



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

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## ABSTRACT

The expansion of urban areas threatens biodiversity and disrupts ecological relationships, thereby impeding key ecosystem services. To avert irreversible consequences, there is a focus on improving the biodiversity value of domestic gardens. We employ machine learning and network analysis and examine gardening practices and garden owners' environmental consciousness in Hungary through a questionnaire-based study to untangle the interplay among socio-demographic factors, garden management and -characteristics. We found that the activities determined as biodiversity-positive were widespread among respondents, but ubiquitous pesticide use (62.14%), lack of undisturbed areas (49.52%), and frequent mowing (32.06%) were also present. Middle-aged respondents demonstrated more biodiversity-supporting activities than those over 55, who had long-term gardening experience and were predominantly conventional gardeners. Respondents 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 for food self-provisioning, ornamental gardens, or those prioritizing biodiversity support. Our results show that garden owners use pesticides independently of socio-demographic parameters, gardening practices, or garden characteristics, suggesting widespread pesticide use in Hungary. Our findings suggest that strategies to promote biodiversity-friendly gardening may not be equally suitable for all gardener owners with different cultural backgrounds, environmental consciousness and gardening habits. Factors like differences between societal groups underscore the preference for in-person programs over online information transfer in several cases, for instance, among the elderly and those living in the countryside. We offer 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 emphasises that optimizing gardens for multiple ecosystem services, including biodiversity conservation and enhancing human well-being, requires a nuanced understanding of both ecological and socio-demographic factors.

## Abbreviations

DG domestic garden  
BFG biodiversity-friendly gardening  
BDF score Biodiversity friendliness score  
NMMc No Mow May campaign

## 2. 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). To avoid

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reaching a state when the result of these effects are irreversible, there is a global need for a better-planned and sustainable urban environment (Breuste et al., 2013; 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).

In some developed countries, the number of urban green areas is increasing (Kabisch & Haase, 2013) and their potential in multi-purpose sustainability development is increasingly recognised. Although 16–27% of urban green spaces in Europe belong to private owners (Goddard et al., 2010), the importance of private or shared gardens in influencing the quality of urban green ecosystem is often underestimated (Camps-Calvet et al., 2016).

Domestic gardens are green spaces in urban ecosystems people use for recreation, outdoor activities, or to connect with nature (Bell et al., 2016). Indeed, as a popular pastime, gardening is beneficial to mental health and strengthens human well-being (Krools et al., 2022). Moreover, domestic gardens (DG) also have 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 1990 s (Delahay et al., 2023). Interest in the role of urban and suburban gardens in the preservation and support of urban ecosystems has increasingly gained attention since then (Delahay et al., 2023) and showed that even small 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). 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 DGs is governed by garden care practices; intensive management can negatively impact garden diversity as well as the gardens' environment (Fontaine et al., 2016). 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), 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 chemical fertiliser use (Law et al., 2004), the frequent irrigation (Egerer et al., 2018), 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.

Gardens can also provide ecosystem disservices, for instance, the increase of pests or disease-carrying insects (Yang et al., 2019), or wildlife causing fear or aversion (Baker et al., 2020; Soulsbury & White, 2015). Nonetheless, increased ecological knowledge stimulates environmental stewardship (Fischer et al., 2020), and garden owners' access to and effective trialling of biodiversity-friendly gardening (BFG) practices can alter public perceptions surrounding contentious issues, such as pesticide phase-down or biodiversity-friendly plant protection (Barthel et al., 2010). Moreover, 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 (Coison et al., 2019) and various management practices (Goddard et al., 2013).

For this reason, 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 to optimise gardening habits and garden management for conservation benefits.

However, BFG is intertwined with the type and layout of the garden (Hanson et al., 2021), as well as with the presence or absence of certain plants (Paker et al., 2014; Salisbury et al., 2015) and this interconnected system is likely to be further shaped by socioeconomic factors (Hoyle et al., 2017). 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 BFG.

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 environmental-friendly practices.

Thus, our main aims was to investigate how gardening practices, motivation for gardening, and garden characteristics can influence BFG. We used a combination of methods of machine learning and network analysis to achieve this and also paid attention to 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 maintaining or improving human well-being linked to DGs and gardening.

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

### 3. Material and methods

#### 3.1. 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: garden location, socio-demographic parameters, garden characteristics, motivation and gardening practices, garden cultivation, pesticide usage, and observed pollinators in the garden. The questionnaire was designed in Google Forms and it took maximum 15 minutes to complete. All responses were recorded anonymously. Respondents could indicate their education on a four- (elementary, middle, postsecondary, and postgraduate), their gender on a three-level scale (male, female, other), and their residency at a county-level.

The questionnaire was distributed between October 2022 and June 2023 in Hungary. The questionnaire was distributed through gardening-related websites, social media platforms, and mailing lists.

The term 'pesticides' was defined as all synthetic and non-synthetic products that are used to control pests. We included in the term all commercially available and homemade 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. However, for the analysis, of the three originally recorded pesticide categories the one referring to synthetic products was used separately, while the other two categories (eco/bio/green labelled and self-made pesticides) were merged as non-synthetic products. Although herbicides are also pesticides, because of the importance of some (e.g. glyphosate is widely used in agriculture and gardening practices (Benbrook, 2016)) we separately recorded whether garden owners used them (Supplementary Table 1). Furthermore, 'gardening' included all garden work and -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 are permanently undisturbed areas that are independent of mowing. Although the responses about whether garden owners know plant, insect or bird diversity in their garden were self-evaluated, and thus subjective, we keep referring to them using the absolute term 'knowledge'.

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, 2022) in the Northern Hemisphere. Since this campaign was adopted in Hungary, and we asked the respondents about their knowledge/participation. The question assessing garden pollinator diversity was picture-based.

