Landscape and Urban Planning 211 (2021) 104084

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Species richness is positively related to mental health – A study for Germany

Joel Methorst [a,*], Aletta Bonn [b], Melissa Marselle [b], Katrin Böhning-Gaese [c], Katrin Rehdanz [d]

[a] *German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Senckenberg Biodiversity and Climate Research Centre (SBiK-F) & Goethe University Frankfurt am Main, Frankfurt am Main, Germany*
[b] *Helmholtz-Centre for Environmental Research – UFZ, Friedrich Schiller University Jena & German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany*
[c] *Senckenberg Biodiversity and Climate Research Centre (SBiK-F), Goethe University Frankfurt am Main & German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Frankfurt am Main, Germany*
[d] *Department of Economics, Kiel University, Kiel, Germany*

HIGHLIGHTS

- National epidemiological study on relationship between biodiversity and human health.
- Plant and bird species richness are positively related to mental health.
- No relationship between plant nor bird species and physical health.
- Access to local green space improves both mental and physical health.
- Species diversity could be a salutogenic (health promoting) nature characteristic.

ARTICLE INFO

Keywords:
Nature contributions to people
Ecosystem services
Biodiversity
Birds
Plants
Human health

ABSTRACT

Nature benefits human health. To date, however, little is known whether biodiversity relates to human health. While some local and city level studies show that species diversity, as a measure of biodiversity, can have positive effects, there is a lack of studies about the relationship between different species diversity measures and human health, especially at larger spatial scales. Here, we conduct cross-sectional analyses of the association between species diversity and human health across Germany, while controlling for socio-economic factors and other nature characteristics. As indicators for human health, we use the mental (MCS) and physical health (PCS) component scales of the German Socio-Economic Panel (SOEP, Short Form Health Questionnaire – SF12). For species diversity, we use species richness and abundance estimates of two species groups: plants and birds. We phrase the following hypotheses: plant and bird species are positively associated with mental and physical health (H1 & H3); bird abundance is positively related to mental health (H2). Our results demonstrate a significant positive relationship between plant and bird species richness and mental health across all model variations controlling for a multitude of other factors. These results highlight the importance for species diversity for people's mental health and well-being. Therefore, policy makers, landscape planners and greenspace managers on the local and national level should consider supporting biodiverse environments to promote mental health and wellbeing. For this purpose, we propose to use species diversity measures as indicators for salutogenic (health promoting) characteristics of nature, landscape and urban green space.

1. Introduction

A large number of studies has examined the beneficial effects of nature for human health (Gascon et al., 2015; Kondo et al., 2018; Sandifer et al., 2015). Nature positively influences multiple aspects of human health, ranging from mental to physical health. For example, it

* Corresponding author.
E-mail addresses: joel.methorst@senckenberg.de (J. Methorst), aletta.bonn@idiv.de (A. Bonn), melissa.marselle@idiv.de (M. Marselle), katrin.boehning-gaese@senckenberg.de (K. Böhning-Gaese), rehdanz@economics.uni-kiel.de (K. Rehdanz).

https://doi.org/10.1016/j.landurbplan.2021.104084
Received 3 July 2020; Received in revised form 2 March 2021; Accepted 4 March 2021
Available online 25 March 2021

has been shown that living in close proximity to urban parks or water bodies is related to better perceived physical health and mental health (e.g. Gascon et al., 2015; Triguero-Mas et al., 2015). The majority of these studies, however, focuses on the quantity (size and proximity) of greenspace without consideration of its quality (e.g. van den Berg et al., 2015). Consequently, little is known about how the different qualities of nature, such as biodiversity, contribute to physical and mental health (Aerts et al., 2018; Marselle et al., 2019).

A few studies have found positive associations between biodiversity and human health (e.g. Aerts et al., 2018; Marselle et al., 2019) and some specifically focus on species diversity as a measure for biodiversity. For instance, higher bird and plant species richness in urban parks was related to heightened psychological well-being (Fuller et al., 2007) and afternoon bird abundance was associated with better mental health in urbanized areas (Cox et al., 2017b). Two mechanisms have been proposed. The Attention Restoration Theory refers to the possibility that an environment can influence a person's ability to concentrate or direct attention (Kaplan, 1995). The Stress Reduction Theory considers the physiological impact of viewing environments which then facilitates the reduction of psychological stress (Ulrich, 1991).

Beyond mental health and well-being, people visiting urban parks with high species diversity (including plants and insects) reported higher overall health, a composite measure covering both mental and physical health aspects, and perceived restoration (Carrus et al., 2015). Similarly, a higher prevalence of 'good' overall human health was observed among people living in areas with higher bird species richness (Wheeler et al., 2015). These studies used objective measures for species richness based on ecological monitoring schemes. However, efforts have also been made to explore the effect of perceived species richness, a subjective measure where people are asked to estimate species richness in a specific area (e.g. Dallimer et al., 2012; Lindemann-Matthies et al., 2010). In particular, Dallimer et al. (2012) found, that perceived – but not objective (ecological) – bird, plant and butterfly species richness was positively related to psychological well-being in urban parks.

Most of the studies examining the effect of species diversity on human health were conducted at a smaller scale (e.g. urban parks, neighbourhoods, cities), apart from one national-scale study so far (i.e. Wheeler et al., 2015). To better understand how general the relationship between species diversity and human health is, epidemiological studies on a larger spatial scale are needed to identify relevant associations and provide evidence-based information for local and national policy design, landscape planning as well as urban greenspace management.

In this study, we go beyond previous efforts and study the relationship between species diversity and human health at the regional scale, using Germany as a case study. We combine and analyse macroecological data from across Germany and socio-economic data from the German Socio-Economic Panel (SOEP, Goebel et al., 2019). We use both species richness and abundance as measures for species diversity and focus on two taxonomic groups: plants (only species richness) and birds. Species richness captures the number of different species of plants and animals, while abundance accounts for the number of individuals, here for birds, as no appropriate abundance data were available for plants at this scale. Both variables represent objective measures of species diversity and are based on ecological data. Human health is separately investigated as mental and physical health. We use the mental health component scale (MCS) and physical health component scale (PCS), two important indicators for 'Health Related Quality of Life' (e.g. Busija et al., 2011; Coons et al., 2000). MCS and PCS are composite variables derived from a set of questions which each address specific aspects of human health (e.g. mental and emotional state for the MCS, physical pain for the PCS). We also make use of the large amount of socio-economic and demographic variables provided by the SOEP, including household income, education status or employment status.

We address three hypotheses:

1. Plant and bird species richness have a positive influence on mental health (H1). Local scale studies have shown that both plant and bird species richness are positively related to mental health and well-being (Dallimer et al., 2012; Fuller et al., 2007).
2. Bird abundance is positively associated with mental health (H2). Studies have shown that bird afternoon abundance in urban parks influences mental health (Cox et al., 2017b).
3. Bird and plant diversity variables are positively associated with physical health (H3). Species richness (e.g. birds and plants) has shown a positive influence on general human health measures (Carrus et al., 2015; Wheeler et al., 2015). Furthermore, species richness has shown potential benefits in regard to vector-borne diseases, gut microbial communities, allergies or asthma (Aerts et al., 2018; Lovell et al., 2014; Sandifer et al., 2015).

2. Data and method

2.1. Socio-economic and demographic variables

Socio-economic data were obtained from the German Socio-Economic Panel (SOEP), a longitudinal panel survey of private households across Germany which now includes nearly 15,000 households and about 30,000 persons (Goebel et al., 2019). The SOEP data provides socio-economic, demographic and health information on the individual and household level. It also provides the geographical location of each household at the county level (German: "Landkreise", county codes from 31.12.2013, n = 402). Access to the SOEP data were granted by the German Institute for Economic Research (German: "Deutsches Institut für Wirtschaftsforschung") after specific preconditions were met and the data protection regulations signed.

The SOEP panel was started in 1984 and new surveys are added annually. Data are usually collected with face-to-face interviews. Our analysis focuses on SOEP data from the year 2008 (SOEP-Data Version 33.1), covering a sample of more than 13,000 individuals located in 394 counties (a slight reduction in the number of counties due to missing data and data removal). These counties differ in their size, ranging from 37.2 to 5470.3 square kilometres (see Table 1). We chose the survey year 2008 as it lies within the collection period of the bird atlas data for Germany (for further details see section 2.3.1) and also includes information on respondents' mental and physical health. In addition, data only available in the 2009 SOEP survey on walking distance to parks (green space availability) and the 'Big Five'-personality variables (openness, conscientiousness, extraversion, agreeableness, and neuroticism) is included. We combine information from the two survey years using respondent's unique identifiers. For consistency, our final sample includes only those individuals that did not move between 2008 and 2009, ensuring that walking distance did not change.

Our selection of socio-economic and demographic variables is based on previous studies explaining differences in MCS and PCS (e.g. Nesterko et al., 2013) as well as studies examining the influence of green space and neighbourhood environment on PCS and MCS (Petersen et al., 2018; Sugiyama et al., 2008). Socio-economic and demographic variables include: age, gender, household income, family status, labor force status, educational attainment, migratory background, and urban residency. Health-related information includes: frequency of doctor visits, body mass index, frequency of sport exercise, disability, and number of friends. The 'Big Five' personality variables (Costa and McCrae, 1985) were also included in order to account for personality differences between survey respondents. All socio-economic, demographic, health and personality variables were obtained from the SOEP.

2.2. Physical and mental health

Every second year the SOEP survey incorporates physical and mental health questions, which includes the German version of the Short Form 12 (SF-12, version 2) health (Andersen et al., 2007; Ware et al., 1995).

