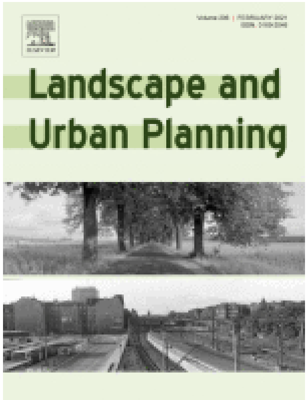

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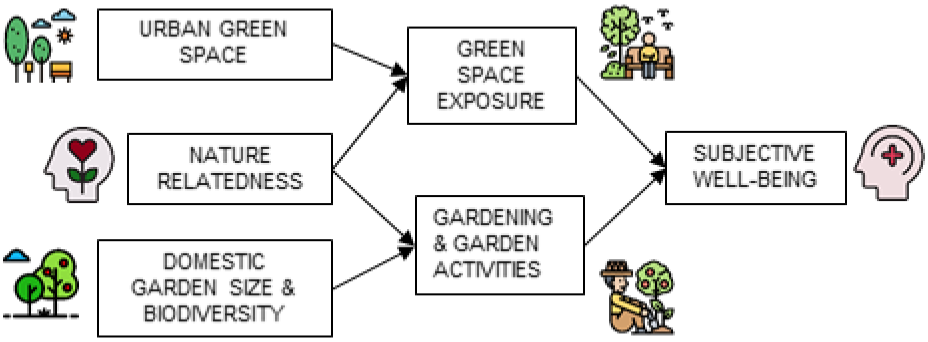

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Residential green space, gardening, and subjective well-being: a cross-sectional study of garden owners in northern Belgium

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Abstract

Urban green spaces and the biodiversity therein have been associated with human health and well-being benefits, but the contribution of domestic gardens to those benefits is insufficiently known.

Using data from a cross-sectional sample (n=587) of domestic garden owners in Flanders and Brussels (northern Belgium), associations between residential green space quality in and around domestic gardens, green space related activities and socioeconomic background variables of the gardeners, and self-reported health (stress and depression) were investigated with structural equation models.

Socioeconomic security was associated with lower stress and depression. Nature relatedness and green space in the neighbourhood of the house were associated with higher exposure to green space, which was in turn negatively associated with stress and depression. Garden quality, indicated by biodiversity values and size, and nature relatedness were associated with being active in the garden, which was in turn associated with lower values of depression, but not stress.

Nature relatedness seems to play a key role in the pathway linking gardens to improved health. Improving biodiversity and ecosystems services in gardens may increase exposure to green space and help to restore and enhance nature relatedness. This, in turn, could potentially improve human health and well-being, and contribute to the conservation of biodiversity in urban environments.

Highlights

- We examined how domestic gardens contribute to health benefits of urban green space.
- We used data from 587 domestic garden owners in northern Belgium.
- Higher exposure to green space was associated with lower stress and depression.
- Higher garden quality was associated with gardening and lower values of depression.
- Nature relatedness seems to shape the pathway linking green space to improved health.

CRediT author statement

Jeroen Krols: Formal analysis, Data Curation, Writing – Original Draft, Visualization. **Raf Aerts**: Conceptualization, Methodology, Writing – Original Draft, Writing – Review & Editing, Visualization, Supervision. **Naomi Vanlessen**: Writing – Review & Editing. **Valerie Dewaelheyns**: Writing – Review & Editing. **Sebastien Dujardin**: Formal analysis, Writing – Review & Editing. **Ben Somers**: Conceptualization, Writing – Review & Editing, Project Administration, Resources, Funding Acquisition, Supervision.

1. Introduction

Urban green space is commonly defined as the complex of natural and semi-natural vegetation in urban environments (Taylor & Hochuli, 2017) and is associated with multiple health benefits (van den Berg et al., 2010; Kardan et al., 2015; Frumkin et al., 2017; Twohig-Bennett & Jones, 2018). Nature exposure in general has been shown beneficial for subjective well-being, quality of life, and for lowering stress levels (White et al., 2019; de Bell et al., 2020). Myriad potential pathways underlying these effects have been suggested, with the most frequently mentioned the restorative effects of contact with nature on attention (Kaplan, 2001; Corley et al., 2021), reducing stress and negative affect, increasing positive affect, and improving emotion regulation (Kondo, Jacoby, & South, 2018; Bratman, et al., 2021). In addition, exposure to (urban) green space may promote physical activity and social cohesion, and hereby improve perceived and objective general and mental health (Gianfredi et al., 2021).

Domestic gardens are a significant component of urban green space, yet the health impacts of gardens and gardening are often overlooked (Ambrose, Das, Fan, & Ramaswami, 2020). A review of studies on green space and mental health benefits found that only 1% of 263 studies included in the analysis involved private gardens (Wendelboe-Nelson, Kelly, Kennedy, & Cherrie, 2019). In some studies, domestic gardens are entirely excluded (Mitchell & Popham, 2008; Nutsford, Pearson, & Kingham, 2013), while other studies found that including domestic gardens resulted only in minimal changes of the associations between green space and health outcomes (Alcock, White, Wheeler, Fleming, & Depledge, 2014; White, Alcock, Wheeler, & Depledge, 2013). Nevertheless, a review that included 77 studies and 35 health outcomes associated with gardens and gardening demonstrated links between gardens and improved mental well-being (Howarth, Brettle, Hardman, & Maden, 2020). Garden owners themselves attribute various physical and psychological health benefits to their garden, report to recover from stress from their daily (work)lives by being in the garden, and see their garden as a place where they can connect with nature (de Bell et al., 2020; Freeman, Dickinson, Porter, & van Heezik, 2012; Young, Hofmann, Frey, Moretti, & Bauer, 2020). In a study among 5,766 gardeners and 249 non-gardeners in the UK, the most important motivators to garden were the direct pleasure, joy, and aesthetics derived from the garden, while gardeners were less driven by potential health benefits (Chalmin-Pui, Griffiths, Roe, Heaton, & Cameron, 2021). Nevertheless, studies at the population level in England found that local health deprivation decreased with domestic garden cover (Dennis & James, 2017), and self-reported health status increased and income-related health inequalities decreased with increasing domestic garden sizes (Brindley, Jorgensen, & Maheswaran, 2018). Earlier literature on gardens focused mainly on communal and allotment gardens [gardening on public or semi-public land e.g. van den Berg et al., 2010; Heise et al., 2017; Soga, Cox et al., 2017] or horticultural therapy [gardening or other plant-based activities as a treatment for mental health issues e.g. Gonzalez, Hartig, Patil, Martinsen, & Kirkevold, 2010; Adevi & Martensson, 2013]. In this study we specifically focus on domestic gardens and their health benefits experienced by the garden owners.

