The potential of green space in schools to enhance biodiversity, ecological knowledge and student wellbeing

Katherine Anne Howlett

Newnham College

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This thesis is submitted for the degree of Doctor of Philosophy at the University of Cambridge.

Declaration

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the preface and specified in the text.

I further state that no substantial part of my thesis has already been submitted, or is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the preface and specified in the text.

It does not exceed the prescribed word limit for the Biology Degree Committee.

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Thesis Summary

Children in the UK are increasingly disconnected from the natural world, a trend often attributed to rapid urbanisation and reduced daily contact with nature. Spending time in the presence of biodiversity is known to benefit mental health, physical health and wellbeing, and increase awareness of the natural world and conservation, yet there are concerns that direct experiences in nature are being replaced by indirect, technology-mediated experiences, such as through television programmes. However, there is little understanding of how the natural world is portrayed within these media, or how new types of nature experience contribute to the development of a connection with nature, ecological knowledge or the wellbeing benefits of biodiversity. There is also concern that an increasing disconnect between children and the natural world could lead to the attrition of ecological knowledge, reducing awareness of biodiversity loss and eroding support for conservation.

In this context, the relationship between children and the natural world is of crucial importance to the future of conservation and children's wellbeing. In this thesis, I use school grounds in the UK as a focal point for studying the relationship between children and the natural world, and nature-documentary content to assess portrayals of the natural world in the media, as well as exploring the effects of the COVID-19 lockdown in the UK on parental attitudes to green space.

Chapter One: A wide range of disciplines are currently involved in research investigating people's relationship with the natural world. I conducted a literature review and used an evidence-mapping approach to quantify existing research focused on human relationships with the natural world and to identify the extent of overlap between disciplines. I also quantified which disciplines use which terminology and to what extent terminology is discipline-specific. I found that research on people and nature is generally well integrated,

with disparate disciplines citing each other fairly well. However, the communities of disciplines cited were significantly different between publishing disciplines, with research from psychology, education and public health being particularly distinct. There were also consistent differences between publishing disciplines in the terminology used to refer to nature, with a particularly broad range of terms used in psychology and public health research. This could act as a barrier to efficient knowledge exchange, potentially limiting both development of further research and the translation of findings into effective policy.

Chapter Two: To assess the biodiversity that children are exposed to while at school, I conducted biodiversity surveys of 14 primary schools in England. I quantified the amount of green space and levels of associated biodiversity, surveying for invertebrates, birds, plant cover and trees. I assessed whether amount of green space, species abundance, species richness or community composition of taxa varied with school fee-paying status (state-funded, including state and academy, or non-state-funded). Non-state-funded schools had higher levels of vegetation than state-funded schools, and this translated into higher invertebrate abundance, higher species richness of plant cover and larger, more mature trees. My findings have implications for the development of nature connection in children from different socioeconomic backgrounds and provide a powerful case for increasing funding to state-funded schools to improve biodiversity-related management of school grounds.

Chapter Three: During the COVID-19 lockdown in 2020, I designed and distributed an online survey for parents of primary school-aged children to investigate the importance of green space, the amount of time children spent outside and whether this changed as a result of lockdown. 83.3% of rural parents reported being happy with the amount of green space to which their children had access, in contrast with only 40.5% of urban parents. Lockdown restrictions affected parents' attitudes to the importance of green space, with 77.8% of urban parents saying their views had changed during lockdown, in contrast with 41.2% of rural parents. Further, most urban children spent more time inside during lockdown, while most rural children spent more time outside. These findings suggest that lockdown restrictions exacerbated pre-existing differences in nature access between urban and rural children.

Chapter Four: To assess the current state of ecological awareness among UK children, I asked children (aged between seven and 11 years old) from 12 primary schools in England to draw the wildlife in their local green space. I quantified animal and plant species richness and community composition of drawings, as well as the taxonomic level to which terms used in the captions and labels could be identified. I assessed whether there were differences in these metrics between state-funded and non-state-funded school pupils, and whether the level of identification differed between taxa. Children's awareness was skewed towards mammals and birds over invertebrates, reptiles and plants, and children were also better at identifying mammals and birds over other groups. These differences were consistent across the state and non-state education systems, suggesting these biases are cultural rather than educational in origin.

Chapter Five: To investigate the level of information and coverage of the natural world provided by media portrayals, I analysed the content of wildlife documentaries to assess whether they provide an accurate reflection of the natural world and whether conservation messaging in documentaries has changed over time. Sampling an online film database showed that vertebrate groups, particularly mammals and birds, were overrepresented compared to their actual diversity in the natural world, while invertebrate groups and plants were underrepresented. This mirrored the precision with which these organisms were referred to, with mammals and birds being the most well identified and invertebrates and plants being the least identified. The frequency of conservation messaging increased over time, as did mentions of anthropogenic threats to biodiversity, which were not mentioned at all before 1970.

Chapter Six: To assess potential wellbeing benefits of exposure to biodiversity in school children, I collaborated with a secondary school to establish an experiment within their grounds, which assessed species richness in three different settings within the school and quantified changes in student anxiety and pulse rate after walking through different settings. I found that species richness differed significantly between settings, with a restored area of the school grounds having more species of both plants and butterflies. Both state anxiety and pulse rate showed a greater reduction in children who had walked through the most biodiverse setting. This case study has important implications for long-term wellbeing in children and highlights the value of green space in schools for enhancing biodiversity and wellbeing, as well as the role of university-school collaborations in helping ecology come alive in schools.

My findings show that there are differences in children's exposure to biodiversity between school types and that current inequalities in nature access in the UK may have been exacerbated by lockdown restrictions, with implications for children's exposure to nature during key, formative years for nature connection. The patchiness in interactions between children and nature across socioeconomic groups and regions in the UK has long-term implications for which species and ecosystems attract conservation funding and continue to feature prominently in collective cultural memory. While media portrayals of nature are diverse, there are limitations in the coverage afforded to different taxa, which is reflected in children's awareness of nature in their local green spaces. Taken together, my results highlight the need for more concerted work to engage children with the natural world, both in natural environments and through other media, to foster a better understanding of biodiversity and threats the natural world faces. Only by doing so can we successfully engage the next generation with nature conservation, fostering the skills and motivation necessary to halt and reverse biodiversity declines.

Statement of Contributions

Thesis Introduction: I wrote this chapter, with comments from Edgar Turner.

Chapter One: Edgar Turner and I conceived the idea for the study. I collected, processed and analysed the data and wrote the paper. Edgar Turner commented on the paper. This paper is currently in review with *People and Nature* (Howlett & Turner, In review).

Chapter Two: This chapter is reproduced from a paper that is currently under revision in *Environmental Conservation* (Howlett & Turner, Under revision). Edgar Turner and I conceived the idea for the study. I collected, processed and analysed the data, and wrote the paper. Michael Pashkevich provided advice on statistical analyses. Edgar Turner commented on the paper.

Chapter Three: This chapter is reproduced from a paper that has been published in *People and Nature* (Howlett & Turner, 2021). Edgar Turner and I conceived the idea and designed the study. I distributed the online survey, collected, processed and analysed the data, and wrote the paper. Edgar Turner, William Foster, Cecily Maller (Lead Editor at *People and Nature*) and two anonymous reviewers commented on the paper.

Chapter Four: This chapter is reproduced from a paper that has been published in *PLoS ONE* (Howlett & Turner, 2023). Edgar Turner and I conceived the idea and designed the study. I collected, processed and analysed the data, and wrote the paper. Michael Pashkevich provided advice on statistical analyses. Edgar Turner, Daniel de Paiva Silva (Academic Editor at *PLoS ONE*) and two anonymous reviewers commented on the paper.

Chapter Five: This chapter is reproduced from a paper that has been published in *People and Nature* (Howlett et al., 2023). Edgar Turner conceived the initial idea for the study. Edgar Turner, Ho-Yee Lee and Amelia Jaffé (two Part II students in the Department of Zoology) designed the study. Ho-Yee Lee, Amelia Jaffé and I collected the data. I processed and analysed the data, and wrote the paper. Edgar Turner, Ho-Yee Lee, Amelia Jaffé, Matthew Lewis, Cecily Maller (Lead Editor at *People and Nature*), an anonymous Associate Editor at *People and Nature* and two anonymous reviewers commented on the paper.

Chapter Six: This chapter is reproduced from a paper that is currently in review with *People and Nature* (Howlett et al., In review). Sam Goodfellow and Helen Vaughan (biology teachers at Simon Langton Girls' Grammar School (SLGGS)) and Edgar Turner conceived the idea and designed the study. Sam Goodfellow, Helen Vaughan, Iona Selman and Jade Dunn (then sixth-form students at SLGGS), and I collected the data. I processed and analysed the data, and wrote the paper. Edgar Turner, Sam Goodfellow, Helen Vaughan, Iona Selman and Jade Dunn commented on the paper.

Thesis Discussion: I wrote this chapter, with comments from Edgar Turner.

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Contents

Thesis Introduction

1. Habitat and biodiversity loss

The natural world is under increasing threat from accelerating habitat loss, primarily due to land conversion for agriculture, resource extraction, urbanisation and livelihood support, resulting in widespread biodiversity losses (WWF, 2018). Globally, 52% of land has been moderately modified by people, with only 5% remaining entirely unmodified, and human settlement being the dominant driver for 48% of all land conversions (Kennedy et al., 2019). Deforestation is a well characterised problem: the current estimate for net conversion of tropical humid forest is 5.8 million hectares per year (ha/y), with another 2.3 million ha/y visibly degraded (Achard et al., 2002). Conversion of tropical sub-humid and dry forests runs at an additional 2.2 million and 0.7 million ha/y respectively (Mayaux et al., 2005). Despite large variation among estimates, the consensus is that deforestation increased by ~10% between the 1980s and 1990s (DeFries et al., 2002), and that the rate continues to increase (Kim et al., 2015). Concurrently, biodiversity is in decline at global and local scales, with estimated species extinction levels currently 100-1000 times the background rate (De Vos et al., 2015). The latest Living Planet Report estimates that vertebrate populations have declined by an average of 69% from 1970 levels, despite 30 years of policy interventions that have attempted to reverse these declines (WWF, 2022). Flourishing biodiversity across all spatial scales is vital for the provision of ecosystem services, which underpin global food security, economic development and geopolitical stability, and support human health and wellbeing (Klein et al., 2007; WWF, 2022).

2. Nature and human health and wellbeing

Increasingly, we are becoming aware of the essential role that the natural world plays in people's health and wellbeing, with an expanding number of studies focused on this area (Fig 0.1). Exposure to nature is associated with numerous mental health benefits. For example, moving to greener areas is associated with sustained improvements in mental health (Alcock et al., 2014), including better self-reported health (de Bell et al., 2020; de Vries et al., 2003; Maas et al., 2006), increased social interaction (Sullivan et al., 2004), lower crime rates and less aggressive behaviour (Kuo & Sullivan, 2001), and improved stress amelioration (Parsons et al., 1998; Ulrich et al., 1991; Yamaguchi et al., 2006). Prolonged visits to green spaces are associated with lower rates of depression, and more frequent visits to green spaces are associated with greater social cohesion (Shanahan et al., 2016). The beneficial effects of residential greenness on reducing the risk of depression have been observed consistently, with a 4% reduction in the chance of developing major depressive disorders for every interquartile increase in Normalised Difference Vegetation Index (NDVI) (Sarkar et al., 2018). Additionally, exercise in the presence of nature—'green exercise'—has been shown to have greater mental health benefits than exercise in the absence of nature, including positive short- and long-term improvements in self-reported mood and self-esteem (Barton et al., 2012; Barton & Pretty, 2010).

Exposure to nature also benefits physical health, with increases in exposure to green space associated with lower all-cause mortality (Faselis et al., 2014), faster post-operative recovery rates and fewer post-operative complications (Ulrich, 1984), increased longevity (Takano et al., 2002), improved immune function (Li, 2010; Li et al., 2008) and increased expression of anti-cancer proteins (Li et al., 2008). Residential green space can also reduce socioeconomic health inequalities, with populations in greener neighbourhoods showing a reduction in income-related inequalities in all-cause and circulatory disease mortality (Mitchell & Popham, 2008).

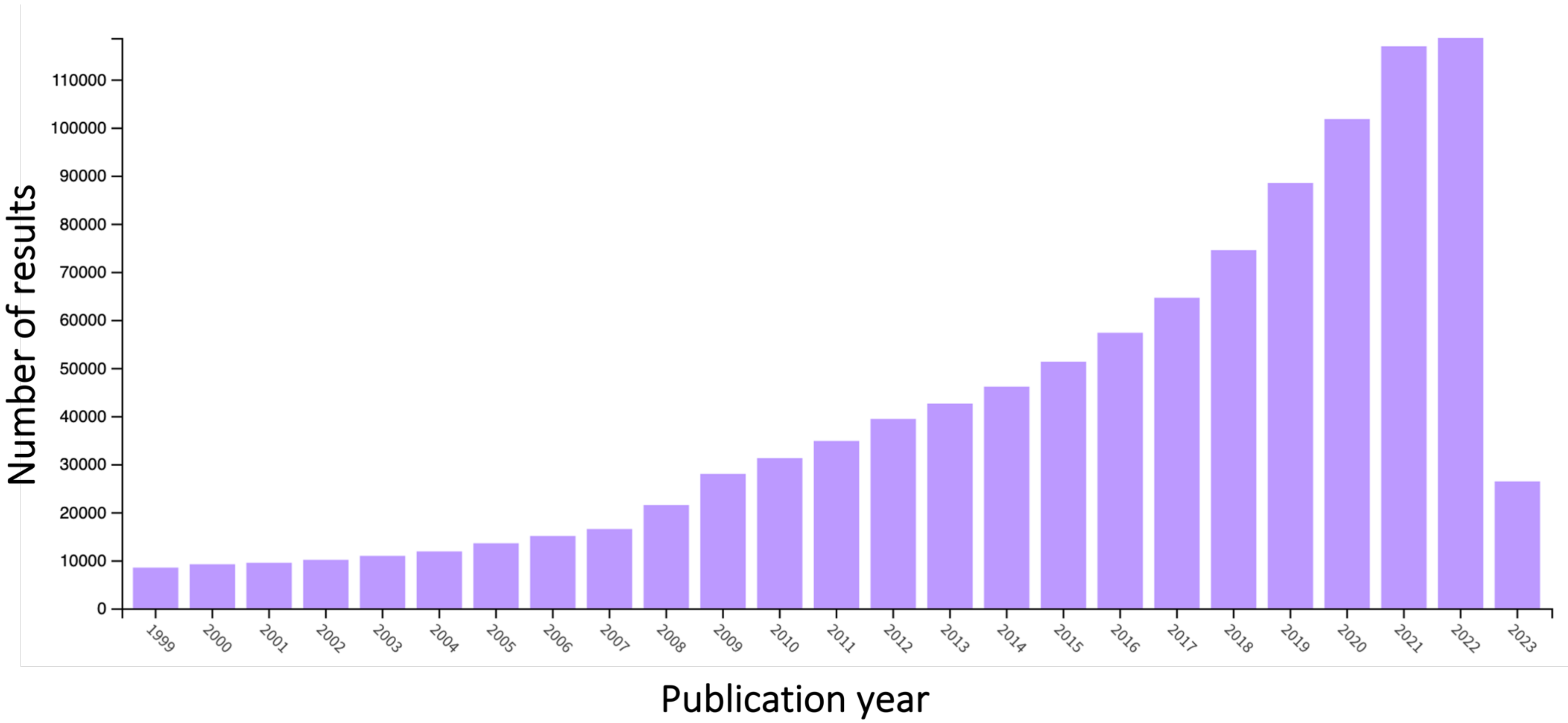

Figure 0.1. Bar chart showing results from Web of Science for the search string 'ALL = ((health OR wellbeing) AND (natur* OR biodiversity OR green*))', ordered by publication year from 1999 to date of search in 2023 (24/04).

3. Nature disconnect

Even as research exploring the relationship between people and nature is in its infancy, it is conducted against a backdrop of increasing urbanisation and disconnect with nature. Over half the world's population now lives in urban areas, with 68% projected to be urban by 2050 (United Nations, 2019). In the UK, the proportion of the population living in cities is predicted to reach over 90% by 2050 (United Nations, 2019), and concerns about the effects of urbanisation on the growth of socioeconomic health inequalities are rising (Dye, 2008). Linked with the trend of urbanisation is one of an increasing disconnect with nature—a gap which is likely to widen in the near future (Miller, 2005). Even by the early 1990s in the USA, there was greater familiarity with corporate logos than with native plant species (Hawken, 1993) and a general ignorance of the relationship between urbanisation, habitat loss and species declines (Adams et al., 1987). In the UK in the early 2000s, children entered secondary school able to name less than 50% of common wildlife types but capable of correctly identifying over 60% of Pokémon 'species' (Balmford et al., 2002). The recent replacement of natural words, such as acorn, buttercup and catkin, in the Oxford Junior Dictionary, with words deemed more relevant to modern life, such as analogue, blog and chatroom, is symptomatic of this increasing disconnect with the natural world (Flood, 2015)—a phenomenon that has coined the term 'nature-deficit disorder' (Louv, 2005).

Nature deficit disorder matters because of its links with a loss of ecological knowledge (Moss, 2012; National Trust, 2008), with knock-on effects for a species' risk of biological and cultural extinction (Jarić et al., 2022). Cultural extinction occurs when the collective memory of a species is lost from society; this happens when references to a species disappear from all aspects of a society's culture: literature, art, music, commercial products and memory. Cultural extinction and biological extinction are linked, such that the more salient or prominent a species appears in wider society, the greater the conservation attention it is likely to receive, in principle reducing its risk of biological extinction (Jarić et al., 2022). In reality, species that are at high risk of extinction because of steep population declines often display an increase in social attention directly before they go extinct, due in part to their relative rarity and therefore how interesting they are perceived to be (Jarić et al., 2022). Often, this increase in attention happens too slowly or too late to translate into effective conservation action, so species may peak in cultural salience immediately before becoming biologically extinct (Jarić et al., 2022).

A good illustration of this principle is a quote often attributed to both the artist Banksy and the psychiatrist Irvin Yalom: 'Species go extinct twice—one time when the last individual stops breathing, and a second time when the collective memory about the species disappears'. Switching our usage of the verb 'disappear' from transitive to intransitive (e.g., 'The shiny horned dung beetle disappeared from the UK in 1974 as a result of intensive farming of grasslands' to 'By intensively farming grasslands, we disappeared the shiny horned dung beetle from the UK in 1974' (The Wildlife Trusts, 2023)) is a confronting, perspective-shifting exercise that can serve to maintain collective cultural responsibility for a species' dual cultural and biological extinctions. This idea comes from Ursula K. Le Guin, known for her writings on feminism and science fiction with deep roots in ecology and environmentalism—an idea that she draws on and develops particularly in her essay 'Disappearing Grandmothers', in the context of 'disappearing' women writers from history (Le Guin, 2023).

In addition to developing ecological knowledge and awareness, time spent in contact with the natural world at a young age is also important for developing a connection with nature and associated pro-environmental behaviours, such as volunteering at a local nature reserve, later in life (Wells & Lekies, 2006). Collectively then, these associated trends of increasing urbanisation and disconnection from nature are likely to make the recruitment of tomorrow's conservationists and ecologists more difficult at a time when the need to find, develop and implement solutions to the interrelated environmental crises of climate change, habitat loss and degradation, and biodiversity loss is increasingly urgent.

4. Schools as centres of biodiversity and human-nature research

School grounds represent a particularly promising focal point for ecological research into nature conservation within urban areas and human connection with the natural world, potentially representing a win-win-win scenario for conservation, education and wellbeing. Firstly, the collective area of land covered by school grounds in the UK is large, with potential for joined-up, centralised, collective management to enhance biodiversity. Secondly, using these spaces as focal points for engagement of school children with the natural world and the science of ecology has the potential to improve ecological knowledge, nature connection and general educational outcomes through improvements in attentional functioning (Sivarajah et al., 2018), thus working to reduce the trend of nature disconnect and facilitating future recruitment of conservationists. Thirdly, school children spend a large portion of their lives in schools, so making these areas more diverse would increase the amount of time children spend in the presence of nature, with knock-on benefits for physical and mental health and wellbeing.

This thesis employs a partnership approach with schools across England to address a wide range of questions related to children's connections with the natural world and impacts of this on health and wellbeing. This approach has benefits that snowball beyond those listed above, including the development of 'soft skills' for students and staff involved in the project, such as teamwork, leadership, problem-solving and creativity, as well as stretching students beyond the national science curriculum. Through this partnership approach, we quantified the biodiversity present in the grounds of UK schools (Chapter Two), gathered information on children's current state of knowledge about UK wildlife through drawings (Chapter Four) and established an experimental set-up within a senior school to explore the effects of biodiversity on student anxiety and pulse rate (Chapter Six). The development of the COVID-19 pandemic in 2020 shifted the focus of this thesis to include investigation of the effects of lockdown restrictions on parents' attitudes to green space and the natural world (Chapter Three), providing a natural experiment to explore these timely questions. To achieve this, we drew on contacts at our existing partnership schools and connections through the University Museum of Zoology public engagement programme.

Chapter One: How integrated is research on interactions between people and nature?

Abstract

1. Research on the diverse interactions between people and nature is characterised by a broad range of disciplines involved, encompassing a variety of approaches, methods and terminologies. While a diversity of approaches is valuable for fully exploring a subject, it can also lead to difficulties in integrating and sharing findings, and could form a barrier to effective knowledge exchange, hindering the development and applications of research outputs.
2. To quantify the extent of integration between disciplines studying people and nature, we conducted a scoping review through a combination of expert consultation and a snowball-based approach. Using a resulting sample of 210 papers, spanning 10 publishing disciplines and eight first-author disciplines, we quantified the overlap in communities of papers cited across disciplines (cited disciplines). We also assessed whether the terms used to describe nature in paper titles and abstracts differed between publishing or first-author disciplines.
3. We found that communities of cited disciplines were significantly different between publishing and first-author disciplines, with papers from psychology, education and public health citing distinct communities of papers. However, disciplines generally cited a wide range of other disciplines, with articles in medical journals being particularly broadly cited.
4. The terms used to describe nature in paper titles and abstracts were also significantly different between publishing and first-author disciplines, with some degree of consistency in usage within disciplines (e.g., education papers consistently used a narrow range of nature terms, such as ‘outdoor learning’). However, there was a notably high range of nature terms used within psychology and public health papers, indicating that research from these disciplines is particularly prone to being overlooked by search strings, with implications for how likely papers are to be found, read and cited, both within and between disciplines.
5. The wide range of disciplines cited is encouraging, since this indicates that diverse research areas are generally aware of each other’s work. However, to avoid unnecessary

expansion of the terms used to refer to nature, we propose that greater attention is paid by authors to the selection of nature terms and that these are clearly defined within a paper's abstract. We propose four key terms for nature, at least one of which we propose should be included in every paper and all four of which should be included in review search strings. This is likely to result in a better understanding of the valuable, disparate contributions made by different disciplines to this expanding and important topic.

Introduction

Research into the health and wellbeing benefits of biodiversity is characterised by the involvement of a wide range of disciplines, terminologies and methods. Several existing systematic reviews have attempted to capture this range (Browning & Rigolon, 2019; Collins et al., 2020; Lovell et al., 2014, 2015; Wolf et al., 2020), but they are often hindered by the diversity of terms and approaches used across disciplines, making it difficult to bring together all relevant research through standard systematic search approaches. This lack of integration between disciplines could prove a significant barrier to development of the field, since findings are not efficiently disseminated, collaborations are not supported, and techniques are not shared. At a basic level, if research from different disciplines uses different terms to refer to nature and its benefits, searching the published literature to find the most up-to-date work, either to inform new research or shape policy, becomes a challenge. This hinders not just research in this area but also its applications in the real world.

Comparing the findings of two well executed flagship systematic reviews illustrates the problem well. 'A systematic review of the health and wellbeing benefits of biodiverse environments' by Lovell et al. (2014) used a narrative synthesis approach to map the interdisciplinary field of inquiry and to synthesise the current evidence base on whether biodiverse environments are health-promoting. 'Benefits of nature contact for children' by Chawla (2015) also used a narrative approach to characterise research from the 1970s to 2015, mapping changes in approaches and focus on different dimensions of children's wellbeing. Both reviews state that they took a narrative synthesis approach in order to account for the heterogeneity of the literature. Despite this, no papers cited in Lovell et al.

include any aspect of learning, nature connection or creative play in the range of benefits measured, while these types of benefits are a key theme within the Chawla review.

This is understandable given that the Chawla (2015) focused on benefits specific to children, which are more likely to include an education or school focus, while Lovell et al. (2014) set out to characterise evidence on the health and wellbeing benefits of nature, which may not extend to education directly. However, the fact that natural environments can affect the instance of creative play among children and promote children's learning (Kuo et al., 2019) suggests that there may be parallel benefits to explore in adults—research which, if it exists and if the definition of wellbeing were sufficiently broad, would ideally also be synthesised in the Lovell et al. review. This suggests both that research stemming from an education background might exclude research with adults as a study group, and that research stemming from a public-health or clinical discipline might not include relevant findings from the education literature.

Characterising research on people and nature as broad is not new. Several reviews exist on the topic (e.g., Lovell et al., 2014), as do several reviews of reviews (e.g., Hartig et al., 2014). Hartig et al. (2014) identified three central problems with reviews of this research. Firstly, that search strategies often fail to capture the full range of 'natural environments' because of the need to use multiple terms for 'nature' in the search string and the resulting high likelihood of missing relevant work. They also highlighted that part of this issue lies with the challenge of defining 'nature'. For example, in some research, the term 'natural environment', meaning one with an absence of human presence or interference, is adequate and appropriate. However, in other papers, the 'nature' of interest is part of the built environment (e.g., view of trees through a window, urban parks), so other terms, such as 'urban nature', 'green space' or 'nature experience' are more appropriate. The plethora of terms used, therefore, often have distinct meanings, suggesting that all disciplines using the same term is not constructive or feasible.

Secondly, Hartig et al. (2014) highlighted that disciplines with an individual-based approach (e.g., psychology, education) often ignore research from disciplines with a population-based approach (e.g., public health). Again, the challenge is how to capture and exchange knowledge across such different approaches, since both perspectives, at the individual- and population-level, offer important insights on the benefits that nature can offer. Thirdly, Hartig et al. highlighted the failure of reviews to successfully address the variety of health outcomes explored. This is partly because outcomes are sensitive to contact with nature through different pathways and over different timescales, so reviews that pool results, in an attempt to make up for a lack of multiple studies following consistent methods, may mischaracterise the evidence base. For example, in a systematic review on the health outcomes of having urban trees, Wolf et al. pooled outcomes into three broad groups to account for the wide range of outcomes recorded: Reducing Harm (e.g., UV exposure, pollen, air pollution), Restoring Capacities (e.g., attentional restoration) and Building Capacities (e.g., birth outcomes, active living) (2020). While this approach was valuable for bringing out consensus findings, it does mean that more specific effects are likely to have been obscured.

Therefore, the fact that such a broad range of research exists, spanning multiple keywords, measuring multiple outcomes and adopting a range of approaches, is a challenge that has already been well characterised. However, having such a broad evidence base is not necessarily a problem if the involved disciplines read and cite each other, and understand each other's language and approaches. In this paper, we quantify this challenge by mapping the overlap between research disciplines (publishing disciplines and first-author disciplines) with regard to the disciplines represented in the research cited (cited disciplines) and the terminology used to describe nature. By doing so, we aim to identify areas of commonality and suggest pragmatic approaches to better integrate disciplines, fostering efficient collaboration and knowledge exchange.

Specifically, we address the following key questions:

1. What disciplines are carrying out research on interactions between people and nature?
2. What disciplines are being cited by this research, and does this vary between publishing or first-author disciplines?
3. What terms are used to refer to nature, and does this vary between publishing or first-author disciplines?

Methods

1. Selection of benchmark papers

In a conventional systematic literature review, the first stage is often to design a search string that best captures the keywords of the research topic of interest. This search string is then used to generate a list of all relevant published papers. However, the topic 'people and nature' is so broad, encompassing disciplines that use vastly different approaches, perspectives, methods and terminologies, that designing a search string broad enough to capture all relevant papers generates an unmanageably large, and majority irrelevant, dataset of papers. If the search string is made more specific, the list of results is then too narrow to capture the full range of relevant research. To circumvent this issue, from our knowledge of the literature, we identified four broad research areas, each spanning multiple disciplines, that we used as a framework to draw up a list of benchmark papers and experts, whom we consulted to generate a starting list of relevant papers. We then applied a snowball-based approach (Moher et al., 2009) on this starting list, resulting in a final sample that captured a snapshot of all relevant research but likely not including every relevant published paper (Fig 1.1).

We began by identifying four research areas that captured the full breadth of research into people and nature: Medicine, Psychology, Education and Environment (Table 1.1). We chose these four areas because our knowledge of the literature indicated that research into people and nature in each of these areas adopts a distinct perspective and often uses different terminology to explore their respective research questions. For example, research in psychology often uses 'attentional restoration theory' as a framework, using language such as 'restorative settings' and 'attentional fatigue', while a superficially similar paper in the medicine research area might take a physiological approach, talking about 'stress', 'cortisol levels' and 'green space'.

Using these four broad research areas as our initial framework, we identified a list of 10 'benchmark' papers published between 1984 and 2017 (Medicine: 3, Psychology: 2, Education: 2, Environment: 3) and a list of 21 experts (Medicine: 2, Psychology: 8, Education: 3, Environment: 8), ensuring all four research areas were represented in each list. The experts included authors of influential and well cited research studies in the field of people and nature, including authors of some in our benchmark list, and academics whom we knew to have expertise in this area.

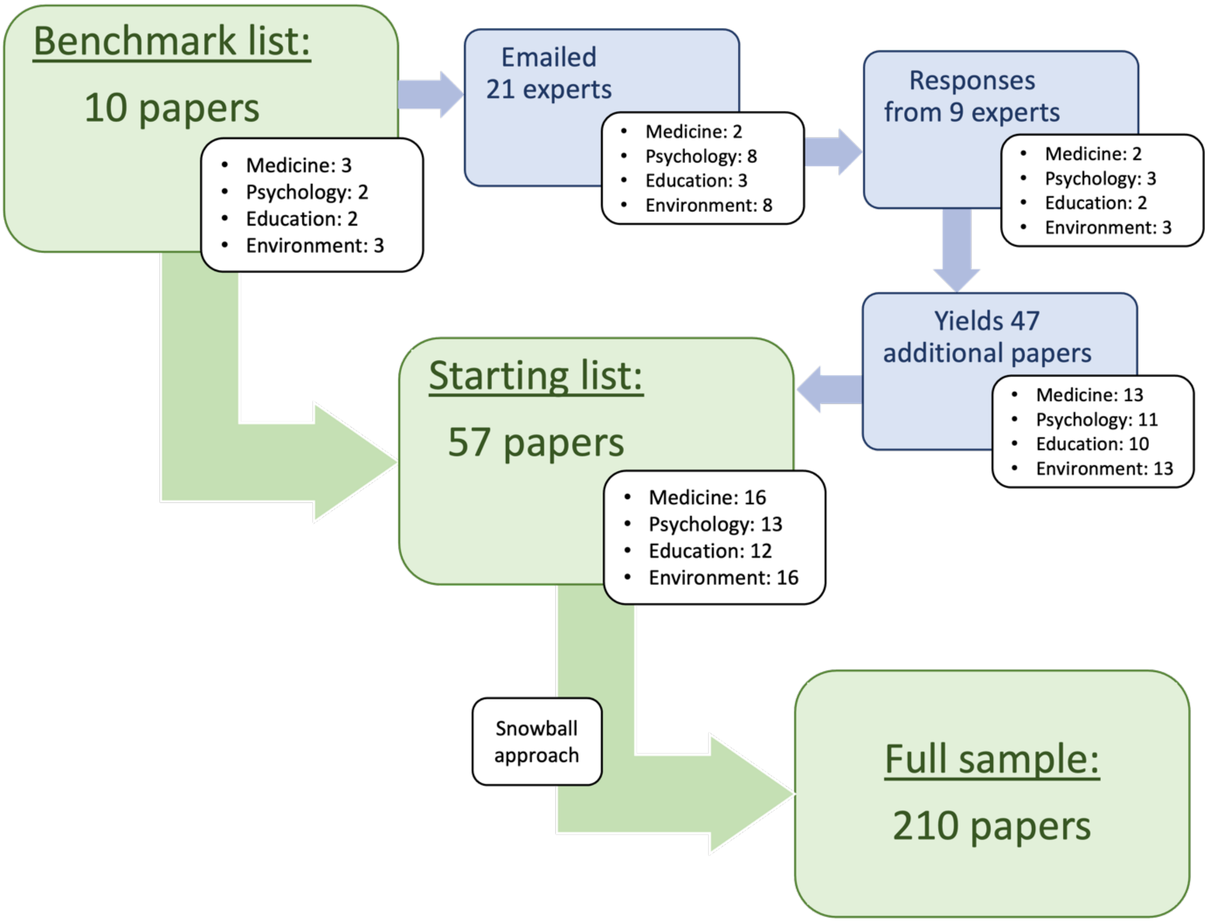

Figure 1.1. Flowchart showing the stages followed to source our sample of 210 papers. White boxes show the distribution of papers at each stage across the four relevant research areas.

Table 1.1. Table showing the four starting research areas, along with the topics that each includes.

Research area	Included topics
Medicine	Public health, physiology, physical activity, mental health, physical health
Psychology	Behaviour (e.g., self-regulation), attention restoration, wellbeing
Education	Learning, effectiveness of learning programs, academic performance, teacher and student experience
Environment	Conservation, ecology, urban planning, pollution, nature connection

2. Expert consultation

We emailed our list of benchmark papers to all 21 experts in July 2020, asking them to suggest other papers that could be added to this list (Fig 1.1; see Appendix S1.1 for the full email request). We gave them the 10 benchmark papers to enable them to appreciate the full scope of the work we wanted to capture, and to encourage them to think of relevant papers beyond their own research area.

Nine experts responded in July and August 2020 (Medicine: 2, Psychology: 3, Education: 2, Environment: 2), yielding a total of 47 additional papers (Medicine: 13, Psychology: 11, Education: 10, Environment: 13). Only two of these 47 additional papers were recommended by more than one expert. Combining these 47 with our 10 benchmark papers gave us a starting list of 57 papers spread across the four research areas, on which we carried out a snowball-based approach to achieve our full sample (Fig 1.1). From this point on, we no longer used our four research areas as a classification basis, since these were designed solely as a starting point from which to expand our search.

3. Snowball-based approach

We exported the bibliographies of all 57 papers and identified all citations that were relevant to our research area. We classed as relevant any paper that explored the relationship between some aspect of nature and some benefit to humans, inclusive of benefits to physical health, mental health, wellbeing, behaviour, psychology, education and nature connection. We then randomly selected up to three relevant citations from each paper to add to our sample. If a randomly selected citation was either not relevant, already present in our sample, or unavailable in English, we continued randomly selecting citations until we had up to three new, relevant citations from the bibliography. This approach resulted in a total sample of 210 papers (Fig 1.1).

4. Data gathering

For each paper, we recorded the discipline of the journal in which it was published (publishing discipline), the discipline of its first author (first-author discipline), the number of times journals of each discipline were cited in its bibliography (cited discipline) and the term(s) used in the paper's title or abstract to describe the aspect of nature being explored (nature term). Publishing disciplines and cited disciplines were decided from a combination of a journal's title and scope (title and summary for grey literature, or title and blurb for books). First-author discipline was decided by looking at a combination of the author's affiliation and list of publications. Nature terms were selected from a paper's title (n = 194), only referring to the paper's abstract if no nature term was present in the title (n = 16). All data gathering was carried out by KH in September-November 2022 to ensure consistency.

5. Statistical analyses

All statistical analyses were performed in R version 4.1.3 (R Core Team, 2022) within R Studio version Build 461 (RStudio Team, 2022). We used *tidyr* (Wickham & Girlich, 2022), *RColorBrewer* (Neuwirth & Brewer, 2022), *ggsignif* (Ahlmann-Eltze & Patil, 2021), *ggplot2* (Wickham, 2016) and *cowplot* (Wilke, 2020) for data wrangling, exploration and visualisation. Exploration followed Zuur et al. (2010). We fitted multivariate generalized linear models (mGLMs) using *mvabund* (Wang et al., 2022), and chi-square tests of independence using *stats* (R Core Team, 2022). Unless otherwise stated, we fitted models to negative binomial distributions, including publishing discipline and first author discipline as fixed effects.

5.1 Cited disciplines

We used mGLMs (Warton et al., 2012; Warton & Hui, 2017) to analyse communities of cited disciplines, followed by univariate analyses if publishing discipline or first-author discipline was significant (p = 0.05).

We validated mGLMs by plotting Dunn-Smyth residuals against fitted values and covariates, and verifying no patterns were present (Wang et al., 2012, 2022). We determined the significance of fixed effects using LRTs and by bootstrapping probability integral transform (PIT) residuals using 10,000 resampling iterations (Warton et al., 2017). If either fixed effect was significant ($p < 0.05$), we ran univariate analyses. We adjusted univariate p values to correct for multiple testing using a step-down resampling algorithm (Wang et al., 2012), but otherwise our statistical approach remained unchanged from the multivariate parent models.

5.2 Nature terms

Chi-square tests of independence were used to test for differences in the proportion of papers using nature terms in their title or abstract from different categories between publishing disciplines and between papers with first authors from different disciplines.

Results

1. Publishing disciplines

Based on journal title and scope, the total number of publishing disciplines within our sample of 210 papers was 10: Biology (*n* = 5), Education (*n* = 9), Environment (*n* = 35), Geography (*n* = 1), Medicine (*n* = 24), Psychology (*n* = 48), Public health (*n* = 50), Science (*n* = 8), Social science (*n* = 5) and Urban planning (*n* = 25).

2. First-author disciplines

Based on first authors' affiliations and list of published papers, the total number of first-author disciplines within our sample of 210 papers was eight: Conservation (*n* = 6), Education (*n* = 14), Environment (*n* = 41), Geography (*n* = 1), Medicine (*n* = 31), Psychology (*n* = 46), Public health (*n* = 58) and Urban planning (*n* = 13).

3. Cited disciplines

Overall, among the bibliographies of our sample of 210 papers, 1,603 different journals or other sources (e.g., grey literature, books) were cited, with the 65 most commonly cited journals each being cited at least 20 times (Figure S1.2). Based on journal title and scope (title and summary for grey literature, or title and blurb for books), the total number of cited disciplines within the bibliographies of our sample of 210 papers was 12: Biology (*n* = 133), Education (*n* = 112), Engineering (*n* = 9), Environment (*n* = 263), Geography (*n* = 47), Medicine (*n* = 427), Psychology (*n* = 220), Public health (*n* = 108), Science (*n* = 55), Social science (*n* = 182), Urban planning (*n* = 38) and Other (*n* = 9). The category 'Science' includes journals that cannot be assigned to a more precise discipline since they publish research across the sciences (e.g., physics, biology, chemistry, materials science, engineering, medicine, psychology, social science etc.). The category 'Other' was created to accommodate nine publications in law, philosophy and current affairs.

Both publishing discipline (LRT = 300.7, $p < 0.0001$; Fig 1.2A) and first-author discipline (LRT = 201.6, $p < 0.0001$; Fig 1.2B) differed significantly in the communities of disciplines cited. Specifically, the communities of cited disciplines in papers published in education journals differed from those published in environment, public health and urban planning journals, and papers published in psychology journals differed from those published in environment and public health journals ($p < 0.05$ for post-hoc comparisons). For first-author discipline, the communities of cited disciplines in papers with a first author in education differed from those with a first author in environment, medicine and public health; those with a first author in psychology differed from those with a first author in environment, medicine and public health; and those with a first author in public health differed from those with a first author in environment ($p < 0.05$ for post-hoc comparisons).

Univariate analyses indicated that different cited communities in education (LRT = 53.91, p = 0.0005), environment (LRT = 78.57, p = 0.0001), geography (LRT = 46.87, p = 0.0009), medicine (LRT = 47.49, p = 0.0009), psychology (LRT = 65.01, p = 0.0001), public health (LRT = 61.86, p = 0.0002) and urban planning (LRT = 58.21, p = 0.0003) papers were the primary drivers of these differences. For first-author discipline, univariate analyses indicated that different cited communities in papers with a first author in education (LRT = 53.91, p = 0.0002), environment (LRT = 78.57, p = 0.0001), geography (LRT = 46.87, p = 0.0009), medicine (LRT = 47.49, p = 0.0009), psychology (LRT = 65.01, p = 0.0001), public health (LRT = 61.86, p = 0.0001) and urban planning (LRT = 58.21, p = 0.0001) were the primary drivers of differences.

4. Nature terms

A total of 103 different terms for nature were used in the titles or abstracts of our sample of 210 papers (Figure S1.3), which we lumped into 12 broad categories: Biodiversity, Forest bathing, Forest school, Green, Natural, Nature, Outdoor, Restorative, Trees, Urban, Other and Multiple (Table 1.2; see Table S1.4 for full list of terms in each category). The majority of papers used a nature term in their title (n = 164), with only 16 needing us to refer to the abstract to find a nature term (e.g., Title: ‘View through a window may influence recovery from surgery’).

The frequency of papers using nature terms from different categories was significantly different between publishing disciplines (χ^2 = 227.81, df = 99, p < 0.0001; Fig 1.3A) and between papers with first authors from different disciplines (χ^2 = 236.48, df = 77, p < 0.0001; Fig 1.3B).

Table 1.2. Table showing categories of nature terms used in paper titles and abstracts, along with the inclusion criteria and the number of terms for each. See Table S1.4 for a full list of terms in each category.

