The importance of urban gardens in supporting children's biophilia

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Exposure to and connection with nature is increasingly recognized as providing significant well-being benefits for adults and children. Increasing numbers of children growing up in urban areas need access to nature to experience these benefits and develop a nature connection. Under the biophilia hypothesis, children should innately affiliate to nature. We investigated children's independent selection of spaces in their neighborhoods in relation to the biodiversity values of those spaces, in three New Zealand cities, using resource-selection analysis. Children did not preferentially use the more biodiverse areas in their neighborhoods. Private gardens and yards were the most preferred space, with the quality of these spaces the most important factor defining children's exposure to nature. Children's reliance on gardens and yards for nature experiences raises concerns for their development of a nature connection, given disparities in biodiversity values of private gardens in relation to socioeconomic status, and the decline in sizes of private gardens in newer urban developments.

biophilia | children | urban biodiversity | resource selection | home range

The biophilia hypothesis proposes that humans have an innate tendency to affiliate toward life and life-like processes as a consequence of evolution, where survival and reproduction were dependent on interactions with the natural environment (1). Research support for this hypothesis has shown that humans prefer green and natural over built landscapes (2), and derive physical and psychological benefits from exposure to green areas (3, 4). In recent studies, there has been a shift away from regarding biophilia as cognitive awareness of life-like processes, to an affective affiliation with life (5). This affective component might be strongest in children, with phenomenological research revealing a deep appreciation of nature in 6- to 12-y-olds in the United States (6). Biophilia is thought to recognize innate relationships between children and nature (7), and an emphasis on children's nature orientation could provide a better framework within which to address 21st century environmental issues, as these affect children (8).

Despite evidence of ingrained biophilia, children's association with natural areas appears to be declining (9). Today the near majority of the world's children grow up in urban areas, where their ability to interact with nature can be limited by the low biodiversity associated with highly modified environments (10), and curtailed by declining independence and reduced freedom to roam (11). Prioritization of vehicle mobility over pedestrians has created barriers to children's movement (12), and parental concerns over traffic and neighborhood safety affect children's desire and ability to play outdoors (13). Moreover, technology might divert children from spending time in accessible natural space. Pergams and Zaradic (14) describe a trend toward "videophilia," the attraction to electronic media, which might be replacing children's interest to explore outdoors.

The loss of children's connection to nature and suppression of the expression of biophilia is concerning for two reasons. First, reduction in access to greenspace and time spent outdoors has a detrimental impact on children's health and well-being, with links to increased obesity (15) and a reduced ability to problem-solve and evaluate risks, which negatively affect mental well-being (16). Second, lack of early connection to nature might result in loss of motivation to protect nature (17). Children's early experiences are crucial in establishing a lifelong connection to nature (18). Reports of children expressing fear of nature (19), and their inability to name common wildlife species (20), are indicators of a growing divide. This disconnection appears strongest in children with the least exposure to nature (21).

Studies of children's affiliation with nature are typically based on verbal reports by children or on observations of play in different settings. Behaviors such as play and learning, and well-being states such as blood pressure, allergies, physical fitness, and attention, are compared between environments with differing levels of green (22). Both approaches have methodological weaknesses. There can be a lack of correspondence between what children say and what they do in natural settings (8), and the interpretation of differences in functioning and well-being between green environments in relation to biophilia can be difficult. An alternative approach is to relate where children independently choose to spend time outside to the biodiversity values of those spaces. We argue that, if children are biophilic, they will use biodiverse spaces within their nearby neighborhoods more than would be expected given the availability and size of those spaces. Urban areas are not necessarily depauperate in biodiversity: some support greater species diversity with more diverse assemblages of habitats than are found in natural ecosystems, providing opportunities for nature-rich experiences (23).

Preference can be robustly evaluated only by estimating probability of use in relation to availability via resource selection analysis (RSA) (24), a mathematical method that is often used in wildlife

Significance

Nature exposure is an important determinant of human mental and physical well-being, but rapid urbanization means that accessing natural areas is increasingly challenging. Children in particular are thought to show a deep affective affiliation with life (biophilia), and health disorders, such as attention-deficit hyperactivity disorder, stress, obesity, and depression, are attributed to lack of interaction with wild nature, termed "nature-deficit disorder." We tested biophilia in children by quantitatively evaluating the availability and use of biodiverse spaces, and found no evidence of preference for biodiverse or wild areas, even where children had access to highly biodiverse areas. Because of constrained movements, children's exposure to nature occurred mostly in private gardens, which are disappearing with densification and ongoing loss of private greenspace.

