



# Leisure Sciences

## An Interdisciplinary Journal

ISSN: (Print) (Online) Journal homepage: [www.tandfonline.com/journals/ulsc20](http://www.tandfonline.com/journals/ulsc20)

# Associations Between Biodiversity, Forest Characteristics, Distance to Blue Space and Accelerometer-Measured Physical Activity—Northern Finland Birth Cohort 1966 Study

Katja Kangas, Riitta Pyky, Oili Tarvainen, Soile Puhakka, Jouni Karhu, Maarit Kangas, Anne Tolvanen, Raija Korpelainen & Tiina Lankila

To cite this article: Katja Kangas, Riitta Pyky, Oili Tarvainen, Soile Puhakka, Jouni Karhu, Maarit Kangas, Anne Tolvanen, Raija Korpelainen & Tiina Lankila (15 Nov 2024): Associations Between Biodiversity, Forest Characteristics, Distance to Blue Space and Accelerometer-Measured Physical Activity—Northern Finland Birth Cohort 1966 Study, Leisure Sciences, DOI: [10.1080/01490400.2024.2427677](https://doi.org/10.1080/01490400.2024.2427677)

To link to this article: <https://doi.org/10.1080/01490400.2024.2427677>



© 2024 The Author(s). Published with license by Taylor & Francis Group, LLC



[View supplementary material](#)



Published online: 15 Nov 2024.



[Submit your article to this journal](#)



Article views: 97



[View related articles](#)



[View Crossmark data](#)

# Associations Between Biodiversity, Forest Characteristics, Distance to Blue Space and Accelerometer-Measured Physical Activity—Northern Finland Birth Cohort 1966 Study

Katja Kangas<sup>a\*</sup>, Riitta Pyky<sup>b\*</sup>, Oili Tarvainen<sup>a</sup>, Soile Puhakka<sup>b,c,d</sup>, Jouni Karhu<sup>a</sup>, Maarit Kangas<sup>e</sup>, Anne Tolvanen<sup>a</sup>, Raija Korpelainen<sup>b,d,f</sup> and Tiina Lankila<sup>b,c</sup>

<sup>a</sup>Natural Resources Institute Finland, Oulu, Finland; <sup>b</sup>Department of Sports and Exercise Medicine, Oulu Deaconess Institute Foundation sr., Oulu, Finland; <sup>c</sup>The Geography Research Unit, Faculty of Science, University of Oulu, Oulu, Finland; <sup>d</sup>Research Unit of Population Health, Faculty of Medicine, University of Oulu, Oulu, Finland; <sup>e</sup>Northern Finland Birth Cohorts, Arctic Biobank, Infrastructure for Population Studies, Faculty of Medicine, University of Oulu, Oulu, Finland; <sup>f</sup>Medical Research Center, Oulu University Hospital and University of Oulu, Oulu, Finland

## ABSTRACT

We studied how the quantity and quality of residential green spaces and distance to different types of blue spaces are associated with the accelerometer-measured physical activity (PA) among adults with different levels of total daily PA. The associations of the participants' socio-demographic and personal characteristics and environmental features with light PA (LPA) and moderate-to-vigorous PA (MVPA) were analyzed using linear mixed models ( $n=5470$ ). The results indicated that greater residential forest area was associated with higher LPA among those with high level of total daily PA and with less MVPA among those with low level of total daily PA. Environments with high tree stand structure diversity or close to sea were associated with higher MVPA in high PA group. Varied natural environment can encourage leisure time activities in nearby nature, but individuals' personal and socioeconomic variables seemed to be more strongly associated with LPA and MVPA than environmental characteristics.

## ARTICLE HISTORY



Received 4 January 2024  
Accepted 29 October 2024

## KEYWORDS

Accelerometer-measured physical activity; biodiversity; blue space; cohort study; forest characteristics

## Introduction

The level of urbanization has been increasing globally and more than half of the world's population already lives in urban areas (United Nations, Department of Economic and Social Affairs, Population Division, 2019). There are concerns that due to the increasing urbanization, people are getting distant from nature (Fuller et al., 2007; Wilson, 1984), and natural environments have diminished and become fragmented. Green spaces have been shown to mitigate air and noise pollution and heat, and they also provide a setting for esthetic, spiritual, educational, and recreational values (Millennium Ecosystem Assessment, 2005).

**CONTACT** Tiina Lankila  [tiina.lankila@odl.fi](mailto:tiina.lankila@odl.fi)  Department of Sports and Exercise Medicine, Oulu Deaconess Institute Foundation sr., Oulu, Finland

\*These authors contributed equally to this work.

 Supplemental data for this article is available online at <https://doi.org/10.1080/01490400.2024.2427677>

© 2024 The Author(s). Published with license by Taylor & Francis Group, LLC  
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

There is growing evidence of the beneficial impacts of natural environments on human health and well-being (e.g., Bowler et al., 2010; Fong et al., 2018; Gascon et al., 2017; Houlden et al., 2021; James et al., 2015). Residential greenness is associated with improvements in both physical (Pereira et al., 2012; Vienneau et al., 2017) and psychological well-being (e.g., James et al., 2015; McEachan et al., 2016). Moreover, visits to green spaces have proven benefits for mental health (e.g., Simkin et al., 2020; White et al., 2013). Also, greater exposure to outdoor blue spaces (lakes, rivers, sea, etc.) has been positively associated with mental health and physical activity (Gascon et al., 2017).

Almost a third of the world's adults do not meet the global recommendation for physical activity (PA) (WHO, 2022). Behavioral and environmental factors, such as rapid urbanization and the use of motorized transportation, have most likely affected PA. Leisure-time PA has increased in high-income countries, whereas occupational PA has decreased (Hallal et al., 2012). PA reduces, e.g., the rates of all-cause mortality, coronary heart disease, high blood pressure, type-2 diabetes, and depression (Lee et al., 2012), and improves, e.g., cardiometabolic health (Farrahi et al., 2021), bone health, cognitive function, cardiorespiratory and muscular fitness (Lee et al., 2012).

Due to the global decrease in PA at the population level, the role of green spaces and blue spaces in promoting PA has attracted increasing interest over the last few decades. Green spaces and blue spaces provide a setting for PA (e.g., Gascon et al., 2017; Markevych et al., 2017; Neuvonen et al., 2019), and easy access to natural environments promotes overall and leisure time PA (Astell-Burt et al., 2014; Dewulf et al., 2016; Kaczynski et al., 2009; Kemperman & Timmermans, 2008; McMorris et al., 2015; Pyky et al., 2019). Furthermore, exercising in green spaces (i.e., green exercise) has been proposed to have additional health benefits over indoor exercise (e.g., Bowler et al., 2010; Thompson Coon et al., 2011).

So far, most studies investigating the relationship between greenness and PA have focused on moderate-to-vigorous physical activity (MVPA) (Astell-Burt et al., 2014; Smith et al., 2019), whereas light PA (LPA) has received negligible attention (Dewulf et al., 2016; Markevych et al., 2016; Puhakka et al., 2020). The previous PA recommendations highlighted the importance of MVPA for health, while the latest global, American and Finnish PA recommendations suggest that considerable health benefits can be derived from fairly low PA volumes (UKK Institute, 2019; U.S. Department of Health and Human Services, 2018; WHO, 2022), which is also supported by many previous studies (Riou et al., 2014; Saint-Maurice et al., 2018; Warburton & Bredin, 2017). Therefore, LPA, such as light household tasks, and leisure time activities (yard work and light effort walking and cycling) can play an important role in improving and maintaining health (Farrahi et al., 2021). In addition, the possible impacts of the quantity and quality of green areas can differ between individuals with different leisure time activity levels, and green areas may be important for engaging in PA for those with low levels of leisure time PA (Pyky et al., 2019).

Although presence and accessibility are important in promoting the use of green spaces and blue spaces for PA, the quality of the natural environment is also essential (Björk et al., 2008; Giles-Corti et al., 2005; Markevych et al., 2017; Neuvonen et al., 2019). For instance, the bigger size and the attractiveness of public open spaces have been found to be related to higher engagement in walking activity (Giles-Corti et al., 2005). In Sweden, Björk et al. (2008) found that recreational values of the nearby