Category	Inclusion criteria	No. terms

Biodiversity	Terms that require measurement of a quantifiable aspect of biodiversity (e.g., species richness, vegetation)	11
Forest bathing	Terms that refer to the Japanese practice of shinrin-yoku	6
Forest school	Terms that refer to the specific form of outdoor education that originated in Denmark in the 1950s and is now practiced in multiple countries	2
Green	Terms that use the word 'green' to describe the aspect of the environment being tested or of interest	15
Natural	Terms that use the word 'natural' to describe the aspect of the environment being tested or of interest	6
Nature	Terms that use the word 'nature' to describe the aspect of the natural world of interest (e.g., nature) or to describe interactions with people (e.g., nature connection, nature experience)	6
Outdoor	Terms that refer to the broad category of outdoor education (e.g., outdoor learning, adventure education), or those that use the word 'outdoor' to describe the public or outside space being tested or of interest	12
Restorative	A specific term used in psychological literature and of relevance to Attention Restoration Theory	1
Trees	Aspects of nature specific to trees but not quantifiable in an ecological sense (e.g., tree effects (such as removal of air pollution), as opposed to tree species richness)	7
Urban	Terms that refer to aspects of the built, human environment (e.g., parks, public open space)	16
Other	Terms that do not fit into any of the other categories, but are unique and thus cannot form a category of their own (e.g., gardening, blue space)	9
Multiple	Terms that span multiple of the above categories, either between terms (e.g., nature AND greenness) or within terms (e.g., green outdoor environments)	12

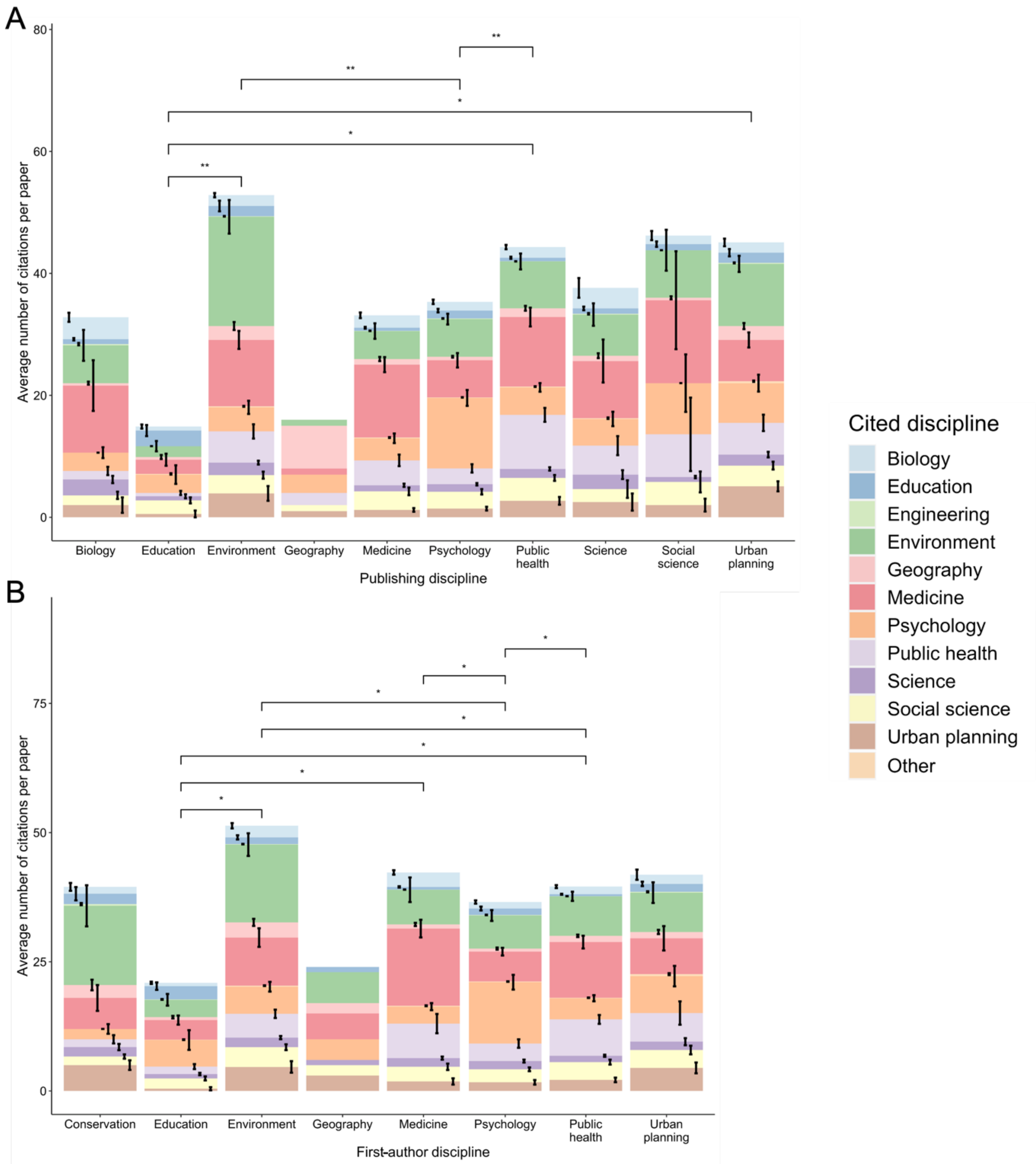

Figure 1.2. Stacked bar graphs showing communities of cited disciplines by (A) publishing discipline and (B) first-author discipline. Each bar is a separate (A) publishing discipline or (B) first-author discipline, arranged alphabetically. Bars are coloured by discipline of cited journals. Error bars indicate the minimum and maximum number of citations in the dataset. Significant differences between pairs of publishing and first-author disciplines are indicated by square brackets. *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$. Not all cited disciplines are represented in the lists of publishing or first-author disciplines.

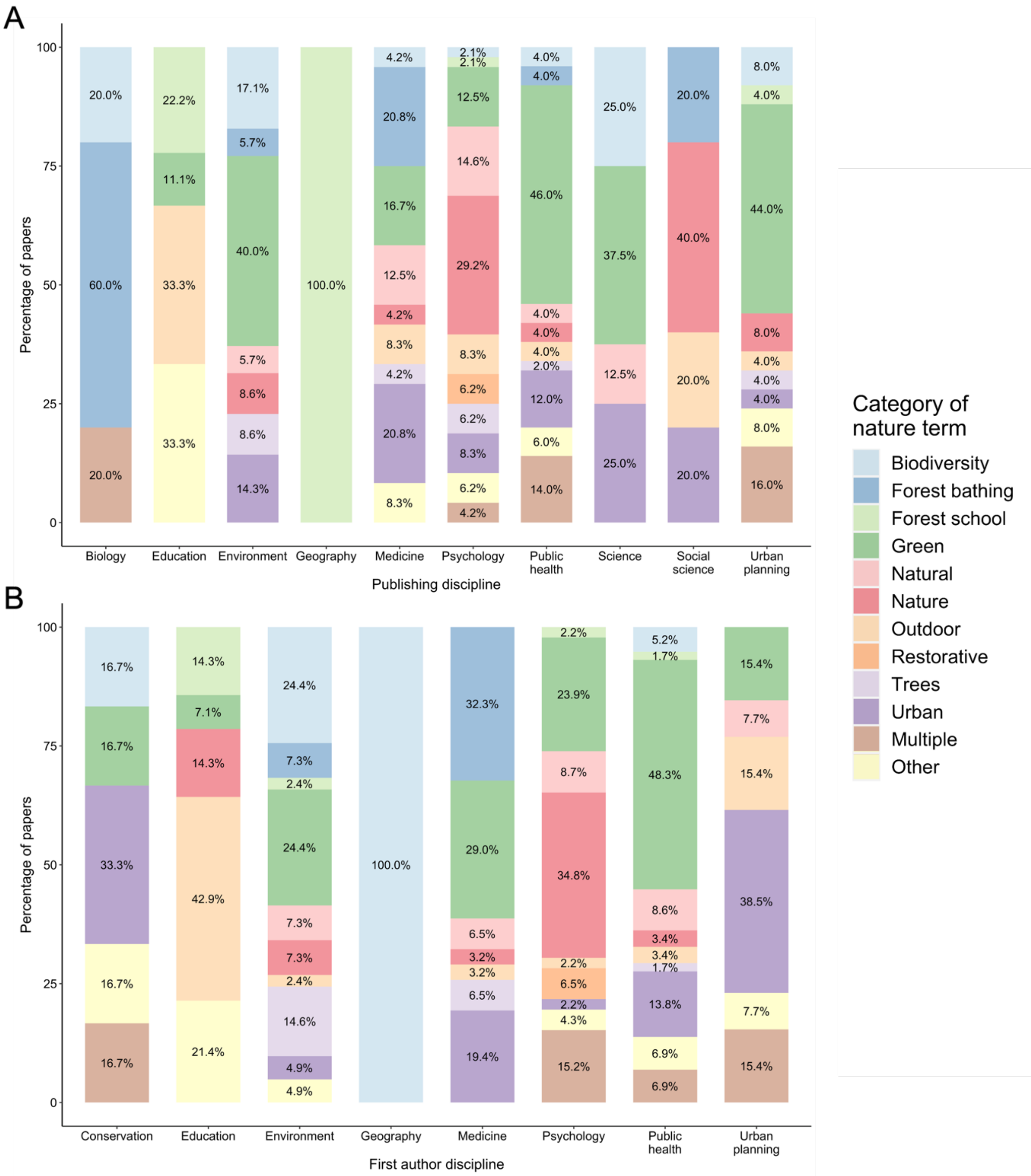

Figure 1.3. Stacked bar graphs showing the percentage of papers using different categories of nature terms in the paper title or abstract, split by (A) publishing discipline and (B) first-author discipline. Each bar is a separate (A) publishing discipline or (B) first-author discipline, arranged alphabetically. Bars are coloured by category of nature term (see Table 1.2).

Discussion

1. Key results

We found that the communities of disciplines cited differed between publishing disciplines and first-author disciplines. The communities cited by psychology, education and public health papers were particularly distinct, each citing a larger proportion of papers within their own disciplines. Medicine was the most consistently cited discipline across publishing and first-author disciplines. This difference in the focus of citations between disciplines is not surprising given the need for research to be informed by and grounded in similar work and approaches. However, given the multidisciplinary characteristics of research focused on humans and nature, and the wide range of potential outcomes from this work, this bias in some disciplines could limit transfer of ideas and wider applications of research findings. In contrast, it is encouraging to see the generally wide of range of disciplines being cited across publishing and first-author disciplines, since this suggests that disparate disciplines are generally aware of each other's work, although more integration is possible.

Similar results were found in the communities of disciplines cited based on both publishing and first-author disciplines. Specifically, both education- and psychology-based papers differed in their cited communities from environment- and public health-based papers when analysed based on both publishing discipline and first-author discipline. This consistency in findings suggests that authors are generally publishing in journals of their own discipline. While this might be effective in disseminating findings to peers within disciplines, this approach is likely to be less effective in communicating findings across disciplinary boundaries—a particular problem for an inherently multidisciplinary field such as human-nature research. To address this, we suggest authors aim to publish in a wider range of journal disciplines, beyond those closely aligned with their own area. This might encourage the use of nature terms beyond those usually used in the research discipline, making research more easily findable.

The types of nature terms used in paper titles and abstracts were also significantly different between different publishing and first-author disciplines. Part of this is likely due to logical consistency seen within disciplines. For example, 'green' terms were favoured by public health-authored papers (48.3% of papers), ‘outdoor’ terms by education-authored papers (42.9%), ‘urban’ terms by urban planning-authored papers (38.5% of papers), ‘nature’ terms by psychology-authored papers (34.8%) and ‘forest bathing’ terms by medicine-authored papers (32.3%). This makes sense given the different approaches and focuses taken by these disciplines. For example, public health papers are often focused on ‘public green space’ (e.g., Benton et al., 2018) or take a measure of ‘residential greenness’ (e.g., Markevych et al., 2014); education papers often explore the effects of ‘outdoor learning’ (e.g., Christie et al., 2016) or ‘outdoor education’ programmes (e.g., Quibell et al., 2017); urban planning papers often focus on the function of ‘urban trees’ (e.g., Donovan et al., 2011) or the effects of the ‘built environment’ (e.g., Helbich et al., 2016); psychology papers often talk about ‘nature restoration’ (e.g., White et al., 2013) in the context of attentional restoration theory; and medicine papers are the most common home for studies examining the clinical effects (e.g., T-killer cell activity or cortisol levels) of ‘forest bathing’ (e.g., Li et al., 2008). This suggests that disciplines are using distinct terms to refer to the aspect of nature relevant to their own discipline with a good degree of consistency and logic. Given the wide range of pathways through which the people-nature relationship can form and manifest, consistent use of nature terms within disciplines is helpful, since it is likely to clarify the distinct contribution made by each discipline to understanding this multifaceted relationship.

However, within certain disciplines there were a large range of nature terms used. This was particularly the case for psychology (11 categories by publishing discipline, nine by first-author discipline), public health (10 categories by publishing discipline, 10 by first-author discipline), environment (seven categories by publishing discipline, 10 by first-author discipline), medicine (nine categories by publishing discipline, seven by first-author discipline) and urban planning (nine categories by publishing discipline, six by first-author discipline). By contrast, education papers showed greater consistency in the nature terms used in their titles and abstracts (only four categories by publishing discipline, five by first-author discipline). This suggests that there is progress to be made to achieve full consistency within each discipline, or that some disciplines are covering a wider range of research topics than others. While some degree of variation in nature terms within a discipline is expected (e.g., it is reasonable to expect medicine papers to investigate the clinical effects of ‘green exercise’ (e.g., Duncan et al., 2014) and ‘forest bathing’ (e.g., Li, 2010)), the wide range of categories used by disciplines such as psychology and public health could be acting as a barrier to effective knowledge exchange between disciplines, adding noise and inefficiency to literature searches that are intended to inform research and underpin systematic reviews.

2. Implications

As Hartig et al. (2014) identified, the problem of defining ‘nature’, and the variety of ways in which the nature-human pathway can act, has led to a plethora of nature terms in regular use in the literature (Hartig et al., 2014). To some degree, this is necessary in order to describe accurately and precisely the various aspects of nature (e.g., urban nature such as allotments versus natural landscapes such as forests) and the various pathways of interaction with people (e.g., attention restoration versus facilitation of active lifestyles). However, this can cause problems for defining efficient search strings and retrieving all published work on a topic, whether to inform new research, draw policy conclusions or support literature reviews (Hartig et al., 2014).

Similar pairwise groupings between disciplines were present in both sets of results: communities of cited disciplines and nature terms used. This speaks to consistent, greater similarities and cross-over between some discipline groupings than between others. Specifically, education, psychology, environment and public health emerged as consistently different from each other, while medicine and public health appeared consistently similar, as did environment and urban planning. The four consistently different disciplines we have identified in our results (education, psychology, environment and public health) align closely with the four broad research areas we used at the start of this study (medicine, psychology, education, environment), from which we built our benchmark list and expanded our search. Our results therefore provide validation of our methods and of our identification of these broad research areas as using significantly different frameworks and terminologies to frame and explore the human-nature relationship. We suggest that it is the boundaries between these four research areas in particular that could be hindering better integration of human-nature research. While efficient communication within these areas makes intuitive sense, we propose that focusing on better knowledge exchange between these four research areas would significantly improve the development of human-nature research and consequent communication and application of findings.

3. Recommendations

Therefore, we propose the following terms as central to human-nature research: (‘outdoor learning’ OR ‘outdoor education’), (‘nature’ OR ‘natural’), (‘green space’ OR ‘greenspace’) and (‘biodiversity’ or ‘trees’). We propose that:

1. At least one of the above four key terms should be included in the title or abstract of every paper exploring the human-nature relationship, and
2. All reviews aiming to capture the full range of research into the human-nature relationship should include all four of the above key terms in their search string.

We propose that all papers should include the most appropriate, general nature term for their discipline in their title and abstract, to avoid the work being missed by search strings (as above), and that this term be adhered to throughout the paper, unless a more specific nature term is necessary for the particular research question being investigated, in which case it should be used in addition to, not instead of, the more general nature term. When more specific, additional nature terms are necessary, we propose that these are clearly defined within a paper’s abstract. Where the introduction of a novel term is necessary for the particular research question being tackled, this should be clearly defined and justified in the paper abstract, and it should again be used in addition to, not instead of, the more general nature term. We hope that these recommendations, over time, will lead to a narrowing of the range of nature terms used within disciplines, avoid unnecessary expansion as the body of literature grows, and improve the efficiency of knowledge exchange between the disparate disciplines that contribute to this uniquely broad area of research.

Chapter Two: The greenness of primary schools in England and their local surroundings

Abstract

1. There is increasing disconnect between children and nature in the UK. Despite children spending a large portion of time at schools, there has not yet been a systematic assessment of the biodiversity present in school grounds.
2. We assessed biodiversity in 14 English schools, including state-funded and non-state-funded, using remote images to quantify green-space area within a 3km buffer around (buffer greenness) and within (school greenness) each school, and *in situ* images to quantify vegetation visible to children within each school (visible vegetation), surveying for trees, ground plants, ground invertebrates and birds within school grounds.
3. School greenness correlated positively with visible vegetation, but buffer greenness affected neither school greenness nor visible vegetation. Buffer greenness correlated positively with plant richness, and school greenness correlated positively with tree abundance and richness. Visible vegetation correlated positively with tree abundance and richness, maximum tree DBH, plant richness and invertebrate abundance. Non-state-funded schools had higher visible vegetation than state-funded.
4. Our study indicates that schools can support considerable biodiversity and that this is broadly consistent across state-funded and non-state-funded sectors. We suggest that maximising vegetation is the most effective method of increasing school biodiversity, since greenness at this scale had effects on the greatest number of taxa.

Introduction

People in more economically developed societies are increasingly disconnected from the natural world (Soga & Gaston, 2016; Turner et al., 2004), a trend often attributed to urbanisation and reduced daily contact with nature (Maller et al., 2009; Miller, 2005). In this context, green spaces in urban areas are central to mitigating this trend, since for many they are the main way to interact with the natural world on a daily basis (Natural England, 2020a). In the UK, provision of green space is highly variable across socioeconomic groups and geographic regions (Barbosa et al., 2007), and green space access is generally lower for children than for adults (Hand et al., 2018; Veitch et al., 2008).

However, urban green spaces can house a surprising amount of biodiversity. For example, one UK-based study found that urban areas contain significantly higher densities of blackbirds, song thrushes and mistle thrushes than the surrounding rural landscape (Mason, 2000), while another found that domestic gardens across five UK cities had higher flora richness than several natural habitats, including acidic grassland, acidic woodland, scrub and limestone grassland (Loram et al., 2008).

Interaction with biodiversity is crucial for building a connection with nature and developing pro-environmental attitudes and behaviours later in life (The Wildlife Trusts & University of Derby, 2019; Wells & Lekies, 2006). For example, in one USA-based study, participation in both 'wild' nature experiences (such as camping or hiking) and 'domesticated' nature experiences (such as harvesting or planting seeds) had a positive effect on likelihood of displaying environmental attitudes and behaviours in adulthood (such as recycling or volunteering at a nature reserve) (Wells & Lekies, 2006). In the UK, those who took part in a month-long campaign to do something nature-related daily reported feeling more connected to nature and happier two months later (The Wildlife Trusts & University of Derby, 2019). Improving access to experiences in the natural world from a young age is therefore important for ensuring future engagement with conservation.

Several studies have assessed the impacts of green school grounds on aspects of childhood wellbeing. Studies based in the Netherlands and the USA found that providing more green areas within school playgrounds led to a decrease in sedentary activity and an increase in physical activity (Bates et al., 2018; van Dijk-Wesselius et al., 2018), increases in positive social interactions and decreases in negative ones (such as bullying or injuries) (Bates et al., 2018), positive effects on children's appreciation of these spaces, attentional restoration and social wellbeing (van Dijk-Wesselius et al., 2018), and a greater sense of competence and formation of supportive relationships, providing protective resilience and improvements in response to stress (Chawla et al., 2014). Children who spent more time in green playgrounds performed better on tests of self-regulation (Taylor & Butts-Wilmsmeyer, 2020) and rated playgrounds with greater volumes of vegetation as more restorative (Bagot et al., 2015). Benefits may also extend to educational attainment, with one study in Toronto finding that tree cover and species composition was a positive predictor of student performance on standard assessments (Sivarajah et al., 2018).

In this context, school grounds represent a potential priority area for biodiversity conservation because of their combined size and potential for joined-up management, their role in delivering wellbeing benefits, and their central position in mediating the relationship between children and nature. Despite this, no studies have yet, to our knowledge, systematically assessed the biodiversity present in these spaces within the UK.

In this study, we assessed levels of green space and conducted biodiversity surveys across 14 primary schools in England, including three fee-paying school types (two state-funded: state and academy, and one non-state-funded: private). We quantified greenness at three different scales and surveyed for associated biodiversity within the schools, assessing whether there were correlations between the three levels of greenness, whether the three levels of greenness varied between school types, and whether abundance, richness and community composition of taxa varied with the three levels of greenness or school type.

Methods

1. Site selection

We sent out information about the study via the University Museum of Zoology, Cambridge (UMZC)'s mailing lists and social media accounts. 79 primary-school teachers at 57 different primary schools said they were happy to be contacted with further information. We arranged visits to as many of these as possible, limited by the schools' capacities to host us, and collected biodiversity data from 14 schools in total (Table S2.1). Schools were distributed across England with the highest concentration in the southeast (Fig S2.2). We visited both state-funded and non-state-funded schools, which we hereafter refer to as 'school types', a factor with three levels: state, academy and private. We split state-funded schools into two categories, state and academy, since they reflect different management practices. Although they are both free to attend, academies are administratively free from local-authority control, while state schools are administered by their local authority with regards to admissions and day-to-day running. Private schools are paid for by parents and are not subject to local-authority control.

Using QGIS (QGIS Development Team, 2022), we calculated the area (m^2) of outside space to which children had access for each school, as well as the area of a 3km buffer around the school grounds. Using R version 4.1.3 (R Core Team, 2022) and R Studio Build 461 (RStudio Team, 2022), we then calculated the total number of pixels and the number of green pixels in each of these areas, which allowed us to calculate the area of green space (ha) in each of the schools (school greenness) and each of the buffers (buffer greenness). For each of the 14 schools, we also used Google Earth to overlay a 10 x 10 grid onto the outside area to which children had access during the school day. We then used a random number generator to select 10 coordinates within this grid, which acted as our within-school sample locations.

2. Data collection

All school site visits were made in May-August 2019, September 2020 or August-September 2021 (Table S2.1).

2.1 Visible vegetation

At each of the 10 sample points per school, we took a photograph with an iPhone placed at 1m above the ground facing each of the cardinal compass points, giving four images per sample point and 40 images per school. We then used an online image editor (MockoFUN, 2022) to overlay a 10 x 10 grid onto each of the images and counted the number of squares in which any plant life was visible. Bare soil was not counted but fallen leaves were. We then took the proportion of squares in which plant life was present as a measure of 'visible vegetation'.

2.2 Trees

For all trees within school grounds, we identified each to morphospecies and measured its diameter at breast height (DBH, cm). For each school (n = 13), we calculated the number of trees (abundance), number of tree morphospecies (richness), mean DBH, maximum DBH and standard deviation in DBH. We were unable to collect these data for one of our 14 schools

(Table S2.1) since maintenance staff estimated that there were >800 trees, and so, due to research team staff and resource constraints, we could not survey the whole site.

2.3 Ground plants

At each of the 10 sample points per school, we used a 0.5m x 0.5m quadrat (*n* = 110) to count the number of squares in which each morphospecies of plant, type of non-plant organic matter (e.g., bare soil, dead leaves, dead wood) or type of artificial surface (e.g., tarmac, AstroTurf) was present. All quadrats were taken in late July, August or early September.

2.4 Ground invertebrates

At each of the 10 points per school, we sampled ground invertebrates using a Vortis suction sampler (*n* = 100), sampling for 16 seconds at each of the four corners of the quadrat (Arnold, 1994; Brook et al., 2008). All samples were collected in August or early September, and between 09:00 and 15:00. Samples were preserved in 70% alcohol before being sorted and identified using a stereo microscope.

We identified most invertebrates to order level. Exceptions were Annelids (phylum), Diplopoda, Collembola, Acari and Mollusca (class), and Formicidae (family). Hereafter, we collectively refer to all invertebrate groups as orders. Identifying to order level allowed all samples to be identified with the resources available and provided an overview of the ground invertebrate community present in each school. One sample was degraded, so we assigned the average of the other nine samples from this school for abundance, order richness and community composition for analyses.

2.5 Birds

At each of the 10 sample points per school, we conducted a bird point count (*n* = 110), during which all birds seen in the school grounds or flying directly overhead were counted and identified. All point counts were conducted in August or early September, and between 09:00 and 17:00, since this is when children are most likely to see birds. All birds were identified to species level, apart from gulls, which we identified to family (Laridae) since they generally flew too high overhead to be reliably identified to a greater taxonomic resolution. Hereafter, we collectively refer to all bird groups as species.

Due to the enforcement of COVID-19 lockdown restrictions from March 2020, it was not possible to arrange a second site visit to four of our 14 schools, so we are lacking biodiversity data in some categories (Table S2.1).

3. Data processing and statistical analyses

All statistical analyses were performed in R version 4.1.3 (R Core Team, 2022) within R Studio Build 461 (RStudio Team, 2022). We used *tidyr* (Wickham & Girlich, 2022), *RColorBrewer* (Neuwirth & Brewer, 2022), *ggsignif* (Ahlmann-Eltze & Patil, 2021), *ggplot2* (Wickham, 2016) and *cowplot* (Wilke, 2020) for data wrangling, exploration and visualisation. Exploration followed (Zuur et al., 2010). We conducted Spearman's rank correlation tests and Kruskal–Wallis tests using *stats* (R Core Team, 2022), and fitted generalized linear mixed models (GLMMs) using *glmmTMB* (Brooks et al., 2017) and multivariate generalized linear models (mGLMs) using *mvabund* (Wang et al., 2022).

We used Spearman's rank-order coefficient to test for correlations between all three pairs of levels of greenness, and for correlations between each of tree abundance, morphospecies richness, mean DBH, maximum DBH and standard deviation in DBH, and the three levels of greenness. Visible vegetation was averaged across all 40 images for each school, to give a single score per school.

We used Kruskal-Wallis tests to test for differences between school types in each of the three levels of greenness and on each of the tree metrics, followed by Dunn's tests with Bonferroni correction where school type was significant (p < 0.05). Visible vegetation was averaged across the four images taken at each sample point.

We used GLMMs to assess factors affecting ground plant morphospecies richness, ground invertebrate abundance and order richness, and bird abundance and species richness. We fitted models to negative binomial distributions, including buffer greenness, school greenness, visible vegetation and school type as fixed effects, and school as a random intercept effect to account for multiple measures at each school. GLMMs for ground invertebrate order richness and bird species richness were fitted to Poisson distributions due to issues with model fit with negative binomial distributions. Ground cover data for non-plant organic matter (e.g., bare soil, dead leaves, dead wood) and artificial surfaces (e.g., tarmac, AstroTurf) were excluded from ground plant morphospecies richness analyses.

We validated GLMMs by plotting quantile residuals against predicted values and covariate school type to verify that no patterns were present. To ensure our GLMMs fitted the observed data, we ran simulation-based dispersion tests using *DHARMa* (Hartig, 2022) to compare the variance of the observed residuals against the variance of the simulated residuals with variances scaled to the mean simulated variance, and checked that our model was within the range of our simulations (Zuur & Ieno, 2016). Our simulations indicated that there were no issues with model fit. We determined the significance of fixed effects to each model by comparing fitted models with null models using LRTs. If mixed models suggested a moderately significant effect ($0.03 < p < 0.07$), we re-calculated p values based on parametric bootstrapping using *DHARMa* (Bates et al., 2015; Hartig, 2022). If school type was significant, we used *multcomp* (Hothorn et al., 2019) to conduct post-hoc analyses (Tukey all-pair comparisons, adjusting p values using Bonferroni correction) to identify school types between which significant differences occurred.

We used mGLMs to analyse community composition of all taxa (Warton et al., 2012; Warton & Hui, 2017), fitting models to negative binomial distributions and including buffer greenness, school greenness, visible vegetation and school type as fixed effects, and school as a blocking variable to account for non-independence of samples within each school. Ground cover data for non-plant organic matter (e.g., bare soil, dead leaves, dead wood) and artificial surfaces (e.g., tarmac, AstroTurf) were included in ground cover community composition analyses.

We validated mGLMs by plotting Dunn-Smyth residuals against fitted values and covariate school type and verifying no patterns were present (Wang et al., 2012, 2022). We determined the significance of fixed effects using LRTs and by bootstrapping probability integral transform (PIT) residuals using 10,000 resampling iterations (Warton et al., 2017). If school type was significant ($p < 0.05$), we ran univariate analyses on individual taxa. We adjusted univariate p values to correct for multiple testing using a step-down resampling algorithm (Wang et al., 2012), but otherwise our statistical approach remained unchanged from the multivariate parent models.

For both GLMMs and mGLMs, visible greenness was averaged across the four images taken at each sample point.

Results

Across the 14 schools, there were 36 tree morphospecies, 47 types of ground cover (including 40 plant morphospecies, four types of non-plant organic matter and three types of artificial surface), 17 invertebrate orders and 23 bird species. The most abundant tree morphospecies were birch, maple and lime (Fig S2.3A). The most common types of ground cover were grass, tarmac and bare soil (Fig S2.3B). The most abundant plant morphospecies were grass, white clover (*Trifolium repens*) and greater plantain (*Plantago major*) (Fig S2.3B). The most abundant ground invertebrate orders were Collembola, Acari and Hemiptera (Fig S2.3C). The most abundant bird species were wood pigeons (*Columba palumbus*), crows (*Corvus corone*) and house sparrows (*Passer domesticus*) (Fig S2.3D).

1. Correlations between levels of greenness

Visible vegetation correlated with school greenness (S = 46, p = 0.006, ρ = 0.7909; Fig 2.1A), such that schools with larger areas of green space in their grounds had higher amounts of visible vegetation, a trend that was particularly driven by a single private school with an especially large area of green space (Fig 2.1A). Buffer greenness did not correlate with school greenness (S = 350, p = 0.4265, ρ = 0.2308, Fig 2.1B) or visible vegetation (S = 132, p = 0.225, ρ = 0.4, Fig 2.1C).

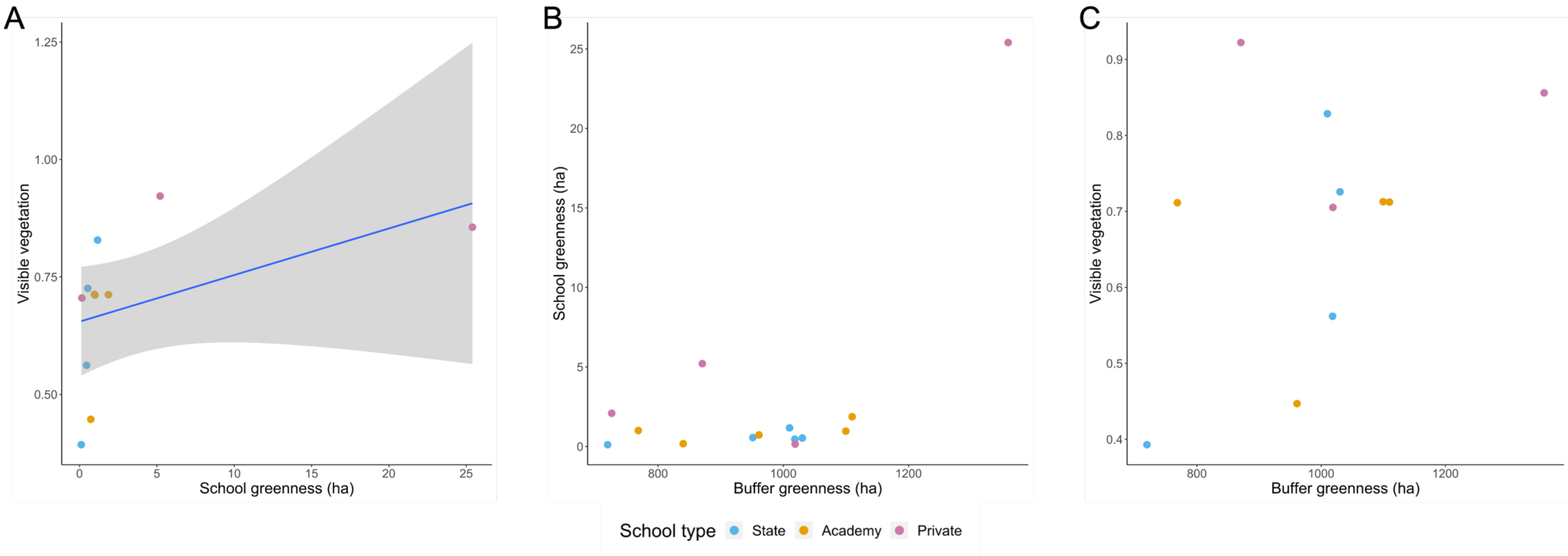

Figure 2.1. Relationships between levels of greenness. Points are coloured by school type. A: Scatter plot showing school greenness (ha) against visible vegetation, as an average of 40 photographs per school (n = 11). Blue line shows a simple linear model, with the grey area indicating a 0.95 confidence interval. B: Scatter plot showing buffer greenness (ha) against school greenness (ha) (n = 14). C: Scatter plot showing buffer greenness (ha) against visible vegetation, as an average of 40 photographs per school (n = 11).

2. Buffer greenness

Schools with greater buffer greenness had higher quadrat plant morphospecies richness (LRT = 6.9104, p = 0.00857; Fig 2.2). There were no effects on any other biodiversity measure.

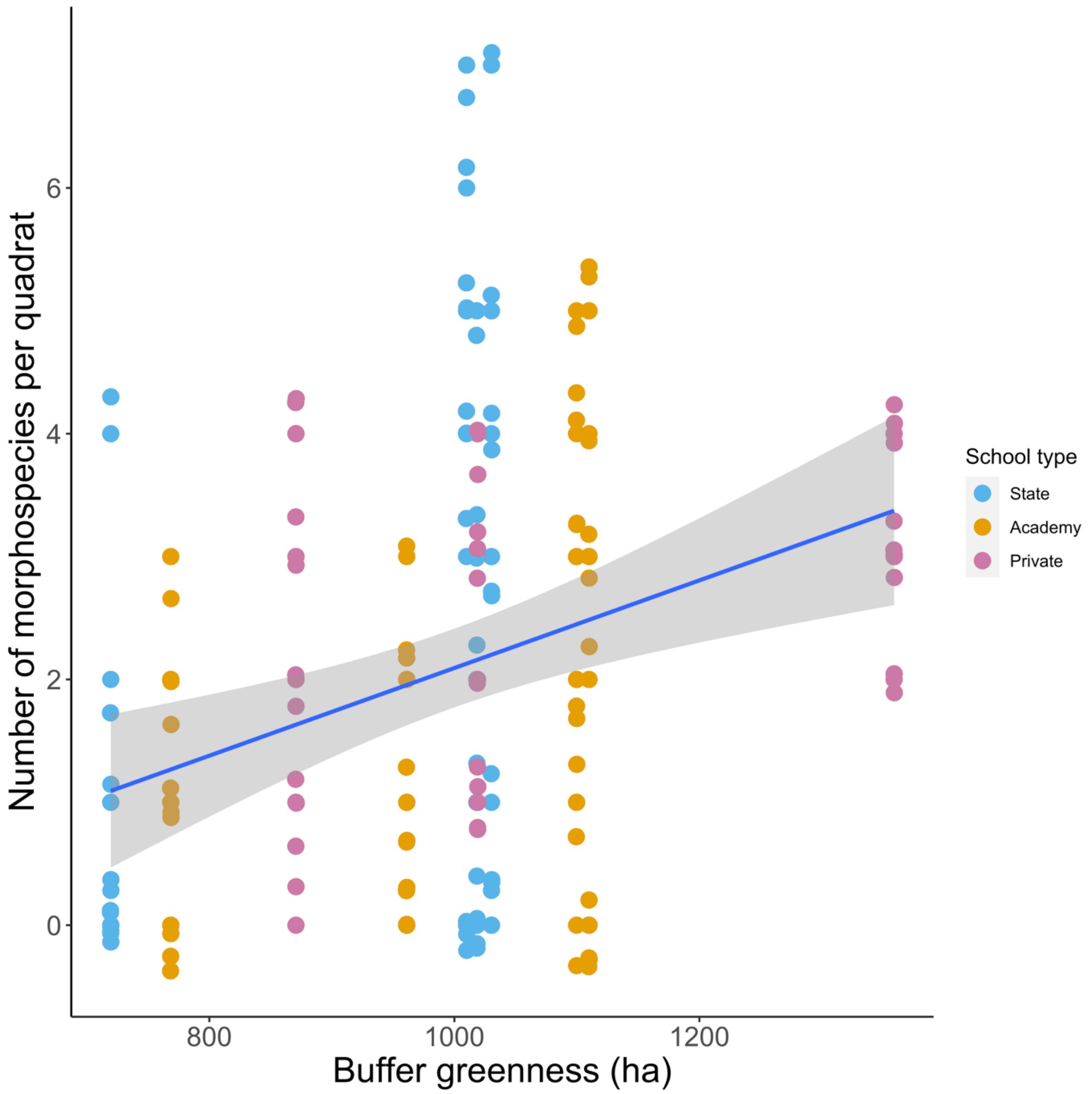

Figure 2.2. Scatter plot showing buffer greenness (ha) against quadrat plant morphospecies richness (n = 110). Points are coloured by school type. Blue line shows a simple linear model, with the grey area indicating a 0.95 confidence interval.

3. School greenness

Schools with higher school greenness had greater tree abundance (S = 114, p = 0.01201, ρ = 0.6868132; Fig 2.3A) and morphospecies richness (S = 106.29, p = 0.006772, ρ = 0.7079917; Fig 2.3B). There was also a significant effect of school greenness on tree community composition (LRT = 144.4282, p = 0.03040), although univariate analyses indicated that this was not driven by any morphospecies in particular. There were no effects on any other biodiversity measure.

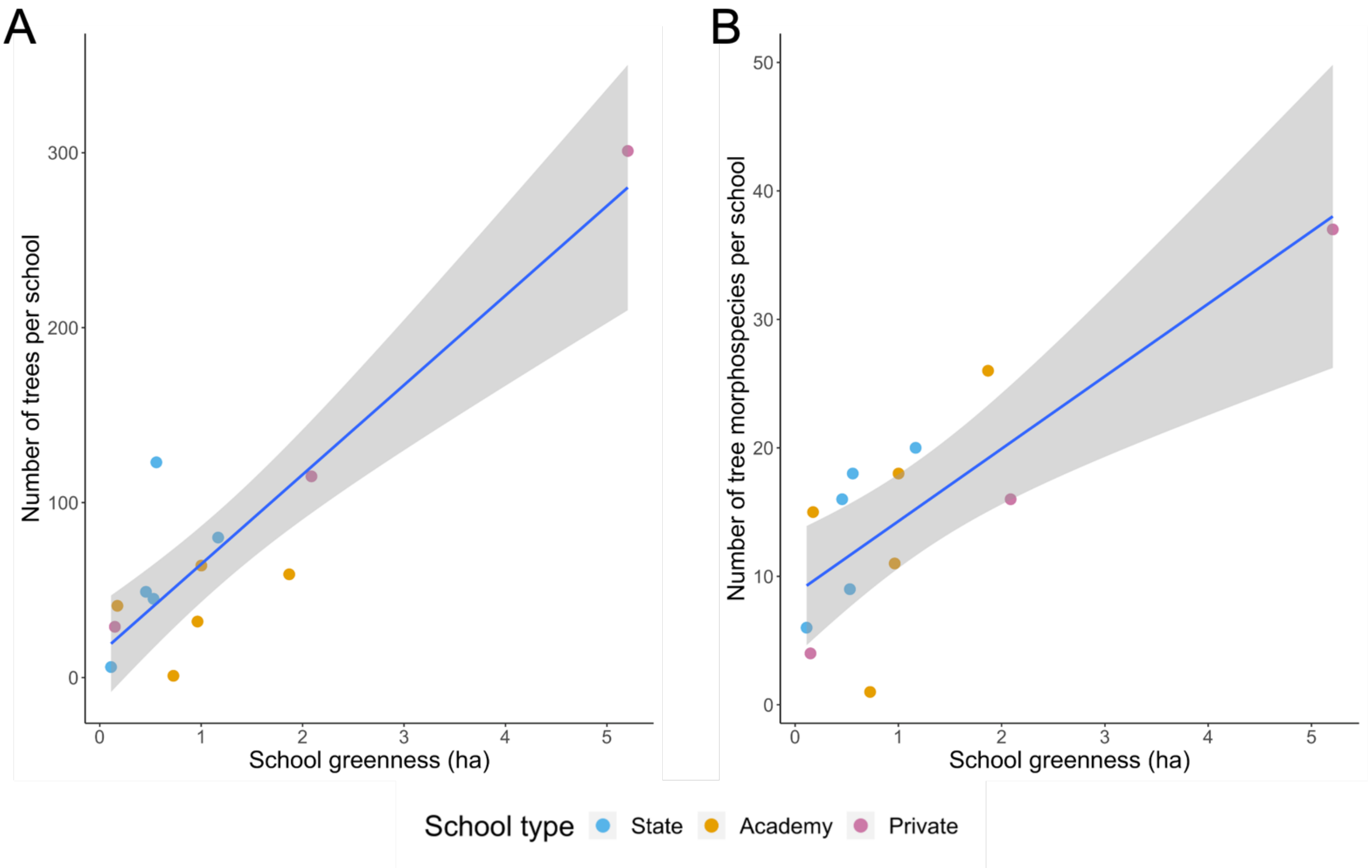

Figure 2.3. Points are coloured by school type. Blue lines show simple linear models, with the grey area indicating a 0.95 confidence interval. A: Scatter plot showing school greenness against tree abundance per school (n = 13). B: Scatter plot showing school greenness against tree morphospecies richness per school (n = 13).

4. Visible vegetation

Schools with higher visible vegetation had higher tree abundance (S = 40, p = 0.01592, ρ = 0.7575758; Fig 2.4A), morphospecies richness (S = 52, p = 0.03509, ρ = 0.6848485; Fig 2.4B) and greater maximum tree DBH (S = 48, p = 0.02751, ρ = 0.7090909; Fig 2.4C), higher quadrat plant morphospecies richness (LRT = 22.3433, p < 0.0001; Fig 2.4D), and higher invertebrate abundance (LRT = 68.494, p < 0.0001 Fig 2.4E) and order richness (LRT = 76.332, p < 0.0001 Fig 2.4F). There was a significant effect of visible vegetation on quadrat community composition (LRT = 207.5057, p < 0.0001), with univariate analyses indicating that this effect was driven by differences in coverage by tarmac (p = 0.04590), dead leaves (p < 0.0001) and grass (p = 0.0009999). There was also a significant effect of visible vegetation on ground invertebrate community composition (LRT = 261.8301, p < 0.0001), with univariate analyses indicating that this effect was driven by differences in abundance of Formicidae (p = 0.0066), Coleoptera (p = 0.0002), Hemiptera (p < 0.0001), Diptera (p = 0.0006), Hymenoptera (p < 0.0001), Araneae (p < 0.0001), Collembola (p < 0.0001), Thysanoptera (p = 0.0039), Acari (p < 0.0001), Isopoda (p = 0.0227) and Psocoptera (p = 0.0227). There was no effect of visible vegetation on any other biodiversity measure.