The health effects of domestic gardens may be related to i) their biodiversity; to ii) the duration or frequency of the exposure to domestic gardens; and to iii) the nature of the activities that are carried out in domestic gardens (Chalmin-Pui, Grifiths, Roe, Heaton, & Cameron, 2021). Earlier studies have investigated the role of biodiversity in explaining the health effects of green spaces, but the evidence for a positive role of biodiversity was often mixed (Aerts, Honnay, & Van Nieuwenhuyse, 2018). Comparing biodiversity estimates between different studies has proven difficult as biodiversity indicators often relied on different indicators for objective or perceived species richness. Young et al. (2020) investigated psychological restoration after spending time in domestic gardens and found a positive effect of the number of plant species through the perceived restorativeness of the garden, while feeling garden-related stress had a negative impact.

The second factor that may explain the magnitude of health effects of gardens is related to exposure. Increasing duration, frequency, and intensity of exposure to urban green has been associated with decreasing occurrence of depression and high blood pressure (Shanahan et al., 2016).

The third factor that has an influence on the health impacts of gardens is what garden owners or users do within the garden or how garden owners are connected to their garden. Positive associations between greenness of the neighbourhood and increased physical activity and a lower occurrence of mental health problems have also been documented earlier (James, Banay, Hart, & Laden, 2015). An experimental study in 30 allotment gardens in the Netherlands demonstrated the ability of gardening to promote relief from acute stress (van den Berg & Custers, 2011). Domestic gardening on a regular basis (at least 2-3 times a week) corresponded with improvements in well-being, physical activity, and a reduction in perceived stress (Chalmin-Pui et al., 2021). Cervinka et al. (2016) found that perceived restorativeness of a garden was influenced by characteristics of a garden such as the size and number of natural elements, but also by the garden-user relationship (connectedness, enjoyment, and satisfaction with the garden). In a study in England, persons who used their garden both for relaxation and the activity of gardening reported better levels of general health and well-being, more frequently visited other natural areas, and were more likely to reach recommended levels of physical activity (de Bell et al., 2020). Gardening has been associated with benefits on social health too (Soga, Gaston, & Yamaura, 2017). Especially for the elderly gardening has a positive effect on their quality of life, cognitive ability, and socialization (Wang & MacMillan, 2013).

During the COVID-19 pandemic, scientific interest grew for the effects of spending time in the garden specifically, showing a positive association with well-being (de Bell et al., 2020; Theodorou et al., 2021) and resilience in times of hardship (Sia et al., 2020). Gardening, as a particular way of experiencing nature, allows people to find rest, pleasure, and relief (Kingsley, Foenander, & Bailey, 2019) and promotes the experience of positive mood (van den Berg & Custers, 2011), which all counter stress and depressive feelings. During COVID-19 lockdowns in Scotland, older people who frequently used their garden scored higher on physical and mental health as well as sleep quality (Corley et al., 2021). Another study performed during the COVID-19 pandemic demonstrated that people "experienced an increased sense of nature connection than they had at other times", because "birds felt louder" (Marsh et al., 2021).

In Flanders, the densely populated northern region of Belgium, approximately 21% of residential cores and more than 8% of the total land cover consists of domestic gardens (Dewaelheyns et al. 2014). In 2021, the proportion of inhabitants that reported to have access to a private or shared garden ranged from 66% in the major cities to 93% in small municipalities (overall average 82%; Pisman et al., 2021). This means that gardens are a natural environment experienced by the majority of the Flemish citizens in their daily lives. In terms of total surface area gardens are comparable to forests (~10%; Dewaelheyns et al. 2014). The totality of domestic gardens in a Flanders can be considered as a region-wide landscape structure, a concept called the 'garden complex' by Dewaelheyns et al. (2014). Therefore, the exposure to domestic gardens in Flanders can be considered relatively high. As such, the mental health benefits of gardens and gardening could have potential economic and public health relevance, in particular during the COVID-19 pandemic.

The mental health benefits of gardens are influenced by complex interactions of characteristics of the garden and the environment, human behaviour, and personal background variables. Therefore, this study aims to analyse the relationship between domestic gardens and potential well-being effects for the gardeners, measured in the form of stress and depression indicators. We used structural equation models, which are suitable for testing a-priori models of these complex interactions. We hypothesized that higher garden quality (increasing with size, biodiversity, and number of natural elements) is associated with reduced stress and depression symptoms, and that these associations may be impacted by garden-related activities, nature relatedness, visits to public green space, and the quantity of green space in the neighbourhood.

2. Methods

2.1. Study design and setting

This study was designed as a self-selected cross-sectional study of garden owners in the Flemish Region and the Brussels Capital Region in northern Belgium. On January, 1st, 2020, there were 1.2 million inhabitants in the Brussels Capital Region (50.9% women) and 6.6 million inhabitants in the Flemish Region (50.5% women) (Statbel, 2022). According to the Health Interview Survey of 2018 (the most recent survey), 77% of women and 80% of men reported to be in good (to very good) subjective health in both regions (HIS, 2022). Nevertheless, before the COVID-19 pandemic, 27% of women and 18% of men in the Flemish Region and 46% of women and 33% of men in the Brussels Capital Region reported anxiety or depression according to the EQ-5D instrument (HIS, 2022). In the Flemish Region only 3% of the population reported lack of access to parks or other green or recreational public spaces; in the Brussels Capital Region, which is more urbanized, this proportion was 7% (HIS, 2022).

Participants were recruited through MijnTuinlab (www.mijntuinlab.be). This online citizen science platform is designed to solicit citizen's contributions to research projects focused on the assessment of biodiversity and ecosystem services in domestic gardens, and is connected to the platforms waarnemingen.be and observations.org focusing on biodiversity observations. Participants for MijnTuinlab were recruited via a media campaign supported by the large newspaper Het Nieuwsblad (circulation: ~22,5000 copies; readership 1,130,710; reach 14.5%). The campaign included dedicated articles about the importance of gardens and the objectives of MijnTuinlab, advertisements in the printed and online editions of the newspaper, and direct mailing. Advertisements were also published in other large newspapers, on social media, and broadcasted on television. In a first phase, self-selected participants were asked to register their garden and to complete a survey on the biotic and abiotic properties of their garden. These questionnaires were available from the launch of MijnTuinlab on 24 April 2020 (near the first peak of the COVID-19 pandemic), but answers could permanently be updated. In a second phase, participants provided data on their exposure to green space (including their garden), physical and mental health, feelings towards nature, and socio-economic background. These questionnaires were open to the public from 17 August 2020 until 31 October 2020. In November 2020 follow-up e-mails were sent out to respondents with missing data on garden properties to minimize exclusions (Fig. 1).

The protocol of this study was approved by the Social and Societal Ethics Committee of the KU Leuven (G-2020-1988) and respondents provided their informed consent before starting and completing the survey. All questionnaires were administered in Dutch.