### 3.2. Data processing

For the analysis, we used 27 questions relevant to our aims. The original categorical responses were on a few occasions re-categorised for analytical purposes (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 were excluded from the analysis.

Due to methodological constraints, for parts of the analysis we used binarized data. Some of our questions inherently had binary responses 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.

### 3.3. 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 as dependent variables and gender, age, education level, whether the garden owners 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.

To assess the major garden characteristics 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 sources of water or nectar- and pollen-rich flowers, the active support of pollinators by natural, or artificial habitats, leaving unmown patches, having a pond and complete avoidance of pesticides. The negative ones included the use of synthetic pesticides, (additionally) herbicides or synthetic fertilisers, having no undisturbed patches, and mowing the lawn several times a month. For each respondent, both 'good' and 'bad' attributes were counted, each of these values was 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 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 (Supplementary Table 6). After an optimisation process (see Code Availability Statement), 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 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 results, we used 'gbm' (Greenwell, 2022), 'caret' (Kuhn et al., 2023), 'shapviz' (Mayer & Stando, 2023) and 'kernelshap' (Mayer et al., 2023) R packages in an R environment (R Core Team, 2021).

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, 2014). We considered positive associations as synergies and negative ones as antagonistic effects (trade-offs) in shaping gardening practices. Only associations with probabilities over 0.6 were considered in the final networks. Thus, the network consisted of garden characteristics and gardening practices as nodes and the associations between them as links. We examined the interdependencies in the association network and recorded the answers which were the most connected to other answers (i.e. had the most links to other nodes in the network). Groups of densely associated responses (modules) were detected by the Louvain community detection algorithm (Blondel et al., 2008).

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; 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 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) 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, with the help of 'cooccur' (Griffith et al., 2016), 'dplyr' (Wickham et al., 2023) 'ggplot2' (Wickham, 2016), 'igraph' (Csardi & Nepusz, 2006), and 'vegan' (Oksanen, 2022) packages.

## 4. Results

Of the 1260 people who completed the questionnaire, 343 were males (27.22%), 916 were females (72.70%), and one person's gender was other (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 those with middle-level education ( $n = 385$ , 28.10%), and 616 respondents had children (48.89%). The questionnaire was mostly filled out for the size category of DGs being over  $500 \text{ m}^2$  ( $n = 580$ , 46.03%) (Supplementary Table 2).

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 (Fig. 1). The model ( $p \leq 0.001$ ) and all explanatory variables were significant (Supplementary Table 3). Although most garden characteristics and gardening practices were located close to the origin, some were highly correlated 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.

In the study population, the most common activity that had a biodiversity-positive effect in gardens was supporting pollinators with water sources ( $n = 870$ , 69.05%) (Fig. 2). This was followed by 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%), only 37.86% ( $n = 477$ ) avoids pesticides completely. Neither creating artificial habitats ( $n = 423$ , 33.60%) nor joining the NMMc ( $n = 284$ , 22.54%) were common activities. Only 184 respondents (14.60%) had a pond (Supplementary Table 4A).

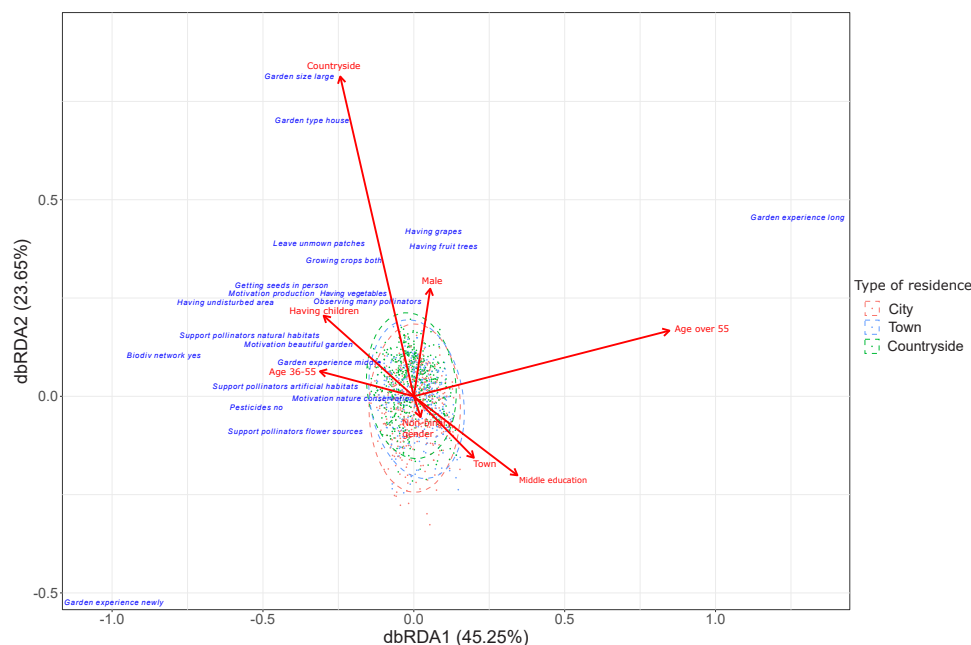
Among the gardening activities that may negatively impact DGs' biodiversity, the lack of undisturbed areas (624 respondents, 49.52%) was the most common, followed by mowing several times a month ( $n = 404$ , 32.06%). Synthetic pesticides were used by 26.98% ( $n = 340$ ) of the respondents, whilst herbicides ( $n = 190$ , 15.10%) and synthetic fertilisers ( $n = 158$ , 12.54%) were less often used (Fig. 2, Supplementary Table 4B). Of the herbicide users, 68.94% use glyphosate-containing herbicides (Supplementary Table 5).

