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Residential green space types, allergy symptoms and mental health in a cohort of tree pollen allergy patients

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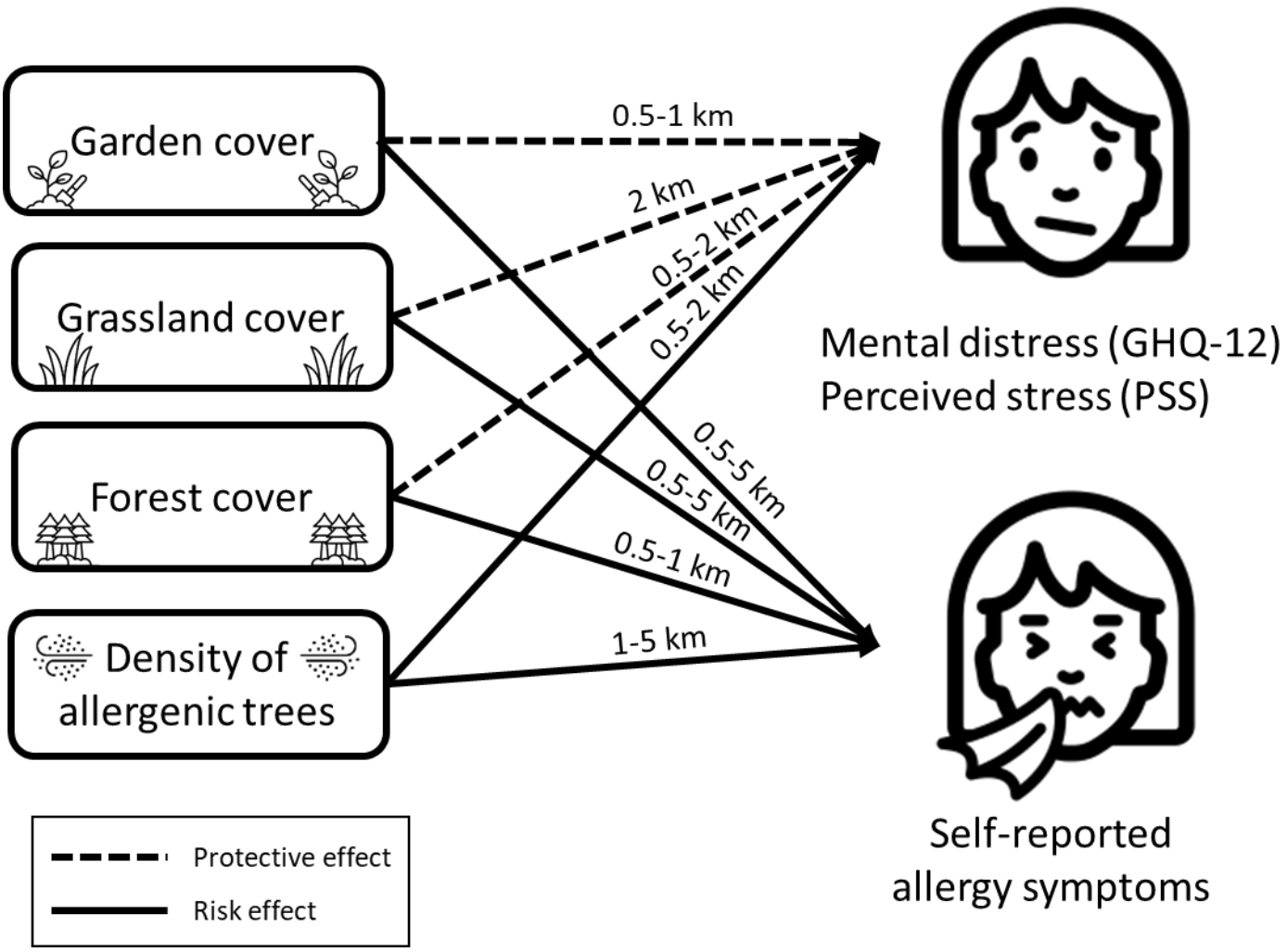
Graphical Abstract



Highlights

- We studied residential green space exposure of 157 adults with tree pollen allergy.
- Residential green space was associated with reduced mental distress and perceived stress.
- Allergenic tree species within 2 km distance contributed to mental distress.
- Residential green space exposure was associated with more severe allergy symptoms.
- Green space had mixed health effects during the pollination season.

Abstract

Background: Exposure to green space has been associated with positive mental and physical health outcomes. Nevertheless, green space can also act as a source of aeroallergens and exacerbate allergic disease and related mental distress. We examined impacts of exposure to residential green space on respiratory health and well-being in a cohort of adults sensitized to tree pollen allergens.

Methods: In a panel of 157 tree pollen allergy patients in Belgium we analyzed average allergy symptom scores, average mood scores, distress (GHQ-12) and perceived stress (PSS). Generalized linear models were used to investigate associations between health outcomes and garden cover, grassland cover, forest cover and density of trees of the allergenic *Alnus, Betula* and *Corylus* genera in forests within a 1, 2 and 5 km distance from the residence. Models were adjusted for sex, age, BMI, allergy medication use, chronic respiratory disease, smoking behavior, education level, physical activity and perceived presence of allergenic trees.

Results: We observed inverse associations between residential garden cover within 1 km distance and perceived stress (PSS) (unadjusted β = -0.020; 95% CI [-0.031; -0.008]) and between forest cover within 1 km and distress (GHQ-12) (-0.048 [-0.085; -0.011]). Higher densities of allergenic trees in forests within 2 km distance were associated with higher PSS (0.003 [0.000 – 0.006]) and GHQ-12 scores (0.020 [0.014; 0.027]). Residential green space variables within 1 km distance were associated with higher symptom scores: garden cover β = 0.013 [0.007; 0.018], grassland cover β = 0.020 [0.014; 0.026], forest cover β = 0.016 [0.010; 0.021], density of allergenic trees in forests β = 0.005 [0.001; 0.009]. The parameter estimates became smaller at larger scales and remained significant in the fully adjusted models.

Conclusion: Green space is associated with more symptoms but lower distress and allergenic trees in forests are associated with higher distress Residential green space has mixed health effects in tree pollen allergy patients.

Residential green space types, allergy symptoms and mental health in a cohort of tree pollen allergy patients

1. Introduction

Exposure to green space is often found to improve human physical and mental health (Aerts et al., 2018; Fong et al., 2018; Twohig-Bennett and Jones, 2018). Exposure and proximity to green space has been associated with higher birth weights (Agay-Shay et al., 2014), lower blood pressure (Grazuleviciene et al., 2014), reduced risk in diabetes (Dalton et al., 2016), lower risks of prostate cancer (Demoury et al., 2017), lower risk of psychiatric disorders (Engemann et al., 2019) and better mental health (Bratman et al., 2019). These studies often target vulnerable population groups such as pregnant women (Grazuleviciene et al., 2014), elderly people (Dalton et al., 2016), and children (Engemann et al., 2018; Rufo et al., 2019). So far, tree pollen allergy patients, who may experience ecosystem disservices from exposure to green space, are an understudied group.

Sensitization to common aeroallergens is expected to increase in the following decades due to urbanization, air pollution, and climate change (D'Amato et al., 2016; Lake et al., 2017). To improve air quality and mitigate climate change effects, such as urban heat, urban planners promote the creation of additional green space and urban forests (Livesley et al., 2016). While tree planting in cities might contribute to better respiratory health through improvement of air quality and thermal comfort, some tree species may also emit aeroallergens and trigger allergies and asthma (Eisenman et al., 2019).

Recently a considerable number of studies on residential green space exposure and respiratory health in children has emerged. These studies reported that residential proximity to green space and residential greenness is associated with a reduced risk of bronchitis and wheezing (Tischer et

al., 2017). Other studies, however, find that children living with more green space near their home suffer more from wheezing and have an increased risk of allergic rhinitis (Parmes et al., 2020) and asthma (Andrusaityte et al., 2016). Other studies have documented that higher levels of grassland cover around the residence of children were associated with an increased risk of grass pollen sensitization in children (Gernes et al., 2019) and prescribed asthma medication sales (Aerts et al. 2020a). From these studies it is clear that green space in children's neighborhoods has an effect on their respiratory health. Whether this is a protective factor or a risk might be determined by confounders such as biodiversity, environmental microbiome, or behavior (Rufo et al., 2019).

Only a limited number of studies on green space and respiratory health in adults are available. A first large scale study in England found that the presence of more tree cover, gardens, and green space in residential areas was associated with fewer asthma hospitalizations (Alcock et al., 2017). Ulmer et al. (2016) found that urban tree cover was associated with less diagnoses of current asthma. In a previous study in Northern Belgium, we found that adults sensitized to tree pollen experience mental health benefits from residential exposure to green, despite their tree pollen allergy (Aerts et al., 2020b). However, the perceived presence of allergenic tree species was found to be associated with higher mental distress (Aerts et al., 2020b). The aim of this study was to examine whether different types of residential green space cover, i.e. forests, gardens, and grasslands, and the objectively measured quantity of allergenic tree species in forests near the residence have impacts on allergy symptoms and mental health of allergy patients sensitized to hazel, alder and/or birch pollen.

2. Methods

2.1 Study design and population

The RespirIT study on health effects of green on respiratory health was approved by the Ethical Commission of the KU Leuven University Hospital (Belgian registration number B322201629692). Adults were recruited from the general population of Belgium in 2016 and 2017 by various online platforms and physical newspaper calls. To participate, the person needed to be over the age of 20 years old, residing in Belgium, and sensitized to pollen of common hazel (*Corylus avellana*), alder (*Alnus* spp.) and/or birch (*Betula* spp.). After obtaining informed consent, the patients used the RespirIT smartphone application to score and log their daily mood and allergy symptoms at the end of every day during the tree pollen season (January – May) of 2017 and/or 2018. One month after the start of the pollen season as defined by the Belgian Aerobiological Surveillance Network (Sciensano, www.airallergy.be), the patients completed a questionnaire providing detailed background information.

Of the 225 persons interested in participating 189 (84%) were included in the RespirIT study. Ultimately 32 participants dropped out and thus anonymized data from 157 (70%) participants were used in this cross-sectional study (Figure 1). The participants used the mobile app on 8123 person-days of which 4714 were symptom-days used in the analysis. A symptom-day corresponds to a person-day on which the participant reported pollen allergy symptoms. The spatial distribution of the residences of the participants are visualized in the supplementary material (Figure S1).

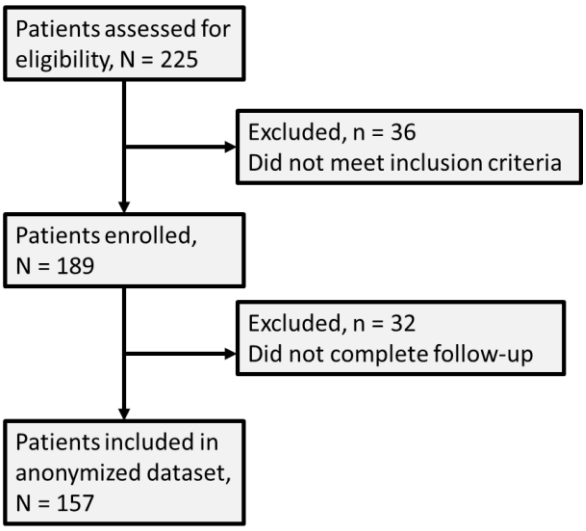


Figure 1: Flow diagram of the selection process for the tree pollen allergy patients suitable for analysis.

2.2 Definition of the outcome variables

Participants reported their mood and allergy symptoms daily in the diary of the Dutch or French language smartphone application specifically created for the RespirIT study (RespirIT app for Android OS for mobile phones, BioRICS NV, Belgium). The user-manual encouraged the participants to fill in the diary at the end of every day as to have an idea of the overall mood and symptoms during the past day. In case the participants experienced symptoms that were not due to a regular cold or a flue they were asked to record these at the end of the day in the diary of the RespirIT app. The diary asked the question 'What symptoms are bothering you today and to what degree?', followed by a list of eleven symptoms related to seasonal pollen allergy: wheezing, dyspnea, coughing, sneezing, runny or stuffy nose, itching, fatigue, headache, bad sleep, difficulty concentrating, and irritation of the eyes. Under every symptom the participant could move a slider from 0 (never) to 4 (always). The daily symptom score was calculated by summing the individual values for the eleven symptoms resulting in a scale from 0 to 44, 0 corresponding to no allergy

symptoms. We calculated the average symptom score on symptom days (AvgSy) multiplied by 10 and truncated to no decimals.

