Full title

Bridging biodiversity and gardening: unravelling the interplay of socio-demographic factors, garden practices, and garden characteristics

Running title

Social drivers, synergies and trade-offs in biodiversity-focused gardening

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Abstract

The expansion of urban areas poses a threat to biodiversity, disrupting essential ecological relationships and jeopardizing fragile ecological networks, thereby impeding key ecosystem services. To avert irreversible consequences, there is a global imperative for well-planned and sustainable urban environments, with a focus on improving the biodiversity value of domestic gardens for both human well-being and conservation. To untangle the complex interplay among socio-demographic factors, garden management, and garden characteristics we employed machine learning and network analysis methods and examined garden care practices and garden owners' environmental consciousness in Hungary. We found that biodiversity-positive activities were widespread among garden owners, but a lack of undisturbed areas and frequent mowing were also present along with the ubiquitous use of pesticides. Middle-aged respondents demonstrated more biodiversity-supporting activities compared to those over 55, who had long-term gardening experience and were predominantly engaged in conventional gardening practices. Residents of towns showed the least biodiversity-positive activities, whereas those living in cities and the countryside fared better. Additionally, multiple interconnected garden characteristics revealed various types of gardens distinguished by care practices and use, such as gardens with a predominance of plants suitable for consumption, those with primarily ornamental function, or prioritizing biodiversity support. Our findings suggest that strategies, developed in Western-European countries to promote biodiversity-friendly gardening practices may not be suitable for countries with different cultural backgrounds, such as Hungary, where conventional gardening practices, notably extensive pesticide use, are widespread, and environmental consciousness is lower. In particular, factors such as the lack of social trust and an ageing society underscore the preference for in-person programs over online information transfer among specific societal groups. This study offers fresh perspectives on the intricate connections between garden diversity, characteristics, and practices, and it lays the groundwork for future research into the sociological drivers of gardening practices in Eastern Europe. Our work also emphasises that optimizing domestic gardens for multiple ecosystem services, including biodiversity conservation and enhancing well-being across diverse societal groups, requires a nuanced understanding of both ecological and socio-demographic factors.

Keywords: urban ecology, domestic gardens, environmental consciousness, sustainable gardening, environmental sensitivity

Introduction

The expansion of urban areas poses an increasing threat to biodiversity, negatively affects crucial ecological relationships and threatens fragile complex ecological networks (Hagen et al., 2012), which, in turn, hamper ecosystem services such as pollination and biological pest control, and ultimately human well-being (Jabbar et al., 2022). In order to avoid reaching a state when the result of these effects are irreversible, there is a global need for better better-planned and sustainable urban environment (Breuste et al., 2013; Heidt & Neef, 2008; Ramalho & Hobbs, 2012). One important aspect of these needs is improving the quality and quantity of urban green spaces, both for human well-being and biodiversity conservation (Baldock, 2020). Indeed, in some developed countries, the number of urban green areas (such as public parks, green roofs, and community and private gardens) is increasing (Kabisch & Haase, 2013) and their potential in multi-purpose sustainability development is increasingly recognised. Although 16 to 27% of urban green spaces in Europe belong to private owners (Goddard et al., 2010), the importance of private or shared gardens (e.g. community gardens) in influencing the quality of urban green ecosystem is often underestimated (Camps-Calvet et al., 2016).

Domestic/home gardens and allotments are green spaces in urban ecosystems where people usually cultivate various plants (mostly fruits, vegetables and ornamental plants), and areas they use for recreation, outdoor activities, or even to connect with nature (Bell et al., 2016). Indeed, as a popular pastime, gardening is beneficial to mental health and strengthens well-being (Krols et al., 2022). On the other hand, domestic gardens also have a great potential as habitat refuges for wildlife and they can strongly contribute to maintaining high biodiversity (Cameron et al., 2012).

The first studies aiming to detect the biodiversity of gardens in Western Europe and North America were conducted at the beginning of the 1990s (Delahay et al., 2023). Interest in the role of urban and suburban gardens in the preservation and support of urban ecosystems has increasingly gained interest since then (Delahay et al., 2023) and showed that even small, but resource-rich, garden habitats can significantly increase insect diversity (Griffiths-Lee et al., 2022) and support ecological services such as pollination, biological pest control or climate regulation (Andersson et al., 2007; Cavan et al., 2021). Gardens can function as ecological corridors or stepping stones for a multitude of organisms in the otherwise barren and often hostile urban landscape and, particularly when they have favourable habitat features (e.g. ponds, (Hill et al., 2021), can become local biodiversity hotspots (Baldock et al., 2019; Prendergast et al., 2022).

However, the true conservation potential of domestic gardens is governed by garden care practices; intensive garden management can negatively impact garden diversity as well as the gardens' environment (Fontaine et al., 2016; Lerman et al., 2018). There is a proven link between environmental degradation, the decline of the abundance and diversity of birds and insects, and environmentally aggressive gardening practices (Muratet & Fontaine, 2015; Tassin de Montaigu & Goulson, 2023a), such as the uncontrolled use and overuse of pesticides. The use of neonicotinoid-based insecticides, and herbicides containing glyphosate is of particular concern for insect biodiversity in gardens (Tassin de Montaigu & Goulson, 2023a, 2023b). Additionally, through spillover effects, the excessive fertilising with synthetic products (Law et al., 2004), the frequent irrigation (Egerer et al., 2018; Fernández-Cañero et al., 2011), as well as the introduction of potentially invasive ornamental plants (Süle et al., 2023) contribute to environmental degradation of not only the garden but also the adjacent areas.

Moreover, gardens can also provide ecosystem disservices, for instance, the increase of pests or disease-carrying insects (such as mosquitos and ticks), or wildlife causing fear or aversion. Indeed, recent studies highlighted a central role of garden owners' attitudes and consciousness in either promoting or impeding wildlife-friendly gardening. Wildlife-friendly gardening is a multifaceted issue which is influenced by several factors, such as demographics, socio-demographic drivers, motivations for gardening (García-Antúnez et al., 2023; Philpott et al., 2020), and appreciation for nature (Clayton, 2007), as well as trust in environmental associations and access to biodiversity-related information (Coisnon et al., 2019) and various management practices (Goddard et al., 2013).

For this reason, it is necessary to find and maintain a balance between the ecosystem services and disservices provided by the gardens, and it is key to gain a mechanical understanding of how gardeners' cultural background, their aim for gardening, and their connection with the natural environment in their garden can affect their willingness for optimising gardening habits and garden management for conservation benefits.

However, biodiversity-friendly gardening and gardening practices are intertwined with the type and layout of the garden, as well as with the presence or absence of certain plants and this interconnected system is likely to be further shaped by socioeconomic factors. Little research has been done so far to untangle the joint impact of linked gardening practices, garden characteristics, socio-demographic parameters, and motivations for gardening, and it also remains unclear how tightly garden and garden owner characteristics are linked, and which combination of these, leads to biodiversity-friendly gardening practices.

Yet, if these were to show clear patterns, they could provide an easy means to assess the gardens' potential for supporting biodiversity or whether they could serve as parts of a habitat network that supports biodiversity. With this information, specific recommendations could also be suggested to guide favourable modifications in gardening habits, leading garden owners toward environmentally friendly practices.

Thus, in this study, we use a combination of methods of machine learning and network analysis to investigate how gardening practices, motivation for gardening, and garden characteristics can influence biodiversity-friendly gardening. We paid particular attention on the interlinked characteristics of gardens and gardening practices and examined how socio-demographic factors influence biodiversity-positive or -negative practices. Nonetheless, our ultimate goal is to explore pathways for maximizing conservation benefits and, at the same time, maintaining or improving human well-being linked to domestic gardens and gardening.

We focused our work on Hungary, a country characterized by conventional gardening practices in home gardens, widespread in Eastern European countries, including excessive use of pesticides (Varga-Szilay & Pozsgai, 2022).

Material and methods

Questionnaire Design

We distributed an online questionnaire that consisted of 58 questions, with all but 4 questions requiring mandatory responses. These questions were organized into nine sections, covering: (i) garden location, (ii) socio-demographic parameters, (iii) garden characteristics, (iv-v) motivation and gardening practices, (vi) garden cultivation, (vii) pesticide usage, (viii) presence of insects (mostly pollinators) in the garden, and (ix) closing questions. The questionnaire was designed in Google Forms and it took 10 to 12 minutes to complete.

All responses were recorded anonymously, however, respondents could provide their email addresses. Respondents could indicate their education on a four-, their gender on a three-level scale (male, female, other), and their residency at a county-level (NUTS3, https://ec.europa.eu/eurostat/web/nuts/background, accessed 30th November 2023).

