Life-history traits predict ability of British wild bees to fill their climate envelopes

Article

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Life-history traits predict the ability of British wild bees to fill their climate envelopes

Chris Wyver | Simon G. Potts | Stuart P. M. Roberts | Deepa Senapathi

Sustainable Land Management Department, School of Agriculture, Policy and Development, University of Reading, Reading, UK

Correspondence
Chris Wyver, Sustainable Land Management Department, School of Agriculture, Policy and Development, University of Reading, Whiteknights, Reading RG6 6AR, UK.
Email: c.wyver@reading.ac.uk

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Abstract

1. Understanding a species' ability to fill its climate envelope is crucial to understanding barriers to dispersal, and for predicting capacity to respond to climate change. If a species is not present in its climate envelope, its absence is likely due to non-climatic environmental factors including (1) dispersal limitations, (2) unsuitable habitat and resources, and (3) insufficient data. This study investigates the relationship between British wild bees' life-history traits and their ability to occupy their climate envelopes.
2. The ability of a species to fill its climate envelope was calculated as the proportion of its climate envelope containing a presence record. The relationship between climate envelope filling ability and four life-history traits – lecty (pollen foraging specialisation), overwintering stage, body size and habitat breadth was assessed.
3. Across 64 species of wild bees, this study reveals large species, with generalist foraging behaviour and wide habitat breadth, filled a greater proportion of their climate envelope than smaller bees, with restricted foraging preferences and narrow habitat requirements. This study also found that while larger, generalist species are relatively more successful at filling their climate envelopes, many species do not fill the entirety of their potential climate envelopes.
4. In the context of climate change, this study raises the issue that Great Britain may experience a homogenisation of future bee communities, dominated by widespread generalist species, better able to overcome the non-climatic barriers to filling their climate envelope.

KEYWORDS
climate envelope, dispersal, dispersal barriers, range filling, species distributions, wild bees

INTRODUCTION

Climate plays a large role in determining species' distributions (Thomas, 2010), so understanding a species' suitable climate envelope –the area containing climate suitable for its survival– can help predict where the species may occur. Most species, however, are not present throughout their entire climate envelope. There are several factors that can lead to a species not filling its entire climate envelope, including limited dispersal ability, insufficient habitat availability, and insufficient forage availability (Pearson & Dawson, 2003). One group of species where knowledge of climate envelopes, and species' ability to fill them, are of particular importance is wild bees. In Great Britain, wild bees comprise 270 species (Falk, 2019), many of which provide important pollination services to a wide range of wild and cultivated plants valued at approximately £630 m/year (Breeze et al., 2021).

The geographic extent of pollination by wild bees is dependent on both species' climate envelopes and the ability of a species to fill its climate envelopes, and this can have important consequences for the spatial overlap between pollinators and plants, both wild and cultivated (Gorostiague et al., 2018; Polce et al., 2014). A species' ability to fill its climate envelope has been linked to a variety of life-history traits across different taxa, including mammals, birds and plants. Such traits include habitat breadth (habitat generalists are better at filling their climate envelopes than specialists), diet breadth (diet generalists are better at filling their climate envelopes than specialists), and overwintering stage (species that overwinter in adult stages are better at shifting ranges than those overwintering in less developed stages) (Estrada et al., 2015; Morimoto, 2020; Pöyry et al., 2009). Body size has also been linked to geographic distributions of insects (Calosi et al., 2010; Pöyry et al., 2009). The importance of these traits in various other taxa indicates that they may also be important predictors of climate envelope filling in wild bees.

Many species, including wild bees, are undergoing shifts in climate envelopes in response to changing climate (Wyver et al., 2023), and understanding both current and future climate envelopes is important from both species' conservation and ecosystem service perspectives (Senapathi, et al., 2021a). Equally important is understanding why some species do not fill their entire climate envelopes. If a species is not present in a climatically suitable area, its absence may be due to other environmental factors, such as unsuitable habitat type and inadequate dispersal ability to overcome geographic barriers (distance or physical barriers) between existing populations and uncolonised areas (Estrada et al., 2018), with species that fill greater proportions of their climate envelope facing fewer barriers, and/or being better able to overcome barriers. There are a range of non-climatic factors that influence a species' ability to fill its climate envelope, and these can be grouped into two primary categories.

Where species do not fill their climate envelopes, it is likely caused by a combination of (i) dispersal limitation, where a species cannot disperse far enough to reach a new site, driven by a species' intrinsic dispersal ability and extrinsic barriers to dispersal (Baselga et al., 2012; Munguía et al., 2008), and (ii) unsuitable/insufficient habitat and resources—where a species can reach a new site, but the new site contains unsuitable or insufficient nesting and/or foraging resources (Gaston, 2009).