In total 907 responses were registered throughout both phases of the study, 786 of which were filled in completely. Of these, 115 responses were excluded (after sending follow-up emails) as either no corresponding profile existed on the MijnTuinlab platform or information regarding their garden was incomplete. Potential confounders age and sex were registered separately on the MijnTuinlab platform, but were missing in a number of cases. This resulted in a total sample of 587 responses included in the analysis, or 65% of the original survey response (Fig. 1). The sample comprises 3‱ of the total number of private garden parcels in the study area (approximately 2 million) and is geographically well distributed (Fig. A1).

2.2. Outcome variables

Mental health was assessed using the depression and stress subscales of the Depression Anxiety Stress Scale (DASS). The full scale exists of 42 items, but we used 14 items (7 items per dimension) of the 21-item short form DASS-21 (Lovibond & Lovibond, 1995). Respondents had to indicate if a statement was applicable to them during the past week on a 4-point Likert scale from 0 to 3 ranging from "did not apply to me at all" to "applied to me very much, or most of the time". For example, two statements from the depression scale are: "*I couldn't seem to experience any positive feeling at all*" and "*I found it difficult to work up the initiative to do things*". The stress scale consisted of statements such as "*I found it hard to wind down*" or "*I tended to over-react to situations*". The DASS-21 subscales are scored by adding up the scores on the subscale items and multiplying this result by a factor two, yielding a subscale range between 0 and 42.

2.3. Explanatory variables

2.3.1. Nature relatedness

Connection with nature was estimated using responses to the six items of the short-form nature relatedness scale (NR-6; Nisbet & Zelenski, 2013). A high score is typically associated with high environmental concern. Examples of the items are "*I always think about how my actions affect the environment*", and "*My relationship to nature is an important part of who I am*". Items were measured on a five-point Likert scale (1–5) on a range from "completely disagree" to "completely agree". The NR-6 scale is obtained by calculating the average score of the six items, with high scores indicating high nature relatedness.

2.3.2. Garden quality

We focussed on biodiversity to quantify garden quality. An empirical biodiversity score was calculated based on self-reported properties of the gardens. In the first phase of the data collection, garden owners digitized the perimeter of their parcel on an interactive map. Subsequently, each participant subdivided his/her garden polygon into smaller polygons, representing the house, water, vegetated areas, and other buildings, impervious areas and bare soil. Water polygons were further split into two subcategories: (semi-)natural water and artificial waterbodies without the presence of plants. Vegetated area was further subdivided in eight categories: three possible types of grass (short cut lawn, flowery or species-rich grassland, grazing meadow), planted flowers or shrubs, trees (later divided in categories of higher and lower than 6 m), bushes, wild vegetation, and vegetable garden. Furthermore, the presence of four types of climbing plants, a green roof and the type of trees in the garden (deciduous, fruit- and coniferous or needle-leaved trees) were registered. Participants then indicated the total number of plant species in their garden (less than 10, between 10 and 100 or more than 100) and the presence of certain animal-friendly features (feeding/drinking place in winter for animals, passage for hedgehogs, dead wood, or a nesting place) or compost infrastructure. Each land cover type was given a separate score for biodiversity, ranging between 1 (e.g. manicured lawn) and 5 (e.g. species-rich grassland) (see Table 2.1). A total garden biodiversity score was then calculated as the product of feature scores and their area, with additional points for the presence of certain features without specific surface area. The garden biodiversity score was then converted to a relative score (%) by dividing the score by the maximum score observed in the sample and multiplying by 100. Higher garden biodiversity scores indicated higher (subjective) garden quality.

The number of natural elements in the garden was calculated as the number of features of the following list present in the garden: (semi-)natural water, green roof, the subcategories of vegetated area (with a maximum of eight), dead wood, a vertical garden, and the (combined) presence of any of the three other forms of wall vegetation. The maximum for this indicator was 13 natural elements.

To take into account the green space in the surrounding neighbourhood, three buffers were made around the perimeter of the garden with buffer distances of 100, 500, and 1000 meter. In these buffers the size of forest patches, grassland, and other gardens was calculated in m² and in % cover. These land covers were derived from the Top10Vector land cover geodataset for Belgium (National Geographic Institute (NGI), 2014). For forest, classes belonging to coniferous woodland, predominantly coniferous mixed woodland, mixed woodland, predominantly broad-leaved mixed woodland or broad-leaved woodland were used to define forest cover. For grassland, the classes permanent grassland or hay meadow and lawn were used.

2.3.3. Green space related activities

To gain information about the respondent's activities in nature, a set of questions around this topic was made. A first question was related to how often respondents visit public green spaces. This was measured on a seven-point ordinal scale with options "never", "once a year", "once every three months", "once a month", "multiple times a month", "once a week", or "multiple times a week". Coupled with this, the number of visits to public green spaces during the last week was measured on a scale of 0 to 7 and if there were visits in the last week the average duration of these was asked. Available options were "less than 30 minutes", "30 minutes to one hour", "between one and two hours", "two to three hours", "three to four hours", or "more than four hours". These last two questions were then repeated for visits to gardens other than the primary (own) garden. This could for example be an allotment garden owned by the respondent, or the garden of a friend or relative. Next, participants recorded how many days they spent in their own garden in the past week and the average daily time spent in their garden during summer. In total there were 20 options starting from “less than one hour” to “ten hours or more” with steps of 30 minutes. Finally, respondents indicated how their time in their own garden was divided between being active (gardening, doing sports in the garden …) and being passive (resting, observing the fauna and flora …).

2.4. Potential confounders

Earlier studies in Belgium have demonstrated that associations between green space and health outcomes are influenced by socio-economic background variables, and notably by socio-economic deprivation (e.g. Aerts et al., 2020a). Education, profession, and income are dimensions of socioeconomic deprivation that strongly correlate to socio-economic status in Belgium (Bossuyt, Gadeyne, Deboosere, & Van Oyen, 2004). The net monthly income of the household was measured in six categories (“Less than 1000 euro”, “1001 -2000 euro”, “2001-3000 euro”, “3001-4000 euro”, “4001-5000 euro” and “more than 5000 euro”). Ownership of the house to which the garden belonged was assessed and treated as a binary variable of ownership. Low values for income and ‘not owning the house’ were used as indicators of potential income deprivation. Education was measured in eleven options, and reduced to a binary variable of post-secondary education. We used ‘no post-secondary education’ as an indicator of potential education skills and training deprivation. Employment status was questioned through seven options and reduced to a binary variable currently employed or not, and we used ‘not employed’ as an indicator of potential employment deprivation. Finally, participants also provided information on age, sex (man/woman), marital status (having a partner/no partner), and having children living at home (yes/no), because these variables could have an impact on both stress/depression levels and garden activities.

2.5. Data analysis

The main analysis was carried out with structural equation models (SEM) in which effects between measured (observed) variables and outcomes can be linked through latent (unobserved) variables (Kaplan, 2009). We hypothesized that depression and stress would be associated with garden activities, activities in other gardens, and time spent in public green, and that socio-economic security, garden quality, neighbourhood green space, and nature relatedness may impact this association through direct and indirect impacts on symptoms of depression and stress (Fig. 2).