The questionnaire was actively spread between the 26th of October 2022 and the 1st Jun 2023 in Hungary. The questionnaire was distributed through gardening-related websites, various social media platforms (including Facebook and Instagram), and mailing lists. Additionally, we reached out for professional bodies, non-governmental organizations, gardening- and biodiversity-protection-related foundations, societies and organizations via email. Moreover, we used QR codes and hashtags to extend sharing efficiency.

As an important node, ‘pesticides’ were defined as all synthetic and non-synthetic products that are used to control pests. We included in the term all commercially available and homemade/self-made plant protection products, either those allowed in organic gardening/farming or used in conventional practices. The terms 'pesticide' and 'plant protection products’ were used as synonyms. Similarly, the terms ‘domestic garden’, ‘house garden’, and ‘home garden’ were used as synonyms and the term ‘gardening’ included all garden work and all garden care practices, such as the cultivation of flowers, fruits, vegetables, and ornamental plants, mowing, and soil management.

In our interpretation, unmown patches refer to areas which otherwise would be mown but garden owners (intentionally) avoid mowing them, while undisturbed areas/fallow were permanently undisturbed areas that are independent of mowing.

The No Mow May campaign (NMMc) urged garden owners not to mow their lawns in May, as this is the month with the most abundant food sources for pollinators (Plantlife’s No Mow May Movement, https://www.plantlife.org.uk/campaigns/nomowmay/, accessed 30th November 2023) in the Northern Hemisphere. Since this campaign was adopted in Hungary, translated as ‘Vágatlan Május’, and widely promoted across the country, as well as its biodiversity-friendly approach had a clear relevance to our study, we asked the respondents about their knowledge/participation.

Data processing

For the analysis, we used 27 questions from the original 58 ones. The original categorical responses were on a few occasions re-categorised for analytical purposes (for details, please see Supplementary Table 1). For instance, the answers of ‘My favourite hobby’, ‘A pleasant pastime’, and ‘Opportunity to exercise’ were merged into ‘Pastime’ and the ‘Duty’ and ‘Work’ original levels into 'Duty'. Respondents under the age of 18 (n = 5) were excluded from the analysis.

Due to methodological constraints, for parts of the analysis we used binarized data (see below). Some of our questions inheritably had binary responses (Yes/No) but those with multiple choices were converted to binary variables by providing a separate data variable for each choice. Since they provide little information, yet burden computational processes, variables in which response agreement was over 95% were removed for the co-occurrence analysis (see below).

Statistical analysis

To investigate how garden characteristics and gardening practices were influenced by socio-demographic factors, a distance-based redundancy analysis (db-RDA) was conducted by using the binarized responses of all respondents as response variables and gender, age, education level, whether the respondents had children, and whether they lived in a city, town, or countryside, as explanatory variables. Distances were calculated using the Jaccard distance measure. The significance of the model, the axes, and the variables were tested using an ANOVA-like permutational test for Constrained Correspondence Analysis (CCA), with 999 iterations.

In order to assess the major garden characteristic and socioeconomic factors driving biodiversity-positive and biodiversity-negative gardening practices, we selected six and five (respectively) proxy variables to represent the extremes of these habits. The positives included the active support of pollinators either by water or nectar- and pollen-rich flowers (1); the active support of pollinators by natural (for example wildflower strips) (2); or artificial habitats (insect- or bee hotels, hoverflies-lagoons) (3); leaving unmown patches (4); having a pond (5) and complete avoidance of pesticides (6). The negative ones included the use of synthetic pesticides (1), herbicides (2) or synthetic fertilisers (3), having no undisturbed patches (4), and mowing the lawn very often (5). For each respondent, both 'good' and 'bad' attributes were counted, each of these values were rescaled to between zero and one and the biodiversity-negative values were set to their corresponding negative values. The sum of these values (biodiversity friendliness score, BDF score, henceforth) was used as the response variable for Gradient Boosting Machine (GBM) learning processes.

Highly subjective questions, such as garden owners' perceptions of their gardens as pollinator-friendliness and their willingness to participate in a garden network that helps maintain biodiversity, were excluded. All other garden characteristic, gardening practices, and socioeconomic factors, but those from which we calculated the BDF score, were included in the model as explanatory variables. For instance, since synthetic pesticide use was included among the biodiversity-negative practices, the variable coding pesticide use was excluded (see Supplementary Table 4 for the full list). After an optimalisation process (see code on https://github.com/zsvargaszilay/gardening_in_hungary), we fit the GBM model using a Gaussian distribution in 3 levels of interaction depth, with 0.1 shrinkage and 0.80 bag fraction on 85 trees. The model fit was evaluated by calculating the R-squared and root mean standard error (RMSE) values.

To improve interpretability, we used the SHapley Additive exPlanations (SHAP) of our GBM model. SHAP comprehensively assesses individual variable contributions, by considering variable interactions, assigns importance values and ensures fair comparisons through evaluations in all possible variable orders (Lundberg & Lee, 2017). For modelling and the visualization of model results, we used the '*gbm*' (Greenwell et al., 2022, version 2.1.8.1), '*caret*' (Kuhn et al., 2023, version 6.0-94), '*shapviz*' (Mayer & Stando, 2023, version 0.9.2) and '*kernelshap*' (Mayer et al., 2023, version 0.4.0) R packages in an R environment (R Core Team, 2021, version 4.3).

A probabilistic co-occurrence model analysis was used to investigate which responses were associated to each other. The analysis identifies pairwise associations based on the comparison of observed frequencies against those anticipated by chance. A positive association is inferred when the observed frequency exceeds the expected baseline and, conversely, a negative association is concluded when observed frequencies fall below the expected values (Veech, 2013). Only associations with probabilities over 0.6 were considered in the final networks.

We examined the interdependencies in the association network and recorded the answers which were the most connected to other answers. We considered positive associations as synergies and negative ones as antagonistic effects (trade-offs) in shaping gardening practices. Groups of densly associated responses (modules) were detected by the Louvain community detection algorithm (Blondel et al., 2008).

In order to identify the major socioeconomic factors driving these associations, we conducted a redundancy analysis (RDA) using the similarity of subnetworks built for varying socio-demographic backgrounds. First, we generated all unique combinations of the responses of five socio-demographic variables: 1) the respondent's gender (female, male, other); 2) age in three categories (younger than 36 years, between 36 and 55, and over 55); 3) whether the respondent lived in a city, a town, or in the countryside; 4) the respondent's highest level of education (middle and high), and 5) whether they have children. This yielded 108 unique combinations (e.g. a younger than 36-year old city-living female, with middle-level of education and children), which we individually used to query our dataset. If the query yielded at least 30 respondents, we used the same method as above to build association sub-networks. A matrix of either the positive (+1) or negative (-1) sign or the absence (0) of the pairwise associations in each query was used to conduct the RDA, with the five socio-demographic factors as explanatory variables and Bray-Curtis distance measures. An ANOVA-like permutation test for

CCA, with 999 permutations, was conducted to test the model significance, the significance of each canonical axis and that of the explanatory variables.

Preliminary data clean-up was done in a Python (Python Software Foundation, 2019, version 3.8) environment, with the help of '*NumPy*' (Harris et al., 2020) and '*Pandas*' (The pandas development team, 2022) libraries. All further data manipulation, analysis, and visualisations were conducted in R version 4.3, with the help of the '*cooccur*' (Griffith et al., 2016), '*dplyr*' (Wickham et al., 2023, version 1.1.2) '*ggplot2*'(Wickham, 2016), '*igraph*' (Csardi & Nepusz, 2006, version 1.5.1), and '*vegan*' (Oksanen et al., 2022, version 2.6-4) packages.

Results

Socio-demographic drivers

Of the 1260 people who completed the questionnaire, 343 were males (27.22%), 916 were females (72.70%), and one person's gender was not binary (0.08%). The majority of respondents were between 36 and 55 years old (53.10%). More garden owners with high education completed the questionnaire (n = 906, 71.90%) than with middle-level education (n = 385, 28.1%), and almost half of the respondents had children (n = 616, 48.89%). The questionnaire was mostly filled out for domestic gardens larger than 500 m^2 (n = 580, 46.03%) (for details of socio-demographic characteristics of the study population, please see the Supplementary Table 2). The willingness to respond was slightly unbalanced, with more respondents from the Western than from Eastern counties (Supplementary Figure 1). In terms of population, Zala county (HU223) was the most responding region (2.8 respondents for 100,000 inhabitants), and Szabolcs-Szatmár-Bereg county (HU323) was the least.