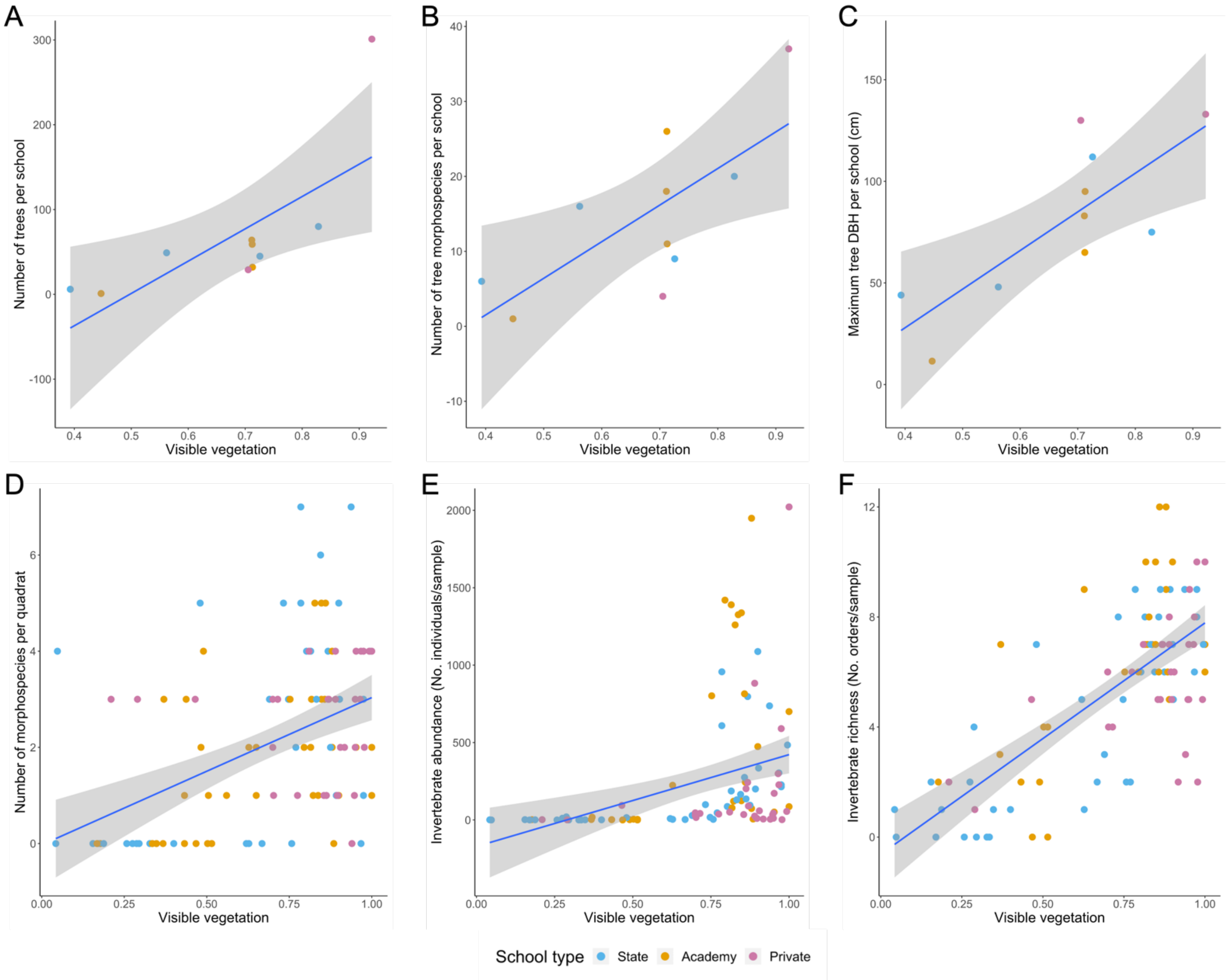

Figure 2.4. Effects of visible vegetation. Points are coloured by school type. Blue lines show simple linear models, with the grey area indicating a 0.95 confidence interval. A: Scatter plot showing visible vegetation against tree abundance per school (*n* = 13). B: Scatter plot showing visible vegetation against tree morphospecies richness per school (*n* = 13). C: Scatter plot showing visible vegetation against maximum tree DBH (cm) per school (*n* = 13). D: Scatter plot showing visible vegetation against plant morphospecies richness per quadrat (*n* = 110). E: Scatter plot showing visible vegetation against invertebrate abundance per sample (*n* = 100). F: Scatter plot showing visible vegetation against invertebrate order richness per sample (*n* = 100).

5. School type

Visible vegetation differed significantly between school types (χ^2 = 33.648, *df* = 2, $p < 0.0001$; Fig 2.5A), with post-hoc tests showing that visible vegetation was higher in private schools than the other two school types, which did not differ from each other (Table S2.4). However, there was no difference between school types in buffer greenness (χ^2 = 0.11143, *df* = 2, *p* = 0.9458) or school greenness (χ^2 = 3.2429, *df* = 2, *p* = 0.1976).

Maximum tree DBH differed marginally between school types (χ^2 = 6.4879, *df* = 2, *p* = 0.03901; Fig 2.5B), although post-hoc analyses indicated that there were no pairwise differences (Table S2.4). Standard deviation in tree DBH differed between school types (χ^2 = 6.5423, *df* = 2, *p* = 0.03796; Fig 2.5B), with post-hoc analyses indicating that the standard deviation in DBH in private schools was higher than in state schools, but that there were no differences between the other two pairs of school types (Table S2.4). There was a significant effect of school type on ground invertebrate community composition (LRT = 151.2539, *p* = 0.007599), with univariate analyses indicating that this effect was driven by greater numbers of Hymenoptera in academies than in state schools (*p* = 0.04260). There was no effect of school type on any other biodiversity measure.

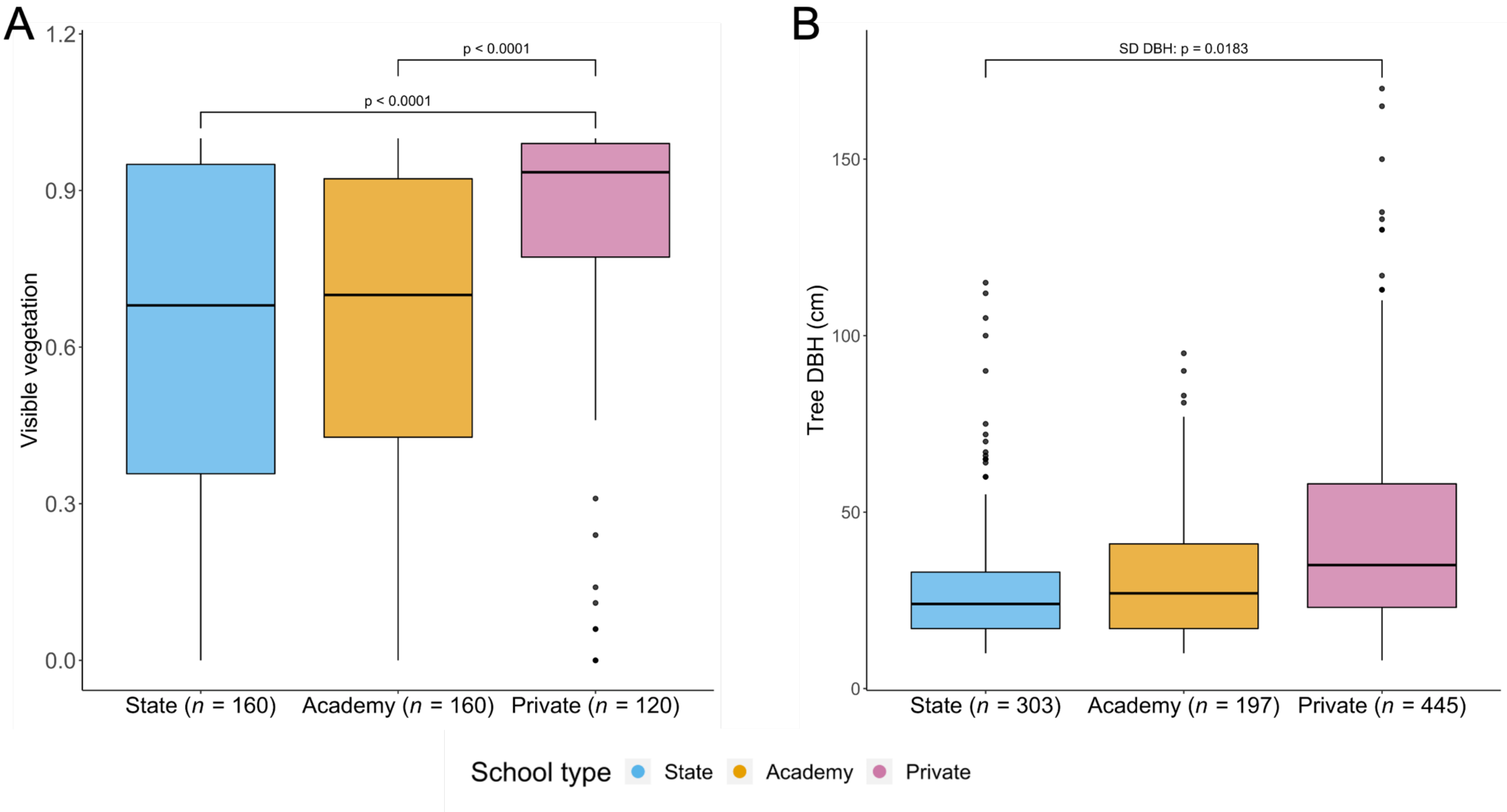

Figure 2.5. Boxplots showing differences between school types. Brackets labelled with adjusted p values show significant differences between pairs of school types following post-hoc analyses (Table S2.4). Black lines indicate median values. Coloured boxes show interquartile ranges (IQR). Whiskers extend to the largest and smallest values no further than 1.5*IQR. A: Boxplot showing visible vegetation per image (n = 440) by school type. B: Boxplot showing tree DBH (cm) (n = 945) by school type.

Discussion

1. Key results

This is the first study we are aware of that has systematically recorded the environmental characteristics and biodiversity of multiple school grounds in the UK. Our findings suggest that, while the amount of green space both surrounding and within schools is highly variable, these spaces house a range of different taxa, and they are therefore likely to be important for the development of nature connection and ecological knowledge (The Wildlife Trusts & University of Derby, 2019; Wells & Lekies, 2006). This mirrors research on other types of urban green space, which has recorded relatively high levels of species richness (Gaston, 2007; Ives et al., 2016; Loram et al., 2008) but patchiness of provision across demographic groups and geographic regions (Barbosa et al., 2007; Dunton et al., 2014; Mathieu et al., 2007).

2. Correlations between levels of greenness

The area of green space in a 3km buffer around a school did not correlate with the area of green space within a school's grounds, nor with the amount of vegetation visible in images taken in the grounds. However, schools with a larger area of green space in their grounds had higher levels of vegetation within their grounds. This suggests that the amount of green space children have access to at school is not reflective of the amount of green space in the local environment, but that schools with larger areas of outside space with natural cover are able to support greater levels of vegetation within their grounds. This finding highlights the importance of the provision of green space in school grounds beyond that used for sports or exercise for increasing children's exposure to nature.

3. Impacts of levels of greenness on biodiversity

Larger areas of green space in the buffer correlated with higher morphospecies richness of ground plants, but buffer greenness had no effect on any measure of tree, invertebrate or bird biodiversity, nor on community composition of ground cover. This indicates that greener local environments may be important for maintaining diversity of ground plants but have limited impacts on larger taxa or those of higher trophic levels. This presumably reflects the potential for plant species within urban green spaces to colonise via seed rain from surrounding areas (Jim et al., 2018; Mathey et al., 2015), leading to higher diversity where such areas are more extensive.

Schools with larger areas of green space in their grounds had more trees and greater tree morphospecies richness. The area of green space in a school's grounds also affected community composition of trees, but it had no effect on any measure of ground plant, invertebrate or bird biodiversity. This suggests that larger amounts of green space in school grounds result in greater tree diversity, but that greenness at this scale does not translate into greater diversity of other taxa. This is most likely related to what trees school staff decide to plant on the basis of the space they have available, indicating that schools with more green space at their disposal are able to take advantage of this through increasing tree diversity.

Schools with higher visible vegetation in their grounds had more trees, greater tree morphospecies richness and a higher maximum tree DBH, higher morphospecies richness of ground plants and higher abundance of ground invertebrates. The amount of vegetation also affected community composition of ground cover and ground invertebrates, but had no effect on community composition of trees, invertebrate order richness or any measure of bird biodiversity. This suggests that greenness at this finest scale affects the greatest number of taxa, and this is therefore the most important scale to prioritise for management strategies that seek to maximise school biodiversity. This is also the scale at which children are most likely to experience greenness, since photographs were captured at a height of 1m above the ground, so maximising biodiversity at this scale is also likely to have the greatest impact on children.

4. Effect of school type on biodiversity

Private schools had higher levels of visible vegetation than both types of state-funded schools, which did not differ from each other. There were no differences between school types in the area of green space in the buffer or within school grounds. This suggests that the amount of vegetation within school grounds is reflective of management practices rather than surrounding green space, and consequently that children who attend fee-paying schools in England are exposed to more vegetation than those who attend state-funded schools. Previous research has shown that higher levels of vegetation can lead to improved educational performance in primary school pupils (Sivarajah et al., 2018; Wu et al., 2014) and that greener school grounds are associated with improved cognitive, emotional and behavioural performance (Bijnens et al., 2020; Taylor & Butts-Wilmsmeyer, 2020; Wells, 2000), so our findings have implications for educational outcomes in the state- versus non-state education systems in the UK.

Standard deviation and maximum tree DBH per school differed between school types, with private schools having greater standard deviation in tree DBH than state schools but with no pairwise differences in maximum DBH. School type also affected community composition of ground invertebrates, with academies having greater numbers of Hymenoptera than state schools. It is likely that the greater range in tree DBH in private schools than in both kinds of state schools represents greater long-term consistency in ground management, giving trees more time to mature. This is therefore likely to reflect differences in management decisions or school age. State-funded schools have declining rates of retention for those in leadership roles (Department for Education, 2018; Lynch et al., 2017), and there is currently high pressure on the state school system in England, with rising demand for places and increasing class sizes (Morse, 2013), so state schools may have been forced to prioritise infrastructure developments over maintaining mature trees.

5. Conclusions and recommendations

Collectively, our study indicates that UK primary school grounds can house a wide range of taxa, and that these are broadly consistent across private- and state-funded systems, making school grounds a priority for biodiversity conservation and engaging younger generations with nature. This implies that a similar conservation strategy, which will benefit biodiversity, provide educational opportunities and wellbeing improvements, can be applied across education systems.

However, we also found that levels of greenness likely to be seen by students, as well as some aspects of biodiversity, were higher in private than state-funded schools, indicating that students at state-funded schools may have less exposure to green space and associated nature. We suggest that prioritising increasing the amount of vegetation in school grounds represents both the most practical and most effective method to increase biodiversity within schools.

Given that our measure of within-school greenness was a reasonable indicator of school biodiversity, a similar measure, based on photographs of school vegetation, could be used as a surrogate for more in-depth biodiversity surveys to build a national picture of school biodiversity through remote methods, allowing identification of schools with especially low biodiversity that could benefit from targeted additional funding to enhance their green spaces. Given our relatively modest sample size of 14 schools, this represents a promising remote method through which to quantify biodiversity across a larger national network of schools, also providing the opportunity for school students themselves to get involved in citizen science.

Finally, we recommend that greater requirements for outside learning and ecology-specific topics are integrated into national curricula to take advantage of the existing green space schools have access to and to maximise the benefits of this important resource.

Chapter Three: Effects of COVID-19 lockdown restrictions on parents' attitudes towards green space and time spent outside by children in Cambridgeshire and North London, United Kingdom

Abstract

1. In the United Kingdom, children are spending less time outdoors and are more disconnected from nature than previous generations. However, interaction with nature at a young age can benefit wellbeing and long-term support for conservation. Green space accessibility in the UK varies between rural and urban areas and is lower for children than for adults. It is possible that COVID-19 lockdown restrictions may have influenced these differences.
2. In this study, we assessed parents' attitudes towards green space, as well as whether the COVID-19 lockdown restrictions had affected their attitudes or the amount of time spent outside by their children, via an online survey for parents of primary school-aged children in Cambridgeshire and North London, UK (n = 171). We assessed whether responses were affected by local environment (rural, suburban or urban), school type (state-funded or fee-paying) or garden access (with or without private garden access).
3. Parents' attitudes towards green space were significantly different between local environments: 83.3% of rural parents reported being happy with the amount of green space to which their children had access, in contrast with only 40.5% of urban parents.
4. COVID-19 lockdown restrictions also affected parents' attitudes to the importance of green space, and this differed between local environments: 77.8% of urban parents said their views had changed during lockdown, in contrast with 41.2% of rural parents. The change in amount of time spent outside by children during lockdown was also significantly different between local environments: most urban children spent more time inside during lockdown, whilst most rural children spent more time outside.
5. Neither parents' attitudes towards green space nor the amount of time spent outside by their children varied with school type or garden access.
6. Our results suggest that lockdown restrictions exacerbated pre-existing differences in access to nature between urban and rural children in our sampled population. We suggest

that the current increased public and political awareness of the value of green space should be capitalised on to increase provision and access to green space and to reduce inequalities in accessibility and awareness of nature between children from different backgrounds.

Introduction

Experiences in nature at a young age are important for developing a connection with the natural world and for engendering support for conservation later in life (Soga, Gaston, Koyanagi, et al., 2016; Wells & Lekies, 2006), as well as benefitting children's mental and physical health, skill development and general wellbeing (Mygind et al., 2019; E. A. Richardson et al., 2017). However, there is an increasing disconnect between humans and the natural world (Soga & Gaston, 2016; Turner et al., 2004), now termed 'nature deficit disorder' (Louv, 2005). This is often blamed on rapid urbanisation and less daily contact with nature (Maller et al., 2009). As such, the importance of urban green spaces for residents' wellbeing is now accepted as central to good urban planning (Handley et al., 2011; Kaźmierczak et al., 2010).

However, in the United Kingdom (UK), current provision of green space is patchy (Barbosa et al., 2007), tending to be concentrated in more affluent areas (Pauleit et al., 2005; Turner et al., 2004). In the UK, over 2.5 million people live over a 10-minute walk away from a green space, with provision calculated as just 32.94m^2 per person, or just over a third of the area of the six-yard box on a football field (Fields in Trust, 2020). Access to green spaces is complex and determined by several factors, including distance from the home, perception of safety and individuals' demographic characteristics (Coombes et al., 2010; Dunton et al., 2014; Harrison et al., 1995). A large proportion of urban green space is often publicly inaccessible, existing as private land, especially as private household gardens (Mathieu et al., 2007). Access to a private garden varies with socioeconomic background and is generally higher for older individuals and those in higher income brackets (Judge & Rahman, 2020; Office for National Statistics, 2020). In the UK, 12% of households have no garden access, but this rises to 21% in highly urbanised areas such as London (Office for National Statistics, 2020), so disparity exists both within urban areas, and between urban and rural areas.

In addition, green space accessibility is lower for children than it is for adults, limited by urban barriers such as roads and parental restrictions on independent movement (Carver et al., 2008; Freeman & Quigg, 2009; Veitch et al., 2008; Villanueva et al., 2012). Across Europe and North America, the extent of children's independent movement has declined significantly in the last few decades (Fyhri et al., 2011; Karsten, 2005; Kyttä et al., 2015; O'Brien et al., 2000; Shaw et al., 2013), partly driven by parental concerns around child safety (Timperio et al., 2004). As a result, a large proportion of green space is inaccessible for children, especially in urban areas (Hand et al., 2018).

A higher proportion of green space close to a child's home has been linked with better cognitive functioning in children (Bijnens et al., 2020; Wells, 2000) and can be important for buffering stress (Wells & Evans, 2003), whilst a child's freedom to explore their local environment has also been linked to a range of health and social benefits (McCormick, 2017; Veitch et al., 2008). Exposure to the natural world during childhood has been shown to affect long-term cognitive development (Kellert, 2002, 2005; McCormick, 2017), as well as environmental attitudes, behaviours and values later in life (Strife & Downey, 2009; Wells & Lekies, 2006). However, evidence suggests that children's freedom to play locally, especially free from adult supervision, has declined in recent decades (Karsten, 2005), such that children now do not generally venture far from home on their own (Loebach & Gilliland, 2014). From 2013 to 2015, 12% of UK children under 16 hadn't visited a natural environment in over a year (Hunt et al., 2016), and fewer than one in 10 children in the UK now regularly play outside in wild places (Natural England, 2009). Collectively, these trends pose issues for children's wellbeing, as well as endangering future long-term support for conservation.

There is evidence that urban children, especially those from low-income backgrounds, are experiencing a nature deficit that affects their perceptions and awareness of nature (Aaron & Witt, 2011). For example, a survey of children conducted in the UK found that only one in three children could identify a magpie and only half could tell the difference between a bee and a wasp, despite nine out 10 being able to identify a dalek, a fictional extra-terrestrial race from the science-fiction series *Doctor Who* (Moss, 2012). Other studies have found that those children who have visited wild areas have a more accurate understanding of the wildlife that lives there (Aaron & Witt, 2011). Given that domestic gardens in the UK have been shown to house a surprising diversity of species (Davies et al., 2009; Smith et al., 2005, 2006), theses spaces may represent a key pathway for tackling nature deficit disorder.

COVID-19 lockdown restrictions in the UK, brought in between March and July 2020, resulted in a nationwide closure of schools and limits on the amount of time that could be spent outside of the home, restricting children and adults to the green space to which they had immediate access. Internationally, similar restrictions have been linked with an increase in severity and incidence of mental health symptoms (Pouso et al., 2021), and an increase in people emphasising the importance of green spaces for wellbeing (Berdejo-Espinola et al., 2021). Restrictions in different countries caused significant and varied changes in green space visitation rates. For example, in Oslo, Norway, recreational green space use increased by 291% during lockdown (Venter et al., 2020), whilst in the UK, there was an overall decrease in time spent visiting green space, with those from lower socioeconomic backgrounds experiencing the greatest decline (Burnett et al., 2021). Other studies suggest changes in the motivations for visiting green spaces, including a shift from 'non-essential' uses, such as meeting friends or observing nature, to 'essential' uses, such as dog walking, and an increase in associating these spaces with wellbeing benefits (Berdejo-Espinola et al., 2021; Ugolini et al., 2020).

Given the high degree of variation in the effects of lockdown restrictions on green space usage and attitudes, both between and within countries, we wanted to assess whether restrictions in the UK exacerbated or reduced differences in access to nature between urban and rural children. In particular, we assessed parents' attitudes towards green space, as well as whether the COVID-19 lockdown restrictions had affected their attitudes or the amount of time spent outside by their children, via an online survey distributed to 171 parents of primary school-aged children in Cambridgeshire and North London, UK from May to July 2020. Through this localised sample, we aimed to provide a snapshot of parents' and children's experiences of the COVID-19 lockdown restrictions in the southeast of the UK. We assessed whether responses were affected by respondents' local environment (rural, suburban or urban), the school type of their children (state-funded or fee-paying) or garden access (with or without private garden access). Our key hypotheses were as follows:

1. Parents in rural areas with private garden access would be more aware of the general importance of green space than those in more urban areas without access to a private garden.
2. The attitudes of parents in rural areas with private garden access would have been less influenced by the effects of lockdown restrictions than those of parents in more urban areas without access to a private garden, whose appreciation would have increased during lockdown.
3. Children in rural areas with private garden access would have spent more time outside during lockdown than those in more urban areas without access to a private garden.

Methods

1. Data collection

We designed an online survey for parents of primary school-aged children in Cambridgeshire and North London, UK (Appendix S3.1). The survey was distributed in May to July 2020 through pre-existing relationships with Cambridgeshire primary schools and a tuition centre in North London, on social media (Facebook and Twitter) through the researchers' own accounts and through those of the University Museum of Zoology Cambridge (UMZC), and via UMZC newsletters. The survey contained a mixture of closed and open questions.

2. Survey content

We asked parents about three key demographic factors via multiple-choice questions: their local environment (rural, suburban or urban), the type of school their children attended (state-funded or free-paying) and whether or not their children had access to a garden (Appendix S3.1). We split state-funded schools into two categories, state and academy, since they reflect different management practices, although they are both free for children to attend. Academies are administratively free from local-authority control, whilst state schools are administered by their local authority with regards to admissions and day-to-day running. Private schools are paid for by parents and are not subject to local-authority control. We split green space access into four categories: private garden, communal garden, local park, or none. In the UK, private gardens are spaces accessible only to those who own or rent the property it is attached to (Loram et al., 2007). Communal gardens are accessible only by those in a small collection of households, such as a block of flats, and are defined as open spaces managed by local community members for a range of purposes (Holland, 2004). Both garden access and school type are therefore reflective of household income and socioeconomic background. Collectively, these three factors represent key demographic parameters which might influence parents' attitudes and children's access to green space.

To assess parents' attitudes towards green space, we asked two open questions: 'Has your thinking on the importance of green space changed since lockdown began? Please explain how your views have changed or why they haven't' and 'Do you have any other thoughts about green space and its impact on children's wellbeing or learning?', and one multiple-choice question: 'How do you feel about the amount of green space your children have access to?' with the options 'I would like them to have more access to green space', 'I would like them to have less access to green space' and 'I am happy with the amount of green space my children have access to' (Appendix S3.1). To ensure our sample of parents were unbiased with respect to nature engagement or pro-environmental attitudes, we asked about participation in the following three nature-friendly activities: regular feeding of garden birds or other wildlife (yes or no), encouragement of garden wildlife (yes or no) and participation in citizen-science nature projects (yes, no, or no but planning to in the future) (Appendix S3.1).

To explore whether there had been an effect of the COVID-19 lockdown restrictions, we asked two closed questions: 'Has your thinking on the importance of green space changed since lockdown began?' with the options 'Yes' and 'No', and 'Are your children spending more or less time outside now than before lockdown began?' with the options 'My children are spending more time outside since lockdown began', 'My children are spending less time outside since lockdown began' and 'The amount of time my children are spending outside has not changed on account of lockdown' (Appendix S3.1). Interpretation of results from the first of these questions was aided by responses from the first of the above open questions, asking them to elaborate on why their thinking had or hadn't changed.

3. Research ethics

Electronic consent was required on the first page of the survey in order to proceed to the survey questions themselves. Respondents were provided with full Participant Information before being asked to provide electronic consent (Appendix S3.1). Participation was voluntary, and it was made clear to respondents that they were under no obligation to take part and that they could remove their consent at any point with no penalties. Our protocol was reviewed and approved by the Cambridge Psychology Research Ethics Committee.

4. Data processing and analyses

All analyses were carried out in R Version 4.0.2 GUI 1.72 Catalina build and R Studio Version 1.3.959.

4.1 Associations between factors

Responses to demographic factor questions were compared to distributions reported in national statistics (Department for Education, 2019; Green & Kynaston, 2019; Office for National Statistics, 2020; World Bank & United Nations Population Division, 2019b, 2019a). Chi-square tests with Holm's sequential Bonferroni correction were used to assess whether there were any associations between the three factors. Due to low numbers of respondents with access to only a local park or with no green space access, type of green space access was lumped into two categories: 'garden' and 'no garden', and termed 'garden access' for this and all later analyses.

4.2 Parents' attitudes towards green space

Word-clouds were produced from responses to the two open questions, separated by respondents' local environment, school type of their children and garden access. Each word-cloud contained a maximum of 200 words, with a minimum usage of three per word. More frequent usage was denoted through a larger font size and more central positioning of the word. Answers to both open questions were combined for each individual respondent.

All responses were read through twice before identifying a set of common themes and sentiments within each of these themes. The responses were then read through for a third time to code for the presence/absence of the identified sentiments. Any sentiment included in two or more responses was included in our dataset. Chi-square tests with Holm's sequential Bonferroni correction were used to assess whether there was a difference in the frequency of occurrence for each of the sentiments based on local environment, school type or garden access. Local environment, school type and garden access data were hidden during reading and coding to avoid biasing these processes.

Following the same processes as above, a set of commonly given reasons for the importance of green space were identified from the open responses, and responses were coded for their presence/absence. Any reason provided by two or more respondents was included. The reasons for the importance of green space were then ranked according to their frequency of occurrence amongst respondents. Chi-square tests with Holm's sequential Bonferroni correction were used to assess whether there was a difference in the frequency of occurrence for each of the reasons based on local environment, school type or garden access.

Finally, chi-square tests with Holm's sequential Bonferroni correction were used to assess whether local environment, school type or garden access affected parents' satisfaction with the amount of green space to which their children had access.

4.3 Effects of COVID-19 lockdown restrictions

Chi-square tests with Holm's sequential Bonferroni correction were used to assess whether local environment, school type or garden access affected whether parents' thinking on the importance of green space had been affected by lockdown and whether the amount of time their children spent outside had changed during lockdown.

Results

Results are presented in the following order: breakdown of respondents' characteristics; investigation into associations between factors; parents' attitudes towards green space (descriptive word-clouds, identification of common themes and sentiments, identification of common reasons given for the importance of green space, and satisfaction with the amount of green space to which their children have access); and effects of COVID-19 lockdown restrictions (change in thinking on the importance of green space and change in time spent outside by children during lockdown).

1. Respondents

The survey received 171 responses in total, with 141 respondents providing answers to at least one of the two open questions. Respondents were spread across all local environments, school types and type of green space access, encapsulating the range of conditions reported in national statistics but not following exactly the same distributions (Department for Education, 2019; Green & Kynaston, 2019; Office for National Statistics, 2020; World Bank & United Nations Population Division, 2019b, 2019a) (Table S3.2).

2. Associations between factors

There was a significant association between school type and local environment (χ^2 = 12.2, *df* = 4, *p* = 0.0471), with higher numbers of private schools found in more urbanised areas in our sample (Fig S3.3). There were no associations between garden access and local environment (χ^2 = 3.87, *df* = 2, *p* = 0.144; Fig S3.3) or between garden access and school type (χ^2 = 0.485, *df* = 2, *p* = 0.785; Fig S3.3).

3. Parents' attitudes towards green space

3.1 Word-clouds

Each respondent's answers to the open questions 'Has your thinking on the importance of green space changed since lockdown began? Please explain how your views have changed or why they haven't' and 'Do you have any other thoughts about green space and its impact on children's wellbeing or learning?' were grouped to form one open-text response, giving 141 responses in total. The most commonly used words were 'time', 'nature', 'space', 'wellbeing' and 'play', appearing in all word-clouds (Fig 3.1). 'Always' and 'learning' were the next most common, appearing in every word-cloud except that from respondents with no garden (Fig 3.1H). Exercise-associated words were also common, with at least one of 'exercise', 'walk' or 'walking', 'run' or 'running', or 'cycling' appearing in every word-cloud except that from respondents with no garden (Fig 3.1H). The words 'health' and 'mental' appeared in every word-cloud except those from respondents with no garden (Fig 3.1H) and respondents in rural areas (Fig 3.1A). All word-clouds, except those from respondents with no garden (Fig 3.1H) and respondents whose children attended academy (Fig 3.1E) or private (Fig 3.1F) schools, contained words associated with gratitude, i.e., at least one of 'grateful', 'lucky', 'appreciative' or ‘appreciate’. Collectively, the common themes that emerged were exercise, mental health and gratitude.

Figure 3.1. Word-clouds produced from responses to open questions ‘Has your thinking on the importance of green space changed since lockdown began? Please explain how your views have changed or why they haven't.’ and ‘Do you have any other thoughts about green space and its impact on children's wellbeing or learning?’. Words in the word-clouds are the most frequently used, with a minimum usage of three times, up to a maximum of 200 words. The more frequent a word’s usage, the larger its font and the more central its position. Rotation is random. A: responses from parents in rural areas (*n* = 30). B: responses from parents in suburban areas (*n* = 80). C: responses from parents in urban areas (*n* = 31). D: responses from parents of children at state schools (*n* = 100). E: responses from parents of children at academies (*n* = 22). F: responses from parents of children at private schools (*n* = 19). G: responses from parents with garden access (*n* = 129). H: responses from parents with no garden access (*n* = 11).

3.2 Common themes and sentiments

Three common themes and 15 common sentiments were identified in the open-text responses (Table 3.1). The five most commonly expressed sentiments across all 141 open-text responses were (Fig 3.2): ‘Always been grateful for or aware of the importance of green space’ (42.6% of responses), ‘Grateful for green space’ (24.8% of responses), ‘Became more grateful for green space during lockdown’ (22.7% of responses), ‘General importance of green space’ (12.1% of responses) and ‘Importance of local accessible green space’ (11.3% of responses).

There were no differences in the proportions of responses in which any of the sentiments were expressed between categories within local environment, school type or garden access (Table S3.4).

Table 3.1. Common themes and sentiments selected from responses to open questions from the survey for parents of primary school-aged children in the UK (*n* = 141). The open questions were 'Has your thinking on the importance of green space changed since lockdown began? Please explain how your views have changed or why they haven't.' and 'Do you have any other thoughts about green space and its impact on children's wellbeing or learning?'. Responses to the two questions were combined for each individual respondent. Any sentiment included in two or more responses was included. The sentiments are not listed here in any particular order other than being grouped by theme.

Common theme	**Common sentiment**	**No. responses**
Realisation	General importance of green space	17
	Importance of having a garden	10
	Importance of locally accessible green space	16
	Lack of current access to green space	5
	Positive effects on children (e.g., mood, behaviour)	15
Opportunity	More time spent in the garden	6
	Exploration of local area	8
	Observation of wildlife	10
	Slowing down	6
Attitude	Need for more outdoor learning at school	10
	Grateful for green space	35
	Sympathy for those without access	10
	Always been grateful for or aware of importance of green space	60
	Became more grateful for green space during lockdown	32
	Desire to protect green spaces	6

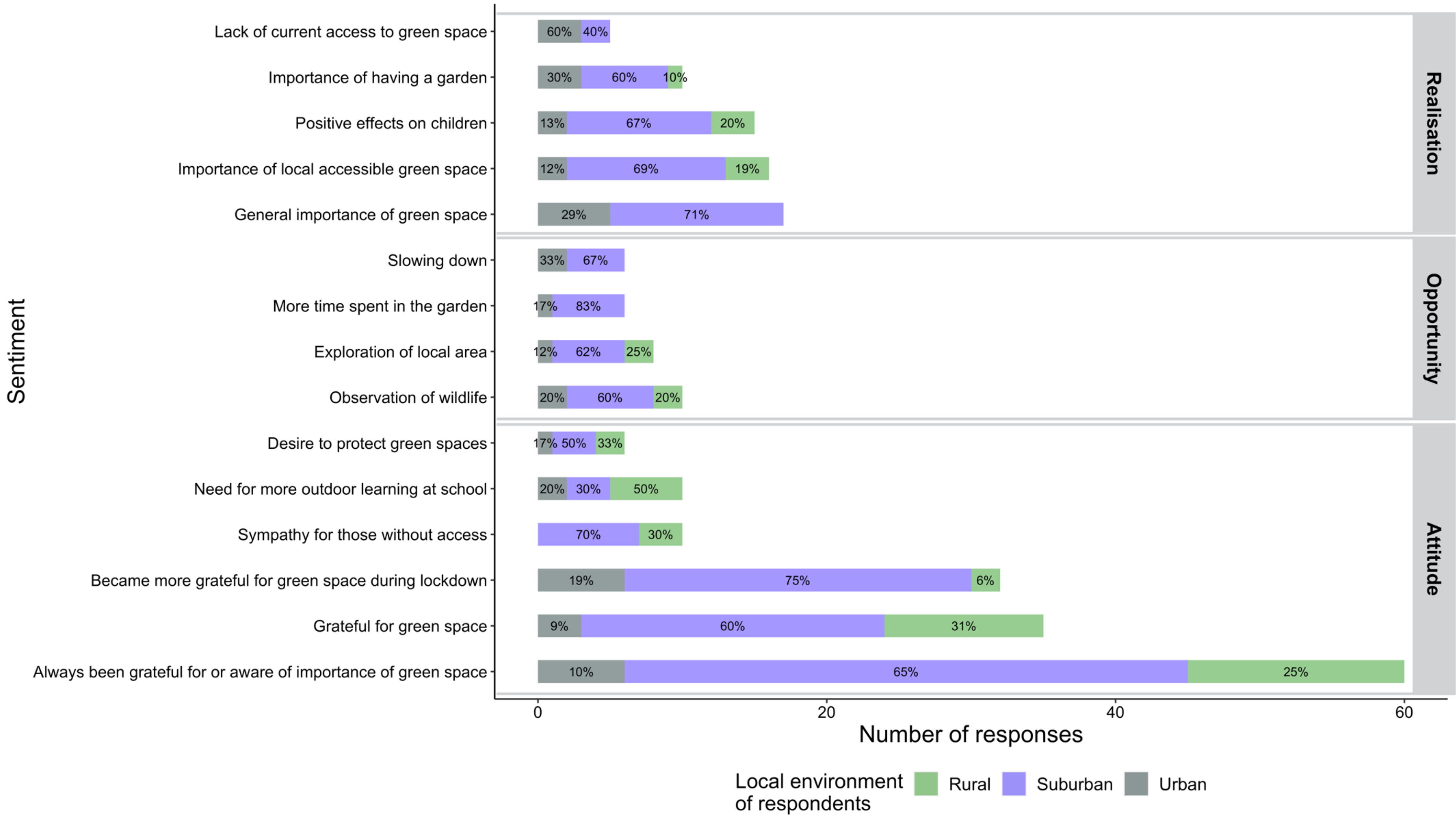

Figure 3.2. Summary of common sentiments extracted from responses to the open questions 'Has your thinking on the importance of green space changed since lockdown began? Please explain how your views have changed or why they haven't.' and 'Do you have any other thoughts about green space and its impact on children's wellbeing or learning?'. Answers for the two questions were combined for each individual respondent, giving n = 141 open-text responses. Bar chart shows total number of responses that contained each sentiment. Responses are coloured by local environment of respondents (Rural, Suburban, Urban) and grouped by common theme (Realisation, Opportunity, Attitude).

3.3 Reasons for the importance of green space

16 reasons for the importance of green space were given by more than one respondent and thus identified as common (Table 3.2). Ranking the common reasons given for the importance of green space reveals broadly similar values placed on these spaces by parents from all local environments, school types and garden access groups (Fig 3.3). The five most popular reasons given for the importance of green space were (Fig 3.3): importance for spiritual wellbeing, space to play, space to exercise and importance for general learning (joint), and importance for mental health. There were no differences in the proportions of responses in which any of the reasons were reported between different categories of local environment, school type or garden access (Table S3.4).

Table 3.2. Commonly stated reasons given for the importance of green space in responses to open questions from the survey for parents of primary school-aged children in the UK (n = 141). The open questions were 'Has your thinking on the importance of green space changed since lockdown began? Please explain how your views have changed or why they haven't.' and 'Do you have any other thoughts about green space and its impact on children's wellbeing or learning?'. Responses to the two questions were combined for each individual respondent. Any reason given by two or more respondents was included. The reasons are not listed here in any particular order.

Commonly stated reason for the importance of green space	No. responses
1. Good for spiritual wellbeing	45
2. Good for mental health	18
3. Good for general health	16
4. Important for social interactions (e.g., with neighbours or friends)	5
5. Space to exercise	27
6. Space to play	32
7. Space to release energy	7
8. Good for creativity, imagination or curiosity	7
9. Important for general learning	27
10. Important for learning about nature	16
11. Important for learning social skills (e.g., resilience, self-confidence)	4
12. Important for learning about growing food	4
13. As a counter to screen time	6
14. As a source of fresh air	11
15. Important for a sense of freedom	4
16. Important for building a connection to nature	8

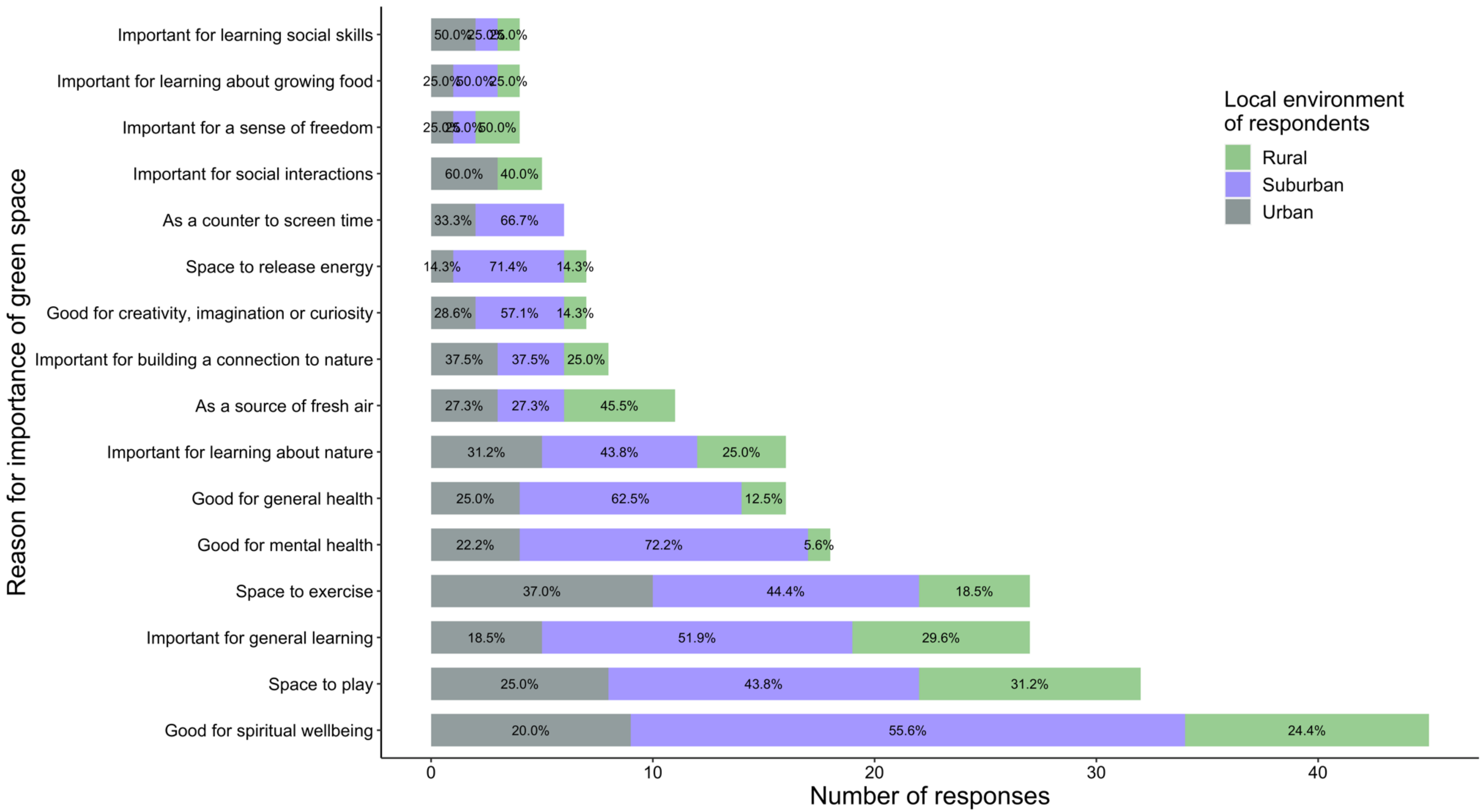

Figure 3.3. Summary of reasons given for the importance of green space, extracted from responses to the open questions 'Has your thinking on the importance of green space changed since lockdown began? Please explain how your views have changed or why they haven't.' and 'Do you have any other thoughts about green space and its impact on children's wellbeing or learning?'. Answers for the two questions were combined for each individual respondent, giving *n* = 141 open-text responses. Bar chart shows total number of responses that reported each reason. Responses are coloured by local environment of respondents (Rural, Suburban, Urban).

3.4 Satisfaction with amount of green space

61.8% of respondents reported being happy with the amount of green space their children had access to, whilst 36.5% said they would like their children to have more access to green space (Fig 3.4). No respondents said they would like their children to have less access to green space. The proportion of parents who were happy with the amount of green space their children had access to differed significantly between local environments ($\chi^2 = 14.4$, $df = 2$, $p = 0.00224$), being highest amongst rural parents and lowest amongst urban parents (Fig 3.4A).