Daily mood was assessed on the same symptom days with one question 'How did you feel today?' and scored on a five-point rating scale represented by minimalist smileys (Figure S2). A score from 1 to 5 was assigned to the moods: 1) poor, 2) fair, 3) neutral, 4) good 5) excellent. We calculated the average mood score on symptom days (AvgMo) multiplied by 10 and truncated to no decimals.

Two validated questionnaires were used to quantify mental health outcomes during the tree pollen season. The Dutch and French version of the standardized questionnaires were integrated in the follow-up questionnaire sent out to the participants during the pollen season. First, the 12-item General Health Questionnaire (GHQ-12) is a shorter version of the fully detailed 60-item General Health Questionnaire (https://www.gl-assessment.co.uk/products/general-health-questionnaire-ghq/). In the GHQ respondents were asked how their mental state during the past month differed from the usual state. The GHQ is sensitive to short-term psychiatric disorders and can be interpreted as a measure for psychological distress. To score the GHQ-12 we used the standard bimodal scoring method (0-0-1-1) resulting in a scale range of 0–12, a higher score meaning more distress. Second, the Perceived Stress Scale (PSS) is a widely used validated questionnaire to measure the perception of stress over the past month (http://www.mindgarden.com/documents/PerceivedStressScale.pdf). The scale includes items about current levels of stress as well as items on stressful times during the past month. Questions are scored on a five-point rating scale (0-4). Four of the questions, however, are formulated in a positive way and needed to be scored in reverse. After summation of the scores the scale ranges from 0 to 40, where 0 is best.

2.3 Definition of potential predictors

Residential green space was objectively quantified from geodatasets for a 0.5, 1, 2 and 5 km radius around each of the 157 residences. Using topological overlay between the corresponding circular zones and the Top10 Vector land cover geodataset for Belgium ("Soil cover and vegetation" dataset, version 1.1 2011, National Geographic Institute, equivalent scale level of 1:10,000), the cumulative cover (m^2) of three green space types (gardens, grassland and forest) was determined for the three radii. Gardens are included as a unique land cover type in the dataset. Grassland cover was calculated as the sum of permanent grassland or hay meadow and lawns. Forest cover was determined as the sum of all five forest-related land cover types in the geodataset: 1) coniferous forests, 2) mixed forests dominated by conifer species, 3) mixed forests, 4) mixed forests dominated by deciduous species, 5) deciduous forests. Garden, grassland and forest covers within each radius were then expressed in 10 ha units.

The Belgian forest inventory uses a regular grid of 0.5 × 1 km covering the entire area of Belgium. The grid points that occur in forested areas were visited by experienced surveyors who record the species type and circumference at 1.30 m above ground level of trees and woody vegetation in an 18 m radius around the point (Westra et al., 2015). From the circumference and the plot area we were able to calculate the basal area (m^2/ha) of the three main allergenic taxa *Alnus* (alder), *Betula* (birch), and *Corylus* (hazel) from the Belgian forest inventory. The total basal area of the allergenic trees can be interpreted as the density of allergenic trees in the forest.

2.4 Definition of potential confounders

We included the participant's sex and age as sociodemographic characteristics. Next, we included three indicators of physical fitness: body mass index (BMI), smoking behaviour (yes/no), and physical activity (at least 1 × /week 20 min of activity vs. less). Education level (higher education vs. no higher education) was included as indicator of socio-economic status of the participants. Higher education is defined as having obtained an academic degree through a tertiary education. Regarding the health status of the participants we included two items: medication use (antihistamines and/or corticosteroids: yes/no) and chronic disease (asthma and/or chronic respiratory disease: yes/no). Participants were asked to report whether hazel, alder and/or birch trees were present or absent in close proximity to their residence. The objective presence of these allergenic trees was not verified (outside forested areas). Therefore, the reported presence of allergenic trees is interpreted as perceived presence (Aerts et al., 2020b).

2.5 Statistical analyses

Generalized linear models based on the Poisson probability distribution for count data with log-link function were used to estimate the effects of residential green space exposure on allergy symptoms and mental health of participants. The unadjusted models included only objective green space predictors. In the fully adjusted model all the confounders were included at once. To test whether having more severe allergy symptoms may reduce a potential positive effect of exposure to forests on distress, we included allergy symptoms as additional explanatory variables in models for mental health. We calculated both unadjusted and confounder-adjusted estimates and their 95% Wald confidence intervals. Model performance was evaluated using Akaike's Information

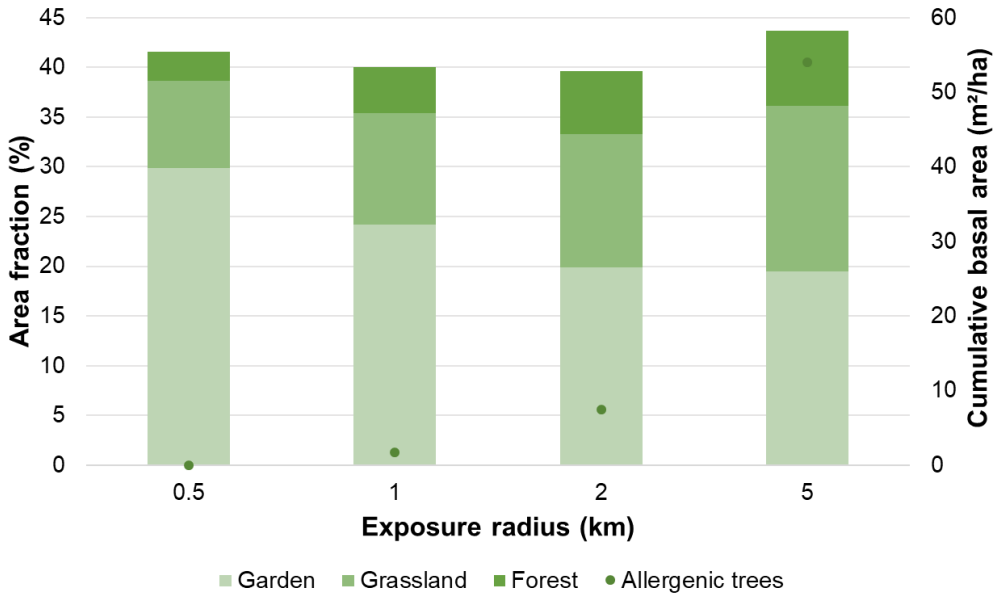
Criterion (AIC). Models were created and evaluated using IBM SPSS (Version 26) predictive analytics software.

3. Results

3.1 Population characteristics

The summary of the study population characteristics is given in Table 1. Our cohort consisted of 95 women (60.5%) and 62 men (39.5%). All participants were adults aged between 21 and 67 years (median age 39, IQR 16). Over half of the patients had a normal body weight (58.6% normal BMI; median BMI 23.5 kg m^{-2}, IQR 5.5). The majority of the patients were non-smokers (96.2%), were physically active (≥ 20.min active/week: 91.1%) and had a higher education level (91.1%). Almost all of the allergy patients took medication (93.3%), with 52.9% of the allergy patients using antihistamines, 7.0% using corticosteroids, and 34.4% taking a combination of both. Some patients suffered from other chronic respiratory health issues besides pollen allergy, mostly asthma (28.6%).

The most prevalent green space types present around the residency was gardens, followed by grasslands, and then forests (Table 1 and Figure 2). As the distance from the residence increased the area fraction of gardens decreased, while the area fraction of grassland and forest increased. The density of allergenic trees in the forest increased with the increasing forest area fraction.



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165 **Figure 2:** A stacked bar plot presenting area fractions of residential green space (garden cover, grassland
166 cover and forest cover) within the four exposure radii (0.5, 1, 2 and 5 km) studied. The cumulative density
167 of allergenic trees within the entire forest area fraction is presented as a dot.

168 **Table 1:** Study population characteristics, potential predictors and mental and respiratory health
169 outcomes (n=157).

Characteristic	**n (%), or mean (SD), and median (25^{th}-75^{th} percentiles)**
Sex	
female	95 (60.5%)
male	62 (39.5%)
Age in years	40.2 (9.8) 39.0 (32.0-48.0)
BMI	24.4 (4.4) 23.5 (21.2-26.7)
BMI classes	
underweight (<18.5)	6 (3,8%)

normal (18.5 – 24.9)	92 (58,6%)
overweight (25.0-29.9)	36 (23.0%)
obesity (≥30)	23 (14,6%)
Smoking behavior	
non-smoker	151 (96.2%)
smoker	6 (3.8%)
Physical activity (20 min or more)	
< 1×20'/week	14 (8.9%)
≥ 1×20'/week	143 (91.1%)
Education level	
lower education	14 (8.9%)
higher education	143 (91.1%)
Allergy medication use	
antihistamines	83 (52.9%)
corticosteroids	11 (7.0%)
both	54 (34.4%)
none	9 (5.7%)
Chronic respiratory problems	
asthma	45 (28.6%)
chronic respiratory disease	0 (0.0%)
both	4 (2.6%)
none	108 (68.8%)
Perceived presence of allergenic tree species	
Alnus, *Betula*, and/or *corylus* present near residence	123 (78.3%)
not present near residence	34 (21.7%)
Garden cover (ha)	
0.5 km radius	23.0 (11.4) 23.6 (15.4-30.2)
1 km radius	80.6 (37.5)

	75.9 (56.2-106.2)
2 km radius	271.5 (118.7) 252.1 (190.9-353.8)
5 km radius	1485.0 (424.8) 1532.5 (1276.4-1793.9)
Grassland cover (ha)	
0.5 km radius	9.3 (8.5) 6.9 (3.7-14.9)
1 km radius	45.0 (35.6) 35.1 (20.9-62.1)
2 km radius	195.9 (125.1) 169.2 (99.6-252.8)
5 km radius	1355.3 (651.6) 1304.2 (819.7-1755.6)
Forest cover (ha)	
0.5 km radius	5.9 (10.2) 2.4 (0.5-5.9)
1 km radius	28.2 (39.5) 14.4 (6.2-31.4)
2 km radius	132.1 (141.4) 79.5 (35.2-187.4)
5 km radius	1055.7 (904.6) 593.5 (346.4-1604.6)
Density of *Alnus*, *Betula* and *Corylus* in forest plots (m^2/ha)	
0.5 km radius	0.4 (2.4) 0.0 (0.0-0.0)
1 km radius	1.7 (5.7) 0.0 (0.0-0.0)
2 km radius	7.5 (15.3)

	0.0 (0.0-7.5)
5 km radius	54.0 (74.2) 32.2 (7.3-55.6)
Mental health endpoints	
Distress (GHQ-12)	2.2 (2.8) 1.0 (0.0-3.0)
Perceived stress scale (PSS)	13.6 (6.7) 14.0 (9.0-18.0)
Average daily mood	37.9 (5.5) 38.0 (36.0-40.0)
Respiratory health endpoint	
Average symptom score	56.4 (38.1) 48.0 (31.0-72.0)

3.2 Predictors of mental health and allergy symptoms

3.2.1 Predictors of mental health

The parameter estimates [β (95% CI)] of the unadjusted associations between possible predictors and mental health (Average Mood, GHQ-12, PSS) are presented in Table S1 and Figure 3. Distress (GHQ-12) was inversely associated with forest cover within 0.5, 1 and 2 km distance [0.5 km: –0.274 (–0.443; –0.104) and 1 km: –0.048 (–0.085; –0.011) and 2 km: –0.023 (–0.034; –0.012)]. Perceived stress (PSS) was inversely associated with garden cover within 0.5 and 1 km distance [0.5 km: –0.065 (–0.105; –0.026) and 1 km: –0.020 (–0.031; –0.008)] and grassland cover within 2 km distance [–0.005 (–0.009; –0.001)]. Both distress and perceived stress were associated with the density of allergenic trees (*Alnus, Betula* and *Corylus*) within 0.5 and 2 km distance [distress: 0.5 km: 0.037 (0.001 – 0.073) and 2 km: 0.020 (0.014; 0.027); perceived stress: 2 km: 0.003 (0.000; 0.006)]. Average daily mood on symptom days was not associated with measures of exposure to

green assessed in this study. In the set of green space indicators calculated for a 5 km radius, only perceived stress was inversely associated with density of allergenic trees [–0.001 (–0.001; 0.000)] and with forest cover [0.001; (0.000; 0.001)].