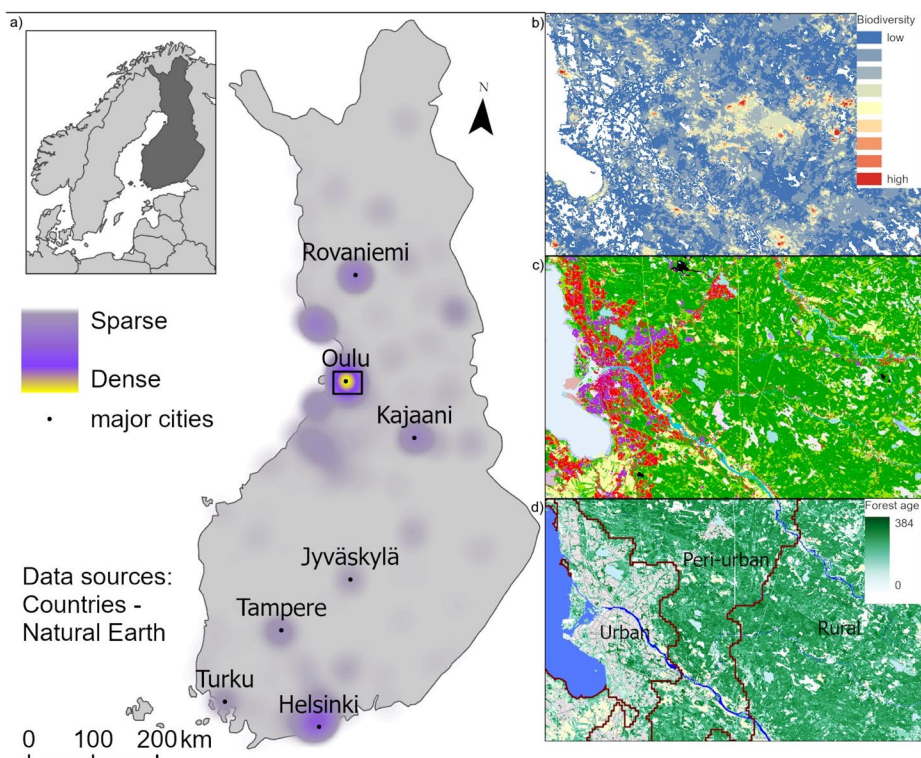
natural environment (serene, wild, lush, spacious, and culture) were positively associated with physical activity and neighborhood satisfaction. In a study conducted in Finland, the respondents valued the provisions of recreational and sports facilities, beautiful scenery, and possibilities to experience nature and silence in the green spaces used for green exercise and outdoor recreation (Neuvonen et al., 2019). Also, tree cover has been associated with the preference for green space (Shanahan et al., 2015, 2016), and forest environments characterized by openness, light, and a pleasant view are preferred (Sonntag-Öström et al., 2014). People also tend to prefer the presence of blue spaces in landscapes, and thus sceneries including seas, rivers, or lakes can encourage people to visit, walk and exercise (Karusisi et al., 2012). Biodiversity, the variety and variability among living organisms, including diversity within species, between species, and in ecosystems (CBD Secretariat, 2010), makes an essential contribution to the quality of green environments, as diverse ecosystems can provide a greater variety of ecosystem services and are more resistant to disturbances (Aerts et al., 2018). Biodiverse natural forest normally includes trees of different species and ages, variation in tree cover and size (tree stand structure diversity from here on), and thus also variation in openness and light, providing diverse microhabitats for several other species. There is already evidence of positive associations between biodiversity and psychological and physical well-being and the regulation of the immune system (Aerts et al., 2018; Fuller et al., 2007; Houlden et al., 2021; Lovell et al., 2014), though there are inconsistencies too (Aerts et al., 2018; Dallimer et al., 2012; Houlden et al., 2021).

However, the studies on the association between biodiversity and PA are nearly missing. de Jong et al. (2012) found that the perceived availability of an environment considered rich in species within 5–10 km walking distance from home is positively associated with PA. In Finland, higher habitat diversity within natural areas near home was found to correlate with higher PA among older people with no walking difficulties and the presence of water with higher PA among those with walking difficulties (Keskinen et al., 2018). However, to the best of our knowledge, no studies have specifically focused on investigating the association between biodiversity and LPA and MVPA in residential areas. Additionally, as differences in the importance of green areas for leisure time PA among people with different leisure time activity levels have been suggested (Pyky et al., 2019), people with different levels of total activity should be studied as well.

This study aimed to bridge these knowledge gaps by exploring the role of biodiversity and forest characteristics on both LPA and MVPA. In addition, we study whether the different types of blue spaces, i.e., lakes, rivers, sea, are associated with LPA and MVPA. More specifically, we aimed to investigate: (1) the associations of biodiversity, forest characteristics and distance to different types of blue spaces to accelerometer-measured LPA and MVPA and (2) whether the possible association varies between individuals with different levels of total PA. We hypothesize that biodiversity and diverse habitats and blue spaces near home can provide variability in scenery, ecosystem services, and possibilities for positive nature experiences that may promote everyday and leisure time physical activity. This might be seen especially among those with low levels of total daily PA, for whom the attractiveness of green and blue areas may be more important motivators for outdoor physical activity than for physically active people motivated to regular exercise regardless of the environment.

## Methods

Data on PA, background, and personal factors were derived from the Northern Finland Birth Cohort 1966 (NFBC1966) which is a longitudinal research program that aims to promote the health and well-being of the Finnish population (University of Oulu, 1966). Northern Finland Birth Cohort 1966 comprised all individuals born in 1966 (12,058 live births) in the two northernmost provinces of Finland (Nordström et al., 2022). The majority of the cohort members still live in Northern Finland, but a large number of cohort members have since migrated within Finland (Figure 1), and the most migration outside of Northern Finland has been to the Helsinki metropolitan area. Participants in the NFBC1966 cohort have been followed regularly since their birth through health care records, clinical examinations, and questionnaires. In this cross-sectional study, we used the data from the most recent follow-up, which was conducted when the participants were on average 46 years old in 2012–2014. The study



**Figure 1.** Maps presenting (a) the distribution of the Northern Finland Birth cohort 1966 members in 2012 in Finland and the location of Oulu region with densest population of cohort members, (b) the distribution of high diversity forests in Oulu region (Source: High biodiversity value forests 2018 (Zonation) nationwide–data, Finnish Environment Institute), (c) the distribution of CORINE land cover classes at level 4, each color presenting different land cover classes (classes not presented in legend due their large number, 49, in dataset) in Oulu region (Source: Finnish national CORINE Land Cover 2012 data, Finnish Environment Institute), and (d) the distribution of forests of different age in urban, peri-urban and rural areas in Oulu region (Source: the Multi-Source National Forest Inventory database 2013, Natural Resources Institute Finland; the Monitoring System of Spatial Structure and Urban Form Urban-rural classification 2010, Finnish Environment Institute).

was approved by the Ethical Committee of the Northern Ostrobothnia Hospital District in Oulu, Finland (94/2011), and it was performed in accordance with the ethical guidelines set for by the Declaration of Helsinki. The subjects provided written consent for the study. Personal identity information was encrypted and replaced with identification codes to provide pseudonymized data for research.

### **Questionnaire and clinical examination**

From 2012 to 2014, all the cohort participants with known addresses were sent a postal questionnaire that included items on health, health behaviors, subjective well-being, life satisfaction, happiness, socio-demographic and socioeconomic characteristics, and an invitation to a clinical examination. Of all the approached participants, 6851 (67%) responded. A total of 5852 individuals participated in the clinical examinations, where trained nurses measured their weight, height, and waist circumference. All the variables concerning cohort individuals and the variable descriptions that were used in the final models are presented in [Supplementary Material Table S1](#)).

### **Physical activity measurement**

PA was measured using a waterproof uniaxial wrist-worn activity monitor, Polar Active (Polar Electro Oy, Kempele, Finland). After the clinical examinations, the participants were asked to wear a blinded monitor on the wrist of their non-dominant hand for 24h over a two-week period. The Polar Active monitor calculates daily PA based on estimated metabolic equivalent (MET) values for every half minute (Hautala et al., 2012), and it has been shown to correlate with the double-labeled water technique, assessing energy expenditure during exercise training and in daily-living (correlation coefficients 0.86 and 0.88, respectively) (Kinnunen et al., 2012, 2019). The daily average duration spent on different activity levels (min/day) was calculated for the participants that had at least four valid days, i.e., monitoring time at least 600 min/day (Husu et al., 2014; Niemelä et al., 2019). PA of the participants was expressed as the total daily average MET minutes spent in LPA (light physical activity, 2–3.49 METs) and MVPA (moderate to very vigorous physical activity,  $\geq 3.5$  MET). MET minutes were calculated by multiplying each MET value by its duration (30 s).

### **Environmental variables**

Several variables describing the built and natural environment were measured from the 1-km buffers created around each participant's home (coordinates) where the participant had lived during the PA measurement (see [Table S1](#)). We calculated variables that described the quantity and quality of the green space. Three variables were calculated from the Corine Land Cover 2012 dataset to describe habitat diversity: (1) the number of all habitat types, including built areas (Land Cover Diversity), (2) the number of green habitat types, including man-made green areas, such as agricultural and sport areas (Green area Diversity), and (3) the number of natural green habitat types (Natural Habitat Diversity). Another variable describing the variability of natural habitat types, including forest, wetland, and other sparsely wooded areas (Forest-Wetland Diversity),

was calculated using the Finnish Multi-Source National Forest Inventory (MS-NFI) database (2013). The nationwide data from High Biodiversity Value Forests 2018 (Zonation) were used to calculate a variable indicating the biodiversity value of forests (High Diversity Forest). The calculated variable describes the area of high biodiversity value forest in the buffer when the top 40% of the forest with high biodiversity values is considered. We calculated two variables describing the quantity of forests, other (Forest Area I) using Corine Land Cover 2012 data and another (Forest Area II) using MS-NFI data. The following variables were calculated using MS-NFI data to describe forest quality: (1) variation in tree cover and size (Tree Stand Structure Diversity), (2) amount of deciduous trees (Deciduous Trees), and (3) mean age of forests (Forest Age). The Corine Land Cover 2012 dataset (resolution  $20 \times 20$  m) was provided by the Open Spatial datasets of the Finnish Environment Institute (SYKE). The Finnish Multi-Source National Forest Inventory (MS-NFI) database from the year 2013 (resolution  $16 \times 16$  m) was provided by the open spatial datasets of Natural Resources Institute Finland (Tomppo et al., 2008). Nationwide data from High Biodiversity Value Forests 2018 (Zonation) (resolution  $96 \times 96$  m) were provided by SYKE (Mikkonen et al., 2018).

Other variables calculated to describe the features of the natural environment were distance to different blue spaces, i.e., the nearest river, lake (including ponds), and seashore. Data for waterbodies were derived from the topographic database of the National Land Survey of Finland. We also calculated the distance to the nature protection areas, as they are often popular destinations for outdoor recreation. Spatial data on protected areas was derived from open spatial datasets of SYKE.