The GBM model suggested that the best indicators for predicting

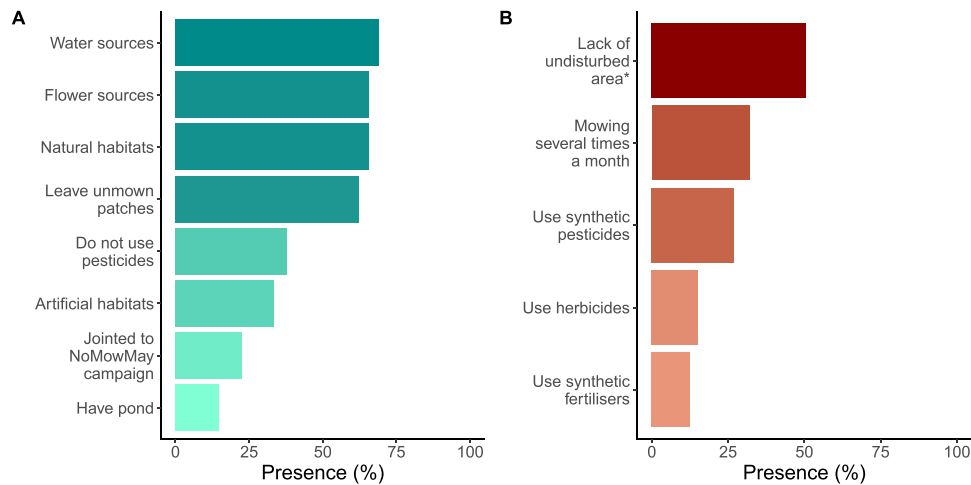
whether gardening practices can be considered biodiversity-positive or biodiversity-negative were the number of pollinator groups garden owners usually observe (relative influence: 11.68) and the type of the gardens, such as village- or kitchen gardens (relative influence: 9.14) (Supplementary Table 6). The model explained 16.00% of the variance of the dataset with the RMSE value of 0.32. The SHAP analysis determined that the information through personal links was the most important variable (SHAP value = 0.038), followed by the garden type (SHAP value = 0.032) (Fig. 3). Variables, such as information through personal links, kitchen garden and orchard, knowledge about insects, less than 10 years of gardening experience, and middle age shifted the outcome toward the biodiversity-positive direction. Having a flower- and house garden, observing few pollinator groups, medium garden size ( $100\text{--}500 \text{ m}^2$ ), more than 10 years of gardening experience, living in town, and lack of herbs in the garden drove the outcome toward the biodiversity-negative direction.

Whether or not herbs were present in the garden had the most associations (i.e. links) in the network (15 positive, 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 fertilisers 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 (Fig. 4).

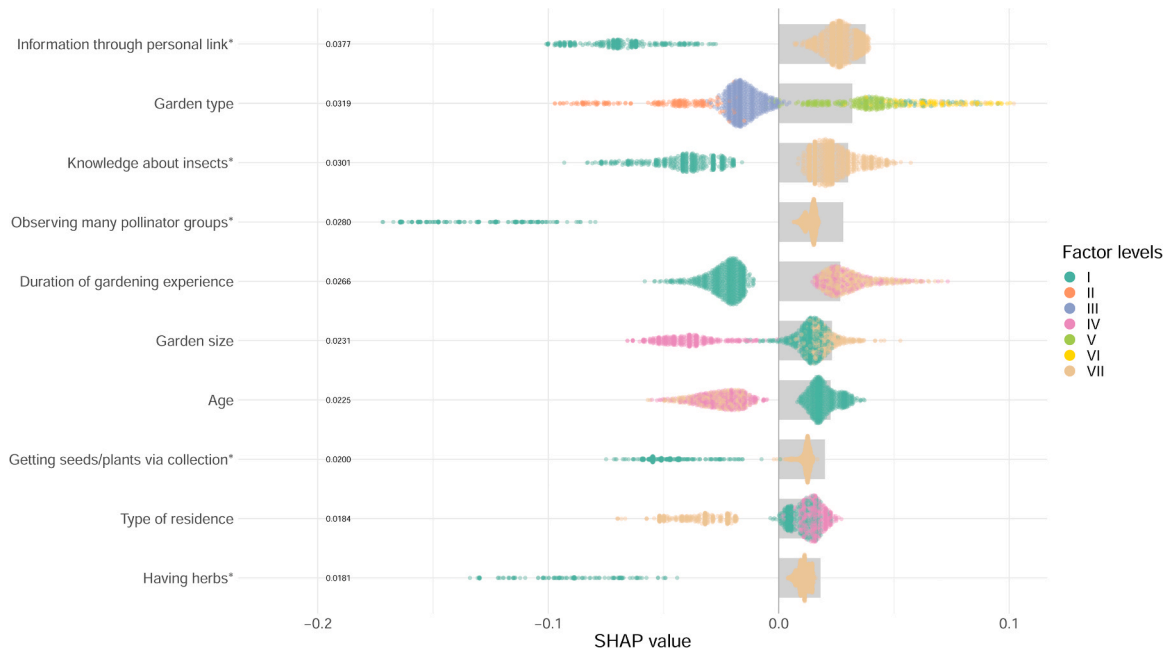
The community-detection algorithm identified four large modules and a module solely containing the variable of the lack of awareness about the NMMc. The largest group comprised of having fruits, vegetables, and herbs in the garden, along with a positive connection to a desire to make gardens beautiful, cultivating for own use and the use of non-synthetic fertilisers (Fig. 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,



**Fig. 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.



**Fig. 2.** Presence (%) of the biodiversity-positive (A) and biodiversity-negative (B) gardening practices among respondents (n = 1260). Since the question of 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.