Dispersal limitation has been shown to be a major driver of a species' ability to fill its climate envelope in a wide variety of taxa including plants (e.g., Arnell & Eriksson, 2022; Seliger et al., 2021) and mammals (Munguía et al., 2008). Poor dispersal has previously been linked to physical barriers (Dániel-Ferreira et al., 2022), which are becoming larger owing to increased habitat fragmentation (Fletcher et al., 2018). Relatively little is known about the dispersal capabilities of wild bees in Great Britain (Torné-Noguera et al., 2014), although dispersal ability may be linked to body size (Greenleaf et al., 2007), with bigger bees generally able to fly farther than smaller bees. A further barrier to dispersal could be development time, which will influence how quickly a species can respond to favourable climate and ultimately how long it has to disperse. Stevens et al. (2014), for example, found that aerial dispersers with good dispersal ability tended to overwinter in more advanced developmental stages than those with poor dispersal.

Different species have different levels of generalism when it comes to diet breadth, which in the case of bees is characterised by pollen foraging specialisation ("lecty") (Robertson, 1925), and habitat requirements. There are conflicting theories as to whether generalists or specialists are better at dispersing. It is possible that generalists are better at dispersing than specialists, owing to a higher likelihood of finding suitable habitat. Conversely, specialists may be better at dispersing than generalists, owing to their need to be able to move greater distances to find suitable habitat and resources (Martin & Fahrig, 2018).

Loss of suitable habitat and increased habitat fragmentation have occurred in Great Britain, with marked declines in heathland and grassland, and increases in urban and arable areas occurring since 1950 (Senapathi, Biesmeijer, et al., 2015a), as well as increases in barriers to dispersal such as roads (Fitch & Vaidya, 2021). The loss of suitable habitat also has impacts on the ability of bees to fill their climate envelopes, both by reducing the area of suitable habitat within the climate envelope and reducing the ability to maintain viable populations in the smaller, more fragmented patches of suitable habitat. Given the historic loss of important habitats such as heathland and grassland (Senapathi, Biesmeijer, et al., 2015a), there are likely to be fewer feeding and nesting resources available in the landscape, ultimately resulting in landscapes with fewer bees. Traits including habitat specificity and lecty are likely to be linked to how well a species can cope with the loss of suitable feeding and nesting habitat, and thus fill its climate envelope.

A third potential reason why a species may not appear to be present in its climate envelope is that it is data deficient. It may be the case that a species already exists in an area, but it is not adequately documented (Rocha-Ortega et al., 2021). Data used to assess a species' ability to fill its climate envelope often comes from presence-only observations from publicly accessible databases such as GBIF (GBIF, 2024a) or datasets held by organisations such as the Bees, Wasps, and Ants Recording Society (BWARS – www.bwars.com). Opportunistic citizen science datasets often come with biases towards easy-to-detect species in easy-to-access locations (Cretois et al., 2021), meaning that a species not being found in an area could be due to a lack of sampling effort.

Choosing between conservation priorities, such as focussing on reversing habitat fragmentation or improving existing habitat, is an important part of conservation planning. The complex nature of these three drivers of apparent climate envelope filling success (dispersal limitation, unsuitable/insufficient habitat and resources, and insufficient data) therefore pose challenges for policymakers and conservation practitioners, and understanding why a species is not present in a climatically suitable area is crucial for informing conservation policy and practice. Understanding the barriers to climate envelope filling is particularly important in the context of climate change. Previous research predicted that the climate envelopes of wild bees will shift under future climate scenarios (Wyver et al., 2023). Investigating how life-history traits influence climate envelope filling can therefore provide valuable insights into which species may struggle to adapt, and may require additional support to overcome these barriers, preventing them from shifting their distributions in the face of a changing climate.

This study looks to build on Wyver et al. (2023) by answering the question 'Do life-history traits of British wild bees influence their ability to fill their climate envelopes?' through the following hypotheses:

1. Species with limited dispersal abilities will occupy a smaller proportion of their climate envelopes compared with species with greater dispersal capacities, as species with greater dispersal capacity can access a larger part of their climate envelopes (Arnell & Eriksson, 2022; Munguía et al., 2008).
2. Species that rely on specialised feeding resources will occupy a smaller proportion of their climate envelopes than those able to feed on a wider variety of plants, as less of their suitable climate envelope contains suitable resources for species' persistence (Martin & Fahrig, 2018).
3. Species that rely on specific habitats will occupy a smaller proportion of their climate envelopes compared with species able to survive in a wider variety of habitats, as less of their suitable climate envelope contains habitat suitable for species' persistence (Martin & Fahrig, 2018).