Fully adjusted beta-coefficients and 95% confidence intervals are presented in Table S2 and Figure 4 (Figure S2 includes adjustment variables). Mental distress remained inversely associated with exposure to forest within 0.5, 1, and 2 km distance [0.5 km: –0.048 (–0.086; –0.011) and 1 km: –0.048 (–0.086; –0.011) and 2 km: –0.020 (–0.030; –0.009)]. Distress remained associated with the density of allergenic trees within 2 km distance (but not 0.5 km) [0.021 (0.014; 0.028)]. There were no significant associations between distress and objective exposure to green types within 5 km distance. After full adjustment, perceived stress remained inversely associated with objective exposure to gardens within 0.5 and 1 km distance [0.5 km: –0.025 (–0.037; –0.012) and 1 km: –0.025 (–0.037; –0.012)], and was inversely associated with density of allergenic trees within 1 km [–0.011 (–0.020; –0.001)]. Perceived stress was inversely associated with residential exposure to grassland cover within a 2 and a 5 km distance [2 km: –0.006 (–0.009; 0.002) and 5 km: –0.001 (–0.002; 0.000)]. No significant associations were found between average daily mood on symptom days and any of the potential predictors.

At all the spatial scales average symptom score (AvgSy) was associated with the mental health outcomes (Figure 5 and Table S3). The associations with the greenspace remained unchanged for the response variable GHQ12 when including AvgSy as a condounder. For the model outcome PSS the inclusion of AvgSy modified the effect of the density of allergenic trees in forests within a 0.5 [–0,069 (–0,112; –0,026)] and 1km [–0,010 (–0,019; –0,001)]exposure radius.

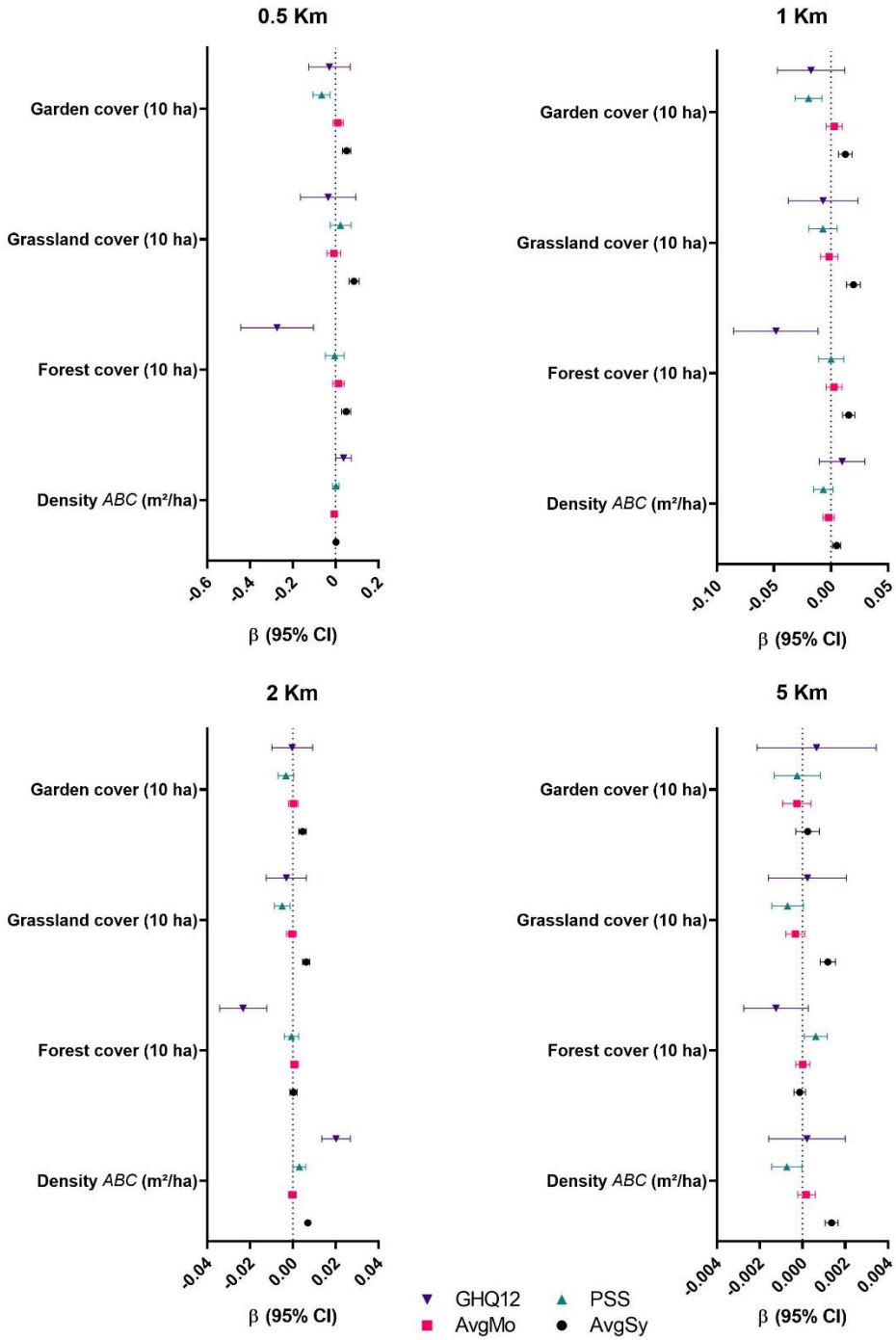
3.2.2 Predictors of allergy symptoms

The parameter estimates [β (95% CI)] of the unadjusted associations between predictors of green space type in the residence with the average symptom score (AvgSy) are presented in Figure 3 and Table S1. Symptom scores (higher AvgSy) were associated with exposure to garden cover [0.5 km: 0.051 (0.032; 0.071) and 1 km: 0.013 (0.007; 0.018) and 2 km: 0.005 (0.003; 0.006)], grassland cover [0.5 km: 0.086 (0.062; 0.110) and 1 km: 0.020 (0.014; 0.026) and 2 km: 0.006 (0.005; 0.008) and 5 km: 0.001 (0.001; 0.002)], forest cover [0.5 km: 0.049 (0.027; 0.070) and 1 km: 0.016 (0.010; 0.021)] and density of *Alnus*, *Betula* and *Corylus* trees in forests [1 km: 0.005 (0.001; 0.009) and 2 km: 0.007 (0.007; 0.008) and 5 km: 0.001 (0.001; 0.002)]. The parameter estimates decreased with increasing radius around the residence.

Fully adjusted beta-coefficients and 95% confidence intervals for associations of respiratory health outcomes (AvgSy) with all predictors are presented in Figure 3 and Table S2 (Figure S2 includes adjustment variables). The associations between allergy symptoms and green space types of the fully adjusted model are the same as for the unadjusted model. Symptom scores (AvgSy) were associated with exposure to garden cover [0.5 km: 0.008 (0.002; 0.014) and 1 km: 0.008 (0.002; 0.014) and 2 km: 0.004 (0.002; 0.006)], grassland cover [0.5 km: 0.013 (0.006; 0.019) and 1 km: 0.013 (0.006; 0.019) and 2 km: 0.005 (0.003; 0.007) and 5 km: 0.001 (0.001; 0.002)], forest cover [0.5 km: 0.017 (0.011; 0.022) and 1 km: 0.017 (0.011; 0.022)] and density of allergenic trees in forests [2 km: 0.005 (0.004; 0.007) and 5 km: 0.001 (0.001; 0.001)].

3.3 Model performance

Table S4 contains the values of Akaike's information criterion (AIC) used to evaluate and compare the models performance. The lowest AIC was obtained in unadjusted and fully adjusted models for GHQ12 and Average Symptom score that used exposures calculated within 2 km distance. The unadjusted PSS model performed best at the 0.5 km radius, while the adjusted PSS model performed best at the 1 km radius and worst at the 0.5 km radius.



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232 **Figure 3:** Associations (beta-coefficients with 95% confidence interval limits) between health outcomes
233 and residential green space indicators in a 0.5 km, 1 km, 2 km and 5 km radius around the residence in a
234 cohort of 157 tree pollen allergy patients in Belgium. Models were not adjusted for patient background
235 variables. The response variables are the score of the 12-item General Health Questionnaire (GHQ-12),
236 score of the Perceived Stress Scale (PSS), average mood score (AvgMo) and average symptom score
237 (AvgSy).