Table 1
Summary statistics for selected variables (n = 13,328). Shown are only the continuous variables. Summary statistics of all variable are shown in the Supplementary Material (Appendix A, Table A.4 & A.5).

	Min.	Mean	Median	Max.
Personal characteristics				
MCS	5.32	50.83	52.52	76.54
PCS	12.27	49.29	51.44	73.61
Income (EUR)	554	2817	2500	9200
Age (years)	18	50.18	50	99
Doctor visits (no./year)	0	9.79	8	396
Hospital visits (no. in year 2007)	0	1.37	0	240
Body mass index	13.36	26.13	25.59	59.03
No. of friends (no./person)	0	4.21	3	90
Macro-economic characteristics (at the county level)				
GDP per capita (1000 EUR)	13.20	29.85	27.20	91.80
Unemployment rate (%)	1.60	8.34	7.80	19.40
Population density (no. people/ km^2)	39.10	828.40	299.80	4274.50
Species diversity (county level)				
Plant species richness (no. of species)	670.17	1134.00	1130.80	1785.86
Bird abundance (no. breeding pairs)	10601.36	38269	38710	69514.08
Bird species richness (no. of species)	59.16	104.80	105.46	145.65
Nature and climate characteristics (at the county level)				
Blue space (%)	0	1.10	0.37	32.45
Green space (%)	2.49	42.15	38.62	97.76
Landscape heterogeneity (Shannon index, H')	0.77	1.36	1.36	1.91
Topographic heterogeneity (metre)	9.94	178.30	158.09	1307.97
Protected areas (%)	0.00	20.45	8.12	99.99
Temperature (°C)	5.69	9.24	9.31	10.95
Precipitation (cm/year)	51.52	80.77	79.97	190.70
County area size (km^2)	37.22	973.90	839.90	5470.34

The SF-12 contained 12 questions of positively and negatively worded items (on a 5 or 6 point ordinal scale) addressing eight domains of mental and physical health-related topics: general health; vitality; mental health; emotional roles; social functioning; physical functioning; role physical, and; bodily pain (see Appendix A, Table A.1 for more information on the wording). The answers to each of the 12 items are used to calculate MCS and PCS component scale scores which are provided with the SOEP data. The MCS and PCS scores range from 0 to 100, with higher scores indicating better health (Fig. 1, Appendix A, Table A.4). MCS and PCS are well-established indicators for human Health-Related Quality of Life (HRQoL) (Ware and Sherbourne, 1992). HRQoL refers to an individuals' perceptions of their physical, psychological, and social functioning (e.g. Testa and Simonson, 1996). Both the MSC and PCS have been successfully used in previous green space and health studies (Petersen et al., 2018; Sugiyama et al., 2008).

2.3. Access to parks and gardens

To account for people's potential access to nature, reported information on walking distance to public parks and green space (German: 'Entfernung zu Fuss zu Grünanlagen') was included. Walking distance is a subjective measure which accounts for potential physical limitations and was assessed in terms of minutes by participants (Siegel et al., 2010). In addition, information on the availability of a private garden was also provided and converted to a dummy variable (1 = garden, 0 = no garden). Both variables were obtained from the 2009 SOEP questionnaire.

2.4. Macro-economic data

The following macro-economic factors, which might influence human health, were also taken into account: population density, GDP per capita, unemployment rate, and county area size (km^2). All macro-economic variables are measured at the county level. Information on GDP per capita and unemployment rate were provided by SOEP, data on population density and county size were available from the Federal Statistical Office of Germany (German: Statistisches Bundesamt). In addition, we created a dummy variable (East-Germany dummy) for federal states which were formerly part of the German Democratic

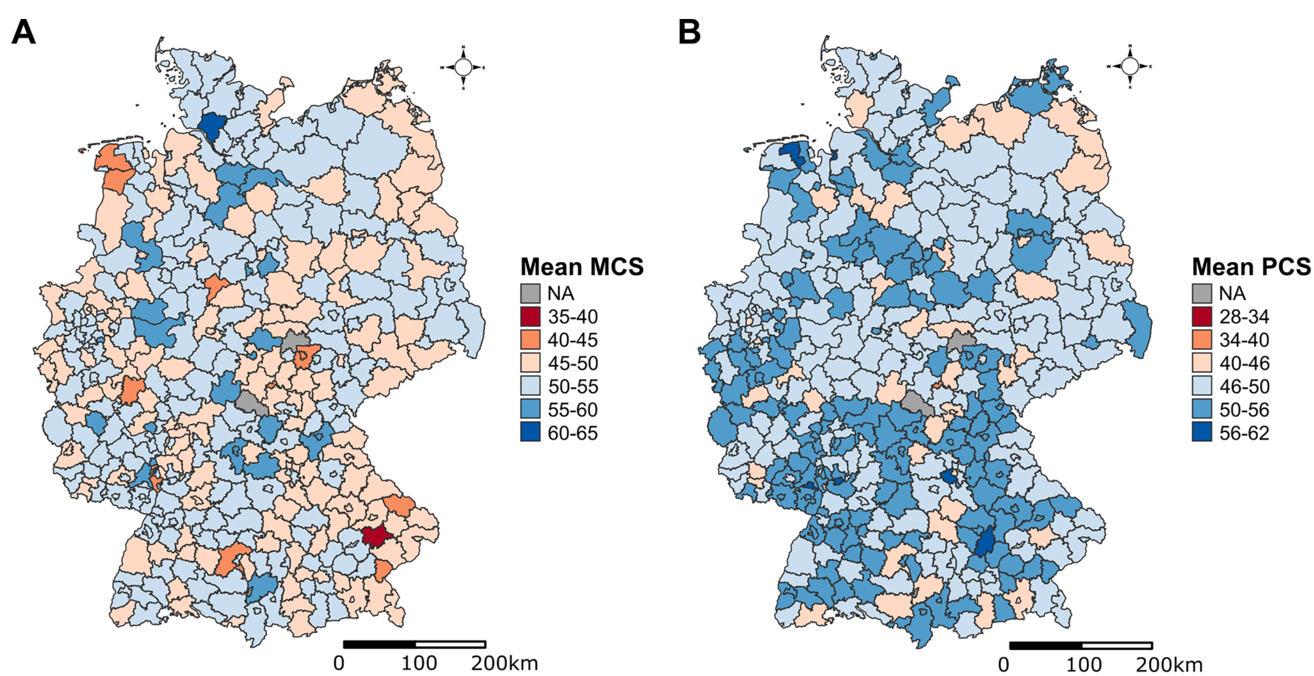

Fig. 1. Mental health (A, mean MCS) and physical health (B, mean PCS) scores on county level across Germany from 2008. Higher mean MCS and PCS scores indicate better mental or physical health. Shown are values for 394 counties based on SOEP (Socio-Economic Panel Germany) survey data (n = 13,328). Data for some counties was not available due to missing data. The number of observations per county ranges from 1 to 480 (median = 25). MCS = Mental Health Component Scale. PCS = Physical Health Component Scale. For more information see Methods section.

Republic to account for potential socio-economic differences between people living in East or West-Germany (e.g. Bramesfeld et al., 2010; Easterlin and Plagnol, 2008).

2.5. Macroecological data

2.5.1. Species diversity

To study the role of species diversity for human health across Germany we collated macroecological data on species richness (number of different species) and abundance for two taxonomic groups: plant and bird species. These two species groups were the only taxa for whom nationwide data was available. A plant species richness map (Fig. 2) was calculated based on plant distribution data for Germany. The data was obtained from the German atlas for flowering plants and ferns 'Verbreitungsatlas der Farn- und Blütenpflanzen Deutschlands' (Deutschland Netzwerk Phytodiversität & Bundesamt für Naturschutz, 2013), which provides occurrence data on a 10x10km grid ('Topographische Karte' - TK 25 grid). The atlas was created by merging multiple plant databases from German federal states and validating the results with expert knowledge.

Bird species richness and abundance maps (Fig. 2) were created based on data provided by the 'Atlas of German Breeding Birds' (Gedeon et al., 2014). The monitoring for the bird atlas was conducted by volunteers between the years 2005–2009 and similar to the plant atlas, the final data on bird species distribution and population size (number of breeding pairs) is provided for the same 10x10km grid as used for the plant atlas. The population sizes of birds were provided as grouped or discretized continuous variables (e.g. 1–100, 101–200, 201–300 breeding pairs) and we therefore calculated the mean for these groups in order to obtain continuous abundance estimates for each species within a 10x10km grid cell. If an abundance estimate for a specific species and a specific grid cell was missing, the abundance was calculated based on the mean of neighbouring grid cells (max. = 8 grid cells). Total bird abundance was the sum of all abundance data for one grid cell.

2.5.1.1. Nature characteristics. It has been shown that green space or protected area cover influence human health in epidemiological studies (e.g. van den Berg et al., 2015; Wheeler et al., 2015). Similarly, blue space is also known to positively affect human health and well-being (de Vries et al., 2016; e.g. Gascon et al., 2015). Furthermore, different nature characteristics and land cover types may also influence species richness patterns (e.g. Atauri and De Lucio, 2001; Deutschewitz et al., 2003). We therefore include different nature characteristics in our analyses to identify the independent effect of species diversity on mental and physical health (MCS and PCS). The following variables were included: blue space cover, green space cover, protected area cover, landscape heterogeneity and topographic heterogeneity.