The models were evaluated in the R environment for statistical computing with the package *lavaan* (Rosseel, 2012). Variables derived from Likert scales were treated as continuous variables (Rhemtulla, Brosseau-Liard, & Savalei, 2012). Explanatory variables related to garden and surrounding green space quantity and quality were first converted to z-scores. The model was evaluated using the cut-off criteria presented in Hu and Bentler (1999). They specify that an ideal model has a root mean square error of approximation (RMSEA) smaller than or equal to 0.06, a standardized root mean square residual (SRMSR) smaller than or equal to 0.08, and a comparative fit index (CFI) larger than or equal to 0.95. Two SEMs were run separately for stress and depression outcomes. Internal consistency of the indicator variables for the latent variables was calculated with the Cronbach's alpha in R with the package *psych* (Revelle, 2021). Scores higher than 0.7 are generally considered acceptable.

3. Results

The geographical distribution of included gardens is presented in Figure A1. The characteristics of the study population are presented in Table 1. The sample included 55% women, and garden owners were on average aged 54.8 years old (SD 13.0). The mean size of the included gardens was 1827 m² (standard deviation (SD) 8930 m²). The median garden size was 734 m² (interquartile range difference 1387 m²). The majority of respondents reported normal values for depression (depression scale <10, n = 479, 81.6%) and stress (stress scale < 15, n = 516, 87.9%) . The average nature relatedness score was 4.05 (SD 0.6) on a maximum of 5. The internal consistencies of the latent variables stress, depression, and nature relatedness were high to acceptable (Cronbach's alpha α(Stress) = 0.89, α(Depression) = 0.87, α(NR-6) = 0.76).

The model for stress had better fit indices than the model for depression, although the CFI was still not optimal (N = 587, CFI = 0.907, AIC = 41482, RMSEA = 0.055, SRMR = 0.068). The obtained fit indices for depression were a bit lower (N = 587, CFI = 0.899, AIC = 40675, RMSEA = 0.057, SRMR = 0.069).

In the SEM for stress, there was evidence for protective associations between stress and socio-economic security (standardized parameter estimate/regression coefficient β = -0.14, p = 0.016, SE = 0.034) and nature exposure (β = -0.07, p = 0.079, SE = 0.009). Nature relatedness had an indirect effect through a positive association with exposure to nature (β = 0.11, p = 0.012, SE = 0.191). Green space in the surrounding neighbourhood contributed to nature exposure (β = 0.07, p = 0.060, SE. = 0.100). Nature relatedness and garden quality were positively linked to garden activities (NR: β = 0.16, p = 0.001, SE= 0.135; quality: β = 0.12, p = 0.003, SE= 0.071) but garden activities were not associated with levels of stress (Fig. 3, Table B2).

In the SEM for depression, similar associations were found: there were protective associations between depression and socio-economic security (standardized parameter estimate/regression coefficient β = -0.22, $p < 0.001$, SE = 0.032) and nature exposure (β = -0.08, p = 0.059, SE = 0.007); nature relatedness had an indirect effect through a positive association with exposure to nature (β = 0.11, p = 0.012, SE = 0.191); and green space in the surrounding neighbourhood contributed to nature exposure (β = 0.07, p = 0.058, SE = 0.100). Nature relatedness and garden quality were positively linked to garden activities (NR: β = 0.15, p = 0.002, SE = 0.134; quality: β = 0.12, p = 0.003, SE = 0.071) and, in contrast to stress, garden activities exhibited a weak inverse association with depression (β = -0.09, p = 0.075, SE = 0.013) (Fig. 4; Table B3). Both models were subject to confounding by age, while only the model for stress was subject to confounding by sex.

4. Discussion

We examined how domestic gardens contribute to health benefits of urban green space. We found that i) higher exposure to neighbourhood green space was associated with lower reported stress and depression symptoms; ii) higher garden quality was associated with more frequent gardening and lower values of depression symptoms; and iii) nature relatedness seems to shape the pathway linking gardens to improved well-being by having an impact on both exposure to green space and activities in gardens.

Several mechanisms for these effects of garden activities can be put forward. First of all, gardening facilitates mindful engagement with nature (Macaulay, Lee, Johnson, & Williams, 2022). The direct and intentional interaction with nature allows for a heightened sensitivity to sensory experiences (March et al., 2021) and experiences of interest and curiosity (Nisbet, Zelenski, & Grandpierre, 2019), inviting people to a more mindful state. Second, gardening might reduce stress and alleviate depressive symptoms by providing the opportunity to perform tasks that are meaningful (e.g. they lead to a more beautiful or healthier garden, food production, …) and relatively easy to execute, providing the gratification of having fulfilled a meaningful task, and a sense of autonomy and competence (Nisbet et al., 2019) and self-esteem (Wood, Pretty, & Griffin, 2016). Finally, being in the garden allows people to experience a strengthened sense of connection with nature (Egerer et al., 2022). A meta-analysis showed a positive link between experiencing nature connectedness and positive affect, vitality, and life satisfaction (Capaldi et al., 2014). Nature connectedness can give rise to a sense of belonging (Mayer et al., 2009) and experiencing a sense of meaning or purpose in life (Capaldi et al., 2014; Martin et al., 2020), key protective resources against depression and the debilitating effects of stress, especially in times of adversity, like a pandemic (White, 2020). Indeed, nature relatedness has been linked to self-reported (mental) health outcomes before. For instance, in a population study including 1536 inhabitants of Brisbane, Australia, (subscales of) nature relatedness scale were associated with increased self-reported health (Dean et al., 2018). In the same study, lower values for depression, anxiety, and stress were associated with higher scores for nature relatedness. In a study including 1,005 individuals in Ecuador, home garden users were more satisfied with gardens if their motives for garden use were related to nature (Cruz-Cárdenas & Oleas, 2018). Nature relatedness has also been linked to higher values in well-being (Nisbet, Zelenski, & Murphy, 2011). The short form NR-6 used in the present study has also been correlated with happiness indicators before, although no link with depression was found (Nisbet & Zelenski, 2013).

The positive effect of gardening activities on depression is in line with findings from the meta-analysis on the health effects of gardening performed by Soga et al. (2017) where 8 of the 11 studies investigating the effect of daily gardening or horticultural therapy on depression found a protective effect against depression. For stress, 4 of the 6 studies included in this analysis found a protective effect against stress, which is not replicated in our study. In a study of 529 university students in Bulgaria, Dzhambov et al. (2019) found a link between residential green space and reduced scores on depression, and this was mediated by the restorative quality of the green space, which we did not measure in our study.

The structural equation models used in this study are a strength, because they allow us to infer some degree of causality in an observational study. However, as in other epidemiological studies relying on self-reported data, our study may be prone to self-reporting bias (Rosenman, Tennekoon, & Hill, 2011) and thus be affected by over- or underestimation in the outcome variables (stress and depression) and by exposure misclassification. Because we have included objective indicators of green space exposure in addition to self-reported green space exposure data, i.e. the relative covers of green space types in different buffers around the home derived from detailed land cover maps, and because self-reported garden properties of several gardens were validated by field workers in the context of another project, we are confident that exposure misclassification is limited.