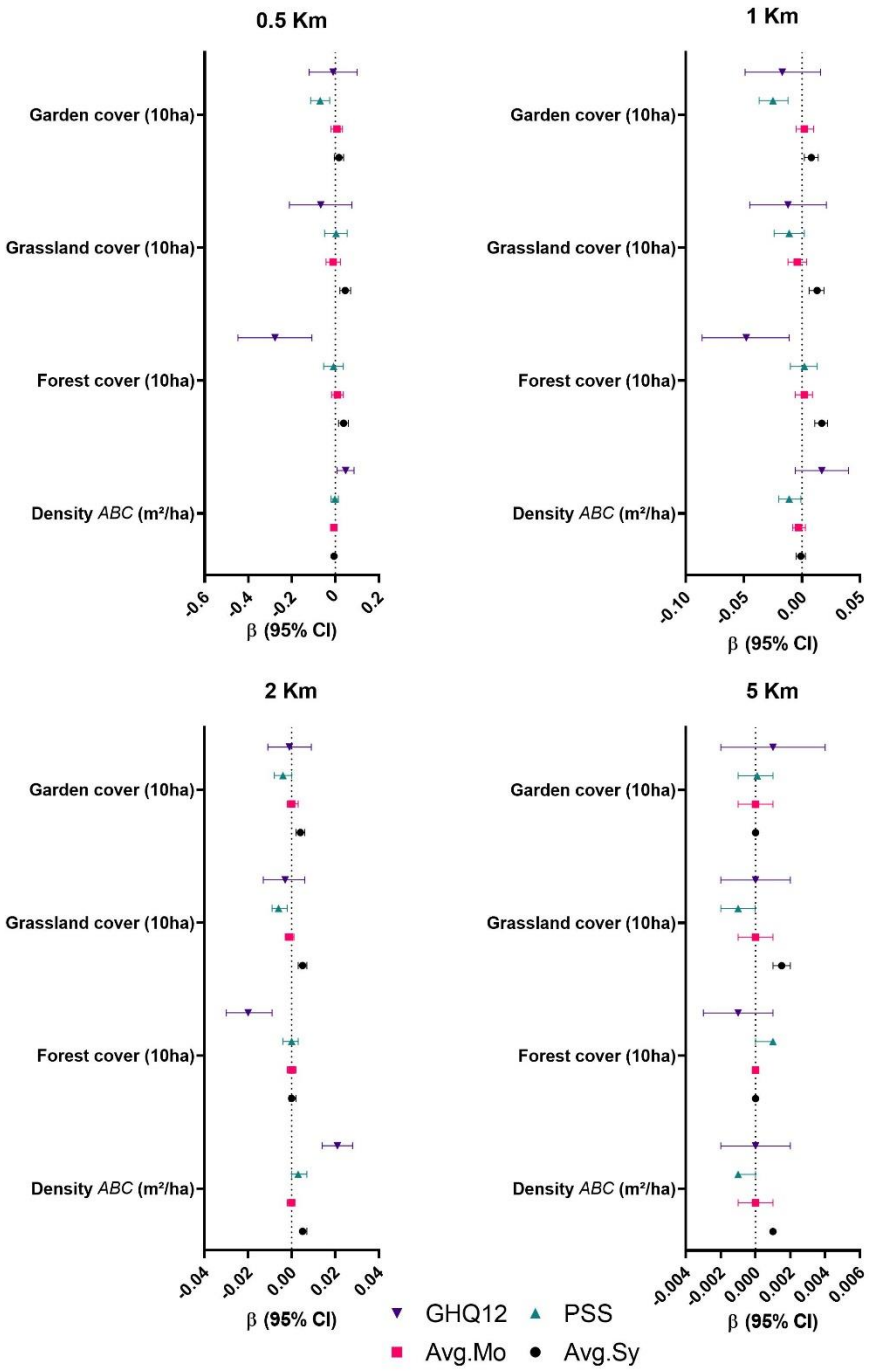
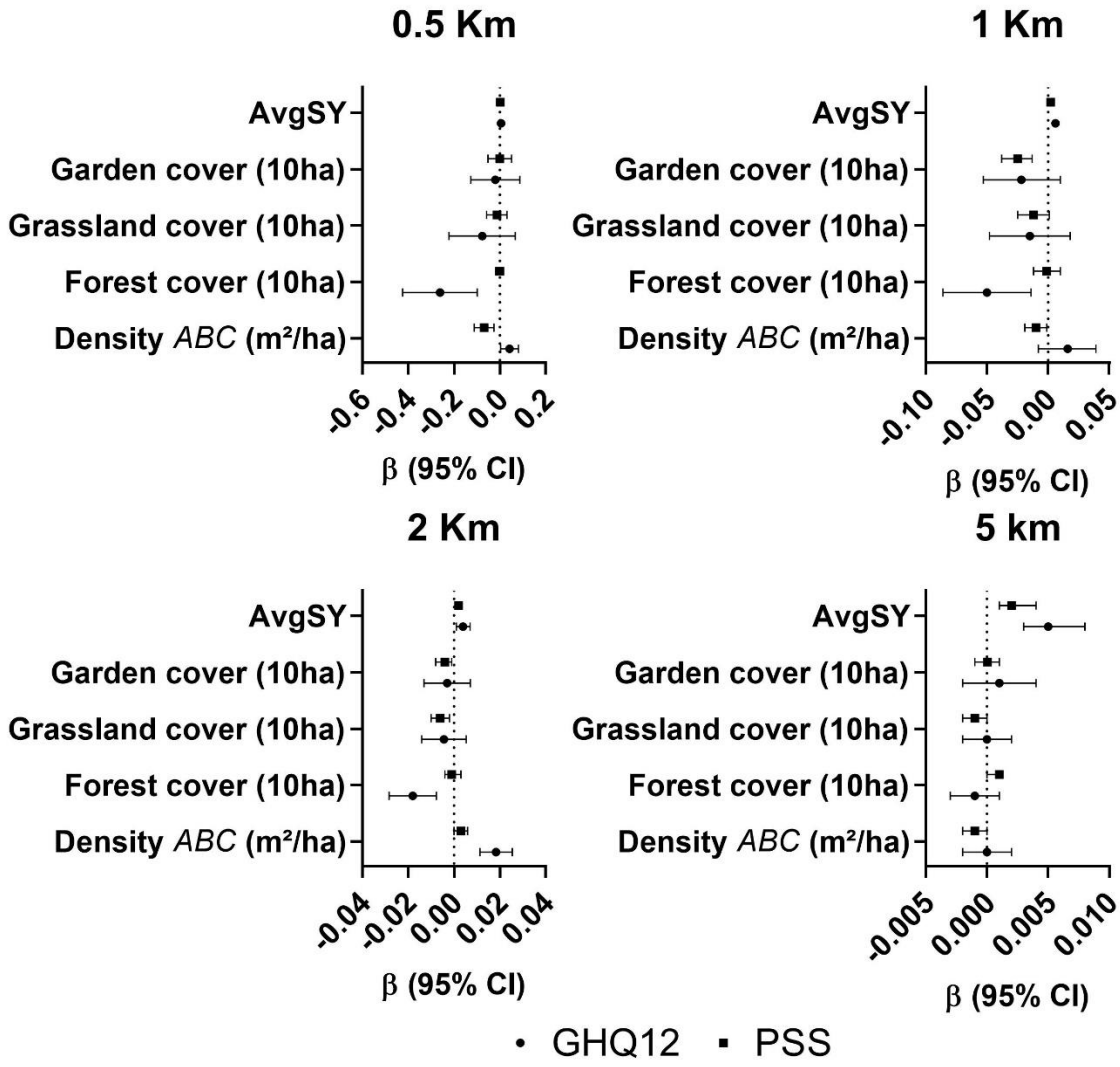


Figure 4: Associations (beta-coefficients with 95% confidence interval limits) between health outcomes and objective residential green space indicators in a 0.5 km, 1 km, 2 km and 5 km radius around the residence in a cohort of 157 tree pollen allergy patients in Belgium. Parameter estimates are adjusted for sex, age, BMI, medication intake, chronic respiratory disease, smoking behavior, higher education, physical activity and perceived presence of allergenic trees. The response variables are the score of the 12-item General Health Questionnaire (GHQ-12), score of the Perceived Stress Scale (PSS), average mood score (Avg.Mo) and average symptom score (Avg.Sy).



246

247 **Figure 5:** Association between exposure to green space and mental health (GHQ12 and PSS) adjusted for
248 all confounders including average allergy symptom severity. Exposure to green space was determined for
249 radii of 0.5 km, 1 km, 2 km and 5 km around the residence in a cohort of 157 tree pollen allergy patients in
250 Belgium.

251

4. Discussion

4.1 Key findings

In our cohort of 157 tree pollen allergy patients residing in Belgium, exposure to residential green space (gardens, grasslands and forests) had a protective effect on short-term mental distress (GHQ-12) and perceived stress (PSS) during the tree pollen season. However, the objective presence of allergenic trees in forests near the residence, in particular within a 2 km distance, was found to be a risk factor for short-term mental distress and perceived stress. More severe allergy symptoms were associated with worse mental health. Exposure to residential green space was associated with higher allergy symptom scores but did not affect daily mood. We did not find evidence that green space had a mitigating effect on respiratory health complaints of allergy patients during the tree pollen season.

4.2 Comparisons with other studies

Mental well-being. In agreement with other studies we find that residential green is beneficial for mental well-being and contributes to lower perceived stress levels. In the UK, a study with 263 respondents found that increased vegetation cover around the residence was associated with better mental health outcomes based on the Depression Anxiety Stress Scale (Cox et al., 2017). Data from 8793 respondents in the Catalonia Health Survey in Spain showed that presence of green space within 300 m of the residence was associated with better mental health, expressed as GHQ-12 (Triguero-Mas et al., 2015). Data from the British Household Panel Survey, with over 10,000 respondents, showed that individuals living in urban areas with more green space reported better mental health, indexed by GHQ-12 (White et al., 2013). A study with 106 adults in disadvantaged

districts in the UK found that inhabitants of neighborhoods with more green space reported lower perceived stress levels (PSS) (Roe et al., 2013).

Daily mood. We did not find associations between residential exposure to green space and daily mood. In contrast, a large scale study in the UK running from August 2010 until February 2011 did find that their panel of 20,000 users scored their own happiness 1.8-2.7 points higher on a 0-100 scale when in a green or natural environment compared to continuous urban fabric (MacKerron and Mourato, 2013). A study with 155 adolescents in Illinois (USA) found that exposure to an objectively higher concentration of nature was associated with a better overall mood (Profile of Mood States questionnaire; Edition 2 -Youth) (Li et al., 2018). Our results do not confirm the short term effect of green space on daily mood, possibly because the 5-point-scale we used is not sufficiently sensitive and a 0-100 scale (MacKerron and Mourato, 2013) or a standardized questionnaire (Li et al., 2018; Neill et al., 2019) may be needed to find statistically significant results.

Mental distress. When exposure to airborne pollen or allergenic trees cannot be avoided during the pollen season, sensitized individuals may experience psychological stress (Aerts et al., 2020b). Our results add the suggestion that the presence of allergenic trees in nearby forests are a risk factor for mental distress of allergy patients although exposure to residential green space is positively associated with mental well-being. We found that allergy symptoms were associated with higher mental distress, which has been reported in previous studies (Oh et al., 2018). The burden of allergic rhinitis has a far-reaching negative impact on the quality of life of adolescents (Blaiss et al., 2018). Trikojat et al. (2017) found that, during the pollen season, depressive symptoms were stronger in allergy patients compared to control persons while no significant difference in depressive symptoms could be found between controls and allergy patients outside

297 the pollen season (Trikojat et al., 2017). Pollen allergy patients experience mental distress because
298 of their condition and our results show that objective exposure to allergenic trees in forests within
299 1-2 km distance from the residence and self-reported allergy symptoms contribute to increased
300 mental distress.

301 *Respiratory health.* In a panel of 4000 people in Barcelona (Spain), participants living in a greener
302 neighborhood (defined as characterized by a higher satellite based greenness index (NDVI) within
303 500m) reported better subjective general health (Su et al., 2019). A study with 3000 people in the
304 UK, found that people in more urbanized areas experienced lower amounts of nature or green
305 space and reported worse mental and physical health (Cox et al., 2018). While literature provides
306 evidence of general physical health benefits of nature and green space, we found that green space
307 and presence of allergenic trees are risk factors for respiratory health. Recent studies on respiratory
308 health of children revealed that exposure to green space was associated with increased rhinitis
309 (Parmes et al., 2020) and risk of pollen sensitization (Gernes et al., 2019). In a study with 7910
310 adult participants in California (USA), Ulmer et al. (2016) found that neighborhood tree cover was
311 associated with fewer asthma diagnoses. Additionally, in a large study in England green space,
312 gardens and urban trees were associated with less asthma hospitalizations (Alcock et al., 2017).
313 Even though residential green can be associated with better general health (Cox et al., 2018; Su et
314 al., 2019) and respiratory health (Alcock et al., 2017; Ulmer et al., 2016), our results do not support
315 this evidence for pollen allergy patients. We find that higher exposure to residential green space,
316 gardens, forest, and grasslands alike, is associated with more allergy symptoms in pollen allergy
317 sufferers during the pollen season, despite its beneficial effect on mental health. These results are
318 in line with earlier research in Belgium that reported associations between gardens and grasslands
319 and medication sales for childhood asthma (Aerts et al., 2020a)

Distance effects: The associations between residential green space area and respiratory health and mental well-being become smaller when the considered exposure radii become larger. Additionally, we find different significant associations at different spatial scales. The recent literature review of Labib et al. (2020a) concluded that associations between green and health outcomes are significant at different scales. It is insufficiently known how to quantify green space for health effect studies objectively. Browning and Lee (2017) suggest that buffer sizes of 1 and 2 km are best to predict health outcomes. While aggregation of landscapes might reduce the effect size when using larger buffer sizes (Labib et al., 2020b). We find that forest cover within 0.5, 1 and 2 km distance are protective against mental distress. Forest further away (5 km) did not contribute to lower distress. It is possible that green space does not affect mental health at such distances, but most studies on green space and mental health do not include buffer sizes over 1000 m (Labib et al., 2020a).

Nearby gardens (within a 0.5 and 1 km distance) were associated with a lower PSS. Nearby garden cover can indicate the presence of a private garden. An Austrian study with 856 respondents reported that personal gardens are perceived to contribute to restoration of psychological fatigue (Cervinka et al., 2016).

Grasslands at all studied distances (0.5-5 km) contributed to allergy symptoms, even though the data were not recorded during the grass pollen season. It is possible that the appearance of individual trees in wood-pastures, making up 2% of the terrain in Belgium (Plieninger et al., 2015), contribute to tree pollen exposure. Nearby forests, within 0.5 and 1 km distance, contribute to allergy symptoms, while forests further away, within a distance of 2 or 5 km are not associated with more symptoms. Nevertheless the allergenic trees in forests within a 2-5 km distance do contribute to symptoms. Airborne pollen can travel over longer distances, hence pollen sources at

a 2-5 km distance can contribute to allergy symptoms (Bogawski et al., 2019). Grasslands may therefore also contribute to tree pollen allergy symptoms by transmitting, rather than emitting, tree pollen, because there is no high vegetation that is able to intercept airborne pollen. In-situ measurements of airborne pollen may be used to elucidate this hypothesis.