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studies to inform on how animals interact with their environment by identifying the most important environmental features driving space use at given spatial scales. Specifically, RSA quantifies and models the disproportionate use of environmental features by animals in relation to their availability over an area of interest. This approach has never before been applied to children's space use. In contrast to wildlife, a child's home provides the majority of the resources that largely motivate wild animals' use of space, such as shelter and food, and instead children's main motivations to travel outdoors are to play and visit friends (25–27). Children might avoid habitats they are not allowed to visit alone or where they feel threatened, such as major roadways (13) or parks that are viewed as unsafe (12, 28). In addition to seeking biodiversity for its own value, children may use biodiverse spaces more if they provide greater opportunities for play; alternatively they could avoid these spaces if they are seen as too "wild" or unmanaged (19). Although these motivations for using spaces are clearly different from those of wild animals, the comparison of selected space against its availability using an RSA approach remains a valid tool independent of the motivations driving the identified selection patterns.

We explored how urban children in three New Zealand cities interact with their environment and whether their use of space conforms to the biophilia hypothesis. We focused on the expression of biophilia in children's selection of outdoor space, as this is thought be more valuable than interaction with nature via electronic media (29), and is also associated with multiple health and well-being benefits (22). We used a multiscale approach to assess children's preference for natural areas both within the area they can potentially roam, and within the area they actually frequent (home range, HR). We evaluated the biodiversity values of the spaces used in relation to their availability, and identified whether preferences were conditioned by demographic factors, such as ethnicity, gender, and deprivation. By examining preferences in relation to biodiversity availability, we could determine whether a lack of nature availability limits children's ability to express biophilia. If children have access to greenspaces but do not show positive selection toward them when they are outdoors, then the urban environment might not stimulate the development of biophilia.

Results

Resource Selection Analyses. Model selection results from RSA using resource selection functions (RSF) on the second order of selection to determine where children established their normal activities within surrounding available habitats ["potential range" (PR)] revealed a significant selection of areas close to "gardens" (or "yards," in the American sense) (Fig. 1*A*) (β = –2.43; SE = 0.04; $P < 0.001$), sport grounds (β = −0.46; SE = 0.03; $P < 0.001$), and parklands (β = −0.05; SE = 0.02; $P = 0.04$), and a negative relationship with proximity to both woodlands (β = 0.64; SE = 0.02; $P < 0.001$) and streets (β = 0.14; SE = 0.02; $P < 0.001$). "Natural habitats" was also included in the model but showed no significance (β = 0.03; SE = 0.02; $P = 0.28$). There was little support for the rest of the candidate models, which are listed in Table S1, with the top model scoring a weight of 1. The best model showed that the fixed effects accounted for half of the variation in the data [marginal $R^2 = 0.55$; conditional (fixed and random effects) $R^2 = 0.71$] and a high predictive capacity as estimated from the fivefold cross-validation ($r = 0.96$; $P < 0.001$).

Results of second-order analyses after splitting samples into groups based on deprivation and environmental factors revealed that the model comprising the full set of habitats and including distance to gardens was ubiquitously the top model for all subsets (see Table S2 for model results for all subsets). Children of low deprivation positively selected for street and natural habitats, whereas children of medium and high deprivation showed negative