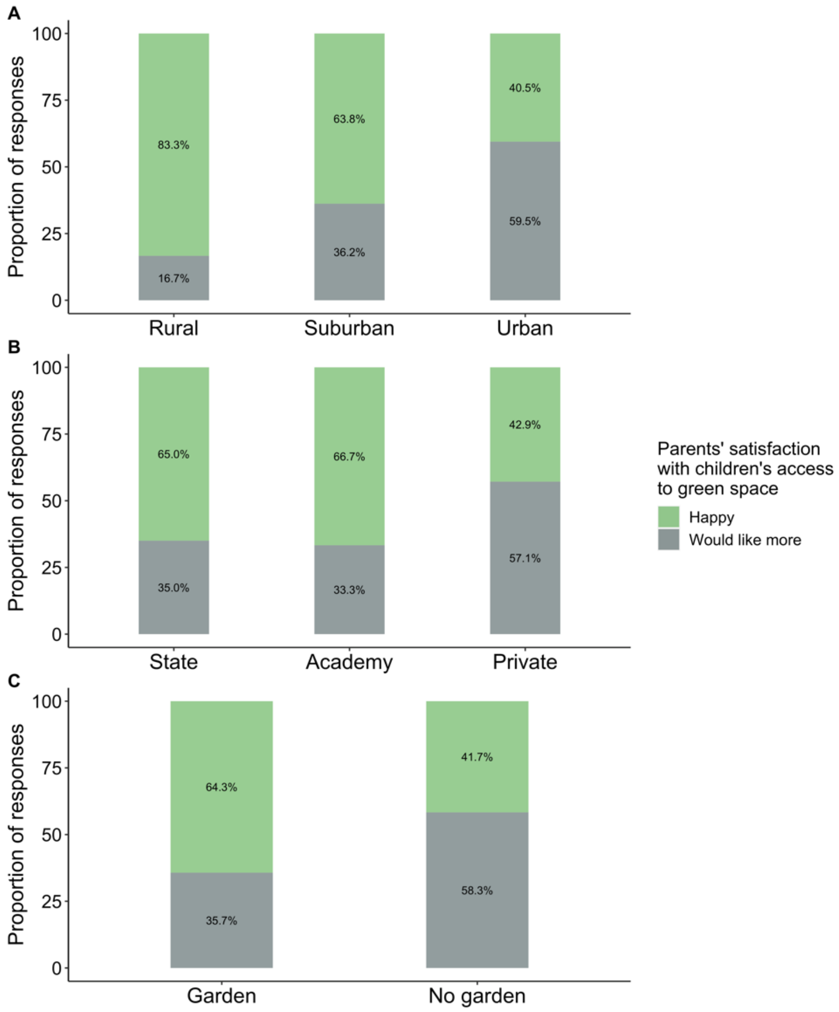

Figure 3.4. Responses to the multiple-choice question 'How do you feel about the amount of green space your children have access to?' (*n* = 167) from the survey for parents of primary school-aged children in the UK, excluding responses of 'I don't know'. A: responses grouped by local environment of respondents. B: responses grouped by school type of respondents' children. C: responses grouped by garden access. No respondents chose the answer option 'I would like them to have less access to green space.'

Neither school type (χ^2 = 3.96, *df* = 2, *p* = 0.138; Fig 3.4B) nor garden access (χ^2 = 1.56, *df* = 1, *p* = 0.211; Fig 3.4C) had a significant effect on parents' satisfaction with green space access.

4. Effects of COVID-19 lockdown restrictions

4.1 Change in thinking on the importance of green space

54.1% of respondents said their thinking on the importance of green space had changed during lockdown, whilst 39.4% said their views hadn't changed (Fig 3.5). The proportion of parents who said their thinking on the importance of green space had changed during

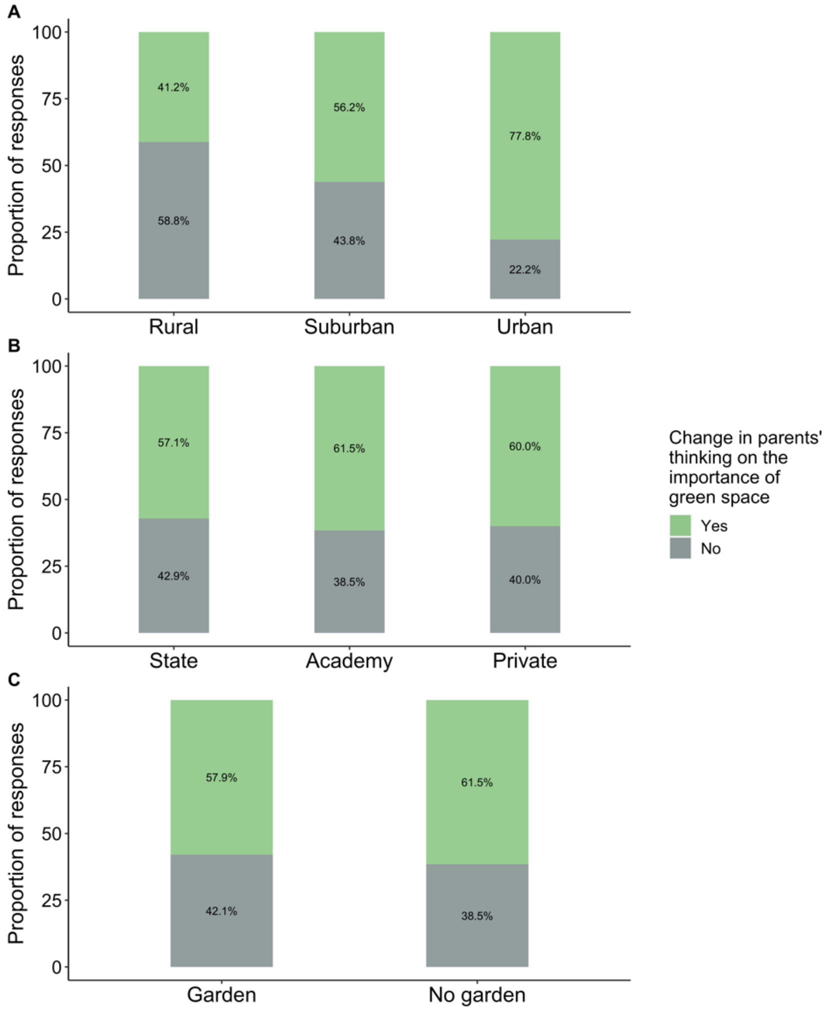

Figure 3.5. Responses to the multiple-choice question 'Has your thinking on the importance of green space changed since lockdown began?' (*n* = 159) from the survey for parents of primary school-aged children in the UK, excluding responses of 'I don't know' and 'Prefer not to say'. A: responses grouped by local environment of respondents. B: responses grouped by school type of respondents' children. C: responses grouped by garden access.

lockdown differed significantly between local environments (χ^2 = 9.84, *df* = 2, *p* = 0.0219), being lowest amongst rural parents and highest amongst urban parents (Fig 3.5A). Neither school type (χ^2 = 0.197, *df* = 2, *p* = 0.906; Fig 3.5B) nor garden access ($\chi^2 \sim 0$, *df* = 1, *p* = 1; Fig 3.5C) had a significant effect on whether parents' attitude to the importance of green space changed during lockdown.

4.2 Change in time spent outside by children

45.3% of respondents reported that the amount of time their children spent outside during lockdown had increased in comparison to before lockdown, 35.3% said the amount of time had decreased, and 15.3% said it hadn't changed (Fig 3.6). The proportion of parents who reported that their children spent more time outside during lockdown in comparison to before was significantly different between local environments (χ^2 = 12.3, *df* = 4, *p* = 0.0465), being lowest amongst urban children and highest amongst rural children (Fig 3.6A). Neither school type (χ^2 = 8.86, *df* = 4, *p* = 0.0647; Fig 3.6B) nor garden access (χ^2 = 5.89, *df* = 2, *p* = 0.0527; Fig 3.6C) had a significant effect on change in amount of reported time spent outside by children during lockdown.

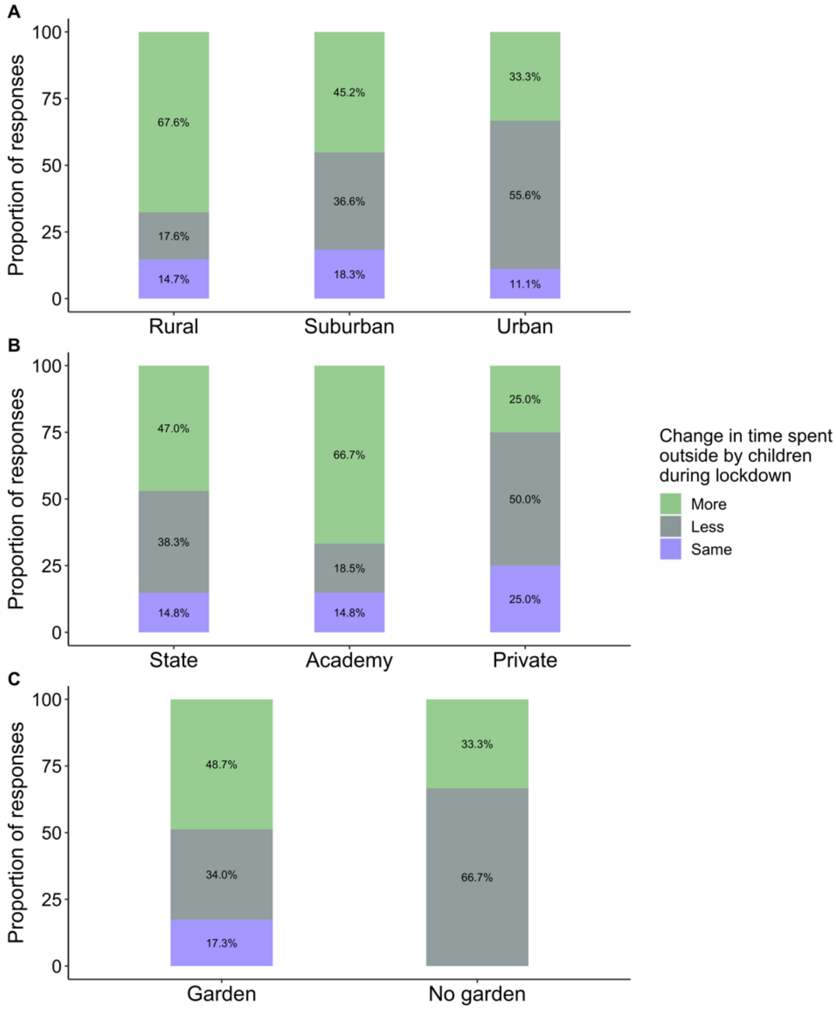

Figure 3.6. Responses to the multiple-choice question 'Are your children spending more or less time outside now than before lockdown began?' (n = 163) from the survey for parents of primary school-aged children in the UK, excluding responses of 'I don't know'. A: responses grouped by local environment of respondents. B: responses grouped by school type of respondents' children. C: responses grouped by garden access.

Discussion

1. Key results

In our sample, parents' attitudes towards green space differed by local environment, with urban parents reporting less satisfaction with current access and a greater increase in appreciation through lockdown than rural parents. COVID-19 lockdown restrictions also affected the amount of time spent outside by children, with most urban children spending more time inside and most rural children spending more time outside. These results offer a snapshot into the relationship of parents and children to green space in a specific location within the UK during the COVID-19 pandemic in 2020.

2. Parents' attitudes towards green space

Broadly similar values were placed on green space by parents from all groups, with themes of space, wellbeing, learning, play, exercise, nature and gratitude appearing in all word-clouds. One of the most common sentences in the open text answers was 'I have always been aware of the importance of green space', so this is likely responsible for the appearance of 'always' in all word clouds except one. These themes were mirrored by the most common reasons given for the importance of green space by parents from all groups: importance for spiritual wellbeing, space to play, space to exercise, importance for general learning, and importance for mental health. This complements previous research in which some of the most common reasons given for visiting green space were for health, exercise, to relax and to unwind (Neil & Nevin, 2014), as well as more recent research in the context of the COVID-19 pandemic, which has demonstrated an increase in the perceived importance of these spaces for wellbeing (Berdejo-Espinola et al., 2021; Pouso et al., 2021). However, our findings show a greater emphasis on benefits specific to children, such as play and learning, likely as a result of our target group being parents as opposed to the general population.

Gratitude for green space emerged as a key theme amongst the common sentiments extracted from open-text answers, featuring in the three most frequently expressed sentiments: 'Always been grateful for or aware of the importance of green space' (42.6% of responses), 'Grateful for green space' (24.8% of responses) and 'Became more grateful for green space during lockdown' (22.7% of responses). There were no significant differences in the sentiments expressed or reasons given for the importance of green space by parents from different local environments, school types or garden access. Our findings are in agreement with those from other studies in showing both a growth in people's appreciation for green space and in awareness of its importance, especially for wellbeing, over the lockdown period of March to July 2020 in the UK (Berdejo-Espinola et al., 2021; Campaign to Protect Rural England & National Federation of Women's Institutes, 2020; Pouso et al., 2021; Vivid

Economics & Barton Willmore, 2020). Collectively, these results suggest broadly similar attitudes towards green space across parents of primary school-aged children in our sample population, regardless of local environment, school type or garden access, with gratitude for these spaces being ubiquitous across groups. Gratitude has frequently been associated with increased subjective wellbeing (Alkozei et al., 2018), so it is not surprising that gratitude was a key theme amongst responses, especially given that 'importance for spiritual wellbeing' was the most commonly given reason for the importance of green space.

The majority of parents surveyed said they were happy with the amount of green space to which their children had access, but this attitude was significantly more common amongst rural parents than urban parents in our sample. Previous studies have found the lowest levels of satisfaction with the availability of local green space in the UK amongst the most deprived groups in urban areas (Neil & Nevin, 2014), yet some of the most deprived communities of the UK are found in rural areas (DEFRA, 2019). As such, it would be useful to assess how satisfaction with local green space compares between rural and urban communities with comparable levels of deprivation, since the lack of satisfaction found amongst deprived urban communities might be more than that found amongst rural communities experiencing a similar level of deprivation.

3. Effects of COVID-19 lockdown restrictions

The majority of parents surveyed said their thinking on the importance of green space had changed during lockdown, but this change was significantly more common amongst urban parents than rural parents in our sample. This supports findings from international research on the effects of lockdown restrictions, which identified changes in motivations for green space usage, an increase in appreciation for green space being important for wellbeing, and a need amongst urban residents for integrating urban green space within the built environment (Berdejo-Espinola et al., 2021; Ugolini et al., 2020). Most parents in our sample reported that the amount of time spent outside by their children had increased during lockdown in comparison to before, although the proportion of urban parents reporting this was significantly lower than the proportion of rural parents. This is in contrast with the Natural England People and Nature Survey, which found that the majority of children in the UK were spending less time outside during lockdown (Natural England, 2020a), in contrast with the majority of adults reporting that they were spending more time outside (Natural England, 2020b). However, these studies also found significant variation around these trends, associated with household income, age, ethnic group, local deprivation, health and the presence or absence of children in the household. Our results suggest there may also be significant differences between rural and urban groups.

Overall, the results from our sample suggest that urban parents' thinking on the importance of green space changed during lockdown, that their children spent less time outside during this period than they had before, and that they would like their children to have greater access to green space, whilst the reverse pattern was true for rural parents. This suggests that lockdown may have exacerbated pre-existing differences in access to green space between the rural and urban communities in our sample. This complements other research that suggests lockdown restrictions in the UK sustained, and possibly exacerbated, green space inequalities across different socioeconomic groups (Burnett et al., 2021). In similar research comparing the effects of restrictions in countries across Europe, urban residents expressed a need for integrating urban green space within the built environment (Ugolini et al., 2020), whilst urban green and blue space was found to be important for buffering the negative effects of the pandemic on mental health across Europe, North America and Australasia (Pouso et al., 2021).

We also found a non-significant trend in change in time spent outside during lockdown based on school type in our sample: for private-school pupils, more respondents reported spending less time outside, but for state-funded pupils, more reported spending more time outside. This could reflect the differing amounts of structured work provided by private and state-funded schools during lockdown (Cullinane & Montacute, 2020; Green, 2020), potentially reflecting differential resource availability (Henshaw, 2018) and suggesting that children at private schools spent more time on indoor, structured learning, whilst children at state-funded schools spent more time on outdoor, unstructured play. If this is the case, it has important and contrasting implications for the wellbeing and education attainment of primary school-aged children during lockdown. It is possible that pre-existing education attainment gaps between private and state-funded schools may have been exacerbated during this period (Hemsley-Brown, 2015), whilst the wellbeing of privately educated children may have suffered as a result of reduced time spent outside in green space (Ergler et al., 2013).

4. Implications

Important limitations of this study are the small sample size, with only 171 responses restricted to Cambridgeshire and North London in the UK, a small number of respondents with no garden access, and an uneven representation of different local environment types, school types and garden access. However, proportions were comparable to the distributions amongst these categories in the UK as a whole, based on nationally representative datasets (Department for Education, 2019; Green & Kynaston, 2019; Office for National Statistics, 2020; World Bank & United Nations Population Division, 2019b, 2019a). Nonetheless, the significant results and trends found here merit further research and investigation across larger sample groups, since they provide a snapshot of parents' and children's experiences of the COVID-19 lockdown restrictions in the southeast of the UK.

Our results have implications for children's wellbeing, connection with nature and future long-term support for conservation and ecology (Chawla, 2015, 2020). Lockdown may have exacerbated pre-existing differences between urban and rural children's access to nature and opportunities to form personal experiences and memories in the natural world, something that is known to have important implications for development, future wellbeing and likelihood of future pro-environmental behaviours in children (Kellert, 2002, 2005; Strife & Downey, 2009; Wells & Lekies, 2006). In our sample, these differences manifested themselves during lockdown in differing amounts of time spent outside by urban and rural children and in differing parental attitudes towards green space. Given children's increasing disconnection from nature, particularly amongst urban groups (Aaron & Witt, 2011), it is important that this trend is investigated in children from different backgrounds in order to ensure interventions are targeted towards those children most at risk of developing a larger nature deficit.

Chapter Four: What can drawings tell us about children's perceptions of nature?

Abstract

1. The growing disconnect between children and nature has led to concerns around the attrition of ecological knowledge, reduced opportunities for developing a connection with nature at a young age and the associated potential of waning support for future conservation. Understanding perceptions of the natural world among children is vital to engage them with local wildlife and mitigate the growing disconnect between children and nature. This study investigated children's perceptions of nature by analysing drawings made by children of their local green spaces.
2. We collected 401 drawings by children aged 7-11 years, from 12 different primary schools (including state-funded and privately funded schools) in England, and assessed which animal and plant groups were drawn the most and least often. We quantified the species richness and community composition of each drawing, and identified all terms used in the labels and captions to the highest level of taxonomic resolution possible. We estimated the greenness of each school's surroundings and tested whether there were differences in taxonomic resolution between taxa and whether school type or school greenness affected animal or plant species richness, community composition or taxonomic resolution of terms.
3. Mammals and birds were the most commonly drawn groups, appearing in 80.5% and 68.6% of drawings respectively. The least commonly drawn group was herpetofauna, appearing in just 15.7% of drawings. Despite children not explicitly being asked about plants, 91.3% of drawings contained a plant.
4. Taxonomic resolution was higher for mammals and birds than other taxa, with 90% of domestic mammals and 69.6% of garden birds identifiable to species, compared to 18.5% of insects and 14.3% of herpetofauna. No invertebrates other than insects were identifiable to species. Within plants, trees and crops were the most identifiable to species, at 52.6% and 25% of terms respectively.
5. There was no difference in animal species richness or plant community composition between school types, but drawings from state-school children had higher plant species

richness than those from private-school children. Animal community composition was different between school types, with more types of garden birds drawn by private-school children than state-school children, and more types of invertebrates drawn by state-school children than private-school children. School greenness had no effect on species richness or on plant community composition, but we found an effect on animal community composition. There was no difference in the taxonomic resolution of terms between school types.

6. Our findings indicate that children's awareness of local wildlife is focused on mammals and birds, with significantly less attention given to invertebrates and herpetofauna. While plants feature highly in children's perceptions of nature, their knowledge is less specific than that of animals. We suggest that this skew in children's ecological knowledge towards familiar, charismatic animals be addressed through better integration of ecology within national curricula and more funding for green space within school grounds, since smaller invertebrate taxa are likely to be more abundant in these spaces. Encouragingly, levels of awareness did not systematically differ between school types, indicating that similar approaches to engage children with nature should be made across school types.

Introduction

The growing disconnect between people and nature has often been linked to rapid urbanisation and reduced daily contact with nature, resulting in a reduction of interactions and experiences both in childhood and across lifetimes (Gaston & Soga, 2020; Maller et al., 2009; Miller, 2005). In the UK, accessibility of green space is highly heterogeneous (Barbosa et al., 2007; Pauleit et al., 2005; Turner et al., 2004), varying by socioeconomic background and distance from the home (Coombes et al., 2010; Dunton et al., 2014; Harrison et al., 1995). In addition, green space accessibility is lower for children than adults because of extra barriers, such as parental restrictions on independent movement, in part driven by parental concerns around safety (Timperio et al., 2004), and urban barriers, such as roads (Carver et al., 2008; Freeman & Quigg, 2009; Veitch et al., 2008; Villanueva et al., 2012). Across Europe and North America, the area across which children regularly and independently move around the home has declined in recent decades (Fyhri et al., 2011; Karsten, 2005; Kyttä et al., 2015;

O'Brien et al., 2000; Shaw et al., 2013). As a result, a large proportion of green space is now inaccessible to children, even if physically present near the home (Hand et al., 2018).

Linked with this, frequent concerns have been raised around the 'extinction of experience', where children's opportunities to experience and develop a connection with the natural world are increasingly limited (Soga & Gaston, 2016), with impacts on awareness. For example, children in the UK show greater familiarity with science fiction characters than with the commonest native species (Moss, 2012; Natural England, 2009), demonstrating that, while they have a large capacity for identification, children can be swayed more by images in the media than by those in the natural world (Balmford et al., 2002). A related concept is the 'transformation of experience', where direct experiences of nature are not just removed, but replaced by indirect experiences (Clayton et al., 2017; Truong & Clayton, 2020). These indirect experiences can be incidental or vicarious (Keniger et al., 2013), and include technology-mediated experiences, such as through video games, social media, nature documentaries or other forms of entertainment. Although there is evidence that environmental knowledge, such as species identification and knowledge of species interactions, can be gained from these indirect experiences, even when the technology is not primarily designed for this purpose (Crowley et al., 2021), there is not yet a good understanding of how indirect experiences facilitate a connection with nature (Clayton et al., 2017; Truong & Clayton, 2020), by which we mean an individual's relationship with nature on a physical, emotional, spiritual or intellectual level (Cheng & Monroe, 2012; Gaston & Soga, 2020). However, there is evidence that the frequency of indirect experiences, as well as of direct ones, influences children's attitudes towards biodiversity and their willingness to conserve it (Soga, Gaston, Yamaura, et al., 2016).

So far, there has been a degree of inconsistency over what constitutes 'indirect' nature experiences (Gaston & Soga, 2020); some argue that nature experiences cover a spectrum, from direct to vicarious interactions with nature, which occur when there is a lack of sensory contact and the interaction is instead technology-mediated. In this case, nature experiences are not necessarily reduced or 'extinct', but transformed. However, others argue that the confounding of direct and indirect nature experiences is not what was originally intended by the concept of 'extinction of experience', and that this term is better reserved for the loss of direct experiences with nature (Gaston & Soga, 2020). These two viewpoints are not incompatible: indirect experiences, such as nature documentaries, can be viewed both as part of the trend of the transformation of experience and as concurrent with the extinction of experience. Regardless, indirect experiences are today forming a greater part of children's interactions with nature, and these can be both positive or negative, incidental or intended, just as direct experiences can be (Soga & Gaston, 2020).

More residential green space around a child's home has been linked with improved cognitive functioning, including across measures of intellectual, emotional and behavioural development (Bijnens et al., 2020; Wells, 2000), and reduced psychological impacts of stressful life events (Wells & Evans, 2003), both when based on remote imaging of land-cover and on the 'naturalness' of the home environment (e.g., views of trees through a window). Local green spaces, such as gardens, local parks and school grounds are therefore likely to be important for delivering the wellbeing-related benefits of biodiversity. Indeed, the volume of vegetation in children's school grounds has been found to be associated with the perceived restorativeness of these spaces (Bagot et al., 2015), and newly renovated green schoolyards in urban areas have been shown to increase children's positive social interactions (Bates et al., 2018), attentional development (Taylor & Butts-Wilmsmeyer, 2020) and levels of physical activity, particularly for girls, as well as their appreciation of these spaces (van Dijk-Wesselius et al., 2018) and the development of resilience (Chawla et al., 2014).

A reduced connection with nature is also likely to have detrimental effects on future support for conservation. Although vicarious nature experiences have been shown to influence attitudes to biodiversity conservation (Soga, Gaston, Yamaura, et al., 2016), development of nature connection is highly dependent on direct experiences in the natural world (Project Dirt, 2018; M. Richardson et al., 2020; The Wildlife Trusts & University of Derby, 2019). While artificial exposure has been shown to increase pro-nature conservation behaviours in adults, such as monetary donations to animal protection organisations, it has not been linked to an increase in nature connection (Arendt & Matthes, 2016). Direct experiences during childhood have a particularly significant influence on environmental attitudes later in life, such as recycling, beach clean-ups and political activity (Wells & Lekies, 2006), as well as affecting long-term cognitive development (Kellert, 2002, 2005). Raising support for conservation initiatives and recruitment of the next generation of naturalists and conservationists is therefore likely to become more of a challenge as nature disconnect grows and direct experiences in nature are replaced by indirect experiences. The activities encouraged and facilitated in local green spaces are therefore likely to be particularly important for building children's connection with nature, with both immediate effects and ramifications in later life.

Quantitative social research with child respondents is less common than with adults (Kellet, 2011). This is partly due to concerns over obtaining reliable information from children, linked to issues with children's understanding of what is being asked of them and retaining attention throughout the process (Kellet, 2011; Massey, 2021). However, research shows that respondents as young as five years old can provide reliable information when they are asked in ways they can understand and respond to appropriately (Beilock et al., 2010; Lundqvist et al., 2010; Massey, 2021; Suinn et al., 1988). In particular, approaches using pictures and drawings have yielded detailed information on children's knowledge, feelings and attitudes (Beilock et al., 2010; Lundqvist et al., 2010; Massey, 2021; Montgomery et al., 2022), including on ecological questions. For example, one UK study that asked children to draw a rainforest (Snaddon et al., 2008) found that children have a detailed view of rainforest environments that encompasses a diverse range of habitats and animal species, but that vertebrate taxa, especially mammals, birds and reptiles, were overrepresented, while invertebrate taxa, especially insects and worms, were underrepresented in comparison to their actual contributions to biomass and species richness (Snaddon et al., 2008). A similar result was found by another UK study (Montgomery et al., 2022), in which children were asked to draw what they thought was in their school grounds before and after taking part in a nature engagement programme across the school year. While at first children drew more vertebrate than invertebrate species, their perception was more reflective of reality at the end of the engagement programme, when they drew more invertebrates (Montgomery et al., 2022).

More generally, drawings have been used to assess children's perceptions and meanings of 'nature' in an abstract sense (Aaron & Witt, 2011), to assess the development of children's positive attitudes to small animals and invertebrates (Drissner et al., 2014), to investigate how children perceive the functioning of the natural, geological and anthropic aspects of the environment (Morón-Monge et al., 2021), to explore environmental indictors of children's wellbeing, such as safety (Moula et al., 2021), and to evaluate children's biological understanding of animals as pets (Prokop et al., 2008). In our study, we used drawings to gauge children's awareness of local wildlife. Despite there being questions around the importance of ecological knowledge, such as species identification, for the development of nature connection (Lumber et al., 2017), familiarity for particular taxa can engender positive attitudes (Schlegel & Rupf, 2010) and a greater likelihood to think of a species as requiring conservation (Ballouard et al., 2011), which has implications for both policy and scientific research (Martín-López et al., 2009). We therefore argue that gauging children's ecological knowledge in this way also has implications for nature connection and conservation.

In this study, we asked children (all aged between seven and 11 years) from 12 different primary schools across England to draw the local wildlife living in their garden or local green space. We quantified animal and plant species richness and community composition of the drawings, as well as the taxonomic level to which drawings and associated labels could be identified. We also estimated the amount of green space to which children are regularly exposed on a daily basis by calculating the total area of green space in a 3km buffer around their school. We then assessed whether level of representation and identification differed between taxa, and whether there were differences in representations between state-funded and non-state-funded school pupils, and across schools with differing levels of greenness of their surroundings. Specifically, we asked the following questions:

1. What are the most common types of animals and plants drawn, and does the level of taxonomic resolution change between taxa?
2. Does species richness, community composition and level of taxonomic resolution of animals and plants change between drawings from different school types or with greenness of school surroundings?

We expected that vertebrates, specifically mammals and birds, would be the most commonly drawn and identified to the highest taxonomic resolution. Secondly, we expected that both species richness and resolution of taxonomic identification would be higher in drawings from schools with greener surroundings. We interpret our findings in the context of their potential implications for future connection with nature.

Methods

1. Data collection

Drawings were collected from 401 primary-school children, aged between seven and 11, at 12 different primary schools, distributed across England but with the highest concentration around the southeast (Fig S4.1). Using the University Museum of Zoology, Cambridge (UMZC)'s mailing lists and social media accounts, we sent out information about the study, asking whether any primary school teachers would be happy to be contacted with further information. The mailing lists are specifically for primary-school teachers and are free for anyone to sign up to via the Museum's website. In total, 79 primary-school teachers at 57 different English primary schools said they were happy to be contacted with further information about the study. We arranged for children at as many of these schools as possible to provide drawings for us, limited by the teachers' and schools' capacity to support us. This totalled 401 children across 12 schools, including three different 'school types', that varied by fee-paying status and governance: three private, four academy and five state schools (Table S4.2).

We split state-funded schools into two categories, state and academy, since they reflect different management practices. Although they are both free for children to attend, academies are administratively free from local-authority control, whilst state schools are administered by their local authority with regards to admissions and day-to-day running. Private schools are paid for by parents and are not subject to local-authority control. This means that state schools receive their funding from local authorities and are constrained by them in how budgets are spent, while academies receive funding directly from central government and have more freedom over spending. Private schools have complete freedom over how they spend their budgets. Given that outside space in schools, including green space, is not held to any particular standards by the Department for Education in the UK and budgets vary between school types, it is possible that the amount of money allocated to and availability of outside space varies between school types. In addition, given the fee-paying status of private schools and the subsequently greater proportion of children in higher income brackets attending private than state-funded schools, it is possible that privately educated children have greater access to private, domestic gardens. Collectively, these differences might influence daily exposure to nature for children attending different school types and consequently on awareness of local wildlife.

Children were provided with a worksheet (Appendix S4.3) and the following instruction: 'Please draw and label a picture of your garden or local park showing the animals you think live there'. The worksheet also provided space for children to write a caption beneath their drawing. We asked children about the green space they were exposed to outside school rather than about school grounds specifically to allow them to express their wider ecological knowledge, without being constrained by specific characteristics of their school. We specified local spaces to avoid children viewing the activity as a species-listing exercise and including all species they were aware of, regardless of whether or not they thought of them as local wildlife (e.g., elephants). The worksheet was emailed to teachers, who were asked to print them out, distribute them to their class during a spare 10 minutes in the school day and to read the instruction at the top of the worksheet out loud. Teachers were asked not to give any extra information or guidance to children other than the written instruction.

2. Research ethics

Written consent was obtained from parents or guardians of all children who provided a drawing through a letter sent home via schools. Parents or guardians were provided with full Participant Information before being asked to provide written consent (Appendix S4.4). Participation was voluntary, and it was made clear to parents or guardians that they were under no obligation for their child to take part and that they could withdraw their consent at any point (up to three months after the end of the study) with no penalties. Our protocol was reviewed and approved by the Cambridge Psychology Research Ethics Committee (PRE.2019.009).

3. Data processing

At the first stage of processing, we made a comprehensive list of all terms used in the labels and captions to refer to animals (n = 123) and plants (n = 56) (Table S4.5). We decided to include plants in our analysis at this stage, despite not specifically asking children about plants, because they appeared in the majority of drawings, indicating that children connected plants with their local green spaces and therefore that they merited analysis. At the second stage of processing, we went back through each individual drawing to record whether each term was present or absent. Where a term was misspelled or hard to read, we marked it as present only if it was independently interpreted in the same way by a second member of the research team.

Where a drawing was not labelled, but the broad identity of the animal or plant was clear after independent agreement by a second researcher, we marked the most specific term possible as present (e.g., where a tree or flower was drawn but not labelled, ‘tree’ or ‘flower’ was marked as present). Where an unlabelled drawing had an unambiguous, diagnostic detail (e.g., a bird was drawn with a brown body and red breast, or an invertebrate was drawn with eight legs or dangling from a web), we afforded it a greater level of taxonomic identification (e.g., ‘robin’ rather than ‘bird’, or ‘spider’ rather than ‘minibeast’), again following independent agreement by a second researcher, and marked this term as present. We then identified every term to the greatest taxonomic resolution possible (Species, Genus, Family, Order, Class, Phylum or Kingdom). Where a term had no taxonomic meaning (e.g., ‘tree’, ‘blossom’), we recorded ‘None’ (Table S4.5). We recorded the total number of different terms per drawing as the ‘species richness’, which we kept separate for animals and plants. We decided on the term ‘species richness’ since this is understandable by a broad audience, rather than because we wish it to be interpreted in a strictly ecological sense.

For the purposes of analysing community composition, we grouped all animal terms into one of the following categories: General (broad terms for groups of animals, e.g., ‘Mammals’, ‘Birds’, ‘Creepy crawlies’), Domestic Mammals, Wild Mammals, Garden Birds (species regularly attracted to feed or nest in domestic gardens, e.g., ‘Robin’, ‘Blue tit’, ‘Magpie’), Other Birds (species just as likely or more likely to be seen in parks or nature reserves than in a domestic garden, e.g., ‘Duck, ‘Swift’, ‘Red kite’), Herpetofauna, Insects, Other Invertebrates. We decided to separate mammals into 'Domestic Mammals’ and ‘Wild Mammals’ because domestic species featured in such a high proportion of drawings and in such high diversity (i.e., a high number of different domestic animals per drawing). As such, this distinction allows us to explore whether any trends are true across all mammals, or due more or less to either domestic or wild mammals. Similarly, we grouped all plant terms into one of the following categories: General (broad terms for groups of plants without taxonomic meaning, e.g., 'Trees', 'Flowers', 'Plants'), Trees, Flowers, Crops (plants grown for produce, e.g., Strawberries, Potatoes, Carrots), Other Plants ('Mushroom' is included in 'Other Plants' since it is the only fungal representative, and it appeared in just three drawings) (see Table S4.5 for a full list of terms in each category). Terms classified in the 'General' categories were not counted towards species richness, nor were the terms 'Herbs' or 'Vegetables' (in the 'Crops' category) since these do not have taxonomic meaning (Table S4.5). The purpose of creating 'General' categories for both animals and plants was to remove terms with too low a level of taxonomic meaning to justify inclusion in the species richness total (e.g., 'Creepy crawlies' or 'Plant'), or were too imprecise to justify inclusion in one of the other categories for community composition analyses (e.g., 'Bugs' or 'Blossom').

To test for possible effects of the greenness of children's surroundings on perceptions of local wildlife, we calculated the area of green space in a 3km buffer around each school. We chose 3km since this is a good approximation of the average distance travelled to school by primary school children in the UK (Department for Transport, 2015, 2020), making this a reasonable representation of the greenness to which children are exposed on a regular basis. We first calculated the area of this space in hectares using QGIS (QGIS Development Team, 2022) and imagery from Google Earth. We then used R version 4.1.3 (R Core Team, 2022) and R Studio Build 461 (RStudio Team, 2022) to calculate the total number of pixels and number of green pixels in this area, which allowed us to calculate the area of green space (ha) in the buffer (hereafter referred to as 'buffer greenness').

4. Statistical analyses

All statistical analyses were performed in R version 4.1.3 (R Core Team, 2022) within R Studio version Build 461 (RStudio Team, 2022). We used *tidyr* (Wickham & Girlich, 2022), *RColorBrewer* (Neuwirth & Brewer, 2022), *ggsignif* (Ahlmann-Eltze & Patil, 2021), *ggplot2* (Wickham, 2016) and *cowplot* (Wilke, 2020) for data wrangling, exploration and visualisation. Exploration followed (Zuur et al., 2010). We fitted generalized linear mixed models (GLMMs) using *glmmTMB* (Brooks et al., 2017), multivariate generalized linear models (mGLMs) using *mvabund* (Wang et al., 2022), and chi-square tests of independence using *stats* (R Core Team, 2022). Unless otherwise stated, we fitted models to negative binomial distributions, including school type (levels: state, academy, private) and buffer greenness as fixed effects and, for mixed models, school identity as a random intercept effect.

4.1 Species richness

We analysed animal and plant species richness using GLMMs to account for non-independence of drawings from the same school. We fitted the models for plant species richness to a Poisson distribution, since those fitted to a negative binomial distribution displayed model convergence issues.

We validated GLMMs by plotting quantile residuals against predicted values and covariate school type to verify that no patterns were present. To ensure our GLMMs fitted the observed data, we ran simulation-based dispersion tests using *DHARMa* (Hartig, 2022) to compare the variance of the observed residuals against the variance of the simulated residuals, with variances scaled to the mean simulated variance, and checked that our model was within the range of our simulations (Zuur & Ieno, 2016). Our simulations indicated that there were no issues in model fit. We determined the significance of school type to each model by comparing fitted models with null models using likelihood ratio tests (LRTs). If mixed models suggested a moderately significant effect of school type ($0.03 < p < 0.07$), we re-calculated p values based on parametric bootstrapping using *DHARMa* (Bates et al., 2015; Hartig, 2022). If school type was significant, we used *multcomp* (Hothorn et al., 2019) to conduct post-hoc analyses (Tukey all-pair comparisons, adjusting p values using the Bonferroni correction) to identify school types between which significant differences occurred.

4.2 Community composition

We analysed community composition at the category level, taking the number of terms used per category per drawing as 'abundance'. We used mGLMs (Warton et al., 2012; Warton & Hui, 2017) to analyse animal and plant community composition separately, followed by univariate analyses if school type was significant ($p = 0.05$).

We validated mGLMs by plotting Dunn-Smyth residuals against fitted values and covariate school type, and verifying no patterns were present (Wang et al., 2012, 2022). We determined the significance of school type using LRTs and by bootstrapping probability integral transform (PIT) residuals using 10,000 resampling iterations (Warton et al., 2017). If school type was significant ($p < 0.05$), we ran univariate analyses on individual taxa. We adjusted univariate p values to correct for multiple testing using a step-down resampling algorithm (Wang et al., 2012), but otherwise our statistical approach remained unchanged from the multivariate parent models. We could not include school as a blocking variable to account for non-independence of drawings from the same school since *mvabund* requires an equal number of samples in each level of the blocking variable. Instead, we ran a sensitivity analysis on a random sample of nine drawings from each school using the same statistical approach, since nine was the smallest number of drawings collected from a single school.

4.3 Taxonomic resolution

We used chi-square tests of independence to test for differences in the proportion of animal and plant terms identifiable to species level between categories, and for differences in the proportion of animal and plant terms identifiable to species level within each category between school types. We excluded terms in the 'General' categories for both animals and plants from these analyses since these terms, by definition, are not identifiable to species, and, for plants, no terms in the 'General' category had taxonomic meaning (Table S4.5).

Results

1. Differences between taxa

1.1 Animals

The most frequently represented animals in the children's drawings were mammals (represented in 80.5% of all drawings) and birds (represented in 68.6% of all drawings; Table S4.6; Fig 4.1A). Just over half of drawings contained an insect (54.6%) or another kind of invertebrate (51.4%), and only 15.7% of drawings contained a reptile or amphibian. Around one in three drawings contained no invertebrates (32.4%), and 2.7% of drawings used only 'General' terms for animals in the labels or caption (Table S4.6; Fig 4.1A). In total, 123 different terms were used for animals, and the most 'speciose' categories were 'Insects' (27 terms), 'Garden Birds' (23 terms), 'Other Birds' (22 terms) and 'Wild Mammals' (19 terms) (Table S4.5). The most commonly used animal term was 'Birds', which appeared in 48.6% of drawings, followed by 'Squirrel' (29.9%) and 'Ant' (28.9%) (Fig 4.2A).

The percentage of animal terms identifiable to each taxonomic level was as follows: species: 43.9%, genus: 8.9%, family: 15.4%, order: 19.5%, class: 8.9%, phylum: 1.6%, kingdom: 1.6% (Fig 4.3A). The proportion of animal terms identifiable to species level was significantly different between categories ($\chi^2 = 13.145$, $df = 6$, $p = 0.04079$), with terms in the categories 'Domestic Mammals', 'Garden Birds', 'Wild Mammals' and 'Other Birds' being the most identifiable to species level, at 90%, 69.6%, 57.9% and 54.5% of terms respectively (Fig 4.3A). In contrast, just 18.5% of terms in 'Insects' and 14.3% of terms in 'Herpetofauna' were identifiable to species level, while no terms in the category 'Other Invertebrates' were identifiable to species level (Fig 4.3A).

1.2 Plants

91.3% of drawings contained at least one kind of plant (Table S4.6; Fig 4.1B), despite no explicit mention of plants in the instructions given to the children (Appendix S4.3). 72.3% of drawings contained a plant that was not a tree, flower or crop, mostly due to frequent use of the terms 'grass' (59.1%) and 'bush' (23.2%) (Fig 4.1B). Taking account of both specific (e.g., 'Apple tree', 'Rose') and general (e.g., 'Trees', 'Flowers') representations, trees featured in 67.1% of drawings and flowers in 30.2% of drawings. 8.7% of drawings contained no plants, and 26.4% of drawings used only 'General' terms for plants in the labels or captions (Table S4.6; Fig 4.1B). 56 different terms were used for plants, and the most 'speciose' category was 'Crops' (19 terms) (Table S4.5). The most commonly used plant term was 'Trees', which appeared in 61.6% of drawings, followed by 'Grass' (59.1%) and 'Flowers' (27.9%) (Fig 4.2B).

The percentage of plant terms identifiable to each taxonomic level was as follows: species: 21.4%, genus: 41.1%, family: 12.5%, order: 0%, class: 1.8%, phylum: 0%, kingdom: 1.8%; 21.4% of terms did not have taxonomic meaning (e.g., 'bush', 'flower', 'tree') (Fig 4.3B). The proportion of plant terms identifiable to species level was significantly different between categories ($\chi^2 = 8.6877$, $df = 3$, $p = 0.03374$), with terms in the categories 'Crops' and 'Trees' being the most identifiable to species level, at 52.6% and 25% of terms respectively (Fig 4.3B). No terms in 'Flowers' or 'Other Plants' were identifiable to species level (Fig 4.3B).