The percentages of both blue and green space cover in each German county were calculated based on land cover data from the CORINE Land Cover database from 2006. The CORINE database publishes aggregated sets of land-cover classifications as raster data with a 100 m resolution where the number of land cover types are reduced from 44 to 15 or 5 land cover types. These different categories were organised into blue and green space categories. The blue space category was comprised of mainly terrestrial water bodies. The green space category was comprised of all types of vegetated areas. The percentage of area covered within each county was calculated using the raster cells categorized as either blue or green space (see Appendix A, Table A.3). Due to the spatial resolution of the CORINE data, the variables for blue and green space most likely only include larger water bodies or vegetated areas (approx. 25 ha).

We used the 15 land cover types of the CORINE land cover data from 2006 to calculate landscape heterogeneity (the variation of different landcover types) on the county level. We determined the number of CORINE raster cells for each land cover type within each 10x10km grid cell. Shannon-Index (*H'*) was calculated based on the frequency of the different land cover types within each 10x10km grid cell; this was done using the R package 'vegan' (Oksanen et al., 2017). As additional measure of landscape heterogeneity, we used topographic heterogeneity. Topographic heterogeneity has been identified as indicator for scenic views and landscapes with high recreational and aesthetic value (de Almeida Rodrigues et al., 2018; Sherrouse et al., 2011) and was determined using the elevational range (difference between min and max. elevation) within each 10x10km grid cell. The necessary data for these calculations were quarried from a 200 m Digital Terrain Model (DGM 200) from the Federal Agency for Cartography and Geodesy.

For protected areas in Germany, we collected spatial data from a 2008 Digital Landscape Model (DLM 250) published by the Federal Agency for Cartography and Geodesy (German: Bundesamt für Kartographie und Geodäsie, https://gdz.bkg.bund.de). The DLM 250 provides data on the location and size of national parks, wildlife parks (German: 'Naturparks') and biosphere reserves (German: 'Biosphärenreservat'). In the DLM 250, national parks are classified according to the IUCN category II, wildlife parks were established under section 22, paragraph 4 of Germany's Federal Nature Conservation Act (BNatSchG) and biosphere reserves are assigned by the UNESCO Worlds Network of Biosphere Reserves (Bundesamt für Naturschutz, 2008). We summarized the total area covered by all three protected area types within a county and then calculated the percentages.

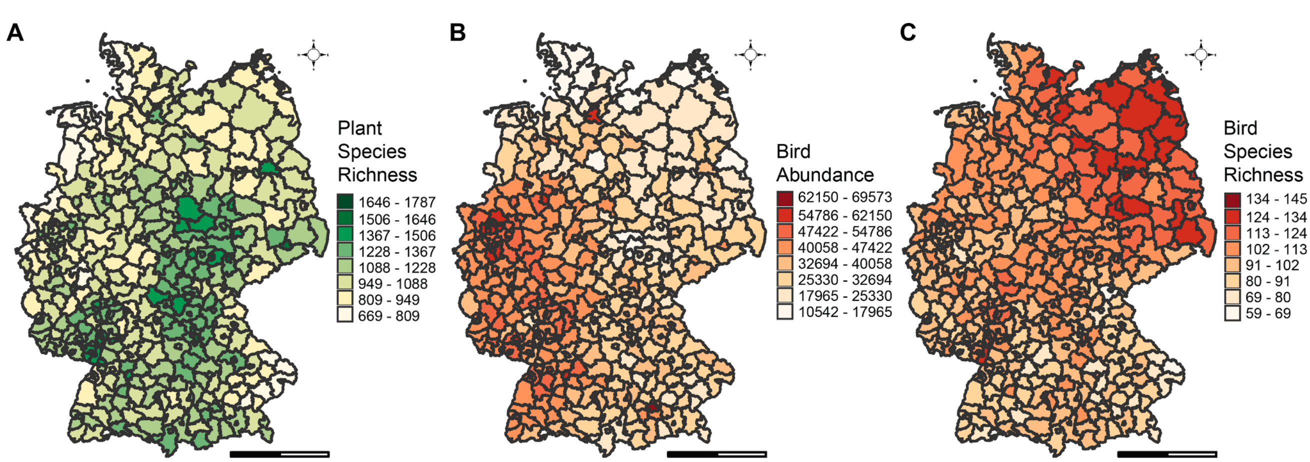

Fig. 2. Species diversity measures on county level across Germany. Shown are area weighted mean plant species richness (A), bird abundance (B) and bird species richness (C). Species richness was measured as the number of species and abundances are based on numbers of bird breeding pairs.

2.5.1.2. Climate characteristics. As atmospheric temperature or temperature fluctuations can pose a risk to human health and well-being (e.g. Basu, 2009; Yu et al., 2012), these climate variables were included in our analyses. We downloaded a multi-annual raster dataset for mean temperature and mean precipitation, for the years 1981–2010. From this raster data, we extracted values (Version v1.0, 1 km resolution) by using the same 10x10km grid as before (TK25, see section 2.3) and then calculated mean temperature and precipitation estimates for each grid cell. These data came from the German weather service's Climate Data Center website (https://opendata.dwd.de/climate_environment/CDC/).

2.6. Merging data

In a final step before the data analysis, we merged the SOEP data with our macroecological data (species diversity, nature characteristics and climate). In order to align the SOEP data with the species diversity and nature indicators we use macroecological data aggregated at the by county level. This spatial level has also been used for aggregated ecosystem services data to assist in decision making and spatial planning in Germany (Rabe et al., 2016). To do this, the 10x10km grids were superimposed over each German county (n = 402, mean area size = 973.90 km^2) to estimate area weighted means for each county. Within each German county we determined the intersecting polygons from the 10x10km grid and then weighed the values of each grid polygon by the percent of area it covers within the county. Area weighted means for the following macroecological variables were calculated: plant species richness, bird species richness, bird abundance, landscape heterogeneity, topographic heterogeneity, temperature and precipitation. Excluded from this data processing step were the variables for percent area covered by blue space, green space and protected areas because they already represented information on county level. The final data set contained socio-economic and health data on the individual level and information on species diversity (Fig. 2), nature characteristics, climate and macro-economic factors on the county level. Our final data set contained information for 13,328 individuals living within 394 counties after removing all missing values (see Table 1, more summary statistics can also be found in Appendix A, Tables A.4 and A.5).

Table 2
OLS models with one species diversity variable. Each model contains the same set of control variables: socio-economic variables[1], macro-economic variables[2], Big 5 personality variables as well as an East-Germany dummy and federal state dummies. Shown are coefficients and standardized coefficients (β), standard errors in parenthesis and t-values. P-values are indicated by asterisk symbols: * <0.05, **<0.01, ***<0.001. Roman numbers I-VI represent different OLS models.

	Mental health			Physical health		
	I	II	III	IV	V	VI
Species diversity						
Log plant species richness	3.27 / 0.06 (0.87) 3.74***	–	–	0.50 / 0.01 (0.67) 0.75	–	–
Log bird species richness	–	3.57 / 0.05 (1.35) 2.65**	–	–	−1.38 / -0.02 (1.05) −1.31	–
Log bird abundance	–	–	−0.6 / -0.02 (0.59) −1.02	–	–	−0.56 / -0.02 (0.51) −1.10
Access garden and parks						
Garden	−0.11 / -0.01 (0.20) −0.54	−0.13 / -0.01 (0.20) −0.66	−0.13 / -0.01 (0.20) −0.63	0.05 / 0.00 (0.17) 0.31	0.05 / 0.00 (0.17) 0.29	0.05 / 0.00 (0.17) 0.31
Park in 10–20 walking minutes [3]	−0.87 / -0.04 (0.22) −3.98***	−0.89 / -0.04 (0.22) −4.03***	−0.89 / 0.04 (0.22) −4.00***	−0.60 / -0.02 (0.16) −3.85***	−0.60 / -0.03 (0.16) −3.85***	−0.60 / -0.03 (0.16) −3.86***
Park > 20 walking minutes [3]	−1.15 / -0.03 (0.37) −3.14**	−1.19 / -0.03 (0.37) −3.28**	−1.19 / -0.03 (0.37) −3.25**	−1.08 / -0.03 (0.35) −3.09**	−1.08 / -0.03 (0.35) −3.10**	−1.09 / -0.03 (0.35) −3.10**
No park [3]	−0.32 / -0.01 (0.29) −1.11	−0.37 /-0.01 (0.29) −1.28	−0.39 / -0.01 (0.29) −1.34	−1.01 / -0.03 (0.26) −3.85***	−1.02 / -0.03 (0.26) −3.91***	−1.03 / -0.03 (0.26) −3.94***
Nature & Climate						
Blue space	0.03 / 0.01 (0.05) 0.60	0.03 / 0.01 (0.05) 0.54	0.04 /0.01 (0.05) 0.85	−0.05 / -0.01 (0.04) −1.55	−0.05 / -0.01 (0.04) −1.29	−0.05 / -0.01 (0.04) −1.49
Landscape heterogeneity	−0.56 / -0.01 (0.74) −0.76	−0.70 / -0.02 (0.76) −0.93	−0.45 / -0.01 (0.78) −0.57	0.41 / 0.01 (0.57) 0.71	0.44 / 0.01 (0.57) 0.77	0.55 / 0.01 (0.58) 0.94
Protected area cover	0.01 / 0.02 (0.01) 1.90	0.01 / 0.02 (0.01) 2.16*	0.01 / 0.03 (0.01) 1.93	0.01 / 0.01 (0.004) 1.34	0.004 / 0.01 (0.004) 1.06	−0.01 / 0.02 (0.003) 1.64
Temperature	0.13 / 0.01 (0.18) 0.70	−0.01 / 0.00 (0.21) −0.05	0.15 / 0.01 (0.19) 0.78	−0.02 / -0.00 (0.13) −0.12	0.06 / 0.01 (0.15) 0.42	−0.03 / -0.00 (1.33) −0.23
Adj. R-squared	0.20	0.20	0.20	0.46	0.46	0.46
AIC	94990.49	95001.93	95012.22	90928.91	90927.25	90927.64
Observations	13,328	13,328	13,328	13,328	13,328	13,328
Clusters	394	394	394	394	394	394

[1] Household income, age, sex, family status, employment status, education, migrant, urban resident, body mass index, doctor visits, hospital visits, strong disability, number of friends, sport exercise.
[2] Unemployment-rate, population density, county area size (km^2).
[3] Reference group = walking distance to park < 10 min.