For variables describing the services and infrastructure in the residential area, we calculated the road distance to the closest shop and length of the cycle ways. These were calculated using the Monitoring System of Spatial Structure and Urban Form (YKR) datasets provided by SYKE, and the Digiroad dataset by the Finnish Transport Infrastructure Agency.

The area of green spaces as well as the extent of services and infrastructure, e.g., cycle ways and distance to the shop, which can affect outdoor PA, can vary along the urban–rural gradient. Thus, each participant’s home address was classified to be located in an urban, peri-urban, or rural area based on the SYKE’s YKR urban–rural classification data (2010) with a resolution of  $250 \times 250$  m.

Spatial analyses were carried out using ESRI ArcGIS for desktop software version 10.5.1. and ArcGIS Pro 2.1 (ESRI, 2001). Examples of the distribution of the used environmental variables are shown in Figure 1.

### **Statistical analyses**

A total of 5470 individuals, having data on clinical measurements, questionnaires, PA measurement, and the environment were included in the analyses. A principal component analysis (PCA) was carried out to investigate the relationship between biodiversity and forest variables and to reduce the number of variables included in the final statistical analyses (see Table S2). The Kaiser-Meyer-Olkin (KMO) index was used to measure the sampling adequacy (MSA) of the used set of data (*KMO* function, *psych* package; Revelle, 2018). The overall MSA for the set of variables and for each variable separately should be higher than 0.5 to be adequate for the following analyses.

The PCA with four components was conducted to select the most important components and the variables that best explain the chosen components (*principal* function, *psych* package; Revelle, 2018). The varimax rotation that maximizes the variance of the components fitted best for the analyses. The variables that had the highest loadings in the first three components of each PCA were included in the final statistical analyses, except for the forest age, which was included, as it describes rather the quality of the forest in terms of biodiversity than solely the area of forest cover.

As the associations of the quantity and quality of green and blue spaces with physical activity may differ among individuals with different levels of physical activity (Pyky et al., 2019), we divided the participants into three PA groups based on the accelerometer-measured total activity: Low PA (lowest quartile, <867.5 MET-minutes), Moderate PA (second and third quartile, ≥867.5 and <1271.3 MET minutes) and High PA (highest quartile, ≥1271.3 MET minutes). Differences in the participants' individual and socio-demographic characteristics between different PA groups were analyzed using chi-squared tests for categorical variables and ANOVA for continuous variables. The normality and homogeneity of the ANOVA model residuals were checked using diagnostic plots, and necessary transformations were made to fit the demands. Multiple comparisons between the groups were analyzed by *dunn.test* (*dunn.test* package, Dinno, 2017) or *TukeyHSD* functions (*stats* package, R Core Team, 2018).

The associations of participants' individual, socio-demographic, residential environmental features, and PA groups on LPA to MVPA were analyzed simultaneously using linear mixed models (*lme4* package, Bates et al., 2015). As the preliminary analyses testing the interactions between the different PA groups and environmental variables showed multicollinearity (results not shown), we decided to study the association of environmental variables to LPA and MVPA separately in groups with different physical activity levels. Furthermore, the urban-rural variable was a significant factor in the analyses, and its impact on the results was accounted for by using it as a random factor in the models. Thus, the models took into account the fact that a participant lived either in urban, peri-urban, or rural areas and analyzed the impacts of other variables of the model within each group. The continuous variables were analyzed using linear models with Gaussian error distribution (lmer with restricted maximum likelihood). The normality and homogeneity of the model residuals were checked using diagnostic plots. Necessary transformations were made to fit the model demands. An analysis of the variance table of type-3 errors was produced for the lmer models using the Satterthwaite approximation for degrees of freedom (*lmerTest* package, Kuznetsova et al., 2017). The estimated impact of each factor was considered statistically significant ( $p < 0.05$ ) when the absolute value of the *t*-score in the mixed models was  $\geq 2$  (Crawley, 2007). The *t*-scores were obtained by dividing the model parameter estimates (coefficients) by the standard errors of the model. All statistical analyses were performed using R 3.6.0 (R Core Team, 2018).

## Results

### *Characteristics of participants and their residential areas*

The characteristics of the study participants are presented in Table 1. More than half (56%) were females, fifth (20%) were single, 76% were couple and 4% did not disclose

**Table 1.** Characteristics of the participants according to their total daily physical activity (PA) level.

Variable	All (n=5470)	Low PA (n=1370)	Moderate PA (n=2733)	High PA (n=1367)	p
Socio-demographic and personal factors					
Gender, N (%)					<0.001
Female	3062 (56.0)	807 (58.9)	1571 (57.5)	684 (50.0)	
Male	2408 (44.0)	563 (41.1)	1162 (42.5)	<b>683 (50.0)</b>	
Marital status, N (%)					<0.001
Single	1089 (19.9)	<b>336 (25.8)</b>	509 (19.5)	244 (18.7)	
Couple	4138 (75.6)	968 (74.2)	2107 (80.5)	1063 (81.3)	
Minors at home (vs. no), N (%)					<0.001
Age from 0 to 6years	676 (12.4)	117 (8.5)	341 (12.5)	218 (15.9)	<0.001
Household income, mean k€ (SD)	72.1 (29.8)	68.5 (90.7)b	78.3 (413)a	63.4 (53.9)b	<0.001
Dogs (vs. no), N (%)	1940 (35.5)	413 (30.1)	974 (35.6)	<b>553 (40.5)</b>	<0.001
BMI, mean kg/m <sup>2</sup> (SD) <sup>1</sup>	26.8 (4.85)	28.3 (5.64)a	26.6 (4.63)b	25.7 (3.98)c	<0.001
Smoking, N (%)					<0.001
Non-smoker	2808 (51.3)	683 (49.9)	1381 (50.5)	744 (54.4)	
Former	1404 (25.7)	323 (23.6)	721 (26.4)	360 (26.3)	
Current	972 (17.8)	<b>285 (20.8)</b>	493 (18.0)	194 (14.2)	
Diagnoses impacting physical activity (vs. no), N (%)	3597 (65.8)	<b>960 (70.1)</b>	1772 (64.8)	865 (63.3)	<0.001
Perceived life satisfaction, median/mean (SD)	3/3.12 (0.57)	4/3.08 (0.59)b	4/3.14 (0.56)a	4/3.12 (0.56)a	0.010
High perceived life satisfaction, N (%)	4744 (86.7)	1156 (84.4)	2390 (87.4)	1198 (87.6)	
Perceived happiness, median/mean (SD)	3/2.99 (0.48)	3/2.95 (0.52)b	3/3.00 (0.47)a	3/3.02 (0.46)a	<0.001
High perceived happiness, N (%)	4873 (89.1)	1181 (86.2)	2453 (89.8)	1239 (90.6)	
Measured daily light PA MET-min, mean (SD) <sup>2</sup>	720 (194)	515 (98)c	721 (122)b	920 (169)a	<0.001
Measured daily MVPA MET-min, mean (SD) <sup>3</sup>	390 (209)	197 (85)c	343 (117)b	598 (239)a	<0.001

The values are numbers of participants (N) and proportions (%), median or mean and standard deviation (SD). The significant differences ( $p < 0.05$ ; chi-squared test or ANOVA) are presented by bolding the proportion that is larger than expected proportion, using *italics* when the proportion is smaller than expected proportion, or using letters to show the order of the groups (letter [a] is given to the group with highest value). <sup>1</sup>BMI: Body Mass Index. <sup>2</sup>Light PA: light physical activity, 2–3.49 metabolic equivalent (MET). <sup>3</sup>MVPA: moderate-to-vigorous physical activity,  $\geq 3.5$  metabolic equivalent (MET).

their marital status. Approximately tenth (12%) of the participants had children aged below 7 years old at home. Most of the participants reported being satisfied with their lives (86.7%) and happy (89.1%).

Compared to the Moderate PA and High PA groups, participants in the Low PA group were more likely to be single, have higher BMI, and be diagnosed with conditions/diseases that can affect the level of PA, be current smokers, and less likely to have young children and dogs. In the High PA groups, more of the participants were males, had young children and dogs, and were less likely to be current smokers compared to the Low and Moderate PA groups.

The environmental factors in participants' residential areas are presented in Table 2. Almost half of the study population lived in urban areas, nearly 30% in peri-urban areas and the remaining 22% lived in rural areas. There were fewer participants in the Low PA group living in rural areas and more in urban areas compared to the