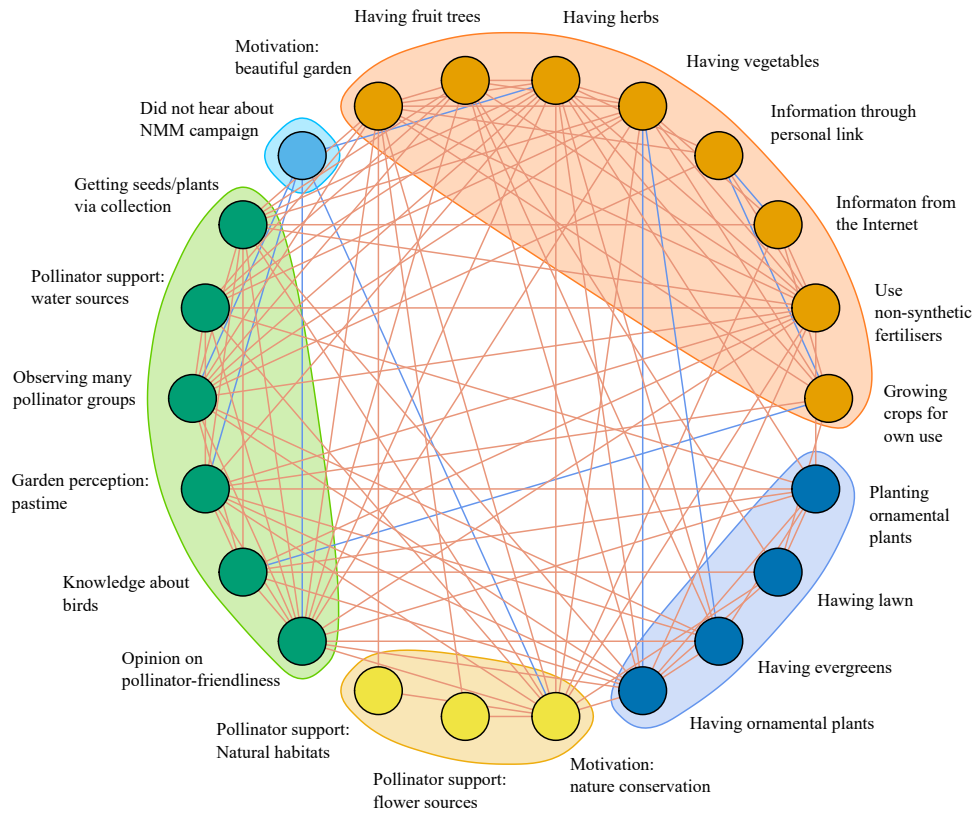
**Fig. 3.** Global SHAP (SHapley Additive exPlanations) summary plot for the GBM model. The y-axis shows study variables ordered by their importance at a global model level by studying average absolute SHAP values as a bar plot (marked with grey). The y-axis also shows the variables’ importance by beeswarm plots of the SHAP values where each point represents one respondent, and colour represents the variable levels (Roman numerals in brackets indicate the factor levels). Variables marked with asterisks (\*) have two levels (I and VII). The colour code for non-binary variables is as follows: 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).

with the cultivation for own use and the lack of awareness about the NMMc. The third largest module, containing variables such 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 (providing natural habitats and flower sources) 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 those related to pesticide or herbicide use, 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.

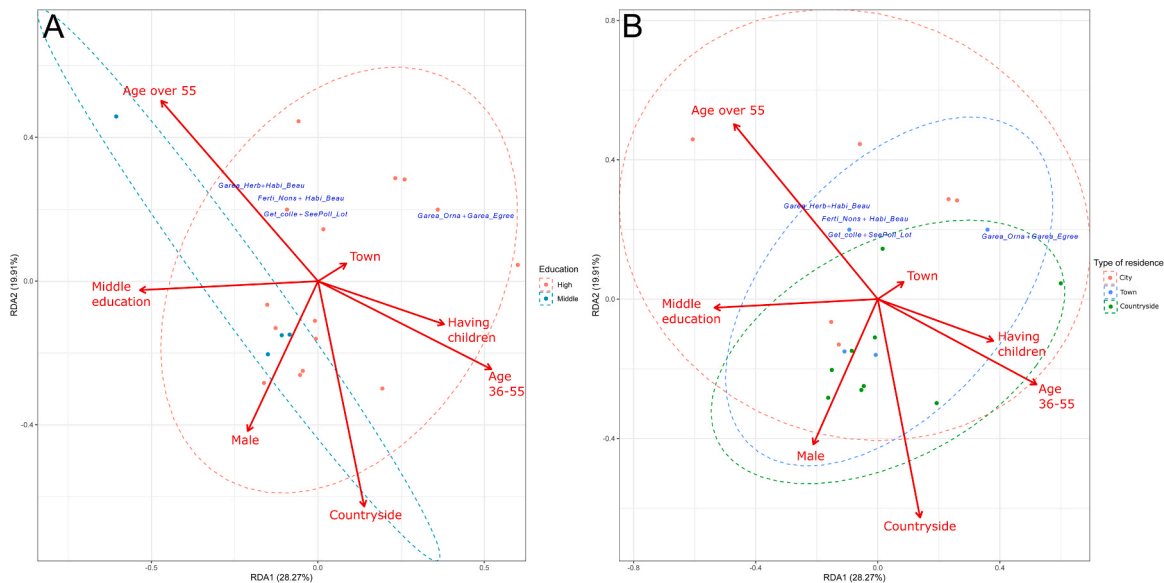
The constrained variables of the RDA model explained 3.35% of the total variance with the first and second RDA axes explaining 28.27% and 19.91% of the filtered variance, respectively (Supplementary Table 7). Only the first axis was significant ( $p = 0.037$ ). The majority of the connections did not 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



**Fig. 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, and blue lines negative associations. Variable colouring and shaded areas indicate modules identified by the Louvain community detection algorithm.