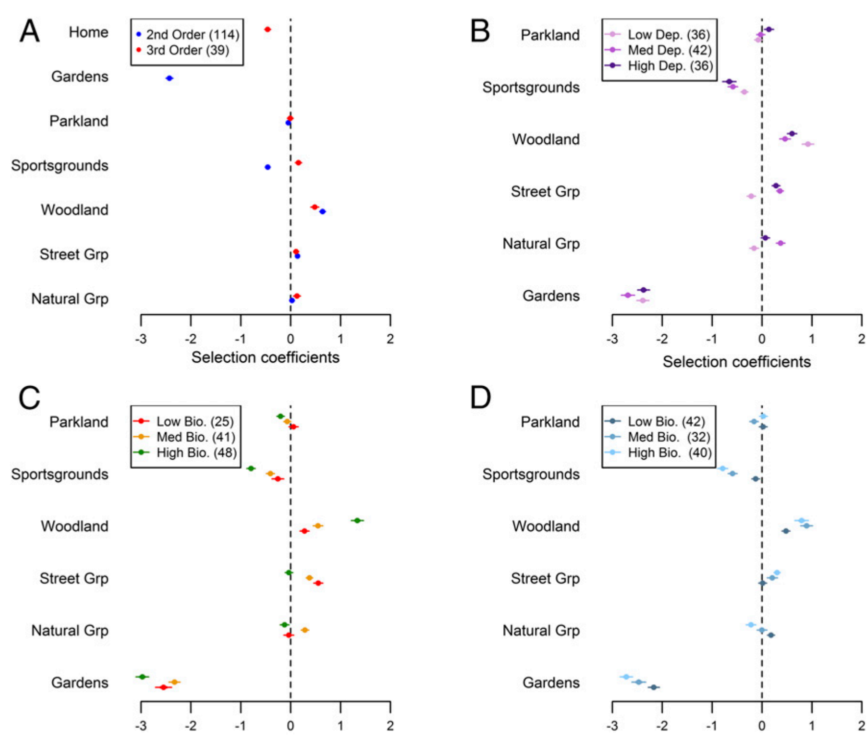

Fig. 1. Children's habitat preferences estimated by the top-ranked model's selection coefficients (±2 SE) based on centered variables. Coefficient values are shown (*A*) for model results for all children assessed at the third order (selection of habitats within the HR) and second order (selection of the HR within the PR) of selection. (*B*–*D*) The selection at the second order for children grouped by deprivation level (*B*), the biodiversity value of the public spaces in their nearby-neighborhood (*C*), and the biodiversity value of their home's garden (*D*). Note that a negative coefficient value indicates a greater use of that habitat type in relation to its availability, and therefore a "positive" selection. The numbers in parenthesis refer to the sample size of each model.

responses to these habitats (Fig. 1*B*). Children from low-deprivation areas also showed a weaker positive association with sport grounds, but a stronger negative response to woodlands. Between-gender comparisons showed boys tended to show greater selection of sport grounds and stronger avoidance of woodlands compared with girls, who had a much stronger preference for gardens or yards (Table S2). The two main ethnic groups included in this study, Pacific Islander/Māori and Pākehā, showed similar habitat preferences (Table S2).

A comparison of children grouped by their access to low-, medium-, and high-biodiversity habitats in their nearby neighborhoods (NN; the area within 500 m of the child's home) indicated that children with more biodiverse neighborhoods showed stronger positive associations with nearly all habitats, particularly gardens, with the exception of woodland (Fig. 1*C*). Children with access to more biodiverse gardens or yards displayed stronger preference toward those areas. However, access to higher-biodiversity gardens did not influence their selection of nongarden habitats (Fig. 1*D*).

The best model at the third order of selection, which identified the habitat patches used within the HR, revealed strong selection of sites close to the child's home (Fig. 1*A*) ($\beta = -0.46$; SE = 0.03; $P < 0.001$), and a significant negative relationship with sites close to woodland (β = 0.48; SE = 0.04; $P < 0.001$), natural habitats ($\beta = 1.41$; SE = 0.11; $P < 0.001$), streets ($\beta = 0.11$; SE = 0.030; $P < 0.001$), and sport grounds ($\beta = 0.16$; SE = 0.03; $P < 0.001$). The variable parkland was also included in the model but was not significant ($\beta = 0.01$; SE = 0.03; $P = 0.76$). There was no support for the other candidate models (Table S3). The model explained only 21% of the total variance of the data (marginal $R^2 = 0.10$, random effect $R^2 = 0.21$), and had a low predictive capability ($r = 0.48$; $P = 0.17$), as estimated from the fivefold cross-validation.

Children's Use of Habitats and Associated Biodiversity. Across all children, the most used habitat types were private gardens (46% of used locations) and residential streets (14%) (Fig. S1). Around 8% of time was spent on sport grounds, and ~5% in woodland, vacant, or natural habitats combined. Most children's NNs contained nearly all habitat types. Over 90% of children had a park within their NN, and 100% had an accessible garden or yard in their NN, whether their own or one they were allowed to visit.

Model-averaged results indicated that the strongest determinant of how much biodiversity children encountered was the biodiversity value of their own garden or yard, with a relative importance of 1 (Table 1). Socioeconomic factors were less important, with deprivation being the third-most important variable, with little difference between genders and ethnicities. The biodiversity of the NN was negatively associated with the amount of biodiversity encountered by children, but this was not significant, with confidence intervals overlapping zero. Larger HRs had a small positive effect on children encountering nature, but this was also not significant.