The constrained variables of the db-RDA model explained 3.72% of the total variance. The first and the second db-RDA axes explained 45.25% and 23.65% of the filtered variance, respectively (Figure 1). The model ($p \leq 0.001$) and all explanatory variables were significant (for details see the Supplementary Table 5). Although most garden characteristics and gardening practices were located close to the origin (indicating a low correlation), some were highly correlating with one or two explanatory variables. For instance, living in the countryside explained the large garden size and house garden type, and the age over 55 correlated positively with gardening for a long time. Furthermore, middle age and having children influenced similar garden characteristics (e.g. growing vegetables and having undisturbed areas) and gardening practices (e.g. producing crops for consumption). The same variables were negatively affected by living in town and having a middle-level education.

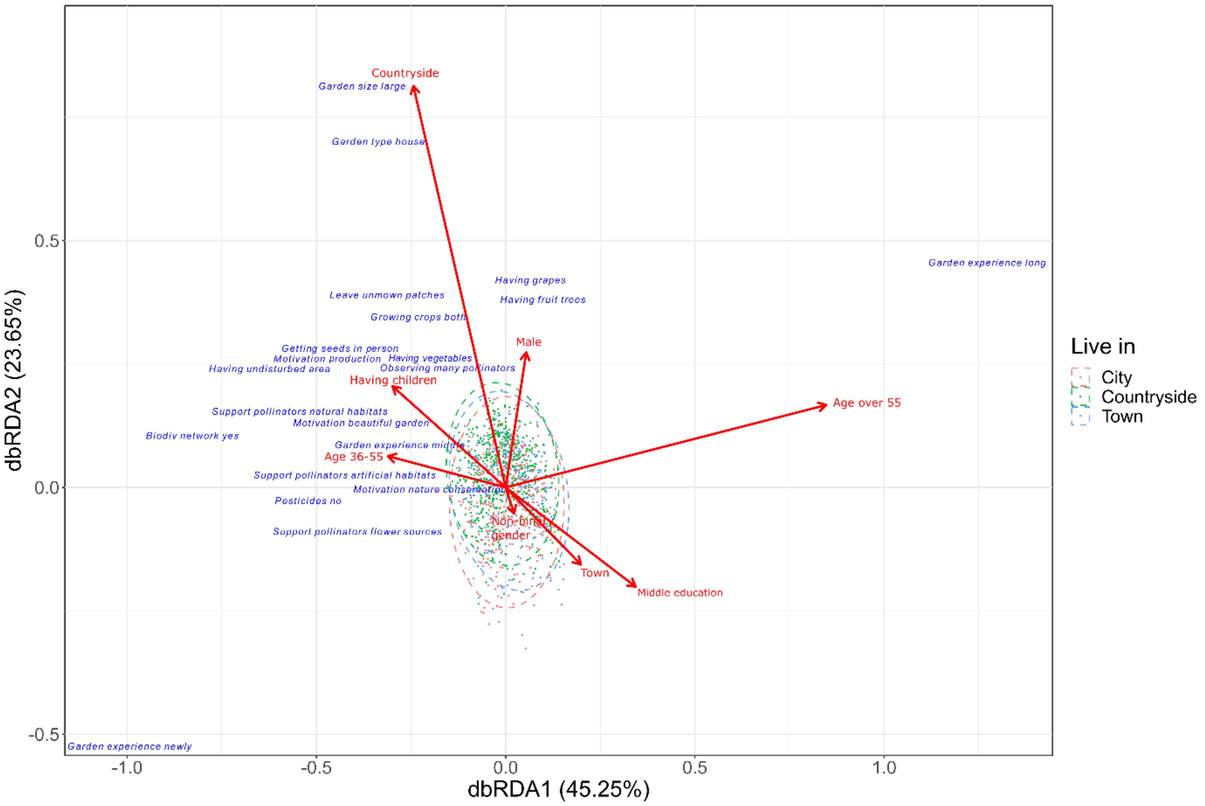

Figure 1: Distance-based redundancy analysis (db-RDA) plot showing the relationship among garden characteristics, gardening practices and socio-demographic (explanatory) variables. The length and direction of the vectors represent the strength and direction of the relationship. The ellipses represent the 95% confidence interval of the groups with different types of residency. Only garden characteristics and gardening practices (blue) whose RDA scores on the first two axes were lower than -0.2 or greater than 0.2 are shown.

Biodiversity-positive and -negative gardening practices

In the study population, the most common activity that had a biodiversity-positive effect in gardens was the supporting pollinators with water sources (n = 870, 69.05%) (**Figure 2**). This was followed by the supporting pollinators with pollen- and nectar-rich plants (n = 828, 65.71%) and establishing natural habitats (n = 827, 65.63%). Although a relatively large proportion of the respondents leave unmown patches (n = 786, 62.38%) when mowing, only 37.86% (n = 477) of the respondents avoid pesticides completely. Neither creating artificial habitats (such as bee hotels) (n = 423, 33.60%) nor joining the NMMc (n = 284, 22.54%) were common activities among the respondents. Only 184 respondents (14.60%) had a pond (Supplementary Table 3).

Among the gardening activities that may negatively impact domestic gardens' biodiversity, the lack of undisturbed areas (624 respondents, 49.52%) was the most common, followed by the frequent mowing (n = 404, 32.06%). Synthetic pesticides were used by 26.98% (n= 340) of the respondents, whilst herbicides (n= 190, 15.10%) and synthetic fertilizers (n = 158, 12.54%) were less often used (Figure 2 , Supplementary Table 3).

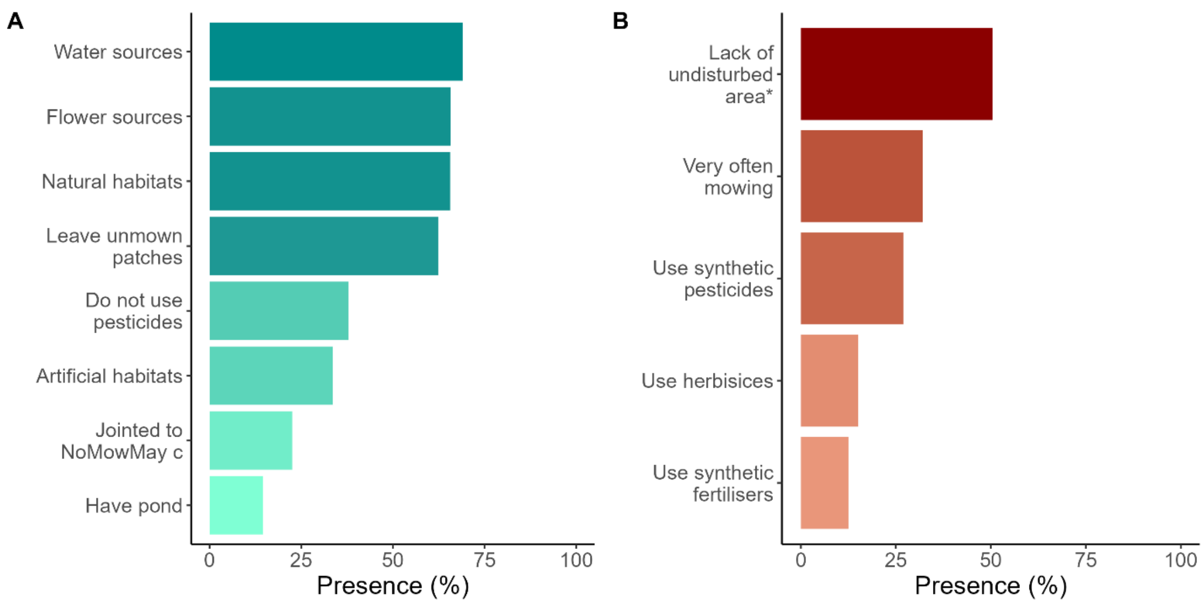

Figure 2: Presence (%) of the biodiversity-positive (A) and biodiversity-negative (B) gardening practices among respondents (n = 1260). Since to the question whether respondents had undisturbed areas (*) the 'no' answer was considered as a biodiversity-negative practice, in this figure, the percent of 'no' answers is shown.

The GBM model suggested that the best indicators for predicting whether gardening practices can be considered as biodiversity-positive or biodiversity-negative were the number of pollinator groups garden owners usually observe (relative influence: 11.68) and the type of the gardens, such as village garden or kitchen garden (relative influence: 9.14) (Supplementary Table 4). The model explained 16.00% of the variance of the dataset with the RMSE value of 0.32. (Supplementary Table 4). The SHAP analysis determined that the information through personal link was the most important variable (SHAP value = 0.038), followed by the garden type (SHAP value = 0.032) (Figure 3). Variables, such as information through personal link, kitchen garden and orchard, knowledge about insects, less than 10 years duration of gardening experience, middle age (36-55) shifted the outcome toward the biodiversity-positive direction. Having a flower garden and house garden, observing few pollinator groups in the garden, medium garden size (100-500 m^2), more than 10 years of duration of gardening experience, living in town, lack of herbs in the garden drove the outcome toward the biodiversity-negative direction.