**Table 2.** Residential environmental features of the participants according to their physical activity (PA) level.

Variable	All (n=5470)	Low PA (n=1370)	Moderate PA (n=2733)	High PA (n=1367)	p
Living area, N (%)					<0.001
Rural	1579 (28.9)	333 (24.3)	736 (26.9)	<b>510 (37.3)</b>	
Peri-urban	1209 (22.1)	286 (20.9)	633 (23.2)	290 (21.2)	
Urban	2682 (49.0)	<b>751 (54.8)</b>	1364 (49.9)	567 (41.5)	
Biodiversity and forest variables					
Land cover diversity (SD)	18.9 (3.02)	18.9 (3.05)	18.9 (9.03)	18.9 (2.99)	0.931
Green area diversity, mean (SD) <sup>1</sup>	11.8 (2.9)	11.6 (2.9)b	11.7 (2.8)b	12.0 (2.8)a	0,005
Natural habitat diversity, mean (SD)	10.1 (2.6)	10.0 (2.7)	10.0 (2.6)	10.2 (2.6)	0,128
Forest–wetland diversity, mean (SD)	10.8 (1.8)	10.7 (1.8)b	10.9 (1.7)a	10.9 (1.7)a	0,005
High diversity forest	63.8 (70.1)	63.1 (68.3)	64.7 (71.1)	62.6 (70.0)	0,725
Forest area I, mean, ha (SD) <sup>1</sup>	99.3 (52.3)	95.6 (51.5)b	97.4 (51.1)b	106 (54.9)a	<0.001
Forest area II, ha (SD)	119 (62.4)	114 (61.5)b	117 (60.5)b	128 (65.9)a	<0.001
Tree stand structure diversity, mean (SD)	257 (68.6)	257 (69.1)	259 (69.5)	255 (66.2)	0,220
Deciduous trees, mean, m <sup>3</sup> (SD) <sup>3</sup>	27.5 (14.9)	27.7 (15.5)	27.7 (14.8)	26.9 (14.2)	0,278
Forest age, mean age of trees (SD) <sup>2</sup>	52.1 (13.3)	51.5 (13.1)b	51.8 (13.0)b	53.1 (14.1)a	0,004
Distance to blue space and protected area					
Distance to river, mean, km (SD) <sup>2</sup>	1.28 (1.35)	1.31 (1.51)	1.28 (1.34)	1.27 (1.19)	0,728
Distance to lake, mean, km (SD) <sup>2</sup>	1.20 (1.03)	1.18 (1.01)	1.22 (1.03)	1.20 (1.08)	0,665
Distance to sea, mean, km (SD) <sup>2</sup>	58.2 (73.6)	53.8 (71.9)c	57.6 (73.2)b	63.8 (75.8)a	<0.001
Distance to protection area, mean, km (SD) <sup>1</sup>	3.16 (2.38)	2.98 (2.26)c	3.15 (2.38)b	3.37 (2.49)a	<0.001
Built environment factors					
Cycleways length, mean, km (SD) <sup>2</sup>	11.3 (10.3)	12.4 (10.6)a	11.5 (10.2)b	9.5 (10.0)c	<0.001
Distance to supermarket, mean, km (SD) <sup>2</sup>	3.12 (5.45)	2.66 (4.92)c	2.96 (5.17)b	3.90 (6.34)a	<0.001

The values are numbers of participants (N) and proportions (%), median or mean and standard deviation (SD). The significant differences ( $p < 0.05$ ; chi-squared test or ANOVA) are presented by bolding the proportion that is larger than expected proportion, using *italics* when the proportion is smaller than expected proportion, or using letters to show the order of the groups (letter [a] is given to the group with highest value).

<sup>1</sup>Square root transformation used.

<sup>2</sup>Logarithmic transformation used.

<sup>3</sup>Cubic root transform.

Moderate PA and High PA groups. Among the High PA group, there were more participants living in the rural environment and fewer in urban areas, compared to the Low and Moderate PA groups. Participants in the Low PA group lived closer to sea and protected areas more often, had more cycleways in residential areas, and had a shorter distance to the supermarket compared to the Moderate and High PA groups. The participants in the High PA group were more likely to live in environments that had a greater proportion of forested area, older forests, greater stand volume of trees, i.e., larger and/or older trees, and had a higher habitat diversity of green environments (both Corine and NFI) than participants in Low and Moderate PA groups. In addition, they mostly lived in environments that were situated further from sea, protected areas, and supermarkets and had fewer cycleways.

**Factors associated with LPA and MVPA among groups with different PA levels**

Both LPA (Table 3a) and MVPA (Table 3b) were mainly associated with the participant's socio-demographic and personal factors. The strength and direction of the relationship between different environmental features, socio-demographic and personal factors, and LPA and MVPA varied between different activity groups.

The tree stand structure diversity—measuring diversity in the number and size of trees had a positive association with MVPA (Table 3a) among individuals in moderate total PA group, and a negative association with LPA in moderate total PA and high total PA groups (Table 3b). The residential forest area was negatively associated with

**Table 3.** Associations between socio-demographic, personal and residential environmental factors, and (a) light (LPA) and (b) moderate-to-vigorous physical activity (MVPA) among 46years old participants ( $N=5470$ ) with different PA level (low, moderate, high) according to linear mixed models (lmer).

Level of total PA	Low ( $n=1007$ )			Moderate ( $n=2020$ )			High ( $n=983$ )		
	Est	(95% CI)	t-Value	Est	(95% CI)	t-Value	Est	(95% CI)	t-Value
<b>(a) LPA</b>									
Socio-demographic and personal factors									
Gender female (vs. male)	<b>45.4</b>	<b>(33.5–57.2)</b>	<b>7.49</b>	<b>67.1</b>	<b>(56.7–77.5)</b>	<b>12.7</b>	<b>72.2</b>	<b>(51.7–92.7)</b>	<b>6.90</b>
Marital status single (vs. couple)	<b>-20.1</b>	<b>(-35.1 to -5.12)</b>	<b>-2.63</b>	<b>-31.2</b>	<b>(-45.3 to -17.1)</b>	<b>-4.35</b>	<b>-47.3</b>	<b>(-75.7 to -18.9)</b>	<b>-3.26</b>
Minors under 7 yrs-old (vs. no)	<b>15.0</b>	<b>(2.38–27.6)</b>	<b>2.33</b>	<b>32.6</b>	<b>(22.7–42.5)</b>	<b>6.47</b>	<b>41.9</b>	<b>(23.2–60.6)</b>	<b>4.39</b>
Income	-21.7	(-83.7–40.2)	-0.69	<b>-0.12</b>	<b>(-0.19 to -0.05)</b>	<b>-3.26</b>	<b>-0.42</b>	<b>(-0.61 to -0.23)</b>	<b>-4.32</b>
Dog owner (vs. no)	3.75	(-8.89–16.4)	0.58	-8.69	(-19.4–2.06)	-1.58	21.0	(-0.27–42.3)	1.94
BMI	-0.82	(-1.89–0.24)	-1.51	1.01	(-0.16–2.18)	1.70	2.29	(-0.33–4.9)	1.71
Former smoker (vs. non-smoker)	11.1	(-2.95–25.2)	1.55	<b>12.8</b>	<b>(1.04–24.5)</b>	<b>2.14</b>	4.69	(-18.4–27.8)	0.40
Current smoker (vs. non-smoker)	12.7	(-2.59–27.9)	1.63	<b>27.6</b>	<b>(13.8–41.4)</b>	<b>3.92</b>	21.3	(-8.31–50.9)	1.41
Current smoker (vs. former smoker)	1.55	(-15.7–18.8)	0.18	14.9	(-0.39–30.1)	1.91	16.6	(-15.5–48.7)	1.01
Disease diagnoses	2.70	(-10.2–15.6)	0.41	4.30	(-6.49–15.1)	0.78	-18.4	(-40–3.16)	-1.67
Satisfaction	1.79	(-8.66–12.2)	0.34	-1.34	(-10.9–8.24)	-0.28	-0.99	(-20.1–18.1)	-0.10
Happiness	5.68	(-6.25–17.6)	0.93	8.54	(-2.86–19.9)	1.47	15.4	(-7.55–38.3)	1.32
Biodiversity and forest									
Land cover diversity	-0.74	(-2.88–1.41)	-0.67	-0.68	(-2.52–1.17)	-0.72	-2.14	(-5.98–1.7)	-1.09
Forest area I	-0.11	(-0.27–0.05)	-1.34	0.07	(-0.07–0.2)	1.01	<b>0.32</b>	<b>(0.07–0.58)</b>	<b>2.47</b>
Forest age	0.42	(-0.12–0.95)	1.54	-0.2	(-0.67–0.28)	-0.80	-0.69	(-1.61–0.22)	-1.48
Tree stand structure diversity	0.04	(-0.06–0.14)	0.74	<b>-0.17</b>	<b>(-0.26 to -0.08)</b>	<b>-3.69</b>	<b>-0.19</b>	<b>(-0.37–0)</b>	<b>-1.99</b>
Accessibility									
Distance to river	-2.62	(-6.30–1.06)	-1.40	1.41	(-2.39–5.21)	0.73	-5.65	(-14.5–3.17)	-1.26
Distance to lake	-5.73	(-12.1–0.59)	-1.78	-1.63	(-7.06–3.8)	-0.59	0.48	(-10.2–11.1)	0.09
Distance to sea	-0.07	(-0.17–0.03)	-1.41	0.07	(-0.02–0.15)	1.51	<b>0.18</b>	<b>(0.01–0.35)</b>	<b>2.13</b>

(Continued)