Discussion

Children's use of different urban habitats and their selection of habitats based on relative use and availability did not conform to the biophilia hypothesis. Other studies using different methods have shown preferences by children for biodiverse spaces (30, 31), and children in our study did use formal greenspaces to some extent (~20% of their time) and displayed a strong affiliation toward gardens or yards, spending over 40% of their outside time in these areas. However, the lack of any positive affiliation with "wild" greenspaces suggests children are either not viewing these spaces positively as interesting and safe places to spend time in, or there are other factors discouraging use of these sites.

At the second order of selection children's strongest preference was to be close to gardens or yards, and they also showed positive selection toward sport grounds, which was not evident at the third order. These changes might be because of the lower availability of gardens and sport grounds at the PR scale than at the HR scale, as children might center their HRs around these sites, but use them only infrequently in comparison with time spent at home. Children's positive selection of gardens and sport grounds, both recreational greenspaces, suggests that opportunities for sports and play might be more important to them than any opportunities associated with biodiverse areas. Additionally these spaces may be seen as safer spaces then the "wild" habitat types of woodland and natural habitats. Other studies also found that children preferred formal and sport settings (30, 32), with the most attractive areas being those with the greatest variety of play opportunities (31).

The preference for gardens was also found in studies of children's use of neighborhoods, which report preferences for being close to home (28, 32). Our findings raise the question of whether by selecting for gardens or yards, children are demonstrating biophilia by choosing the most convenient habitat with high-biodiversity value, or whether they choose to spend time in gardens because these represent safe, nearby, and play-specific habitats. A decline in children's independent mobility levels has been documented (33, 34) and the preference for gardens as outdoor play areas in this study might reflect an unwillingness to move far from home. Parental safety concerns might also play a role; even within the PR area children could be influenced by their parents to be wary of their neighborhood, of traveling far, and visiting new places on their own (11, 35). However, most children thought their neighborhood was safe (36).

Our results lend support to the argument that children are spending less time in nature, despite living in relatively biodiverse neighborhoods. We found neighborhoods generally had high levels of biodiversity, with every child having a greenspace in addition to

Table 1. Summary of model-averaged LMMs identifying the most important variables linked to how much biodiversity children encountered in their time spent outdoors

Fixed effects	Coefficient estimate	Adjusted SE	95% Confidence intervals	Relative importance
Intercept	1.59	0.13	1.33, 1.85	
Garden biodiversity	0.02	0.03	0.02, 0.03	1
Public nearby neighborhood biodiversity	$-3.28E^{-5}$	$1.12E^{-4}$	$-1.17E^{-4}$, $5.15E^{-5}$	0.33
Deprivation	$-8.06E^{-5}$	$2.12E^{-4}$	$-4.95E^{-4}$, $3.34E^{-4}$	0.27
Home range size	$2.18E^{-4}$	$3.62E^{-4}$	$-4.92E^{-4}$, $9.27E^{-4}$	0.29
Gender (male)	$-4.32E^{-3}$	$2.17E^{-2}$	−0.05, 0.04	0.26
Ethnicity: (Asian)				0.10
Pacific Islander/Māori	$-5.56E^{-3}$	0.05	−0.09, 0.08	
Pākehā	0.018	0.04	−0.06, 0.10	
Other	−0.04	0.05	−0.13, 0.06	

All coefficients were standardized and the reference values for categorical variables are shown in brackets.

an accessible garden or yard within 500 m of their home. However, one-third of the children did not have access to all habitat groups, indicating that a degree of restriction in their movements is removing the opportunity to use the spaces available in their neighborhood. The RSA assessed only the children with access to all habitat groups, indicating for the majority of children their limited selection of natural environments was despite having access to these habitats. Weak evidence for a biophilic response was provided by our finding that selection for gardens or yards was stronger when the gardens were more biodiverse. Perhaps these spaces provide more scope for creative play. Reasons behind children not showing greater positive selection for high-biodiversity areas are likely to be complex. For example, we found that children from low-deprivation areas showed positive selection for both streets and natural land cover, whereas children from medium-to-high deprivation areas showed negative selection, possibly because the former group feel safer, or in the case of the latter group, are influenced by parental safety concerns regarding exposure of their children to negative cultures, which is more likely to occur in lower-socioeconomic status neighborhoods (37). Alternatively, wealthier neighborhoods might contain better-resourced and managed public spaces that are more attractive to children if they have more play features (31, 37). Replacement of free time with organized activities could mean that children do not have time to explore the wilder areas of their neighborhood (38). An increase in children's time spent in structured activities would explain the selection for sport grounds. Alternatively, children may be more attracted to spending time indoors with electronic media, such as computer games and social media, than outdoors in greenspaces (14).