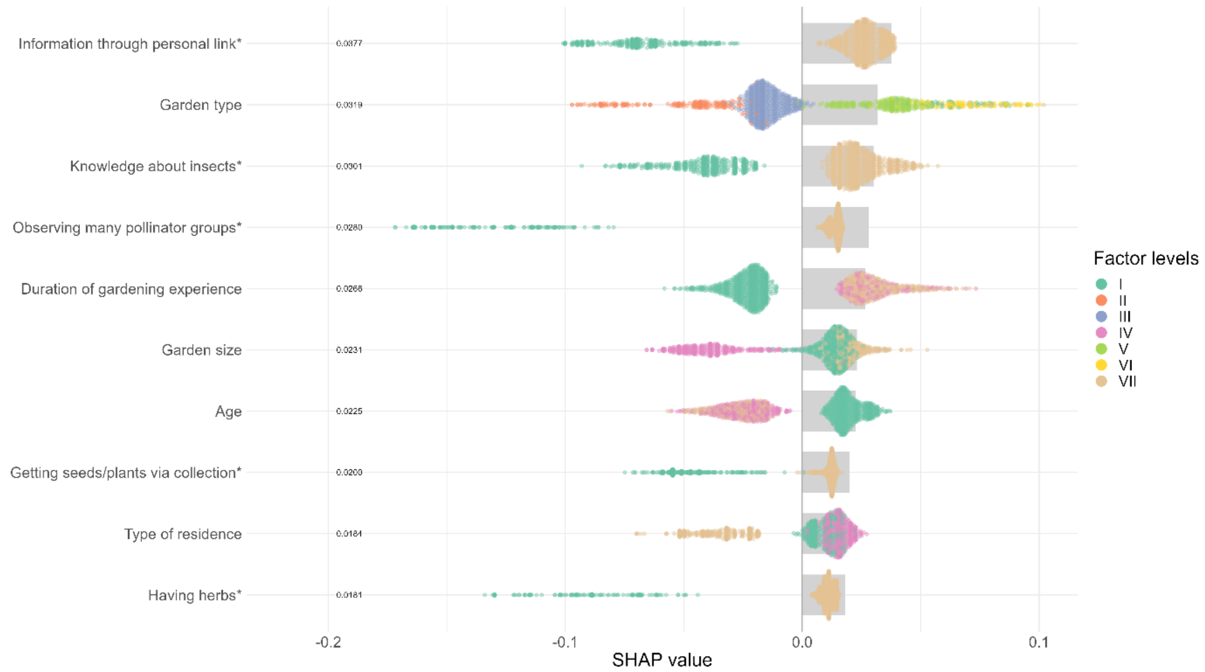

Figure 3: Global SHAP (SHapley Additive exPlanations) summary plot for the GBM model. The y-axis shows study variables ordered by their importance at a global model level by studying average absolute SHAP values as a bar plot (marked with grey colour). The y-axis also shows variables' impotance by beeswarm plots of the SHAP values where each points represents one respondent, and colour represents the variable levels (Roman numerals in bracket indicate the factor levels). Variables marked with asterisks (*) have two levels (I and VII). The colour code for non-binary variables is as follows (from up to down): Garden type: Community garden and other (I), Flower garden (II), House garden (III), Kitchen garden (V), Orchard (VI), Vineyard (VII); Duration of gardening experience: Long ago (I), Middle (IV), Newly (VII); Garden size: Large (I), Medium (IV), Small (VII); Age: 36-55 (I), Over 55 (IV), Under 36 (VII); Type of residence: City (I), Countryside (IV), Town (VII).

Associations among garden characteristics, gardening care practices, and motivations of garden owners

Whether or not herbs were present in the garden had the most associations (15 positive and 1 negative) and the one garden owners considering their garden as pollinator-friendly was the second most connected with both positive and negative associations (14 and 1, respectively). The use of non-synthetic fertilizers had the same number of positive associations as the most connected node. Among the examined parameters, the lack of awareness of the NMMc exhibited negative associations with five variables (Figure 4).

The community-detection algorithm identified four large modules and a module solely containing the variable of the lack of awareness about the NMMc. The largest group comprised of having fruits, vegetables, and herbs in the garden, along with a positive connection to a desire to make gardens beautiful, cultivating for own use and the use of non-synthetic fertilizers (Figure 4). Within this group, the means of gathering information through personal channels and from the Internet were negatively associated. Outside of the module, this group was negatively associated with the lack of awareness about the NMMc, having ornamental plants and evergreens, and the knowledge of birds. The second largest module contained variables such as observing high pollinator diversity, perceiving gardening as a pastime, and the knowledge of birds. This module was negatively associated, outside of the module, with the cultivation for own use and the lack of awareness about the NMMc. The third largest module, containing variables as the planting of ornamental plants and the presence of lawns, evergreens, and ornamental plants in the garden, showed numerous positive associations both within and outside of the group, and one negative with having vegetables in the garden, from the largest group. The fourth module contained only three variables: two types of pollinator support and enthusiasm about nature conservation. These showed positive associations with each other and were negatively associated with the lack of awareness about the NMMc.

Of the variables we investigated, some, such as the use of pesticides and herbicides, were not associated with any other variables (and thus did not appear in the network), indicating that the frequency of their co-occurrence did not deviate from that predicted by random chance.

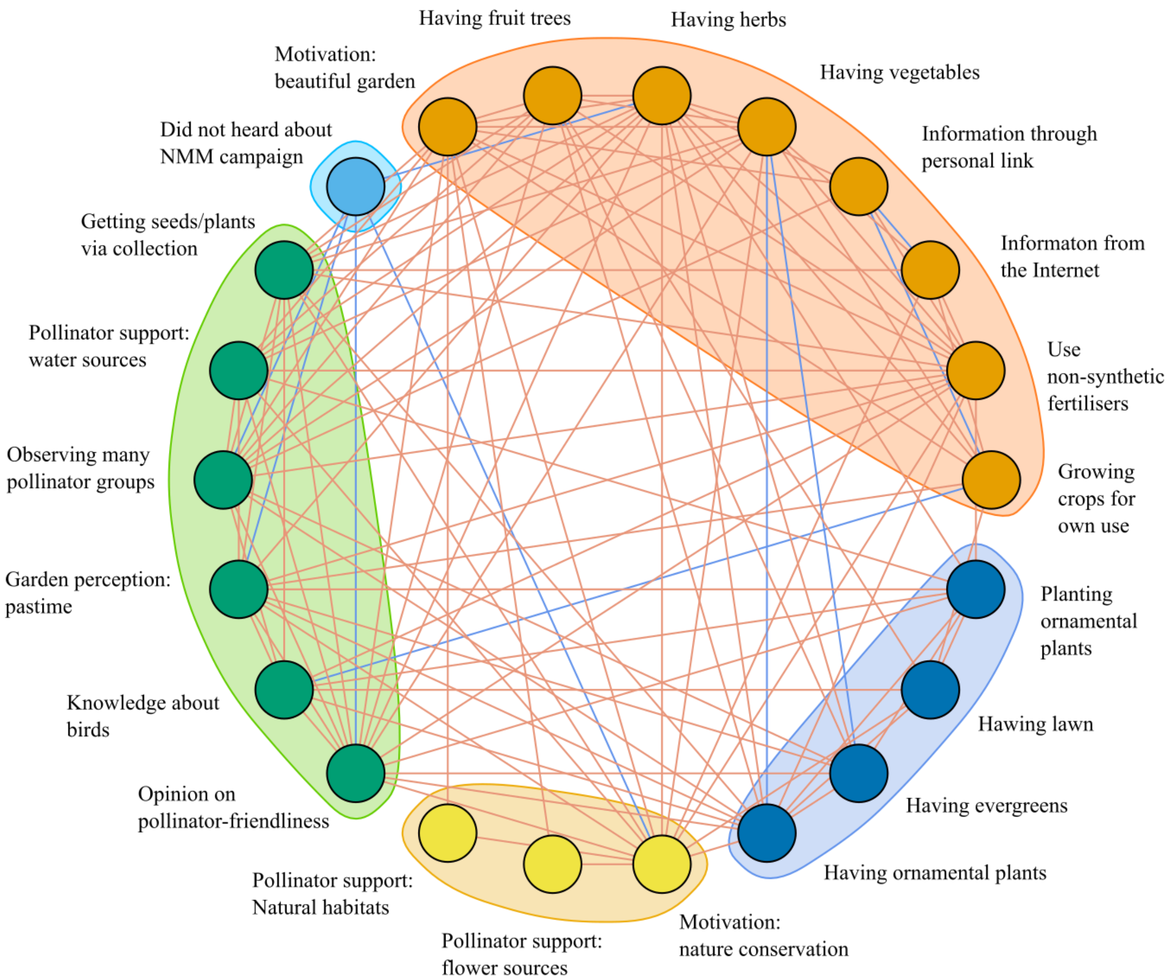

Figure 4: Co-occurrence network illustrating the statistically non-random associations among garden characteristics, gardening care practices, and motivations of garden owners. Red lines indicate positive, blue lines negative associations. Variable colouring and shaded areas indicate modules identified by the Louvain community detection algorithm.