**Table 3.** Continued.

Level of total PA	Low (n=1007)			Moderate (n=2020)			High (n=983)		
	Est	(95% CI)	t-Value	Est	(95% CI)	t-Value	Est	(95% CI)	t-Value
<b>(a) LPA</b>									
Distance to protection area	1.57	(-1.24–4.38)	1.08	1.52	(-0.97–4.01)	1.20	-2.50	(-7.12–2.12)	-1.06
Cycleways length	<b>-0.92</b>	<b>(-1.73 to -0.11)</b>	<b>-2.22</b>	0.09	(-0.65–0.83)	0.24	-0.66	(-2.09–0.79)	-0.89
Distance to supermarket	<b>1.47</b>	<b>(0.05–2.89)</b>	<b>2.03</b>	<b>1.81</b>	<b>(0.6–3.02)</b>	<b>2.93</b>	0.86	(-1.06–2.77)	0.88
<b>(b) MVPA</b>									
Socio-demographic and personal factors									
Gender female (vs. male)	<b>-37.0</b>	<b>(-47.0 to -26.9)</b>	<b>-7.21</b>	<b>-75.7</b>	<b>(-85.6 to -65.9)</b>	<b>-15.0</b>	<b>-137</b>	<b>(-167 to -108)</b>	<b>-9.18</b>
Marital status single (vs. couple)	-3.30	(-16.0–9.38)	-0.51	<b>23.1</b>	<b>(9.74–36.5)</b>	<b>3.39</b>	14.8	(-25.8–55.4)	0.72
Minors under 7 yrs-old (vs. no)	-4.73	(-15.4–5.96)	-0.87	<b>-27.1</b>	<b>(-36.5 to -17.7)</b>	<b>-5.65</b>	-25.2	(-51.9–1.49)	-1.85
Income	42.11	(-10.4–94.6)	1.57	0.04	(-0.03–0.11)	1.15	0.05	(-0.22–0.32)	0.37
Dog owner (vs. no)	<b>14.0</b>	<b>(3.26–24.7)</b>	<b>2.56</b>	<b>13.0</b>	<b>(2.80–23.2)</b>	<b>2.50</b>	-7.15	(-37.5–23.2)	-0.46
BMI	<b>-1.86</b>	<b>(-2.77 to -0.96)</b>	<b>-4.04</b>	<b>-2.61</b>	<b>(-3.72 to -1.5)</b>	<b>-4.62</b>	<b>-6.44</b>	<b>(-10.2 to -2.71)</b>	<b>-3.38</b>
Former smoker (vs. non-smoker)	1.45	(-10.5–13.4)	0.24	<b>-12.1</b>	<b>(-23.2 to -0.97)</b>	<b>-2.13</b>	-31.2	(-64.2–1.79)	-1.85
Current smoker (vs. non-smoker)	<b>-36.5</b>	<b>(-49.4 to -23.6)</b>	<b>-5.53</b>	<b>-41.5</b>	<b>(-54.6 to -28.4)</b>	<b>-6.20</b>	-41.8	(-84.1–0.38)	-1.94
Current smoker (vs. former smoker)	<b>-37.9</b>	<b>(-52.5 to -23.3)</b>	<b>-5.09</b>	<b>-29.4</b>	<b>(-43.9 to -14.9)</b>	<b>-3.98</b>	-10.7	(-56.5–35.2)	-0.46
Disease diagnoses	-7.23	(-18.2–3.71)	-1.30	-3.96	(-14.2–6.29)	-0.76	8.93	(-21.9–39.8)	0.57
Satisfaction	7.36	(-1.49–16.2)	1.63	<b>14.5</b>	<b>(5.44–23.6)</b>	<b>3.13</b>	<b>-32.0</b>	<b>(-59.4 to -4.71)</b>	<b>-2.30</b>
Happiness	<b>12.6</b>	<b>(2.52–22.7)</b>	<b>2.45</b>	-8.86	(-19.7–1.97)	-1.60	-8.70	(-41.4–24.0)	-0.52
Biodiversity and forest									
Land cover diversity	0.28	(-1.53–2.10)	0.31	1.21	(-0.55–2.96)	1.35	1.48	(-4.01–6.96)	0.53
Forest area I	<b>-0.23</b>	<b>(-0.37 to -0.10)</b>	<b>-3.38</b>	-0.04	(-0.17–0.09)	-0.59	0	(-0.37–0.36)	-0.02
Forest age	-0.10	(-0.55–0.35)	-0.43	0.03	(-0.43–0.48)	0.12	0.33	(-0.98–1.64)	0.49
Tree stand structure diversity	0.08	(0–0.17)	1.96	<b>0.12</b>	<b>(0.03–0.20)</b>	<b>2.73</b>	-0.01	(-0.27–0.25)	-0.10
Accessibility									
Distance to river	2.94	(-0.17–6.06)	1.85	-1.80	(-5.41–1.80)	-0.98	-6.16	(-18.8–6.47)	-0.96
Distance to lake	1.19	(-4.16–6.55)	0.44	0.72	(-4.44–5.87)	0.27	-9.12	(-24.4–6.14)	-1.17
Distance to sea	-0.02	(-0.11–0.06)	-0.53	-0.02	(-0.10–0.06)	-0.51	<b>-0.32</b>	<b>(-0.56 to -0.08)</b>	<b>-2.59</b>
Distance to protection area	-1.67	(-4.05–0.71)	-1.38	-0.39	(-2.74–1.97)	-0.32	5.86	(-0.83–12.5)	1.72
Cycleways length	0.08	(-0.61–0.77)	0.23	0.29	(-0.40–0.98)	0.83	1.03	(-1.25–3.31)	0.89
Distance to supermarket	0.27	(-0.93–1.47)	0.44	-1.13	(-2.28–0.01)	-1.94	2.36	(-0.44–5.16)	1.65

Est: model estimate; CI: confidence intervals; t-value: standardized difference.  
 Bolded values represent significant differences ( $p < 0.05$ ).

MVPA among participants with low total PA (Table 3b), but positively associated with LPA among individuals with high total PA (Table 3a).

Distance to sea was negatively associated with LPA (Table 3a) but positively associated with MVPA (Table 3b) in the High PA group. In the Low PA group, the level of LPA was lower in areas with more cycleways (Table 3a). In the Low and Moderate PA groups higher LPA was related to longer distance to supermarket (Table 3a).

Among Low, Moderate, and High PA groups, being a female, a couple, and having small children at home were related to a higher level of LPA (Table 3a), whereas being a male and having lower BMI were related to a higher level of MVPA (Table 3b).

In the Low PA group the higher level of MVPA was related to owning a dog, increased happiness, and lower prevalence of smoking (Table 3b). In the Moderate PA group, higher LPA was related to lower income, and being former or current smoker, whereas the level of MVPA was lower among former and current smoker and higher among dog owners and those who were satisfied with life (Table 3b). In the High PA group, income was negatively associated with LPA (Table 3a), and life satisfaction was negatively associated with MVPA (Table 3b).

## Discussion

In this population-based cross-sectional cohort study, our aim was to investigate how the biodiversity, forest characteristics, and distance to blue spaces in residential area, is associated with accelerometer-measured LPA and MVPA according to PA level in middle aged people. We found that higher tree stand structure diversity was related to higher level of MVPA among individuals with moderate total daily PA, whereas the negative relationship was found with LPA in both Moderate and High PA groups. Higher residential forest area was associated with lower amount of MVPA among the participants with low total daily PA, and higher amount of LPA among individuals with high total daily PA. In the High PA group, the level of LPA was lower and the level of MVPA higher close to the sea. Compared to the socio-demographic and personal factors, the environmental features in the residential area seemed to have a weaker association with the levels of LPA and MVPA.

According to our results, green spaces with high tree stand structure diversity in residential areas were associated with MVPA more than LPA. As stand volume diversity is a measure of habitat heterogeneity in terms of the number and size of trees, it indicates not only greater habitat and species diversity but also variability in the scenery, which can attract those who exercise outdoors. As the other biodiversity variables were not associated with PA, biodiversity as such may not have such an important role regarding PA in residential areas, but a more variable scenery may be preferred over monotonous ones (e.g., Siikamäki et al., 2015; Tolvanen et al., 2020). This is not surprising, as it has been noted that people have limited capacity to observe actual biodiversity (Dallimer et al., 2012), whereas scenery plays an important role in increasing the attractiveness of green spaces (Giles-Corti et al., 2005; Neuvonen et al., 2019).

The amount and proximity of green spaces as well as the provision of recreational facilities (e.g., Giles-Corti et al., 2005; Neuvonen et al., 2019; Pyky et al., 2019) have been shown to be more important than biodiversity for promoting leisure time PA in

residential areas. In Finland, Neuvonen et al. (2019) found that beautiful scenery, accessibility, and provision of good recreational facilities were most often mentioned as important qualities for the green spaces used for outdoor recreation and green exercise, whereas diverse animal and plant species composition were mentioned less often. Also, previous studies have shown that people usually prefer openness and good visibility in the forest (e.g., Sonntag-Öström et al., 2014; Tyrväinen et al., 2001), and the decaying and dead trees, typical for biodiverse environment, are found unpleasant (Gundersen & Frivold, 2011; Tyrväinen et al., 2001).

Earlier results on the importance of the amount of green space (Astell-Burt et al., 2014; Dewulf et al., 2016; Kaczynski et al., 2009; Pyky et al., 2019) are supported by our study, as residential forest area was positively associated with LPA among individuals with high total daily PA. Contrary to earlier studies (e.g., Astell-Burt et al., 2014; Dewulf et al., 2016; Smith et al., 2019), we did not find a positive association between residential greenness and MVPA. Instead, in the Low PA group, MVPA was negatively associated with forest area. In addition, we found no association between natural environment features and physical activity in low PA group contradicting the study by Pyky et al. (2019). Our findings that residential greenness is positively associated with LPA but not with MVPA coincide with the earlier results obtained from NFBC 1966 about PA and residential greenness measured with Normalized Difference Vegetation Index (NDVI) (Puhakka et al., 2020). Dewulf et al. (2016) also observed that LPA was higher in greener areas among late middle-aged adults in Belgium, but unlike our study, the results were even stronger for MVPA than LPA. In a German study of adolescents, neighborhood greenness (NDVI) was associated with more leisure time MVPA among females and rural dwellers, but no association between greenness and LPA was found (Markevych et al., 2016). In Finland, both rural and urban areas are relatively green (Kabisch et al., 2016), and the forest areas are also publicly available to all residents, as the “Every man’s rights” in Finland enables all residents to use green areas for recreation. Our results may suggest that the nearby forest environments encourage those who already are physically active to have additional light leisure time exercise, such as walking in the forest, but for less physically active individuals, the forest may not be the first choice for more vigorous PA.