2.7. Empirical analysis

We used linear regression models (ordinary least squares, OLS) to study the relationship between species diversity and MCS or PCS while accounting for various socio-economic and demographic characteristics as well as macro-economic factors. To answer hypotheses 1–3, we included different measures of species diversity as predictor variables: plant species richness, bird species richness or bird abundance. To avoid multicollinearity issues (Appendix A, Table A.6) each OLS regression contained either one single species diversity variable (Table 2, models I-VI) or a maximum of two species diversity variables (Table 3, models VII-XII). In addition, we include access to parks and gardens as well as nature and climate characteristics, such as blue space cover, green space cover landscape heterogeneity, topographic heterogeneity and protected area cover. All species diversity variables were introduced into the models with their natural logarithm.

To identify and reduce multicollinearity, we calculated Generalized Variance Inflation Factors (GVIF, Fox and Monette, 1992) and correlations (Appendix A, Table A.6). The following control variables with GVIF scores > 10 and correlation coefficients > 0.6 (Dormann et al., 2013) were excluded from our final models: green space, topographic heterogeneity and precipitation (Appendix A, Table A.6). An exception to this rule is the correlation between the East-Germany dummy and unemployment rate. We included these two variables in the same models because both variables can explain the variation of MCS and PCS across Germany. To make sure this decision does not affect our results, we also tested models where we replaced unemployment rate by GDP per capita. These tests produced the same overall results which, however, are not shown here.

Our specification procedure followed a stepwise process (for a definition of the variables see Appendix A, Table A.2). In the first step (aka. the basic model), we added the different combinations of species diversity variables and a set of control variables. In the basic model, the control variables included walking distance to parks and a garden dummy, socio-economic and health variables (log-transformed household income, age, gender, family status, labor force status, education, migratory background, and urban residency, number of doctor visits, number of hospital visits, number of friends, body mass index, frequency of sport exercise, disability status, and personality), macro-economic variables (unemployment rate, population density and area size of each county) as well as the East-Germany and federal state dummies. In the second step we added county-level nature and climate

Table 3

OLS models with two species diversity variables. Each model contains the same set of control variables: socio-economic variables[1,] macro-economic variables[2], Big 5 personality variables as well as an East-Germany dummy and federal state dummies. Shown are coefficients and standardized coefficients (β), standard errors in parenthesis and t-values. P-values are indicated by asterisk symbols: * <0.05, **<0.01, ***<0.001. Roman numbers VII-XII represent different OLS models.

	MCS			PCS		
	VII	VIII	IX	X	XI	XII
Species diversity						
Log plant species richness	2.78 / 0.05 (0.99) 2.82**	3.30 / 0.06 (0.86) 3.83***	–	0.99 / 0.01 (0.73) 1.38	0.53 /0.01 (0.67) 0.79	–
Log bird species richness	1.94 / 0.03 (1.49) 1.30	–	3.55 / 0.05 (1.36) 2.62**	−1.96 / -0.02 (1.14) −1.72	–	−1.40 /-0.02 (1.06) −1.32
Log bird abundance	–	−0.67 / -0.02 (0.58) −1.16	−0.57 / -0.02 (0.60) −0.96	–	−0.57 / -0.02 (0.51) −1.11	−0.57 / -0.02 (0.50) −1.14
Access garden and parks						
Garden	−0.11 / -0.01 (0.20) −0.56	−0.11 / 0.01 (0.20) −0.516	−0.13 / -0.01 (0.20) −0.64	0.06 / 0.00 (0.17) 0.33	0.06 / 0.00 (0.17) 0.33	0.05 / 0.00 (0.17) 0.31
Park in 10–20 walking minutes [3]	−0.88 / -0.04 (0.22) −4.00***	−0.87 / -0.04 (0.22) −3.98***	−0.89 / -0.04 (0.22) −4.03***	−0.60 / -0.02 (0.16) −3.83***	−0.60 / -0.02 (0.17) −3.85***	−0.60 / -0.03 (0.16) −3.85***
Park > 20 walking minutes [3]	−1.16 / −0.3 (0.37) −3.16**	−1.15 / -0.03 (0.37) −3.13**	−1.19 / -0.03 (0.37) −3.27**	−1.07 / -0.03 (0.35) −3.07**	−1.08 / -0.03 (0.35) −3.09**	−1.08 / -0.03 (0.35) −3.10**
No park [3]	−0.32 / -0.01 (0.29) −1.13	−0.33 / -0.01 (0.28) −1.15	−0.38 / -0.01 (0.29) −1.32	−1.00 / -0.03 (0.26) −3.83***	−1.02 / -0.03 (0.26) −3.89***	−1.03 / -0.03 (0.26) −3.96***
Nature & Climate						
Blue space	0.02 / 0.01 (0.05) 0.47	0.03 / 0.01 (0.05) 0.60	0.03 / 0.01 (0.05) 0.55	−0.05 / -0.01 (0.04) −1.32	−0.05 / -0.01 (0.04) −1.55	−0.05 / -0.01 (0.04) −1.28
Protected area cover	0.01 / 0.03 (0.01) 2.12*	0.01 / 0.03 (0.01) 2.15*	0.01 / 0.03 (0.01) 2.34*	0.004 / 0.01 (0.004) 1.01	0.01 / 0.01 (0.004) 1.69	0.59 / 0.01 (0.58) 1.02
Landscape heterogeneity	−0.62 / -0.01 (0.74) −0.84	−0.38 / -0.01 (0.75) −0.51	−0.55 / -0.01 (0.77) −0.71	0.47 / 0.01 (0.57) 0.82	0.56 / 0.01 (0.58) 0.96	−0.05 / 0.01 (0.04) −1.28
Temperature	0.04 / 0.00 (0.20) 0.17	0.10 / 0.01 (0.19) 0.55	−0.03 / -0.00 (0.21) −0.15	0.08 / 0.01 (0.15) 0.53	−0.04 / -0.00 (0.13) −0.29	0.01 / 0.00 (0.004) 1.39
Adj. R-squared	0.20	0.20	0.20	0.46	0.46	0.46
AIC	94989.47	94990.32	95002.35	90926.72	90928.81	90927.15
Observations	13,328	13,328	13,328	13,328	13,328	13,328
Clusters	394	394	394	394	394	394

[1] Household income, age, sex, family status, employment status, education, migrant, urban resident, body mass index, doctor visits, hospital visits, strong disability, number of friends, sport exercise.

[2] Unemployment-rate, population density, county area size (km^2).

[3] Reference group = walking distance to park <10 min.

characteristics (blue space cover, protected area cover, landscape heterogeneity and mean temperature). Here (Tables 1 and 2, Appendix A, Tables A.7 and A.8) we show OLS models with all variables, including nature and climatic factors. To account for heteroscedasticity in the OLS models and the hierarchical structure (individuals living in countries) of the data set, we used heteroscedasticity-robust clustered standard errors. This procedure relaxes the assumption that observations are independent and adjusts standard errors for intra-regional correlation (Moulton, 1990). Data preparation and all analyses were conducted with R Studio (Version 1.0.143).

3. Results

Figs. 1 and 2 display the variation of human health (Fig. 1) and species diversity (Fig. 2) across Germany. Mean values for MCS and PCS per county range between 37 and 61 and 28–59 for mental and physical health, respectively (Fig. 1). The county with the highest number of plant species reports approx. 1786 different species (Min. = 670, based on area weighted mean values). Bird richness in a county ranges from 59 to 146 species while total bird abundance can range between 1000 and 6000 breeding pairs (Fig. 2 and Table 1). Values for the species diversity measures also show specific spatial patterns (Fig. 2). For example, high plant species richness can be observed in regions of central and south-western Germany while high values of bird species richness are found in Eastern Germany. In contrast, bird abundance estimates are highest in Western Germany (Fig. 2).

3.1. Species diversity

3.1.1. Species diversity and human health

Our models with mental health (MCS) as dependent variable show a significant positive correlation between plant and bird species richness and mental health (Fig. 3, Tables 2 and 3), supporting hypothesis 1 (H1). Plant species richness was positively associated with mental health in model I ($t = 3.74$, $p < 0.001$), model VII ($t = 2.82$, $p < 0.01$), and model VIII ($t = 3.83$, $p < 0.001$). Model II ($t = 2.65$, $p < 0.01$) and model IV ($t = 2.62$, $p < 0.01$) show that bird species richness is positively related to mental health. For bird abundance, there is no significant relationship with mental health (Tables 2 and 3); hypothesis 2 is not supported (H2). Looking at the combined effect of two species diversity variables together in the same model, plant species richness is always significant - independent of bird species richness or abundance (Table 3, Models VII & VIII). In addition, bird species richness is only significant when omitting plant species richness (compare Models II, VIII and IV).