Children's preference for gardens makes these an important resource for supporting children's connection to nature, particularly given that the main determinant of how much biodiversity children encountered was the biodiversity value of their home garden. Gardens and yards, particularly when they are large and complex, can be rich in biodiversity. However, despite being biodiverse, gardens are often highly artificial modified environments dominated by exotic species (39), providing a biased experience of nature. Wilder spaces, such as woodlands, afford more complex and challenging experiences for children's play, and may be more important for generating connection to nature (18).

Gardens and yards as private spaces are also not an equally provisioned resource among children, creating inequality in children's opportunity to interact with nature. Garden and neighborhood biodiversity tends to be linked to socioeconomic status (40, 41). Finally, gardens are at risk in urban areas. Densification and land-sparing strategies, which involve more public ecological spaces and "walkable" neighborhoods at the expense of a matrix of private gardens or yards, may be essential for ecosystem services, but won't accommodate the needs of children (42, 43).

Our study suggests any policy of urban densification should be adopted with caution: the replacement of private space with public space might not see equal replacement of time spent in these areas. Children's use of public space was low, and children with more biodiverse neighborhoods did not show any greater preference for biodiverse areas. Establishing and enhancing connection to nature is more important than providing nature nearby (44). Urban planning policies should also focus on supporting children's mobility in urban areas. One-third of children in our study did not have access to all habitat types within their PR. Reducing barriers could lessen safety concerns and encourage children to roam more freely in safe environments, to make more use of nearby greenspaces.

Programs to improve children's knowledge of the environment could establish an early nature connection and encourage visits to natural spaces (45). Benkowitz and Kohler (46) found gardening school programs improved children's ability to name species. Samborksi (21) found children with more biodiverse schoolyards engaged in more interactive play and were more nature-oriented. Children's existing predilection to spending time in gardens could be enhanced by supporting family gardening with combined benefits of improved mental well-being, local biodiversity, and nature connection (47).

By using a quantitative approach we were able to robustly test for children's selection patterns, and account for differing levels of accessibility and quality of nearby biodiversity. The interpretation of these results was facilitated from qualitative analysis of children's interview responses on their use and opinion of their neighborhood. We believe this combined approach is an insightful method in addressing the complex and innately intertwined connections of human interaction and connection to nature. Further research could assess differences in children's selection of habitats along an urban gradient, and whether children exhibit any preference at a finer-scale within each habitat type, such as a preference for the greener parks available to them. We selected children across varying socioeconomic conditions, but with roughly equal availability of greenspace, and cannot extend our results to children living in more urbanized settings, who might not have the same access to gardens and public greenspace. How urban children interact with public greenspace in comparison with "garden-based children" could provide inferences on how urban planning affects children's use of their neighborhood. Furthermore, tying explicitly into our models the effects of barriers to movement and incorporating other factors, such as social and play resources, could improve our ability to predict whether children will use greenspace. Such a model could be used to assess the quality of urban development schemes, from a child's point of view.

Conclusion

Despite the proximity of biodiverse spaces in urban neighborhoods, the majority of children in this study instead stayed close to home and within their gardens or yards. Although these gardens might be selected in part because of their high biodiversity, it is likely that garden use is motivated by other factors; overall, our findings do not support the biophilia hypothesis. Any reduction in nature connection is not because of a lack of biodiversity in urban areas, but because of lifestyle factors, including parental limits and the attraction of electronic media over natural play spaces (14). Greater interaction with biodiversity could be supported by enhancing local biodiversity across a range of urban habitats, especially private gardens, and supporting children's time in natural spaces. In particular, urban planning needs to acknowledge the important role gardens and yards play in relation to children's connection to nature, as currently gardens represent the main source of biodiversity children interact with in their daily lives.