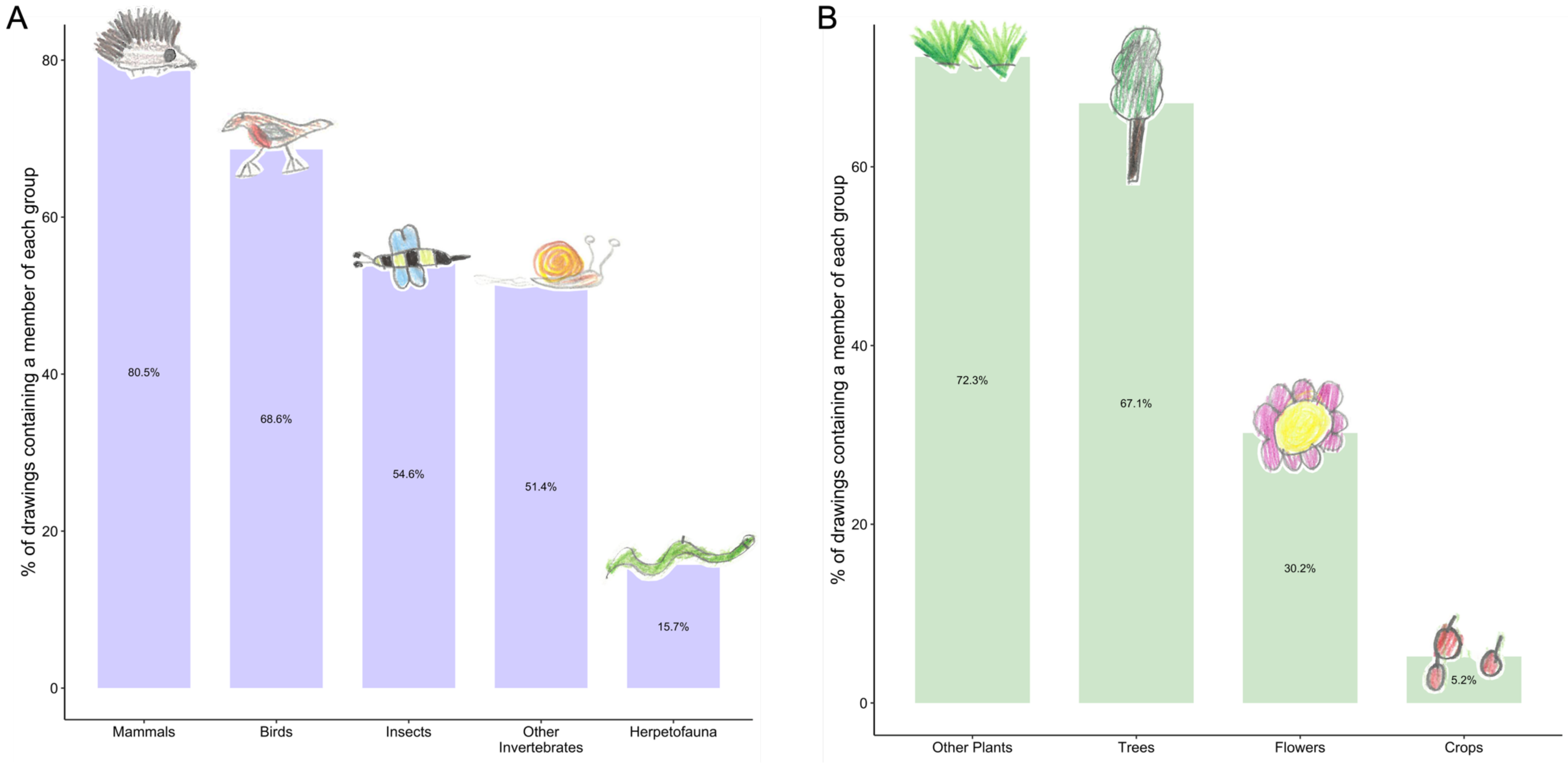

Figure 4.1. Histogram showing the percentage of drawings containing at least one representative of each group for A: animals and B: plants. These data represent the combined totals of both specific (e.g., ‘Robin’, ‘Daisy’) and general (e.g., ‘Bird’, ‘Flower’) representations.

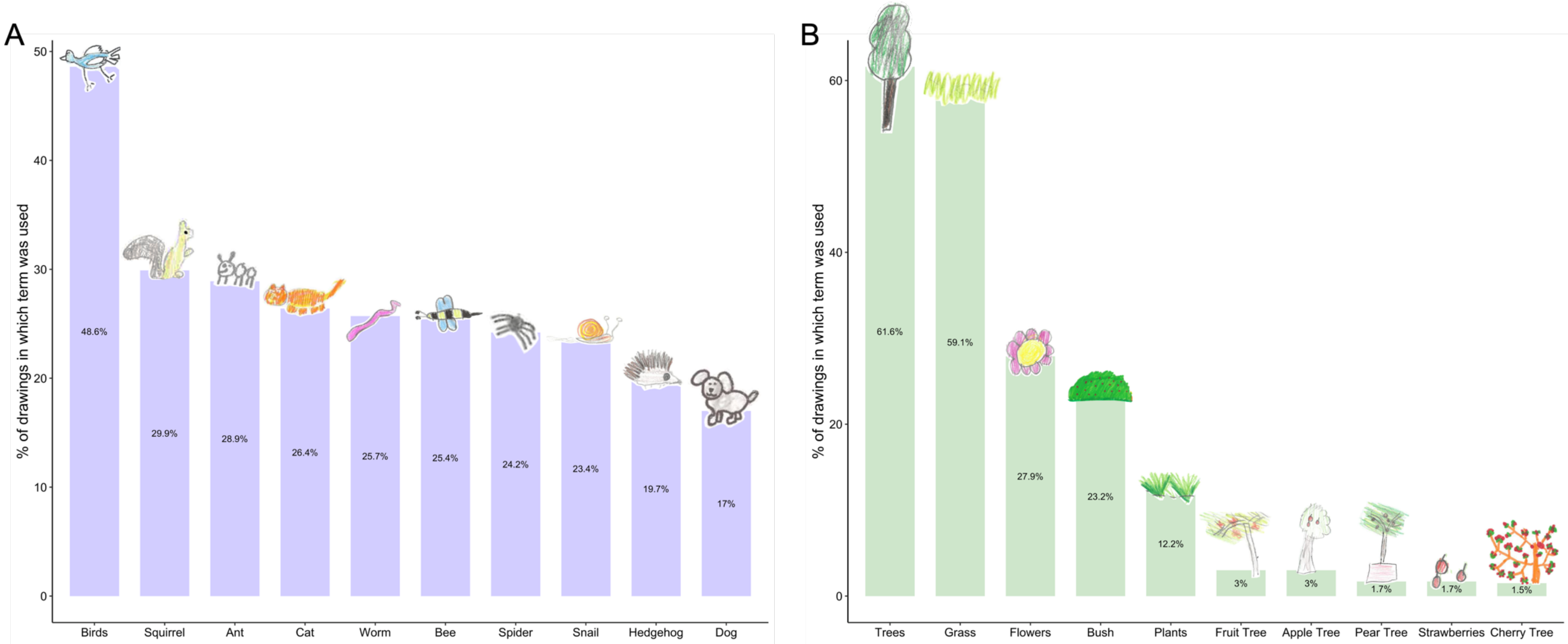

Figure 4.2. Histogram showing the percentage of drawings containing each of the 10 most commonly used terms for A: animals and B: plants.

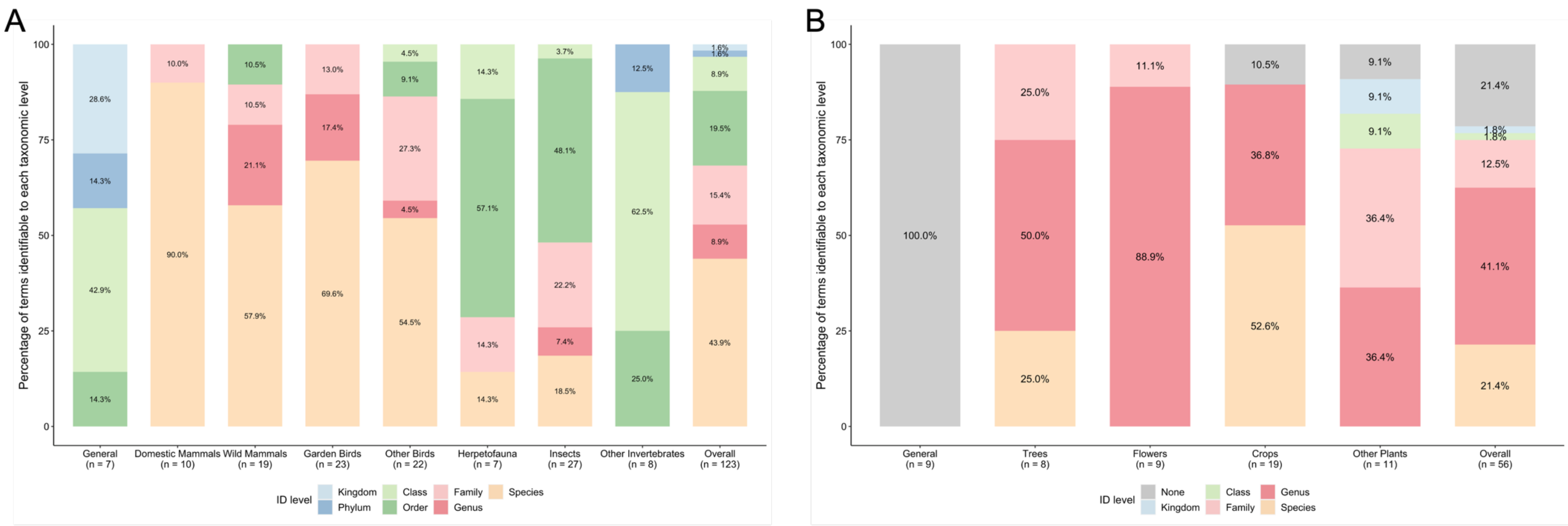

Figure 4.3. Bar graphs showing the percentage of terms used in the labels and captions of children's drawings identifiable to each taxonomic level. Separate bars show percentages for each category, and far right bars show overall percentages with all categories combined. Bars are coloured by taxonomic level of identification. A: Animal terms (n = 123). B: Plant terms (n = 56).

2. Differences between school types

2.1 Species richness

There was no effect of school type on animal species richness (LRT = 1.8706, $p = 0.3925$; Fig 4.4A), but plant species richness differed between school types (LRT = 7.2149, $p = 0.02712$; Fig 4.4B), with state school drawings having significantly higher plant species richness than those from private schools, although there was no difference between those from state and academy schools or between those from academy and private schools (Table S4.7). There was no effect of buffer greenness on animal species richness (LRT = 0.14475, $p = 0.7036$) or plant species richness (LRT = 1.6772, $p = 0.19530$).

2.2 Community composition

Animal community composition was significantly different between school types (LRT = 53.19, $p < 0.0001$; Fig 4.5A), with post-hoc tests showing this differed between all three pairs of school types (Table S4.7). Univariate analyses indicated that the categories 'Garden Birds' (LRT = 10.091, $p = 0.0446$) and 'Other Invertebrates' (LRT = 22.660, $p = 0.0001$) were the primary drivers of these differences (Fig 4.5B), with a greater number of terms for garden birds listed in drawings from private schools than from other school types, and a greater number of terms for invertebrates (other than insects) listed in drawings from state schools than from other school types. There was a significant effect of buffer greenness on animal community composition (LRT = 15.91, $p = 0.047$), although univariate analyses indicated that this was not driven by any group of animals in particular. However, neither the significant differences between school types, nor the effect of buffer greenness, were replicated in our sensitivity analysis (School type: LRT = 31.296, $p = 0.178$; Buffer greenness: LRT = 4.332, $p = 0.765$).

Plant community composition did not differ between school types (LRT = 13.45, $p = 0.119$ [sensitivity analysis: LRT = 15.305, $p = 0.162$]; Figs 4.6A-B), and there was no effect of buffer greenness (LRT = 5.614, $p = 0.262$ [sensitivity analysis: LRT = 3.284, $p = 0.498$]).

2.3 Taxonomic resolution

Differences in the level of taxonomic resolution between animal categories were consistent across school types, with no significant differences within each category between school types (Table S4.8). Differences in the level of taxonomic resolution between plant categories were also consistent across school types, with no significant differences within each category between school types (Table S4.9).

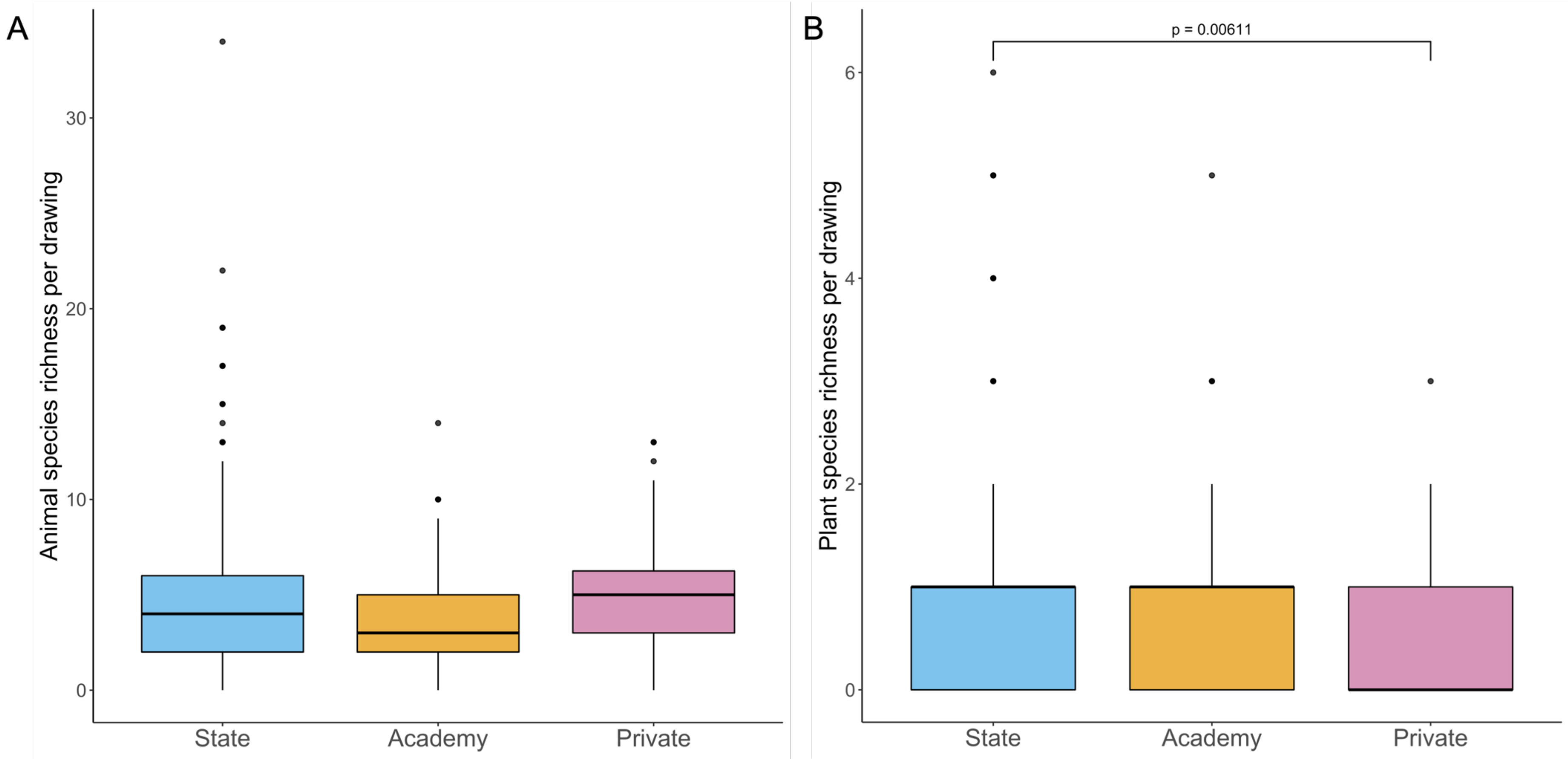

Figure 4.4. Boxplots showing species richness of children's drawings (n = 401) by school type. Black lines indicate the median values. Coloured boxes show the interquartile ranges (IQR). Whiskers extend to the largest and smallest values no further than 1.5*IQR. A: Animal species richness by school type. B: Plant species richness by school type. Bracket labelled with adjusted p value shows a significant difference between state and private schools after post-hoc analyses.

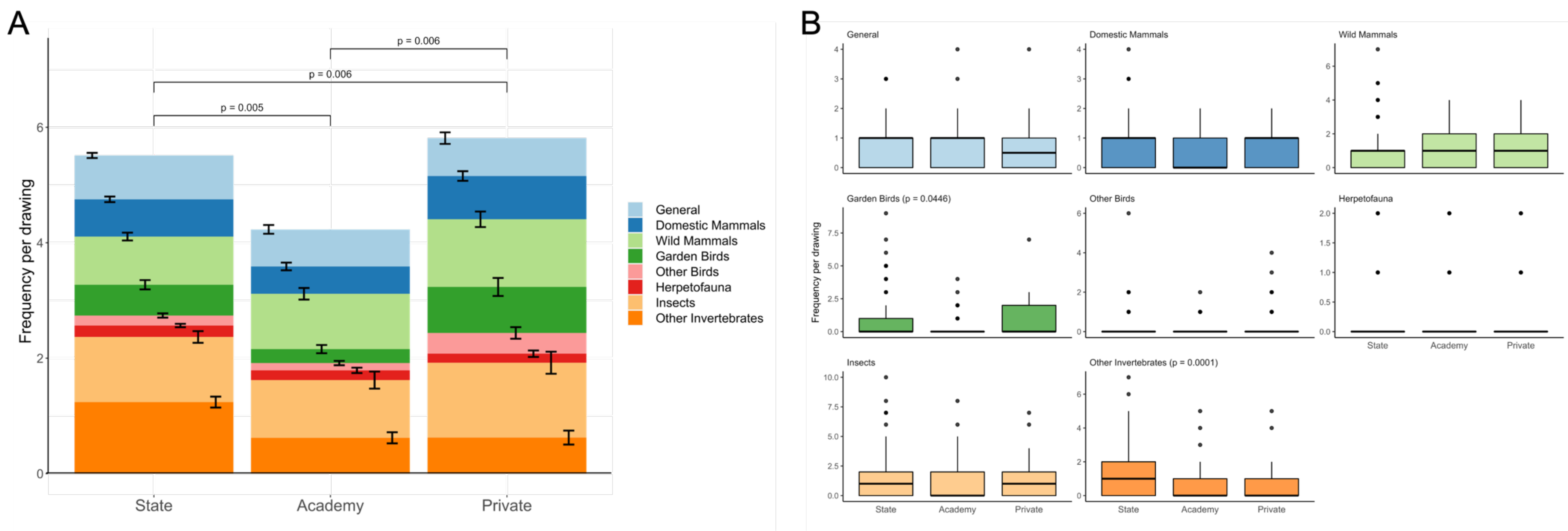

Figure 4.5. Animal community composition of children's drawings (n = 401) by school type. A: Stacked bar graph showing category-level community composition with separate bars for each school type and coloured by category. Brackets labelled with p values show significant differences between pairs of school types. B: Boxplots showing category-level community composition by school type separated by category. Black lines indicate the median values. Coloured boxes show the interquartile ranges (IQR). Whiskers extend to the largest and smallest values no further than 1.5*IQR. P values are provided for the categories found to be primary drivers of differences following univariate analyses.

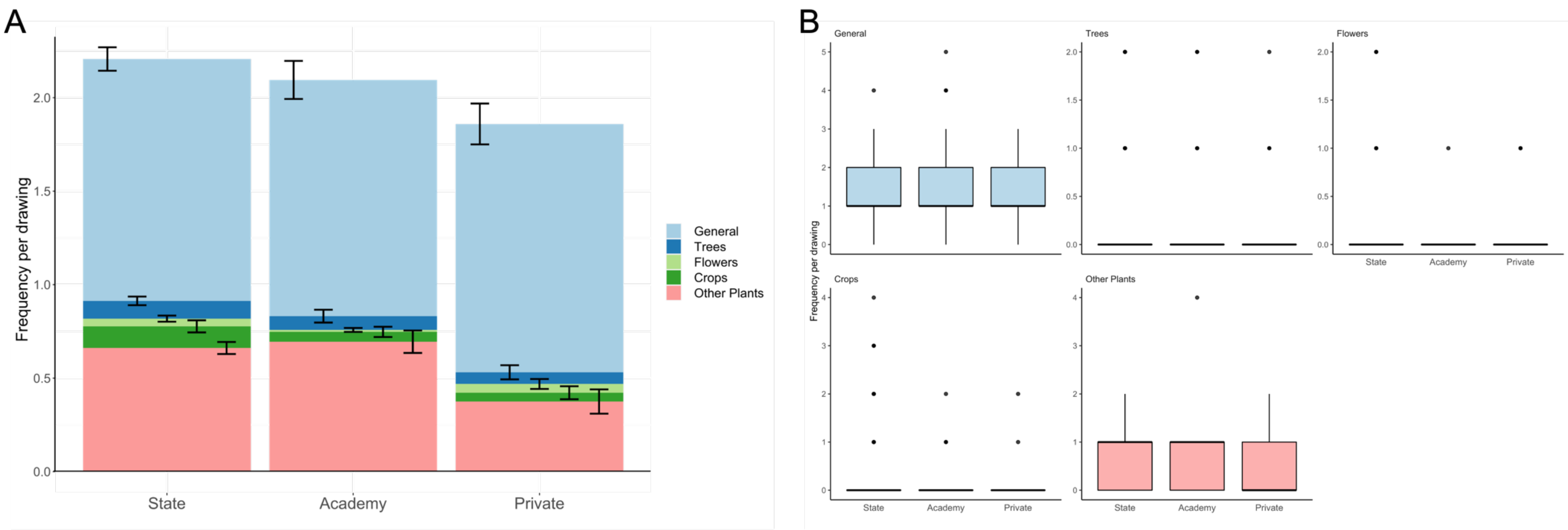

Figure 4.6. Plant community composition of children's drawings (*n* = 401) by school type. A: Stacked bar graph showing category-level community composition with separate bars for each school type and coloured by category. B: Boxplots showing category-level community composition by school type separated by category. Black lines indicate the median values. Coloured boxes show the interquartile ranges (IQR). Whiskers extend to the largest and smallest values no further than 1.5*IQR.

Discussion

1. Key results

A wide range of animals and plants were represented in the children's drawings, with the majority (91.3%) containing plants, despite children not explicitly being asked to draw them. The most well represented group of animals was mammals, appearing in 80.5% of drawings, and the least well represented was herpetofauna, appearing in only 15.7% of drawings. Invertebrates appeared in just over half of drawings, with 54.6% containing at least one insect and 51.4% containing at least one invertebrate other than an insect. Just under half (43.9%) of all animal terms were identifiable to species. However, while most mammal (69%) and bird (62.2%) terms were identifiable to species, the majority of invertebrates and herpetofauna were not: just 18.5% of insects, 0% of invertebrates other than insects and 14.3% of herpetofauna were identifiable to species. 21.4% of plant terms were identifiable to species, with all of these being crop plants or trees. Overall, we found no effect, or a limited effect, of school type on animal and plant species richness, community composition or taxonomic resolution of terms. Buffer greenness had no effect on species richness of drawings or plant community composition, but there was an effect on animal community composition, although this was not driven by any group of animals in particular. Collectively, these trends suggest that differences in ecological awareness between taxonomic groups amongst young children in England are fairly consistent and likely to reflect biases in portrayals in wider culture or innate biases, rather than differences in education. The 401 drawings used in this study were sourced from just 12 primary schools across England, and so represent a small sample compared to the numbers of children and primary schools in the country. The lack of differences we recorded between school types should therefore be treated with caution, as it is possible that a larger sample across a wider area could produce differing results. However, our findings of awareness across taxa are likely to be robust, since our analyses were conducted across the whole sample and so are unlikely to be heavily influenced by individual school effects.

The greater representation of, and higher taxonomic resolution afforded to, mammals and birds over invertebrates and herpetofauna is consistent with discrepancies found in children's drawings of other schools in the UK (Montgomery et al., 2022) and the tropics (Snaddon et al., 2008), nature documentaries (Howlett et al., 2023) and flagship species used by NGOs for fundraising campaigns (Smith et al., 2012), and mirrors preferences for species that are larger, more colourful, have forward-facing eyes and are phylogenetically or physically similar to humans (Jarić et al., 2022; Smith et al., 2012). These same taxa are also more likely to be ranked as conservation priorities and attract monetary donations, trends which are mirrored in children as well as adults (Ballouard et al., 2011). Generally, species with which people are less familiar and perceive as dangerous, such as reptiles and invertebrates, are perceived more negatively (Schlegel & Rupf, 2010), potentially in part explaining their relative rarity in the children's drawings in our study. Indeed, conservation research over the last three decades has given greater focus to vertebrate groups than to invertebrate and plant groups (Di Marco et al., 2017). The higher representation of mammals and birds over invertebrates and herpetofauna within children's drawings is therefore consistent with current understanding of people's perceptions of wildlife. It is difficult to unpick the directionality of this relationship—preferences for certain taxa could both influence and be determined by representations in wider culture (Jarić et al., 2022)—but our findings complement another recent UK-based school study (Montgomery et al., 2022) in demonstrating that this skew in awareness of biodiversity towards mammals and birds, and away from invertebrates and herpetofauna, is already apparent in children as young as 7-11 years old.

The high rate of plant representation in drawings, despite children not explicitly being asked to draw plants, is consistent with previous research on children's perceptions of rainforests, which found that children drew a wide variety of vegetative components and non-animal habitat features when asked to draw their ideal rainforest while on a museum visit in the UK (Snaddon et al., 2008). The generally low level of taxonomic resolution for plants found here, and the high inclusion of general, common terms, such as 'grass' and 'trees', over specific ones also mirrors findings from these rainforest drawings, which included a similarly high frequency of trees but little specificity beyond this (Snaddon et al., 2008). This may also reflect the prominence of Cultivars within botanical taxonomy—a formal category in the International Code of Nomenclature for Cultivated Plants (Brickell et al., 2009), which groups plants within the same genus that share defined characteristics (Hortax, 2013), and may mean that genus level terms are more familiar. The lack of specificity for plants that we recorded reflects current understanding of people's perceptions (Lindemann-Matthies, 2005), with public identification of plants being less accurate than that of animals (Höbart et al., 2020; Schlegel & Rupf, 2010).

We found no effect of school type on animal species richness, but drawings from children at state schools had significantly higher plant species richness than those from children at private schools. There were also effects of school type and buffer greenness on animal community composition but not on plant community composition. However, the effects of school type and buffer greenness on animal community composition were not replicated in our sensitivity analysis, so were likely to be driven by uneven sample sizes across school types. There were no differences between the taxonomic resolution of terms used between school types. Collectively, these results suggest that children's awareness of local biodiversity is little influenced by school type, but instead by factors external to their education, such as exposure to wildlife in a home setting or representations of nature in wider culture (e.g., television programmes, social media or nature-inspired consumer products), despite the differences in budgets and curriculum-based requirements between state-funded and private education settings. The limited effect of residential greenness on ecological awareness suggests that passive exposure to greener surroundings is not sufficient to produce an ecologically accurate awareness of local biodiversity, indicating that active engagement with overlooked taxa, such as invertebrates and herpetofauna, may be necessary to address the disparate awareness across taxa recorded here. Encouragingly, our findings also suggest that neither wealth nor residential greenness are primary determinants of ecological awareness, and that similar approaches to improve children's connection to and engagement with nature should be made across school types and degrees of urbanisation.

2. Implications

Our findings that children's drawings mirror taxonomic biases found in conservation literature (Di Marco et al., 2017), nature documentaries (Howlett et al., 2023) and marketing materials used by NGOs (Smith et al., 2012) suggest either that these biases are innate or that representations in wider culture or family settings have already coloured young children's perceptions of biodiversity across school types by the time they enter secondary education. This matters because how species are perceived can have indirect effects on their risk of extinction (Jarić et al., 2022): the prominence of a species in wider society (societal salience) can make it more or less at risk of societal extinction (the loss of collective memory of a species, through the loss of attention, knowledge and representations associated with it from cultures and societies). This, in turn, can have knock-on effects on its risk of biological extinction, through difficulties in attracting conservation funding for relevant habitats or for the species directly. Therefore, the fact that young children's impressions of local biodiversity is skewed away from invertebrate, plant and herpetofauna groups, despite their vital roles in ecosystem functioning and high levels of biodiversity (D. J. Lee & Choi, 2020; Stork, 2018), has the potential to place organisms within these overlooked groups at higher risk of societal extinction, making it harder to secure conservation funding to mitigate and avoid future species losses.

Interpretation of our findings should also take into account the following caveats. Firstly, using children's drawings to quantify awareness comes with potential disadvantages, such as children feeling limited to including features they feel able to draw. However, for children aged 7-11, asking them to write the names of animals and plants could be more limiting, due to requiring knowledge of spelling and writing, while children of this age generally enjoy drawing. Secondly, the instructions provided did not explicitly ask about plants. However, since 91.3% of drawings contained at least one plant, we felt plants merited analysis, albeit in light of this caveat. Finally, our sample was not balanced across the different school types or greenness of surrounding area, which is why we have used broad-brush tests of difference rather than more complex mixed-effects models, making our results robust to influences of particular schools.

3. Recommendations

We recommend that the skewed perception of biodiversity we have recorded among young children in England be addressed through targeted adjustments to national curricula, starting in early years teaching and continuing through to the age of 18, and that these adjustments should be applied across state-funded and private education settings. The current focus on improving climate and carbon literacy within the UK, through the introduction of sustainability leads at all nurseries, schools and higher education institutions in England (*UK to Lead the Way in Climate and Sustainability Education*, 2022), is welcome and creates an ideal climate in which to better integrate biodiversity literacy within school-based education.

Indeed, the introduction of the new natural history GCSE makes a start on this (*UK to Lead the Way in Climate and Sustainability Education*, 2022), but this is optional and neglects biodiversity-focused education before the age of 14, and most other additions are heavily weighted towards carbon and climate, with relatively little attention currently paid to biodiversity conservation. This mirrors the relative media attention afforded to these dual issues, with climate change garnering up to eight times greater coverage across the USA, Canada and the UK than biodiversity loss (Legagneux et al., 2018). Given that policy, scientific research and public opinion are part of a complex positive feedback mechanism (Martín-López et al., 2009), it is vital that tomorrow’s young adults are also equipped with the knowledge, skills and awareness to understand and conserve biodiversity.

Chapter Five: Wildlife documentaries present a diverse, but biased, portrayal of the natural world

Abstract

1. Wildlife-documentary production has expanded over recent decades, while studies report reduced direct contact with nature. The role of documentaries and other electronic content in educating people about biodiversity is therefore likely to be growing increasingly important. This study investigated whether the content of wildlife documentaries is an accurate reflection of the natural world and whether conservation messaging in documentaries has changed over time.
2. We sampled an online film database (n = 105) to quantify the representation of taxa and habitats over time, and compared this with actual taxonomic diversity in the natural world. We assessed whether the precision with which an organism could be identified from the way it was mentioned varied between taxa or across time, and whether mentions of conservation and anthropogenic impacts on the natural world changed over time.
3. Mentions of organisms (n = 374) were very biased towards vertebrates (76.8% of mentions) relative to invertebrates (17.9% of mentions), despite vertebrates representing only 3.4% of described species, compared to 74.9% for invertebrates. Mentions were highly variable across groups and between time periods, particularly for insects, fish and reptiles. Plants (5.3% of mentions) had a consistently low representation across time periods.
4. A range of habitats was represented, the most common being tropical forest and the least common being deep ocean, but there was no change over time.
5. Mentions identifiable to species were significantly different between taxa, with 41.8% of mentions of vertebrates identifiable to species compared with just 7.5% of invertebrate mentions and 10% of plant mentions. This did not change over time.
6. Conservation was mentioned in 16.2% of documentaries overall, but in almost 50% of documentaries in the current decade. Anthropogenic impacts were mentioned in 22.1% of documentaries and never before the 1970s.

7. Our results show that documentaries provide a diverse picture of nature with an increasing focus on conservation, with likely benefits for public awareness. However, they overrepresent vertebrate species, potentially directing public attention towards these taxa. We suggest widening the range of taxa featured to redress this and call for a greater focus on threats to biodiversity to improve public awareness.

Introduction

The natural world is under increasing threat from accelerating habitat and biodiversity losses (WWF, 2018, 2020), with estimated species extinction levels at 100-1,000 times the background rate (De Vos et al., 2015). Despite urban areas supporting a surprisingly high diversity of species (Ives et al., 2016), disconnect between people and nature is growing, a trend which is often linked to reduced daily contact with nature (Maller et al., 2009; Miller, 2005). Frequent concerns are now raised around the ‘extinction of experience’, where children’s opportunities to experience and develop a connection with the natural world are increasingly limited (Soga & Gaston, 2016). Contact with the natural world during childhood is positively related both to emotional connectedness to nature and to perceptions of local nature (Soga, Gaston, Koyanagi, et al., 2016). Given the decline in children’s daily contact with nature (Louv, 2005; Moss, 2012), public appreciation of the natural world could decrease in the near future.

In this context, technology-mediated portrayals of the natural world form an increasingly important component of people’s experience of nature (Truong & Clayton, 2020). Popular media plays a key role in shaping public values and awareness (Boissat et al., 2021; Östman, 2014), and documentaries in particular have become an increasingly effective tool for social change (Whiteman, 2004), with potential to shape public perceptions of the environment (Jones et al., 2019; van Eeden et al., 2017). For example, watching nature documentaries is positively correlated with donating to pro-environmental organisations (Arendt & Matthes, 2016; Martín-López et al., 2007; Zaradic et al., 2009; Zhang et al., 2014).

However, nature documentaries have been accused of presenting a pristine view of the natural world and excluding the presence and impacts of humans (Jones et al., 2019), potentially as a result of commercial pressure to provide entertainment to viewers (Aitchison et al., 2021). This is also the case for other media designed primarily for entertainment value, such as video games, which can present the natural world as more risky and dangerous than reality (e.g., predators are often portrayed as aggressive towards humans, despite the contemporary risk they pose to humans being relatively low) (Crowley et al., 2021). Moreover, the natural world is often presented in popular media through a white, colonial lens (Humphreys, 2012)—as a pool of resources that humans should extract from or manage, rather than existing as an environment in its own right, which can be enjoyed passively or merely observed (Crowley et al., 2021). Technology-mediated nature experiences are therefore subject to a high degree of editing and optimisation (Clayton et al., 2017); in practice, this means that scientific accuracy is sometimes compromised in favour of the primary purpose of a particular medium. As a result, a greater reliance on vicarious, indirect nature experiences than on direct experiences could produce a general bias or filter in people's expectations of the natural world (Truong & Clayton, 2020).

Given the capacity of technology-mediated nature experiences to influence people's environmental knowledge (Crowley et al., 2021), there is also substantial scope to amend or exacerbate existing biases in public awareness and appreciation of biodiversity. Current awareness of biodiversity is skewed towards vertebrate taxa, despite the fact that global animal diversity is dominated by invertebrates (Snaddon et al., 2008). Surveys conducted across children and adults show a preference for charismatic, familiar fauna, such as birds and mammals, over species perceived as less safe or less attractive, such as insects, reptiles and amphibians, and these attitudes can predict the likelihood of conservation support for these species (Liordos et al., 2017; Schlegel & Rupf, 2010). Biases towards large, charismatic species are not limited to the public; they are also apparent in scientific research, which displays a similar skew towards vertebrate over invertebrate taxa and, within vertebrates, towards mammals over other groups (Bonnet et al., 2002; Clark & May, 2002; Titley et al., 2017). This mirrors a reliance by NGOs on a relatively small number of flagship species in their fundraising campaigns: one study found that NGOs used just 80 flagship species, 58% of which were primates or carnivores (Smith et al., 2012). In general, these charismatic, flagship species are relatively large and colourful, have forward-facing eyes and are phylogenetically similar to humans (Jarić et al., 2022; Smith et al., 2012). While these species are selected in order to maximise monetary donations and engagement, similar levels of engagement could be achieved using other species that are less often used to head flagship campaigns, while simultaneously expanding the taxonomic diversity of species presented to the public (Shreedhar, 2021; Smith et al., 2012).

The selection of flagship species is dependent on the context of the particular conservation message being promoted (for example, does it need to have local versus international appeal?) (Smith et al., 2012; Verissimo et al., 2011). As a result, children surveyed across a range of countries consistently referred to the same few mammals as deserving of priority protection, and were less good at identifying local animals and less likely to identify them as conservation priorities (Ballouard et al., 2011). This illustrates how the charisma of a species can affect its prominence in wider society (societal salience) and thus make it more or less prone to societal extinction (the loss of collective memory of a species, through the loss of attention, knowledge and representations associated with it from cultures and societies (Jarić et al., 2022)), with knock-on effects for biological extinction (Jarić et al., 2022).

Since public perception of the natural world can influence the amount of support conservation initiatives receive and their overall success (Champ, 2002; Fischer & Young, 2007; Shunula, 2002), as well as the development of environmental policies (Martín-López et al., 2009; Renn, 2006), unbiased nature documentaries could play an important role in promoting the conservation of undervalued species. Despite portrayals being optimised for entertainment value, technology-mediated nature experiences can still hold significant educational value: for example, those playing a video game that focused on North American fauna performed significantly better in a wildlife identification quiz than gamers who had not played the same game (Crowley et al., 2021). As such, technology-mediated nature experiences, despite being standardised and less sensorially rich than direct nature experiences and therefore not a substitute for building a full connection with the natural world (Truong & Clayton, 2020), are nevertheless important avenues for ecological and environmental education (Crowley et al., 2021). Indeed, some argue that it is more useful to think not of the ‘extinction of experience’ but of a ‘transformation of experience’ (Clayton et al., 2017; Truong & Clayton, 2020), as vicarious, indirect, incidental experiences of nature start to become people’s primary nature experiences (Keniger et al., 2013; Truong & Clayton, 2020). Since this transformation is unlikely to be reversed, it is important to understand the role of these vicarious interactions with the natural world in forming a connection with and awareness of nature (Crowley et al., 2021; Truong & Clayton, 2020).

In this paper, we assessed whether there are biases towards certain taxa or ecosystems within wildlife documentaries and whether conservation and anthropogenic threat messaging has changed over time. We sourced documentaries produced between 1918 and 2021 using an online movie database and assessed whether there were biases in the representation or identification level of taxonomic groups, or the representation of habitats, and whether any biases changed over time. We also assessed whether conservation messages or anthropogenic impacts on the environment were mentioned and whether this has changed over time.

Methods

1. Documentary sourcing

We collated a list of nature documentaries released between 1918 and June 2021 from the *Internet Movie Database* (*IMDb*) website (IMDb, 2021), accessed in January 2019 for all releases prior to February 2019 and in July 2021 for all releases from February 2019 onwards. *IMDb* is popular globally and features information about productions from around the world. However, it is biased towards English-language productions, especially those produced in the United States (Bioglio & Pensa, 2018), and production companies with the highest budgets and distributional power. Nonetheless, it provides a good overview of current production and is likely to feature those documentaries that have had the greatest influence on audiences.

We identified documentaries by searching *IMDb* using the genre ‘documentary’ with the keywords ‘wildlife’ or ‘nature’. We considered relevant documentaries to be those that focused specifically on flora or fauna, judged holistically by considering the title, synopses and thumbnail images. When this information was ambiguous, the inclusion of a documentary was decided by discussion between authors or by watching the documentary itself. We did not sample documentaries with a main focus on activism or animal ethics, only those with a focus on animal behaviour, conservation or ecology. We defined an individual documentary either as a stand-alone film or as one season of a documentary series. This allowed us to consider separate seasons from long-running series (e.g., *Natural World*) as separate documentaries, since we expected their content to evolve over time, while avoiding pseudo-replication of episodes within a season, which were likely to contain similar content. We treated 'specials' of a series (e.g., National Geographic specials) as individual documentaries. We only selected documentaries with background information available on *IMDb* to ensure that we had consistent information.

This produced a list of 945 documentaries in total, which we split into seven time periods: pre-1970s (1918 to 1969; n = 51), 1970s (n = 43), 1980s (n = 64), 1990s (n = 142), 2000s (n = 281), 2010s (2010 to 2019; n = 318) and 2020s (2020 to June 2021; n = 46).

2. Documentary sample selecting

From the compiled list of eligible documentaries, only 15 pre-1970 documentaries were accessible online. For every other time period, we randomly selected 15 documentaries for sampling using an online random number generator. If a selected documentary was unavailable online, or unavailable in English or with English subtitles, we repeated the selection process until we had a list of 15 accessible documentaries in each of the seven time periods, totalling 105 documentaries overall (Table S5.1). The decision to exclude documentaries that were unavailable in English was due to resource constraints of the research team and to ensure consistent information was collected.

3. Documentary sampling

For each of the 105 documentaries selected, we generated a random start time between, and inclusive of, the documentary's start and five minutes from the documentary's end, using the same online random number generator. This was to prevent generation of a random start time between five minutes from the end and the end (e.g., two minutes from the end) since this would not allow a full five minutes to be sampled. If the selected documentary formed part of a series, we first randomly selected an episode from that series before generating a random start time in the same way (Table S5.1). From the random start time, we then watched five minutes of the documentary.

We recorded every organism mentioned in the sample period with the word or phrase used to describe them and later identified these to the greatest possible taxonomic resolution from this phrase alone. This meant that some organisms were identifiable to species level (e.g., 'strawberry poison-dart frog', *Oophaga pumilio*), while others were only identifiable to a coarser resolution (e.g., 'corals' to the class Anthozoa). We grouped every organism into one of the following taxonomic groups: mammals, birds, reptiles, amphibians, fish, insects, arachnids, crustaceans, molluscs, other invertebrates, or plants.

We recorded every habitat shown in the sample period broadly following the major (Level 1) habitats listed in the IUCN Habitats Classification Scheme (IUCN, 2021). We differed by grouping savanna and shrubland, since separating these habitats was often difficult from the available footage, and by grouping subtidal and intertidal habitats as 'coastal', since these were often shown together. We further split lentic and lotic freshwater habitats because of the substantially different conditions that these habitats provide, and recorded coral reefs separately to other coastal habitats. We recorded tundra separately to other grassland for the same reason. Forest was so frequently present that we split it into the Level 2 categories of boreal, temperate and tropical. Some Level 1 categories were not seen in any samples (e.g. caves) and so are absent from our data. In full, the categories are: boreal forest, temperate forest, tropical forest, savanna, grassland, tundra, inland rocky areas, desert, lentic wetland, lotic wetland, coastal, coral reef, oceanic, deep ocean, or artificial (e.g., city centres, agriculture).

We also recorded whether there was a conservation message included in the sample period. This was defined as either mention of the need for conservation or an example of conservation in practice. We recorded anthropogenic impacts mentioned in the sample period, classified as one of the following: overexploitation, habitat degradation (including habitat loss), invasive species, extinction cascades or human-wildlife conflict (Diamond, 1989). We chose this classification system since it originates around the middle of the total time span covered by our sample of documentaries, so it is likely to provide good coverage of the anthropogenic threats considered to be key to biodiversity loss within our sample. This classification system does not include climate change, but the relatively recent shift in awareness and discourse around this threat in particular, which has accelerated over the last three decades (Anderson et al., 2021) and may be reflected in increased focus in more recent documentaries, merits its own investigation.

4. Statistical analyses

We used RStudio Version 1.4.1717 (*RStudio 1.4.1717, 'Juliet Rose'*, 2021) and R version 4.1.0 for all analyses.

4.1 Representation of the natural world

A chi-square goodness-of-fit test was used to test for relative differences in the number of times taxa were mentioned compared to the number of described species in each taxonomic group (IUCN Red List, 2020). This allowed us to compare representation across taxa in the documentaries with actual biodiversity across taxa in the natural world. In this sense, a bias towards certain taxa constitutes an overrepresentation in comparison to that found in the natural world, and an unbiased representation is one in which taxa are represented proportionally to their actual biodiversity. While we do not expect representations of taxa to match their actual biodiversity exactly (i.e., be 'unbiased'), making this comparison allows us to contextualise our findings relative to the natural world and discuss the potential implications of current portrayals. We used chi-square tests of independence to test for differences in representation of taxa and habitats between time periods.