A second limitation of the study is the potential bias associated with self-selection of participants. For instance, the gardens in our sample were larger than the average garden in Flanders (average size 688 m², median 400 m²; Somers et al. 2021). Moreover, garden owners with a special interest in their garden and the nature within it may have been more likely to participate in this study, than garden owners that experience stress from their garden. Indeed gardens may cause stress because gardens may require physical work (for instance, to control unwanted species), may contain allergenic tree species (Aerts et al. 2020b), may consume time and money, and may be sources of annoying 'dirt' and 'bugs' (Cruz-Cárdenas & Oleas 2018; Young et al., 2020). In informal interviews with garden owners in Flanders performed by RA, examples of plants inducing garden-related stress included a hazel tree (*Corylus avellana*) '*occupying too much space'*, ivy (*Hedera helix*) '*destroying a wall*', dandelions (*Taraxacum officinale*) '*popping up everywhere*', yew (*Taxus baccata*) '*unpleasant to prune*' and hedge bindweed (*Calystegia sepium*) '*disturbingly climbing over and through hedges*' leading to disputes among neighbours. Most likely, garden owners experiencing such garden-related stress are underrepresented in the sample. This means that garden quality, nature relatedness, or green space related activities are probably biased towards higher values compared to the entire population of garden owners, and compared to the general population. There is no reference data available for the study area, but the average nature relatedness (NR-6 = 4.05, SD 0.60) was higher than the average NR-6 reported in the original study describing the new scale (NR-6 = 3.26, weighted average across three studies of 683 participants; Nisbet & Zelenski, 2013). Although 82% of the inhabitants of Flanders has a garden or has access to a shared garden, the results should not be used to infer about the general population, as socio-economic characteristics of the sample of garden owners may also be biased towards higher values of socio-economic status than those of the general population.

A third limitation of our study is that the restrictions and lockdowns during the COVID-19 pandemic through the data collection period may have had an impact on exposures and outcomes. Exposure – or the need for exposure – to public green space could have been higher than before because people started using green space more actively during the pandemic (da Schio et al., 2021; Lenaerts et al., 2021), and felt more connected to nature than before (Marsh et al., 2021). Conversely, exposure could have been lower or less diverse than before because garden owners may have avoided public green space, spending more time in their own garden (da Schio et al., 2021). Lockdown measures such as home confinement may have affected the outcome too, as people experienced much higher levels of psychological distress during the pandemic than before (a 2.3-fold increase compared to 2018), in particular women and younger people (Lorant, Smith, Van den Broeck, & Nicaise, 2021). Nevertheless, the median scores for depression (4; IQR 0–8) and stress (6; IQR 2-12) were comparable to the median scores for depression (4; IQR 1–10) and stress (7; IQR 3-12) that were obtained in a cross-sectional sample of 7,972 adult subjects in the Netherlands long before the COVID-19 pandemic (2013-2014) (Wardenaar, Wanders, Jeronimus, & de Jonge, 2017).

Finally, the fit indicators of the SEMs are acceptable but not optimal and therefore the interpretation of these models should be done with caution.

Implication for planning

Garden quality, here defined by garden size and the diversity of natural and semi-natural elements of gardens, was associated with lower depression symptoms via its impact on garden activities. Green space in the neighbourhood of the house also contributed to better subjective well-being via its impact on exposure. This means that the *neighbours* of garden owners also benefit from gardens they don't own. These spill-over effects on human health illustrate that the garden complex provides benefits for the society that were not sufficiently recognized until now. For instance, informing citizens on health benefits of biodiverse gardens may help to motivate behaviour change towards climate change adaptation (Semenza, Ploubidis, & George, 2011). Our results therefore lend support to ongoing efforts to improve urban environmental quality by informing garden owners on the biodiversity and ecosystem services in their gardens and by engaging them towards improvement of these garden properties, for instance via citizen science projects. Our results demonstrate that gardens are an important component of the urban green infrastructure, and that despite their status as private property, should be considered in landscape and urban planning for their collective impact on health, biodiversity, and climate.

5. Conclusion

This cross-sectional study in Flanders investigated effects of domestic gardens on subjective well-being, indicated by self-reported stress and depression. Well-being was associated with nature relatedness and green space in the neighbourhood of the home because these had an impact on exposure to green space. The quality of the garden, which is a function of size and diversity, and nature relatedness also had an impact on subjective well-being because these variables had an impact on garden activities. Nature relatedness therefore seems to play a key role in the pathway linking gardens to improved health. Improving biodiversity and ecosystem services in gardens could potentially improve human health and well-being, and contribute to the conservation of biodiversity in urban environments.

Data Statement

The garden data and health data are confidential. The land cover data that were used to quantify residential green space (Top10Vector, identifier BE.NGI-IGN/5F4130E6-DF5C-41E6-A956-BB9F04088D11) are copyrighted (©Institut Géographique National) and were used under federal use license 2016_F014 granted by the Institut Géographique National (NGI-IGN) to the Belgian Science Policy Office (BELSPO).

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Table 1. Characteristics of the study population of garden owners in Flanders, Belgium (N = 587)

Characteristic	N (%) or mean (SD)
Sex	
Male	264 (45.0 %)
Female	323 (55.0 %)
Age in years	54.8 (12.9)
Higher education: yes	453 (77.1%)
Currently employed: yes	324 (55.1%)
Owner of house: yes	569 (96.9%)
Children living in household: yes	237 (40.3%)
Partner: yes	470 (80.1%)
Green space around garden	
Buffer of 100m (ha)	2.7 (1.3)
Buffer of 100m (%)	59.0 (17.8)
Buffer of 500m (ha)	46.7 (13.5)
Buffer of 500m (%)	54.6 (14.8)
Buffer of 1000m (ha)	172.6 (46.4)
Buffer of 1000m (%)	52.6 (13.8)
Garden size (m^2)	1827.6 (8930.1)
Median (m^2)	734 (IQR 1386.5)
Relative biodiversity score	
Average	71% (4.0%)
Median	27% (IQR 56%)
Natural elements	8.5 (2.2)
Nature relatedness scale (range 1-5)	4.05 (0.6)
Exposure to green space	
Total time in garden (hours/day)	3.25 (2.13)
Time active in garden (hours/day)	1.66 (1.32)
Days spent in garden (days in past week)	4.83 (2.16)
Time spent in other gardens (median)	less than 30 minutes
Days spent in other gardens (days in past week)	0.60 (1.25)
Time spent in public green space (median)	30 minutes to one hour
Frequency visits to public green spaces (median)	multiple times a month
Days spent in public green spaces (days in past week)	1.94 (1.93)
Depression scale	median 4 (IQR 0–8)
Normal (<10)	479 (81.6%)
Mild (10-13)	50 (8.5%)
Moderate (14-20)	36 (6.1%)
Severe (21-27)	13 (2.2%)
Extremely severe (> 27)	9 (1.5%)
Stress scale	median 6 (IQR 2–12)
Normal (<15)	516 (87.9%)
Mild (15-18)	20 (3.4%)
Moderate (19-25)	28 (4.7%)
Severe (26-33)	19 (3.2%)
Extremely severe (> 33)	4 (0.7%)