Methods

Study Participants and Data Collection. We assessed children's HRs and habitat use in three cities in New Zealand: Auckland, Wellington, and Dunedin [populations 1,415,550, 471,315, and 127,500, respectively (48)]. Schools were selected using socioeconomic and ethnicity data available through the New Zealand Government's school reports, but were all located in suburbs with similar levels of greenspace. We used Statistics New Zealand's (49) census-based deprivation index to assess socioeconomic status at the mesh-block scale. Some 187 children were recruited from year 5–6 classes (ages 9–11 y) from the nine schools. Participants required parental consent and signed their own child consent form.

We interviewed children about their movements (unaccompanied by adults), with each child building their own personal nature map in an adapted aerial photo interface application we implemented in ArcGIS 10 (ESRI). This map included the identification of home, school, and places they visited (see also ref. 50). Approximately 20 children were interviewed from each class. Each child was interviewed with only the researcher(s) present, minimizing the influence of any social pressures on their responses. This research was approved by the University of Otago Human Ethics Committee (#13/119).

Multiscale Analyses on Children's Space Use. During the interviews, we asked children to place at least 30 dots on the aerial photo interface to indicate where they spent most time outdoors; these points represented their use of the environment (51). We asked children to place dots proportionally to represent

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the amount of time they spent in different areas, with more dots placed in frequently visited areas, and fewer dots in less well-used areas. We asked children to only identify locations which they were able to access without being accompanied by an adult, which excluded trips to areas in cars. We quantified space use using a hierarchical approach at two spatial scales: (*i*) a coarse-scale, where children established where their normal daily activities fell within the range of habitats potentially available to them; and (*ii*) a finer-scale, where children selected specific locations within habitats composing the areas they conduct their normal activities. This is equivalent to second- and third-order selection defined by Johnson (52), where an individual animal selects a HR, and then selects patches to use within the HR, respectively. We adopted the traditional HR definition as the area an individual traverses in its normal activities (53) and estimated HRs for all children who placed ≥30 dots (n = 178, 9 children were excluded for not reaching this number) using the 100% minimum convex polygon (MCP) (54), wherein 30 points is the minimum number recommended for MCP calculations (55). We also defined children's NN as a 500-m buffer around each child's house to provide a consistent comparison of biodiversity available to each child.

We established the outermost boundaries of each child's movements to quantify the area within which children could establish their normal activities (i.e., HR) using a circular buffer with a radius equal to each child's maximum distance traveled from home on their own, which we termed the child's PR. The boundary of the PR was altered to exclude any specific areas which the child indicated they could not access on their own, such as a major road they were not allowed to cross (Fig. 2). For both the PR and HR, we mapped habitats, which were classified into six land-cover types (Tables S4 and S5). We excluded any areas that were not publicly accessible unless the child stated they had access to them, such as a friend's garden or yard. In this way, we characterized the individual availability of habitats within the PR and HR for each child.

We performed an RSA (56) based on RSF (57), an approach used in ecological research to identify patterns of habitat selection by animals in response to the occurrence and availability of a number of environmental variables of interest. We compared the habitat variables that children used, as indicated by the dots, to a random selection of points independently generated to represent availability, first within each PR to assess HR selection within the PR (second order selection), and second within the HR to assess patch selection within HRs (third-order selection). We considered that a ratio of 1:4 used/available points was sufficient to characterize availability of habitats within the accessible areas. For each used/available point, we calculated the Euclidean distance to each nearest accessible garden, parkland, sport ground, streets, and woodland as habitat-type categories, and also the distance to the child's home. This approach provides continuous measures of habitat use and responses to habitats that are not themselves used but that are located nearby; for example, a child could use a playground surrounded by woodland and engage with the biodiversity of the woodland, such as birdsong, while remaining in the playground (58). These variables were used as predictors to construct a priori hypothesis and model sets to explore children's selection of different habitats at the two different scales considered (Table S6) and consider only uncorrelated variables within the same model ($r < 0.6$) (59) to avoid multicollinearity. Following an RSF approach, we used a mixed-effect logistic regression generalized linear mixed-models (LMMs), with individual child as the random effect to accommodate autocorrelation among locations, unbalanced samples, and hierarchical structured data (60). We selected the best models for each scale respectively, using Akaike's Information Criterion (AIC) (61). The predictive ability of the model was assessed using a k-fold cross-validation (5-fold) (57). We only assessed selection patterns of children who had access to the full set of habitat categories, resulting in a sample size of 114 for the second-order analysis and 39 children for the third order.