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 (Fig. 5). Respondents under 35 were not separated from the other two age groups. However, the middle-aged and the respondents over 55 were separated



**Fig. 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\_Egrees: having evergreens.).

from each other (Supplementary Fig. 2).

## 5. Discussion

In this study, we distributed an online questionnaire in Hungary to investigate how gardening practices, motivation for gardening, and garden characteristics can influence BFG, 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 their 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. This group can easily embrace novel, BFG practices and therefore involving them into sophisticated conservation gardening and online citizen science projects is likely to be highly rewarding.

On the contrary, respondents over 55 demonstrated less or no support for pollinators, used more pesticides, and had less interest in nature conservation. The reason for this may be that garden owners in this age group have heard less about biodiversity and/or the importance of its protection (European Commission, 2019). This age group also had a long (more than 10 years) gardening experience, during which they were accustomed to conventional garden care practices. Nevertheless, the use of non-synthetic fertilisers and the collection of seeds and plants are also representative to this group. The importance of making their garden 'more beautiful' may however be misleading since traditionally beautiful gardens are often extensively managed and lack natural features (Burr et al., 2018). Of this age group 40% live in the countryside, where biodiversity is relatively high and conservation efforts can be particularly fruitful. Moreover, they can spend more time gardening compared to other age groups of garden owners (Ponižy et al., 2021), and therefore engaging this age group of over 55 in BFG would be of great conservation merit. This becomes especially crucial given the ageing demographic of the Hungarian society (Obádovics & Tóth, 2023).

Although Hungarian circumstances cannot be directly translated to a Europe-wide context, the fact that living in towns scored the worst for biodiversity-positive gardening, and that nearly as many EU residents live in towns and suburbs as in cities (Eurostat, 2022), is highly concerning and may highlight an increasing need of environmental education in towns. At the same time, 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 DGs in Hungarian cities and less flat-based housing than in most Western European cities (Eurostat, 2021). 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 & Györi, 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 in gardening motivation (Jehlička et al., 2020), the frequency of food self-provisioning (Alber & Kohler, 2008; Vávra et al., 2018) and pesticide use (Coisnon et al., 2019) 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 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, and gardens that function mainly as ornamental gardens formed separate modules. The last two modules group gardens whose owners are environmentally conscious, close to nature, and enjoy outdoor activities. Despite 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 (e.g. herbs or evergreens) affects biodiversity-positive gardening. Yet, although with a low importance in the model, the presence of lawns pointed toward lower BDF scores and the presence of vegetables seemed to be related with biodiversity-positive activities. Indeed, the presence of lawns is probably related to increased herbicide use and frequent mowing whereas 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 DG 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 (of whom almost half used synthetic pesticides) in their gardens. Albeit alarming, this is in line with 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 sources of biodiversity-related information as major culprits. Similarly to other countries, information on alternative, less harmful or biological pesticides (e.g. *Bacillus thuringiensis* or baculoviruses) is available in Hungary but the use of these is most likely linked to a narrow environmentally conscious and highly educated stratum of the society. 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 (Wyckhuys et al., 2019) and 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 the future of the next generations as well as to highlight non-chemical

alternatives to the ones who are inclined to adopt biodiversity-friendly measures. 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 mowing several times a month was also one of the common biodiversity-negative practices. For some, such as those who own middle-size gardens, leaving unmown patches may not be an alternative 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 500 m<sup>2</sup>). Indeed middle-sized gardens strongly and negatively affected the BDF score, most likely as a result of mowing several times a month. 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 Mow 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). Whereas, we found an overlap between those who mow several times a month 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 permanent undisturbed areas. Regardless, campaigns focused on biodiversity awareness hold the potential to promptly impact gardening practices, steering them towards sustainable garden care.

### 5.1. Study limits

Since in our work the respondents were not randomly selected, but rather formed 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 of reaching the infrastructurally less developed eastern part of the country.

To engage a broad audience through our questionnaire and to prevent potential respondents from feeling deterred by the length of the questionnaire, we attempted to make it as concise as possible, limited the number of questions, and intentionally prioritized simplicity and clarity in various instances. This sometimes meant compromising to some degree in scientific terminology and precision, for example, gardening practices, and pesticide and fertiliser use could have been recorded on a finer scale. Certain responses, inherently from the method, exhibited subjectivity. For instance, the respondents' knowledge about their gardens' biodiversity was judged on self-assessed and the number of pollinator groups they observed in their gardens, which may have depended on their ecological knowledge. Nevertheless, the introduction of photo-based selection in the corresponding question probably mitigated this subjectivity.

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.

## 6. Conclusions

Our findings 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 BFG 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 BFG 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. Moreover, policy changes, such as restricting the accessibility of pesticides at non-specialist retailers and releasing legislations on obligately well-kempt gardens, could facilitate the transition to BFG. Although our study concentrated exclusively on Hungary, 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 or landscape layout). Ground truth inventories of garden biodiversities are thus also needed, along with the assessment of landscape-level variables. Citizen science projects for DG (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.

### Code Availability

The underlying computer code is available in the GitHub repository [https://github.com/zsvargaszilay/gardening\\_in\\_hungary](https://github.com/zsvargaszilay/gardening_in_hungary).

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### CRediT authorship contribution statement

**Kinga Gabriela Fetykó:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Zsófia Varga-Szilay:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gábor Pozsgai:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gergely Szövényi:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization.