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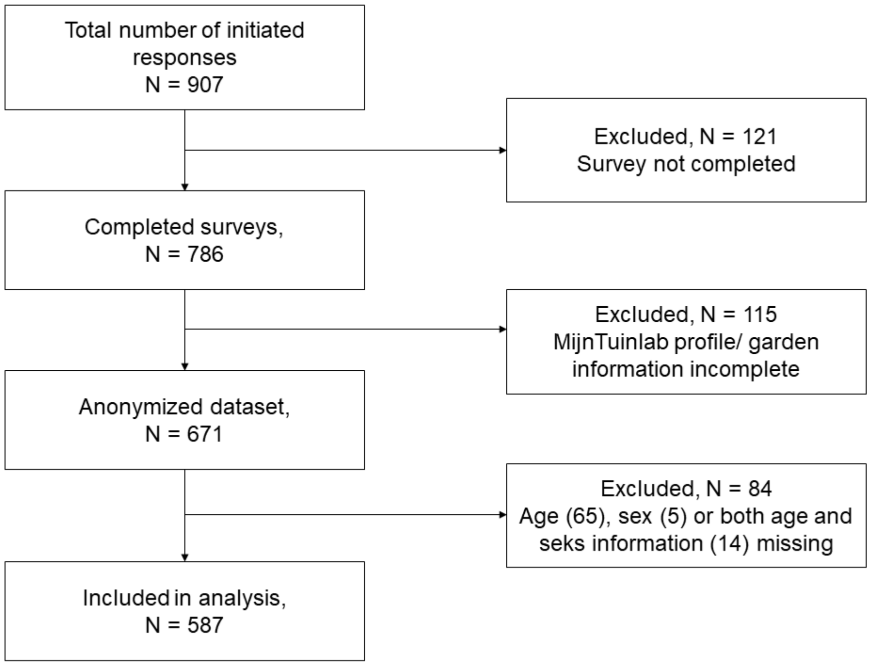
Figure 1. Flow diagram of the garden owners included and excluded in the study.

Figure 2. A-priori structural equation model with hypothesized direct and indirect associations between green space quality, garden use, owner background variables, and self-reported stress and depression in adult garden-owners in Flanders, Belgium.

Figure 3. Structural equation model of the associations between residential green space quality, garden use, owner background variables, and self-reported stress in adult garden owners in Flanders, Belgium (N = 587 gardens). Observed variables and confounders are not included in the figure but are presented in Table B2. Coefficients and thickness of paths represent standardized regression coefficients β.

Figure 4. Structural equation model of the associations between residential green space quality, garden use, owner background variables, and self-reported depression in adult garden owners in Flanders, Belgium (N = 587 gardens). Observed variables and confounders are not included on the figure but are presented in Table B3. Coefficients and thickness of paths represent standardized regression coefficients β.



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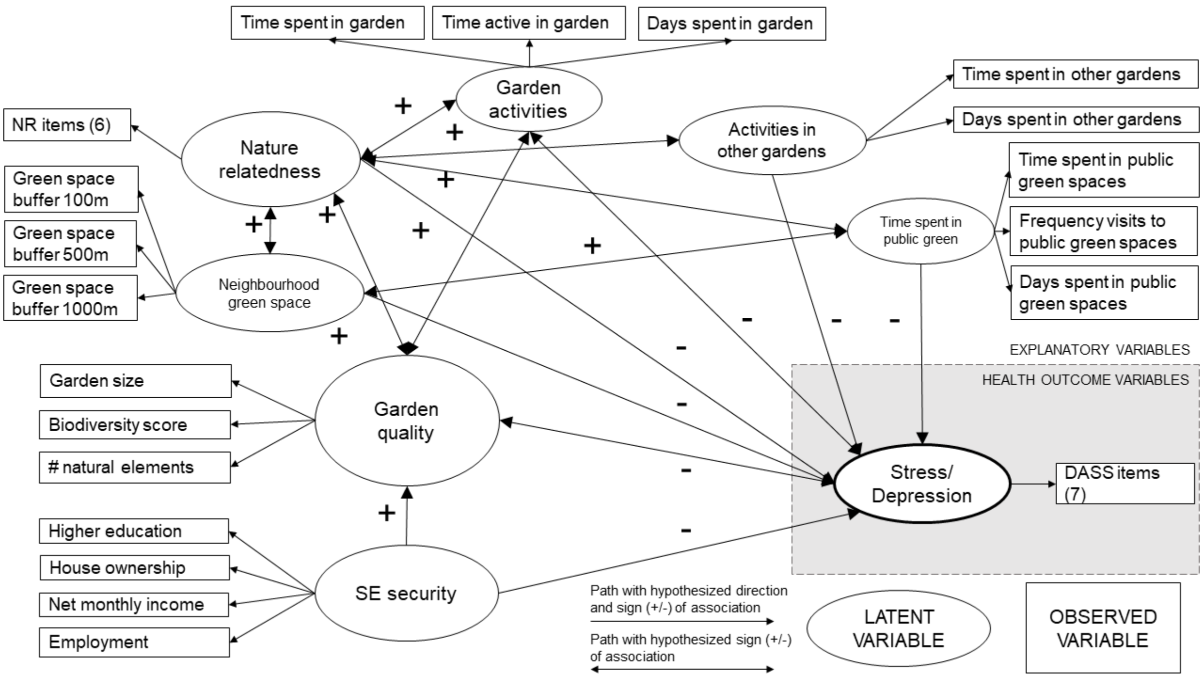


Figure 2. A-priori structural equation model with hypothesized direct and indirect associations between green space quality, garden use, owner background variables, and self-reported stress and depression in adult garden-owners in Flanders, Belgium.

