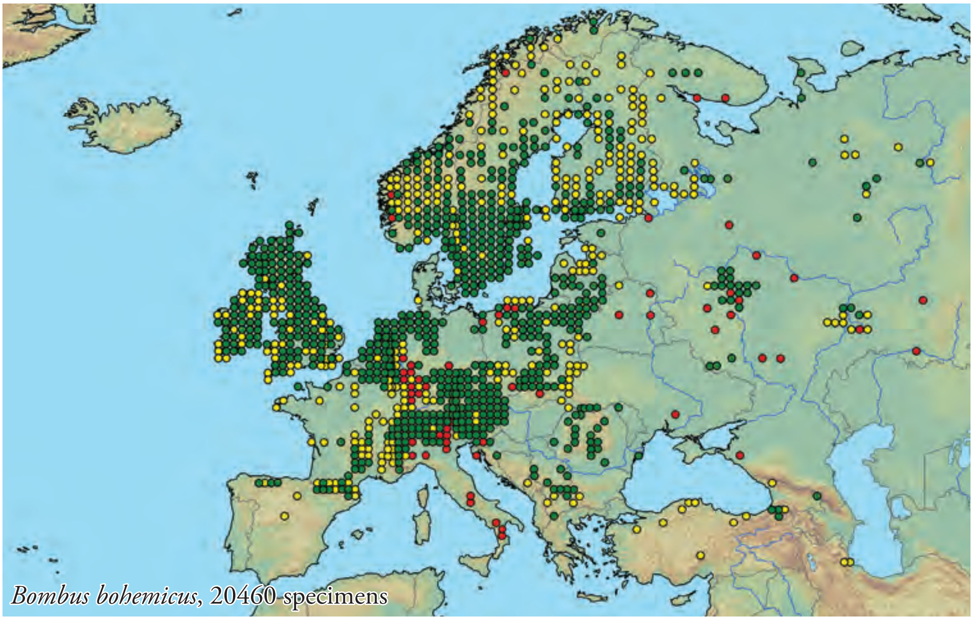

Bombus alpinus, 1424 specimens


Bombus argillaceus, 3688 specimens

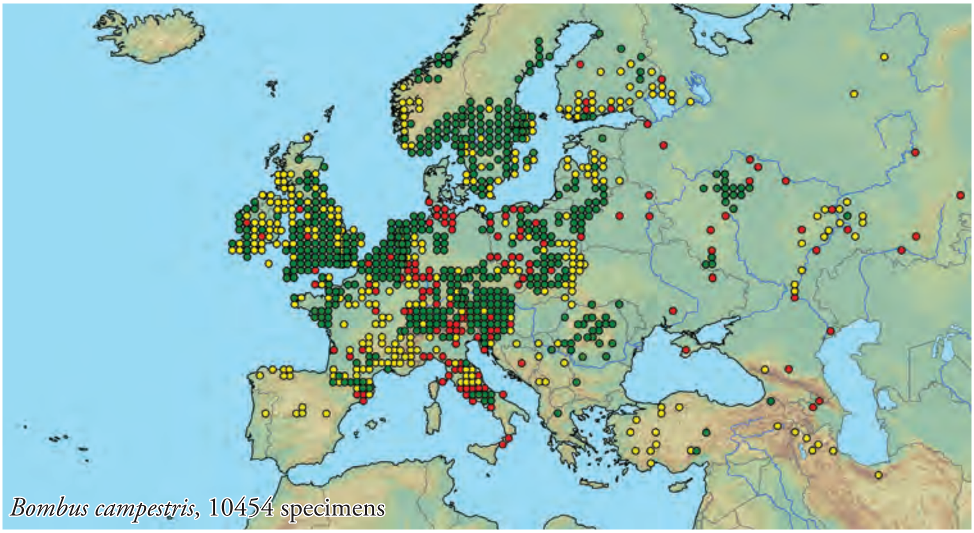

Bombus armeniacus, 2088 specimens


Bombus balteatus, 1713 specimens


Bombus barbutellus, 6095 specimens

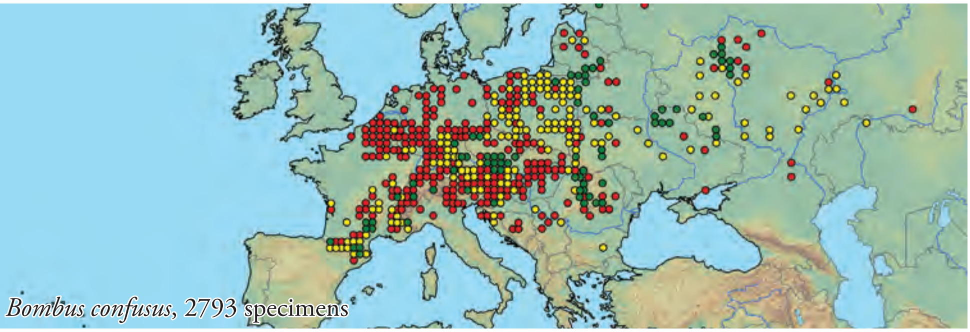

Bombus bohemicus, 20460 specimens

Bombus brodmannicus, 619 specimens

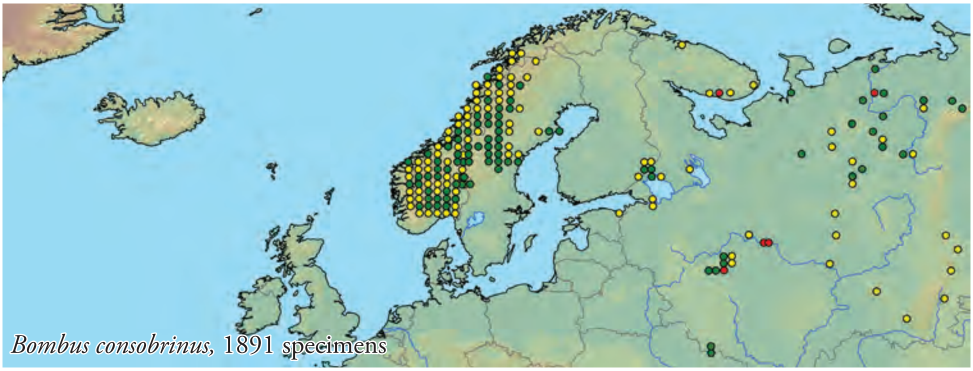


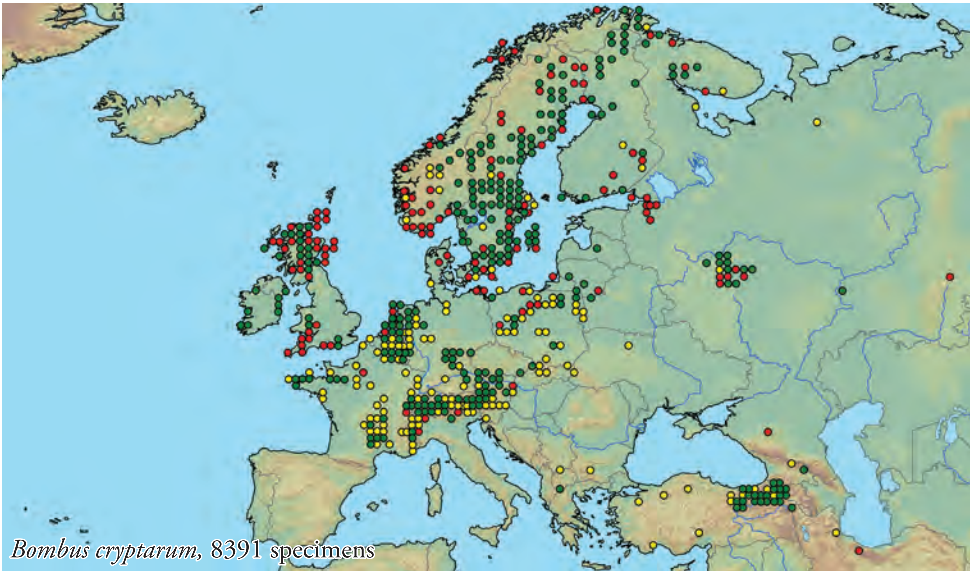
Bombus campestris, 10454 specimens

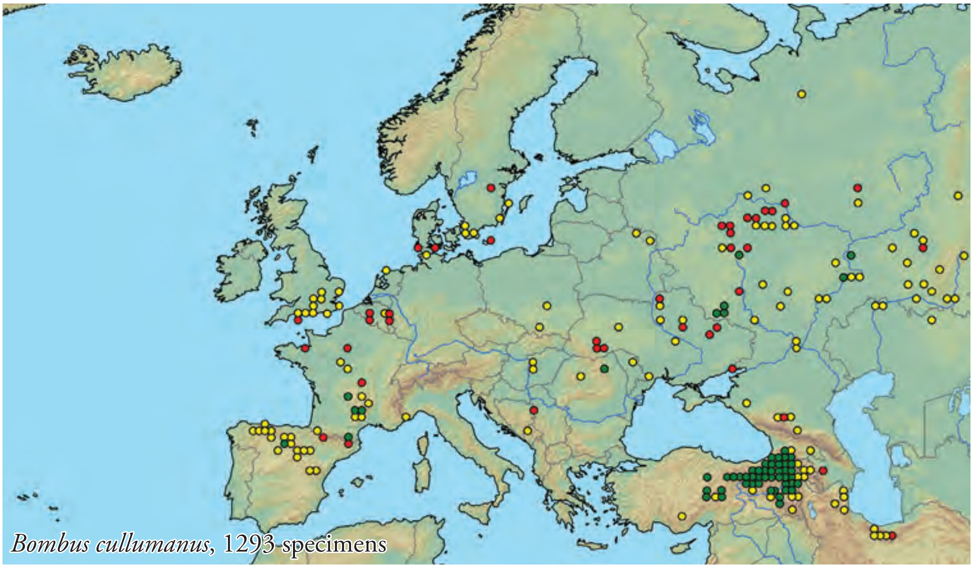
Bombus cingulatus, 1078 specimens

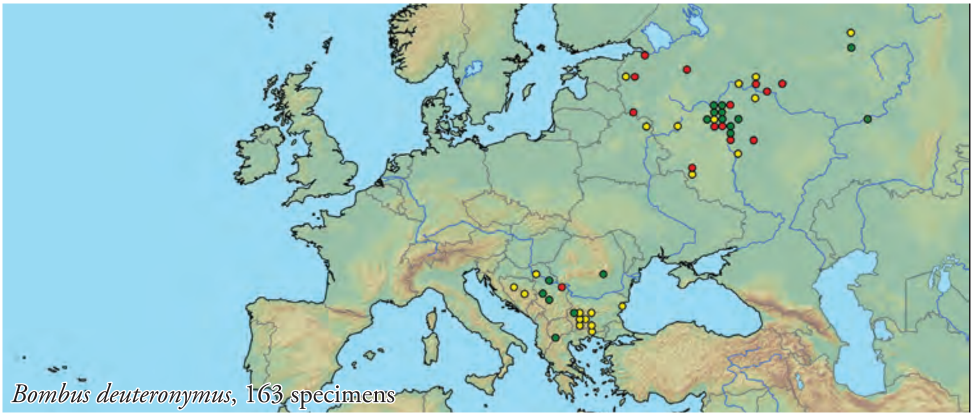


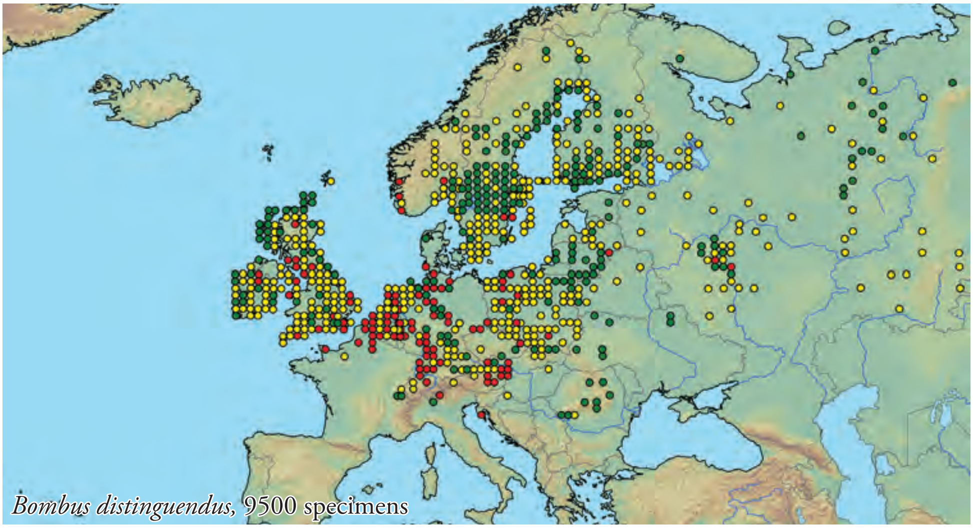
Bombus confusus, 2793 specimens

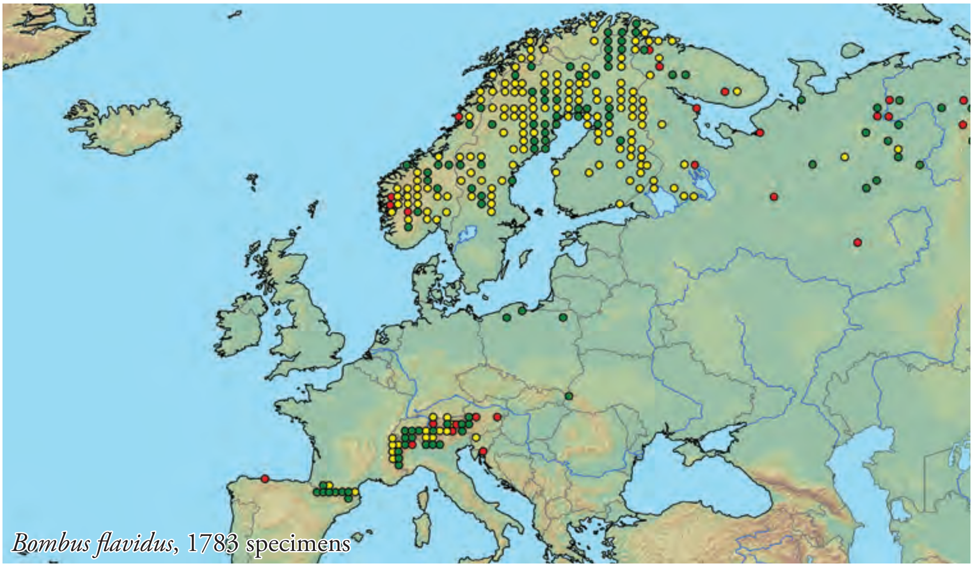

Bombus consobrinus, 1891 specimens


Bombus cryptarum, 8391 specimens


Bombus cullumanus, 1293 specimens


Bombus deuteronymus, 163 specimens


Bombus distinguendus, 9500 specimens

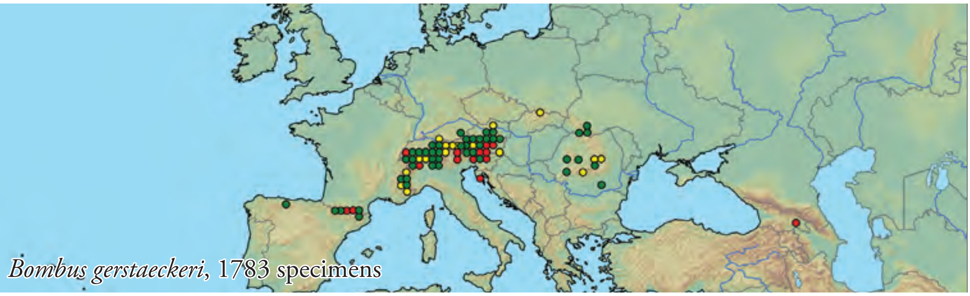

Bombus flavidus, 1783 specimens

Bombus caucasicus, 148 specimens

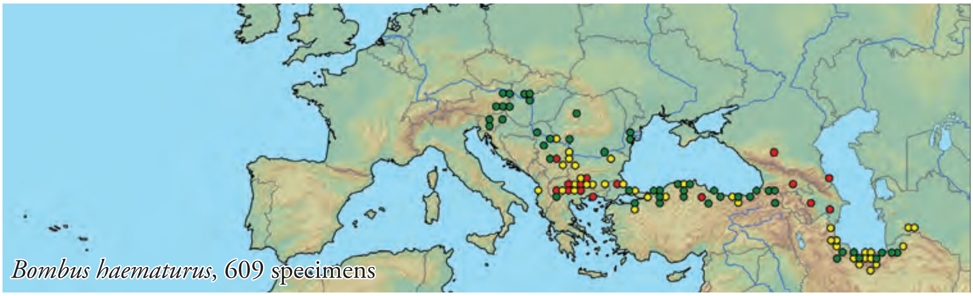
Bombus handlirschianus, 612 specimens

Bombus fragrans, 883 specimens

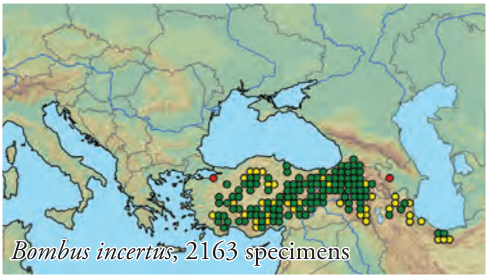
Bombus glacialis, 37 specimens



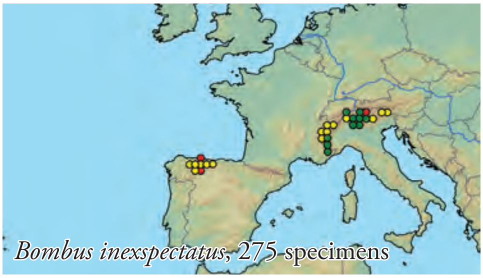
Bombus gerstaeckeri, 1783 specimens



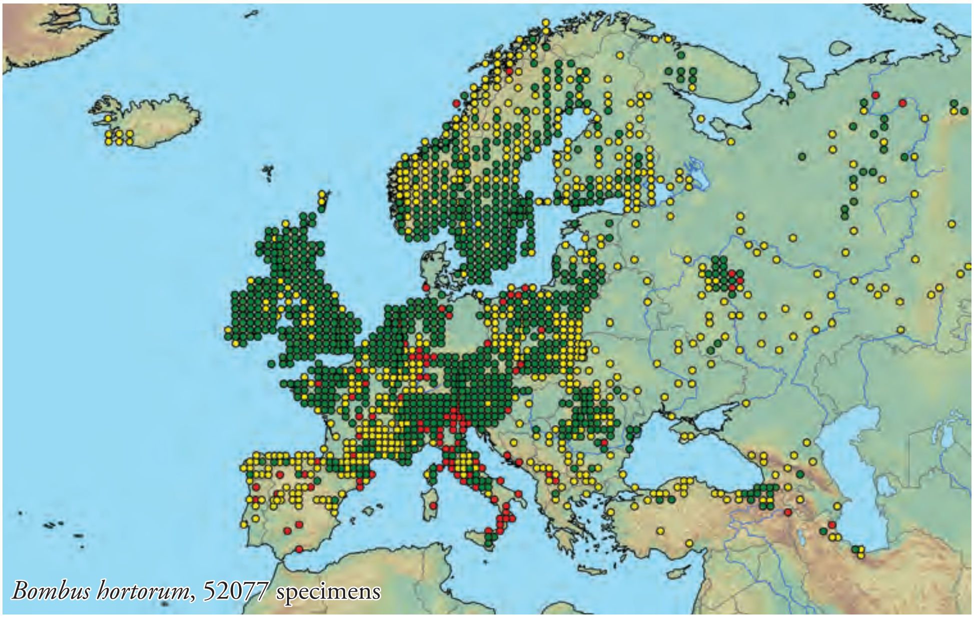
Bombus haematurus, 609 specimens



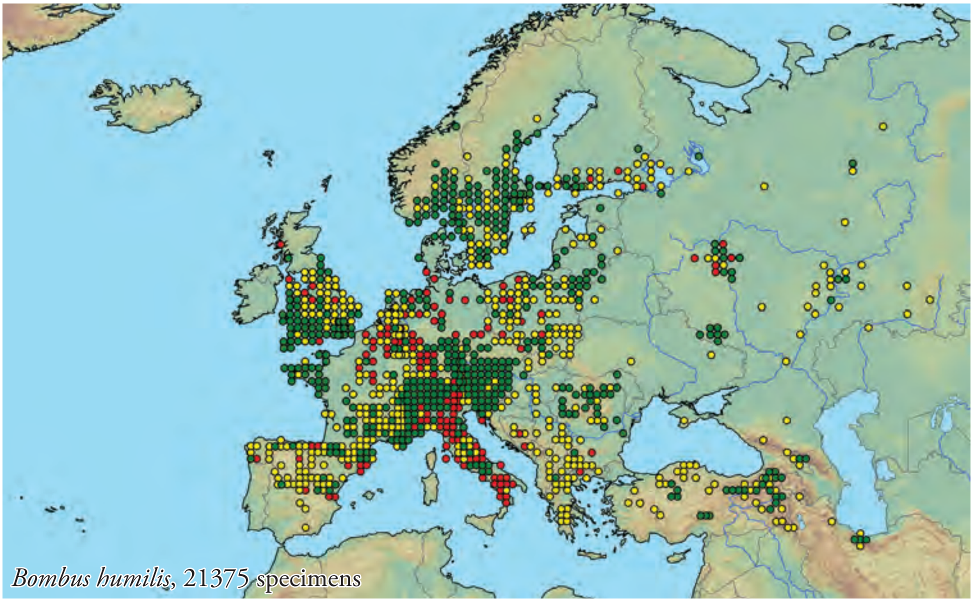