### 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) exclusively to improve readability and language. This, however, affected only a minor part of the text. After using this

tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication. Moreover, two small graphical elements of the graphical abstract were AI-generated.

## Author Statement

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.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.ufug.2024.128367](https://doi.org/10.1016/j.ufug.2024.128367).

## References

- Alber, J., Kohler, U., 2008. Informal food production in the enlarged European Union. *Soc. Indic. Res.* 89 (1), 113–127. <https://doi.org/10.1007/s11205-007-9224-1>.
- Andersson, E., et al., 2007. Measuring social-ecological dynamics behind the generation of ecosystem services. *Ecol. Appl.* 17 (5), 1267–1278. <https://doi.org/10.1890/06-1116.1>.
- Baker, S.E., et al., 2020. Not in my backyard: public perceptions of wildlife and ‘pest control’ in and around UK homes, and local authority ‘pest control’. *Animals* 10 (2). <https://doi.org/10.3390/ani10020222>.
- Baldock, K.C.R., et al., 2019. A systems approach reveals urban pollinator hotspots and conservation opportunities. *Nat. Ecol. Evol.* 3 (3) <https://doi.org/10.1038/s41559-018-0769-y>.
- Baldock, K.C.R., 2020. Opportunities and threats for pollinator conservation in global towns and cities. *Curr. Opin. Insect Sci.* 38, 63–71. <https://doi.org/10.1016/j.cois.2020.01.006>.
- Barthel, S., et al., 2010. Social-ecological memory in urban gardens—retaining the capacity for management of ecosystem services. *Glob. Environ. Change* 20 (2), 255–265. <https://doi.org/10.1016/j.gloenvcha.2010.01.001>.
- Bell, S., et al. (Eds.), 2016. *Urban Allotment Gardens in Europe*. Routledge.
- Beluszky, P., Győri, R., 2005. *The Hungarian urban network in the beginning of the 20th century*. *Discuss. Pap.* 46, 7–133.
- Benbrook, C.M., 2016. Trends in glyphosate herbicide use in the United States and globally. *Environ. Sci. Eur.* 28 (1), 3. <https://doi.org/10.1186/s12302-016-0070-0>.
- Blondel, V.D., et al., 2008. Fast unfolding of communities in large networks. *J. Stat. Mech.: Theory Exp.* 2008 (10), P10008. <https://doi.org/10.1088/1742-5468/2008/10/P10008>.
- Breuste, J., et al., 2013. Applied urban ecology for sustainable urban environment. *Urban Ecosyst.* 16 (4), 675–680. <https://doi.org/10.1007/s11252-013-0337-9>.
- Burr, A., et al., 2018. The perfect lawn: exploring neighborhood socio-cultural drivers for insect pollinator habitat. *Urban Ecosyst.* 21 (6), 1123–1137. <https://doi.org/10.1007/s11252-018-0798-y>.
- Cameron, R.W.F., et al., 2012. The domestic garden – its contribution to urban green infrastructure. *Urban For. Urban Green.* 11 (2), 129–137. <https://doi.org/10.1016/j.ufug.2012.01.002>.
- Camps-Calvet, M., et al., 2016. Ecosystem services provided by urban gardens in Barcelona, Spain: insights for policy and planning. *Environ. Sci. Policy* 62, 14–23. <https://doi.org/10.1016/j.envsci.2016.01.007>.
- Clayton, S., 2007. Domesticated nature: motivations for gardening and perceptions of environmental impact. *J. Environ. Psychol.* 27 (3), 215–224. <https://doi.org/10.1016/j.jenvp.2007.06.001>.
- Coison, T., et al., 2019. Information on biodiversity and environmental behaviors: a European study of individual and institutional drivers to adopt sustainable gardening practices. *Soc. Sci. Res.* 84, 102323 <https://doi.org/10.1016/j.ssrresearch.2019.06.014>.
- Csardi, G., Nepusz, T., 2006. The igraph software package for complex network research. *Inter. Complex Syst.* 1695 (1.5.1).
- De Silva, D.G., Pownall, R.A.J., 2014. Going green: does it depend on education, gender or income? *Appl. Econ.* 46 (5), 573–586. <https://doi.org/10.1080/00036846.2013.857003>.
- Delahay, R.J., et al., 2023. Biodiversity in residential gardens: a review of the evidence base. *Biodivers. Conserv.* 32 (13), 4155–4179. <https://doi.org/10.1007/s10531-023-02694-9>.
- Egerer, M.H., et al., 2018. Water use behavior, learning, and adaptation to future change in urban gardens. *Front. Sustain. Food Syst.* 2 <https://doi.org/10.3389/fsufs.2018.00071>.
- European Commission, Directorate-General for Communication. (2019). *Attitudes of Europeans towards biodiversity* (481; 1.00). ([https://data.europa.eu/data/datasets/s2194\\_90\\_4\\_481\\_eng?locale=en](https://data.europa.eu/data/datasets/s2194_90_4_481_eng?locale=en)).
- Eurostat, 2021. Housing in Europe – House or Flat – Owning Or Renting. Housing in Europe. (<https://ec.europa.eu/eurostat/cache/digpub/housing/bloc-1a.html>) (accessed 30th November 2023).