TABLE 1 Description of bee traits used as explanatory variables in analyses of range-filling ability.

Trait	Levels	Description
Lecty (categorical)	Polylectic	Forages on a wide range of plants
	Oligolectic	Forages on a restricted range of plants
	Clepto- and social parasites	Does not visit plants to forage
Overwintering Stage (categorical)	Adult (female only)	Species that hibernate as adults and which mate prior to hibernation with males dying in the Autumn
	Adult within cocoon	Species which overwinter as adults within cocoon
	Adult (within brood cell)	Species which overwinter as adults, but make no cocoon.
	Prepupa	Species which overwinters as prepupa.
Habitat breadth (categorical)	Ranges from 1: Extremely Specialist to 5: Extremely Generalist	Based on habitat specificity according to European Red List of Bees (Nieto et al., 2014).
Body size (continuous)		Mean intertegular distance, measured in mm.

METHODS

Traits

This study combined four life-history traits with climate envelope filling ability for 64 species of wild bees in Great Britain. These 64 species were selected as they have existing climate envelope models and are well represented in the dataset used to calculate range filling. Selected traits were habitat breadth, lecty (foraging specialisation), overwintering stage and body size (logged to conform with assumptions of normality; Table 1). Intertegular distance (ITD—defined as the distance between the bases of the wings on the thorax (Raiol et al., 2021)) was used as a proxy for body size (Cane, 1987). ITD was calculated as the mean value of multiple female specimens of each species (the exact number of specimens varied by species). Habitat breadth was classified as the number of habitats suitable for each species, as categorised in the European Red List of Bees (Nieto et al., 2014). Body size, lecty and overwintering stage were obtained from a database curated by S.P.M. Roberts. Traits for each species can be found in Table S1.

Climate envelope models

Climate envelopes were taken from previously developed climate envelope models derived from a long-term database of bee recordings held by the Bees, Wasps, and Ants Recording Society (www.bwars.com) developed in Wyver et al. (2023) at 0.0155° gridded resolution. Climate envelopes were modelled using six bioclimatic variables previously used in British pollinator distribution modelling exercises (Polce et al., 2014) derived from the UK CHESS-SCAPE project (Robinson et al., 2023), and produced using the MaxEnt modelling software (Phillips et al., 2008). Detailed descriptions of previously developed climate envelope models can be found in Wyver et al. (2023). This method included initially subsetting the 270 species of wild bees in Great Britain to include only species with 20 or more records (88 species), and climate envelope models were validated by testing whether they were significantly better than a random expectation using bias-corrected null models (Raes & Ter Steege, 2007), resulting in a total of 64 species available for analysis. Additionally, at 0.0155° resolution, many cells contained no presence records; therefore, climate envelopes were resampled to 0.155° gridded resolution.

To ensure that traits were not influencing the initial climate models, and therefore influencing estimates of the relationship between traits and climate envelope filling, a linear model with a gaussian error family was used to test the relationship between climate envelope size developed in Wyver et al. (2023) and life-history traits. It is possible, however, that the climate envelopes (and subsequent ability to fill these envelopes) of closely related species may resemble each other more than a species randomly drawn from the same phylogenetic tree (Blomberg et al., 2003). Therefore, the phylogenetic signal was tested using Pagel's λ, calculated via the *phylosig* function in the "phytools" package (Revell, 2012). The estimated λ was 0.034 ($p = 0.62$), indicating no significant phylogenetic signal in the data, and that linear models were appropriate. Information about the phylogenies of each species was downloaded from the Bee Tree of Life (Figure S1) (Hedtke et al., 2013). No traits had a significant influence on the size of the climate envelopes developed in Wyver et al. (2023), indicating subsequent results reflect biological processes and not modelling artefacts (Table S2 for initial model results). Multicollinearity among predictors was tested using variance inflation factors (VIFs), which showed no evidence of multicollinearity. Model diagnostics were checked using the "DHARMa" package (Hartig, 2022).

Calculating climate envelope filling ability

The ability of a species to fill its climate envelope was calculated as the percentage of grid squares classified as having suitable climate (derived from BWARS data as described previously) containing a presence record from an independent dataset. Presence records were obtained from the Global Biodiversity Information Facility (GBIF, 2024a), including observations for all Hymenoptera (excluding the managed honeybee, *Apis mellifera*) in Great Britain between 2010 and 2019 (GBIF, 2024b). Each record was assigned to a grid square (on the same grid scale as the rescaled climate envelope model) based on its latitude and longitude. No BWARS data is included in the GBIF dataset, and vice versa.