Bombus incertus, 2163 specimens



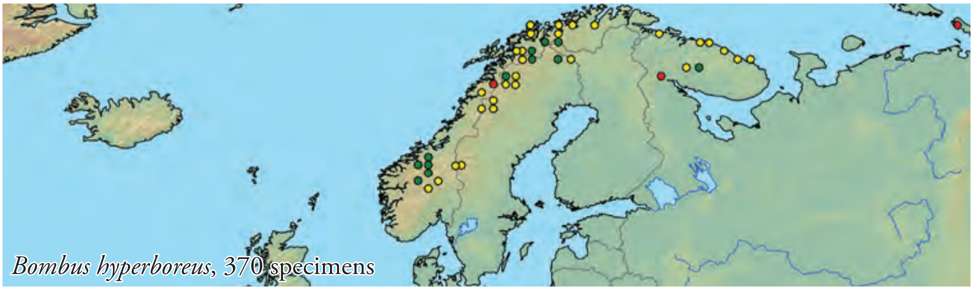
Bombus inexspectatus, 275 specimens



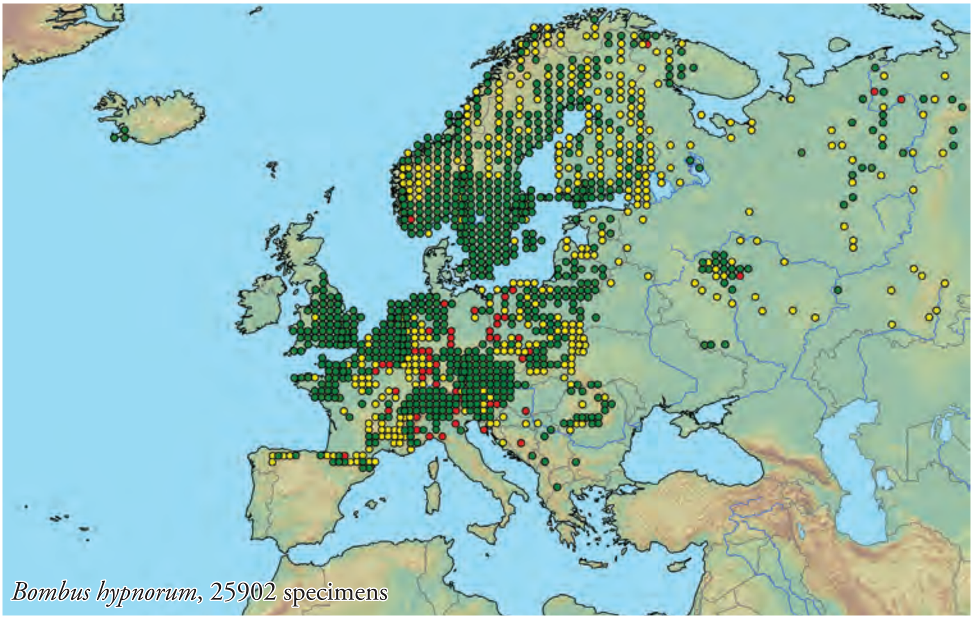
Bombus hortorum, 52077 specimens



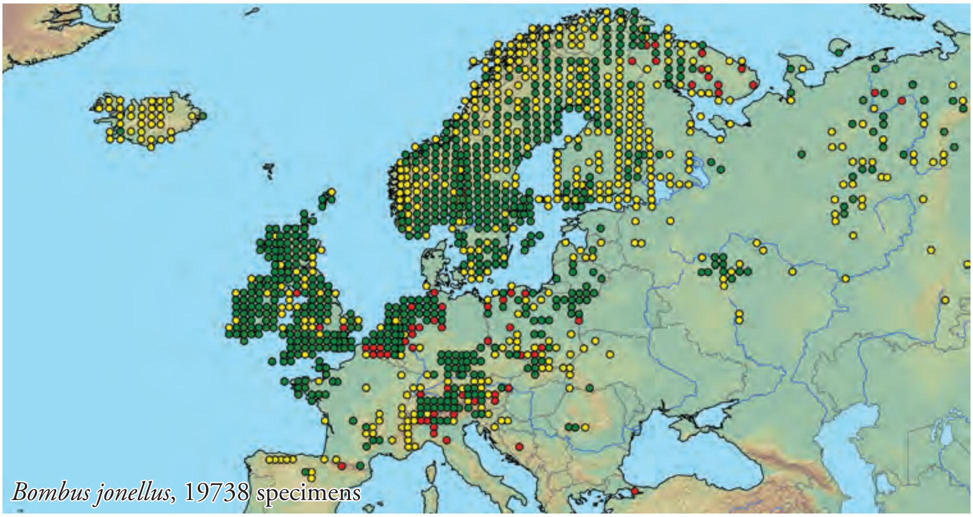
Bombus humilis, 21375 specimens



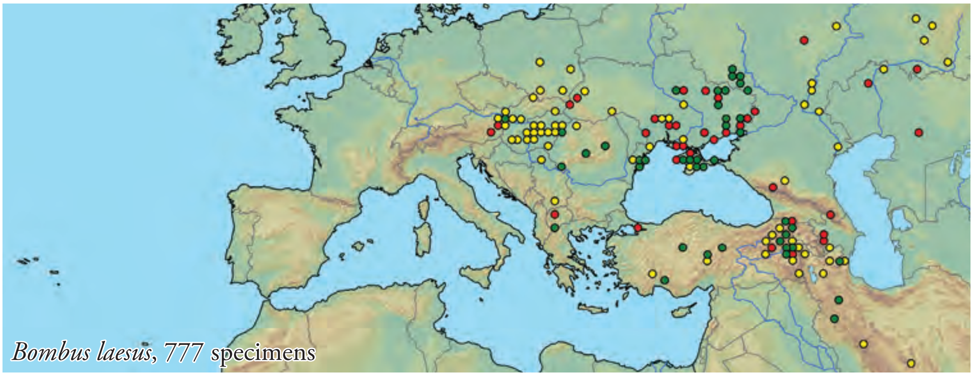
Bombus hyperboreus, 370 specimens



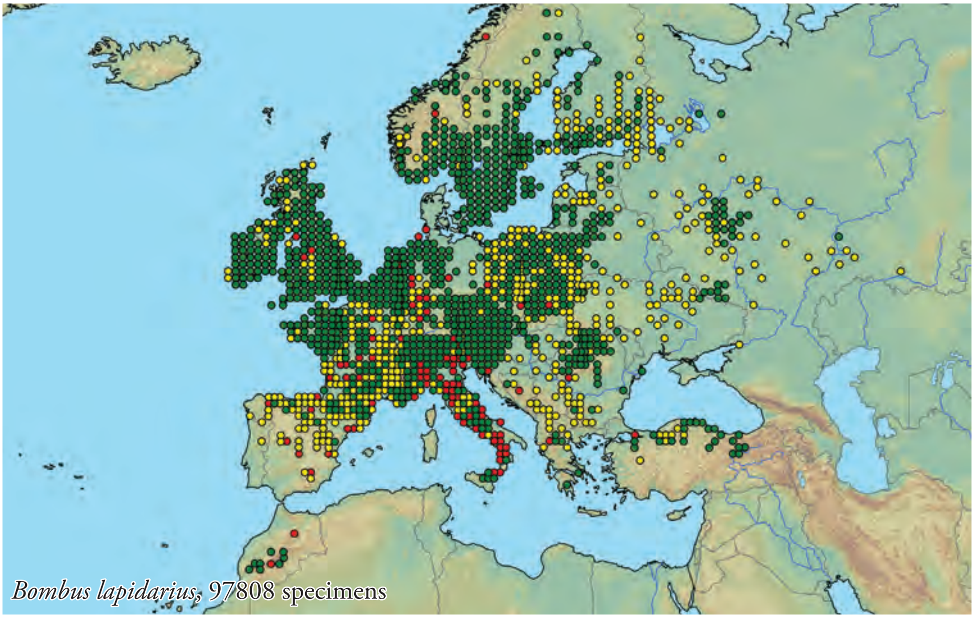
Bombus hypnorum, 25902 specimens



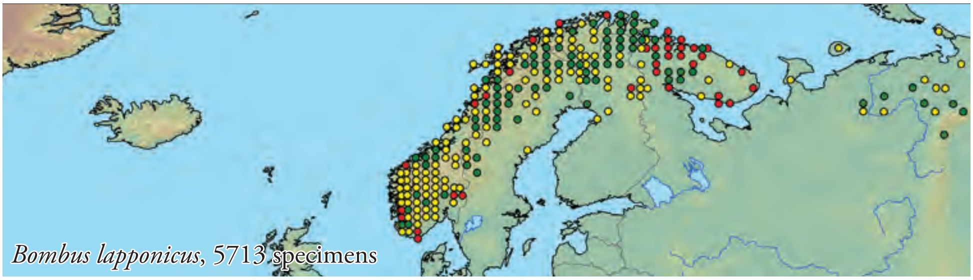
Bombus jonellus, 19738 specimens



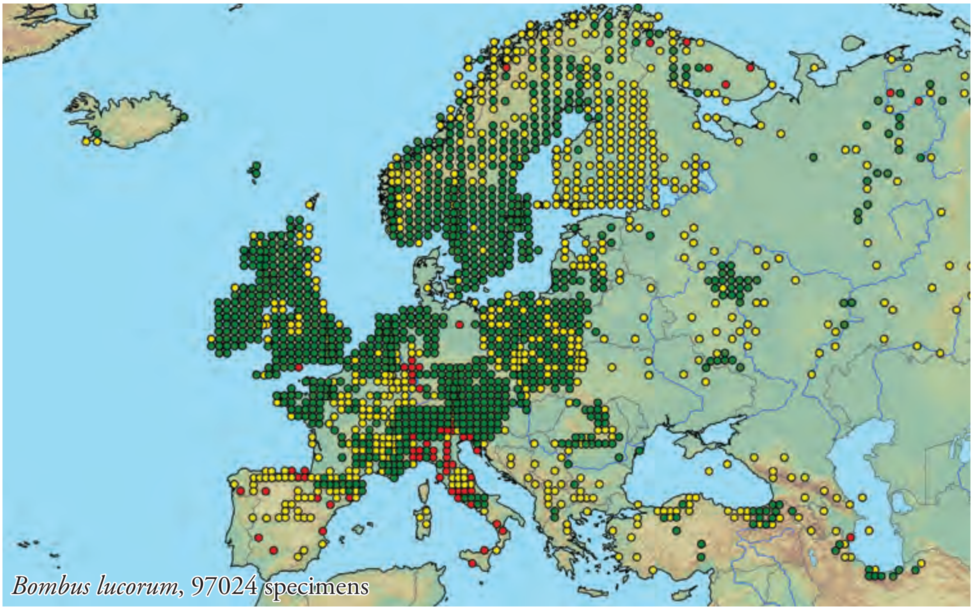
Bombus laesus, 777 specimens



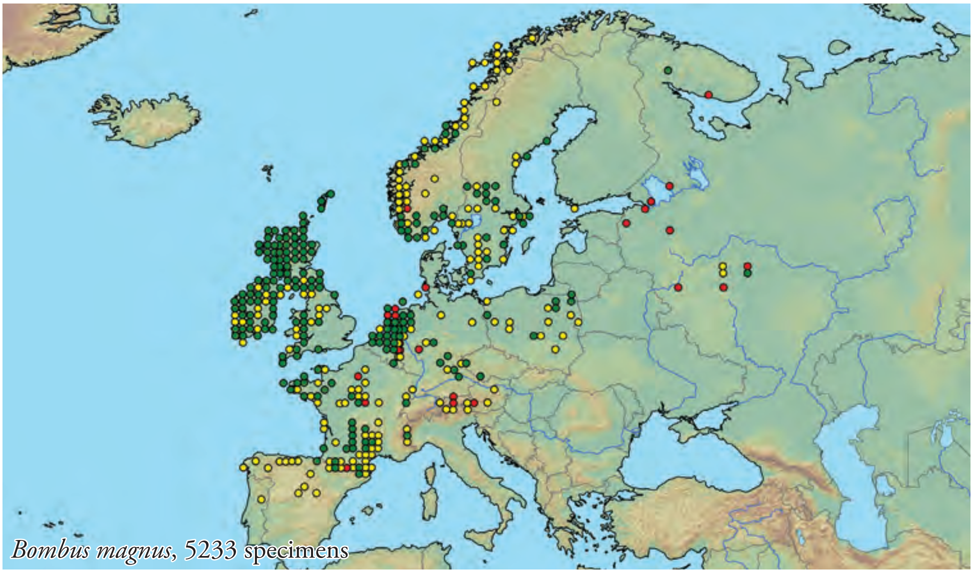
Bombus lapidarius, 97808 specimens



Bombus lapponicus, 5713 specimens



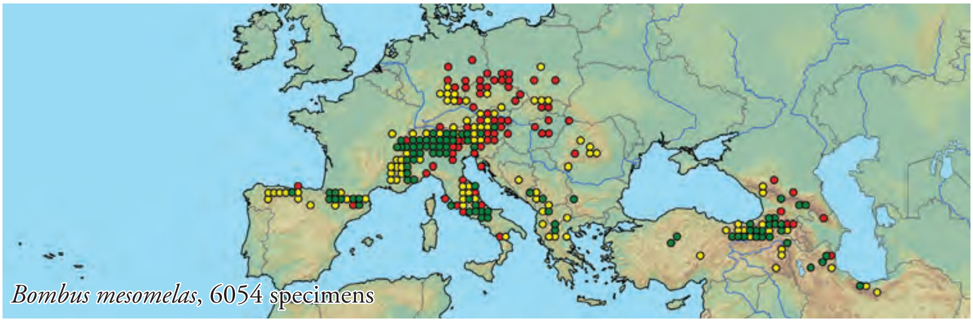
Bombus lucorum, 97024 specimens



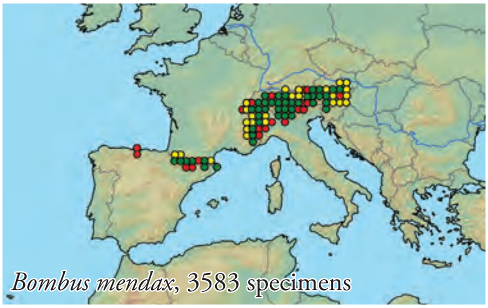
Bombus magnus, 5233 specimens

Bombus melanurus, 307 specimens

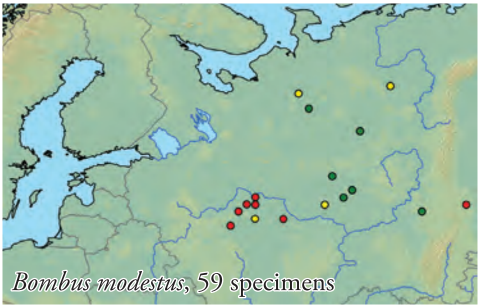
Bombus mlokosievitzii, 334 specimens



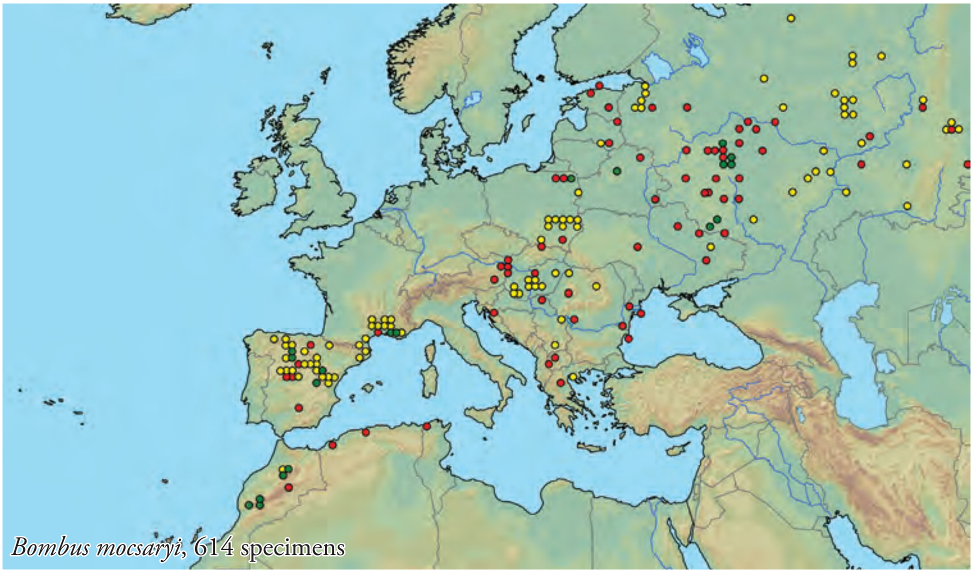
Bombus mesomelas, 6054 specimens



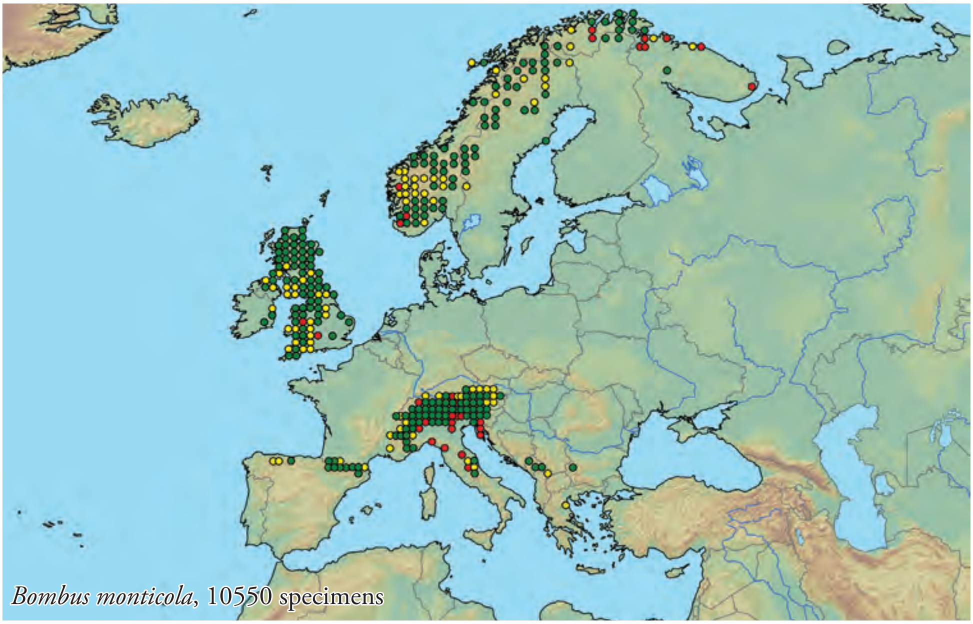
Bombus mendax, 3583 specimens



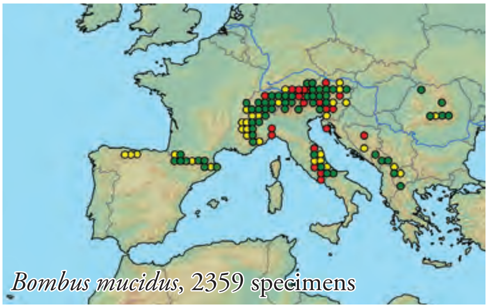
Bombus modestus, 59 specimens



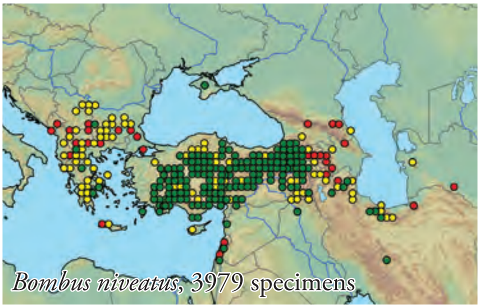
Bombus mocsaryi, 614 specimens



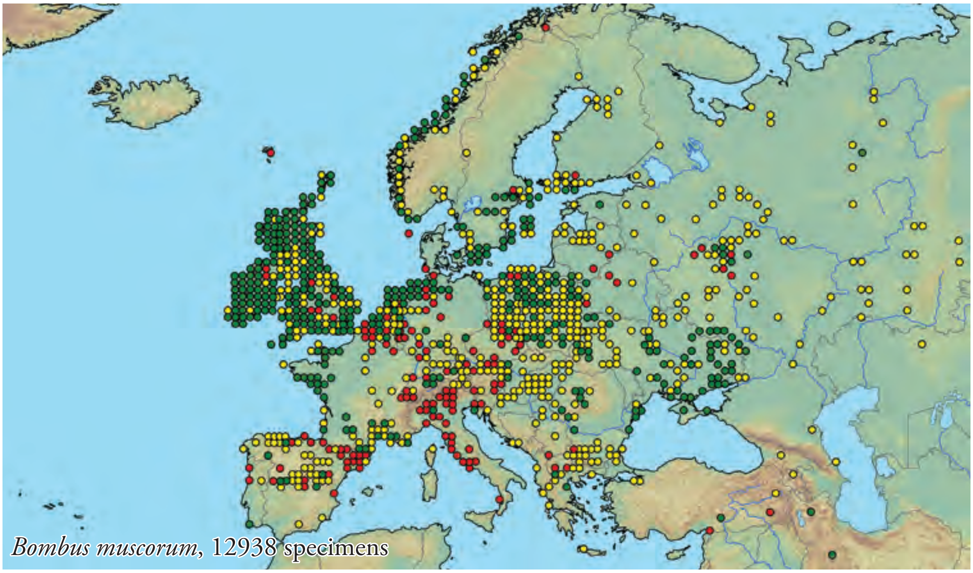
Bombus monticola, 10550 specimens

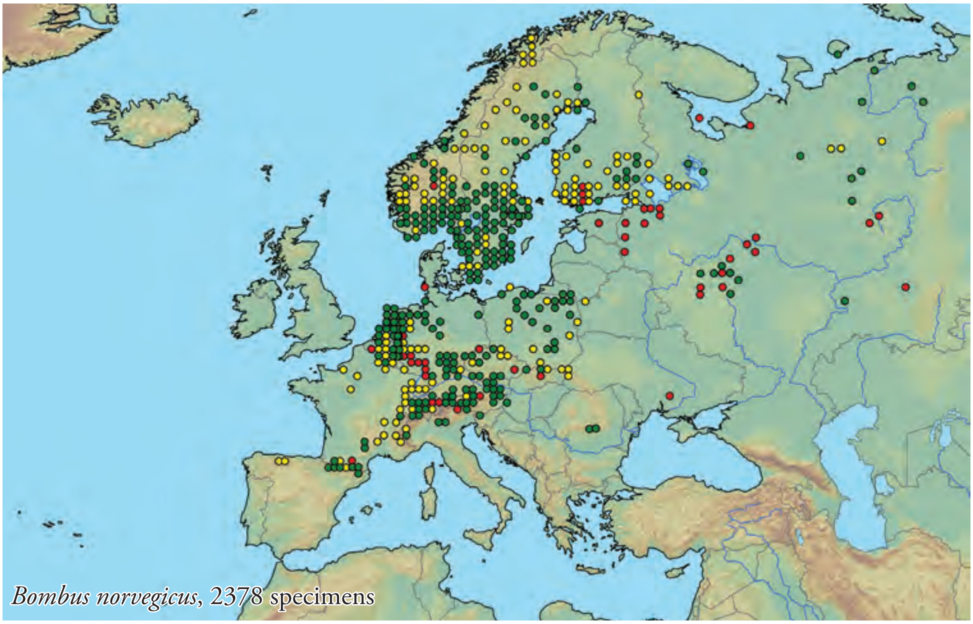