Considering the adjusted R-square values, models with two species diversity measures (Table 3) did not differ in regard to their model fit compared to the models with one single species diversity measure (Table 2). By using the results from these "single variable" models (Table 2, Models I & II) we calculated the potential improvement in mental health (increase of MCS scores) based on percentwise increases in plant or bird species richness. Based on the calculations, a 10% increase in plant species richness is related with an increase in MCS by a score of 0.31 (coef. = 3.27; 95% CI: 1.56, 4.99). Calculations for bird species richness reveal an increase in mean MCS by score of 0.34 (coef. = 3.57; 95% CI: 0.93, 6.21).

In regard to physical health (PCS), we did not find any significant relationship between our species diversity measures and PCS (Fig. 3, Tables 2 and 3). Based on these findings we reject our third hypothesis (H3) that species diversity is positively related to human physical health.

3.2. Access to parks and gardens

Shorter walking distances to public parks improve mental and physical health, while longer walking distances negatively influence both health variables (Tables 2 and 3, Fig. 3). For example, using the mean of the estimated coefficients (Table 2, Models I-III & IV-VI), an increase in walking distance by 10 min decreases mental and physical health (MCS and PCS) scores by approximately 0.86 and 0.60, respectively (mean 95% CI: MCS = -1.31, −0.45; PCS = -0.91, −0.3). Walking distances beyond 20 min decrease mental health values on average by 1.18 (mean 95% CI: −1.90, −0.46) and physical health by about 1.08 (mean 95% CI: −1.77, −0.4) compared to walking distances of less than 10 min. We find a significant negative effect of not having any access to public parks on physical health, which was not found in any mental health model. When parks are not reachable on foot, physical health

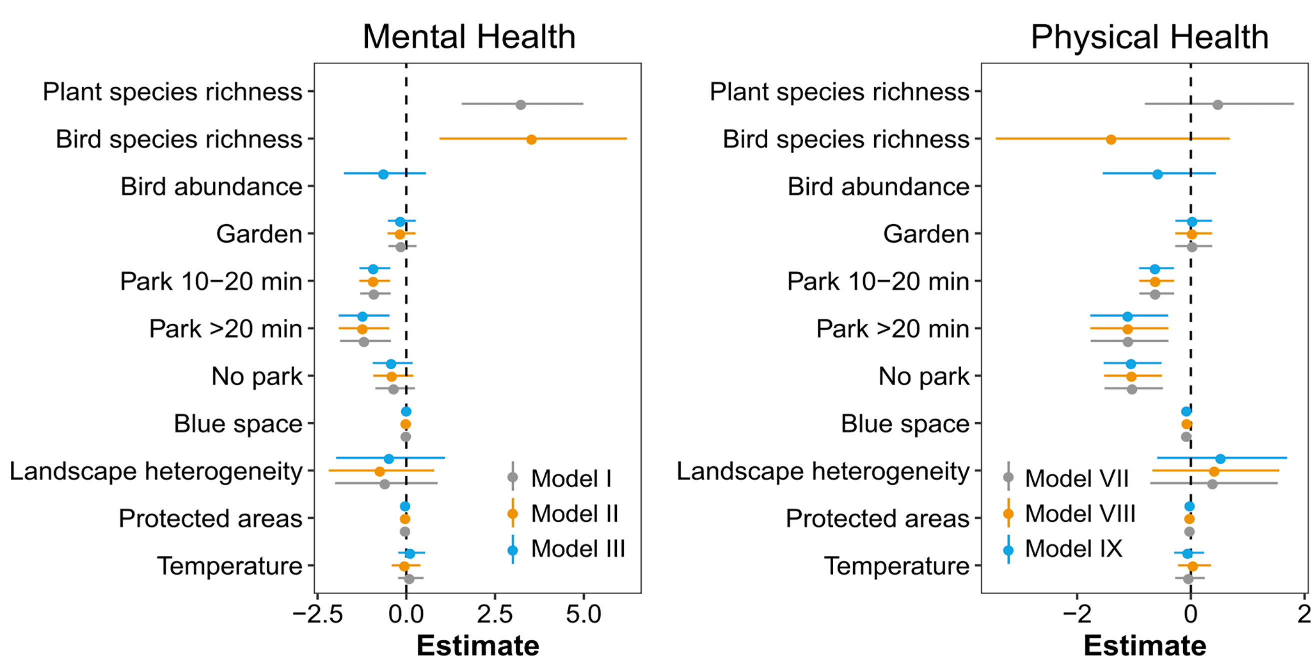

Fig. 3. Selected model coefficients with 95% confidence intervals for species diversity, access to a garden & parks (measured in minutes walking distance), nature characteristics and climate. Shown are all models from Table 2 with mental health and physical health as dependent variables (model names in the legend correspond to the OLS models form Table 2 and 3). Detailed results for all models and independent variables are presented in the Appendix A, Tables A.7 & A.8.

drops by approx. 1.02 points (mean 95% CI: −1.53, −0.51). In our analyses the availability of gardens has no significant effect on mental and physical health.

3.3. Nature and climate characteristics

County level blue space cover, landscape heterogeneity and temperature are not significantly related with mental and physical health (Fig. 3, Tables 2 and 3). However, protected area cover is positively related to mental health (MCS), but not consistently across all models (Tables 2 and 3).

4. Discussion

In accordance with our hypotheses, we find a positive association of plant and bird species richness with mental health (H1). These results report an extensive and robust assessment at a national scale showing a strong relationship between species diversity and mental health. The only comparable study at the national level found a significant positive relationship between bird species richness and 'good' overall health prevalence, an indicator that covers both mental and physical health aspects (Wheeler et al., 2015). Based on previous findings we assumed that higher bird abundance would be related to better mental health (Cox et al., 2017b). Contrary to these expectations, we find no effect of bird abundance on mental health (H2) and no relationship between species diversity measures (birds and plants) and physical health (H3). In the following, we compare our results to those of earlier studies.

Our results on mental health and plant and bird species richness at a regional scale are also in line with previous research conducted in urban areas using the same objective (ecological) measures for species richness. These studies show that plant species richness in public parks can reduce stress (Lindemann-Matthies and Matthies, 2018) and plant and bird species richness can positively affect psychological well-being (Fuller et al., 2007). Furthermore, in an experimental online survey, participants who watched videos with high bird species richness reported less anxiety (Wolf et al., 2017). Studies using subjective measures of perceived species richness find similar significant positive relationships with psychological well-being for birds and plants (e.g. Dallimer et al., 2012). However, the effect of perceived species richness on different well-being measures is not always consistent (Hoyle et al., 2017; Southon et al., 2018). While it is not clear yet whether the influence of objective species richness is more prevalent compared to perceived richness, these results signify that people's identification skills for animals and plants (Dallimer et al., 2012; Shwartz et al., 2014) or their aesthetic taste and appreciation of natural diversity (Lindemann-Matthies et al., 2010) might plays an important role in how species richness affects well-being. Also, acoustics could matter, as studies have demonstrated that listening to bird songs has a positive effect on perceived attention restoration and stress reduction (e.g. Ratcliffe et al., 2013).

We find no significant effect of bird abundance on mental health. This is contrary to results from a previous (local) study that found that afternoon – but not morning – bird abundances can be positively associated with better mental health, suggesting that bird behaviour (different activity levels during the day) and visibility may influence the likelihood of a person experiencing and benefiting from birds (Cox et al., 2017b). The German bird atlas data used in this study was likely sampled in the early morning and therefore provides bird abundance estimates which are probably not correlated to afternoon bird activities. This characteristic of the bird abundance variable may explain our study outcome. In addition, the atlas data were sampled across multiple years and thus cannot be compared to the local afternoon bird abundance estimates collected in an urban neighbourhood (Cox et al., 2017b). Another factor to be considered is that our bird abundance variable might be influenced by certain bird species with high population numbers in urbanized areas (e.g. crows, seagulls). These species are not necessarily popular among the general public (Bjerke and Østdahl, 2004) and thus might not have any positive, possibly even negative, effects on people's emotions and mental state (e.g. Ratcliffe et al., 2013). Overall, our study might indicate that on the national-scale the exposure to more birds (e.g. measured via abundance) may be less important for people, or even less perceivable, compared to bird species richness. Possibly bird species richness is a better predictor for health at larger scales than bird abundance which may vary locally, even considering cases where people struggle to perceive high species richness (Dallimer et al., 2012; Shwartz et al., 2014).

The following two mechanisms might explain this positive effect of species richness on human mental health and well-being. Both attention restoration (Kaplan, 1995) and stress reduction (Ulrich, 1991) may contribute to improved mental health in counties of high plant and bird species richness (e.g. Marselle et al., 2019). However, the mechanistic relationship between species diversity and mental health is not yet clear; no study has tested attention restoration or stress recovery as mediators (Marselle et al., 2019). Positive emotions might be another potential mediator between species diversity and mental health (Irvine et al., 2019) and may offer an alternative explanation for the observed correlation. For example, studies have shown that activities with birds (e.g. feeding and bird watching) may benefit human mental health by fostering positive emotions (e.g. Cox and Gaston, 2016). However, there is no consensus in regard to the mediating role of emotions and future research needs to depict the specific mechanisms that link species diversity and mental health. Triggers for positive emotions could be the attractiveness of species rich plant communities (Hoyle et al., 2017; Southon et al., 2018) or the diversity of bird songs (Hedblom et al., 2014).