4.3 Strengths and limitations

A main strength of this analysis is the size of the available dataset. During the tree pollen seasons of 2017 and 2018 we tracked 157 adults sensitized to pollen of *Alnus, Betula* and *Corylus*. Participants were recruited all over Belgium. The collective effort of the participants resulted in a total of 4714 symptom days.

The available geodataset with detailed information on specific green space types allows for more thematic analyses and insights as opposed to a remotely sensed vegetation index such as greenness estimated by NDVI, which has often been used in previous studies. In addition, we had information on the density of allergenic tree species which is extremely relevant for our panel of adults with tree pollen allergy.

Most previous studies on the association between green space and mental health outcomes used general populations. A strength of this study is that we were able to study the impact of green space exposure during symptom days on the mental health of allergy patients.

Nevertheless, the study has certain limitations such as: self-reported data may be prone to recall bias or mono-method bias and there are possible covariates such as air pollution that are not currently considered.

Self-reported symptom scores using the Likert scales can be subject to a certain level of subjectivity. Nevertheless, this approach could easily be integrated into the smartphone application and is often favored over Visual Analog Scales because of the simplicity of Likert scales.

The available densities of allergenic trees were limited to forest plots. Data on the presence of allergenic trees in streets, parks, vacant lots, and private gardenswould be a valuable contribution to this exposure study.

5. Conclusion

Distress and perceived stress of 157 adults with pollen allergy exhibited various associations with the extent and composition of green space types around their residence. Increased cover of green space around the residence was protective against distress and perceived stress. However, high amounts of allergenic tree species in nearby forests were a risk factor for distress in tree pollen allergy patients. Higher residential green cover and presence of allergenic trees was also associated with more severe allergy symptoms. Our results contribute evidence for mental health benefits of green space, also for pollen allergy sufferers. There are, however, risks related to specific tree species for both mental and respiratory health during the pollen season which must be further elaborated into recommendations for design of allergy-friendly urban green spaces and other city greening (Aerts et al., 2021; Cariñanos et al., 2019; Jochner-Oette et al., 2018). Moreover, apart from residential green areas sensu stricto also more distant green areas should be taken into account (Jochner-Oette et al., 2018), since we find associations up to a distance of 5 km while pollen can travel over even larger distances.

6. Ethical clearance

This study was registered with the Clinical Trial Center of the KU Leuven University Hospital as a national, monocentric, non-commercial study commissioned by the Belgian Science Policy Office BELSPO (study number S59404). The protocol for this study was approved by the Ethical Commission of the KU Leuven University Hospital (Belgian registration number B322201629692). Informed consent was obtained and documented.

Data Statement

The research data is 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).

401 **References**

402 Aerts, R., Bruffaerts, N., Somers, B., Demoury, C., Plusquin, M., Nawrot, T.S., Hendrickx, M.,
403 2021. Tree pollen allergy risks and changes across scenarios in urban green spaces in
404 Brussels, Belgium. Landsc. Urban Plan. 207, 104001.
405 https://doi.org/10.1016/j.landurbplan.2020.104001

406 Aerts, R., Dujardin, S., Nemery, B., Van Nieuwenhuyse, A., Van Orshoven, J., Aerts, J.M.,
407 Somers, B., Hendrickx, M., Bruffaerts, N., Bauwelinck, M., Casas, L., Demoury, C.,
408 Plusquin, M., Nawrot, T.S., 2020a. Residential green space and medication sales for
409 childhood asthma: A longitudinal ecological study in Belgium. Environ. Res. 189, 109914.
410 https://doi.org/10.1016/j.envres.2020.109914

411 Aerts, R., Honnay, O., Van Nieuwenhuyse, A., 2018. Biodiversity and human health:
412 mechanisms and evidence of the positive health effects of diversity in nature and green
413 spaces. Br. Med. Bull. 127, 5–22. https://doi.org/10.1093/bmb/ldy021

414 Aerts, R., Stas, M., Vanlessen, N., Hendrickx, M., Bruffaerts, N., Hoebeke, L., Dendoncker, N.,
415 Dujardin, S., Saenen, N.D., Van Nieuwenhuyse, A., Aerts, J.-M., Van Orshoven, J., Nawrot,
416 T.S., Somers, B., 2020b. Residential green space and seasonal distress in a cohort of tree
417 pollen allergy patients. Int. J. Hyg. Environ. Health 223, 71–79.
418 https://doi.org/10.1016/j.ijheh.2019.10.004

419 Agay-Shay, K., Peled, A., Crespo, A.V., Peretz, C., Amitai, Y., Linn, S., Friger, M.,
420 Nieuwenhuijsen, M.J., 2014. Green spaces and adverse pregnancy outcomes. Occup.
421 Environ. Med. 71, 562–569. https://doi.org/10.1136/oemed-2013-101961

422 Alcock, I., White, M., Cherrie, M., Wheeler, B., Taylor, J., McInnes, R., Otte im Kampe, E.,

Vardoulakis, S., Sarran, C., Soyiri, I., Fleming, L., 2017. Land cover and air pollution are associated with asthma hospitalisations: A cross-sectional study. Environ. Int. 109, 29–41. https://doi.org/10.1016/j.envint.2017.08.009

Andrusaityte, S., Grazuleviciene, R., Kudzyte, J., Bernotiene, A., Dedele, A., Nieuwenhuijsen, M.J., 2016. Associations between neighbourhood greenness and asthma in preschool children in Kaunas, Lithuania: A case-control study. BMJ Open 6, e010341. https://doi.org/10.1136/bmjopen-2015-010341

Blaiss, M.S., Hammerby, E., Robinson, S., Kennedy-Martin, T., Buchs, S., 2018. The burden of allergic rhinitis and allergic rhinoconjunctivitis on adolescents: A literature review. Ann. Allergy, Asthma Immunol. https://doi.org/10.1016/j.anai.2018.03.028

Bogawski, P., Borycka, K., Grewling, Ł., Kasprzyk, I., 2019. Detecting distant sources of airborne pollen for Poland: Integrating back-trajectory and dispersion modelling with a satellite-based phenology. Sci. Total Environ. 689, 109–125. https://doi.org/10.1016/j.scitotenv.2019.06.348

Bratman, G.N., Anderson, C.B., Berman, M.G., Cochran, B., de Vries, S., Flanders, J., Folke, C., Frumkin, H., Gross, J.J., Hartig, T., Kahn, P.H., Kuo, M., Lawler, J.J., Levin, P.S., Lindahl, T., Meyer-Lindenberg, A., Mitchell, R., Ouyang, Z., Roe, J., Scarlett, L., Smith, J.R., van den Bosch, M., Wheeler, B.W., White, M.P., Zheng, H., Daily, G.C., 2019. Nature and mental health: An ecosystem service perspective. Sci. Adv. https://doi.org/10.1126/sciadv.aax0903

Browning, M., Lee, K., 2017. Within What Distance Does "Greenness" Best Predict Physical Health? A Systematic Review of Articles with GIS Buffer Analyses across the Lifespan.

Int. J. Environ. Res. Public Health 14, 675. https://doi.org/10.3390/ijerph14070675

Cariñanos, Grilo, Pinho, Casares-Porcel, Branquinho, Acil, Andreucci, Anjos, Bianco, Brini, Calaza-Martínez, Calvo, Carrari, Castro, Chiesura, Correia, Gonçalves, Gonçalves, Mexia, Mirabile, Paoletti, Santos-Reis, Semenzato, Vilhar, 2019. Estimation of the Allergenic Potential of Urban Trees and Urban Parks: Towards the Healthy Design of Urban Green Spaces of the Future. Int. J. Environ. Res. Public Health 16, 1357. https://doi.org/10.3390/ijerph16081357

Cervinka, R., Schwab, M., Schönbauer, R., Hämmerle, I., Pirgie, L., Sudkamp, J., 2016. My garden - my mate? Perceived restorativeness of private gardens and its predictors. Urban For. Urban Green. 16, 182–187. https://doi.org/10.1016/j.ufug.2016.01.013

Cox, D., Shanahan, D., Hudson, H., Fuller, R., Anderson, K., Hancock, S., Gaston, K., 2017. Doses of Nearby Nature Simultaneously Associated with Multiple Health Benefits. Int. J. Environ. Res. Public Health 14, 172. https://doi.org/10.3390/ijerph14020172

Cox, D.T.C., Shanahan, D.F., Hudson, H.L., Fuller, R.A., Gaston, K.J., 2018. The impact of urbanisation on nature dose and the implications for human health. Landsc. Urban Plan. 179, 72–80. https://doi.org/10.1016/J.LANDURBPLAN.2018.07.013

D'Amato, G., Vitale, C., Lanza, M., Molino, A., D'Amato, M., 2016. Climate change, air pollution, and allergic respiratory diseases. Curr. Opin. Allergy Clin. Immunol. 16, 434–440. https://doi.org/10.1097/ACI.0000000000000301

Dalton, A.M., Jones, A.P., Sharp, S.J., Cooper, A.J.M., Griffin, S., Wareham, N.J., 2016. Residential neighbourhood greenspace is associated with reduced risk of incident diabetes in older people: a prospective cohort study. BMC Public Health 16, 1–10.

https://doi.org/10.1186/s12889-016-3833-z

Demoury, C., Thierry, B., Richard, H., Sigler, B., Kestens, Y., Parent, M.E., 2017. Residential greenness and risk of prostate cancer: A case-control study in Montreal, Canada. Environ. Int. 98, 129–136. https://doi.org/10.1016/j.envint.2016.10.024

Eisenman, T.S., Jariwala, S.P., Lovasi, G.S., 2019. Urban trees and asthma: a call for epidemiological research. Lancet Respir. Med. https://doi.org/10.1016/S2213-2600(19)30193-6

Engemann, K., Pedersen, C.B., Arge, L., Tsirogiannis, C., Mortensen, P.B., Svenning, J.C., 2019. Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. Proc. Natl. Acad. Sci. U. S. A. 116, 5188–5193. https://doi.org/10.1073/pnas.1807504116

Engemann, K., Pedersen, C.B., Arge, L., Tsirogiannis, C., Mortensen, P.B., Svenning, J.C., 2018. Childhood exposure to green space – A novel risk-decreasing mechanism for schizophrenia? Schizophr. Res. https://doi.org/10.1016/j.schres.2018.03.026

Fong, K.C., Hart, J.E., James, P., 2018. A Review of Epidemiologic Studies on Greenness and Health: Updated Literature Through 2017. Curr. Environ. Heal. reports. https://doi.org/10.1007/s40572-018-0179-y

Gernes, R., Brokamp, C., Rice, G.E., Wright, J.M., Kondo, M.C., Michael, Y.L., Donovan, G.H., Gatziolis, D., Bernstein, D., LeMasters, G.K., Lockey, J.E., Khurana Hershey, G.K., Ryan, P.H., 2019. Using high-resolution residential greenspace measures in an urban environment to assess risks of allergy outcomes in children. Sci. Total Environ. 668, 760–767. https://doi.org/10.1016/J.SCITOTENV.2019.03.009

Grazuleviciene, R., Dedele, A., Danileviciute, A., Vencloviene, J., Grazulevicius, T., Andrusaityte, S., Uzdanaviciute, I., Nieuwenhuijsen, M.J., 2014. The influence of proximity to city parks on blood pressure in early pregnancy. Int. J. Environ. Res. Public Health 11, 2958–2972. https://doi.org/10.3390/ijerph110302958

Jochner-Oette, S., Stitz, T., Jetschni, J., Cariñanos, P., 2018. The Influence of Individual-Specific Plant Parameters and Species Composition on the Allergenic Potential of Urban Green Spaces. Forests 9, 284. https://doi.org/10.3390/f9060284

Labib, S.M., Lindley, S., Huck, J.J., 2020a. Spatial dimensions of the influence of urban green-blue spaces on human health: A systematic review. Environ. Res. https://doi.org/10.1016/j.envres.2019.108869