To investigate the taxonomic level to which organisms were identified, chi-square tests of independence were used to test for differences in the frequencies of mentions identifiable to species versus other taxonomic levels within each of our 11 taxonomic groups and within each of our seven time periods.

4.2 Conservation messages and anthropogenic impacts

Chi-square tests of independence were again used to test for differences in the frequency of documentaries containing a conservation message between time periods, and for differences in the frequency of documentaries that mentioned different anthropogenic impacts between time periods.

We opted to use simple tests of differences between groups and across time periods rather than more complex regression analyses in order to be confident that any significant differences found are robust to biases from individual documentaries.

Results

1. Representation of the natural world

We recorded 374 mentions of organisms across all sampled documentaries (Fig 5.1A). Of these, 94.7% were animals, the majority being mammals (36.4%) or birds (23.8%). Vertebrates made up 76.8% of all organisms mentioned, with insects amounting to 11.5% and all other invertebrates only 6.4% of mentions. Plants made up 5.3% of all organisms mentioned. These percentages were significantly different from the number of described species in each group ($\chi^2 = 18717$, $df = 10$, $p < 0.0001$; Fig 5.1A). Compared to relative percentages of described species, all vertebrate taxa were overrepresented, and all invertebrate taxa were underrepresented (Fig 5.1A). Representation of taxonomic groups was significantly different and variable between time periods ($\chi^2 = 124.83$, $df = 60$, $p < 0.0001$), with mammals and birds always collectively making up more than 50% of mentions, despite high variability in their respective proportions between time periods (Fig 5.1A). There was a distinct lack of pattern or trend across time, particularly in the representation of insects, fish and reptiles. While representations of mammals and birds remained consistently high across time, representations across these three groups showed large variations from one time period to the next. For example, representation of insects reduced from 21.1% of mentions in the pre-1970s to 3% in the 1970s; for fish, it increased from 1.7% in the pre-1970s to 12.1% in the 1970s; and for reptiles, it dropped from 23.9% in the 2000s to 2.8% in the 2010s. There was a consistently low representation of plants throughout time periods, which was highest in the 1990s at 12.1%.

A wide range of habitats was represented in the documentaries, with the three most commonly featured being tropical forest, lotic wetland and temperate forest, and the three least common being deep sea, tundra and coral reef (Fig 5.1B). Artificial habitats tended to be featured only rarely in documentaries, with an overall percentage occurrence of 10.1%. This appeared to increase in frequency between the 1990s and the 2020s, with the highest frequency appearing in the current decade at 17.5% (Fig 5.1B). However, overall representation of habitats did not differ significantly between time periods (χ^2 = 88.13, *df* = 84, *p* = 0.358; Fig 5.1B).

Overall, the percentages of mentions identifiable to each taxonomic level were as follows: species: 34.0%, genus: 17.7%, family: 25.7%, order: 14.0%, class: 8.0%, phylum: 0.8%. The frequency of mentions identifiable to species level was not different between time periods (χ^2 = 5.36, *df* = 6, *p* = 0.4983; Fig 5.2A). However, the frequency of mentions identifiable to species level was significantly different between taxonomic groups (χ^2 = 28.14, *df* = 10, *p* = 0.001715), with 41.8% of vertebrate mentions identifiable to species compared with just 7.5% of invertebrate mentions. Mammals, birds and fish were the most identifiable to species, at 50.7%, 41.6% and 32% of mentions respectively (Fig 5.2B). Just 9.3% of insect mentions were identifiable to species, while no arachnids, crustaceans or molluscs were identifiable to species (Fig 5.2B). Plants were poorly identified to species, at just 10% of mentions; however, plants were the group most identified to genus level, at 50% of all plant mentions.

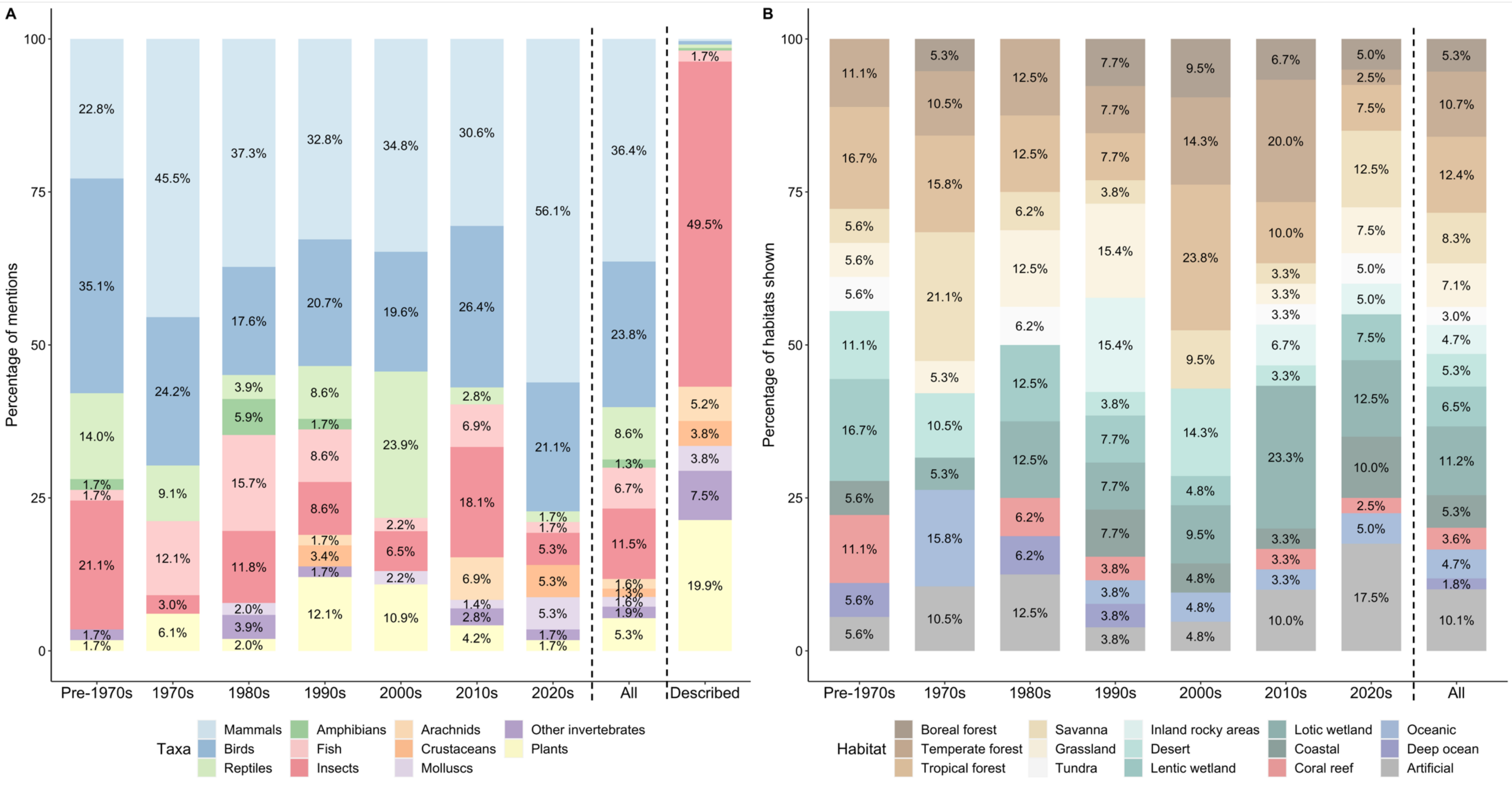

Figure 5.1. Representations of taxa (A) and habitats (B) in wildlife documentaries (*n* = 105) across time periods. Percentages lower than 1% are not labelled. A: Percentage of mentions within each time period and overall, coloured by taxonomic group. The total number of separate mentions of taxa was 374. The far-right column shows the total number of described species coloured by taxonomic group (IUCN Red List, 2020). B: Percentage of habitat types shown within each time period and overall, coloured by habitat type. The total number of separate times ecosystems were shown was 169.

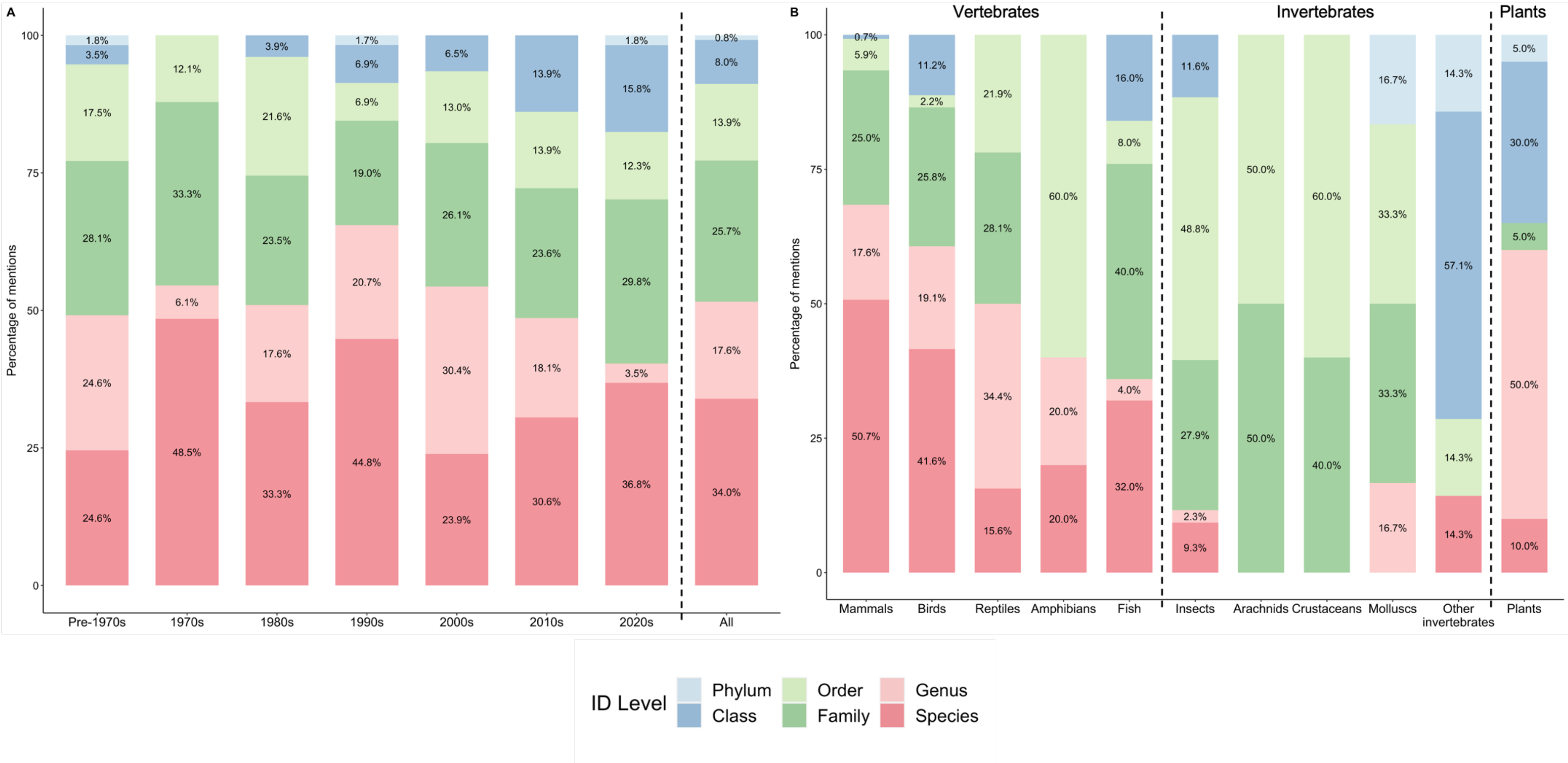

Figure 5.2. Percentage of mentions of taxa (n = 374) in wildlife documentaries (n = 105) identifiable to each taxonomic level. Bars are coloured by taxonomic group. A: Percentage of mentions split by time period. The far-right bar shows all mentions across all time periods and taxonomic groups. B: Percentage of mentions split by taxonomic group.

2. Conservation messages and anthropogenic impacts

The frequency of documentaries sampled containing a conservation message was significantly different between time periods (χ^2 = 20.50, *df* = 6, *p* < 0.00226; Fig 5.3A). No documentaries before the 1980s contained a conservation message. In both the 1980s and 1990s, 6.7% of samples contained a conservation message. This increased to >25% in each of the 2000s, 2010s and 2020s, reaching 46.7% in the current decade. Overall, conservation was mentioned in 16.2% of all documentaries sampled (Fig 5.3A).

Anthropogenic impacts on the natural world were mentioned in 22.1% of documentaries sampled (Fig 5.3B). 36.7% of mentions were of overexploitation, 16.7% of habitat degradation, 10% of invasive species, and 36.7% of human-wildlife conflict. However, extinction cascades were not mentioned at all. The frequency of types of anthropogenic impacts mentioned were not significantly different between time periods (χ^2 =24.79, *df* = 18, *p* = 0.131), although no anthropogenic impacts were mentioned in documentaries before the 1970s (Fig 3B).

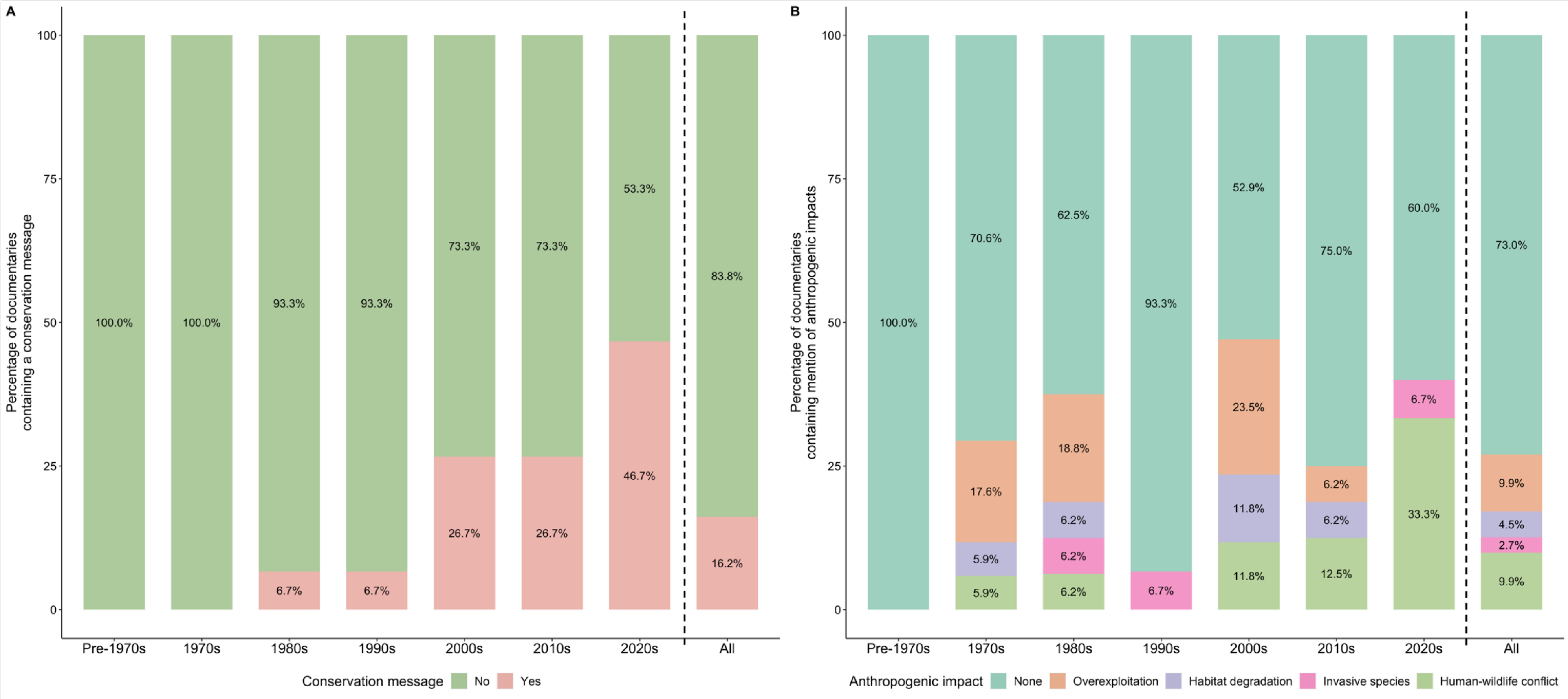

Figure 5.3. Conservation messaging in wildlife documentaries (*n* = 105) across time periods. A: Percentage of documentaries within each time period including a conservation message. B: Percentage of documentaries within each time period including mentions of different anthropogenic impacts.

Discussion

1. Key results

A wide range of taxa and habitats was represented in the documentaries sampled across all time periods. However, there were large differences in the representation of different groups and habitats, with a higher frequency of vertebrate taxa and a lower frequency of invertebrates and plants compared to the numbers of described species in these groups. This is consistent with findings that conservation science has been focused more on vertebrate than invertebrate and plant groups over the last three decades (Di Marco et al., 2017). Similarly, some habitats (specifically tropical forest, lotic wetland and temperate forest) were more commonly depicted than others (specifically deep sea, tundra and coral reef), again consistent with a larger long-term focus on terrestrial than marine and freshwater systems (Di Marco et al., 2017; Miles & Kapos, 2008). In addition, the level of taxonomic identification in documentaries differed significantly between groups, being higher for vertebrate taxa than invertebrate taxa. Indeed, no arachnids, crustaceans or molluscs were identifiable to species level in our sample. Strikingly, although a low percentage of plants was identified to species level, a much higher percentage were identified to genus level, perhaps reflecting the prominence of Cultivars or Cultivar-Groups within botanical taxonomy. This is a formal category in the International Code of Nomenclature for Cultivated Plants (Brickell et al., 2009) and reflects groups of plants within the same genus that share defined characteristics (Hortax, 2013), which might explain the relative ease of identifying plants to genus. A conservation message was found in less than one in five documentaries sampled, but the frequency increased over time. Anthropogenic impacts were mentioned in 22.1% of documentaries but never before the 1970s, while the relative focus given to different anthropogenic threats did not always mirror their relative severity in the real world. Collectively, these represent clear trends despite the relatively small sample of 105 documentaries spread across a 70-year period.

2. Representation of the natural world

The wide range of taxa and habitats depicted in documentaries highlights the current importance and future potential of this medium for increasing awareness of global biodiversity and ecosystems. With an increasing proportion of the global population living in urban environments (United Nations, 2019) and increasingly disconnected from nature (Maller et al., 2009; Miller, 2005), widening the range of taxa and habitats shown could enable people to experience wildlife and ecosystems that are not accessible in everyday life. Such a global coverage also allows people to experience wildlife in diverse and inaccessible environments, including difficult-to-reach or sensitive, high-biodiversity habitats, potentially increasing awareness of their importance and support for their conservation (Fernández-Bellon & Kane, 2020; Hynes et al., 2021; LaMarre & Landreville, 2009; Martín-López et al., 2009). This effect may be particularly important currently, with the COVID-19 pandemic still restricting international travel. Given the low but potentially increasing frequency of documentaries featuring artificial habitats, such as city centres, found here, there is also significant scope for documentaries to focus on urban wildlife that viewers are likely to be able to see in their local area. This could prove an important pathway for inspiring people to engage more actively with local biodiversity.

The differences in representations across groups and habitats are likely to be the result of existing biases in preferences for different taxa, geographical and technological accessibility (Titley et al., 2017), and pre-conceptions about which taxa and habitats are most appealing to target audiences (Jones et al., 2019; Martín-López et al., 2007). For example, species that are more familiar, larger, phylogenetically closer or physically similar to humans, and culturally or socially important tend to illicit more positive reactions (Martín-López et al., 2007) and so may be featured more. It is also the case that people tend to prefer groups they can identify more easily over unfamiliar groups, potentially explaining the link between the lower proportion of invertebrates and plants identifiable to species than other groups and their similarly low representation in documentaries (Lindemann-Matthies, 2005; Schlegel & Rupf, 2010). Similarly, ecosystems tend to be shown as pristine with an abundance of wildlife, devoid of negative anthropogenic impacts, since this is assumed to be more palatable (Jones et al., 2019).

Existing preferences and accessibility could also explain the high variability seen in representations of groups across time. For example, it’s possible that the relatively less-advanced equipment used before the 1970s could have made taxa such as birds, in which males of many species call in predictable locations, relatively easier to film than other taxa, explaining their high frequency in this period and subsequent drop between the pre-1970s and 1970s. In contrast, as technology has advanced (including motion-activated filming technology), filming of more elusive species, such as big cats, might have become more viable, explaining the large focus on mammals in the 2020s. Similarly, the increase in focus on plants, from 2% of mentions in the 1980s to 12.1% in the 1990s, could be due to the novel use of timelapse photography, which was the focus of the series *The Private Life of Plants* in 1995 (*The Private Life of Plants*, 1995). Finally, the lower representation of invertebrate taxa could also be due to our sample's bias towards documentaries available in English; public perceptions of insects are more negative in western cultures, as compared with more positive cultural perceptions in Asian cultures, where insects feature more widely in culture and are more commonly eaten (Tan et al., 2015). It is therefore possible that examining the same metrics in wildlife documentaries originating from countries in Asia might reveal less of an underrepresentation of invertebrate groups.

Despite a wide range of taxa being represented in the documentaries overall, some taxa showed more consistency in their representation over time than others. In particular, birds and mammals showed consistently high representation, whilst molluscs and other invertebrates showed a consistently low representation. In contrast, representations of insects, reptiles and fish showed especially high variability, ranging from relatively high to relatively low representation between consecutive decades. The high representation of mammal and bird species is consistent with biases towards large vertebrate species, both within public perceptions and within conservation research (Di Marco et al., 2017; Smith et al., 2012). The lower focus on plants also complements previous research showing that the public's identification of plants is less accurate than that of animals, while nature users also care less about plants than animals, being more likely to accept lethal chemical control methods for the former than the latter (Höbart et al., 2020; Schlegel & Rupf, 2010).

Our finding that reptiles group with insects in terms of their high variability in representation across time is consistent with findings that these groups are consistently rated as less attractive than mammals and birds and engender negative attitudes (Schlegel & Rupf, 2010). However, the finding that fish group with reptiles and insects in terms of high variability in representation is novel. Previous research shows that conservation science has consistently focused more on vertebrates than on invertebrates and plants across the last three decades (Di Marco et al., 2017), and, within vertebrates, there is a greater focus on large, colourful animals with forward-facing eyes that are phylogenetically closer to humans (Smith et al., 2012). This could explain why reptiles and fish, although vertebrates, group with insects; they are often less colourful than birds and are phylogenetically further from humans than other mammals. Our finding that marine systems (e.g., deep sea and coral reefs) were poorly represented in documentaries is consistent with research showing a greater focus on terrestrial than aquatic systems (Di Marco et al., 2017; Miles & Kapos, 2008). This could also partly explain why fish and crustaceans are less well represented in documentaries. Finally, it should be noted as a caveat that the high variability in taxa we observed between decades could be due to our relatively small sample size per time period, which was 15 documentaries or 75 minutes. Therefore, large differences in study focus in one or two documentaries could have resulted in large fluctuations. However, our approach of analysing data by decade rather than documentary should have reduced this effect.

The recorded disparity in relative representation across taxa and habitats could have a large influence on public perceptions of the natural world and support for conservation (Martín-López et al., 2007, 2009), potentially directing more funds towards larger, vertebrate species, especially given current, low levels of public awareness of biodiversity and related issues (Lindemann-Matthies & Bose, 2008; Natural England, 2020c). In particular, the relatively low representation of invertebrates and plants, both in terms of their appearance and level of identification, could mean that people place less value on these groups, despite their high biodiversity and important roles in ecosystem functioning (D. J. Lee & Choi, 2020; Stork, 2018). Significantly, although the relative representation of taxa varied across time periods, there was no obvious trend for less represented groups to increase over time, indicating that such differences are likely to continue in the future without concerted action, both by documentary makers and researchers studying these groups. However, there may be a trade-off between representation of different taxa and potential conservation benefit of a documentary, as the portrayal of familiar, charismatic species has been found to be particularly effective in increasing conservation donations (Shreedhar & Mourato, 2019), suggesting that showcasing less familiar species could limit the conservation benefit of a documentary.

We therefore call for more work to identify the barriers associated with showcasing less-popular groups, informing the development of strategies to reduce these long-term biases. For example, identifying 'Cinderella' mammal species (183 threatened, overlooked mammal species with socially appealing traits, Smith et al., 2012) has been suggested as a useful framework for broadening the range of flagship species currently used by NGOs in fundraising campaigns, since these share similar traits with species already used but have thus far been overlooked. Similar approaches could also be used for selecting a broader range of species to be included in wildlife documentaries. More work is also needed to understand whether focusing on non-mammal, invertebrate or plant species could increase their societal salience and thus reduce their risk of societal extinction (Jarić et al., 2022), or whether it is better to ensure a representative portrayal across all taxonomic groups, mirroring their actual diversity in the natural world. Just as flagship species are chosen by international NGOs to maximise international appeal and thus the global reach of fundraising messages, it is vital that we understand how best to improve public awareness of biodiversity and biodiversity losses, with an emphasis on ensuring scientific accuracy as well as securing support for conservation, both locally and globally.

This is especially important where biodiversity preservation depends on knowledge of local species and ecosystems (Fernández-Llamazares et al., 2015; Kai et al., 2014). Local ecological knowledge, traditional ecological knowledge or indigenous knowledge is now widely acknowledged as being central to sustainable resource use, biodiversity conservation, the capacity of societies to adapt to socio-ecological change and the formation of people's attitudes to conservation (Berkes et al., 2000; Brook & McLachlan, 2008; Gadgil et al., 1993; Gilchrist et al., 2005; Shen et al., 2012). The standardisation of nature portrayals in mass media (Truong & Clayton, 2020), including an overemphasis on species that are internationally salient at the cost of including species that are locally salient (Ballouard et al., 2011), could therefore accelerate loss of local knowledge, as well as the societal extinction of local biodiversity, with knock-on effects for its conservation and risk of biological extinction (Jarić et al., 2022). Therefore, in addition to research into why particular taxa or habitats are underrepresented, work is also needed to understand the relative emphases on species with local versus international relevance, and how local ecological knowledge can be better included in nature documentaries.

3. Conservation messages and anthropogenic impacts

A conservation message was found in 16.2% of documentaries sampled, with the frequency increasing over time. Anthropogenic impacts were mentioned in 22.1% of documentaries, with no mentions pre-1970s. Significantly, the most recent documentaries contained conservation messages or information about anthropogenic impacts in roughly 50% of cases. This finding is likely to reflect an increasing awareness of human impacts on the natural world amongst the public, particularly over the last decade, and an increasing willingness for documentary makers to highlight this (Jones et al., 2019), although it is hard to unpick the directionality of this relationship. Such coverage is likely to have significant benefits for conservation, since conservation policy, scientific research and social aspects, such as public awareness, preference and willingness to donate, are part of a complex positive feedback mechanism (Martín-López et al., 2009), in which science and public opinion foster each other. It is important that documentary makers and conservation scientists continue to assess the focus on conservation in documentaries in order to strike the right balance between keeping the public engaged and enthused in the natural world, while raising awareness of global issues.

There was high variability between the frequency of mentions of different anthropogenic threats. For example, invasive species and habitat degradation received less attention than other threats in all time periods. This difference in representation of threats does not necessarily reflect their relative importance globally but may instead reflect changes in media attention, public awareness or relative ease of depiction in media format. Indeed, changes in land and sea use, including habitat loss and degradation is, in reality, recorded as the current greatest threat to species worldwide, followed by species overexploitation, invasive species and climate change (WWF, 2020). Such differences in media coverage versus relative impact have also been recorded in other studies. For example, Legagneux et al. (2018) identified a discrepancy in media coverage between climate change and biodiversity loss, with the former receiving up to eight times higher coverage than the latter in the media. Since the classification system for anthropogenic threats used here was based on Diamond (1989) and did not include climate change, a useful follow up to this study would be to assess how coverage of this specific threat has changed over the most recent three decades (Anderson et al., 2021), given the marked increase in public awareness of this issue over this period.

The changes in mentions of anthropogenic threats found here broadly mirror changes in the conservation literature over the last eight decades (Anderson et al., 2021) but with a few key differences. For example, we found that mentions of human-wildlife conflict showed a large increase over time. Conservation literature likewise shows that human-wildlife conflicts are increasing as the human population expands and natural habitats dwindle (WWF, 2008), such that they are now a top priority for wildlife management across the world (Center for Wildlife Studies, North Yarmouth, Maine, USA et al., 2021). Similarly, habitat degradation was one of the most commonly mentioned threats in documentaries in the 1970s and 1990s, and this increased in the 2000s. This threat included aspects of habitat loss and pollution, which also increased in the conservation literature in the 1990s and 2000s, and 1960s to the 1980s respectively (Anderson et al., 2021). On the other hand, the changes we found in mentions of overexploitation and invasive species did not clearly reflect the wider conservation literature. For example, we found overexploitation to be one of the most commonly mentioned anthropogenic threats, particularly before the 2010s. In contrast, overexploitation has consistently been overlooked in conservation research (Anderson et al., 2021), despite being a key cause of biodiversity losses worldwide (Brondizio et al., 2019). In contrast to this, invasive species were rarely featured in documentaries, appearing in just three decades: the 1980s, 1990s and 2020s, but this threat has seen a huge increase in the conservation literature in recent decades, reflecting invasive species' role in extinctions worldwide (Anderson et al., 2021).

In line with biases in taxonomic focus, it could also be beneficial for documentaries to broaden their coverage of anthropogenic threats, particularly of the most pressing issues, as this could raise public awareness and help to generate public support for policies to tackle these issues (Aitchison et al., 2021; Hynes et al., 2021). For example, no sampled documentary mentioned extinction cascades as an anthropogenic impact, despite models identifying coextinction as the most common form of species loss (Dunn et al., 2009). This omission is consistent with calls to better integrate coextinction within global threat assessments, which generally use threat criteria less relevant to invertebrates, which are often dependent on host species (Moir & Brennan, 2020). A concerted effort to include mention and discussion of extinction cascades as a threat to biodiversity has the potential to increase public awareness and lead to an increase in policies targeted towards this issue (Aitchison et al., 2021; Martín-López et al., 2009).

When wildlife documentaries first appeared as a medium, film and television screens were the only means of accessing their content and experiencing nature digitally. However, we now live in a world with platforms that offer diverse indirect experiences of nature, including social media and video games (Keniger et al., 2013). It is therefore important that more work is carried out to assess the relative contributions of different media to people’s experiences of nature and whether alternative media differ in their nature-based content. Given the recent emphasis by YouTube and social networks on shorter videos or social media-originated content (Jaffe, 2020; Sherman, 2021; Singer, 2021), it is possible that, over time, this could alter people’s interactions with and expectations of nature, potentially favouring aesthetics or excitement over the reality of the natural world (Truong & Clayton, 2020). As such, it is possible that nature documentaries now occupy a niche within media portrayals of nature, uniquely providing longer-form, nuanced content. This provides nature documentary-makers with the opportunity to lean into this role, focusing on the provision of scientifically accurate content over and above that which prioritises entertainment value.

4. Implications and conclusion

Wildlife documentaries have clear capacity for depicting a wide range of species and ecosystems, with potential to increase public awareness and appreciation of a broader range of groups and support for conservation efforts. This is especially important in the context of the COVID-19 pandemic, which has restricted international travel. However, the range of species and habitats represented has not increased over time, potentially limiting the medium’s ability to engage audiences with less-familiar taxa and habitats, or to increase engagement with more familiar, local, urban areas. We call for more work to identify reasons why certain taxa and habitats are underrepresented and solutions to make them more attractive to documentary makers and public audiences alike.

In contrast, the frequency of conservation messages has increased over time, and human impacts on the environment have been mentioned more since the 1970s than before. However, certain threats are mentioned more commonly than others, potentially giving a biased view of their importance. Given the current critical point in conservation and the urgency needed to tackle global biodiversity losses, this increased mention of conservation is crucial and positive, but we call for a more concerted effort to weigh mention of threats by their importance. This is likely to be facilitated by increased engagement between documentary makers and conservation researchers. It is important that the attention given to human threats to the natural world is regularly reviewed by documentary makers and conservation researchers alike. This would ensure an appropriate balance is struck between educating audiences and providing hope and tangible solutions to conservation problems, without being off-putting.

Chapter Six: Walking through a biodiverse setting reduces anxiety and pulse rate of children at a grammar school in Kent

Abstract

1. An increasing proportion of people live in urban areas worldwide, leading to concerns over growing human disconnect with the natural world, with impacts on wellbeing and connection with nature. The majority of research on the relationship between nature and health has focused on adults, although childhood experiences can be instrumental in determining long-term wellbeing and interactions with nature.
2. This study represents a collaboration between Simon Langton Girls' Grammar School, Kent and the University of Cambridge and examines the relationship between nature and wellbeing in school children, using a case study set-up.
3. The study explored differences in species richness, state anxiety and pulse rate across three different settings in the school (a corridor, playing field and orchard). We quantified plant and butterfly biodiversity in each setting, and children (aged 11-17, *n* = 602) walked established 300m routes through each. Before and after their walk, each child recorded their state anxiety, using Spielberger's State-Trait Anxiety Inventory, and pulse rate.
4. We found that species richness differed significantly between settings, with the orchard having more species of both plants and butterflies. Both state anxiety and pulse rate showed a greater reduction in children who had walked through the more biodiverse orchard setting.
5. This case study has important implications for long-term wellbeing in children and highlights the value of green space in schools for enhancing biodiversity and wellbeing, as well as the role of school-university collaborations in making ecology come alive at school and engaging school-age children in research.

Introduction

The natural world is under increasing threat from accelerating habitat and biodiversity losses (WWF, 2018, 2020), with estimated species extinction levels 100-1,000 times the background rate (De Vos et al., 2015). Over half the world's population now lives in urban areas (United

Nations, 2019), with this proportion increasing annually. In the UK, for example, the percentage of the population living in cities is predicted to reach over 90% by 2050 (United Nations, 2019), and there are growing concerns about the effects of urbanisation on human mental and physical health (Dye, 2008).

Accompanying these trends is an increasing disconnect between people and nature, a gap which is likely to widen in the near future (Miller, 2005). Children in the UK show greater familiarity with science fiction characters than with the commonest native species (Moss, 2012; National Trust, 2008; Natural England, 2009), demonstrating that, while they have a large capacity for identification, children are often influenced more by images in the media than by those in the natural world (Balmford et al., 2002). However, recent analysis of the content of nature documentaries showed that media portrayals of the natural world are not always accurate, providing a picture that is skewed towards mammals and birds over invertebrate groups (Howlett et al., 2023). While there is evidence that ecological knowledge can be gained from technology-mediated experiences such as video games (Coroller & Flinois, 2023; Crowley et al., 2021), we do not yet know enough about the role played by artificial nature experiences in developing a connection with the natural world (Gaston & Soga, 2020). The replacement of natural words, such as acorn, buttercup and catkin, in the Oxford Junior Dictionary, with words deemed more relevant to modern life, such as analogue, blog and chatroom, is symptomatic of this increasing disconnect with the natural world (Flood, 2015), now labelled ‘nature-deficit disorder’ (Louv, 2005).

Exposure to and contact with nature is associated with numerous health and wellbeing benefits, which are now well established (Chawla, 2015; Collins et al., 2020; Hartig et al., 2014; Lovell et al., 2014). These include benefits for mental health (Alcock et al., 2014; Sarkar et al., 2018), physical health (Li, 2010; Li et al., 2008; Ulrich, 1984), mood (Barton et al., 2012; Barton & Pretty, 2010), attention (Taylor et al., 2001, 2002; Taylor & Kuo, 2009) and behaviour (F. E. Kuo & Sullivan, 2001; Sullivan et al., 2004), as well as reductions in socioeconomic health inequalities (Mitchell & Popham, 2008). As a result, there has been an increasing focus on the role of urban green spaces, including gardens and parks, for improving human health and wellbeing (Cariñanos et al., 2017; de Bell et al., 2020; Gaston, 2007; Nugent, 2017). However, whether the wellbeing benefits of nature scale with aesthetic preferences, such as landscape openness or colour diversity, or with actual or perceived species richness, and the relationship between these factors, is not yet clear.

There is evidence to support a link between wellbeing and both actual and perceived richness: self-reported mental wellbeing has been shown to correlate with perceived species richness but not with actual richness (Dallimer et al., 2012), whilst psychological benefits have been found to increase with habitat heterogeneity and actual plant richness (Fuller et al., 2007). Moreover, perceived biodiversity has been found to correlate positively with connection to nature and with actual biodiversity (Southon et al., 2018). Such apparent contradictions may be related to variation in people's ability to accurately assess biodiversity, which has been shown to vary with levels of connection to nature (Southon et al., 2018) and across different taxonomic groups. For example, estimates of species richness for static components of a habitat (e.g., plants) have generally been found to be more accurate than those for mobile components (e.g., birds) (Dallimer et al., 2012; Fuller et al., 2007).

Benefits of green space to human health and wellbeing, as well as effects on human perceptions, are also likely to be mediated by aesthetic reactions to greenness and other landscape features, such as openness of view, colour diversity and vegetation height (Hoyle, 2020; Southon et al., 2018), and it is possible that people use aesthetic cues, such as flower colour, to assess species diversity (Hoyle et al., 2018). Indeed, many studies examining the health and wellbeing benefits of green space have used settings which vary in visual greenness, rather than actual biodiversity (Hartig et al., 2003; Sullivan et al., 2004; Taylor et al., 2001, 2002; Tyrväinen et al., 2014; Ulrich, 1983, 1984, 1986). Distinguishing between biodiversity and aesthetics, as well as avoiding confounding these two variables, is important for improving understanding of the relationship between these factors and their relative importance for wellbeing benefits.

The mental health of children is of increasing concern in the UK (Pitchforth et al., 2018). In 2005, the Office for National Statistics declared that 4% of children aged 5-16 years had anxiety or depression (Green et al., 2005). Anxiety has been associated with decreased satisfaction (Court et al., 2009), disrupted recall of information and poor attention (Mathews & MacLeod, 2005), and can act as a barrier to effective communication (Lang et al., 2000). These factors are likely to result in worsened academic and social performance at school and a general decline in mental health. Conversely, exposure to natural environments has been associated with improved attentional functioning in children and young adults (Hartig et al., 2003; Taylor et al., 2001, 2002; Tennessen & Cimprich, 1995). Given that stress is associated with decreased competence and increased disruptiveness in school children (Masten et al., 1988), stress amelioration in schools through increased access to nature is an important potential avenue in enhancing student learning.

Decreased exposure to the natural world is also likely to have detrimental effects on the future of conservation. Connection with nature is dependent on personal experiences in the natural world (Project Dirt, 2018; The Wildlife Trusts & University of Derby, 2019), and, whilst nature documentaries have been shown to increase pro-environmental behaviours, such as monetary donations, in those with an already strong connection, they do not increase connectedness to nature (Arendt & Matthes, 2016). Raising support for conservation initiatives and recruitment of the next generation of naturalists and conservationists is therefore likely to become more of a challenge as nature disconnect increases. Childhood experiences in nature have been shown to significantly influence environmental attitudes, behaviours and values later in life (Strife & Downey, 2009; Wells & Lekies, 2006), as well as affecting long-term cognitive development (Kellert, 2002, 2005). Both 'wild nature' experiences during childhood, such as camping or playing in the woods, and 'domesticated nature' experiences, such as planting seeds, are associated with pro-environmental behaviour later in life (Wells & Lekies, 2006). Therefore, the use of green space within schools could have a direct benefit for future conservation and serve to close the gap in the curriculum on ecology-related topics, something that plans for a new Natural History GCSE—a curriculum-based qualification for 14-16 year-olds in the UK to focus on organisms, environments and sustainability—are seeking to achieve (Cambridge Assessment, 2020).

Few research projects have investigated the value of school grounds for biodiversity conservation, and research into the role of these areas in the provision of wellbeing benefits and the support of children's connection with the natural world is in its infancy. The volume of vegetation in children's school playgrounds has been associated with perceived restorativeness of these spaces (Bagot et al., 2015), whilst newly renovated green schoolyards in urban areas have been shown to increase children's positive social interactions, attentional restoration and levels of physical activity, particularly for girls, as well as appreciation of these spaces (Bates et al., 2018; Taylor & Butts-Wilmsmeyer, 2020; van Dijk-Wesselius et al., 2018). The greening of schoolyards has implications for stress management in children and adolescents and has been associated with building competence, social groups and resilience (Chawla et al., 2014).

This study investigates the effects of exposure to biodiversity on self-reported state anxiety and pulse rate of school children aged 11-17 years within a senior school in Kent, UK. We used biodiversity surveys to investigate how species richness varied across different settings within the school grounds. We then investigated whether state anxiety and/or pulse rate of children differed between school settings with different levels of biodiversity. The project set-up involved staff and students from the school designing the study and collecting data for the project, providing a setting in which to engage school children with science and research, and affording them the opportunity to ask questions, collect data and learn about study design.

Methods

This study was designed and carried out as a full collaboration between the staff and students at Simon Langton Girls' Grammar School (SLGGS) in Canterbury, Kent, UK and the University of Cambridge, UK and represents a case study to investigate the role of green space in schools. Its set-up was funded by a Royal Society Partnership Grant, which aims to bring science alive in schools (Royal Society, 2019a). Conducting this study engaged over 600 school children in real science and encouraged them to spend time outdoors. The work forms part of a larger-scale and longer-term project at SLGGS, which has restored an area of the school grounds, now known as 'The Orchard', which is used for cross-curricular activities, as well as forming an important part of the school grounds for nature. All data for this study were collected within the grounds of SLGGS.

1. Experimental design

One 300m route was set up in each of three distinct settings that children regularly experience in the school: along a corridor with no windows (Fig 6.1A), across a playing field (Fig 6.1B) and through an orchard (Fig 6.1C). There were clear aesthetic differences between these three settings, particularly in vegetation height and openness of view (Fig 6.1).

Figure 6.1. Photographs of settings through which children walked pre-set routes: (A) Corridor, (B) Field, (C) Orchard.

The corridor (Fig 6.1A) was within the main school building and was used regularly by students and staff at the school. There were no windows along the 300m route. The playing field (Fig 6.1B) measured approximately 200m x 200m and was bounded by hedgerows and trees on three sides, and by a car park, a school building and tarmacked tennis courts on the fourth side. It had a pavilion midway along one of the hedgerows and two football goals in the centre. The 300m route ran across the centre of the field. The orchard (Fig 6.1C) was an area that has recently been restored by school staff and students. It contained a variety of habitats, including rough grassland, a wooded area, a meadow, a pond and a mound planted with butterfly-friendly plants.

2. Biodiversity

Quadrat sampling of plants and transect surveys of butterflies were used to quantify relative biodiversity across the three settings. These surveys were carried out by school children under the supervision of sixth-form students and biology teachers. All biodiversity data were collected in July 2016.