For physical health, we find no significant relationship with species diversity even though some studies show the positive effects of species richness as well as microbial diversity on human health (Aerts et al., 2018; Wheeler et al., 2015). Compared to mental health, physical health might not be directly influenced by species richness or abundance. Instead, the relationship between physical health and species diversity could be more indirect, i.e. mediated through other factors (Hartig et al., 2014; Markevych et al., 2017). For instance, studies highlighted the importance of outdoor physical activity as well as the frequency and duration of green space use for the relationship between nature and human health (Cox et al., 2017a; Sugiyama et al., 2008). With regard to species diversity, we argue that a potential relationship between species diversity and physical health may only be expected, when mediators such as physical activity in green space are accounted for. However, this assumption remains speculative and needs to be tested in future research as the SOEP survey does not include detailed information on people's use of nature or outdoor activities in species-rich environments.

Similar to previous studies we show that better mental and physical health is associated with shorter walking distance between the place of residence and parks or recreational areas, i.e. the availability of green space (e.g. World Health Organization, 2016). Importantly, we find that people's mental and physical health is at lower levels (lower MCS and PCS scores) when they live further away from parks compared to people living closer to parks (see Results). This finding is in line with the concept of nearby nature and WHO guidelines for accessibility to urban greenspace (World Health Organization, 2016). Unfortunately, the measure of distance to public parks does not provide any information on whether or not a person actually uses the park or green space. Nonetheless, this indicator is a valid approximation of green space use as the proximity to green space is an important determinant of usage (e.g. Coombes et al., 2010) and, notably, because we used the reported proximity estimated by survey participants, not a geographical distance measure derived from maps.

It is important to note, that access to green space and parks can be influenced by social and economic factors (e.g. Dai, 2011; Hoffimann et al., 2017). This is relevant, since the association between human health and neighbourhood green space can differ in regard to the socio-economic status (e.g. income, education) of people (Cole et al., 2019; Ruijsbroek et al., 2017) and because socio-economic status also often determines human health and well-being (e.g. Adler et al., 1994). Similar to green space, the availability of biodiversity may also be related to higher socio-economic status, especially in cities (e.g. Leong et al., 2018). This so-called 'luxury effect' might also influence the relationship between biodiversity and human health. Future research should address this topic and disentangle the complex relationship between socio-economic factors, biodiversity and human health.

We find a positive effect of protected area cover on mental health, albeit not robust, that corresponds to previous findings (e.g. Wheeler et al., 2015). This could hint towards the benefits of outdoor recreational activities offered by protected areas (e.g. Puhakka et al., 2017). Some epidemiological studies find positive associations between blue space or landscape heterogeneity (Gascon et al., 2015; Rantakokko et al., 2017) and human health. However, we fail to find a significant relationship between regional blue space cover or landscape heterogeneity and mental or physical health. Overall, our county-level nature variables might not reflect access to recreational areas or salutogenic (health promoting) nature characteristics well enough to show any influence on our dependent variables. Our landscape heterogeneity variable might be too coarse and, to some extent, also includes various land cover types which might not provide benefits to human health. Instead, we argue that the reported walking distance data on the individual level better describes the real access and use of green space compared to our measures on county level. This argument is supported by our results (see above).

Due to the cross-sectional nature of our analyses our study has limited power to infer causal links between species richness and mental health. One possible strategy to report a causal relationship in empirical studies is to use panel data. While the SOEP provides such data across longer time periods, we are limited by the availability of appropriate, representative data for bird and plant species richness across the same time period. Another caveat is related to the spatial scale of our study where we use German counties as a unit to describe people's experienced environment, as this was the finest resolution at which information was available for all variables across Germany. As a consequence, there might be a pronounced local variation in species richness and other nature characteristics within each county, which can influence estimated confidence intervals in our results.

As this study is an epidemiological study on the macro-level, we do not know whether or not people directly experience higher plant and bird species richness, for instance via visits to urban parks or green space. Therefore, an alternative explanation for our results might be that high species richness is a proxy for a salutogenic nature characteristics (de Vries and Snep, 2019) or good environmental quality (Wheeler et al., 2015). Multiple other studies support this argument by presenting evidence that plant species richness declines in areas with lower environmental quality (e.g. Duprè et al., 2010) or that bird species richness may be higher in landscapes characterized by elements with high restorative potential (e.g. Velarde et al., 2007) such as local landscape diversity or diverse forests (Gil-Tena et al., 2007; Weber et al., 2004).

Based on this assumption, we propose the use of species diversity measures (e.g. species richness) as indicators to nature's salutogenic effects on a macro level (e.g. regional and national level), as we show that simple measures of green or blue space cover or other nature characteristics might not be adequate proxies. Some studies have used bird species richness as an indicator for environmental quality (see Wheeler et al., 2015) and a report by the EU Joint Research Council presented a European map for habitat quality based on common bird species distribution data (Maes et al., 2015), albeit its original purpose was to help to monitor breeding habitats for birds. It might therefore be possible to create regional and national level indicators based on measures of species diversity whose functionality go beyond the maintenance of ecosystems and species conservation, but in addition help monitor species diversity as a health promoting nature characteristic. On the local and city level, species diversity can be used as a quality indicator for green space and should therefore be highly relevant for urban planning, but more research on this subject is necessary (Taylor and Hochuli, 2017).

5. Conclusion

Our study results may demonstrate that the protection of rural and urban habitats promoting high species richness not only serves conservation goals but also improves human well-being and good health-related quality of life (Cook et al., 2019). This is especially important since it is projected that our world will face major biodiversity loss in the future (Díaz et al., 2019; IPBES, 2019) which will also threaten the benefits provided by biodiversity to human well-being. Securing species diversity can be considered as additional means to foster public health and to avoid increasing public health services costs, especially since countries of the Global North are facing rising problems of mental health and associated high costs to society (e.g. OECD / European Union, 2018). For this purpose, species diversity might present a good macro-level indicator to not only monitor species loss and conservation success but also to assess salutogenic nature characteristics, i.e. health-related ecosystem services and Nature's Contributions to People (e.g. Geijzendorffer and Roche, 2013).

Knowledge of biodiversity-health linkages can inform landscape planners and urban greenspace managers to devise strategies to employ nature-based solutions to promote human well-being (Heiland et al., 2019). In regard to cities and urban areas, our results may be helpful for a better management of green space quality; i.e., the planning and layout of urban parks and recreation areas should foster high species richness and enable access, for example, to plants and wildlife to promote positive experiences and restoration (e.g. Bell et al., 2017; Carrus et al., 2015). In addition, landscape and urban planning should foster easy access to biodiverse areas in daily life as an important measure to promote public health. Likewise, protected areas should not only be valued for their contribution to biodiversity conservation, but also as 'health hubs' (MacKinnon et al., 2019). Conversely, health aspects of biodiverse areas and their spatial arrangements should be incorporated in environmental impact assessments and national and local environment strategies. Overall, we hope our study provides tangible evidence to employ species richness not only as an indicator for conservation planning but also for landscape planning and for policies promoting public health.

CRediT authorship contribution statement

Joel Methorst: . : Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Aletta Bonn:** Writing - review & editing. **Melissa Marselle:** Writing - review & editing. **Katrin Böhning-gaese:** Supervision, Conceptualization, Writing - review & editing. **Katrin Rehdanz:** Supervision, Conceptualization, Writing - review & editing.

Acknowledgements

The authors kindly acknowledge the support by the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, funded by the German Science Foundation (FZT 118, 202548816). We would also like to thank all bird recorders and the Dachverband Deutscher Avifaunisten (DDA) for providing the bird data for Germany (ADEBAR atlas). Special thanks also to Prof. Helge Brühlheide (University Halle, Germany) and his team for sharing the plant atlas data for Germany.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2021.104084.

References

Adler, N. E., Boyce, T., Chesney, M. A., Cohen, S., Folkman, S., Kahn, R. L., & Syme, S. L. (1994). Socioeconomic status and health: The challenge of the gradient. *American Psychologist, 49*, 15–24. https://doi.org/10.1037/0003-066X.49.1.15.

Aerts, R., Honnay, O., & Van Nieuwenhuyse, A. (2018). Biodiversity and human health: Mechanisms and evidence of the positive health effects of diversity in nature and green spaces. *British Medical Bulletin, 127*, 5–22. https://doi.org/10.1093/bmb/ldy021.

Andersen, H. H., Mühlbach, A., Nübling, M., Schupp, J., & Wagner, G. G. (2007). Computation of standard values for physical and mental health scale scores using the SOEP Version of SF-12v2. *Schmollers Jahrbuch, 127*, 171–182.

Atauri, J. A., & De Lucio, J. V. (2001). The role of landscape structure in species richness distribution of birds, amphibians, reptiles and lepidopterans in Mediterranean landscapes. *Landscape Ecology, 16*, 147–159. https://doi.org/10.1023/A:1011115921050.

Basu, R. (2009). High ambient temperature and mortality: A review of epidemiologic studies from 2001 to 2008. *Environmental Health: A Global Access Science Source, 8*. https://doi.org/10.1186/1476-069X-8-40.

Bell, S. L., Westley, M., Lovell, R., Wheeler, B. W., Bell, S. L., Westley, M., et al. (2017). Everyday green space and experienced well-being: The significance of wildlife encounters. *Landscape Research, 6397*, 1–12. https://doi.org/10.1080/01426397.2016.1267721.

Bjerke, T., & Østdahl, T. (2004). Animal-related attitudes and activities in an urban population. *Anthrozoos, 17*, 109–129. https://doi.org/10.2752/089279304786991783.

Bramesfeld, A., Grobe, T., & Schwartz, F. W. (2010). Prevalence of depression diagnosis and prescription of antidepressants in East and West Germany: An analysis of health insurance data. *Social Psychiatry and Psychiatric Epidemiology, 45*, 329–335. https://doi.org/10.1007/s00127-009-0067-8.