The constrained variables of the RDA model explained 3.35% of the total variance with the first and second RDA axes explaining 28.27% and 19.91% of the filtered variance, respectively (Supplementary Table 6). Only the first axis was significant (p = 0.037). The majority of the connections did not separate well and were grouped near the origin. The associations between using non-synthetic fertilisers, having herbs in the garden and motivation for making the garden more beautiful, as well as that between collecting seeds and/or plants and observing many pollinator groups in the garden, correlated with the socio-demographic variable of the age over

55. Living in towns and having both ornamental plants and evergreens were also correlated. Of the explanatory variables, education was significant (p = 0.035), and the type of residence was marginally significant (p = 0.060). Indeed, there was little overlap between middle and high education levels in the RDA, whereas the confidence ellipse of respondents living in cities almost completely overlapped with those living in town or the countryside (Figure 5). Respondents under 35 were not separated from the other two age groups. However, the middle-aged (35-55 ages) and the respondents over 55 were separated from each other (Supplementary Figure 2)

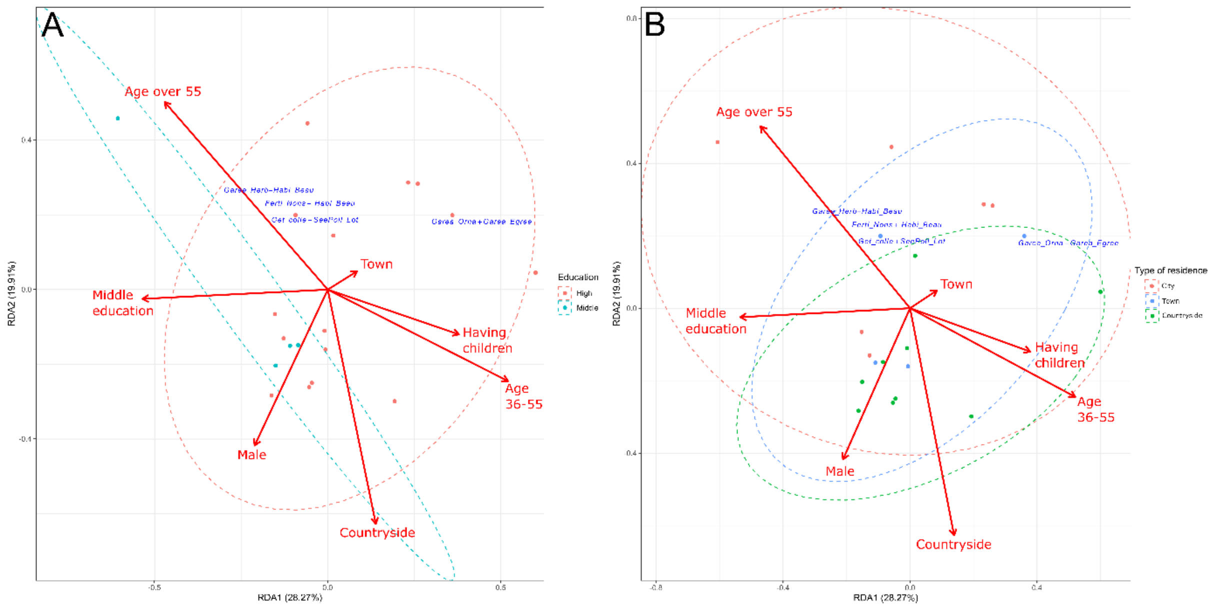

Figure 5: Redundancy analysis (RDA) plot showing the associated pairs of gardening practices and garden characteristics, along with the explanatory socio-demographic variables. The length and direction of the vectors represent the strength and direction of the relationship. The ellipses represent the 95% confidence intervals of associations of education levels (A) and resident types (B). Only associations (blue) whose RDA scores on the first two axes were lower than the mean of zero and the smallest value on the axes or greater than the mean of zero and the greatest value on the axes are shown. (Abbreviations: Garea_Herb: having herbs, Habi_Beau: motivation: beautiful garden, Ferti_Nons: use non-synthetic fertilisers, Get_colle: getting seeds/plants via collection, SeePoll_Lot: observing many pollinators groups, Garea_Orna: having ornamental plants, Garea_Egreev: having evergreens.)

Discussion

In this study, we distributed an online questionnaire in Hungary to investigate how gardening practices, motivation for gardening, and garden characteristics can influence biodiversity-friendly gardening, particularly focused on the interlinked characteristics of gardens and garden care practices and examined how socio-demographic factors influence biodiversity-positive and -negative practices.

We found that various socio-demographic parameters influence gardening practices and several garden characteristics were interlinked with means of garden care. Our results suggest that middle-aged respondents with higher education levels tend to choose biodiversity-positive activities, potentially due to the greater awareness and sensitivity to environmental issues (De Silva & Pownall, 2014; Meyer, 2015). Moreover, the high proportion of this group having children may also indicate that these are conscious decisions.

On the contrary, respondents over 55 demonstrated less or no support for pollinators, used more pesticides, and had less interest in nature conservation. This age group had a long (more than 10 years) gardening experience, probably with conventional garden care practices in Hungary. Of this age group 40% live in the countryside, where biodiversity is relatively high and conservation efforts can be particularly fruitful. Therefore engaging these garden owners in biodiversity-friendly practices would be of great conservation merit. This becomes especially crucial given the ageing demographic of the Hungarian society (Obádovics & Tóth, 2023).

Although, living in towns scored the worst for biodiversity-positive gardening, residing in **cities** does not negatively impact examined gardening activities, suggesting a diverse array of gardens and garden owners within highly urbanised areas. The similarities between the associations among gardening practices and garden characteristics in cities and the countryside imply the presence of traditional house gardens and less flat-based housing than in most Western European cities (European Commission, Eurostat, https://ec.europa.eu/eurostat/cache/digpub/housing/bloc-1a.html, accessed 30th November 2023). This lack of a stark urban(city)- rural(countryside) divide may stem from the historical development of several Hungarian cities evolving from agriculturally oriented rural areas (Beluszky & Győri, 2005) resulting in gardens with mixed uses especially in the suburban zones. Recent trends also indicate a rise in mixed-use gardens driven by financial considerations, with individuals seeking self-sufficiency for higher quality and affordability. The distinctions between Western and Eastern Europe underscore the necessity for distinct approaches when aiming to enhance urban biodiversity in populations residing in cities and emphasise the need for studies from Eastern European countries similar to those already available for the West.

However, our results show that gardening practices and garden characteristics are equally influenced by all socio-demographic parameters. Thus, identifying one particular group of garden owners whose habits are highly biodiversity-negative, and therefore whose gardening practices should be altered to improve biodiversity, proves challenging solely on socio-demographic parameters. Unless a study utilizing a broader set of social-demographic factors manages to pinpoint this specific target group, conservation actions must be directed towards a broader segment of society.

Our results uncovered numerous (positive and negative) associations between garden characteristics and garden care practices. The grouping, based on the non-random, positive associations of the variables, suggests four well-separated approaches in garden care practices and garden use. Gardens with a predominance of plants suitable for consumption (fruit trees, vegetables, and herbs), and gardens that function mainly as ornamental gardens (mostly having evergreens, ornamental plants, and tended lawns) formed separate modules. The last two modules group gardens whose owners are likely environmentally conscious, close to nature, and enjoy outdoor activities. In spite of the differences, inter-module connections were common, indicating that predicting gardening practices from plants grown or garden type is hardly possible. Indeed, we did not find a clear indication that the presence of certain plant types increases biodiversity-positive gardening. Yet, the presence of lawns pointed toward lower BDF scores, probably related to increased herbicide use and frequent mowing, the presence of vegetables seemed to be related with biodiversity-positive activities. Indeed, the presence of vegetables likely lowers pesticide input because in kitchen gardens products are grown for own consumption.