Labib, S.M., Lindley, S., Huck, J.J., 2020b. Scale effects in remotely sensed greenspace metrics and how to mitigate them for environmental health exposure assessment. Comput. Environ. Urban Syst. 82, 101501. https://doi.org/10.1016/j.compenvurbsys.2020.101501

Lake, I.R., Jones, N.R., Agnew, M., Goodess, C.M., Giorgi, F., Hamaoui-Laguel, L., Semenov, M.A., Solomon, F., Storkey, J., Vautard, R., Epstein, M.M., 2017. Climate change and future pollen allergy in Europe. Environ. Health Perspect. https://doi.org/10.1289/EHP173

Li, D., Deal, B., Zhou, X., Slavenas, M., Sullivan, W.C., 2018. Moving beyond the neighborhood: Daily exposure to nature and adolescents' mood. Landsc. Urban Plan. 173, 33–43. https://doi.org/10.1016/j.landurbplan.2018.01.009

Livesley, S.J., McPherson, E.G., Calfapietra, C., 2016. The Urban Forest and Ecosystem Services: Impacts on Urban Water, Heat, and Pollution Cycles at the Tree, Street, and City Scale. J. Environ. Qual. 45, 119–124. https://doi.org/10.2134/jeq2015.11.0567

MacKerron, G., Mourato, S., 2013. Happiness is greater in natural environments. Glob. Environ. Chang. 23, 992–1000. https://doi.org/10.1016/J.GLOENVCHA.2013.03.010

Neill, C., Gerard, J., Arbuthnott, K.D., 2019. Nature contact and mood benefits: contact duration and mood type. J. Posit. Psychol. 14, 756–767. https://doi.org/10.1080/17439760.2018.1557242

Oh, H., Koyanagi, A., Devylder, J.E., Stickley, A., 2018. Seasonal allergies and psychiatric disorders in the United States. Int. J. Environ. Res. Public Health 15. https://doi.org/10.3390/ijerph15091965

Parmes, E., Pesce, G., Sabel, C.E., Baldacci, S., Bono, R., Brescianini, S., D'Ippolito, C., Hanke, W., Horvat, M., Liedes, H., Maio, S., Marchetti, P., Marcon, A., Medda, E., Molinier, M., Panunzi, S., Pärkkä, J., Polańska, K., Prud'homme, J., Ricci, P., Snoj Tratnik, J., Squillacioti, G., Stazi, M.A., Maesano, C.N., Annesi-Maesano, I., 2020. Influence of residential land cover on childhood allergic and respiratory symptoms and diseases: Evidence from 9 European cohorts. Environ. Res. 183, 108953. https://doi.org/10.1016/j.envres.2019.108953

Plieninger, T., Hartel, T., Martín-López, B., Beaufoy, G., Bergmeier, E., Kirby, K., Montero, M.J., Moreno, G., Oteros-Rozas, E., Van Uytvanck, J., 2015. Wood-pastures of Europe: Geographic coverage, social-ecological values, conservation management, and policy implications. Biol. Conserv. https://doi.org/10.1016/j.biocon.2015.05.014

Roe, J., Thompson, C., Aspinall, P., Brewer, M., Duff, E., Miller, D., Mitchell, R., Clow, A., 2013. Green Space and Stress: Evidence from Cortisol Measures in Deprived Urban Communities. Int. J. Environ. Res. Public Health 10, 4086–4103.

https://doi.org/10.3390/ijerph10094086

Rufo, J.C., Paciência, I., Ribeiro, A.I., 2019. Green Environments and Allergic Diseases in Children: a Scoping Review. Curr. Epidemiol. Reports 6, 442–448. https://doi.org/10.1007/s40471-019-00218-0

Su, J.G., Dadvand, P., Nieuwenhuijsen, M.J., Bartoll, X., Jerrett, M., 2019. Associations of green space metrics with health and behavior outcomes at different buffer sizes and remote sensing sensor resolutions. Environ. Int. 126, 162–170. https://doi.org/10.1016/j.envint.2019.02.008

Tischer, C., Gascon, M., Fernández-Somoano, A., Tardón, A., Lertxundi Materola, A., Ibarluzea, J., Ferrero, A., Estarlich, M., Cirach, M., Vrijheid, M., Fuertes, E., Dalmau-Bueno, A., Nieuwenhuijsen, M.J., Antó, J.M., Sunyer, J., Dadvand, P., 2017. Urban green and grey space in relation to respiratory health in children. Eur. Respir. J. 49, 1502112. https://doi.org/10.1183/13993003.02112-2015

Triguero-Mas, M., Dadvand, P., Cirach, M., Martínez, D., Medina, A., Mompart, A., Basagaña, X., Gražulevičiene, R., Nieuwenhuijsen, M.J., 2015. Natural outdoor environments and mental and physical health: Relationships and mechanisms. Environ. Int. 77, 35–41. https://doi.org/10.1016/j.envint.2015.01.012

Trikojat, K., Luksch, H., Rösen-Wolff, A., Plessow, F., Schmitt, J., Buske-Kirschbaum, A., 2017. "Allergic mood" – Depressive and anxiety symptoms in patients with seasonal allergic rhinitis (SAR) and their association to inflammatory, endocrine, and allergic markers. Brain. Behav. Immun. 65, 202–209. https://doi.org/10.1016/j.bbi.2017.05.005

Twohig-Bennett, C., Jones, A., 2018. The health benefits of the great outdoors: A systematic

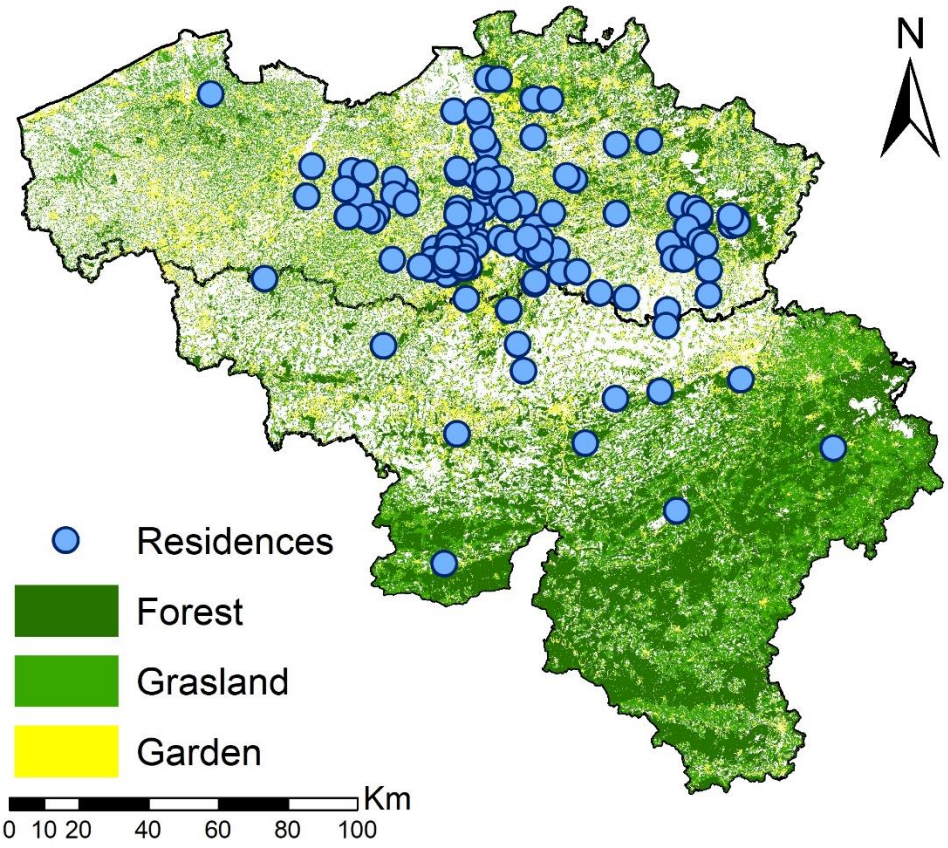
review and meta-analysis of greenspace exposure and health outcomes. Environ. Res. 166, 628–637. https://doi.org/10.1016/J.ENVRES.2018.06.030

Ulmer, J.M., Wolf, K.L., Backman, D.R., Tretheway, R.L., Blain, C.J., O'Neil-Dunne, J.P., Frank, L.D., 2016. Multiple health benefits of urban tree canopy: The mounting evidence for a green prescription. Heal. Place 42, 54–62. https://doi.org/10.1016/j.healthplace.2016.08.011

Westra, T., Verschelde, P., Van Calster, H., Els, L., Onkelinx, T., Quataert, P., Govaere, L., Waterinckx, M., 2015. Opmaak van een analysestramien voor de gegevens van de Vlaamse Bosinventarisatie. Brussels. https://doi.org/INBO.R.2015.903482

White, M.P., Alcock, I., Wheeler, B.W., Depledge, M.H., 2013. Would You Be Happier Living in a Greener Urban Area? A Fixed-Effects Analysis of Panel Data. Psychol. Sci. 24, 920–928. https://doi.org/10.1177/0956797612464659

569 **Supplementary materials**



570

571 **Figure S1:** Distribution of the 157 participants included in the residential exposure study.
572 Residence symbols are oversized due to privacy restrictions. Forest, grassland and garden data are
573 from the Top10 vector dataset of the Belgian National Geographic Institute.

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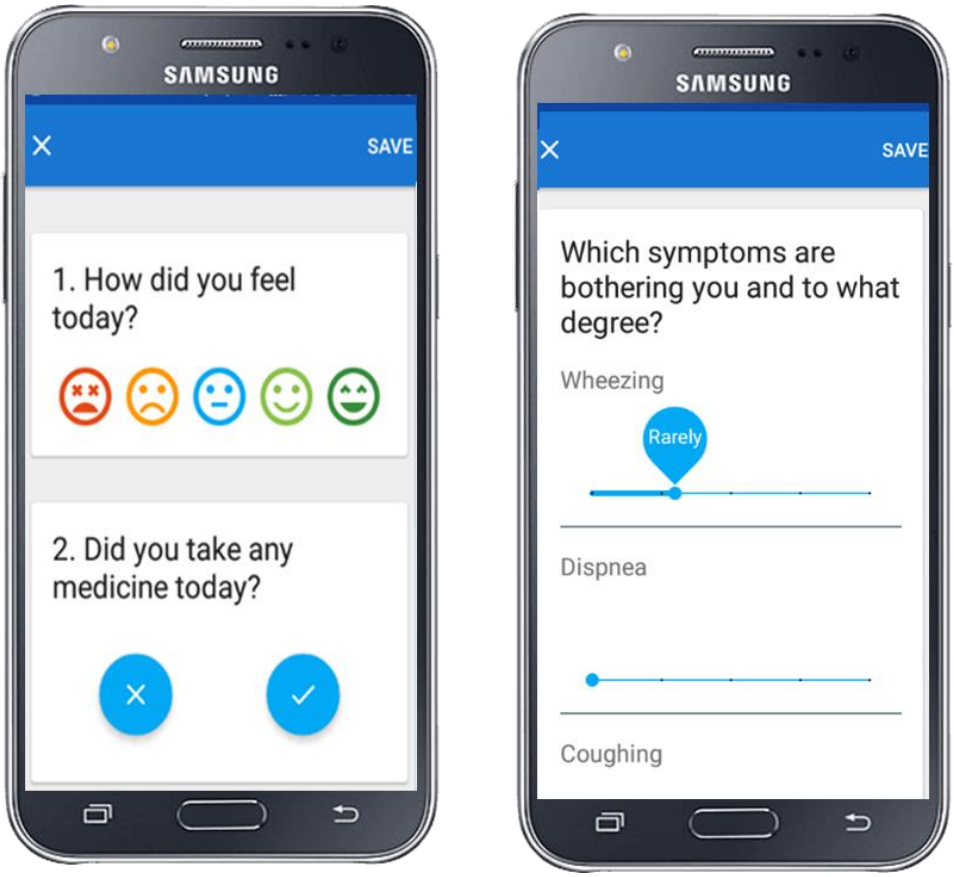