Bombus mucidus, 2359 specimens

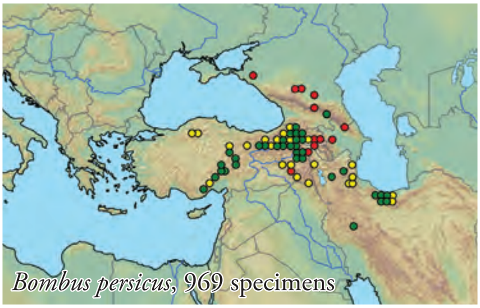


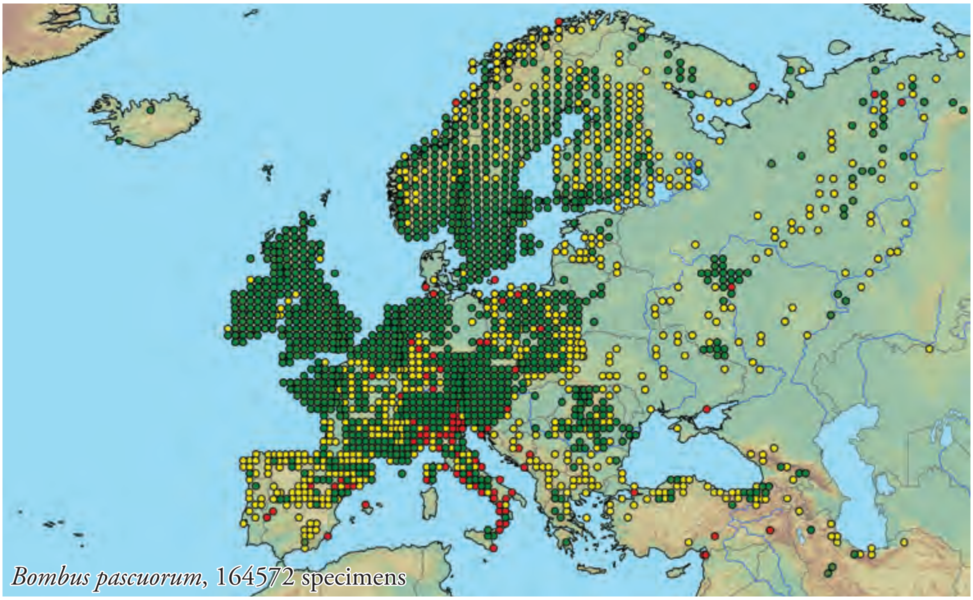
Bombus niveatus, 3979 specimens

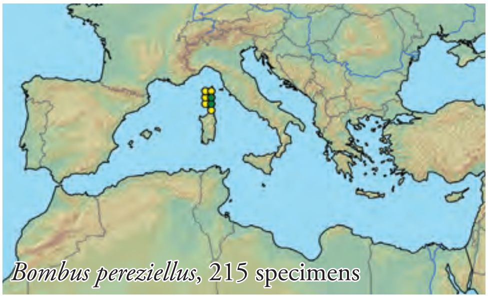

Bombus muscorum, 12938 specimens


Bombus norvegicus, 2378 specimens

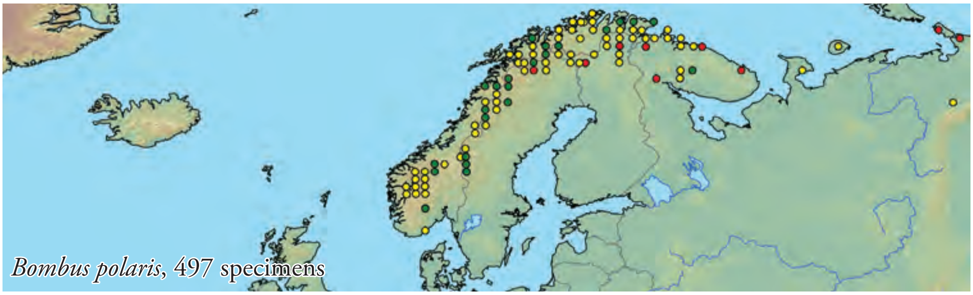

Bombus patagiatus, 31 specimens

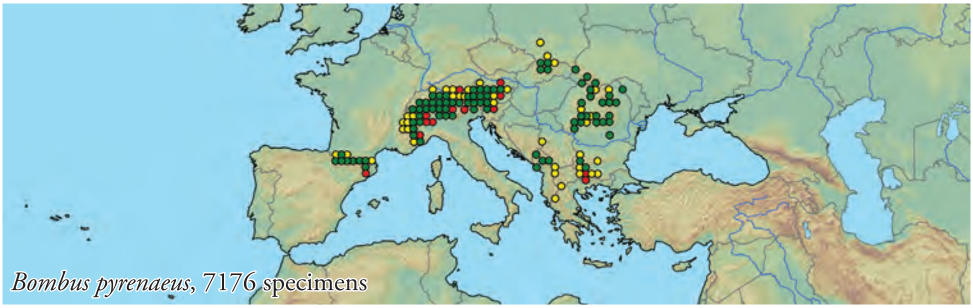

Bombus persicus, 969 specimens

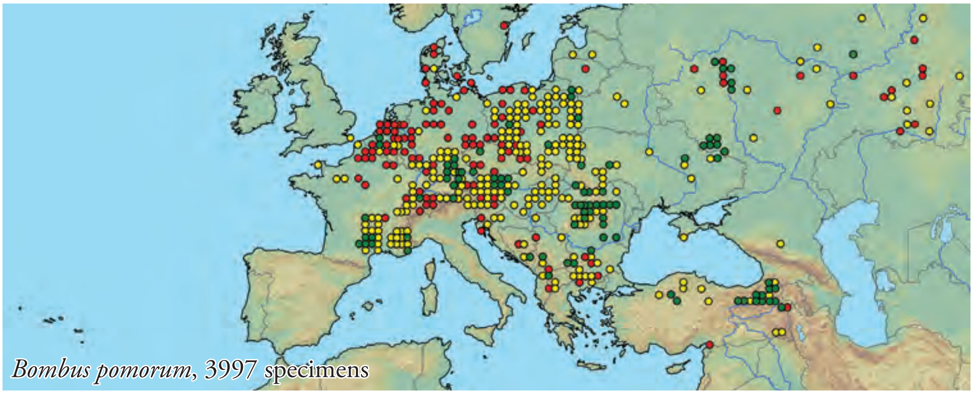

Bombus pascuorum, 164572 specimens


Bombus pereziellus, 215 specimens

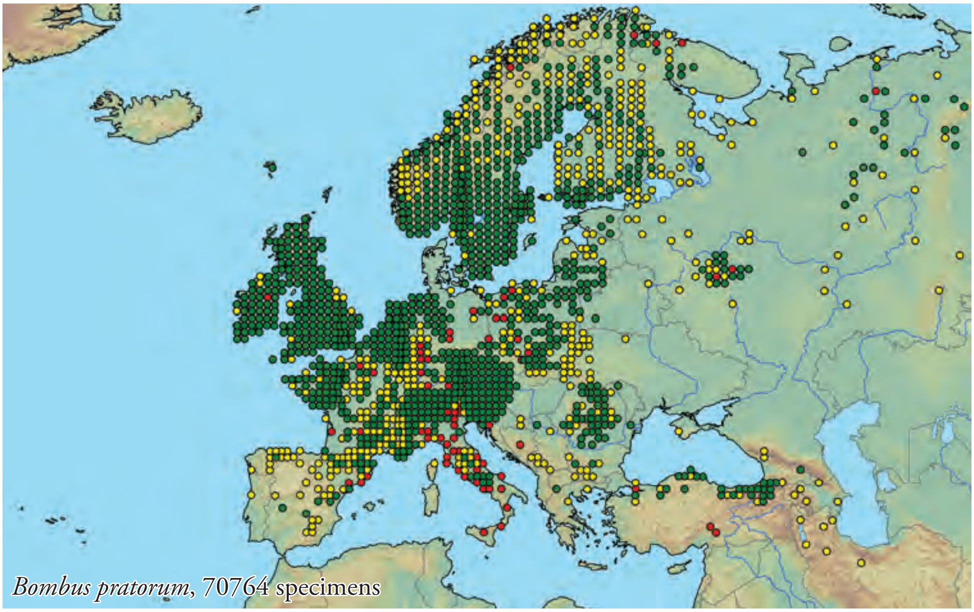

Bombus portchinsky, 417 specimens


Bombus polaris, 497 specimens

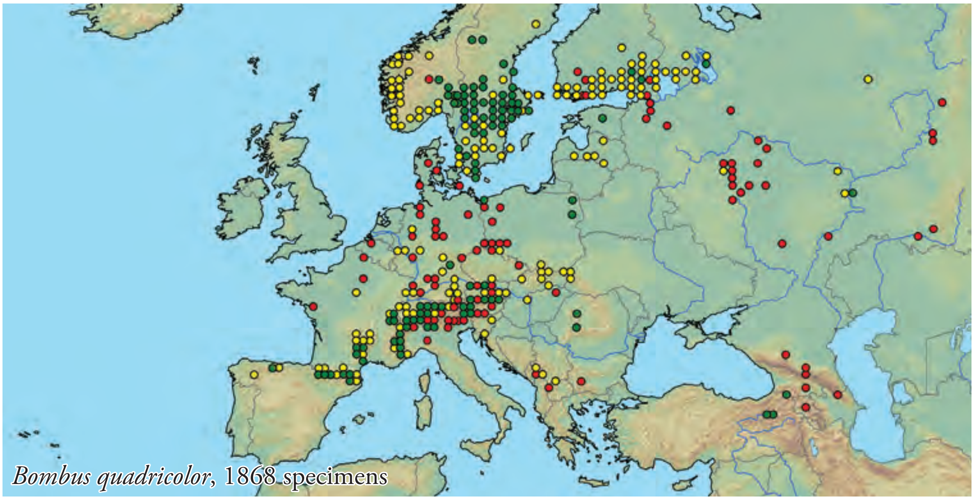

Bombus pyrenaeus, 7176 specimens



Bombus pomorum, 3997 specimens



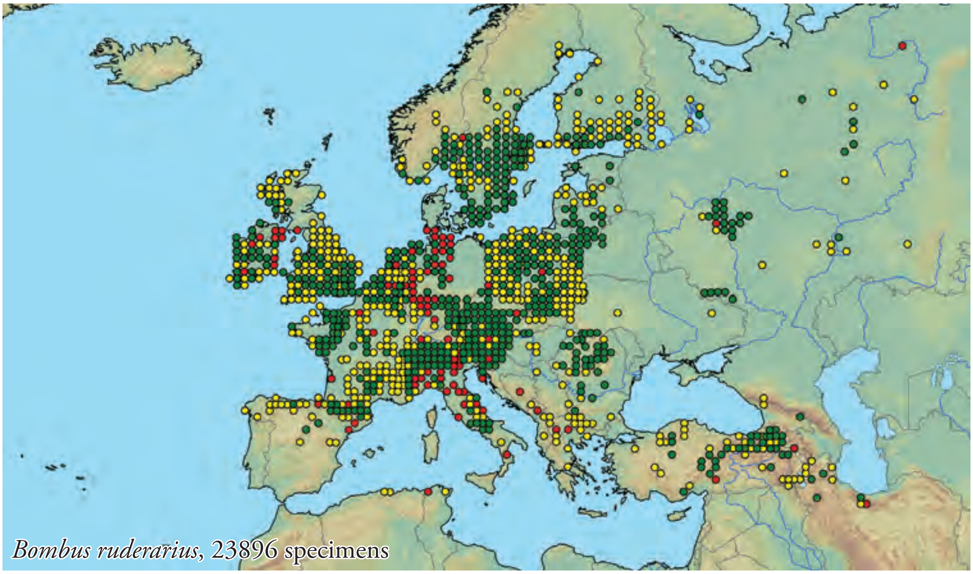
Bombus pratorum, 70764 specimens

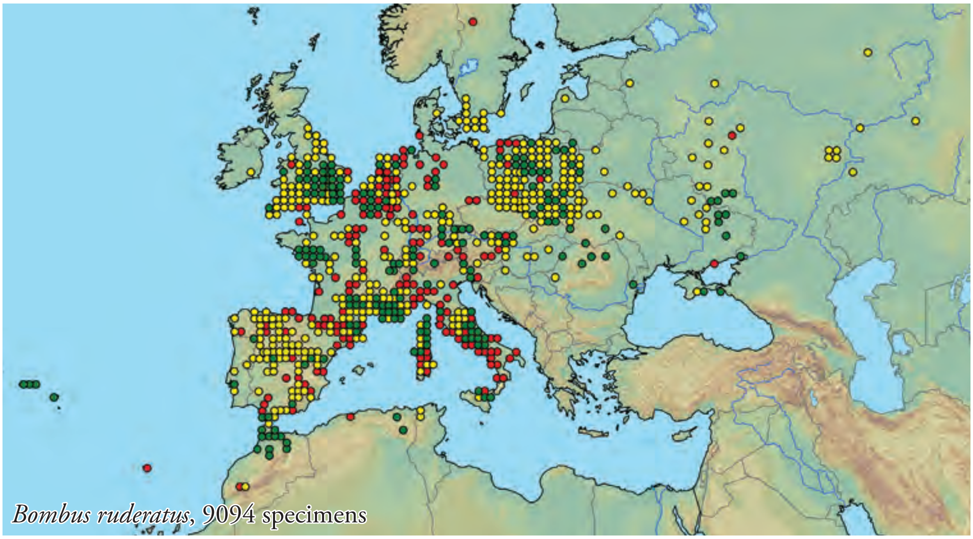


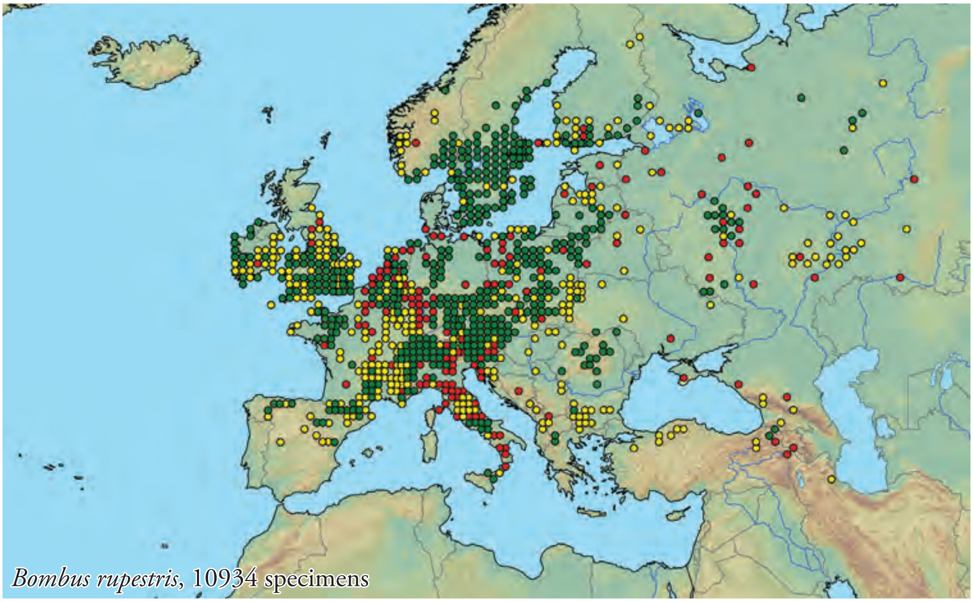
Bombus quadricolor, 1868 specimens

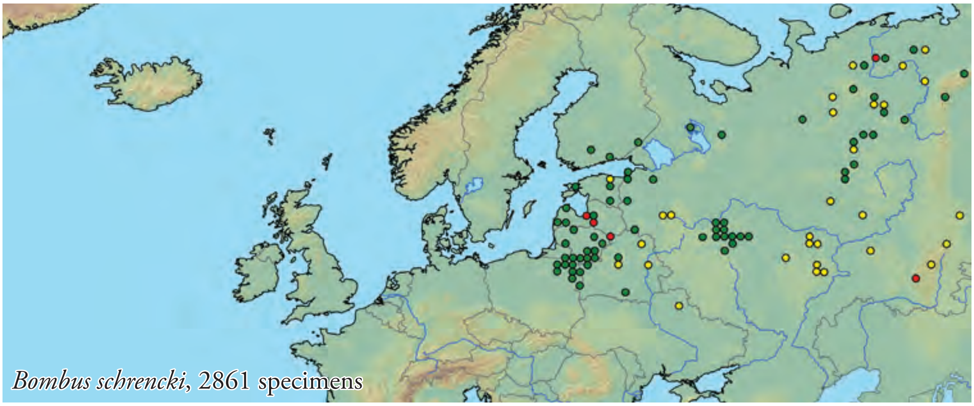

Bombus reinigiellus, 57 specimens

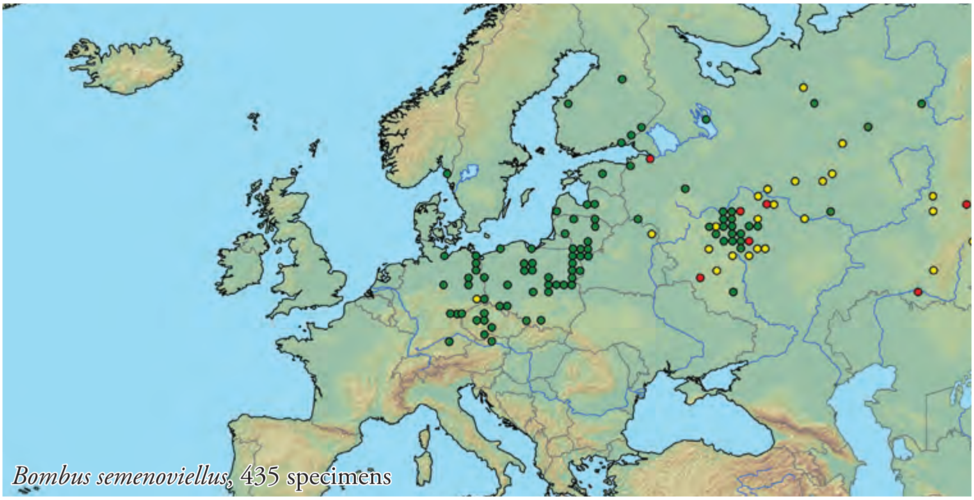

Bombus renardi, 507 specimens


Bombus ruderarius, 23896 specimens

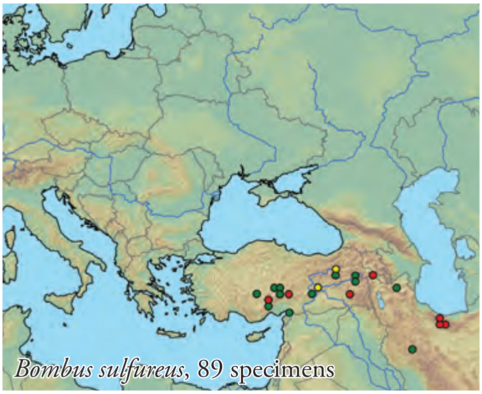

Bombus ruderatus, 9094 specimens

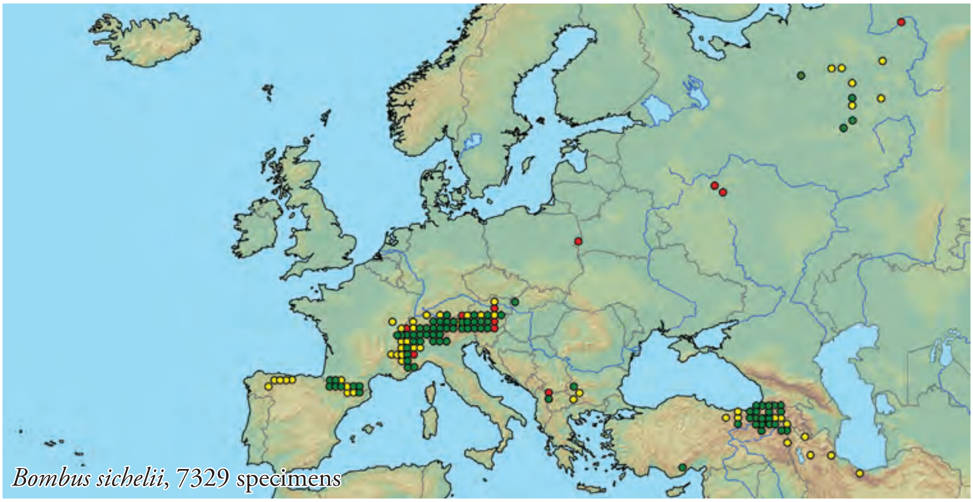

Bombus rupestris, 10934 specimens

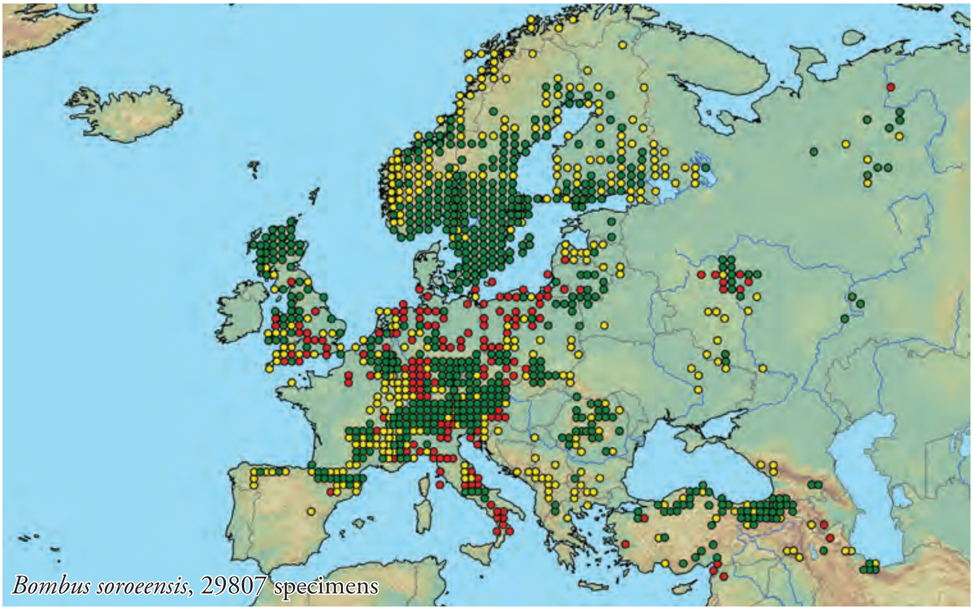

Bombus schrencki, 2861 specimens

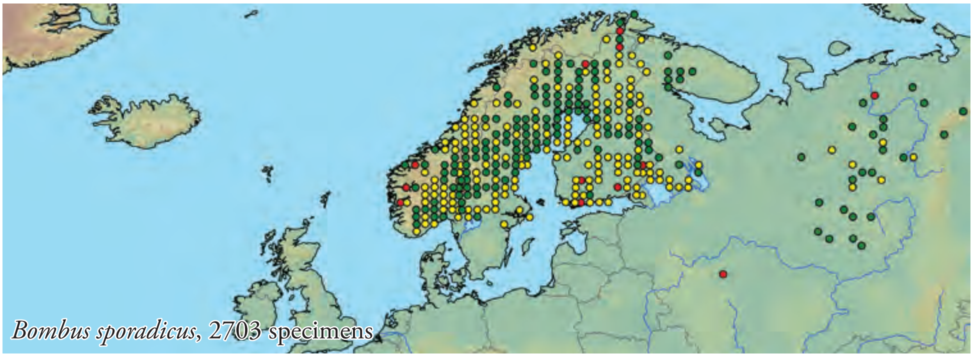