However, based on our analysis of the associations between garden characteristics and garden care practices, no associations were detected between the use of pesticides and herbicides (irrespective of the type) and any other variables. Thus, pesticide and herbicide usage appears to be random among the study population, suggesting that most domestic garden owners, regardless of socio-demographic parameters, gardening care practices, or garden parameters, use plant protection products. Indeed, although biodiversity-positive activities and garden characteristics, such as having a pond and supporting pollinators, were more typical among the respondents than those that were biodiversity-negative, more than 60% of the respondents used some pesticides (including bio and homemade ones) in their gardens. Albeit alarming, this is in line with a the study of Varga-Szilay & Pozsgai (2022), who found excessive pesticide use even in otherwise biodiversity-friendly farmlands, as well as with a European study (Coisnon et al., 2019) in which Hungary was classified as a country least avoiding pesticide use in gardens. The latter work also pointed to the lower trust in environmental associations and the lack of reliable source of biodiversity-related information as major culprits. Yet, 72% of participants in our study had higher education and access to the Internet, and thus information, which suggests that selecting and placing confidence in the available information were to be blamed. This emphasizes the significance of reaching out to garden owners through diverse channels; some may not rely on information from the Internet an in these cases knowledge transfer through personal links is likely to be the most efficient. Indeed, in our network analysis personal links and from the Internet showed a negative association. Therefore, to effectively reach such groups, prioritizing communication means relying on interpersonal interactions, such as gardening associations, community gardens, and workshops should be employed (Barthel et al., 2010). Through these channels, information can be disseminated to garden owners over 55 years old who practice conventional gardening and urban dwellers who may be more disconnected from nature. At these events, it is crucial to emphasize the harmful effects of pesticide use on individuals, the environment, and on the future of the next generations. As an added benefit, community gardens and similar shared gardening practices can also substantially improve human well-being both for isolated urban dwellers (Leavell et al., 2019) and the elderly (Fjaestad et al., 2023).

Besides pesticide use, our results highlight that frequent mowing was also one of the common biodiversity-negative practices. For some, such as for those who own middle-size gardens, this may not be working because the limited size of these gardens potentially prevents owners from setting aside an undisturbed area. Additionally, frequent mowing of the lawn in these gardens may be more manageable, than in larger gardens (over 500m^2). Indeed middle-sized gardens strongly and negatively affected the BDF score, most likely as a result of frequent mowing. Explaining the time and monetary costs of frequent mowing along with the potential harm it causes to biodiversity may however convince owners to decrease mowing activities (Lerman et al., 2018). Campaigns like No Mo May can be of great help in achieving this vision. Indeed, we found that knowing about the NMMc was positively associated with active pollinator support and motivation for nature conservation. Our results also showed that knowledge of insects and observing many pollinator groups favour biodiversity-positive practices (van Heezik et al., 2012). On the other hand, we found an overlap between those who mow frequently and those who leave unmown patches, indicating that even if gardeners can be persuaded to refrain from mowing for a short period, such as one month in the NMMc, this is probably more difficult than pursuing them to leave temporally unmown patches or undisturbed areas. Regardless, campaigns focused on biodiversity awareness hold the potential to promptly impact gardening practices, steering them towards sustainable garden care.

Study limits

Since in our work the respondents were not randomly selected, but they rather form a subsample of garden owners who were aware of the announcement and participated voluntarily, the study is not likely to be representative for the entire Hungarian garden owner population. Indeed, the questionnaire could only be completed online, therefore, it had a lower chance to reach the infrastructurally less developed eastern part of the country. Whilst these, and the limitations arising from the relative weaknesses of our model, may constrain the generalizability and applicability of the findings, a sufficiently large number of people completed our questionnaire, which likely ensures a thorough depiction of common gardening behaviours and trends in garden practices among household garden owners in Hungary.

Conclusion and future perspectives

The findings of our study provide a comprehensive overview on the gardening practices, motivations of garden owners, and garden characteristics in Hungary, discuss linked practices and pave the way to efficiently drive knowledge transfer and education for pursuing people toward biodiversity-friendly gardening practices. In this first step to understanding the little-studied sociological drivers of Eastern European gardening practices, we highlight the distinctions between Hungary and Western European countries and underscore the necessity for customised tactics in promoting biodiversity-friendly and sustainable gardening practices for countries with different cultural backgrounds. Due to the lack of social trust, and the ageing society, this includes, for instance, favouring interpersonal programs over disseminating information online. Although our study concentrated exclusively on Hungary, it is important to recognize that these peculiarities may not be unique to this only country, but are likely to be relevant to a significant, culturally related segment of Eastern European countries. Indeed, our work could function as a novel scheme to raise studies focusing on understanding the links between garden diversities, garden characteristics and gardening practices in Eastern European countries, where environmental consciousness is expected to be lower compared to Western European countries.

However, garden biodiversity is also influenced by factors not discussed here (such as the biodiversity of the surrounding area, landscape layout, or animal behaviour (Goddard et al., 2013)). Ground truth inventories of garden biodiversities are thus also needed, along with the assessment of landscape-level variables. Citizen science projects for domestic garden (and urban greenspace) inventories provide a valuable tool both for low-cost data collection and conservation-minded education at large. Thus combining our questionnaire-based approach, with a volunteer monitoring scheme and remotely sensed datasets would be indispensable to gain vital insight for efficient conservation and maintaining biodiversity in urban areas. Yet, it is key to be mindful that a complementary interplay between social sciences and ecology is essential for substantially advancing the understanding of how the benefits of urban green spaces, including gardens, could be maximised both for conservation and human well-being.

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Author contributions

ZVS and GP conceived the idea of the project, designed the study and created the first version of the questionnaire. ZVS, GP, GS and KGF finalised the questions. ZVS and GP translated and specialised the questionnaire into English. All authors participated in data collection. Analysis was performed by ZVS and GP. The draft of the manuscript was written by ZVS and GP. All authors read and approved the final manuscript.

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Declarations

Conflict of interest

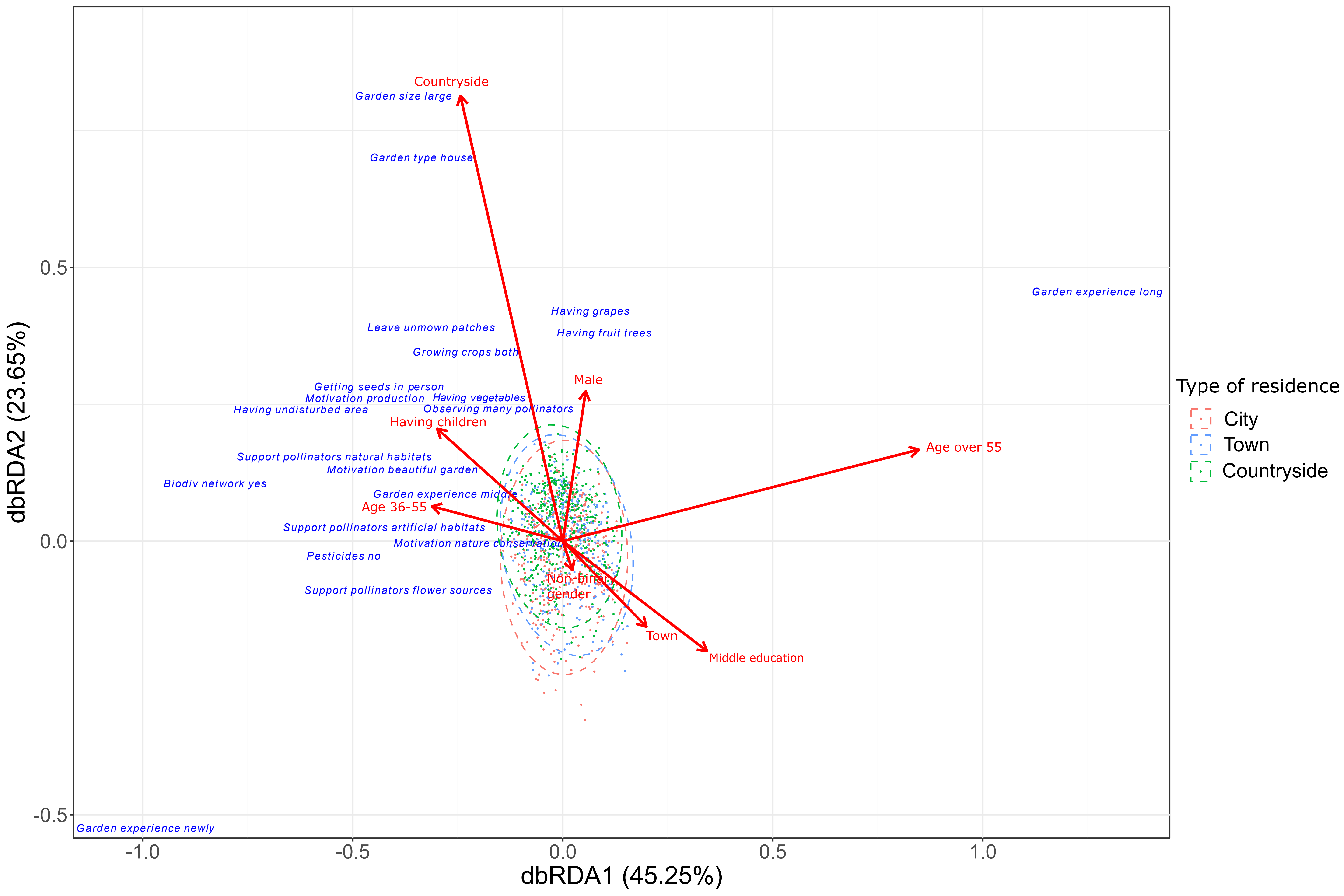
The authors declare no competing interests.