575

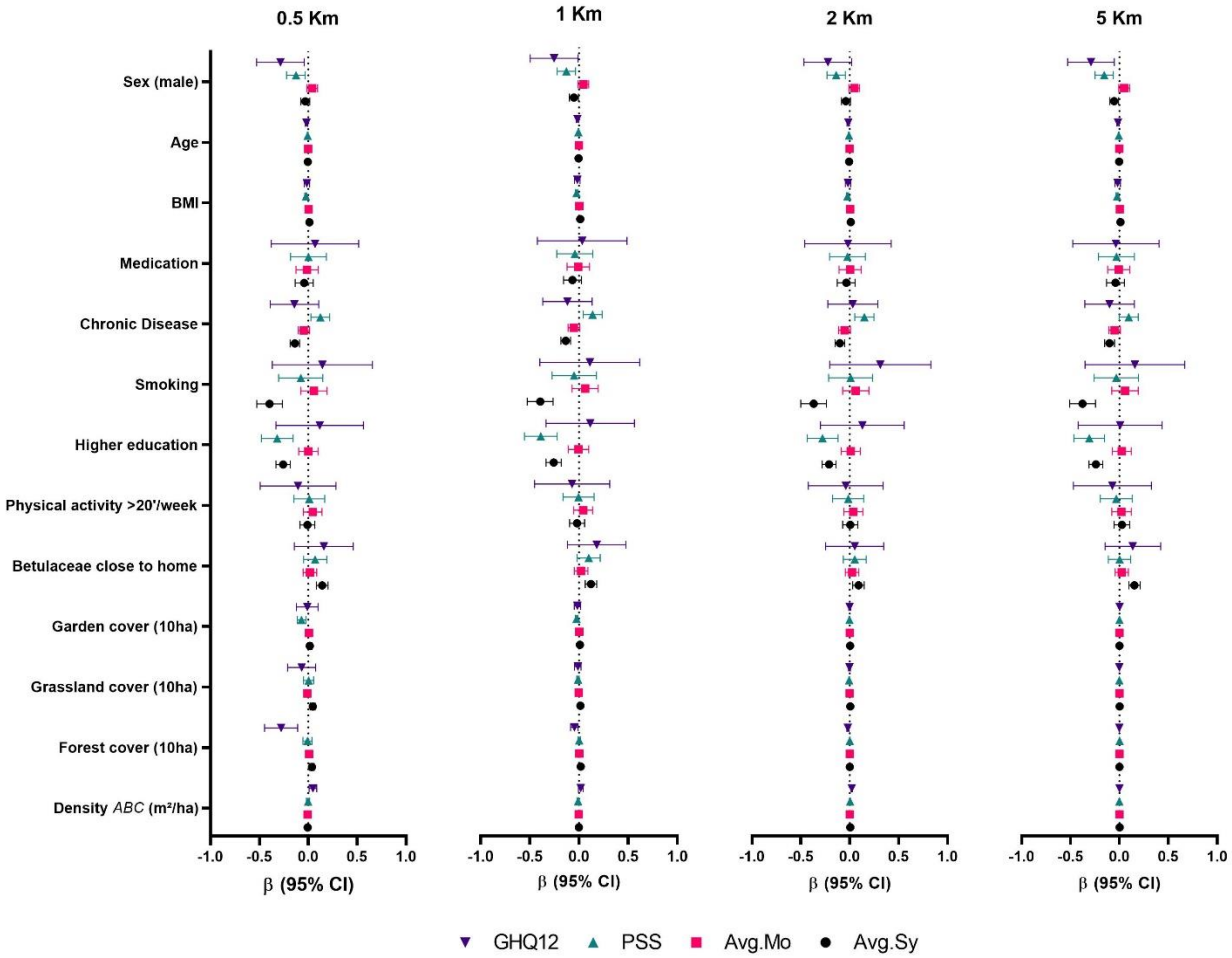
576 **Figure S2:** Two screenshots from the RespirIT app for android used by the participants to log their

577 mood (left) and allergy symptoms (right) at the end of every day.

578

Table S1: Beta-coefficients with 95% confidence intervals for unadjusted models of objective residential green measures in a 0.5, 1, 2 and 5 km radius around the residence. Response variables are the score of the general health questionnaire with 12 questions (GHQ-12), scores of the perceived stress scale (PSS), average mood score (AvgMo) and average symptom score (AvgSy). Significant associations are highlighted in grey boxes.

	Predictor	**Unadjusted GHQ-12**	**Unadjusted PSS**	**Unadjusted AvgMo**	**Unadjusted AvgSy**
		β (95% CI)	**β (95% CI)**	**β (95% CI)**	**β (95% CI)**
0.5 km	Garden (10ha)	-0.029 (-0.126 – 0.068)	-0.065 (-0.105 – -0.026)	0.011 (-0.012 – 0.035)	0.051 (0.032 – 0.071)
	Grass (10ha)	-0.035 (-0.164 – 0.094)	0.023 (-0.025 – 0.072)	-0.008 (-0.040 – 0.023)	0.086 (0.062 – 0.110)
	Forest (10ha)	-0.274 (-0.443 – -0.104)	-0.004 (-0.048 – 0.040)	0.014 (-0.013 – 0.040)	0.049 (0.027 – 0.070)
	Basal Area (m²/ha)	0.037 (0.001 – 0.073)	0.002 (-0.014 – 0.017)	-0.006 (-0.016 – 0.004)	0.002 (-0.006 – 0.009)
1 km	Garden (10ha)	-0.018 (-0.047 – 0.012)	-0.020 (-0.031 – -0.008)	0.003 (-0.004 – 0.010)	0.013 (0.007 – 0.018)
	Grass (10ha)	-0.007 (-0.038 – 0.024)	-0.007 (-0.019 – 0.005)	-0.002 (-0.009 – 0.006)	0.020 (0.014 – 0.026
	Forest (10ha)	-0.048 (-0.085 – -0.011)	0.000 (-0.011 – 0.011)	0.003 (-0.004 – 0.010)	0.016 (0.010 – 0.021)
	Basal Area (m²/ha)	0.010 (-0.010 – 0.030)	-0.007 (-0.015 – 0.002)	-0.002 (-0.007 – 0.003)	0.005 (0.001 – 0.009)
2 km	Garden (10ha)	0.000 (-0.010 – 0.009)	-0.003 (-0.007 – 0.000)	0.000 (-0.002 – 0.002)	0.005 (0.003 – 0.006)
	Grass (10ha)	-0.003 (-0.012 – 0.006)	-0.005 (-0.009 – -0.001)	0.000 (-0.003 – 0.002)	0.006 (0.005 – 0.008)
	Forest (10ha)	-0.023 (-0.034 – -0.012)	-0.001 (-0.004 – 0.003)	0.001 (-0.001 – 0.003)	0.000 (-0.001 – 0.002)
	Basal Area (m²/ha)	0.020 (0.014 – 0.027)	0.003 (0.000 – 0.006)	0.000 (-0.002 – 0.002)	0.007 (0.007 – 0.008)
5 km	Garden (10ha)	0.001 (-0.002 – 0.003)	0.000 (-0.001 – 0.000)	0.000 (-0.001 – 0.000)	0.000 (0.000 – 0.001)
	Grass (10ha)	0.000 (-0.002 – 0.002)	-0.001 (-0.001 – 0.000)	0.000 (-0.001 – 0.000)	0.001 (0.001 – 0.002)
	Forest (10ha)	-0.001 (-0.003 – 0.000)	0.001 (0.000 – 0.001)	0.000 (0.000 – 0.000)	0.000 (0.000 – 0.000)
	Basal Area (m²/ha)	0.000 (-0.002 – 0.002)	-0.001 (-0.001 – 0.000)	0.000 (0.000 – 0.000)	0.001 (0.001 – 0.002)



585

586 **Figure S3:** Fully adjusted associations (beta-coefficients with 95% confidence interval limits) between health outcomes and predictors
587 for residential exposure models of 1 km, 2 km and 5 km radius around the residence. The response variables are the score of the general
588 health questionnaire with 12 questions (GHQ-12), scores of the perceived stress scale (PSS), average mood score on symptom days
589 (AvgMo) and average symptom score on symptom days (AvgSy).

Table S Error! No text of specified style in document.**2:** Beta-coefficients with 95% confidence intervals for unadjusted models of objective residential green measures in a 0.5, 1, 2 and 5 km radius around the residence. Response variables are the score of the general health questionnaire with 12 questions (GHQ-12), scores of the perceived stress scale (PSS), average mood score on symptom days (AvgMo) and average symptom score on symptom days (AvgSy). Data from a cohort of allergy patients in Belgium. Significant associations are highlighted in grey boxes.

	Predictor	**Fully adjusted GHQ-12**	**Fully adjusted PSS**	**Fully adjusted AvgMo**	**Fully adjusted AvgSy**
		β (95% CI)	**β (95% CI)**	**β (95% CI)**	**β (95% CI)**
0.5 km	Sex				
	female	(reference)	(reference)	(reference)	(reference)
	male	-0.285 (-0.528 – -0.043)	-0.126 (-0.222 – -0.031)	0.039 (-0.016 – 0.095)	-0.030 (-0.077 – 0.016)
	Age (years)	-0.018 (-0.030 – -0.005)	-0.007 (-0.011 – -0.002)	-0.001 (-0.003 – 0.002)	-0.005 (-0.007 – -0.002)
	BMI	-0.015 (-0.043 – 0.013)	-0.024 (-0.035 – -0.013)	0.003 (-0.003 – 0.010)	0.012 (0.006 – 0.017)
	Medication				
	no	(reference)	(reference)	(reference)	(reference)
	yes	0.069 (-0.378 – 0.515)	0.002 (-0.181 – 0.185)	-0.013 (-0.126 – 0.101)	-0.042 (-0.133 – 0.050)
	Chronic Disease				
	no	(reference)	(reference)	(reference)	(reference)
	yes	-0.142 (-0.390 – 0.106)	0.123 (0.027 – 0.218)	-0.045 (-0.103 – 0.013)	-0.137 (-0.186 – -0.089)
	Smoking				
	no	(reference)	(reference)	(reference)	(reference)
	yes	0.144 (-0.368 – 0.655)	-0.077 (-0.303 – 0.149)	0.057 (-0.077 – 0.191)	-0.396 (-0.527 – -0.265)

	Higher education no	(reference)	(reference)	(reference)	(reference)
	yes	0.117 (-0.330 – 0.564)	-0.318 (-0.480 – -0.156)	0.000 (-0.099 – 0.100)	-0.257 (-0.331 – -0.184)
	Physical activity (>20'/week) no	(reference)	(reference)	(reference)	(reference)
	yes	-0.105 (-0.491 – 0.282)	0.010 (-0.148 – 0.168)	0.045 (-0.051 – 0.141)	-0.008 (-0.084 – 0.068)
	Betulaceae nearby no	(reference)	(reference)	(reference)	(reference)
	yes	0.159 (-0.142 – 0.459)	0.070 (-0.048 – 0.189)	0.017 (-0.053 – 0.087)	0.142 (0.083 – 0.201)
	Garden (10ha)	-0.010 (-0.120 – 0.100)	-0.070 (-0.113 – -0.026)	0.007 (-0.019 – 0.033)	0.016 (-0.005 – 0.038)
	Grass (10ha)	-0.067 (-0.211 – 0.076)	0.003 (-0.049 – 0.054)	-0.010 (-0.043 – 0.023)	0.045 (0.021 – 0.070)
	Forest (10ha)	-0.277 (-0.447 – -0.108)	-0.008 (-0.054 – 0.037)	0.009 (-0.018 – 0.037)	0.038 (0.015 – 0.060)
	Density *ABC* (m²/ha)	0.047 (0.008 – 0.086)	-0.002 (-0.019 – 0.014)	-0.007 (-0.018 – 0.003)	-0.006 (-0.014 – 0.002)
1 km	Sex female	(reference)	(reference)	(reference)	(reference)
	male	-0.254 (-0.496 – -0.011)	-0.129 (-0.223 – -0.035)	0.044 (-0.011 – 0.099)	-0.052 (-0.098 – -0.007)
	Age (years)	-0.017 (-0.029 – -0.004)	-0.006 (-0.011 – -0.001)	-0.001 (-0.004 – 0.002)	-0.005 (-0.007 – -0.002)
	BMI	-0.017 (-0.045 – 0.011)	-0.025 (-0.037 – -0.014)	0.004 (-0.003 – 0.010)	0.012 (0.007 – 0.017)
	Medication no	(reference)	(reference)	(reference)	(reference)