Bombus semenoviellus, 435 specimens

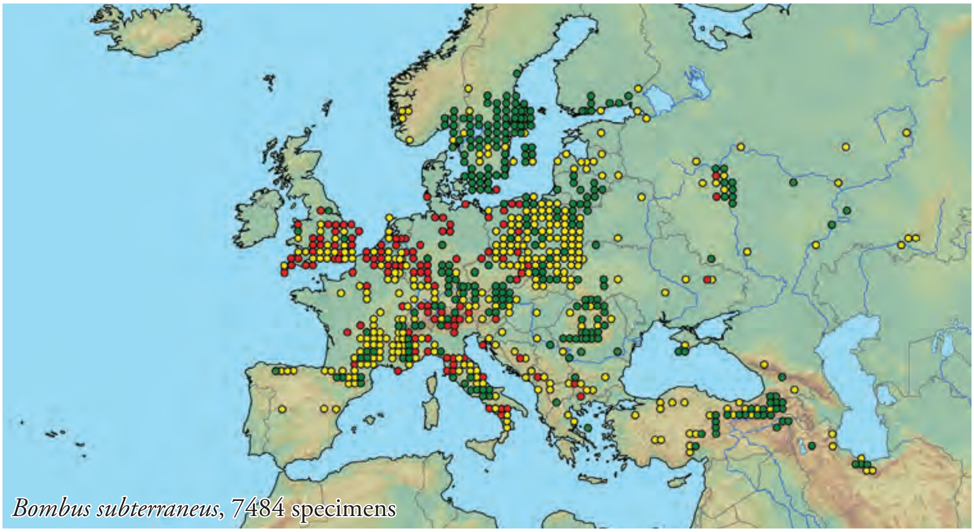

Bombus saltuarius, 22 specimens

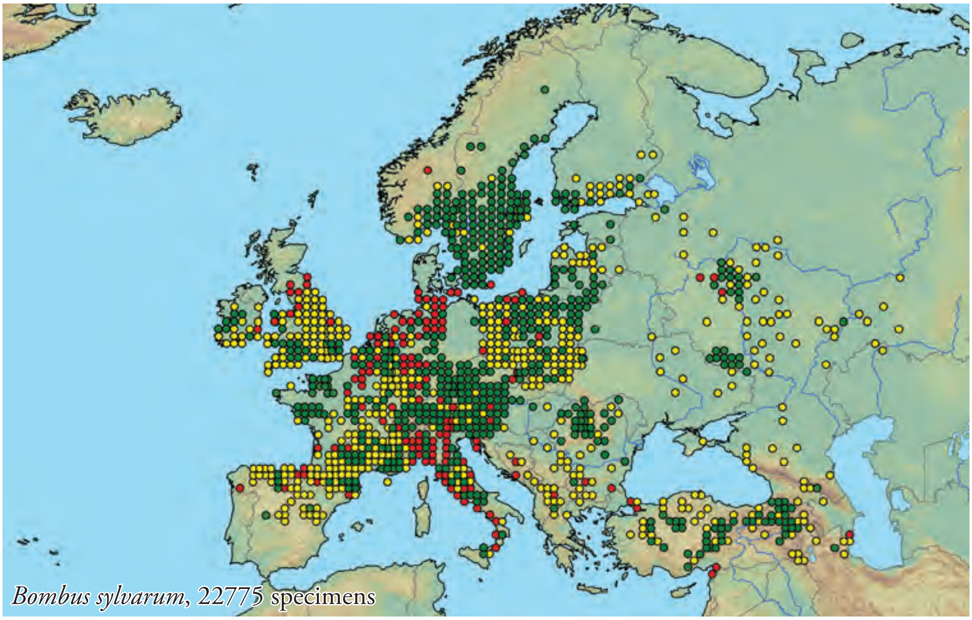

Bombus sulfureus, 89 specimens

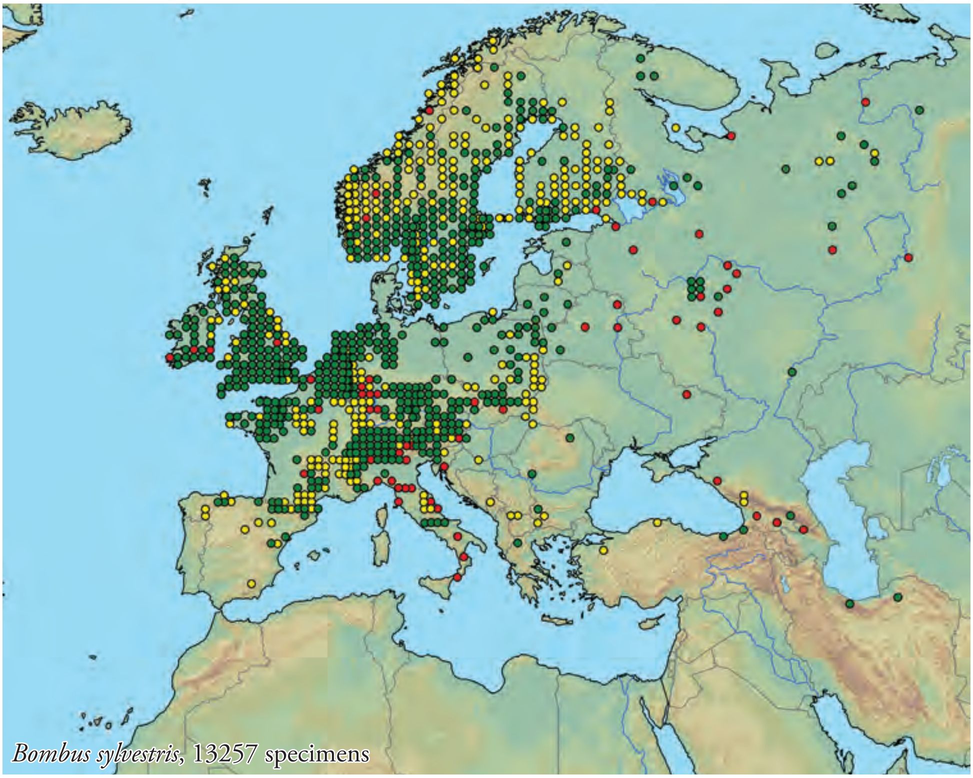

Bombus sichelii, 7329 specimens


Bombus soroeensis, 29807 specimens

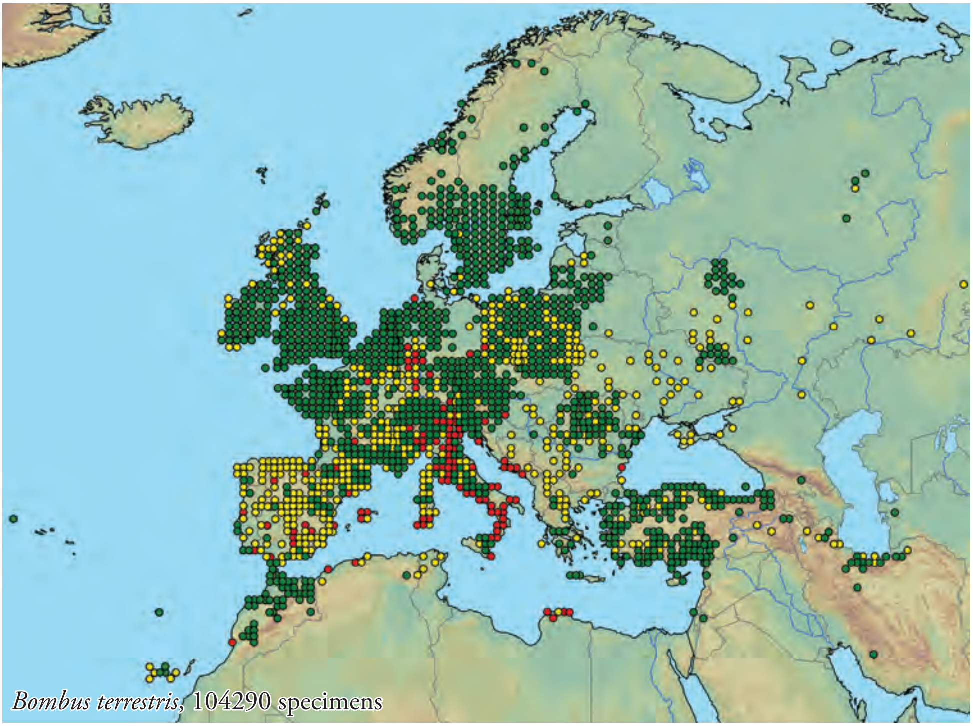

Bombus sporadicus, 2703 specimens


Bombus subterraneus, 7484 specimens

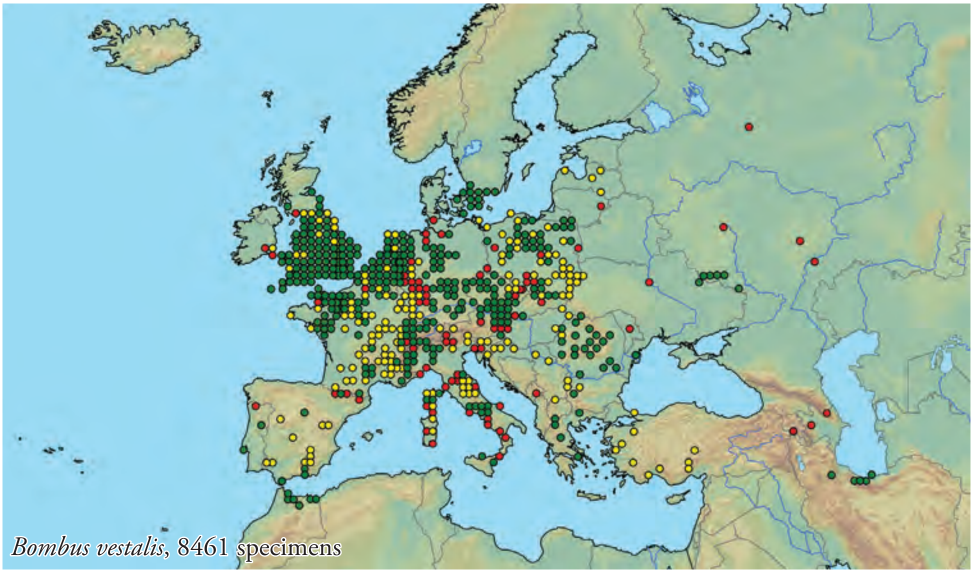

Bombus sylvarum, 22775 specimens



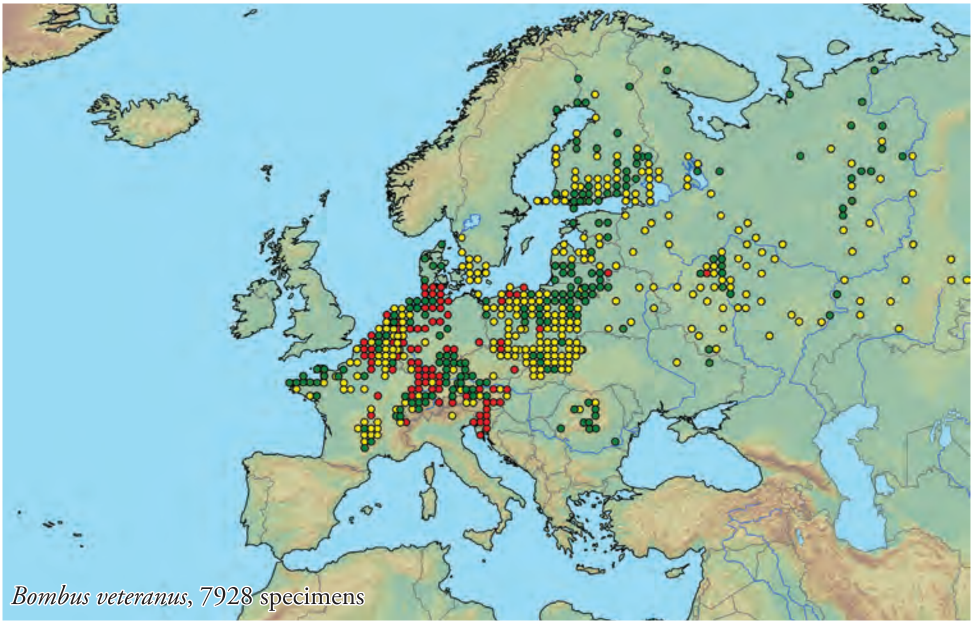
Bombus sylvestris, 13257 specimens



Bombus terrestris, 104290 specimens

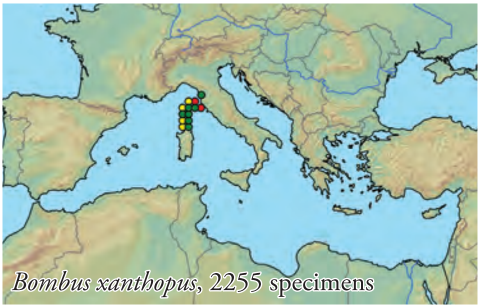


Bombus vestalis, 8461 specimens

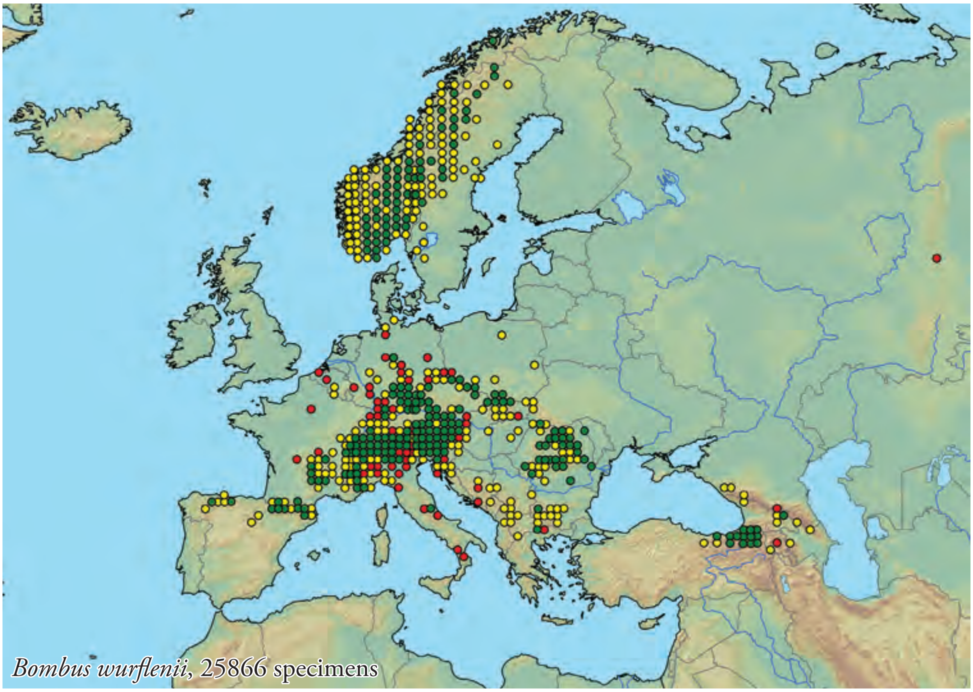


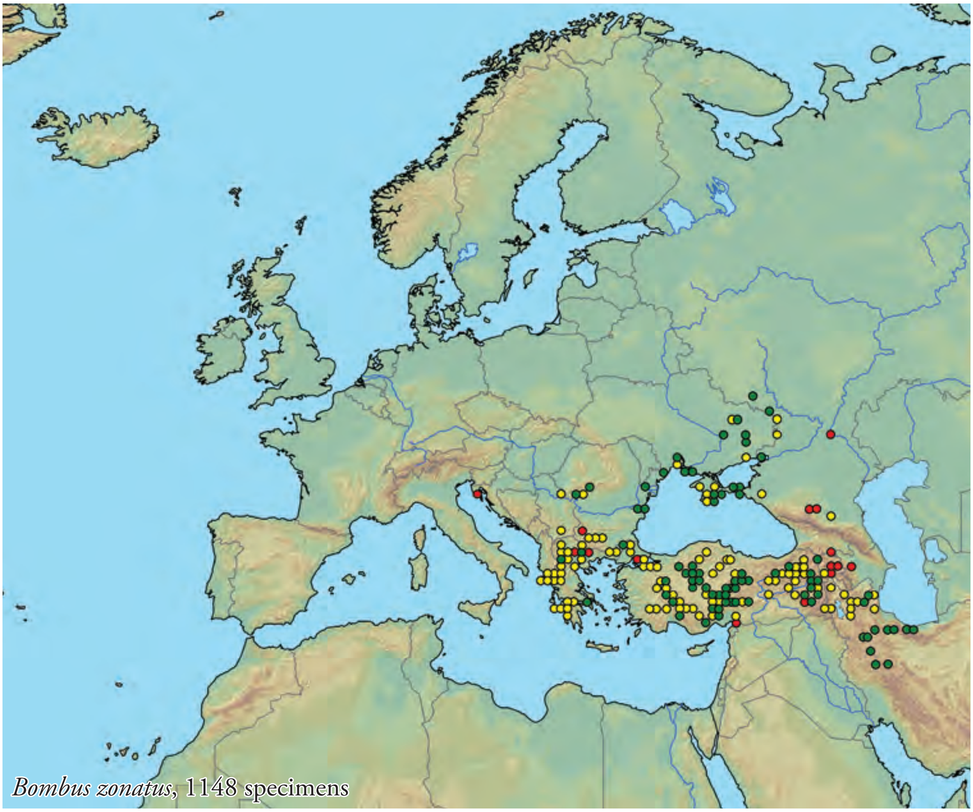
Bombus veteranus, 7928 specimens

Bombus velox, 123 specimens



Bombus xanthopus, 2255 specimens


Bombus wurflenii, 25866 specimens


Bombus zonatus, 1148 specimens

18. Summary

P. Rasmont, M. Franzén, T. Lecocq, A. Harpke, S.P.M. Roberts, J.C. Biesmeijer, L. Castro, B. Cederberg, L. Dvořák, Ú. FitzPatrick, Y. Gonseth, E. Haubruge, G. Mahé, A. Manino, D. Michez, J. Neumayer, F. Ødegaard, J. Paukkunen, T. Pawlikowski, S.G. Potts, M. Reemer, J. Straka, J. Settele, O. Schweiger. 2015.

Climatic Risk and Distribution Atlas of European Bumblebees.
Pensoft publishing, Sofia.