To improve the probability that cells without observations are true absences, all data analyses were carried out only for areas with high sampling effort – also known as "low ignorance" areas (Ruete, 2015). Using low ignorance areas helps overcome issues related to sampling effort and the detectability of rare and small species which are often underrepresented in opportunistic citizen science data (Callaghan et al., 2021). Low ignorance areas were identified following the methodology used by Arnell and Eriksson (2022), who implemented low ignorance maps to identify areas with high sampling effort in Swedish woody plants. Data for all Hymenoptera (excluding *A. mellifera* – 1569 species, 347,731 records) were used to produce a low ignorance map for Hymenoptera within Great Britain. The number of species present in each grid cell was counted, and only grid cells with 20 or more species recorded were used in the climate envelope filling analysis (Figure 1). A bee species was considered if it had 80 or more presence records in the GBIF dataset to ensure that its distribution was accurately represented within the low-ignorance areas, resulting in a total of 64 species available for analysis (Note: *Bombus distiguendus* met this threshold but was also removed from analysis due to its extremely restricted suitable climate envelope).

Impact of traits on climate envelope filling ability

Climate envelope filling ability was calculated as the percentage of cells classified as climatically suitable from the climate envelope

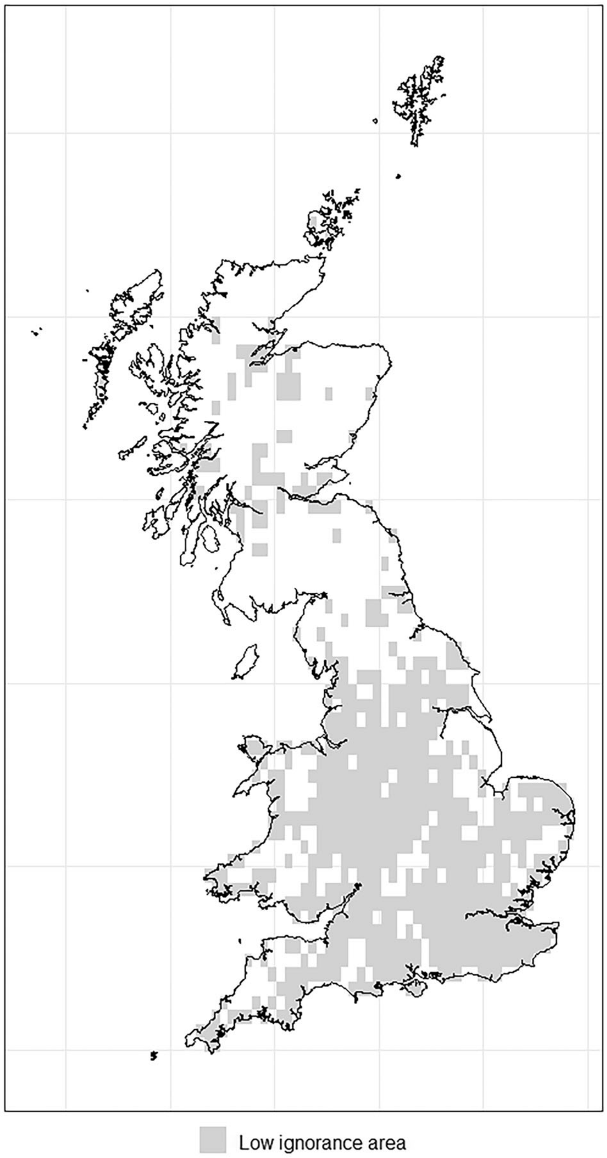

FIGURE 1 Map of Low Ignorance Areas for Hymenoptera recording in Great Britain 2010–2019. Area in grey is the area used in range-filling analysis.

models derived from BWARS data containing a bee observation from the GBIF dataset. The percentage of suitable cells in the climate envelope containing a presence record was used as the dependent variable in a generalised linear model with a Gamma distribution and a log link function, with the logged body size, lecty, overwintering stage, and habitat breadth as potential explanatory factors. Again, multicollinearity among predictors was tested using variance inflation factors (VIFs), which showed no evidence of multicollinearity, and model diagnostics were checked using the "DHARMa" package (Hartig, 2022). To test for pairwise differences between levels of categorical variables shown to have a significant effect on climate envelope filling ability, estimated marginal means were calculated using the "emmeans" package (Lenth, 2022), and pairwise comparisons of the estimated marginal means were conducted with multiple comparison adjustments

(Tukey's honest significant difference) as a post hoc test. All statistical analyses were carried out using RStudio v 2024.09.1 (R Core Team, 2020).

RESULTS

Climate envelope filling varied between species, ranging from 9.7% (*Epeolus cruciger*) to 128.3% (*Bombus lapidarius*) of suitable climate cells within the low ignorance area containing an observation (Figure 2). Across all species, mean climate envelope filling was 43.8%.