Water elements are often preferred in the landscape and have been associated positively with PA in residential areas (Gascon et al., 2017; Karusisi et al., 2012). In our study, living close to sea was associated with lower LPA but higher MVPA among high PA group. Finding is in line with Karusisi et al. (2012) who found that the probability of jogging within a residential neighborhood increased with areas including water bodies. However, Pyky et al. (2019) did not find association between distance to water and green exercise, but in that study the type of blue spaces was not differentiated. We did not find associations between the distance to other blue space types, i.e., rivers and lakes and LPA or MVPA. The lack of appropriate infrastructure for outdoor exercise, such as beaches, coastal paths, and canal towpaths (Elliott et al., 2020), may be one reason why we found that only seas were positively associated with PA. Importance of sea might also be because relatively many of the cohort members live in urban areas located on the sea coast, and MVPA among NFBC66 members have been found to be higher in urban areas (Puhakka et al., 2020).

Despite the increasing evidence of the positive associations of green and blue spaces and PA, inconsistent results have also been reported (e.g., Gascon et al., 2017; Hillsdon et al., 2006; Markevych et al., 2016). Inconsistency may be explained by the multitude of factors affecting the health and well-being outcomes of green and blue spaces. The possible beneficial influence of nature can be covered or modified by socio-demographic and personal factors, such as income, employment, education, or smoking (Hartig et al., 2014; James et al., 2015; White et al., 2013). Socio-demographic and personal factors were most strongly associated with PA in our study. Being a female, being a couple, and having small children were positively associated with LPA, and being male and having a lower BMI were positively related to MVPA among all total daily PA groups. In addition, owning a dog was positively associated with PA among Low and Moderate PA groups, supporting the findings from earlier research (Veitch et al., 2019; Westgarth et al., 2019). The used measures and data of PA, greenness, biodiversity, forest characteristics, and blue spaces can also cause inconsistency in the results. Klompaker et al. (2018) determined that the association with outdoor PA was stronger for greenness calculated using NDVI values than green space calculated from land-use data. Smith et al. (2019) found that greenness was associated with reported but not recorded PA.

The urbanicity level of the living environment is also associated with PA levels and should be considered in future studies. Dewulf et al. (2016) found that spending more time in non-green areas was associated with more sedentary behavior. Our results support their finding as more individuals with low total daily PA lived in urban areas, whereas those with high total daily PA mostly lived in rural areas. The higher activity levels in rural areas can be partly explained by the higher amount of yard work and gardening needed. In addition, the proximity to green spaces in rural areas can promote leisure time physical activities, such as walking, biking, and skiing, as well as traditional activities in rural areas, such as picking berries and mushrooms and hunting. Then, individuals who are more active may choose their living environment accordingly (Eid et al., 2008).

### ***Strengths and limitations of the study and future research needs***

The strengths of our study include the large representative population-based birth cohort data including an extensive set of background and personal variables, and an accelerometer-based PA measured over two-week period. We also had a comprehensive set of spatial variables calculated from high-quality datasets describing the environmental variables of the individuals' residential areas.

Limitations include that we used artificially created buffers with a 1-km radius around the participants' homes. Though the selected 1 km for buffer is commonly used, and the greenness measured from radial buffers between 500 and 999 m around residents' homes has been shown to predict physical health effectively, the buffers can wrongly estimate the actual area that the residents use during PA (Browning & Lee, 2017). Utilizing GPS tracking data to locate actual areas that individuals use for PA (e.g., James et al., 2015) would be a more feasible way to avoid the spatial mismatch. GPS data with information not only on location but also on the specific activity type would help obtain a more exact picture of the associations between PA and green spaces' biodiversity and forest characteristics, and blue spaces. As the environmental data that

we used had different levels of resolution ranging from 16 to 96 m, that may have caused some minor inaccuracy of the actual environmental conditions when matching the environmental and cohort data. We also designated the cohort members to urban, peri-urban, and rural areas, and although the classification was based on several variables describing the environment on rural-urban scale, there may be distinct variability inside these three categories.

The cohort data and environmental data are over ten years old. It is possible that changes in environment and people's leisure time activity have occurred. For example, Covid-19 pandemic may have influenced people's perception and use of their close by environment (Litleskare & Calogiuri, 2023). The possibility of repeating the study with more recent data in the future would strengthen the feasibility of the results. Another limitation is that we did not have variables that measured actual species diversity, though habitat diversity can be expected to correlate with species diversity (Dallimer et al., 2012; Fuller et al., 2007; MacArthur, 1972). We used objectively measured variables on biodiversity and forest characteristics, but as the perceived biodiversity and greenness can be even more important, there is a need for more research considering both of these. Furthermore, as our study is cross-sectional, we cannot determine the causality of the relationship. As we used a wrist-worn activity monitor to measure PA, both the LPA and MVPA can partly be a result of work-related activity (Puhakka et al., 2020), and the weekday and weekend activity was not differentiated. Though accelerometers can be used to capture the total activity, it is possible that some activity, such as swimming or cycling is not recognized by accelerometers.

## Conclusions

This study expands the knowledge of the associations between residential area green space biodiversity, forest characteristics, distance to different blue spaces, and accelerometer-measured LPA and MVPA. Our results show that an abundance of forests in residential areas was associated with LPA among those who were already physically active, whereas environments with high diversity in tree stand structure or close to sea and thus variability in scenery were associated with MVPA. Increase in PA may be partly attributable to increase in leisure time activities in nearby nature. However, in general, the environmental variables had a weaker association with PA than individuals' personal and socioeconomic characteristics. As the association of biodiversity and forest characteristics with PA can also be affected by a multitude of other factors, including accessibility and other qualities of green and blue spaces, type of residential environment, and the methods utilized to measure biodiversity or PA, more research involving these factors is needed. Future research should also investigate the association between PA and biodiversity and forest characteristics at the actual locations that individuals use for PA.

## Acknowledgments

We thank all the cohort members and researchers who participated in the 46-year study. We also wish to acknowledge the work of the NFBC project center.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Funding

NFBC1966 received financial support from the University of Oulu [Grant no. 24000692], Oulu University Hospital [Grant no. 24301140], and ERDF European Regional Development Fund [Grant no. 539/2010 A31592]. The study has also been financially supported by the Finnish Ministry of Education and Culture [grant numbers OKM/86/626/2014, OKM/43/626/2015, OKM/17/626/2016, OKM/54/626/2019, OKM/47/626/2017, OKM/78/626/2018, OKM/88/626/2019, and OKM/28/626/2023], the Strategic Research Council (SRC) established within the Academy of Finland [Grant nos. 345220, 345222, 345221], and the Natural Resources Institute Finland and Oulu Deaconess Institute Foundation.

## Data availability statement

NFBC data is available from the University of Oulu, Infrastructure for Population Studies. Permission to use the data can be applied for research purposes *via* the electronic material-request portal. While using the data, we followed the EU General Data Protection Regulation (679/2016) and the Finnish Data Protection Act. The use of personal data is based on the cohort participants' written informed consent in their latest follow-up study, which may cause limitations to its use. Please, contact NFBC project center ([NFBCprojectcenter@oulu.fi](mailto:NFBCprojectcenter@oulu.fi)) and visit the cohort website ([www.oulu.fi/nfbc](http://www.oulu.fi/nfbc)) for more information.

## References

- Aerts, R., Honnay, O., & Van Nieuwenhuysse, A. (2018). Biodiversity and human health: Mechanism and evidence of the positive health effects of diversity in nature and green spaces. *British Medical Bulletin*, 127(1), 5–22. <https://doi.org/10.1093/bmb/ldy021>
- Astell-Burt, T., Feng, X., & Kolt, G. S. (2014). Green space is associated with walking and moderate-to-vigorous physical activity (MVPA) in middle-to-older-aged adults: Findings from 203 883 Australians in the 45 and up study. *British Journal of Sports Medicine*, 48(5), 404–406. <https://doi.org/10.1136/bjsports-2012-092006>
- Bates, D., Mächler, M., Bolker, B. M., & Walker, S. C. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67(1), 1–48. <https://doi.org/10.18637/jss.v067.i01>
- Björk, J., Albin, M., Grahn, P., Jacobsson, H., Ardö, J., Wadbro, J., Östergren, P.-O., & Skärbäck, E. (2008). Recreational values of the natural environment in relation to neighbourhood satisfaction, physical activity, obesity and wellbeing. *Journal of Epidemiology and Community Health*, 62(4), e2. <https://doi.org/10.1136/jech.2007.062414>
- Bowler, D. E., Buyung-Ali, L. M., Knight, T. M., & Pullin, A. S. (2010). A systematic review of the evidence for the added benefits to health of exposure to natural environments. *Public Health*, 10, 456. <http://www.biomedcentral.com/1471-2458/10/456>
- Browning, M., & Lee, K. (2017). Within what distance does “greenness” bet predict physical health? A systematic review of articles with GIS buffer analyses across the lifespan. *International Journal of Environmental Research and Public Health*, 14(7), 675. <https://doi.org/10.3390/ijerph14070675>
- CBD Secretariat (2010). Retrieved December 2, 2019, from <http://www.cbd.int/2010/biodiversity/>
- Crawley, M. J. (2007). *The R book*. John Wiley & Sons. <https://doi.org/10.1002/9780470515075>
- Dallimer, M., Irvine, K. N., Skinner, A. M. J., Davies, Z. G., Rouquette, J. R., Maltby, L. L., Warren, P. H., Armsworth, P. R., & Gaston, K. J. (2012). Biodiversity and the feel-good factor: Understanding associations between self-reported human well-being and species richness. *BioScience*, 62(1), 47–55. <https://doi.org/10.1525/bio.2012.62.1.9>