Declaration of Generative AI and AI-assisted technologies in the writing process

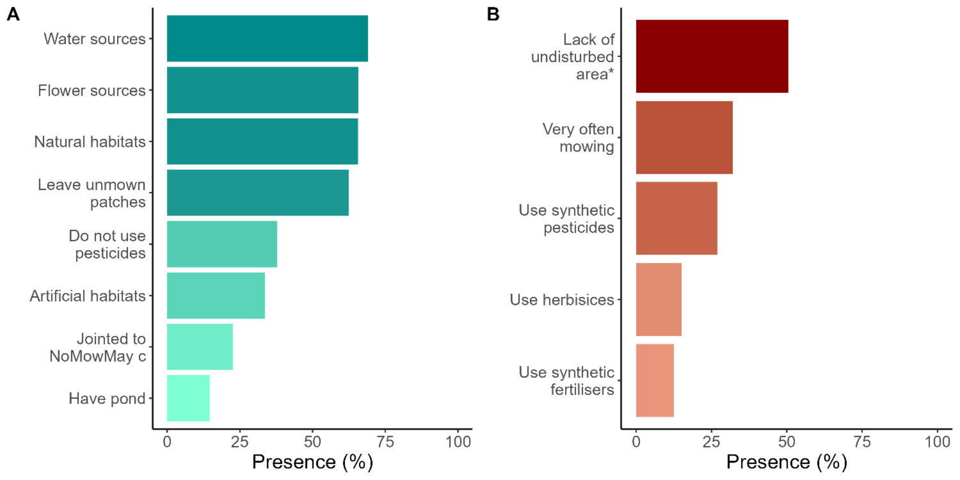
Statement: During the preparation of this work the authors used ChatGPT (version 3.5) in order to improve readability and language. After using this tool, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