Species traits appeared to have a significant impact on the ability of a species to fill its climate envelope (Table 2). Body size was a key determinant of climate envelope filling success, with larger bees filling more of their climate envelopes than smaller bees (Figure 3a). Climate envelope filling was predicted to increase from 33.6% (25.5%, 41.8%) to 60.7% (44.9%, 76.5%) when body size (ITD) was doubled from 2.5 to 5 mm (mean value across all combinations of other traits – figures in brackets indicate 95% confidence intervals).

Polylectic species appeared to fill significantly more of their climate envelope than those that had a restricted foraging breadth, and those species reliant on other species to survive (i.e., clepto- and

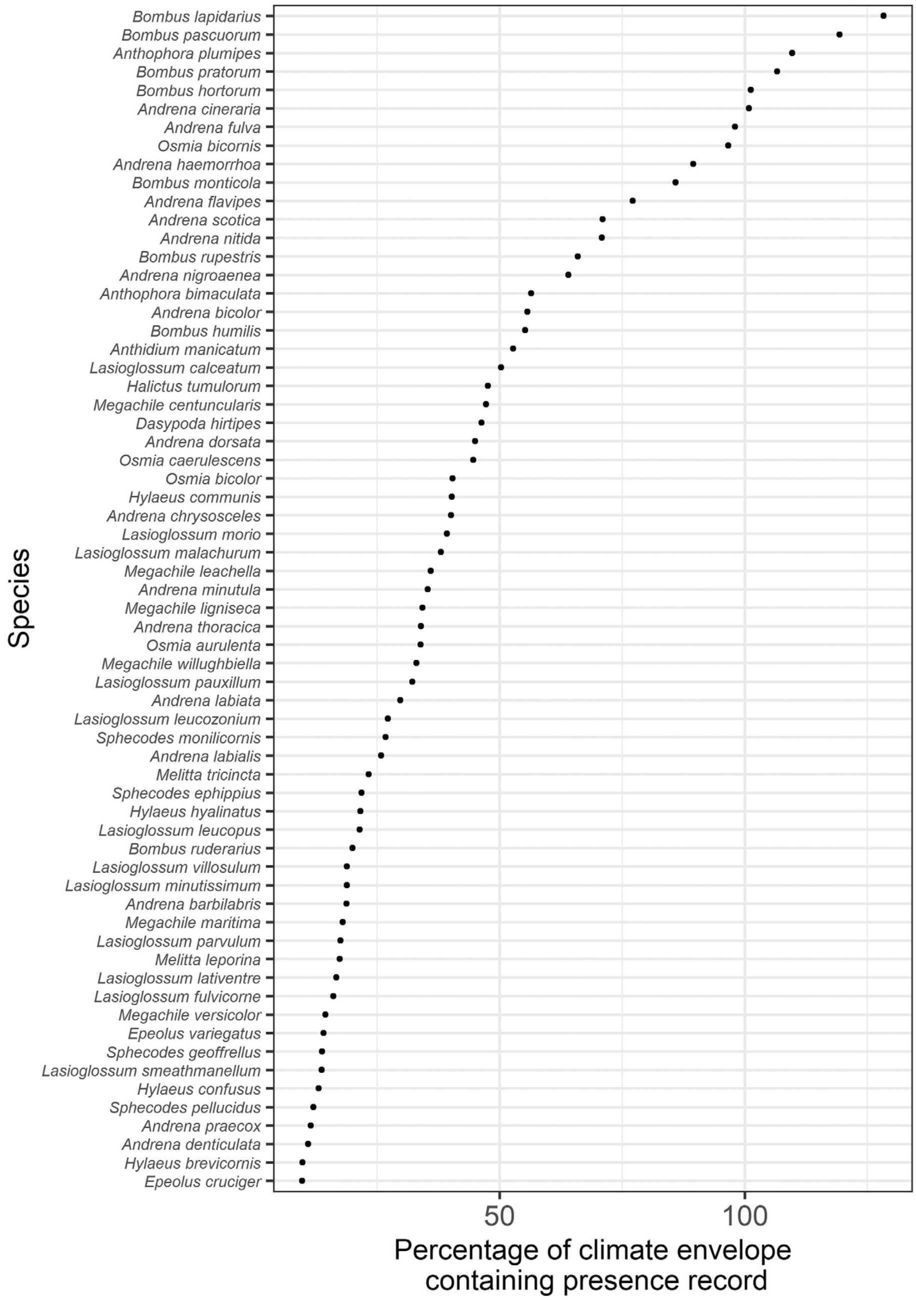

FIGURE 2 Range filling ability of 64 species of bee. Range filling ability is calculated as a percentage of the suitable climate cells containing a presence record (restricted to only include low ignorance areas).