2.1 Quadrat sampling of plants

Random coordinates were generated to select locations for 10 0.25m^2 quadrats within 3m of the 300m route in the corridor, and 35 quadrats in the playing field and orchard. Fewer quadrats were taken in the corridor because it was known to have lower variability. The total number of plant species present in each quadrat was recorded. Plant species were identified using Allen & Denslow (1969) and Phillips (1980).

2.2 Butterfly surveys

All butterflies seen within an estimated five-metre cube in front of the recorder on transect routes were counted, and the total number of species was recorded, following standard butterfly transect methodology (Pollard, 1977). The transects were walked between 11:00 and 16:00 when conditions were suitable for butterfly activity. Five surveys were completed in the corridor, seven on the playing field and nine in the orchard. The transects were walked fewer times in the corridor because it was known to have lower variability, and only seven were conducted on the playing field because of time limitations.

3. Participants

All participants were female students at SLGGS, between the ages of 11 and 17 years old (*n* = 602, Table 6.1). Year group was included as a factor in our analyses to control for the potential effect of age.

Table 6.1. Numbers of participants in each year group assigned to each setting.

Year Group	Age (years)	Number of participants			
		Orchard	Field	Corridor	Total
7	11-12	52	52	48	152
8	12-13	51	50	47	148
9	13-14	35	32	30	97
10	14-15	40	35	36	111
12	16-17	39	33	22	94
Total		217	202	183	602

Participants were instructed to walk along the routes alone and without a phone or MP3 player, to reduce distraction and minimise any potential effects on wellbeing variables. Approximately equal numbers of participants were assigned to each setting (Table 6.1), and the direction in which each participant walked the route was randomised. Routes were walked at a variety of times, between 09:00 and 17:00, depending on student availability. All walks took place in May-July 2022, with each student walking in one setting only.

4. State anxiety

The six-item short form of the state scale of Spielberger's State-Trait Anxiety Inventory (STAI) was used as a measure for participants' self-reported state anxiety (Marteau & Bekker, 1992), which represents an alternative to the 40-item full form STAI (Court et al., 2010). The short form is widely used in clinical settings as a valid and reliable measure of state anxiety (Elliott et al., 2001) and was chosen in this study to increase the chance that participants would complete the survey. The maximum score of 24 indicates high state anxiety (i.e., negative wellbeing), while the minimum score of six indicates low state anxiety (i.e., positive wellbeing). Participants rested for five minutes in a classroom before completing a pre-walk questionnaire (Appendix S6.1), from which their pre-walk STAI was calculated (Marteau & Bekker, 1992). On completion of the walk, participants rested for five minutes in the location of their route and completed the same questionnaire a second time, from which their post-walk STAI was calculated (Marteau & Bekker, 1992). Each participant's change in STAI was calculated from the two questionnaires, with the maximum change being +/-18. A negative change indicates a reduction in state anxiety and an improvement in self-reported mental wellbeing.

5. Pulse rate

Several studies have examined the physiological effects of natural environments, particularly on blood pressure (Lee et al., 2009), salivary cortisol (Lee et al., 2011; Tyrväinen et al., 2014), heart rate (Laumann et al., 2003; Tyrväinen et al., 2014) and muscle relaxation (Chang et al., 2008). Results have recorded reductions in blood pressure, salivary cortisol and heart rate and an increase in muscle relaxation in green spaces, particularly forests. However, participants in all of these studies were adults. To test whether similar physiological effects could be found in children, we measured change in pulse rate resulting from walking through different settings. We selected pulse rate since this was the most practical of these physiological variables to measure in a school setting, and could be recorded readily by school children themselves with some training. Participants were taught how to use a finger-tip monitor, which returned a pulse-rate reading. After resting for five minutes in a classroom, participants used the monitor to measure their own pre-walk pulse rate; three readings were taken, and the mean was recorded on the pre-walk questionnaire (Appendix S6.1). On completion of the walk, participants rested for five minutes in the location of their route and used the monitor to measure their own post-walk pulse rate, again taking three readings and recording the mean on the post-walk questionnaire (Appendix S6.1). Each participant's change in pulse rate was calculated from these readings.

6. Research ethics

Project conception and data collection were led by staff at Simon Langton Girls' Grammar School, and, as such, school ethical guidelines were followed at all points, ensuring no personal data which could identify participants were collected. Written consent was required for participation in the study via letters sent home to parents or guardians, along with information about the study's aims and procedures (Appendix S6.2). Participation was voluntary, and it was made clear to parents and guardians that neither they nor their children were under any obligation to take part and that they could remove their consent at any point with no penalties. Our protocol was reviewed and approved by the Cambridge Psychology Research Ethics Committee.

7. Statistical analyses

All analyses were carried out in R Version 4.1.3 and R Studio Version 2022.02.3 Build 492 (R Core Team, 2022; RStudio Team, 2022). Kruskal-Wallis tests were carried out to test whether species richness differed between settings, followed by Dunn's tests with the Bonferroni correction where setting was significant ($p < 0.05$). Using *glmmTMB* (Brooks et al., 2017), generalised linear mixed models (GLMMs) were used to explore whether change in STAI or pulse rate differed between subjects walking in different settings and whether this was affected by age. We fitted models to Gaussian distributions, including setting and year group as fixed effects.

We validated GLMMs by plotting quantile residuals against predicted values and covariates setting and year group to verify that no patterns were present. To ensure our GLMMs fitted the observed data, we ran simulation-based dispersion tests using *DHARMa* (Hartig, 2022) to compare variance of the observed residuals against variance of the simulated residuals with variances scaled to the mean simulated variance, and checked that our model was within the range of our simulations (Zuur & Ieno, 2016). Our simulations indicated that there were no issues with model fit. We determined the significance of fixed effects to each model by comparing fitted models with null models using likelihood ratio tests. If mixed models suggested a moderately significant effect ($0.03 < p < 0.07$), we re-calculated p values based on parametric bootstrapping using *DHARMa* (Bates et al., 2015; Hartig, 2022). If setting was significant, we used *multcomp* (Hothorn et al., 2019) to conduct post-hoc analyses (Tukey all-pair comparisons, adjusting *p* values using the Bonferroni correction) to identify setting pairs between which significant differences occurred.

Results

1. Biodiversity

Overall, 14 grass species and 23 other plant morphospecies were found in the school grounds. From most to least common, the top three grass species were dwarf rye grass (*Lolium perenne*), Yorkshire fog (*Holcus lanatus*) and rough meadow grass (*Poa trivialis*), and the top three other plant morphospecies were white clover (*Trifolium repens*), field bindweed (*Convolvulus arvensis*) and ivy (*Hedera helix*). Overall, 10 butterfly species were found in the school grounds. From most to least common, the top three butterfly species were meadow brown (*Maniola jurtina*), large white (*Pieris brassicae*) and gatekeeper (*Pyronia tithonus*).

Plant species richness differed significantly between the three settings ($\chi^2 = 25.105$, $df = 2$, $p < 0.0001$; Fig 6.2A), with higher plant richness in the orchard ($p < 0.0001$) and the field ($p < 0.0001$) than the corridor, but with no difference between the orchard and the field ($p \sim 1$; Fig 6.2A). Butterfly species richness differed significantly between the three settings ($\chi^2 = 16.172$, $df = 2$, $p < 0.001$; Fig 6.2B), with higher butterfly richness in the orchard than the field (p = 0.0054) and the corridor (p = 0.0003), but with no difference between the field and the corridor (*p* = 0.465; Fig 6.2B).

2. State anxiety

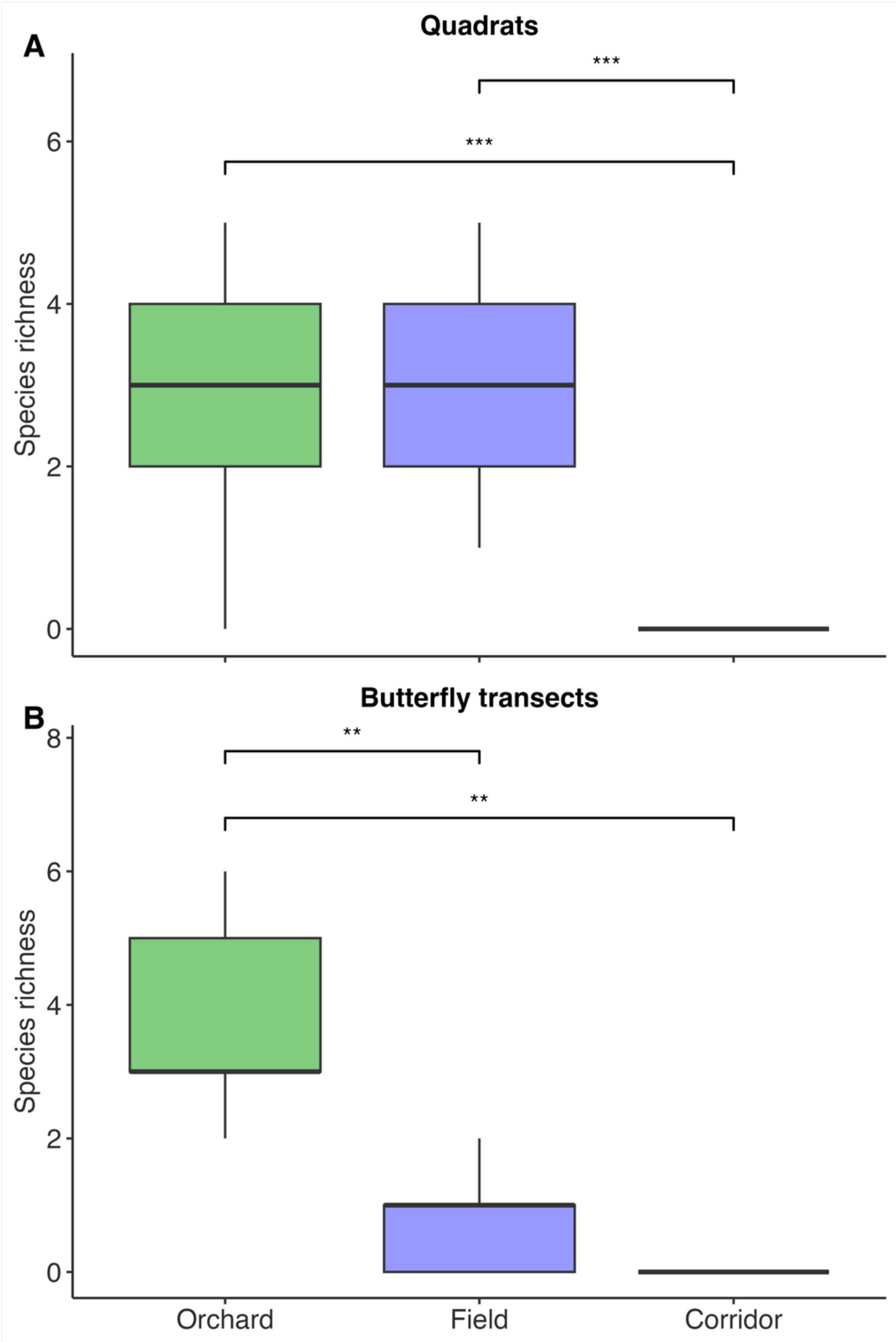

Figure 6.2. Boxplots showing species richness against setting, using data from (A) quadrat sampling (Orchard: *n* = 35, Field: *n* = 35, Corridor: *n* = 10) and (B) butterfly surveys (Orchard: *n* = 9, Field: *n* = 7, Corridor: *n* = 5). Middle bars show median values. Boxes show interquartile range (IQR). Whiskers extend to the largest and smallest values no further than 1.5*IQR. Significant differences shown by brackets: *** < 0.001, ** < 0.01, * < 0.05.

Change in STAI differed significantly between settings (LRT = 28.121, $p < 0.0001$; Fig 6.3), with a greater reduction in state anxiety after walking in the orchard than on the field ($z = 3.999$, $p < 0.001$) or along the corridor ($z = 5.036$, $p < 0.0001$), but with no difference between the field and the corridor ($z = 1.122$, $p = 0.7854$; Fig 6.3). Change in STAI did not differ between year groups (LRT = 2.478, $p = 0.6486$).

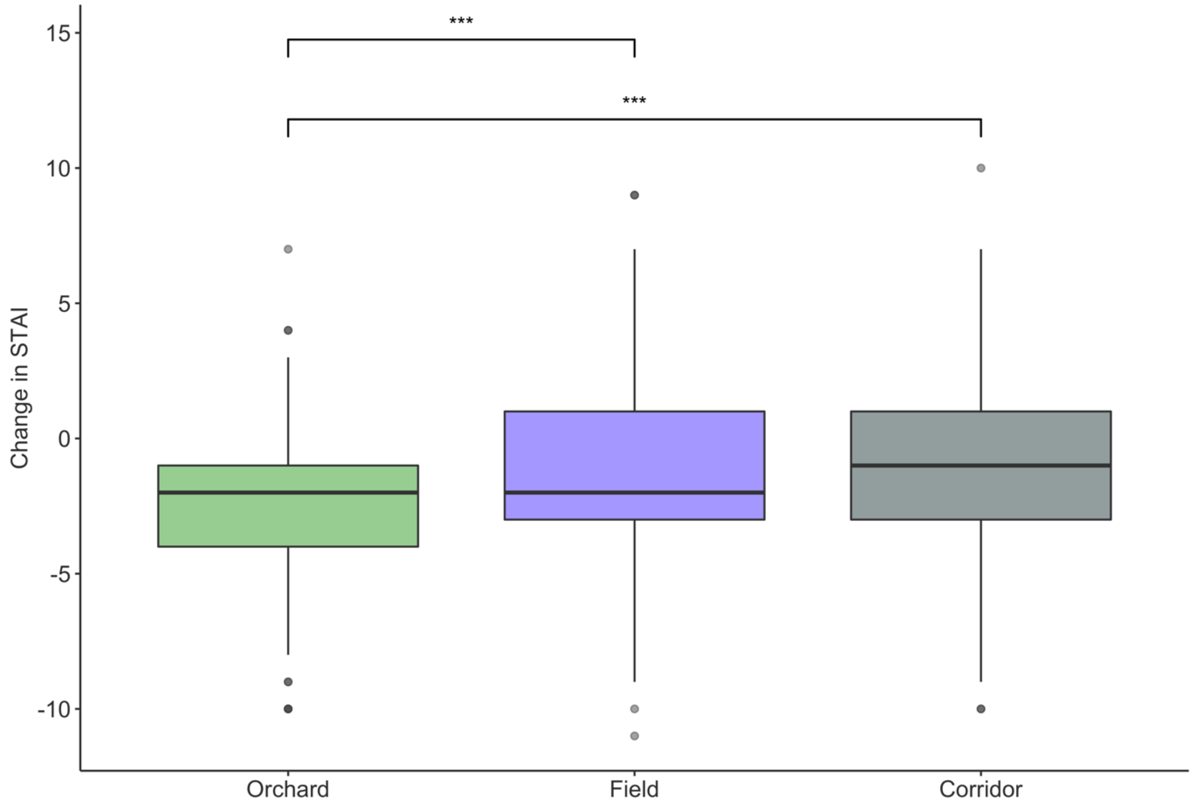

Figure 6.3. Boxplot showing change in STAI against setting. Orchard: $n = 217$, Field: $n = 202$, Corridor: $n = 183$. Middle bars show median values. Boxes show interquartile range (IQR). Whiskers extend to the largest and smallest values no further than 1.5*IQR. Significant differences shown by brackets: *** < 0.001, ** < 0.01, * < 0.05. Mean change in STAI for orchard = -2.396 (IQR = 3), field = -1.198 (IQR = 4), and corridor = -0.847 (IQR = 4).

3. Pulse rate

Change in pulse rate differed significantly between settings (LRT = 10.717, $p = 0.00471$; Fig 6.4), with a greater reduction after walking in the orchard than along the corridor ($z = 3.167$, $p = 0.00463$), but with no difference between the orchard and the field ($z = 2.269$, $p = 0.0697$) or the field and the corridor ($z = 0.940$, $p \sim 1$; Fig 6.4). Change in pulse rate did not differ between year groups (LRT = 1.617, $p = 0.806$.

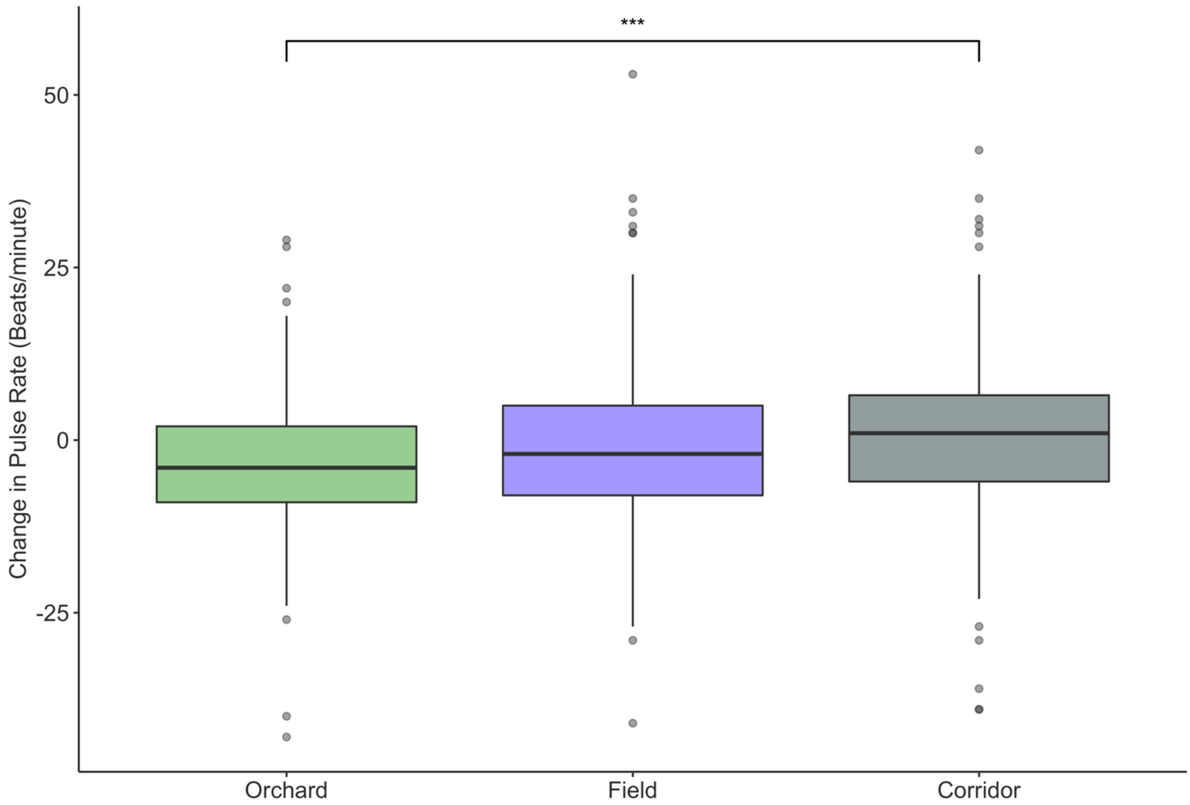

Figure 6.4. Boxplot showing change in pulse rate against setting. Orchard: *n* = 217, Field: *n* = 202, Corridor: *n* = 183. Middle bars show median values. Boxes show interquartile range (IQR). Whiskers extend to the largest and smallest values no further than 1.5*IQR. Significant differences shown by brackets: *** < 0.001, ** < 0.01, * < 0.05. Mean change in pulse rate for orchard = -3.355 (IQR = 11), field = -0.772 (IQR = 13), and corridor = 0.344 (IQR = 12.5).

Discussion

A reasonable number of plant and butterfly species were found in the school grounds, illustrating that these spaces can be important for biodiversity conservation and for facilitating familiarity with common UK species among school children. Species richness differed significantly across the school grounds, in both plant and invertebrate species richness. Both state anxiety and pulse rate of children differed significantly between settings, with children who walked through a more biodiverse setting showing a greater reduction in anxiety and pulse rate. These changes were not affected by age.

1. Biodiversity

The school grounds were variable in biodiversity. This was likely due to the greater structural complexity and habitat heterogeneity in more diverse areas, such as in the orchard and along the edge of the playing field, which can support of a greater number of species (Tews et al., 2004). This demonstrates clear potential for increasing biodiversity within school grounds (Howlett, 2023), as has been achieved here through restoration of the orchard, and for increasing children's exposure to this biodiversity through simple interventions, such as windows that provide views of greenery from inside school buildings. SLGGS is fortunate in having such a diverse range of environments within its grounds, but management interventions to increase exposure to green space can also be achieved in limited spaces (Collins et al., 2017; Helden & Leather, 2004), so we anticipate that these options are viable in most schools (Howlett, 2023). Such considerations must be taken into account in the planning and management of school buildings and grounds, and be highlighted and encouraged in government guidelines.

2. Wellbeing

Children's state anxiety showed a greater reduction in the more biodiverse setting. This effect was true regardless of age, and the effect size was comparable to that found in other studies which examined the effects of green space on the STAI score of adults (Jiang et al., 2019; Song et al., 2015; Wang et al., 2016). Several mental health measures show improvement with increased exposure to biodiversity, in particular, improved self-reported health (Maas et al., 2006) and stress amelioration (Parsons et al., 1998; Ulrich et al., 1991), lower rates of depression (Sarkar et al., 2018; Shanahan et al., 2016) and improved attentional functioning (Taylor et al., 2001, 2002). However, the majority of this research has been conducted on adults. This study confirms that the trend of improved mental wellbeing, specifically of a reduction in anxiety, with exposure to nature can also be true for children.

Children's pulse rate also showed a greater reduction after walking through the more biodiverse setting. This finding is also complementary to previous research, which has found reductions in heart rate and heart rate variability after exposure to natural settings (Laumann et al., 2003; Song et al., 2014; Sonntag-Öström et al., 2014), and that prolonged exposure to green space is associated with a lower risk of hypertension (Shanahan et al., 2016). Again, the majority of previous research has been conducted on adults, so this study confirms the trend can also be true for children.

The potential for school green spaces to improve children's wellbeing has important implications for the planning, building and management of school grounds. Wherever possible, areas of higher species richness should be established, either through restoration projects, similar to that enacted here, or through low-cost options, such as reduced mowing of grass and tree pruning, reduced or ceased application of pesticides and herbicides, and the installation of ponds and wildlife-friendly habitat features such as insect hotels and bird boxes. These interventions would likely increase the biodiversity value of school grounds, with the potential to form a valuable contribution to biodiversity conservation in local settings. Several of these actions would also serve to increase engagement of school children with the natural world, enhancing learning as well as potentially enhancing wellbeing (Burt & Emmerson, 2016). Such win-win strategies are already well known within the education sector, and there are calls for more related approaches (Project Dirt, 2018). A centralised call and financial support for such strategies within government guidelines would avoid a piecemeal approach and ensure such approaches are accessible to all children, regardless of geographical region or school type.

It remains unclear whether wellbeing benefits observed here are due to species richness or aesthetic preferences for different settings, since both species richness and aesthetics differed between sites. More research is needed to dissociate these variables (Dallimer et al., 2012; Fuller et al., 2007). It could be that improving the visual aesthetics of school grounds, such as through providing more open views and increasing general greenness, may be sufficient to deliver wellbeing benefits for school children. However, interventions which increase species richness have the added benefit of contributing to biodiversity conservation, as well as enhancing learning and engagement with the natural world (Burt & Emmerson, 2016). Here, despite a relatively short timescale and budget for the restoration project, significant differences in species richness and anxiety reduction were found between the orchard and playing field, demonstrating that just giving over a greater area of school grounds to green space does not necessarily deliver biodiversity and associated wellbeing benefits. It is possible that the wellbeing benefits found in the orchard could be because the children do not view the orchard as a work area, but more as an escape or restorative area—more work is needed to explore this question. However, regardless of the mechanism behind the anxiety reduction, the differences found here between the orchard and playing field highlight the importance of green space within schools that is managed for biodiversity, rather than solely for school sports.

3. Implications

The implications of our findings should not be lost on decision and policy makers, whose attention should be drawn to their potential for immediate application. SLGGS is unusual amongst secondary schools in the UK in having such a large amount of green space within their grounds readily available for ecological restoration projects, but even schools with a more-limited availability of green space have options to implement related approaches (Howlett, 2023), making findings from this study applicable to a wide range of schools. Given that benefits of engaging with the natural world are larger for those starting out with a weaker connection (The Wildlife Trusts & University of Derby, 2019) and that green space can reduce socioeconomic health inequalities (Mitchell et al., 2015; Mitchell & Popham, 2008), our results indicate that increasing the amount and quality of green space in more urban, comprehensive schools than SLGGS may result in more significant effects than those found here.

In addition to assessing the potential value of green space for biodiversity within schools, the collaborative nature of this project also demonstrates the importance of engaging school children with real science projects through experimental design and data collection, and with ecology more generally (Royal Society, 2019c, 2019b). Over 600 secondary school children took part in this study, participating in science beyond the curriculum and exploring the benefits of nature, with two now-previous sixth-form students, who led previous iterations of this work, listed as co-authors on this paper. Students wrote in testimonials that they would aim to spend more time outside, had been inspired to study a related subject at university, were keen to get involved with conservation in their local areas, and that their understanding and appreciation of ecology had been deepened by being involved in the study. This project highlights the value of schools directly engaging with universities to encourage interest in studying science in further education.

The larger-scale project at SLGGS, of which this study forms a part, has had large, long-term impacts on the whole school community. As well as the direct benefits gained from being outside more frequently, the project still attracts a regular group of around 20 students on a weekly basis, who use the orchard area to develop their own research projects and skills, the results from several of which have been presented at meetings (e.g., Authentic Biology Research Symposium at the Wellcome Trust and The Royal Society's Student Conference). The project has also had profound and formative impacts on subsequent school building development, such that a new school building has been designed around the orchard area, to ensure nature is at the centre of the school. A school governor described its impact on the planning stage as follows: 'Light was discussed, views of nature were to be maximised, creative subjects were to have better light and access to outside (they now sit on the ground floor with doors to the grounds) and, above all, the school was to fit into rather than erode the existing fauna and environments.'

The case-study approach used here represents a focused study conducted within one school, predominantly on female participants. Whilst this has value for engagement, as discussed above, it also has limitations in terms of the extent to which these results can be extrapolated and generalised. Further work should be carried out to explore the relative importance of aesthetic preferences, perceived species richness and actual species richness on wellbeing benefits to children across a wider range of school and demographic settings and with equal numbers of female and male participants. Specifically, the effects of visible greenness and openness of view from classrooms on concentration and attentional functioning, factors not assessed here, could be particularly impactful for improving children's learning and wellbeing.

Whilst the learning benefits of taking part in this case study were specific to learning about experimental design, data collection and analysis, the more general learning benefits of improving green space provision within schools should also be highlighted. The greening of school playgrounds can benefit attentional functioning, such as self-regulation, increased creative play and positive social interactions (Taylor et al., 1998; Taylor & Butts-Wilmsmeyer, 2020; van Dijk-Wesselius et al., 2018). Outdoor learning, as a pedagogical approach to cross-curricular learning, has been linked with attainment improvements in reading, writing and maths, as well as being credited with improving autonomy within learning and critical thinking skills (Christie et al., 2016; Quibell et al., 2017). It is clear that the learning benefits of green space within school grounds cover science-specific learning as well as general learning, along with the potential to reduce the effects of nature-deficit disorder by improving ecological awareness and increase environmental behaviours and attitudes throughout students' lifetimes (Wells & Lekies, 2006).

4. Conclusion

This study shows that biodiversity is variable within school grounds and highlights the potential for biodiversity conservation in these spaces. We also show that the positive relationship between wellbeing and biodiversity established in adults can also be true for children. These results demonstrate the value of integrating more green space into school grounds and indicate that exposure of children to nature and associated wellbeing benefits could be increased through simple management options, such as installing windows in school buildings with views onto green space. We suggest that school days could also be planned to ensure that children spend timetabled periods outside in green areas. Not only do these measures have the potential to increase academic performance through improved concentration and decreased anxiety (Taylor et al., 2002), but they are also likely to improve the general wellbeing of students and increase children's engagement with and appreciation of nature.

Thesis Discussion

1. Key results

This thesis showed that research on people and nature is well integrated, with disparate disciplines citing each other fairly well. However, the communities of disciplines cited were significantly different between publishing disciplines, with research from psychology, education and public health being particularly distinct. There were also consistent differences between publishing disciplines in the terms used to refer to nature, with a particularly broad range of terms used in psychology and public health research. The variety of terms used within single disciplines could act as a barrier to effective knowledge exchange, potentially limiting both development of further research and the translation of findings into effective policy.

Secondly, this thesis found that schools in greener neighbourhoods had higher ground plant species richness, and that schools with a greater area of green space within their grounds had higher tree abundance and species richness. Schools with more visible vegetation within their grounds scored highest on the broadest range of biodiversity measures across taxa, including measures of tree, ground plant and ground invertebrate biodiversity. Furthermore, privately funded schools had higher levels of visible vegetation within their grounds and greater standard deviation in tree diameter than state-funded schools. This has implications for student wellbeing and attentional functioning at private versus state-funded schools.

Thirdly, this thesis found that the COVID-19 lockdown restrictions implemented in May 2020 in the UK may have exacerbated existing inequalities in nature access between urban and rural communities. While the majority of rural parents reported being happy with the amount of green space to which their children had access, and that their thoughts on the importance of green space were unaffected by lockdown, the majority of urban parents said they wanted their children to have more access to green space and that lockdown had made them more aware of the importance of these spaces for wellbeing. There were also differences between urban and rural communities in the amount of time children spent outside during lockdown, with most urban children spending less time outside and most rural children spending more time. The amount of time spent outside during lockdown was also different between school fee-paying types, with most privately schooled children spending less time outside and most state-educated children spending more time outside. This is likely reflective of differences in the provision of online teaching provided by schools during lockdown, with state schools unable to provide as much online structured learning as private schools.

Next, we found that children's drawings were biased towards mammals and birds in both the frequency and taxonomic resolution with which these groups were drawn. Invertebrate groups and herpetofauna were typically less frequently drawn and less precisely identified. While plants were commonly drawn, they were consistently not well identified to a high level of taxonomic resolution. These biases were mirrored in the content of nature documentaries, which devoted more time and detail to mammals and birds than invertebrate and plant groups—biases which remained unchanged from before the 1970s to the current decade. However, the conservation focus of nature documentaries has increased over time, including a shifting focus on anthropogenic impacts on the natural world.

Finally, this thesis found that school children show a reduction in anxiety and pulse rate after walking through a more biodiverse school setting—a finding which highlights both the potential of enhanced biodiversity management of school grounds to improve student wellbeing and the potential of engaging school children with real ecological research.

2. Themes

There are three key themes that emerge from my work:

1. The importance and potential of fine-scale biodiversity management within school grounds

Greenness at the smallest spatial scale we measured—the amount of visible vegetation within a school—had effects on the greatest number of taxa we recorded. It is also evident from children's drawings that a surprising amount of ecological detail is noticed by children through observations of their small, local patches of green space, often immediately outside their windows. We also found that restoration of a relatively small area of school green space resulted in significantly greater species richness than other outside areas of the school—benefits which were evident in a relatively short amount of time. Therefore, management focus at this small scale has the potential to have wide-ranging benefits for biodiversity and children's perceptions, as well as being the most practically feasible scale on which to focus efforts and resources.

2. The need to address consistent taxonomic biases present in children's perceptions of the natural world

A lack of focus on invertebrate, herpetofauna and plant taxa was found both within children's drawings and nature documentaries. Although nature documentaries represent just one of many sources of technology-mediated nature experiences and learning opportunities, nature-documentary makers have a responsibility to produce a factual form of entertainment that leaves the public with a balanced and sound impression of the make-up and functioning of the natural world. This therefore highlights the need for more work, within the education sector, the research sector and the wildlife documentary industry, to redress this imbalance.

3. The value of school-university partnership approaches for the future of conservation

The partnership approach we employed in this thesis yielded a wealth of reliable scientific data, gave our project access to a diverse range of schools and, in the case of Chapter Six, provided an enriching educational experience for students involved in the research, as well as having a profound impact on the attitudes of the school's governing body and teaching staff towards the green space within the school's grounds. While this is a single case study, there is no reason to presume that this is a special case, and it serves to highlight the value and potential of university-school collaborations.

3. Recommendations

The recommendations resulting from this thesis are threefold:

1. School grounds should be considered priority areas for biodiversity conservation.

Increasing the biodiversity of small, often overlooked taxa, such as ground plants and invertebrates, through simple, inexpensive and small-scale management options, such as the establishment of flowerbeds, allotment plots, window-ledge boxes, potted indoor plants and green roofs, is both achievable and affordable in a school setting. These spaces can then become focal points for biological teaching, cross-curricular links and the development of nature connection, as well as benefitting student wellbeing. Channelling more funding to schools for biodiversity interventions therefore represents a cost-effective approach to deliver biodiversity, educational and wellbeing benefits.

2. A whole ecosystem-focused approach should be central to environmental education, from early-years teaching right through to higher education.

The above interventions would not only benefit biodiversity but would also allow for a truly cross-curricular approach to ecology, allowing for the integration of the natural world as a source of creative inspiration for arts subjects and as a playground for scientific enquiry, enabling subsequent development of numeracy and critical-thinking skills. Observation of the natural world at the smallest of scales could improve awareness of invertebrate taxa and plant life, thus redressing the taxonomic biases found in children’s drawings and portrayed in nature documentaries, as well as fostering a better understanding of the importance of functioning ecosystems for underpinning vital ecosystem services, on which all aspects of our society depend.

3. Fostering collaborative projects between universities and schools represents a key pathway to improve access to higher education and careers in conservation.

Universities are too often seen as inaccessible, unwelcoming places, largely because they are unfamiliar. This is true not just of the buildings and people that make up universities, but also because of the leap from a curriculum-focused education to one driven by individual study and enquiry. Partnerships such as the one trialled in Chapter Six of this thesis represent a key pathway for breaking down these barriers, encouraging pupils to see universities as spaces where they belong and can thrive, and providing the support and encouragement needed to step beyond national curricula. Students who feel trusted by school staff and visiting university staff to contribute to collaborations, such as the partnership trialled here, can then apply to higher education courses with a plethora of soft skills that they would not otherwise have had the chance to develop.

4. Conclusion

Investing in biodiversity-enhancing interventions in UK school grounds, implemented through university-school partnerships, is likely to represent one of the most cost-effective ways to deliver immediate and long-term biodiversity benefits, improvements to student wellbeing, and intra- and extracurricular educational outcomes, with future benefits for higher education access. While several organisations within the education and conservation sectors run successful nature-based educational programmes, these remain disparate from the central education system, such that the overall national approach is piecemeal, with access to these schemes highly variable across geographic and socioeconomic regions, and often dependent on the personal interests and passions of individual teaching staff. Integrating the best pedagogical approaches and lessons learned from existing nature-based schemes represents a key pathway to delivering conservation, educational and wellbeing benefits for students. Incorporating ecology through a truly cross-curricular approach that bridges the university-school boundary holds the promise of securing a future generation of conservationists, equipped with both ecological knowledge and a passion for nature—a vital and powerful combination for reversing biodiversity declines and ecosystem degradation.

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Chapter One: Supplementary material

Appendix S1.1. Email request sent to experts in July 2020 as part of the expert consultation process.

Dear _____,

My name is Kate Howlett, and I'm a PhD student at the University of Cambridge with Dr Edgar Turner, in the Insect Ecology Research Group. My research focuses on green space in UK primary schools, specifically on their potential for biodiversity conservation and for improving children's wellbeing and engagement with nature.

We are working on a systematic mapping review of the literature exploring the benefits of green space and biodiversity to people's wellbeing. We would like to capture the full range of benefits currently under research, from psychological to physiological to educational. As a prominent researcher in the field of people and nature, we are asking for your advice about setting a list of 'benchmark' papers from which to start.

We have attached a list of ten benchmark papers which we hope captures the full range of research areas within this topic. Please could you look over this list and let us know if there are any crucial research areas you think have been missed.

The aim of the review is to explore the range of different terms used in this body of literature (e.g., green space/natural landscapes/nature, wellbeing/well-being/health/mood etc.), to see how much overlap there is between the different disciplines, and to identify any research gaps.

Please let me know if there is anything unclear in my explanation or if you would like any more information, and I completely understand if you aren't able to find time.

Many thanks for reading through my email.

Kind regards,

_____

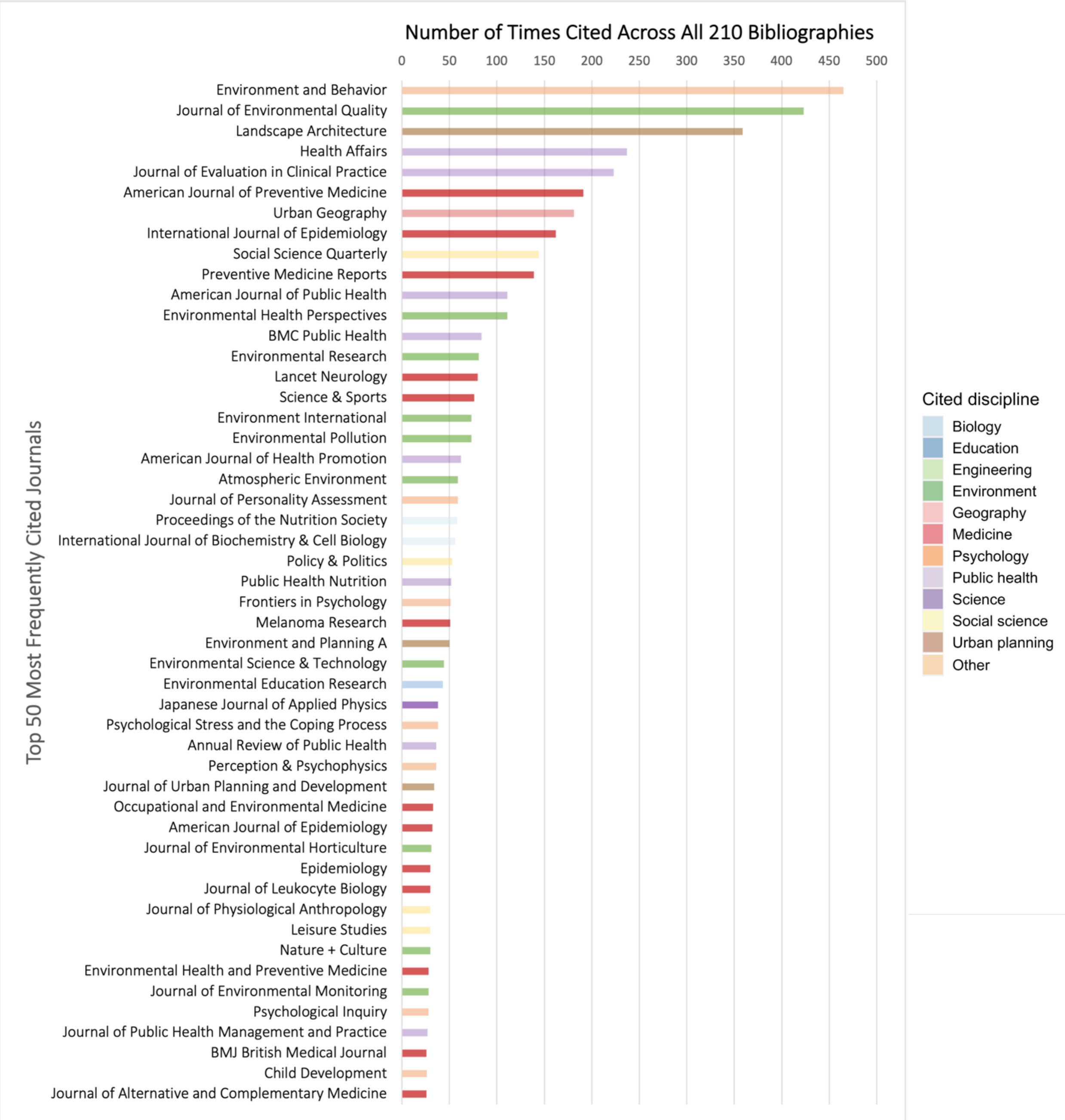

Figure S1.2. Histogram showing the 50 most commonly cited journals amongst all 210 bibliographies. A total of 1,603 different sources were cited across all 210 bibliographies. Bars are coloured by discipline of journal, based on the journal's title and scope, and are ordered from most to least frequently cited.

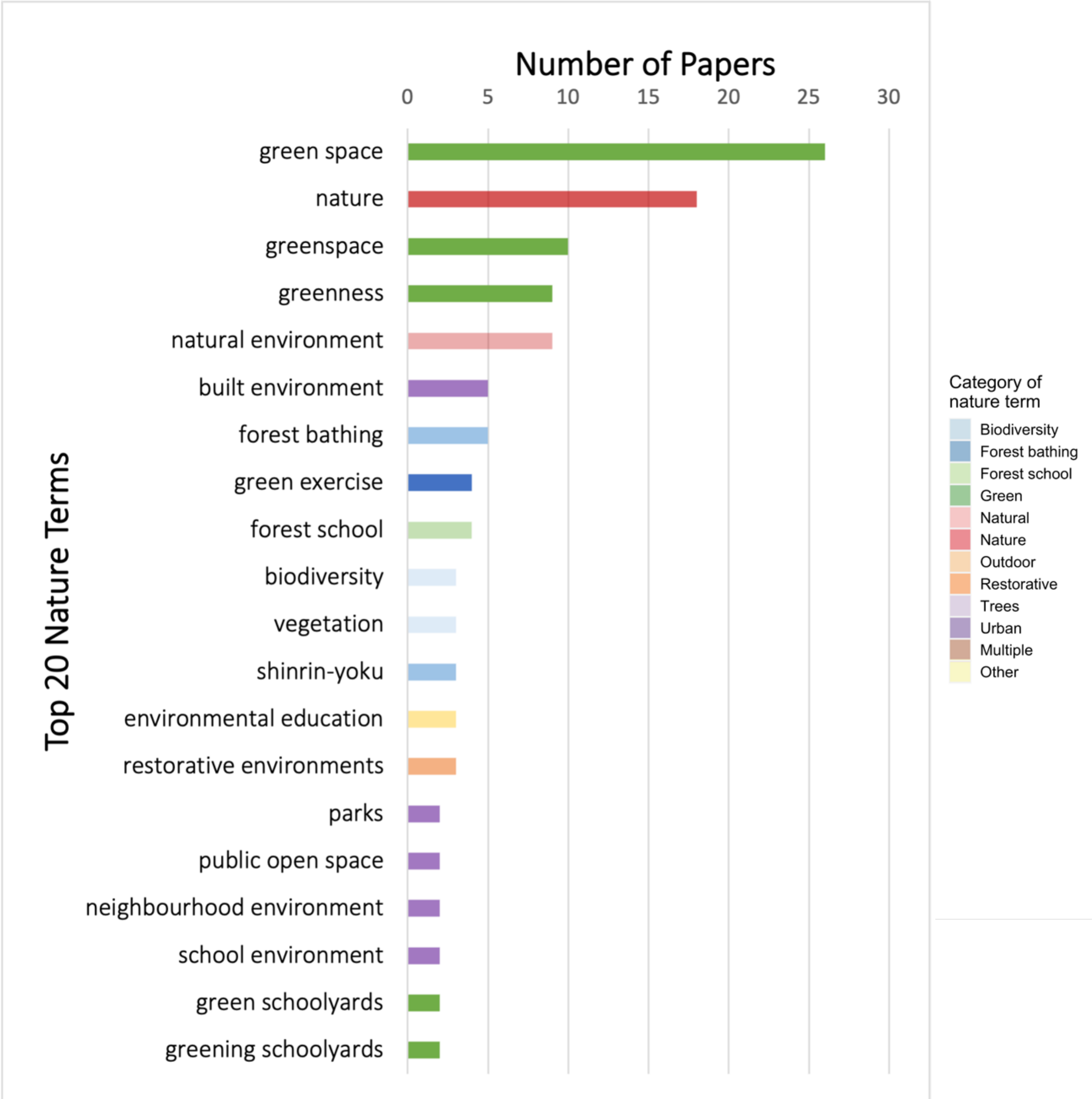

Figure S1.3. Histogram showing the 20 most commonly used nature terms in paper titles and abstracts. A total of 103 different nature terms were used across all 210 paper titles and abstracts, which we classified into 12 different categories (see Table 1.2). Bars are coloured by category of nature term (see Table S1.4) and are ordered from most to least frequently used.