We ran model sets for the second order of selection for subsets of children based on eight demographic and environmental criteria to explore variations in selection of HR establishment (Table S2). The demographic-based groups included city, gender, ethnicity, and socioeconomic status [low, medium, and high; data from Statistics New Zealand (48) based on house location]. Children were also split into equal-sized groups of high, medium, and low value of biodiversity in their HR and NN, as well as the biodiversity value of their used habitats.

Biodiversity Values of Habitats and Used Dots. A habitat map based on aerial photographs and ground-truth information was drawn in ArcGIS for all habitats within children's HR, NN, and PR. We classified land covers into 13 urban habitat types (Table S4) and calculated a biodiversity score for all greenspaces with areas >2 m^2 within each child's HR and NN (41). The scores incorporated species richness, structural complexity of habitats, naturalness, wildness, degree of management, and man-made features or natural elements, such as trees (41). We summed the scores for all habitats within each child's NN into a single biodiversity score, which could be used as an indicator to compare the amount of biodiversity available (41). The NN incorporated both accessible and inaccessible habitats, to use as a standard measure of the nearby nature within 500 m of each child's home. To compare the level of biodiversity that children were encountering when outdoors, to available biodiversity, we estimated a use of biodiversity score by ascribing children's used points the biodiversity value of the habitat in which they were placed. Scores were averaged according to the proportion of dots placed in each habitat, to account for differences in the number of dots placed by children.

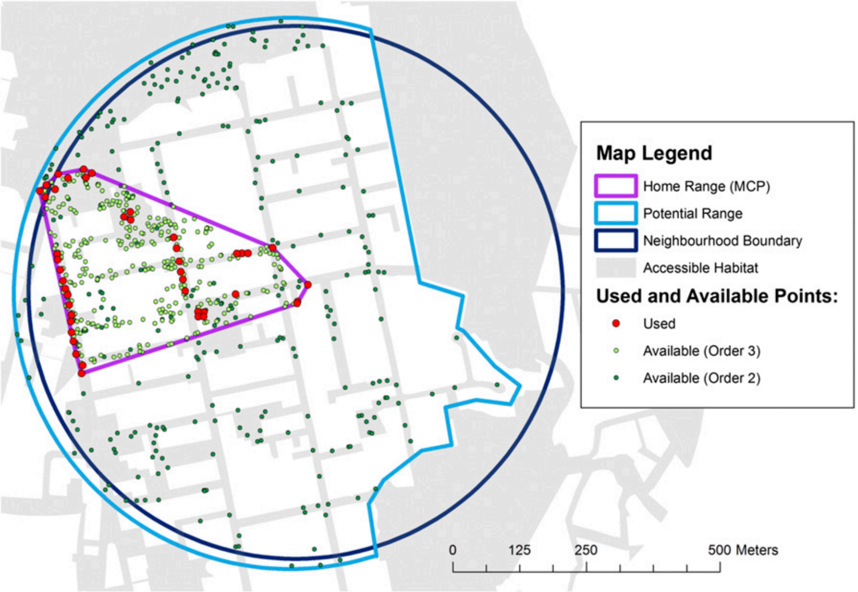

Fig. 2. Scales of children's habitat selection preferences: third order [HR: MCP around the child's used (red dot) locations]; second order [PR: based on the maximum distance traveled at home and excluding areas identified as inaccessible]. In this example, the PR has been amended to exclude woodland habitat on right edge of the buffer that the child was not allowed to visit alone. Randomly generated available points within accessible habitats characterize availability of different habitat types (light green, third order; dark green, second order). The neighborhood boundary is a standard 500-m buffer around each child's home representing the child's NN.

We assessed whether the amount of biodiversity children encounter was influenced by environmental factors (city, HR size, and NN biodiversity) and demographic factors (ethnicity, deprivation, and gender) (Table 1). We ran LMMs in R using the package (62), with neighborhood area nested with city as a random effect to account for repeated sampling within the same neighborhood. Following Grueber et al. (63), we used model averaging from models <10 ΔAICc of the top model to estimate coefficient estimates and calculated the relative importance of each parameter in explaining the variation in the dependent variable, where a value of 1 indicates the parameter was included in all models in the top set using the MuMIn package (64). Residuals conformed to assumptions of homogeneity and normality and variance-inflation factors were less than 3 for all variables (65).

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