Thanks to the EU FP7 project STEP (Potts *et al.* 2011), over one million bumblebee records from all over Europe have been collated. Based on data from 1970 to 2000 we modelled the current climatic niche for almost all European species (56 out of 69) and projected future climatically suitable conditions based on three climate change scenarios (SEDG, BAMBU and GRAS) for the years 2050 and 2100. Due to limited knowledge of actual bumblebee dispersal, we made two extreme assumptions: (i) the species has full dispersal abilities (meaning that the species is able to spread all over its suitable area) or (ii) the species is unable to disperse at all (i.e. that changes in climatic conditions can only lead to projected range retractions). However, to aid the assessment as to which of these two extreme assumptions are more likely to meet reality, we also provide a rough indication of the species' potential dispersal ability based on the ecology of the different bumblebees.

Since bumblebees are mainly adapted to colder conditions, they appear as highly vulnerable to climate change. In 2100, depending on the scenario of climate change, up to 36% of the European bumblebees are projected to be at an high climatic risk (i.e. losing more than 80% of their current range), 41% will be at risk (loss between 50% and 80%). Non-modelled species are all very rare and localised and their ranges are most likely to be shrinking considerably under all of the scenarios. Only a few species are projected to benefit from climate change and can potentially enlarge their current distributions in Europe, such as *B. argillaceus* and *B. haematurus.*