TABLE 2 Linear model output showing influence of species' life-history traits on range filling ability. Reference categories are habitat breadth: 1, Lecty: Polylectic and overwintering: Prepupae.

Term	Estimate	SE	*z* value	Pr(>|*z*|)	
Habitat. breadth: 2	0.57	0.22	2.54	0.014	*
Habitat breadth: 3	0.57	0.20	2.86	0.006	**
Habitat breadth: 4	0.62	0.22	2.79	0.007	**
Habitat breadth: 5	0.83	0.31	2.68	0.009	**
Lecty: Oligolectic	−0.64	0.22	−2.90	0.005	**
Lecty: Clepto- and social parasite	−0.45	0.19	−2.36	0.021	*
Log (body size)	0.85	0.12	7.08	<0.001	***
Overwintering: adult within cocoon	0.25	0.21	1.17	0.247	
Overwintering: adult within brood cell	0.33	0.17	1.90	0.063	
Overwintering: adult (female only)	0.23	0.15	1.52	0.134	

social parasites; Figure 3b). A polylectic bee was predicted to fill 43.7% (30.7%, 56.8%) of its suitable climate area compared with 22.9% (13.6%, 32.3%) for an oligolectic bee and 27.8% (17.0%, 38.7%) for a clepto- or social parasite (mean value across all categorical traits, body size held constant at the median value). There was no significant effect of habitat specificity or overwintering stage. Pairwise comparisons of estimated marginal means revealed significant differences in climate envelope filling ability between levels of lecty, with significantly greater climate envelope filling in polylectic bees compared with oligolectic bees ($p = 0.015$).

Habitat generalists also appeared to fill significantly more of their climate envelopes than habitat specialists, with a species suited to five habitats according to the European Red List of Bees predicted to fill 41.8% (28.5%, 55.0%) of its climate envelope, compared with a species suited to just one habitat, which was predicted to fill 18.1% (13.6%, 22.6%). Pairwise comparisons of estimated marginal means showed significant differences between species capable of surviving in three habitats and those capable of surviving in just one ($p = 0.046$).

DISCUSSION

This study makes use of two large, separate datasets (BWARS and GBIF) of British wild bees to produce a quantitative analysis of bee climate envelope filling ability and the extent to which climate envelope filling ability is driven by life-history traits. Different species filled different proportions of their climate envelope, with larger, generalist bees (both in terms of habitat and foraging generalism) appearing to fill more of their climate envelopes than smaller, more specialist species. Whilst the results here may seem unsurprising -that traits relating to foraging generalism and body size are determinants of successful climate envelope filling- they provide important insights into some of the challenges faced by wild bees in Great Britain.

Body size was a significant determinant of climate envelope filling success, with climate envelope filling higher in larger bees. There are a range of reasons why larger bees appear to fill more of their climate envelopes. Firstly, although there is currently little empirical evidence relating to dispersal distances (Torné-Noguera et al., 2014), it is likely that larger bees have better intrinsic dispersal abilities (i.e., able to fly farther) (Greenleaf et al., 2007) and, therefore, are better able to overcome barriers to dispersal. Larger bees have indeed been found to fly over greater distances when foraging (Greenleaf et al., 2007), and therefore, it could be that they can also disperse farther. If this is the case, it means larger bees might be able to overcome larger distances between suitable habitat patches, and more substantial physical barriers to dispersal, and therefore, could access a larger part of their climate envelope.

Lecty, or pollen foraging specialisation, was also found to be important in determining a species' climate envelope filling ability. Alongside being able to access a new area, it is important that suitable forage plants and nesting resources are available for a population to establish (Gaston, 2009). For many generalist species, this is of minimal concern, as the wide variety of suitable habitat and resources increases the likelihood that a species will encounter suitable resources (Angert et al., 2011). Conversely, for bees that rely on a limited range of plants, the lack of suitable habitat and resources is a much greater concern, as their distribution is closely tied to the availability of their specific forage. The same applies to bees in the clepto- and social parasites group, whose distributions are limited to those of their host species, since the hosts must be present for the parasites to reproduce.

Habitat breadth was also a significant driver of climate envelope filling ability, with species able to utilise a wider range of habitats filling more of their climate envelope than species restricted to specific habitats. This is perhaps unsurprising, as the narrow environmental tolerance of a habitat specialist is likely to create more barriers than for a habitat generalist with wider environmental tolerances (Büchi & Vuilleumier, 2014). There are also likely to be other traits not tested here which could influence climate envelope filling, as data are missing for many species. Unexplored traits could include nesting substrate, which could be expected to act in the same way as habitat breadth, with species with narrow nesting requirements facing more fragmented conditions than generalist nesters (Martin & Fahrig, 2018).