- de Jong, K., Albin, M., Skärbäck, E., Grahn, P., & Björk, J. (2012). Perceived green qualities were associated with neighborhood satisfaction, physical activity, and general health: Results from a cross-sectional study in suburban and rural Scania, southern Sweden. *Health & Place*, 18(6), 1374–1380. <https://doi.org/10.1016/j.healthplace.2012.07.001>
- Dewulf, B., Neutens, T., Van Dyck, D., De Bourdeaudhuij, I., Broekx, S., Beckx, C., & Van de Weghe, N. (2016). Associations between time spent in green areas and physical activity among late middle-aged adults. *Geospatial Health*, 11(3), 411. <https://doi.org/10.4081/gh.2016.411>
- Dinno, A. (2017). dunn.test: Dunn's test of multiple comparisons using rank sums. R package version 1.3.5. <https://CRAN.R-project.org/package=dunn.test>
- Eid, J., Overman, H. G., Puga, D., & Turner, M. A. (2008). Fat city: Questioning the relationship between urban sprawl and obesity. *Journal of Urban Economics*, 63(2), 385–404. <https://doi.org/10.1016/j.jue.2007.12.002>
- Elliott, L. R., White, M. P., Grellier, J., Garrett, J. K., Cirach, M., Wheeler, B. W., Bratman, G. N., van den Bosch, M. A., Ojala, A., Roiko, A., Lima, M. L., O'Connor, A., Gascon, M., Nieuwenhuijsen, M., & Fleming, L. E. (2020). Research note: Residential distance and recreational visits to coastal and inland blue spaces in eighteen countries. *Landscape and Urban Planning*, 198, 103800. <https://doi.org/10.1016/j.landurbplan.2020.103800>
- ESRI (2001). *ESRI, A. & Components, M.* Environmental Systems Research Institute.
- Farrahi, V., Kangas, M., Walmsley, R., Niemelä, M., Kiviniemi, A., Puukka, K., Collings, P. J., Korpelainen, R., & Jämsä, T. (2021). Compositional associations of sleep and activities within the 24-h cycle with cardiometabolic health markers in adults. *Medicine & Science in Sports & Exercise*, 53(2), 324–332. <https://doi.org/10.1249/MSS.0000000000002481>
- Fong, K. C., Hart, J. E., & James, E. (2018). A review of epidemiologic studies on greenness and health: Updated literature through 2017. *Current Environmental Health Reports*, 5(1), 77–87. <https://doi.org/10.1007/s40572-018-0179-y>
- 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(4), 390–394. <https://doi.org/10.1098/rsbl.2007.0149>
- Gascon, M., Zijlema, W., Vert, C., White, M. P., & Nieuwenhuijsen, M. J. (2017). Outdoor blue spaces, human health and well-being – A systematic review of quantitative studies. *International Journal of Hygiene and Environmental Health*, 220(8), 1207–1221. <https://doi.org/10.1016/j.ijheh.2017.08.004>
- Giles-Corti, B., Broomhall, M. H., Knuiaman, M., Collins, C., Douglas, K., Ng, K., Lange, A., & Donovan, R. J. (2005). Increasing walking—How important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine*, 28(Suppl. 2), 169–176. <https://doi.org/10.1016/j.amepre.2004.10.018>
- Gundersen, V., & Frivold, L. (2011). Naturally dead and downed wood in Norwegian boreal forests: Public preferences and the effect of information. *Scandinavian Journal of Forest Research*, 26(2), 110–119. <https://doi.org/10.1080/02827581.2010.536567>
- Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., & Ekelund, U. (2012). Global physical activity levels: Surveillance progress, pitfalls, and prospects. *Lancet*, 380(9838), 247–257. [https://doi.org/10.1016/S0140-6736\(12\)60646-1](https://doi.org/10.1016/S0140-6736(12)60646-1)
- Hartig, T., Mitchell, R., de Vries, S., & Frumkin, H. (2014). Nature and health. *Annual Review of Public Health*, 35(1), 207–228. <https://doi.org/10.1146/annurev-publhealth-032013-182443>
- Hautala, A., Martinmaki, K., Kiviniemi, A., Kinnunen, H., Virtanen, P., Jaatinen, J., & Tulppo, M. (2012). Effects of habitual physical activity on response to endurance training. *Journal of Sports Sciences*, 30(6), 563–569. <https://doi.org/10.1080/02640414.2012.658080>
- Hillsdon, M., Panter, J., Foster, C., & Jones, A. (2006). The relationship between access and quality of urban green space with population physical activity. *Public Health*, 120(12), 1127–1132. <https://doi.org/10.1016/j.puhe.2006.10.007>
- Houlden, V., Jani, A., & Hong, A. (2021). Is biodiversity of greenspace important for human health and wellbeing? A bibliometric analysis and systematic literature review. *Urban Forestry & Urban Greening*, 66, 127385. <https://doi.org/10.1016/j.ufug.2021.127385>
- Husu, P., Suni, J., Vähä-Ypyä, H., Sievänen, H., Tokola, K., Valkeinen, H., Mäki-Opas, T., & Vasankari, T. (2014). The level of physical activity and sedentary behaviour in Finnish adults. *Suomen Lääkärilehti*, 69(Jan), 1860–1866.

- James, P., Banay, R. F., Hart, J. E., & Laden, F. (2015). A review of the health benefits of greenness. *Current Epidemiology Reports*, 2(2), 131–142. <https://doi.org/10.1007/s40471-015-0043-7>
- Kabisch, N., Strohbach, M., Haase, D., & Kronenberg, J. (2016). Urban green space availability in European cities. *Ecological Indicators*, 70, 586–596. <https://doi.org/10.1016/j.ecolind.2016.02.029>
- Kaczynski, A. T., Potwarka, L. R., Smale, B. J. A., & Havitz, M. E. (2009). Association of parkland proximity with neighborhood and park-based physical activity: variation by gender and age. *Leisure Sciences*, 31(2), 174–191. <https://doi.org/10.1080/01490400802686045>
- Karusisi, N., Bean, K., Oppert, J.-M., Pannier, B., & Chaix, B. (2012). Multiple dimensions of residential environments, neighbourhood experienced, and jogging behavior in the RECORD study. *Preventive Medicine*, 55(1), 50–55. <https://doi.org/10.1016/j.ypmed.2012.04.018>
- Kemperman, A. D. A. M., & Timmermans, H. J. P. (2008). Influence of socio-demographics and residential environment on leisure activity participation. *Leisure Sciences*, 30(4), 306–324. <https://doi.org/10.1080/01490400802165099>
- Keskinen, K. E., Rantakokko, M., Suomi, K., Rantanen, T., & Portegijs, E. (2018). Nature as a facilitator for physical activity: Defining relationships between the objective and perceived environment and physical activity among community dwelling older people. *Health & Place*, 49, 111–119. <https://doi.org/10.1016/j.healthplace.2017.12.003>
- Kinnunen, H., Häkkinen, K., Schumann, M., Karavirta, L., Westerterp, K. R., & Kyröläinen, H. (2019). Training-induced changes in daily energy expenditure: Methodological evaluation using wrist-worn accelerometer, heart rate monitor, and doubly labeled water technique. *PLOS One*, 14(7), e0219563. <https://doi.org/10.1371/journal.pone.0219563>
- Kinnunen, H., Tanskanen, M., Kyröläinen, H., & Westerterp, K. R. (2012). Wrist-worn accelerometers in assessment of energy expenditure during intensive training. *Physiological Measurement*, 33(11), 1841–1854. <https://doi.org/10.1088/0967-3334/33/11/1841>
- Klompaker, J. O., Hoek, G., Bloemasma, L. D., Gehring, U., Strak, M., Wijga, A., van den Brink, C., Brunekreef, B., Lebret, E., & Janssen, N. A. H. (2018). Green space definition affects associations of green space with overweight and physical activity. *Environmental Research*, 160, 531–540. <https://doi.org/10.1016/j.envres.2017.10.027>
- Kuznetsova, A., Brockhoff, P. B., & Christense, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software*, 82(13), 1–26. <https://doi.org/10.18637/jss.v082.i13>
- Lee, I. M., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., & Katzmarzyk, P. T. (2012). Effect of physical inactivity on major non-communicable diseases worldwide: An analysis of burden of disease and life expectancy. *Lancet*, 380(9838), 219–229. [https://doi.org/10.1016/S0140-6736\(12\)61031-9](https://doi.org/10.1016/S0140-6736(12)61031-9)
- Litleskare, S., & Calogiuri, G. (2023). Nature visits during the COVID-19 pandemic in Norway: Facilitators, motives, and associations with sociodemographic characteristics. *Frontiers in Public Health*, 11, 1138915. <https://doi.org/10.3389/fpubh.2023.1138915>
- Lovell, R., Wheeler, W. B., 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), 1–20. <https://doi.org/10.1080/10937404.2013.856361>
- MacArthur, R. H. (1972). *Geographical ecology – Patterns in the distribution of species*. Harper.
- Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., de Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M. J., Lupp, G., Richardson, E. A., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J., & Fuertes, E. (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>
- Markevych, I., Standl, M., Sugiri, D., Harris, C., Maier, W., Berdel, D., & Heinrich, J. (2016). Residential greenness and blood lipids in children: A longitudinal analysis in GINIplus and LISAPLUS. *Environmental Research*, 151, 168–173. <https://doi.org/10.1016/j.envres.2016.07.037>
- McEachan, R. R. C., Prady, S. L., Smith, G., Fairley, L., Cabieses, B., Gidlow, C., Wright, J., Dadvand, P., van Gent, D., & Nieuwenhuijsen, M. J. (2016). The association between green space and depressive symptoms in pregnant women: Moderating roles of socioeconomic status and physical activity. *Journal of Epidemiology and Community Health*, 70(3), 253–259. <https://doi.org/10.1136/jech-2015-205954>