Bundesamt für Naturschutz, B., 2008. Forschung und Monitoring in den deutschen Biosphärenreservaten. BfN Broschüre 1–33.

Busija, L., Pausenberger, E., Haines, T. P., Haymes, S., Buchbinder, R., & Osborne, R. H. (2011). Adult measures of general health and health-related quality of life. *Arthritis Care & Research, 63*, S383–S412. https://doi.org/10.1002/acr.20541.

Carrus, G., Scopelliti, M., Lafortezza, R., Colangelo, G., Ferrini, F., Salbitano, F., et al. (2015). Go greener, feel better? The positive effects of biodiversity on the well-being of individuals visiting urban and peri-urban green areas. *Landscape and Urban Planning, 134*, 221–228. https://doi.org/10.1016/j.landurbplan.2014.10.022.

Cole, H. V. S., Triguero-Mas, M., Connolly, J. J. T., & Anguelovski, I. (2019). Determining the health benefits of green space: Does gentrification matter? Heal. *Place, 57*, 1–11. https://doi.org/10.1016/j.healthplace.2019.02.001.

Cook, P. A., Howarth, M., & Wheater, C. P. (2019). Biodiversity and health in the face of climate change: Implications for public health. In M. R. Marselle, J. Stadler, H. Korn, K. N. Irvine, & A. Bonn (Eds.), *Biodiversity and health in the face of climate change* (pp. 251–281). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-02318-8_11.

Coombes, E., Jones, A. P., & Hillsdon, M. (2010). The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Social Science and Medicine, 70*, 816–822. https://doi.org/10.1016/j.socscimed.2009.11.020.

Coons, S. J., Rao, S., Keininger, D. L., & Hays, R. D. (2000). A comparative review of generic quality-of-life instruments. *Pharmacoeconomics, 17*, 13–35. https://doi.org/10.2165/00019053-200017010-00002.

Costa, P.T., McCrae, R.R., 1985. The NEO personality inventory, in: The NEO Personality Inventory: Manual, Form S and Form R. Psychological Assessment Ressources Inc., pp. 223–256. doi: 10.4135/9781849200479.n9.

Cox, D. T. C., & Gaston, K. J. (2016). Urban bird feeding: Connecting people with nature. *PLoS ONE, 11*, 1–13. https://doi.org/10.1371/journal.pone.0158717.

Cox, D. T. C., Shanahan, D. F., Hudson, H. L., Fuller, R. A., Anderson, K., Hancock, S., & Gaston, K. J. (2017). Doses of nearby nature simultaneously associated with multiple health benefits. *International Journal of Environmental Research and Public Health, 14*, E172. https://doi.org/10.3390/ijerph14020172.

Cox, D. T. C., Shanahan, D. F., Hudson, H. L., Plummer, K. E., Siriwardena, G. M., Fuller, R. A., et al. (2017). Doses of neighborhood nature: The benefits for mental health of living with nature. *BioScience, 67*, 147–155. https://doi.org/10.1093/biosci/biw173.

Dai, D. (2011). Racial/ethnic and socioeconomic disparities in urban green space accessibility: Where to intervene? *Landscape and Urban Planning, 102*, 234–244. https://doi.org/10.1016/j.landurbplan.2011.05.002.

Dallimer, M., Irvine, K. N., Skinner, A. M. J., Davies, Z. G., Rouquette, J. R., Maltby, L. L., … Gaston, K. J. (2012). Biodiversity and the feel-good factor: Understanding associations between self-reported human well-being and species richness. *BioScience, 62*, 47–55. https://doi.org/10.1525/bio.2012.62.1.9.

de Almeida Rodrigues, A., da Cunha Bustamante, M. M., & Sano, E. E. (2018). As far as the eye can see: Scenic view of Cerrado national parks. *Perspectives in Ecology and Conservation, 16*, 31–37. https://doi.org/10.1016/j.pecon.2017.11.004.

de Vries, S., & Snep, R. (2019). Biodiversity in the context of 'Biodiversity – Mental Health' research. In M. R. Marselle, J. Stadler, H. Korn, K. N. Irvine, & A. Bonn (Eds.), *Biodiversity and health in the face of climate change* (pp. 159–173). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-02318-8_8.

de Vries, S., ten Have, M., van Dorsselaer, S., van Wezep, M., Hermans, T., & de Graaf, R. (2016). Local availability of green and blue space and prevalence of common mental disorders in the Netherlands. *Br. J. Psychiatry Open, 2*, 366–372. https://doi.org/10.1192/bjpo.bp.115.002469.

Deutschewitz, K., Lausch, A., Kühn, I., & Klotz, S. (2003). Native and alien plant species richness in relation to spatial heterogeneity on a regional scale in Germany. *Global Ecology and Biogeography, 12*, 299–311. https://doi.org/10.1046/j.1466-822X.2003.00025.x.

Díaz, S., Settele, J., Brondizio, E. S., Ngo, H. T., Agard, J., Arneth, A., et al. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science (80-.), 366*, eaax3100. https://doi.org/10.1126/science.aaw3100.

Dormann, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., et al. (2013). Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography (Cop.), 36*, 027–046. https://doi.org/10.1111/j.1600-0587.2012.07348.x.

Duprè, C., Stevens, C. J., Ranke, T., Bleeker, A., Peppler-Lisbach, C., Gowing, D. J. G., et al. (2010). Changes in species richness and composition in European acidic grasslands over the past 70 years: The contribution of cumulative atmospheric nitrogen deposition. *Global Change Biology, 16*, 344–357. https://doi.org/10.1111/j.1365-2486.2009.01982.x.

Easterlin, R. A., & Plagnol, A. C. (2008). Life satisfaction and economic conditions in East and West Germany pre- and post-unification. *Journal of Economic Behavior & Organization, 68*, 433–444. https://doi.org/10.1016/j.jebo.2008.06.009.

Fox, J., & Monette, G. (1992). Generalized collinearity diagnostics. *Journal of American Statistical Association, 87*, 178–183.

Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H., & Gaston, K. J. (2007). Psychological benefits of greenspace increase with biodiversity. *Biology Letters, 3*, 390–394. https://doi.org/10.1098/rsbl.2007.0149.

Gascon, M., Mas, M. T., Martínez, D., Dadvand, P., Forns, J., Plasència, A., & Nieuwenhuijsen, M. J. (2015). Mental health benefits of long-term exposure to residential green and blue spaces: A systematic review. *International Journal of Environmental Research and Public Health, 12*, 4354–4379. https://doi.org/10.3390/ijerph120404354.

Gedeon, K., Grüneberg, C., Mitschke, A., Sudfeldt, C., Eickhorst, W., Fischer, S., Flade, M., Frick, S., Geiersberger, I., Koop, B., Kramer, M., Krüger, T., Roth, N., Ryslav, T., Stübin, S., Sudmann, S.R., Steffens, R., Vökler, F., Witt, K., 2014. Atlas Deutscher Brutvogelarten – Atlas of German Breeding Birds, 1st ed. Stiftung Vogelmonitoring Deutschland & Dachverband Deutscher Avifaunisten (DDA), Münster.

Geijzendorffer, I. R., & Roche, P. K. (2013). Can biodiversity monitoring schemes provide indicators for ecosystem services? *Ecological Indicators, 33*, 148–157. https://doi.org/10.1016/j.ecolind.2013.03.010.

Gil-Tena, A., Saura, S., & Brotons, L. (2007). Effects of forest composition and structure on bird species richness in a Mediterranean context: Implications for forest ecosystem management. *Forest Ecology and Management, 242*, 470–476. https://doi.org/10.1016/j.foreco.2007.01.080.

Goebel, J., Grabka, M. M., Liebig, S., Kroh, M., David, R., Carsten, S., & Schupp, J. (2019). The German Socio-Economic Panel (SOEP). *Journal of Economics and Statistics, 239*, 345–360. https://doi.org/10.1515/jbnst-2018-0022.

Hartig, T., Mitchell, R., de Vries, S., & Frumkin, H. (2014). Nature and health. *Annual Review of Public Health, 35*, 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443.

Hedblom, M., Heyman, E., Antonsson, H., & Gunnarsson, B. (2014). Bird song diversity influences young people's appreciation of urban landscapes. *Urban Forestry and Urban Greening, 13*, 469–474. https://doi.org/10.1016/j.ufug.2014.04.002.

Heiland, S., Weidenweber, J., & Thompson, C. W. (2019). Linking landscape planning and health. In M. R. Marselle, J. Stadler, H. Korn, K. N. Irvine, & A. Bonn (Eds.), *Biodiversity and health in the face of climate change* (pp. 425–448). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-02318-8.

Hoffimann, E., Barros, H., & Ribeiro, A. I. (2017). Socioeconomic inequalities in green space quality and Accessibility—Evidence from a Southern European city. *International Journal of Environmental Research and Public Health, 14*. https://doi.org/10.3390/ijerph14080916.

Hoyle, H., Hitchmough, J., & Jorgensen, A. (2017). All about the 'wow factor'? The relationships between aesthetics, restorative effect and perceived biodiversity in designed urban planting. *Landsc. Urban Plan., 164*, 109–123. https://doi.org/10.1016/j.landurbplan.2017.03.011.

IPBES. (2019). *The global assessment report on biodiversity and ecosystem services – summary for policy makers*. Bonn: IPBES secretariat.

Irvine, K. N., Hoesly, D., Bell-Williams, R., & Warber, S. L. (2019). Biodiversity and spiritual well-being. In M. R. Marselle, J. Stadler, H. Korn, K. N. Irvine, & A. Bonn (Eds.), *Biodiversity and health in the face of climate change* (pp. 213–247). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-02318-8_10.