- Eurostat. (2022). Urban-rural Europe – Introduction. ([https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Urban-rural\\_Europe\\_-\\_introduction](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Urban-rural_Europe_-_introduction)) (accessed 30th November 2023).
- Fischer, L.K., et al., 2020. Public attitudes toward biodiversity-friendly greenspace management in Europe. *Conserv. Lett.* 13 (4), e12718 <https://doi.org/10.1111/conl.12718>.
- Fjaestad, S.L., et al., 2023. Associations of time spent gardening with mental wellbeing and life satisfaction in mid-to-late adulthood. *J. Environ. Psychol.* 87, 101993 <https://doi.org/10.1016/j.jenvp.2023.101993>.
- Fontaine, B., et al., 2016. Impact of urbanization and gardening practices on common butterfly communities in France. *Ecol. Evol.* 6 (22), 8174–8180. <https://doi.org/10.1002/ece3.2526>.
- García-Antúnez, et al., 2023. Gardening for wildlife: a mixed-methods exploration of the factors underlying engagement in wildlife-friendly gardening. *People Nat.* 5 (2), 808–825. <https://doi.org/10.1002/pan3.10450>.
- Goddard, M.A., et al., 2010. Scaling up from gardens: Biodiversity conservation in urban environments. *Trends Ecol. Evol.* 25 (2), 90–98. <https://doi.org/10.1016/j.tree.2009.07.016>.
- Goddard, M.A., et al., 2013. Why garden for wildlife? Social and ecological drivers, motivations and barriers for biodiversity management in residential landscapes. *Ecol. Econ.* 86, 258–273. <https://doi.org/10.1016/j.ecolecon.2012.07.016>.
- Greenwell, B., et al., (2022). *gbm: Generalized Boosted Regression Models* (2.1.8.1) [Software]. (<https://cran.r-project.org/web/packages/gbm/index.html>).
- Griffith, D.M., et al., 2016. Probabilistic species co-occurrence analysis in R. *J. Stat. Softw., Code Snippets* 69 (2), 1–17. <https://doi.org/10.18637/jss.v069.c02>.
- Griffiths-Lee, J., et al., 2022. Sown mini-meadows increase pollinator diversity in gardens. *J. Insect Conserv.* 26 (2), 299–314. <https://doi.org/10.1007/s10841-022-00387-2>.
- Hagen, M., et al., 2012. 2 - Biodiversity, species interactions and ecological networks in a fragmented world. In: Jacob, U., Woodward, G. (Eds.), *Advances in Ecological Research*. Academic Press, pp. 89–210 <https://doi.org/10.1016/B978-0-12-396992-7.00002-2>.
- Hanson, et al., 2021. Gardens’ contribution to people and urban green space. *Urban For. Urban Green.* 63, 127198 <https://doi.org/10.1016/j.ufug.2021.127198>.
- Harris, C.R., et al., 2020. Array programming with NumPy. *Nature* 585 (7825), 357–362. <https://doi.org/10.1038/s41586-020-2649-2>.
- Hill, M.J., et al., 2021. Garden pond diversity: opportunities for urban freshwater conservation. *Basic Appl. Ecol.* 57, 28–40. <https://doi.org/10.1016/j.baee.2021.09.005>.
- Hoyle, H., et al., 2017. “Not in their front yard” The opportunities and challenges of introducing perennial urban meadows: a local authority stakeholder perspective. *Urban For. Urban Green.* 25, 139–149. <https://doi.org/10.1016/j.ufug.2017.05.009>.
- Jabbar, M., et al., 2022. Assessing the role of urban green spaces for human well-being: a systematic review. *GeoJournal* 87 (5), 4405–4423. <https://doi.org/10.1007/s10708-021-10474-7>.
- Jehlička, P., et al., 2020. Thinking food like an East European: a critical reflection on the framing of food systems. *J. Rural Stud.* 76, 286–295. <https://doi.org/10.1016/j.jrurstud.2020.04.015>.
- Kabisch, N., Haase, D., 2013. Green spaces of European cities revisited for 1990–2006. *Landsc. Urban Plan.* 110, 113–122. <https://doi.org/10.1016/j.landurbplan.2012.10.017>.
- Krols, J., et al., 2022. Residential green space, gardening, and subjective well-being: a cross-sectional study of garden owners in northern Belgium. *Landsc. Urban Plan.* 223, 104414 <https://doi.org/10.1016/j.landurbplan.2022.104414>.
- Kuhn, M., et al., 2023. caret: Classif. Regres. Train. (<https://cran.r-project.org/web/packages/caret/index.html>) (6.0-94) [Software].
- Law, N., et al., 2004. Nitrogen input from residential lawn care practices in suburban watersheds in Baltimore county, MD. *J. Environ. Plan. Manag.* 47 (5), 737–755. <https://doi.org/10.1080/0964056042000274452>.
- Leavell, M.A., et al., 2019. Nature-based social prescribing in urban settings to improve social connectedness and mental well-being: a review. *Curr. Environ. Health Rep.* 6 (4), 297–308. <https://doi.org/10.1007/s40572-019-00251-7>.
- Lerman, S.B., et al., 2018. To mow or to mow less: lawn mowing frequency affects bee abundance and diversity in suburban yards. *Biol. Conserv.* 221, 160–174. <https://doi.org/10.1016/j.biocon.2018.01.025>.
- Lundberg, S.M., Lee, S.-I., 2017. A unified approach to interpreting model predictions. *Adv. Neural Inf. Process. Syst.* 30. In: (<https://proceedings.neurips.cc/paper/2017/hash/8a20a8621978632d76c43df28b67767-Abstract.html>).