- McMorris, O., Villeneuve, P. J., Su, J., & Jerrett, M. (2015). Urban greenness and physical activity in a national survey of Canadians. *Environmental Research*, 137, 94–100. <https://doi.org/10.1016/j.envres.2014.11.010>
- Mikkonen, N., Leikola, N., Lahtinen, A., Lehtomäki, J., & Halme, P. (2018). Forests of high biodiversity value in Finland – The final report of forest biodiversity zonation analyzes. *Finnish Environmental Institute Report*, 9/(2018), 104. [https://helda.helsinki.fi/bitstream/handle/10138/234359/SYKEra\\_9\\_2018.pdf?sequence=1&isAllowed=y](https://helda.helsinki.fi/bitstream/handle/10138/234359/SYKEra_9_2018.pdf?sequence=1&isAllowed=y)
- Millennium Ecosystem Assessment (2005). *Ecosystems and human well-being: Synthesis*. Island Press.
- Neuvonen, M., Kangas, K., Ojala, A., & Tyrväinen, L. (2019). Kaupunkiluonto asukkaiden liikunnan edistäjänä Helsingissä. *Liikunta & Tiede*, 56(6), 77–86.
- Niemelä, M. S., Kangas, M., Ahola, R. J., Auvinen, J. P., Leinonen, A.-M., Tammelin, T. H., Vaaramo, E. S., Keinänen-Kiukaanniemi, S. M., Korpelainen, R. I., & Jämsä, T. J. (2019). Dose-response relation of self-reported and accelerometer-measured physical activity to perceived health in middle age—The Northern Finland Birth Cohort 1966 study. *BMC Public Health*, 19(1), 21. <https://doi.org/10.1186/s12889-018-6359-8>
- Nordström, T., Miettunen, J., Auvinen, J., Ala-Mursula, L., Keinänen-Kiukaanniemi, S., Veijola, J., Järvelin, M.-R., Sebert, S., & Männikkö, M. (2022). Cohort profile: 46 Years of follow-up of the Northern Finland Birth Cohort 1966 (NFBC1966). *International Journal of Epidemiology*, 50(6), 1786–1787. [j. dyab109 https://doi.org/10.1093/ije/dyab109](https://doi.org/10.1093/ije/dyab109)
- Pereira, G., Foster, S., Martin, K., Christian, H., Boruff, B. J., Knuiaman, M., & Giles-Corti, B. (2012). The association between neighborhood greenness and cardiovascular disease: An observational study. *BMC Public Health*, 12(1), 466. <https://doi.org/10.1111/aphw.12031>
- Puhakka, S., Lankila, T., Pyky, R., Kärmeniemi, M., Niemelä, M., Kangas, K., Rusanen, J., Kangas, M., Näyhä, S., & Korpelaine, R. (2020). Satellite imaging-based residential greenness and accelerometry measured physical activity at midlife – Population-based Northern Finland Birth Cohort 1966 study. *International Journal of Environmental Research and Public Health*, 17(24), 9202. <https://doi.org/10.3390/ijerph17249202>
- Pyky, R., Neuvonen, M., Kangas, K., Ojala, A., Lanki, T., Borodulin, K., & Tyrväinen, L. (2019). Individual and environmental factors associated with green exercise in urban and suburban areas. *Health & Place*, 55, 20–28. <https://doi.org/10.1016/j.healthplace.2018.11.001>
- R Core Team (2018). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Revelle, W. (2018). *psych: Procedures for Personality and Psychological Research*. Northwestern University. <https://CRAN.R-project.org/package=psych> Version = 1.8.12
- Riou, M., Abdounour, J., Brochu, M., Prud'homme, D., Rabasa-Lhoret, R., & Doucet, E. (2014). Light physical activity is a better determinant of lower adiposity during the menopausal transition. *Climacteric: The Journal of the International Menopause Society*, 17(1), 79–86. <https://doi.org/10.3109/13697137.2013.810715>
- Saint-Maurice, P. F., Troiano, R. P., Berrigan, D., Kraus, W. E., Kraus, M. D., & Matthews, C. E. (2018). Volume of light versus moderate-to-vigorous physical activity: Similar benefits for all-cause mortality? *Journal of the American Heart Association*, 7, e008815. <https://doi.org/10.1161/JAHA.118.008815>
- Shanahan, D. F., Franco, L., Lin, B. B., Gaston, K. J., & Fuller, R. A. (2016). The benefits of natural environments for physical activity. *Sports Medicine*, 46(7), 989–995. <https://doi.org/10.1007/s40279-016-0502-4>
- Shanahan, D. F., Lin, B. B., Gaston, K., Bush, R., & Fuller, R. A. (2015). What is the role of trees and remnant vegetation in attracting people to urban parks? *Landscape Ecology*, 30(1), 153–165. <https://doi.org/10.1007/s10980-014-0113-0>
- Siikamäki, P., Kangas, K., Paasivaara, A., & Schroderus, S. (2015). Biodiversity attracts visitors to national parks. *Biodiversity and Conservation*, 24(10), 2521–2534. <https://doi.org/10.1007/s10531-015-0941-5>
- Simkin, J., Ojala, A., & Tyrväinen, L. (2020). Restorative effects of mature and young commercial forests, pristine old-growth forests and urban recreation forest – A field experiment. *Urban Forestry & Urban Greening*, 48, 126567. <https://doi.org/10.1016/j.ufug.2019.126567>

- Smith, L., Panter, J., & Ogilvie, D. (2019). Characteristics of the environment and physical activity in midlife: Findings from UK Biobank. *Preventive Medicine, 118*, 150–158. <https://doi.org/10.1016/j.ypmed.2018.10.024>
- Sonntag-Öström, E., Nordin, M., Lundell, Y., Dolling, A., Wiklund, U., Karlsson, M., Carlberg, B., & Järvholm, L. S. (2014). Restorative effects of visits to urban and forest environments in patients with exhaustion disorder. *Urban Forestry & Urban Greening, 13*(2), 344–354. <https://doi.org/10.1016/j.ufug.2013.12.007>
- Thompson Coon, J., Boddy, K., Stein, K., Whear, R., Barton, J., & Depledge, M. H. (2011). Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. *Environmental Science & Technology, 45*(5), 1761–1772. <https://doi.org/10.1021/es102947t>
- Tolvanen, A., Kangas, K., Tarvainen, O., Huhta, E., Jäkäläniemi, A., Kytä, M., Nikula, A., Nivala, V., Tuulentie, S., & Tyrväinen, L. (2020). The relationship between people's activities and values with the protection level and biodiversity. *Tourism Management, 81*, 104141. <https://doi.org/10.1016/j.tourman.2020.104141>
- Tomppo, E., Haakana, M., Katila, M., & Peräsaari, J. (2008). *Multi-source national forest inventory methods and applications. Managing forest ecosystems series*. Springer.
- Tyrväinen, L., Silvennoinen, H., Nousiainen, I., & Tahvanainen, L. (2001). Rural tourism in Finland: Tourists' expectation of landscape and environment. *Scandinavian Journal of Hospitality and Tourism, 1*(2), 133–149. <https://doi.org/10.1080/150222501317244047>
- U.S. Department of Health and Human Services (2018). *Physical activity guidelines for Americans* (2nd ed.). Author.
- UKK Institute (2019). Weekly physical activity recommendation for 18–64-year-olds. Retrieved April 6, 2023, from <https://ukkinstituutti.fi/en/products-services/physical-activity-recommendations/weekly-physical-activity-recommendation-for-18-64-year-olds>
- United Nations, Department of Economic and Social Affairs, Population Division (2019). *World urbanization prospects: The 2018 revision (ST/ESA/SER.A/420)*. United Nations.
- University of Oulu (1966). Northern Finland Birth Cohort, 1966. Retrieved May 29, 2023, from <http://urn.fi/urn:nbn:fi:att:bc1e5408-980e-4a62-b899-43bec3755243>
- Veitch, J., Christian, H., Carver, A., & Salmon, J. (2019). Physical activity benefits from taking your dog to the park. *Landscape and Urban Planning, 185*, 173–179. <https://doi.org/10.1016/j.landurbplan.2019.02.013>
- Vienneau, D., de Hoogh, K., Faeh, D., Kaufmann, M., Wunderli, J. M., & Rösli, M. (2017). More than clean air and tranquillity: Residential green is independently associated with decreasing mortality. *Environment International, 108*, 176–184. <https://doi.org/10.1016/j.envint.2017.08.012>
- Warburton, D. E. R., & Bredin, S. S. D. (2017). Health benefits of physical activity: A systematic review of current systematic reviews. *Current Opinion in Cardiology, 32*(5), 541–556. <https://doi.org/10.1097/HCO.0000000000000437>
- Westgarth, C., Christley, R. M., Jewell, C., German, C. J., Boddy, L. M., & Hayley, C. H. (2019). Dog owners are more likely to meet physical activity guidelines than people without a dog: An investigation of the association between dog ownership and physical activity levels in a UK community. *Scientific Reports, 9*(1), 5704. <https://doi.org/10.1038/s41598-019-41254-6>
- White, M. P., Pahl, S., Ashbullby, K., Herbert, S., & Depledge, M. H. (2013). Feelings of restoration from recent nature visits. *Journal of Environmental Psychology, 35*, 40–51. <https://doi.org/10.1016/j.jenvp.2013.04.002>
- Wilson, E. O. (1984). *Biophilia*. Harvard University Press.
- World Health Organization (2022). *Global status report on physical activity 2022*. Author. <https://www.who.int/publications/i/item/9789240059153>