As expected, the three scenarios considerably differed in their projections for 2100. While under the moderate change scenario (SEDG) only five species are projected to be at the verge of extinction by 2100, twenty species are at particularly high risk under the intermediate change scenario (BAMBU). Under the most severe change scenario (GRAS) as many as 34 species are projected to lose almost all of their climatically suitable area.

Also the ability to keep track with climate change has a considerable impact of the projected changes. For instance, under the most severe climate change scenario (GRAS) nine species are at an extremely high climatic risk when full dispersal is assumed for all of them. However, under the assumption of no dispersal within the next 100 years 34 species would fall into this category. When potential dispersal abilities, inferred from species traits and their auto-ecologies, are considered to decide for which species no or full dispersal assumptions are more realistic, it seems that only three might expand their ranges by 2100, no species is likely to remain at the status quo, and 25 species would be at an extremely high climatic risk.

We also found that for many species (about 30%), especially the cold-adapted ones in Alpine and Arctic regions (e.g. *B. alpinus, B. balteatus, B. hyperboreus* and *B. polaris)* their dispersal abilities are actually irrelevant for the assessment of their future fate because climate change will only lead to reductions of areas with suitable climatic conditions while no extra suitable regions will emerge.

Given the great sensitivity of bumblebees to climate change and further considering the severe projected changes in the light of the great relevance of bumblebees as pollinators, designing management plans to sustain the highest level of pollination services on the one hand and to ensure the survival of as many bumblebee species on the other hand is of utmost importance. Given the different mechanisms leading to change, especially at the leading *versus* the trailing edge of species distributions and the geographical differences in the severity of climate change, management actions must be well and target-specific designed. One important issue would be to prioritise management actions across different geographic regions in Europe. We have seen that the expected species loss due to climate change increases with decreasing latitudes, i.e. that regions in the south of Europe will be most affected by pollinator loss.

Important means to support European bumblebees would be to facilitate the movement of species trying to keep track with changing climates at the trailing edge and to prolong the persistence in regions where climatic conditions are deteriorating. Landscape management can be of particular help in this context. Increased connectivity and quality of bumblebee habitats can help colonising species, while habitat heterogeneity will generate heterogeneity in the microclimate and can thus increase population persistence at the trailing edge as a kind of "Noah's Ark". Areas with naturally high levels of microclimatic heterogeneity (such as mountainous areas) can be of particular importance and deserve special attention. Finally, the idea of assisted migration, i.e. purposeful anthropogenic translocations, seems appealing at first sight for species whose original distributional areas are projected to shrink tremendously and cannot move to suitable areas because of natural or anthropogenic barriers. However, the feasibility of such actions is still questionable.

To conclude, climatic risks for bumblebees can be extremely high, depending on the future development of human society, and the corresponding effects on the climate, strong mitigation strategies are needed to preserve this important species group and to ensure the sustainable provision of pollination services, to which they considerably contribute.

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