	yes	0.032 (-0.423 – 0.487)	-0.043 (-0.227 – 0.141	-0.008 (-0.122 – 0.106)	-0.052 (-1.440 – 0.041)
	Chronic Disease no	(reference)	(reference)	(reference)	(reference)
	yes	-0.118 (-0.369 – 0.133)	0.138 (0.042 – 0.234)	-0.052 (-0.111 – 0.007)	-0.136 (-0.184 – -0.087)
	Smoking no	(reference)	(reference)	(reference)	(reference)
	yes	0.110 (-0.398 – 0.617)	-0.050 (-0.275 – 0.176)	0.062 (-0.071 – 0.195)	-0.395 (-0.526 – -0.265)
	Higher education no	(reference)	(reference)	(reference)	(reference)
	yes	0.114 (-0.335 – 0.563)	-0.390 (-0.556 – -0.224)	-0.006 (-0.110 – 0.098)	-0.258 (-0.335 – -0.182)
	Physical activity (>20'/week) no	(reference)	(reference)	(reference)	(reference)
	yes	-0.071 (-0.453 – 0.311)	-0.005 (-0.163 – 0.152)	0.042 (-0.054 – 0.138)	-0.02 (-0.096 – 0.056)
	Betulaceae nearby no	(reference)	(reference)	(reference)	(reference)
	yes	0.179 (-0.119 – 0.476)	0.098 (-0.020 – 0.215)	0.021 (-0.049 – 0.090)	0.121 (0.063 – 0.180)
	Garden (10ha)	-0.017 (-0.049 – 0.016)	-0.025 (-0.037 – -0.012)	0.002 (-0.005 – 0.010)	0.008 (0.002 – 0.014)
	Grass (10ha)	-0.012 (-0.045 – 0.021)	-0.011 (-0.024 – 0.002)	-0.004 (-0.012 – 0.004)	0.013 (0.006 – 0.019)
	Forest (10ha)	-0.048 (-0.086 – -0.011)	0.002 (-0.010 – 0.013)	0.002 (-0.006 – 0.009)	0.017 (0.011 – 0.022)
	Density *ABC* (m²/ha)	0.017 (-0.006 – 0.040)	-0.011 (-0.020 – -0.001)	-0.003 (-0.008 – 0.003)	-0.001 (-0.005 – 0.003)

2 km	Sex female	(reference)	(reference)	(reference)	(reference)
	male	-0.224 (-0.469 – 0.020)	-0.139 (-0.233 – -0.046)	0.047 (-0.008 – 0.102)	-0.040 -0.085 – 0.006
	Age (years)	-0.016 (-0.028 – -0.004)	-0.008 (-0.013 – -0.003)	-0.001 (-0.004 – 0.002)	-0.006 (-0.008 – -0.003)
	BMI	-0.018 (-0.046 – 0.009)	-0.023 (-0.034 – -0.012)	0.004 (-0.003 – 0.010)	0.011 (0.006 – 0.017)
	Medication no	(reference)	(reference)	(reference)	(reference)
	yes	-0.018 (-0.460 – 0.423)	-0.023 (-0.206 – 0.160)	0.003 (-0.110 – 0.116)	-0.036 (-0.128 – 0.055)
	Chronic disease no	(reference)	(reference)	(reference)	(reference)
	yes	0.031 (-0.225 – 0.287)	0.149 (0.051 – 0.247)	-0.053 (-0.113 – 0.007)	-0.102 (-0.151 – 0.052)
	Smoking no	(reference)	(reference)	(reference)	(reference)
	yes	0.312 (-0.205 – 0.828)	0.008 (-0.217 – 0.234)	0.061 (-0.073 – 0.195)	-0.370 (-0.502 – -0.239)
	Higher education no	(reference)	(reference)	(reference)	(reference)
	yes	0.129 (-0.300 – 0.558)	-0.279 (-0.436 – -0.121)	0.010 (-0.088 – 0.107)	-0.211 (-0.282 – -0.140)
	Physical activity (>20'/week) no	(reference)	(reference)	(reference)	(reference)
	yes	-0.041 (-0.424 – 0.341)	-0.016 (-0.176 – 0.143)	0.036 (-0.060 – 0.133)	0.005 (-0.072 – 0.082)
	Betulaceae nearby no	(reference)	(reference)	(reference)	(reference)

	yes	0.051 (-0.246 – 0.347)	0.051 (-0.066 – 0.167)	0.024 (-0.045 – 0.093)	0.090 (0.031 – 0.148)
	Garden (10ha)	-0.001 (-0.011 – 0.009)	-0.004 (-0.008 – 0.000)	0.000 (-0.002 – 0.003)	0.004 (0.002 – 0.006)
	Grass (10ha)	-0.003 (-0.013 – 0.006)	-0.006 (-0.009 – 0.002)	-0.001 (-0.003 – 0.001)	0.005 (0.003 – 0.007)
	Forest (10ha)	-0.020 (-0.030 – -0.009)	0.000 (-0.004 – 0.003)	0.000 (-0.002 – 0.002)	0.000 (-0.001 – 0.002)
	Basal Area (m²/ha)	0.021 (0.014 – 0.028)	0.003 (0.000 – 0.007)	0.000 (-0.002 – 0.001)	0.005 (0.004 – 0.007)
5 km	Sex female	(reference)	(reference)	(reference)	(reference)
	male	-0.291 (-0.530 – -0.052)	-0.156 (-0.249 – -0.062)	0.048 (-0.006 – 0.103)	-0.054 (-0.099 – -0.008)
	Age (years)	-0.015 (-0.027 – -0.003)	-0.007 (-0.012 – -0.002)	-0.001 (-0.004 – 0.002)	-0.004 (-0.006 – -0.002)
	BMI	-0.018 (-0.046 – 0.011)	-0.024 (-0.036 – -0.013)	0.003 (-0.003 – 0.010)	0.011 (0.006 – 0.017)
	Medication no	(reference)	(reference)	(reference)	(reference)
	yes	-0.037 (-0.478 – 0.404)	-0.031 (-0.215 – 0.153)	-0.007 (-0.121 – 0.107)	-0.041 (-0.132 – 0.051)
	Chronic disease no	(reference)	(reference)	(reference)	(reference)
	yes	-0.101 (-0.354 – 0.152)	0.095 (-0.003 – 0.192)	-0.049 (-0.108 – 0.011)	-0.101 (-0.150 – -0.051)
	Smoking no	(reference)	(reference)	(reference)	(reference)
	yes	0.158 (-0.352 – 0.668)	-0.033 (-0.259 – 0.193)	0.057 (-0.078 – 0.191)	-0.377 (-0.508 – -0.245)
	Higher education no	(reference)	(reference)	(reference)	(reference)

	yes	0.007 (-0.423 – 0.436)	-0.309 (-0.466 – -0.153)	0.024 (-0.072 – 0.120)	-0.241 (-0.311 – -0.170)
	Physical activity (>20'/week) no	(reference)	(reference)	(reference)	(reference)
	yes	-0.072 (-0.471 – 0.326)	-0.033 (-0.197 – 0.131)	0.021 (-0.078 – 0.121)	0.025 (-0.055 – 0.104)
	Betulaceae nearby no	(reference)	(reference)	(reference)	(reference)
	yes	0.136 (-0.148 – 0.421)	0.001 (-0.113 – 0.115)	0.024 (-0.044 – 0.091)	0.153 (0.096 – 0.211)
	Garden (10ha)	0.001 (-0.002 – 0.004)	0.000 (-0.001 – 0.001)	0.000 (-0.001 – 0.000)	0.000 (0.000-0.001)
	Grass (10ha)	-0.002 (-0.002 – 0.002)	-0.001 (-0.002 – 0.000)	0.000 (-0.001 – 0.000)	0.001 (0.001 – 0.002)
	Forest (10ha)	-0.001 (-0.003 – 0.001)	0.001 (0.000 – 0.001)	0.000 (0.000 – 0.000)	0.000 (0.000 – 0.000)
	Basal Area (m^2/ha)	0.000 (-0.002 – 0.002)	-0.001 (-0.001 – 0.000)	0.000 (0.000 – 0.001)	0.001 (0.001 – 0.001)

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Table S3: Beta-coefficients with 95% confidence intervals for adjusted models of objective residential green measures in a 0.5, 1, 2 and 5 km radius around the residence, adjusted for average symptom score (AvgSy). Response variables are the score of the general health questionnaire with 12 questions (GHQ-12) and scores of the perceived stress scale (PSS). Significant associations are highlighted in grey boxes.

	Predictor	**GHQ-12**	**PSS**
		β (95% CI)	**β (95% CI)**
0.5 km	AvgSy	0.005 (0.003 – 0.008)	0.002 (0.001 – 0.003)
	Garden (10ha)	-0.020 (-0.127 – 0.087)	-0.001 (-0.052 – 0.051)
	Grass (10ha)	-0.077 (-0.222 – 0.067)	-0.013 (-0.058 – 0.031)
	Forest (10ha)	-0.261 (-0.424 – -0.099)	-0.001 (-0.018 – 0.015)
	Basal Area (m²/ha)	0.042 (0.003 – 0.081)	-0.069 (-0.112 – -0.026)
1 km	AvgSy	0.006 (0.003 – 0.008)	0.002 (0.001 – 0.003)
	Garden (10ha)	-0.022 (-0.053 – 0.010)	-0.025 (-0.038 – -0.013)
	Grass (10ha)	-0.015 (-0.048 – 0.018)	-0.012 (-0.025 – 0.001)
	Forest (10ha)	-0.050 (-0.086 – -0.014)	-0.001 (-0.012 – 0.010)
	Basal Area (m²/ha)	0.016 (-0.008 – 0.039)	-0.010 (-0.019 – -0.001)
2 km	AvgSy	0.004 (0.001 – 0.007)	0.002 (0.001 – 0.003)
	Garden (10ha)	-0.003 (-0.013 – 0.007)	-0.004 (-0.008 – -0.001)
	Grass (10ha)	-0.004 (-0.015 – 0.005)	-0.006 (-0.010 – -0.002)
	Forest (10ha)	-0.018 (-0.028 – -0.008)	-0.001 (-0.004 – 0.003)
	Basal Area (m²/ha)	0.018 (0.011 – 0.025)	0.003 (0.000 – 0.006)
5 km	AvgSy	0.005 (0.003 – 0.008)	0.002 (0.001 – 0.004)
	Garden (10ha)	0.001 (-0.002 – 0.004)	0.000 (-0.001 – 0.001)
	Grass (10ha)	0.000 (-0.002 – 0.002)	-0.001 (-0.002 – 0.000)
	Forest (10ha)	-0.001 (-0.003 – 0.001)	0.001 (0.000 – 0.001)
	Basal Area (m²/ha)	0.000 (-0.002 – 0.002)	-0.001 (-0.002 – 0.000)

606 **Table S4:** Comparison of model quality using Akaike's Information Criterion (AIC) for the unadjusted and
607 adjusted models developed at different scales (0.5, 1, 2 and 5 km radius). The response variables are the
608 score of the 12-item General Health Questionnaire (GHQ-12), score of the Perceived Stress Scale (PSS),
609 average mood score (AvgMo) and average symptom score (AvgSy).

	Unadjusted				**Adjusted**			
	0.5 km	**1 km**	**2 km**	**5 km**	**0.5 km**	**1 km**	**2 km**	**5 km**
AVG.SY	4521.50	4503.43	4393.19	4430.29	4369.66	4346.99	4281.08	4285.29
PSS	1225.64	1225.79	1227.59	1226.19	1188.95	1179.73	1184.92	1185.39
GHQ12	775.88	781.28	753.78	786.95	769.14	776.48	750.44	785.83
AVG.MO	1021.59	1022.81	1024.67	1021.96	1030.99	1031.05	1032.56	1031.60

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