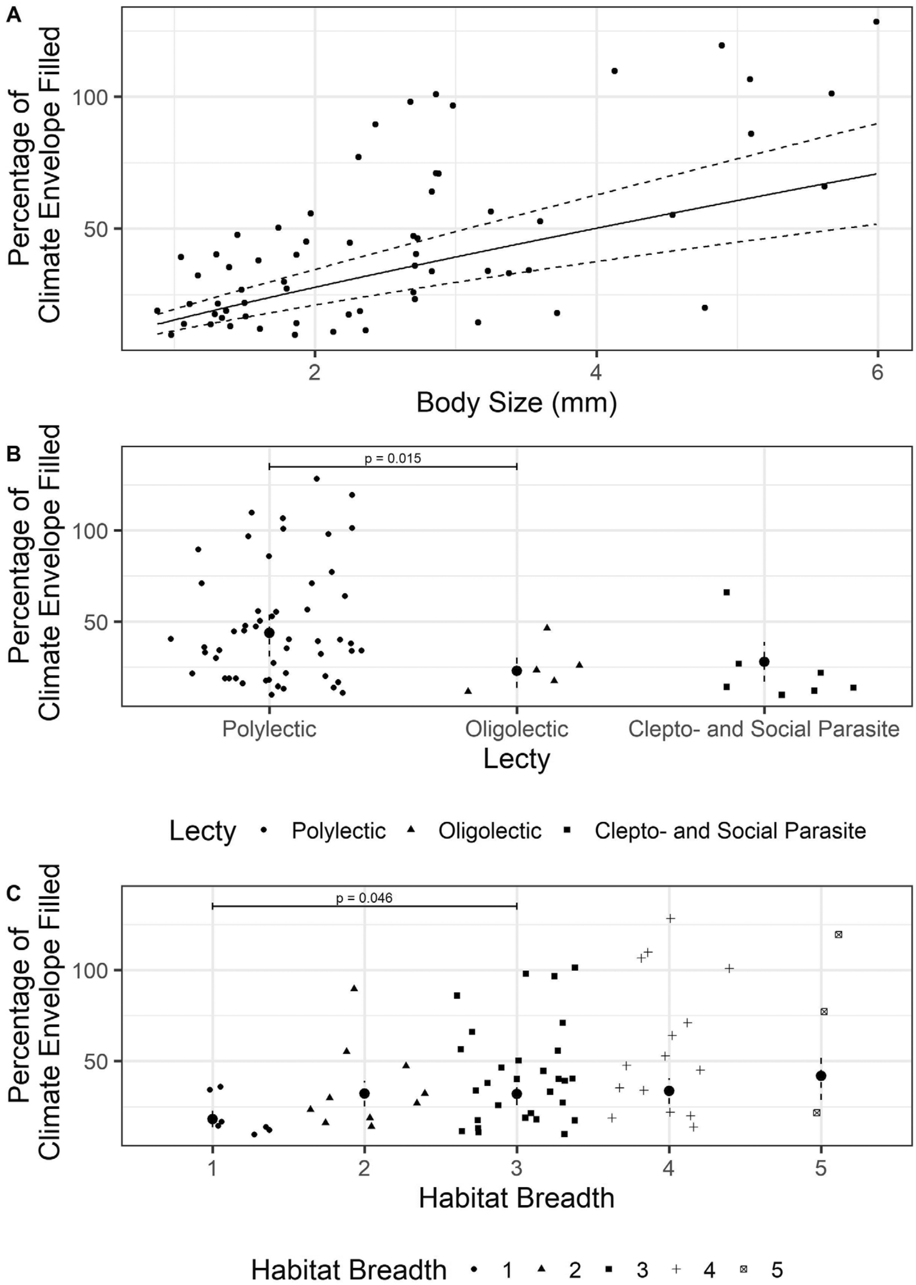

FIGURE 3 Linear model output predicting impact of (A) body size, (B) lecty and (C) habitat breadth on range filling ability. Dashed lines indicate 95% confidence intervals. Habitat breadth classes 1–5 refer to the number of suitable habitats according to the European Red List of Bees (Nieto et al., 2014).

Fecundity and life span could also be drivers, as species that have more offspring and are active for a greater period of the year may have a greater chance of successful dispersal and survival in new areas (Estrada et al., 2018). Overwintering stage was not found to be a significant driver of climate envelope filling ability, despite the expectation that species that overwinter in more advanced developmental stages will be better able to capitalise on optimal conditions and, therefore, have more time to disperse (Martin & Fahrig, 2018).