Kaplan, S. (1995). The resporative benefits of nature: Toward and integrative framework. *Journal of Environmental Psychology, 15*, 169–182. https://doi.org/10.1016/0272-4944(95)90001-2.

Kondo, M. C., Fluehr, J. M., McKeon, T., & Branas, C. C. (2018). Urban green space and its impact on human health. *International Journal of Environmental Research and Public Health, 15*. https://doi.org/10.3390/ijerph15030445.

Leong, M., Dunn, R. R., & Trautwein, M. D. (2018). Biodiversity and socioeconomics in the city: A review of the luxury effect. *Biology Letters, 14*. https://doi.org/10.1098/rsbl.2018.0082.

Lindemann-Matthies, P., Junge, X., & Matthies, D. (2010). The influence of plant diversity on people's perception and aesthetic appreciation of grassland vegetation. *Biological Conservation, 143*, 195–202. https://doi.org/10.1016/j.biocon.2009.10.003.

Lindemann-Matthies, P., & Matthies, D. (2018). The influence of plant species richness on stress recovery of humans. *Web Ecology, 18*, 121–128. https://doi.org/10.5194/we-18-121-2018.

Lovell, R., Wheeler, B. W., Higgins, S. L., Irvine, K. N., & Depledge, M. H. (2014). A systematic review of the health and well-being benefits of biodiverse

environments. *Journal of Toxicology and Environmental Health, Part B: Critical Reviews, 17*, 1–20. https://doi.org/10.1080/10937404.2013.856361.
MacKinnon, K., van Ham, C., Reilly, K., & Hopkins, J. (2019). Nature-based solutions and protected areas to improve urban biodiversity and health. In M. R. Marselle, J. Stadler, H. Korn, K. N. Irvine, & A. Bonn (Eds.), *Biodiversity and health in the face of climate change* (pp. 363–380). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-02318-8_16.
Maes, J., Fabrega, N., Zulian, G., Barbosa, A., Ivits, E., Polce, C., et al., 2015. Mapping and assessment of ecosystems and their services trends in ecosystems and ecosystem – JRC report number JRC94889. doi: 10.2788/341839.
Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., et al. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research, 158*, 301–317. https://doi.org/10.1016/j.envres.2017.06.028.
Marselle, Melissa R., Martens, D., Dallimer, M., & Irvine, K. N. (2019). Review of the mental health and well-being benefits of biodiversity. In M. R. Marselle, J. Stadler, H. Korn, K. Irvine, & A. Bonn (Eds.), *Biodiversity and Health in the Face of Climate Change* (pp. 175–211). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-02318-8_9.
Moulton, B. R. (1990). An illustration of a pitfall in estimating the effects of aggregate variables on micro units. *Review of Economics and Statistics, 72*, 334. https://doi.org/10.2307/2109724.
Nesterko, Y., Braehler, E., Grande, G., & Glaesmer, H. (2013). Life satisfaction and health-related quality of life in immigrants and native-born Germans: The role of immigration-related factors. *Quality of Life Research, 22*, 1005–1013. https://doi.org/10.1007/s11136-012-0239-y.
OECD / European Union, 2018. Health at a Glance: Europe 2018, Health at a Glance: Europe. OECD Publishing, Paris. doi: 10.1787/health_glance-2010-en.
Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., Mcglinn, D., Minchin, P. R., O 'hara, R.B., Simpson, G.L., Solymos, P., Henry, M., Stevens, H., Szoecs, E., Wagner, H., 2017. vegan: community ecology package.
Petersen, E., Schoen, G., Liedtke, G., & Zech, A. (2018). Relevance of urban green space for physical activity and health-related quality of life in older adults. *Quality in Ageing and Older Adults, 19*, 158–166. https://doi.org/10.1108/QAOA-01-2018-0002.
Puhakka, R., Pitkänen, K., & Siikamäki, P. (2017). The health and well-being impacts of protected areas in Finland. *Journal of Sustainable Tourism, 25*, 1830–1847. https://doi.org/10.1080/09669582.2016.1243696.
Rabe, S. E., Koellner, T., Marzelli, S., Schumacher, P., & Grêt-Regamey, A. (2016). National ecosystem services mapping at multiple scales – The German exemplar. *Ecological Indicators, 70*, 357–372. https://doi.org/10.1016/j.ecolind.2016.05.043.
Rantakokko, M., Keskinen, K. E., Kokko, K., & Portegijs, E. (2017). Nature diversity and well-being in old age. *Aging Clinical and Experimental Research, 30*, 527–532. https://doi.org/10.1007/s40520-017-0797-5.
Ratcliffe, E., Gatersleben, B., & Sowden, P. T. (2013). Bird sounds and their contributions to perceived attention restoration and stress recovery. *Journal of Environmental Psychology, 36*, 221–228. https://doi.org/10.1016/j.jenvp.2013.08.004.
Ruijsbroek, A., Droomers, M., Kruize, H., Van Kempen, E., Gidlow, C. J., Hurst, G., et al. (2017). Does the health impact of exposure to neighbourhood green space differ between population groups? An explorative study in four European cities. *International Journal of Environmental Research and Public Health, 14*. https://doi.org/10.3390/ijerph14060618.
Sandifer, P. A., Sutton-Grier, A. E., & Ward, B. P. (2015). Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance health and biodiversity conservation. *Ecosystem Services, 12*, 1–15. https://doi.org/10.1016/j.ecoser.2014.12.007.
Sherrouse, B. C., Clement, J. M., & Semmens, D. J. (2011). A GIS application for assessing, mapping, and quantifying the social values of ecosystem services. *Applied Geography, 31*, 748–760. https://doi.org/10.1016/j.apgeog.2010.08.002.
Shwartz, A., Turbé, A., Simon, L., & Julliard, R. (2014). Enhancing urban biodiversity and its influence on city-dwellers: An experiment. *Biological Conservation, 171*, 82–90. https://doi.org/10.1016/j.biocon.2014.01.009.
Siegel, N. A., Huber, S., Gensicke, A., Geue, D., Stimmel, S., & Stutz, F. (2010). *SOEP 2009 Methodenbericht*. Munich: TNS Infratest Sozialforschung.
Southon, G. E., Jorgensen, A., Dunnett, N., Hoyle, H., & Evans, K. L. (2018). Perceived species-richness in urban green spaces: Cues, accuracy and well-being impacts. *Landscape and Urban Planning, 172*, 1–10. https://doi.org/10.1016/j.landurbplan.2017.12.002.
Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2008). Associations of neighbourhood greenness with physical and mental health: Do walking, social coherence and local social interaction explain the relationships?. e9 e9 *J. Epidemiol. Community Heal., 62*. https://doi.org/10.1136/jech.2007.064287.
Taylor, L., & Hochuli, D. F. (2017). Defining greenspace: Multiple uses across multiple disciplines. *Landsc. Urban Plan., 158*, 25–38. https://doi.org/10.1016/j.landurbplan.2016.09.024.
Testa, M. A., & Simonson, D. C. (1996). Assesment of quality-of-life outcomes. *New England Journal of Medicine, 34*, 835–840. https://doi.org/10.1080/13531048808575938.
Triguero-Mas, M., Dadvand, P., Cirach, M., Martínez, D., Medina, A., Mompart, A., et al. (2015). Natural outdoor environments and mental and physical health: Relationships and mechanisms. *Environment International, 77*, 35–41. https://doi.org/10.1016/j.envint.2015.01.012.
Ulrich, R. S. (1991). Stress recovery during exposure to natural environments. *Journal of Environmental Psychology, 11*, 201–230. https://doi.org/10.1016/S0272-4944(05)80184-7.
van den Berg, M., Wendel-Vos, W., van Poppel, M., Kemper, H., van Mechelen, W., & Maas, J. (2015). Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. *Urban Forestry and Urban Greening, 14*, 806–816. https://doi.org/10.1016/j.ufug.2015.07.008.
Velarde, M. D., Fry, G., & Tveit, M. (2007). Health effects of viewing landscapes – landscape types in environmental psychology. *Urban Forestry and Urban Greening, 6*, 199–212. https://doi.org/10.1016/j.ufug.2007.07.001.
Ware, J.E., Kosinski, M., Keller, S.D., 1995. How to score the SF12 physical and mental health summary scales, Second. ed, New England Medical Center, Boston. New Engloand Medical Center, Boston, MA.
Ware, J. E., & Sherbourne, C. D. (1992). The MOS 36-item short-form health survey (SF-36): I. conceptual framework and item selection. *Medical Care, 30*, 473–483.
Weber, D., Hintermann, U., & Zangger, A. (2004). Scale and trends in species richness: Considerations for monitoring biological diversity for political purposes. *Global Ecology and Biogeography, 13*, 97–104.
Wheeler, B. W., Lovell, R., Higgins, S. L., White, M. P., Alcock, I., Osborne, N. J., et al. (2015). Beyond greenspace: An ecological study of population general health and indicators of natural environment type and quality. *Int. J. Health Geogr., 14*, 1–17. https://doi.org/10.1186/s12942-015-0009-5.
World Health Organization. (2016). *Urban green spaces and health*. Copenhagen: WHO Regional Office for Europe.
Yu, W., Mengersen, K., Wang, X., Ye, X., Guo, Y., Pan, X., & Tong, S. (2012). Daily average temperature and mortality among the elderly: A meta-analysis and systematic review of epidemiological evidence. *International Journal of Biometeorology, 56*, 569–581. https://doi.org/10.1007/s00484-011-0497-3.