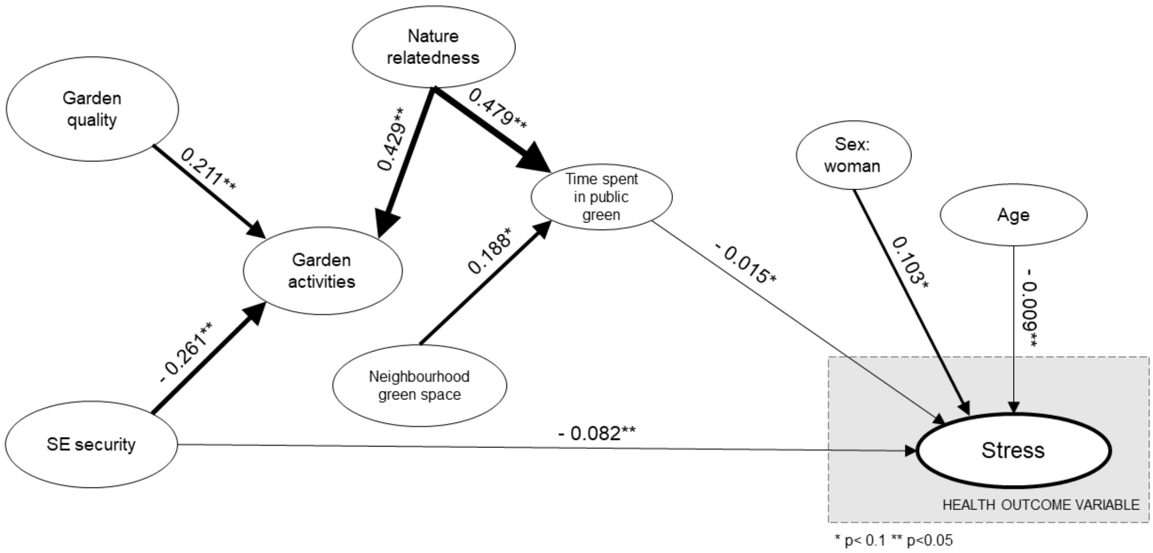
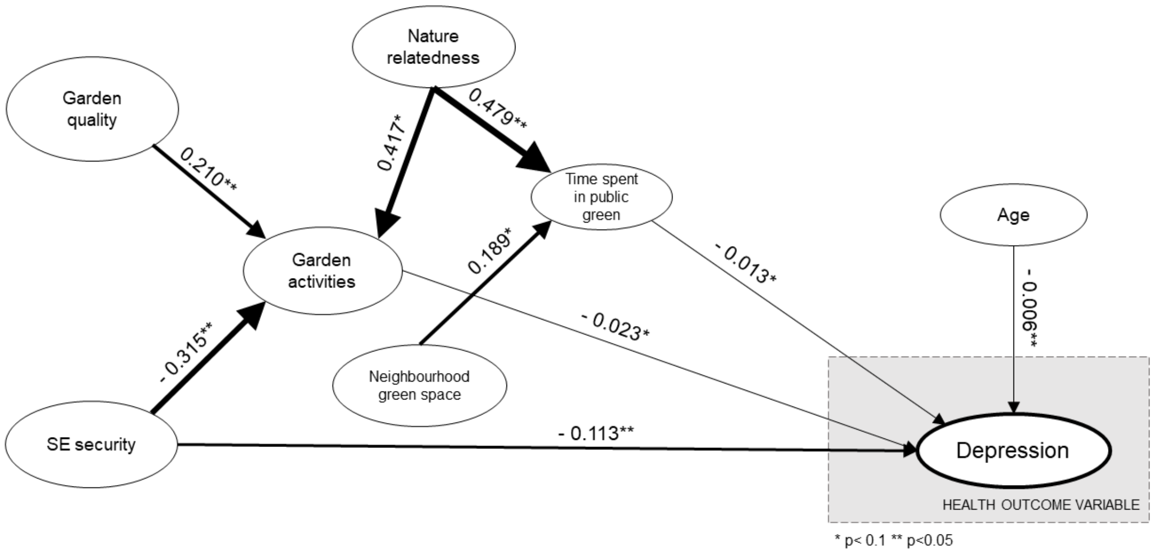


Figure 3. Structural equation model of the associations between garden quality, garden activity, neighbourhood green space, garden owner background variables, and self-reported stress in adult garden owners in Flanders, Belgium (N = 587 garden owners). Observed variables, confounders, and associations with p>0.1 are not included in the figure but are presented in Table B2. Coefficients and thickness of paths represent standardized regression coefficients β.



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Appendix A. Supplementary maps

Appendix B. Supplementary tables

Appendix A. Supplementary maps

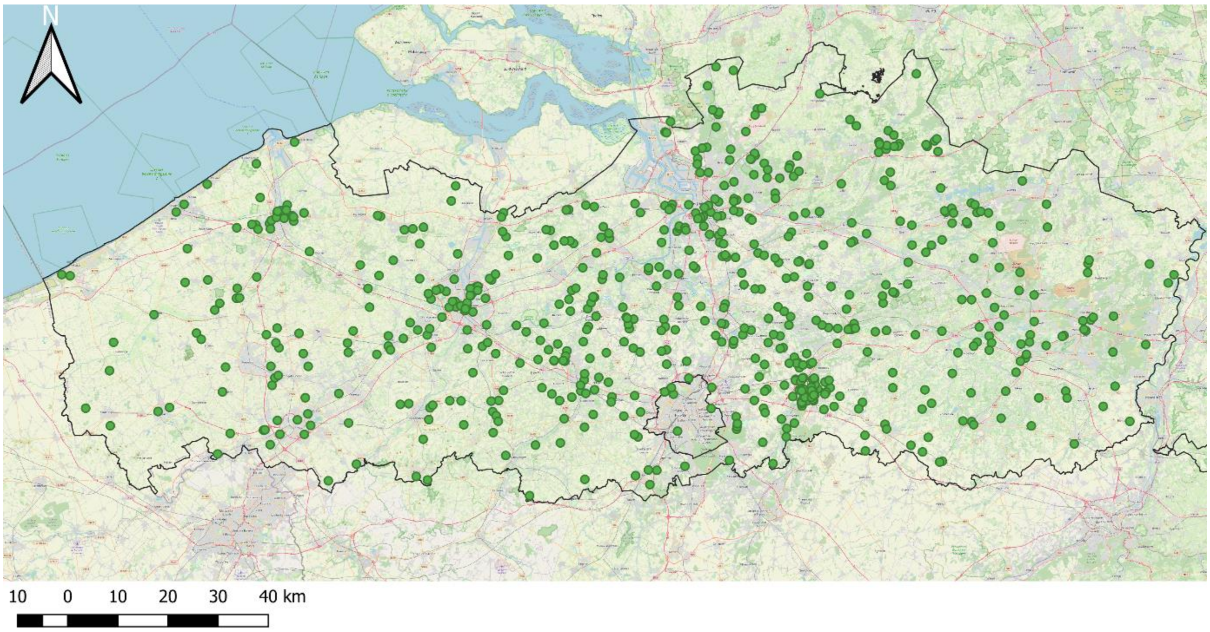

Figure A1. Spatial distribution of garden-owners included in the study in the Flemish and the Brussels-Capital Region, Belgium.

Appendix B. Supplementary tables

Table B1. Partial biodiversity scores for specific garden features, used to calculate overall biodiversity scores of domestic gardens in Flanders, Belgium.