The finding of body size as a predictor of climate envelope filling ability could also be related to data limitations. Larger bees are often easier to spot and identify, and as a result, larger bees could be overrepresented in the BWARS and GBIF datasets. Larger bees being easier to detect has been observed in comparisons of a different opportunistic citizen science scheme, iNaturalist, with collections-based schemes of bees (Turley et al., 2024). This issue is controlled to a certain extent in this study through the use of only data-rich species in low-ignorance areas.

The fact that some very generalist species, such as *B. lapidarius* and *B. pascuorum*, already exist in areas outside of their climate envelope (more than 100% climate envelope filling) indicates high levels of adaptability to climate conditions and habitat and flexible resource specificity. Alongside high levels of adaptability, there are several other reasons for species appearing to fill over 100% of their climate envelope. This analysis was carried out at 0.155° gridded resolution. It is possible that in cells falling outside the suitable climate envelope, fine-scale microclimate conditions within the cell may be suitable for the activity of a species (Lembrechts et al., 2019). It is also possible that observations outside the suitable climate area could represent sink populations, sustained by dispersal from core areas but not viable in the long-term (Gaston, 2009).

When considering the traits that influence climate envelope filling (body size, habitat breadth and lecty) in the context of the three challenges presented earlier in this study (dispersal limitation, unsuitable habitat and resources, and insufficient data), it is probable that all three factors are influencing the climate envelope filling ability of British wild bees to some degree. The results presented here have important consequences for current and potential future biodiversity and ecosystem services bees provide. It has been suggested that climate envelope filling can be used as a proxy for capacity to undergo distributional shifts in the face of a changing climate (Estrada et al., 2018). If this is the case, it is likely that larger, generalist species will be better at adapting to climate change and colonising new areas in the future.

Should climate envelopes change in the future, which is predicted in Wyver et al. (2023), Great Britain may experience a homogenisation of bee communities. Future communities could be dominated by large, generalist species, which are better equipped to expand into their new climate envelopes than smaller, specialist species. The issue of community homogenisation by species better equipped to fill their climate envelopes is a complex topic in the context of conservation. From a crop pollination perspective within the context of Great Britain, community homogenisation may be beneficial, especially for pollination, given that much of the pollination service is carried out by a small subset of the overall bee fauna (Kleijn et al., 2015), including generalists such as *Bombus lapidarius* and *Bombus pascuorum*.

Conversely, the loss of species diversity can lead to less resilient communities and less stable interannual pollination supply (Senapathi, 2021b). Another school of thought is that species have a right to live, and that every species is a "natural share-holder of the biosphere with an inherent right to survival" (Kassas, 2002), In this case, ecosystem service provision alone is an insufficient argument for conservation, and a more holistic approach should be encouraged (Senapathi, Carvalheiro, et al., 2015b).

Whilst recommending conservation priorities is beyond the scope of this study, it does highlight the difficult decisions conservation planners will have to make regarding which species to target for support. This study presents an initial exploration of bee climate envelope filling ability, and further research is recommended, ideally using systematically collected data to better overcome the inherent biases present in presence-only data. This will allow for the refining of the models presented here and to begin to tease apart the individual challenges of dispersal limitation, unsuitable habitat and resources, and to improve the datasets available for this analysis.

In conclusion, this study highlights the importance of life-history traits in determining the ability of British wild bees to fill their climate envelopes. It shows that large-bodied generalists are in a better position to fill their climate envelope than smaller, more specialist species, and that careful conservation planning is needed to determine the future wild bee community in Great Britain. Whatever the conservation priority, be it ecosystem service-based or a more holistic approach, providing more, bigger, better-connected patches of habitat will be essential if wild bees are going to respond successfully to uncertain future climates.

AUTHOR CONTRIBUTIONS

Chris Wyver: Conceptualization; methodology; formal analysis; writing – original draft; writing – review and editing. **Simon G. Potts:** Supervision; writing – review and editing. **Stuart P. M. Roberts:** Data curation; writing – review and editing. **Deepa Senapathi:** Conceptualization; methodology; writing – review and editing; supervision.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data used in this manuscript are available from the Dryad Digital Repository. https://doi.org/10.5061/dryad.3j9kd51sb. Wyver and Roberts (2025).

ORCID

Chris Wyver https://orcid.org/0000-0002-8661-0859
Simon G. Potts https://orcid.org/0000-0002-2045-980X
Deepa Senapathi https://orcid.org/0000-0002-8883-1583

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1. Traits of species used in the analysis.

Table S2. Model summary showing relationship between climate envelope size (developed in Wyver et al. (2023), and life-history traits.

Figure S1. Tree showing phylogenetic relationship between species used in this analysis.

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