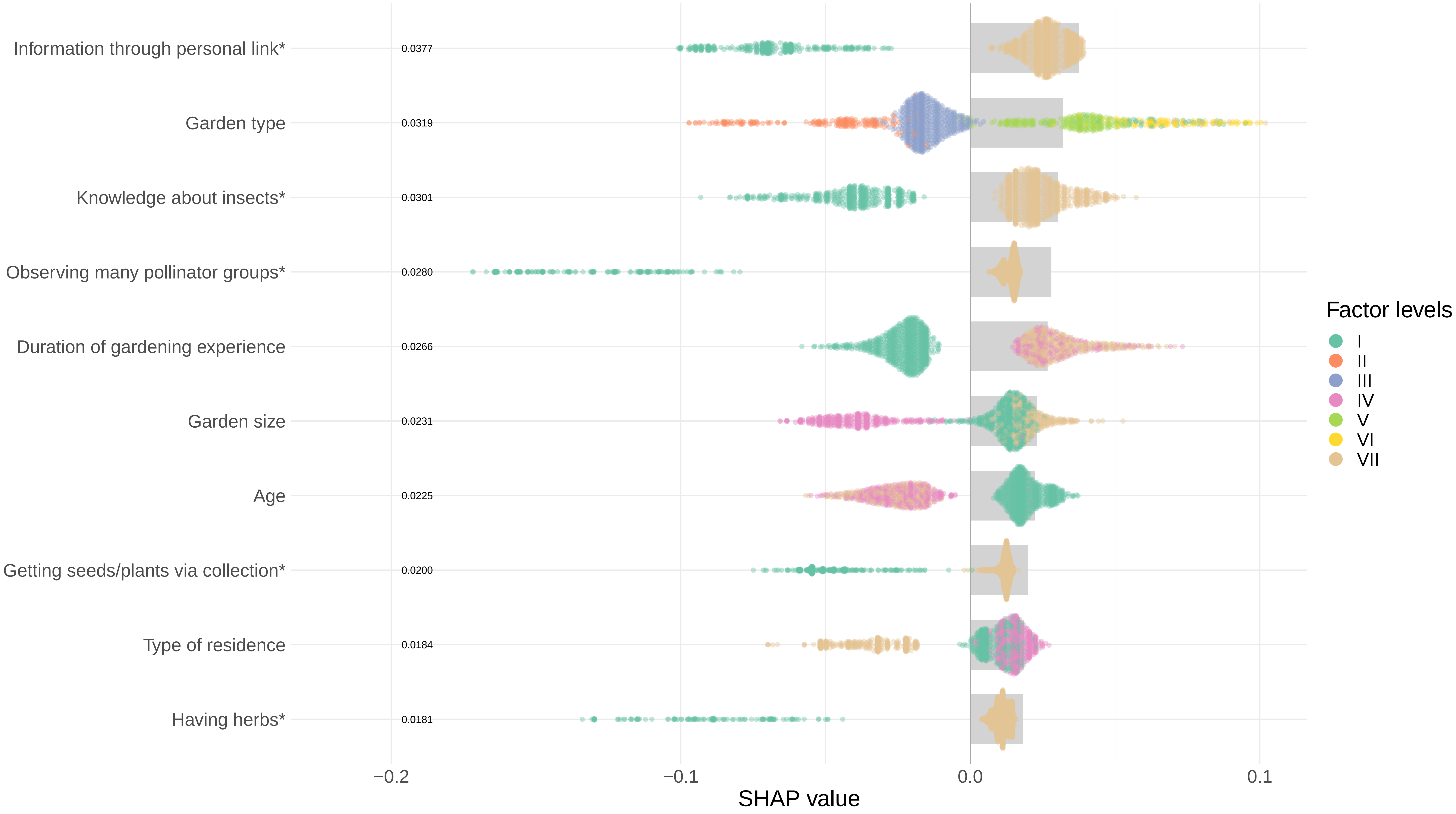
Code availability

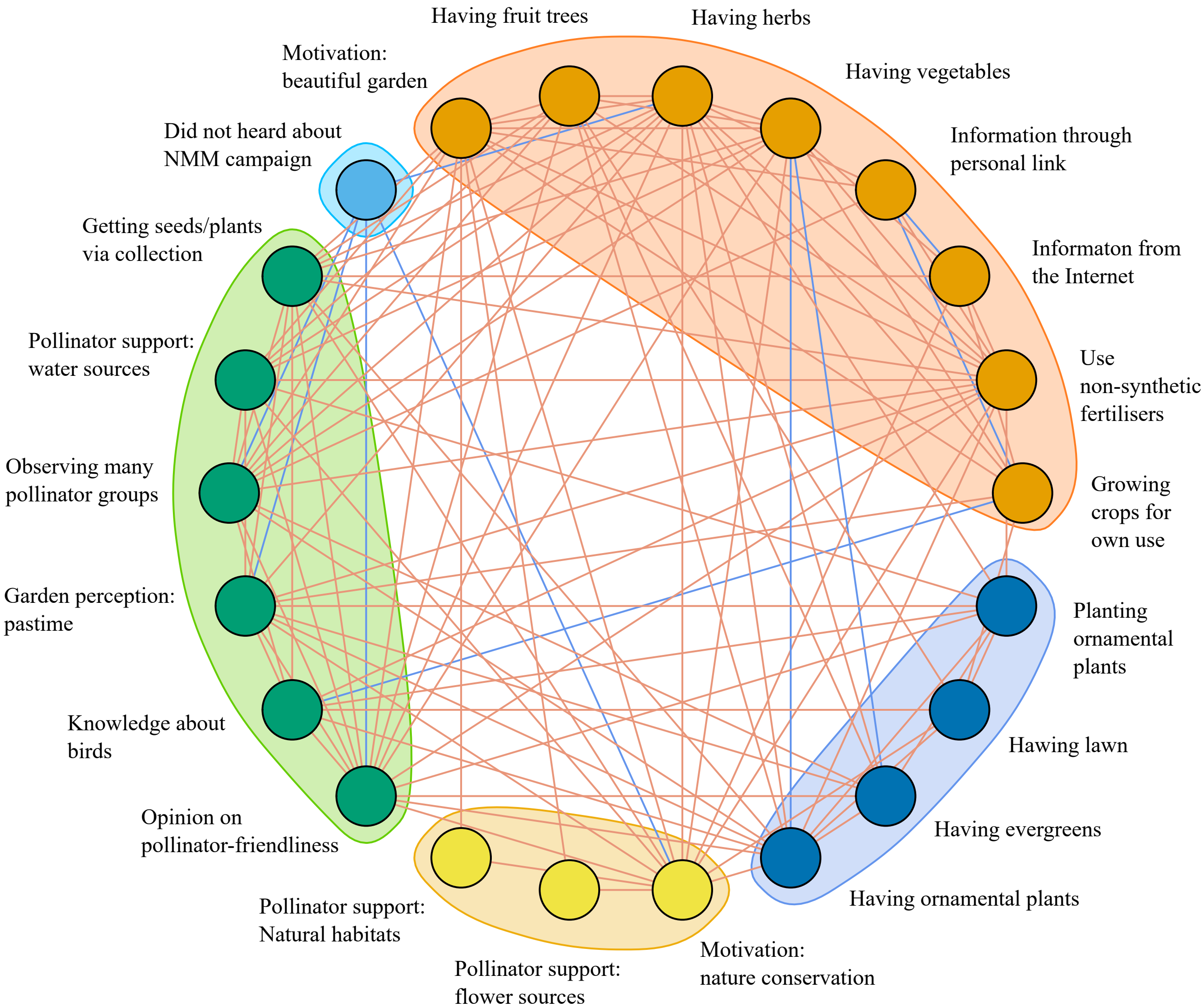
The underlying computer code is available in the GitHub repository https://github.com/zsvargaszilay/gardening_in_hungary.

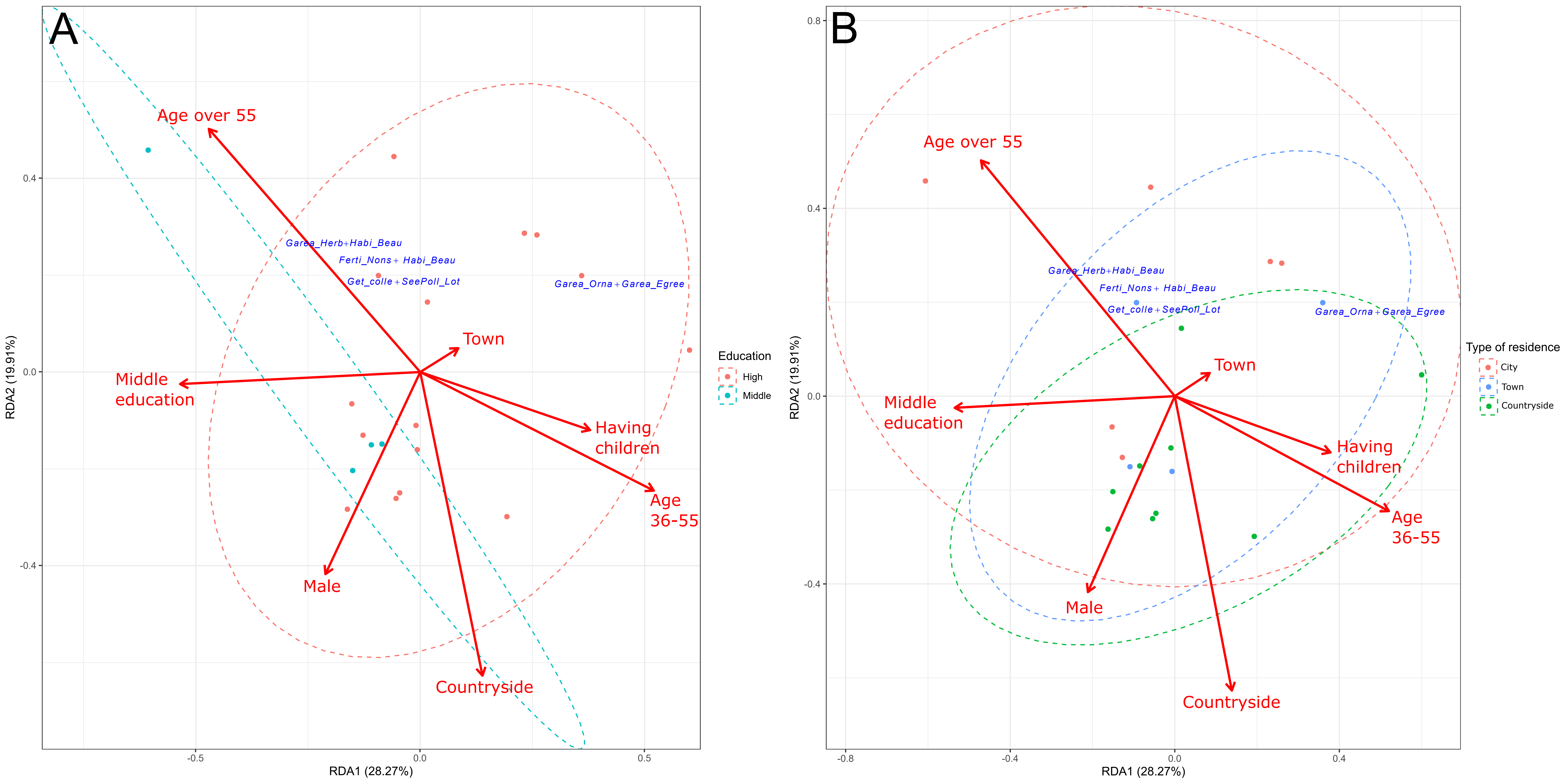


Countryside
Garden size large
Garden type house
Garden experience long
Having grapes
Having fruit trees
Leave unmown patches
Growing crops both
Male
Getting seeds in person
Motivation production
Having vegetables
Having undisturbed area
Observing many pollinators
Having children
Age over 55
Support pollinators natural habitats
Motivation beautiful garden
Biodiv network yes
Garden experience middle
Age 36-55
Support pollinators artificial habitats
Motivation nature conservation
Pesticides no
Non-binary gender
Support pollinators flower sources
Town
Middle education
Garden experience newly
Type of residence
City
Town
Countryside
0.5
0.0
-0.5
-1.0
-0.5
0.0
0.5
1.0
dbRDA1 (45.25%)
dbRDA2 (23.65%)


A
Water sources
Flower sources
Natural habitats
Leave unmown patches
Do not use pesticides
Artificial habitats
Jointed to NoMowMay c
Have pond
0
25
50
75
100
Presence (%)
B
Lack of undisturbed area*
Very often mowing
Use synthetic pesticides
Use herbisices
Use synthetic fertilisers
0
25
50
75
100
Presence (%)


Information through personal link*
Garden type
Knowledge about insects*
Observing many pollinator groups*
Duration of gardening experience
Garden size
Age
Getting seeds/plants via collection*
Type of residence
Having herbs*
0.0377
0.0319
0.0301
0.0280
0.0266
0.0231
0.0225
0.0200
0.0184
0.0181
−0.2
−0.1
0.0
0.1
SHAP value
Factor levels
I
II
III
IV
V
VI
VII


Having fruit trees
Having herbs
Motivation:
beautiful garden
Having vegetables
Did not heard about
NMM campaign
Information through
personal link
Getting seeds/plants
via collection
Informaton from
the Internet
Pollinator support:
water sources
Use
non-synthetic
fertilisers
Observing many
pollinator groups
Growing
crops for
own use
Garden perception:
pastime
Planting
ornamental
plants
Knowledge about
birds
Hawing lawn
Opinion on
pollinator-friendliness
Having evergreens
Having ornamental plants
Pollinator support:
Natural habitats
Motivation:
nature conservation
Pollinator support:
flower sources


A
Age over 55
Garea_Herb+Habi_Beau
Ferti_Nons+ Habi_Beau
Get_colle+SeePoll_Lot
Garea_Orna+Garea_Egree
Town
Middle education
Having children
Age 36-55
Male
Countryside
Education
High
Middle
RDA1 (28.27%)
RDA2 (19.91%)
B
Type of residence
City
Town
Countryside