Garden element (area based)	Biodiversity score
Green roof	1
(Semi-)natural water	4
Short cut lawn	1
Grazing meadow for animals	3
Flowery or species-rich grassland	5
Wild vegetation	5
Vegetable garden	3
Flowers and plants	3
Climbing plants or vertical garden	2
Wall vegetation	3
Shrubs, bushes, small trees and hedges (>1 m)	3
Trees higher than 6 m (deciduous or fruit)	4
Trees higher than 6 m (coniferous or needle-leaved)	3
Garden provisions (present/absent)	Added to overall score
Nesting place, feeding/drinking place for animals in winter, hedgehog passage, presence of dead wood	+3
Compost infrastructure	+3
Number of species (self-reported)	
Less than 10	-6
Between 10 and 100	0
More than 100	6

Table B2. Parameter estimates, SE, and standardized parameter estimates of a structural equation model of the associations between residential green space quality, garden use, owner background variables, and self-reported stress in adult garden owners in Flanders, Belgium (N = 587).

	Estimate β	SE	p	Std. Est. β’
Latent variables				
Garden activities =~				
Time in garden	1			0.87
Days garden	0.370	0.055	< 0.001	0.32
Time active	0.570	0.055	< 0.001	0.80
Time spent in public green space =~				
Time in public green sp.	1			0.70
Days in public green sp.	0.345	0.022	< 0.001	0.65
Frequency visit public green sp.	0.681	0.043	< 0.001	1.02
Act. in other gardens =~				
Time in other gardens	1			0.71
Days in other gardens	0.575	0.268	0.032	1.02
Neighbourhood green space =~				
Green buffer 500m (%)	1			1.07
Green buffer 100m (%)	0.593	0.034	< 0.001	0.63

Green buffer 1000m (%)	0.796	0.028	< 0.001	0.84
Garden quality =~				
Area garden	1			1.03
Biodiversity score	0.948	0.024	< 0.001	0.97
# natural elements	0.093	0.035	0.007	0.10
Socio-economic security =~				
Net income household	1			0.80
House ownership	0.019	0.009	0.035	0.11
Employment	0.252	0.047	< 0.001	0.51
Higher education	0.122	0.027	< 0.001	0.29
Regressions among latent variables				
Garden quality ~				
SE security	0.064	0.048	0.181	0.059
Nature relatedness	0.037	0.062	0.551	0.023
Neighbourhood green space	0.033	0.033	0.316	0.032
Garden activities ~				
SE security	-0.261	0.107	0.015	-0.14
Nature relatedness	0.429	0.135	0.001	0.16
Garden quality	0.211	0.071	0.003	0.12
Time spent in public green space ~				

SE security	-0.001	0.141	0.994	-0.00
Nature relatedness	0.479	0.191	0.012	0.11
Garden quality	-0.002	0.090	0.982	-0.00
Neighbourhood green space	0.188	0.100	0.060	0.07
Neighbourhood green space ~				
SE security	0.060	0.049	0.222	0.057
Nature relatedness	0.052	0.064	0.417	0.033
Activities in other gardens ~				
SE security	-0.030	0.108	0.780	-0.01
Nature relatedness	-0.290	0.201	0.150	-0.09
Garden quality	-0.017	0.069	0.800	-0.01
Regressions with outcome variable				
Stress ~				
Time spent in public green space	-0.015	0.009	0.079	–0.07
Garden activities	-0.018	0.016	0.247	-0.06
Act. in other gardens	0.001	0.012	0.948	0.00
Garden quality	0.005	0.020	0.813	0.01
Neighbourhood green space	-0.012	0.022	0.580	-0.02
SE security	-0.082	0.034	0.016	-0.14
Nature relatedness	0.009	0.042	0.824	0.01
Children living at home	0.041	0.059	0.489	0.03

Partner	0.079	0.065	0.229	0.05
Age	-0.009	0.002	<0.001	-0.18
Sex: women	0.103	0.054	0.055	0.08

Table B3. Parameter estimates, SE, and standardized parameter estimates of a structural equation model of the associations between residential green space quality, garden use, owner background variables, and self-reported depression in adult garden owners in Flanders, Belgium (N = 587).

	Estimate β	SE	p	Std. Est. β'
Latent variables				
Garden activities =~				
Time in garden	1			0.87
Days garden	0.370	0.055	< 0.001	0.32
Time active	0.570	0.055	< 0.001	0.80
Time spent in public green space =~				
Time in public green sp.	1			0.70
Days in public green sp.	0.345	0.022	< 0.001	0.65
Frequency visit public green sp.	0.679	0.042	< 0.001	1.02
Act. in other gardens =~				
Time in other gardens	1			0.73
Days in other gardens	0.563	0.255	0.027	1.00
Neighbourhood green space =~				
Green buffer 500m (%)	1			1.07
Green buffer 100m (%)	0.593	0.034	< 0.001	0.63
Green buffer 1000m (%)	0.795	0.028	< 0.001	0.84

Garden quality =~				
Area garden	1			1.03
Biodiversity score	0.948	0.024	< 0.001	0.97
# natural elements	0.093	0.028	0.008	0.10
Socio-economic security =~				
Net income household	1			0.76
House ownership	0.019	0.009	0.048	0.10
Employment	0.281	0.047	< 0.001	0.54
Higher education	0.134	0.027	< 0.001	0.31
Regressions among latent variables				
Garden quality ~				
SE security	0.061	0.052	0.240	0.05
Nature relatedness	0.034	0.062	0.576	0.02
Neighbourhood green space	0.033	0.033	0.311	0.03
Garden activities ~				
SE security	-0.315	0.116	0.007	-0.16
Nature relatedness	0.417	0.134	0.002	0.15
Garden quality	0.210	0.071	0.003	0.12
Time spent in public green space ~				

SE security	-0.011	0.155	0.941	-0.00
Nature relatedness	0.479	0.191	0.012	0.11
Garden quality	-0.003	0.090	0.977	-0.00
Neighbourhood green space	0.189	0.100	0.058	0.07
Neighbourhood green space ~				
SE security	0.064	0.053	0.229	0.057
Nature relatedness	0.052	0.064	0.413	0.034
Activities in other gardens ~				
SE security	-0.036	0.122	0.769	-0.02
Nature relatedness	-0.301	0.201	0.134	-0.09
Garden quality	-0.020	0.071	0.780	-0.01
Regressions with outcome variable				
Depression ~				
Time spent in public green space	-0.013	0.007	0.059	–0.08
Garden activities	-0.023	0.013	0.075	-0.09
Act. in other gardens	-0.003	0.009	0.758	0.01
Garden quality	-0.007	0.016	0.679	0.02
Neighbourhood green space	0.027	0.018	0.120	0.06
SE security	-0.113	0.032	<0.001	-0.22
Nature relatedness	-0.034	0.034	0.322	-0.05
Children living at home	0.040	0.047	0.401	0.04

Partner	-0.024	0.052	0.644	-0.02
Age	-0.006	0.002	0.001	-0.16
Sex: women	0.021	0.043	0.620	0.02