- Mayer, M., et al. (2023). *kernelshap: Kernel SHAP* (0.4.0) [Software]. (<https://cran.r-project.org/web/packages/kernelshap/index.html>).
- Mayer, M., Stando, A., 2023. *shapviz: SHAP Visualizations* (0.9.2) [Software]. (<https://cran.r-project.org/web/packages/shapviz/index.html>).
- Meyer, A., 2015. Does education increase pro-environmental behavior? Evidence from Europe. *Ecol. Econ.* 116, 108–121. <https://doi.org/10.1016/j.ecolecon.2015.04.018>.
- Muratet, A., Fontaine, B., 2015. Contrasting impacts of pesticides on butterflies and bumblebees in private gardens in France. *Biol. Conserv.* 182, 148–154. <https://doi.org/10.1016/j.biocon.2014.11.045>.
- Obádovics, C., Tóth, G.C., 2023. A magyarországi régiók népességének előreszámítása 2050-ig [Population forecasting of Hungarian regions till 2050]. *Stat. Szle.* 101 (9), 763–792. <https://doi.org/10.20311/stat2023.09.hu0763>.
- Oksanen, J., 2022. *vegan: Community ecology package* (2.6-4) [Software] (<https://CRAN.R-project.org/package=vegan>).
- Paker, Y., et al., 2014. The effect of plant richness and urban garden structure on bird species richness, diversity and community structure. *Landscape Urban Plan.* 122, 186–195. <https://doi.org/10.1016/j.landurbplan.2013.10.005>.
- Philpott, S., et al., 2020. Gardener demographics, experience, and motivations drive differences in plant species richness and composition in urban gardens. *Ecol. Soc.* 25 (4) <https://doi.org/10.5751/ES-11666-250408>.
- Plantlife's No Mow May Movement (2022). (<https://www.plantlife.org.uk/campaigns/nomowmay/>) (accessed 30th November 2023).
- Ponizy, L., et al., 2021. The rich diversity of urban allotment gardens in Europe: contemporary trends in the context of historical, socio-economic and legal conditions. *Sustainability* 13 (19). <https://doi.org/10.3390/su131911076>. Article 19.
- Prendergast, K.S., et al., 2022. Urban native vegetation remnants support more diverse native bee communities than residential gardens in Australia's southwest biodiversity hotspot. *Biol. Conserv.* 265, 109408 <https://doi.org/10.1016/j.biocon.2021.109408>.
- Python Software Foundation. (2019). *Python Language Reference* (3.8) [Software]. (<http://www.python.org>).
- R Core Team. (2021). *R: A language and environment for statistical computing* (4.3) [Software]. (<https://www.R-project.org/>).
- Ramalho, C.E., Hobbs, R.J., 2012. Time for a change: dynamic urban ecology. *Trends Ecol. Evol.* 27 (3), 179–188. <https://doi.org/10.1016/j.tree.2011.10.008>.
- Salisbury, A., et al., 2015. Editor's choice: Enhancing gardens as habitats for flower-visiting aerial insects (pollinators): should we plant native or exotic species? *J. Appl. Ecol.* 52 (5), 1156–1164. <https://doi.org/10.1111/1365-2664.12499>.
- Soulsbury, C.D., White, P.C.L., 2015. Human–wildlife interactions in urban areas: a review of conflicts, benefits and opportunities. *Wildl. Res.* 42 (7), 541–553. <https://doi.org/10.1071/WR14229>.
- Süle, G., et al., 2023. Escape from the garden: Spreading, effects and traits of a new risky invasive ornamental plant (*Gaillardia aristata* Pursh). *NeoBiota* 83, 43–69. <https://doi.org/10.3897/neobiota.83.97325>.
- Tassin de Montaigu, C., Goulson, D., 2023a. Habitat quality, urbanisation & pesticides influence bird abundance and richness in gardens. *Sci. Total Environ.* 870, 161916 <https://doi.org/10.1016/j.scitotenv.2023.161916>.
- Tassin de Montaigu, C., Goulson, D., 2023b. Factors influencing butterfly and bumblebee richness and abundance in gardens. *Sci. Total Environ.*, 167995 <https://doi.org/10.1016/j.scitotenv.2023.167995>.
- The Pandas Development Team. (2022). *pandas-dev/pandas: Pandas* (v1.5.2) [Software]. Zenodo. (<https://doi.org/10.5281/zenodo.7344967>).
- Van Heezik, Y.M., et al., 2012. Closing the gap: communicating to change gardening practices in support of native biodiversity in urban private gardens. *Ecol. Soc.* 17 (1) <https://doi.org/10.5751/ES-04712-170134>.
- Varga-Szilay, Z., Pozsgai, G., 2022. Plant growers environmental consciousness may not be enough to mitigate pollinator declines: a questionnaire-based case study in Hungary. *Pest Manag. Sci.* 79 (4), 1284–1294. <https://doi.org/10.1002/ps.7277>.
- Vávra, J., et al., 2018. Food self-provisioning in Europe: an exploration of sociodemographic factors in five regions. *Rural Sociol.* 83 (2), 431–461. <https://doi.org/10.1111/ruso.12180>.
- Veech, J.A., 2014. The pairwise approach to analysing species co-occurrence. *J. Bio.* 41 (6), 1029–1035. <https://doi.org/10.1111/jbi.12318>.
- Wickham, H., 2016. *ggplot2: Elegant Graphics For Data Analysis*. Springer-Verlag, New York. (<https://ggplot2.tidyverse.org>).
- Wickham, H., et al. (2023). *dplyr: A Grammar of Data Manipulation* (1.1.2) [Software]. (<https://cran.r-project.org/web/packages/dplyr/index.html>).
- Wyckhuys, K.A.G., et al., 2019. Global disparity in public awareness of the biological control potential of invertebrates. *Sci. Total Environ.* 660, 799–806. <https://doi.org/10.1016/j.scitotenv.2019.01.077>.
- Yang, L., et al., 2019. Can urban greening increase vector abundance in cities? The impact of mowing, local vegetation, and landscape composition on adult mosquito populations. *Urban Ecosyst.* 22 (5), 827–839. <https://doi.org/10.1007/s11252-019-00857-7>.