Table S1.4. Table showing all nature terms used in paper titles and abstracts, and their assigned categories.

Category (*n* = 12) ***(No. terms per category)***	**Term used in paper title (*n* = 194) or abstract (*n* = 16)**	**No. papers (*n* = 210)**
Biodiversity *(11 terms)*		
Biodiversity	**1.** Biodiversity	3
Biodiversity	**2.** Vegetation	3
Biodiversity	**3.** Biodiverse environments	1
Biodiversity	**4.** Biodiversity; Species richness	1
Biodiversity	**5.** Ecosystem health	1
Biodiversity	**6.** Ecosystem services; Street trees	1
Biodiversity	**7.** Tree canopy	1
Biodiversity	**8.** Tree cover; Species composition	1
Biodiversity	**9.** Tree cover; Vegetation	1
Biodiversity	**10.** Urban forest species	1
Biodiversity	**11.** Urban tree canopy	1
Forest bathing *(6 terms)*		
Forest bathing	**1.** Forest bathing	5
Forest bathing	**2.** Shinrin-yoku	3
Forest bathing	**3.** Forest therapy	2
Forest bathing	**4.** Forest	1
Forest bathing	**5.** Forest experience	1
Forest bathing	**6.** Forest recreation	1
Forest school *(2 terms)*		
Forest school	**1.** Forest school	4
Forest school	**2.** Forest education	1
Green *(15 terms)*		
Green	**1.** Green space	26
Green	**2.** Greenspace	10
Green	**3.** Greenness	9
Green	**4.** Green exercise	4
Green	**5.** Greening schoolyards	2
Green	**6.** Green schoolyards	2
Green	**7.** Green	1
Green	**8.** Green care farms	1
Green	**9.** Green environments	1
Green	**10.** Green living environment	1
Green	**11.** Green neighbourhoods	1
Green	**12.** Green play settings	1
Green	**13.** Green school grounds	1
Green	**14.** Green space access	1
Green	**15.** School green space	1
Natural *(6 terms)*		
Natural	**1.** Natural environment	9
Natural	**2.** Natural setting	2
Natural	**3.** Natural field setting	1
Natural	**4.** Naturalness	1
Natural	**5.** Natural scene	1
Natural	**6.** Natural visual material	1
Nature *(6 terms)*		

Nature	**1.** Nature	18
Nature	**2.** Nature experience	2
Nature	**3.** Nature connectedness	1
Nature	**4.** Nature connection	1
Nature	**5.** Nature contact	1
Nature	**6.** Nature exposure	1
Outdoor *(12 terms)*		
Outdoor	**1.** Adventure education	2
Outdoor	**2.** Outdoor adventure	1
Outdoor	**3.** Outdoor classes	1
Outdoor	**4.** Outdoor design	1
Outdoor	**5.** Outdoor education	1
Outdoor	**6.** Outdoor learning	1
Outdoor	**7.** Outdoor play environments	1
Outdoor	**8.** Outdoors	1
Outdoor	**9.** Outdoor science teaching	1
Outdoor	**10.** Outdoor settings	1
Outdoor	**11.** Outdoor spaces	1
Outdoor	**12.** Outdoor time	1
Restorative *(1 term)*		
Restorative	**1.** Restorative environments	3
Trees *(7 terms)*		
Trees	**1.** Trees	2
Trees	**2.** Urban trees	2
Trees	**3.** Forest environments	1
Trees	**4.** Tree and forest effects	1
Trees	**5.** Tree effects	1
Trees	**6.** Urban trees and shrubs	1
Trees	**7.** Woodland	1
Urban *(16 terms)*		
Urban	**1.** Built environment	5
Urban	**2.** Neighbourhood environment	2
Urban	**3.** Parks	2
Urban	**4.** Public open space	2
Urban	**5.** School environment	2
Urban	**6.** Neighbourhood environment measures	1
Urban	**7.** Open play space	1
Urban	**8.** Physical environment	1
Urban	**9.** Preschool environment	1
Urban	**10.** Public parks	1
Urban	**11.** School landscapes	1
Urban	**12.** Urban flora	1
Urban	**13.** Urban greening	1
Urban	**14.** Urban green spaces; Open sports spaces	1
Urban	**15.** Urban nature	1
Urban	**16.** Urban parks	1
Other *(9 terms)*		
Other	**1.** Environmental education	3
Other	**2.** Conservation activities	2

Other	**3.** Gardening	2
Other	**4.** Blue space	1
Other	**5.** Environmental design; Forest hike	1
Other	**6.** Field trip methods	1
Other	**7.** Landscape planning	1
Other	**8.** Rural schoolyard	1
Other	**9.** Wilderness adventure therapy	1
Multiple *(12 terms)*		
Multiple	**1.** Green outdoor environments	2
Multiple	**2.** Greenspace; Natural environment	2
Multiple	**3.** Green schoolyards; Natural spaces	1
Multiple	**4.** Green settings; Natural settings	1
Multiple	**5.** Greenspace; Biodiversity	1
Multiple	**6.** Green spaces; Blue spaces	1
Multiple	**7.** Green urban landscapes	1
Multiple	**8.** Nature; Greenness	1
Multiple	**9.** Parks; Green areas	1
Multiple	**10.** Residential environments; Green areas	1
Multiple	**11.** Urban green land cover	1
Multiple	**12.** Vegetation; School ground greening	1

Chapter Two: Supplementary material

Table S2.1. Table showing data collected from each school (n = 14), as well as school location and type. Missing data are due to impacts of the COVID-19 outbreak limiting school site visits.

School type	Local authority	Buffer greenness (ha)	School greenness (ha)	Date of *in situ* data collection	Visible vegetation data	Invertebrate data	Bird data	Quadrat data	Tree data		
									No. trees	No. species	DBH (cm)
State	Cambridge	719.52	0.11	15/08/2019	✓	✓	✓	✓	✓	✓	✓
State	Chorley	1030.28	0.53	29/08/2019	✓	✓	✓	✓	✓	✓	✓
State	Huntingdonshire	951.32	0.56	31/05/2019	X	X	X	X	✓	✓	✓
State	South Cambridgeshire	1018.29	0.46	27/08/2019	✓	✓	✓	✓	✓	✓	✓
State	Stevenage	1009.98	1.17	16/08/2019	✓	✓	✓	✓	✓	✓	✓
Academy	Breckland	1109.91	1.87	28/08/2019	✓	✓	✓	✓	✓	✓	✓
Academy	Cambridge	768.51	1.00	19/08/2019	✓	✓	✓	✓	✓	✓	✓
Academy	Cambridge	961.11	0.73	03/09/2020	✓	X	✓	✓	✓	✓	✓
Academy	South Cambridgeshire	1099.77	0.96	27/08/2019	✓	✓	✓	✓	✓	✓	✓
Academy	Thurrock	840.12	0.17	05/07/2019	X	X	X	X	✓	✓	✓
Private	Cambridge	725.97	2.09	08/06/2019	X	X	X	X	✓	✓	✓
Private	Harrow	870.71	5.21	22/08/2019	✓	✓	✓	✓	✓	✓	✓
Private	South Cambridgeshire	1018.89	0.15	25/08/2021	✓	✓	✓	✓	✓	✓	✓
Private	Warwick	1358.94	25.40	01/09/2021	✓	✓	✓	✓	✓	X	X

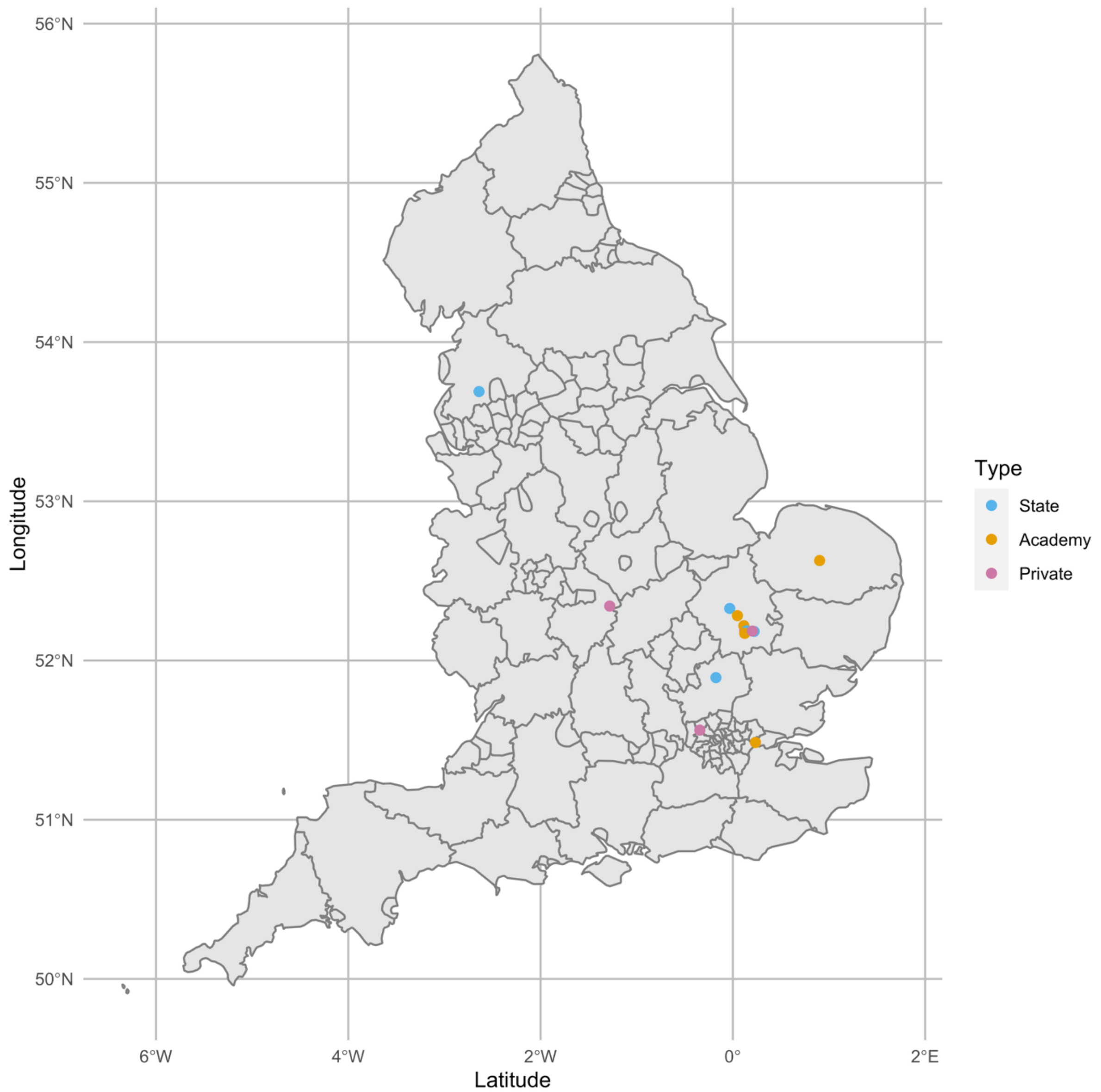

Figure S2.2. Locations of primary schools across England from which biodiversity data were collected, coloured by school type. Each dot represents one school (*n* = 14).

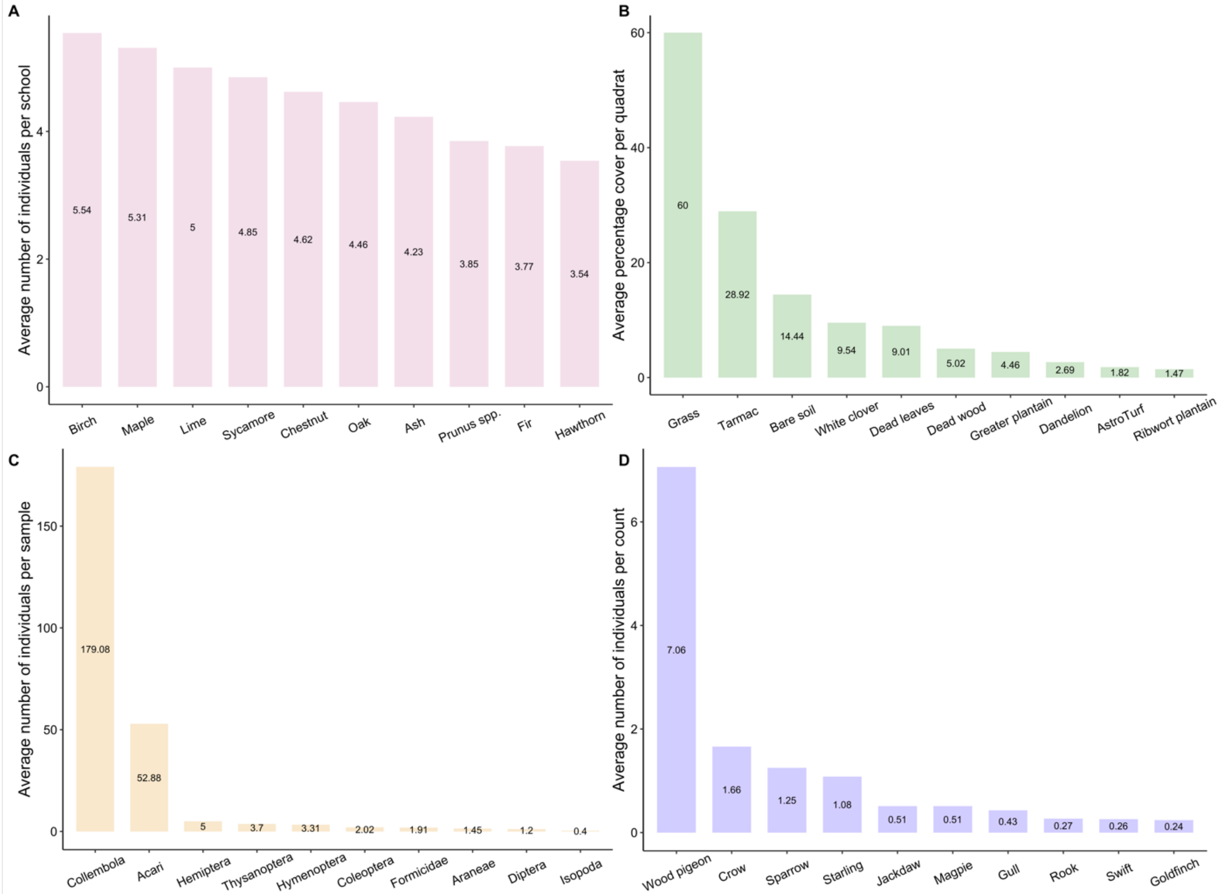

Figure S2.3. Most common groups found in school grounds. A: Bar graph showing the 10 most abundant tree morphospecies by average number of individuals per school. B: Bar graph showing the 10 most common types of ground cover by average coverage per quadrat. C: Bar graph showing the 10 most abundant ground invertebrate orders by average number of individuals per sample. D: Bar graph showing the 10 most abundant bird species by average number of individuals per count.

Table S2.4. Table showing results of post-hoc analyses following a significant effect of school type via a Kruskal-Wallis test. For all variables, *p* values are the result of Dunn's tests with Bonferroni correction. Significant *p* values (< 0.05/2) are shown in bold. Private schools had higher visible vegetation than state schools and academies, and higher standard deviation in DBH than state schools. There were no pairwise differences between school types for maximum DBH despite there being an overall difference between school types.

Pairwise comparison	**Adjusted *p* value**
Visible vegetation	
State—Academy	1
State—Private	**<0.0001**
Private—Academy	**<0.0001**
Standard deviation in DBH	
State—Academy	0.8651
State—Private	**0.0183**
Private—Academy	0.0849
Maximum DBH	
State—Academy	1
State—Private	0.0439
Private—Academy	0.0252

Chapter Three: Supplementary material

Appendix S3.1. Questionnaire and information given to parents or guardians of primary school-aged children in May 2020.

Green Space & Primary School Children

Introduction
Q1a **Your answers to these questions will help researchers at the University of Cambridge Museum of Zoology understand how important green space is for primary school children. The questions in this survey are about the green space to which you and your children have access, the amount of time you spend there, and your views on the importance of these areas. It has been designed for parents of primary school-aged children in the UK. It should take about ten minutes to complete.**

Participant Information
Before you decide to answer this survey, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please contact Kate Howlett [redacted] at the University of Cambridge Museum of Zoology if there is anything that is not clear or if you would like more information. Please take time to decide whether or not you wish to take part.

What is the research about?
We are investigating the green space that UK primary school children have access to at home. We are interested in the importance of these spaces for children's learning and wellbeing, and in the frequency and way in which they are being used. These questions are designed to help us answer these questions.

Why have I been asked to participate?
We hope to collect responses from as a wide a range of parents as possible, so individuals have not been selected on any particular basis.

What does the survey entail?
After giving your consent at the bottom of this page, you will be taken through to the survey. This should take approximately ten minutes to complete. All the information you provide will be confidential, and you can choose to leave the survey at any point with no consequences.

Are there any benefits to my taking part?
As a thank you for filling in this survey, you will be directed towards resources that can be used to engage children with local wildlife at home. All information received will contribute to continuing research at the Museum of Zoology into green spaces and their impact on children. As well as wanting to understand this from a research perspective, we will also use this information to help us develop better public engagement activities in the Museum.

Will my participation be confidential?

Yes. All information collected will remain strictly confidential. All individuals will be identified only by a code, and any contact details will be kept in a password-protected file accessible only by the immediate research team.

General guidance on how the University uses personal data can be found at https://www.information-compliance.admin.cam.ac.uk/data-protection/research-participant-data.

You will not be identified in any report or publication. Results will be presented at conferences and written up in peer-reviewed journal papers. Results will usually be presented in terms of groups of individuals. If data from any individual are presented, the data will be totally anonymous, without any means of identifying the individuals involved.

What happens if I change my mind?
Taking part is entirely voluntary, and refusal or withdrawal will involve no penalty or loss, either now or at any point in the future. You are free to leave the survey at any point or to contact the research team to withdraw your consent at any point in the future, up until three months after taking part in this survey.

This research is funded by the Natural Environment Research Council, and this project has been reviewed by the Psychology Research Ethics Committee of the University of Cambridge.

Researcher: Kate Howlett [redacted]
Supervisor: Dr Edgar Turner [redacted]

Please provide a contact email address below. This is so that we can remove your responses at a later point if you choose to do so, and so that we can email you any follow-up information, should you choose to consent to this at the end of the survey.

____

Q1b Please click below to acknowledge that you have read, understood and agreed to the following statements.

☐ I confirm that I have read and understood the above Participant Information. (1)

☐ I understand that I can contact the research team via [redacted] at any point to ask for more information. (2)

☐ I understand that all personal information will remain confidential and that all efforts will be made to ensure I cannot be identified (except as might be required by law). (3)

☐ I agree that data gathered in this study may be stored anonymously and securely and may be used for future research. (4)

☐ I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason, up until three months after taking part in this survey. (5)

☐ I agree to take part in this survey. (6)

Q1 How would you describe the environment immediately surrounding your home?

○ Urban (1)

○ Suburban (2)

○ Rural (3)

Q2 What type of primary school do your children attend?

○ State (1)

○ Private (2)

○ Academy (3)

○ Prefer not to say (88)

Q2a What is the name of your children's primary school?
Please skip onto the next question if you would prefer not to say.

____

Q3 If you are happy to, please provide the number, gender(s) and age(s) of your children.
If not, please skip onto the next question.

____
____
____
____
____

Q4 What sort of outside space do you have access to?

- My own garden (1)
- Communal garden (2)
- Local park (3)
- None (4)

Q5 What sort of outside space do your children have access to?

- My own garden (1)
- Communal garden (2)
- Local park (3)
- None (4)

Q5a How large is your garden or communal garden?

- About the size of a car (1)
- Larger than the size of a car but smaller than the size of a tennis court (2)
- About the size of a tennis court (3)
- Larger than the size of a tennis court (4)

Q5b Does your garden or communal garden have any of the following habitat features? Please select all that apply.

- Grass (1)
- Artificial grass (2)
- Flowerbed (3)
- Bush or hedge (4)
- Small tree (up to 2m tall) (5)

- ☐ Large tree (taller than 2m) (6)
- ☐ Compost heap (7)
- ☐ Pond (8)
- ☐ Woodland (9)
- ☐ Meadow (an area where the grass is left uncut for at least part of the year) (10)
- ☐ Wood pile (11)
- ☐ Bird or bat box (12)
- ☐ Bird feeder or bath (13)
- ☐ Bug hotel (14)
- ☐ Bench, chair or table (15)
- ☐ Play equipment (e.g., football, climbing frame, trampoline) (16)
- ☐ Patio or path (17)
- ☐ None of these (18)
- ☐ Other (19) ____

Q5c Do you regularly feed the birds or other wildlife in your garden or communal garden?

- ○ Yes (1)
- ○ No (2)

Q5d Do you do anything to encourage wildlife in your garden or communal garden? If so, please tell us briefly what this is.

____
____
____
____
____

Q6 Have you ever taken part in a citizen-science nature project, such the RSPB Big Garden Birdwatch, BTO Garden Birdwatch, Great British Bee Count, Big Butterfly Count or similar?

◯ Yes (1)

◯ No (2)

◯ No, but I am planning to in the future. (3)

Q6a Please list the citizen-science nature project(s) you have taken part in or plan to take part in.

____
____
____
____
____

Q7 How do you feel about the amount of green space you have access to?

◯ I would like more access to green space. (1)

◯ I would like less access to green space. (2)

◯ I am happy with the amount of green space I have access to. (3)

◯ I don't know. (99)

Q8 How do you feel about the amount of green space your children have access to?

◯ I would like them to have more access to green space. (1)

◯ I would like them to have less access to green space. (2)

◯ I am happy with the amount of green space my children have access to. (3)

- I don't know. (99)

Q9 Please list any animals you see regularly through your window or in your garden.

____
____
____
____
____

Q10
As of Monday 23rd March, the UK has been on lockdown in response to the COVID-19 pandemic.

Are your children spending more or less time outside now than before lockdown began?

- My children are spending more time outside since lockdown began. (1)
- My children are spending less time outside since lockdown began. (2)
- The amount of time my children are spending outside has not changed on account of lockdown. (3)
- I don't know. (99)

Q11 Please estimate the number of hours your children were spending outside each day before lockdown began.

____

Q12 Please estimate the number of hours your children are spending outside each day during lockdown.

____

Q13 Have your children been going for a daily walk outside your home since lockdown began?

- Yes (1)
- Sometimes (2)
- No (3)

- ◯ I don't know. (99)
- ◯ Prefer not to say (88)

Q13a Where have they been walking?

- ◯ Around local residential streets (1)
- ◯ Around a local park (2)
- ◯ Around local fields (3)
- ◯ Around a local nature reserve (4)
- ◯ Other (5) ____

Q14 How much do you agree or disagree with each of the following statements?

	Strongly disagree (1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly agree (5)	I don't know. (99)
Green space is important for children's wellbeing. (1)	◯	◯	◯	◯	◯	◯
Green space is important for adults' wellbeing. (2)	◯	◯	◯	◯	◯	◯
Green space is important for children's learning. (3)	◯	◯	◯	◯	◯	◯
I do not think green space is	◯	◯	◯	◯	◯	◯

important. (4)						
I often think about the importance of green space. (5)	○	○	○	○	○	○

Q15 Has your thinking on the importance of green space changed since lockdown began?

○ Yes (1)

○ No (2)

○ I don't know. (99)

○ Prefer not to say (88)

Q15a Please explain how your views have changed or why they haven't.

____

____

____

____

____

Q16 Do you have any other thoughts about green space and its impact on children's wellbeing or learning?

____

____

____

____

____

Q17 Thank you for taking the time to complete this survey. Your response has been recorded.

If you would like more information, please do not hesitate to contact Kate Howlett at [redacted]

If you know of another parent who might be willing to complete this survey, we would be grateful if you could pass the link onto them.

Q17a Please let us know whether you are happy to be contacted with further information about this project.

○ I am happy to be contacted with further information about this project. (1)

○ I do not wish to be contacted with further information about this project. (2)

Q17b Visit the University of Cambridge Museum of Zoology blog to find resources designed to engage children with wildlife at home: https://museumofzoologyblog.com

You will find:
- Craft ideas
- Activities for children under five in 'Puggle Club'
- Activities for children over five in 'Nature Classroom'
- Key Stage 3 & 4 resources in 'Our Changing Planet'
- Content to help you explore nature at home in 'Wildlife from your Window'

If you would like to engage in a bit of friendly competition whilst wildlife watching, download our #OpenYourWindowBingo activity sheet here: https://museumofzoologyblog.com/2020/04/06/open-your-window-bingo/

Table S3.2. Table showing the distribution of respondents to the survey for parents of primary school-aged children in the UK (*n* = 171) across three factors compared to that for the UK population as a whole. Data on the UK population are from the World Bank and United Nations Population Division (2019a, 2019b) for local environment, from Green & Kynaston (2019) and the Department for Education (2019) for school type and from the Office for National Statistics (2020) for type of green space access. Asterisk denotes categories that are not separated out in national figures.

Factor	Percentage of respondents (%)	Percentage of UK population (%)
Local environment		
Rural	22.9	16.3
Suburban	55.3	*
Urban	21.8	83.7
School type		
State	69.4	46.4
Academy	17.1	46.6
Private	12.4	7
Prefer not to say	0.6	
No response	0.6	
Type of green space access		
Private garden	88.2	79
Communal garden	3.5	4
Local park	6.5	*
None	1.2	*
No response	0.6	

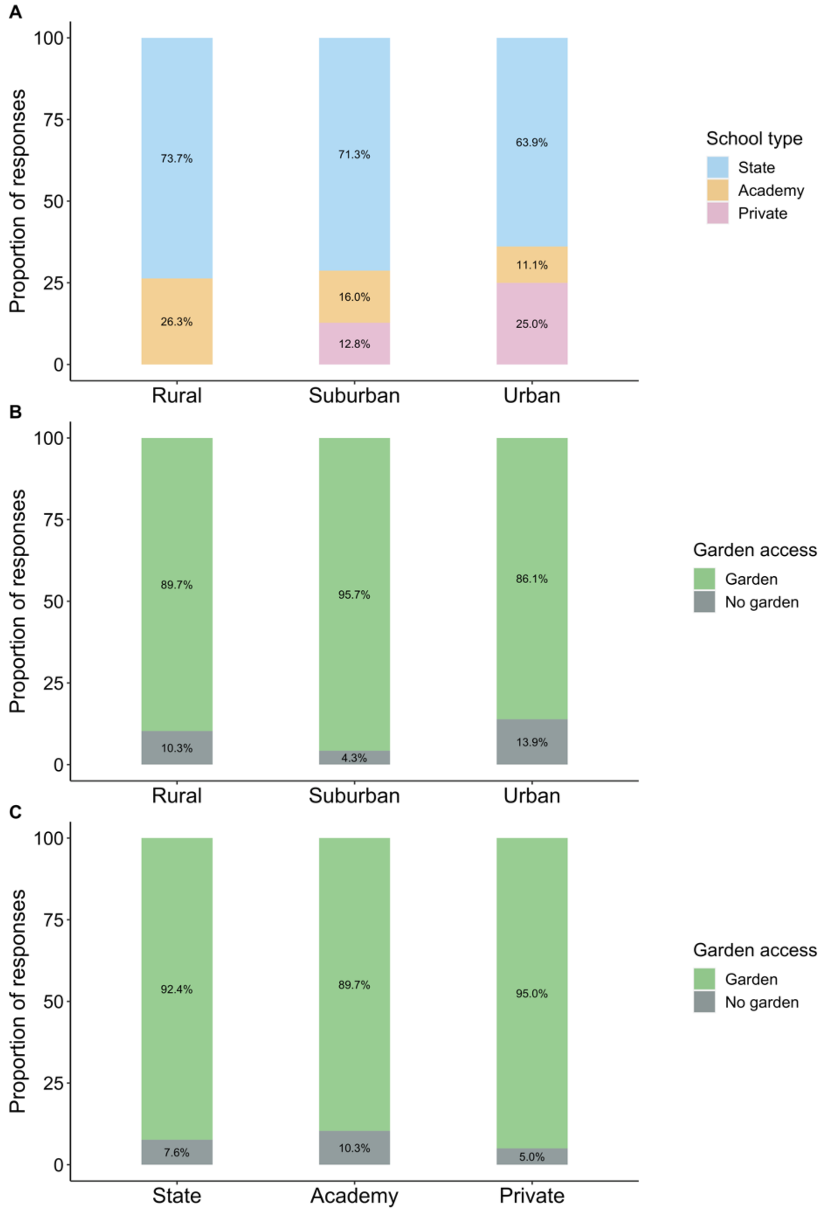

Figure S3.3. Bar graphs showing assessment of associations between factors for respondents to the survey for parents of primary school-aged children in the UK (*n* = 171). A: the relationship between local environment and school type of respondents' children. B: the relationship between local environment and garden access of respondents. C: the relationship between school type of respondents' children and garden access. The only significant association was between private schools and local environment (χ^2 = 12.2, *df* = 4, *p* = 0.0471).

Table S3.4. Table showing results of chi-square tests with Bonferroni correction to assess whether frequency of occurrence for each of the common sentiments or reasons for the importance of green space differed based on local environment, school type or garden access. Bonferroni-adjusted alpha = 0.017. There are no significant results.

	Local environment (*df* = 2)		**School type (*df* = 2)**		**Garden access (*df* = 1)**	
	χ^2	***p***	χ^2	***p***	χ^2	***p***
Common sentiment						
General importance of green space	5.2514	0.0724	1.7380	0.4194	<0.0001	1
Importance of having a garden	0.9779	0.6133	7.4802	0.0238	<0.0001	1
Importance of locally accessible green space	1.2518	0.5348	0.8561	0.6518	0.5588	0.4548
Lack of current access to green space	4.7661	0.0923	1.0328	0.5967	0.0329	0.8561
Positive effects on children	0.8761	0.6453	3.0696	0.2155	<0.0001	1
More time spent in the garden	2.1952	0.3337	2.2252	0.3287	<0.0001	1
Exploration of local area	0.4520	0.7977	3.4773	0.1758	0.0303	0.8619
Observation of wildlife	0.0477	0.9764	2.2193	0.3297	0.1214	0.7275
Slowing down	1.8092	0.4047	0.9851	0.6111	0.0020	0.9647
Need for more outdoor learning at school	5.5492	0.0624	1.7088	0.4255	<0.0001	1
Grateful for green space	6.1530	0.0461	1.8917	0.3883	0	1
Sympathy for those without access	3.0850	0.2138	2.2193	0.3297	<0.0001	1
Always been grateful for or aware of importance of green space	8.7619	0.0125	2.2429	0.3258	0.5219	0.4700
Became more grateful for green space during lockdown	7.0234	0.0299	2.1680	0.3382	0.0001	0.9915
Desire to protect green spaces	0.5589	0.7562	0.0679	0.9666	<0.0001	1
Commonly stated reason for the importance of green space						
Good for spiritual wellbeing	0.4466	0.7999	0.4308	0.8062	<0.0001	1
Good for mental health	3.2694	0.1950	1.0155	0.6019	0.7361	0.3909
Good for general health	0.8336	0.6592	3.4601	0.1773	0.0575	0.8105
Important for social interactions	7.2025	0.0273	0.3152	0.8542	<0.0001	1
Space to exercise	4.4498	0.1081	0.3117	0.8557	0.2448	0.6208
Space to play	3.3369	0.1885	1.5877	0.4521	<0.0001	1
Space to release energy	0.6480	0.7232	1.3801	0.5016	0.0052	0.9426
Good for creativity, imagination or curiosity	0.3147	0.8544	4.3281	0.1149	<0.0001	1
Important for general learning	1.4182	0.4921	0.3219	0.8513	0.0908	0.7631
Important for learning about nature	1.3587	0.5069	3.7117	0.1563	<0.0001	1
Important for learning social skills	2.2272	0.3284	4.7517	0.0929	0.1226	0.7262
Important for learning about growing food	0.0768	0.9623	0.8929	0.6399	<0.0001	1
As a counter to screen time	1.8092	0.4047	0.0679	0.9666	2.5446	0.1107
As a source of fresh air	5.2553	0.0723	0.6942	0.7067	0.5507	0.458
Important for a sense of freedom	2.3442	0.3097	0.8929	0.6399	<0.0001	1
Important for building a connection to nature	1.5370	0.4637	4.7781	0.0917	0.0303	0.8619

Chapter Four: Supplementary material

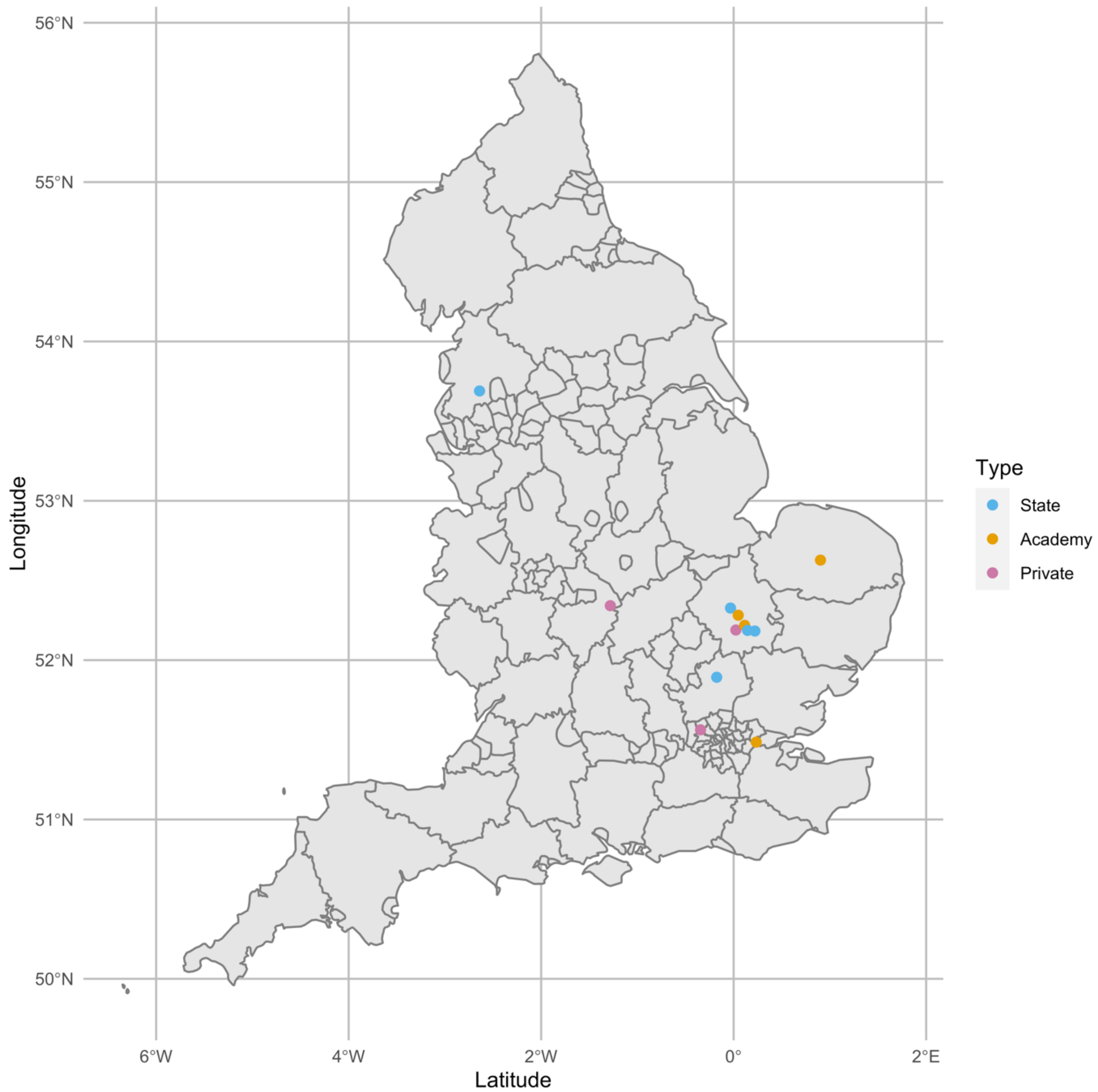

Figure S4.1. Locations of primary schools across England from which drawings were collected, coloured by school type. Each dot represents one school (*n* = 12). The private school in the main cluster of points has been manually moved 0.1 degrees west so that all points are visible.

Table S4.2. Table showing the distribution of children's drawings (*n* = 401) across ages and schools (*n* = 12), including school location and type.

Type	Local authority	Children's age	No. of drawings
State	Cambridge	7-8 years	29
State	Chorley	10-11 years	34
State	Huntingdonshire	8-9 years	27
State	South Cambridgeshire	9-11 years	80
State	Stevenage	9-10 years	72
Academy	Breckland	7-8 years	30
Academy	Cambridge	9-10 years	24
Academy	South Cambridgeshire	7-10 years	12
Academy	Thurrock	7-8 years	29
Private	Cambridge	9-10 years	17
Private	Harrow	10-11 years	9
Private	Warwick	8-11 years	38

Appendix S4.3. Worksheet with instructions given to primary-school children. Font size and box dimensions have been reduced in order to fit within document margins.

Please draw and label a picture of your garden or local park showing the animals you think live there.
Tell us a little bit about what you have drawn below.

I have drawn ____

____

____

Appendix S4.4. Information provided to parents or guardians of children before the study.

Information for Potential Child Participants and their Families

Before you decide to give consent for your child to take part in this study, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please contact Kate Howlett [redacted] at the University of Cambridge Museum of Zoology if there is anything that is not clear or if you would like more information. Please take time to decide whether or not you wish your child to take part.

What is the research about?

We are investigating the green space that UK primary school children have access to at school. We are interested in the importance of these spaces for children's learning and wellbeing, and in how they affect children's relationship with and awareness of nature. These drawings will help us answer these questions.

Why has my child been asked to participate?

We hope to collect responses from as a wide a range of children as possible, so individuals have not been selected on any particular basis.

What does the study entail?

After giving your consent for your child to take part, your child will be given a worksheet to complete in class, under supervision by their teacher, along with their classmates. This worksheet will ask them to draw a picture of their garden or local park, labelling all the animals they think live there. At the bottom of the sheet, there will be a couple of lines in which they can tell us a bit more about what they have drawn. The drawings will then be collected in by their teacher and passed onto the researchers for analysis.

Does my child have to take part?

No. You do not have to give consent to your child taking part in this research. But, if you did consent, researchers know from past experience that most children have enjoyed the task.

Will participation be confidential?

Yes. No personal data will be collected at any point, and your child will not be identifiable from their drawings. All information collected will remain strictly confidential and will not be shared beyond the small research team of two. Drawings will be linked to each child’s school by a numerical code, the details of which will be stored in a password-protected file, accessible only by the immediate research team.

General guidance on how the University uses personal data can be found at https://www.information-compliance.admin.cam.ac.uk/data-protection/research-participant-data.

Your child will not be identified in any report or publication. Results will be presented at conferences and written up in peer-reviewed journal papers. Results will usually be presented in terms of groups of individuals. If data from any individual are presented, the data will be totally anonymous, without any means of identifying the individual(s) involved.

What happens if I change my mind?

Taking part is entirely voluntary, and refusal or withdrawal will involve no penalty or loss, either now or at any point in the future. You are free to contact the research team at [redacted] to withdraw your consent at any point in the future, up until three months after taking part.

This research is funded by the Natural Environment Research Council, and this project has been reviewed by the Psychology Research Ethics Committee of the University of Cambridge.

<u>Consent Form</u>

Please tick each box below to acknowledge that you have read, understood and agreed to the following statements, then sign and date below.

☐ I confirm that I have read and understood the Information for Potential Child Participants and their Families.

☐ I understand that I can contact the research team via [redacted] at any point to ask for more information.

☐ I understand that all information collected will remain confidential and that all efforts will be made to ensure my child cannot be identified.

☐ I agree that data gathered in this study may be stored anonymously and securely and may be used for future research.

☐ I understand that my consent is voluntary and that I am free to withdraw my consent at any time without giving a reason, up until three months after taking part, by contacting [redacted]

☐ I give consent for my child to take part.

Name: _________________________________

Signed: _________________________________

Child's name: _________________________________

Date:_____________

Table S4.5. Table showing all terms used in the labels and captions of children's drawings, detailing assigned categories, whether or not a term's presence was counted towards the species richness of a drawing, and the count and ID level for each term. Despite technically being the same species, 'Pony' and 'Horse' are both counted towards species richness because, to a child, these are different animals. 'Mushroom' is included in the category 'Other Plants' since it is the only fungal representative, and it appeared in just three drawings.

Category ***(% drawings containing at least one member)***	**Term used as label or in caption**	**Included towards species richness count?**	**Taxonomic ID level**	**No. drawings containing term (*n* = 401)**	**% drawings containing term**
Animals *(Total: 123 terms)*					
General *(57.6%)*	**1.** Birds	n	Class	195	48.6
General	**2.** Bugs	n	Order	27	6.7
General	**3.** Creepy crawlies	n	Kingdom	1	0.2
General	**4.** Fish	n	Phylum	20	5.0
General	**5.** Insects	n	Class	24	6.0
General	**6.** Mammals	n	Class	10	2.5
General	**7.** Minibeasts	n	Kingdom	3	0.7
Domestic Mammal *(49.6%)*	**1.** Cat	y	Species	106	26.4
Domestic Mammal	**2.** Dog	y	Species	68	17.0
Domestic Mammal	**3.** Gerbil	y	Species	1	0.2
Domestic Mammal	**4.** Guinea pig	y	Species	9	2.2
Domestic Mammal	**5.** Hamster	y	Family	2	0.5
Domestic Mammal	**6.** Horse	y	Species	2	0.5
Domestic Mammal	**7.** Pig	y	Species	2	0.5
Domestic Mammal	**8.** Pony	y	Species	2	0.5
Domestic Mammal	**9.** Rabbit	y	Species	56	14.0
Domestic Mammal	**10.** Sheep	y	Species	1	0.2
Wild Mammal *(57.1%)*	**1.** Badger	y	Species	3	0.7
Wild Mammal	**2.** Bat	y	Order	8	2.0
Wild Mammal	**3.** Deer	y	Family	23	5.7
Wild Mammal	**4.** Flying squirrel	y	Family	1	0.2
Wild Mammal	**5.** Fox	y	Species	56	14.0
Wild Mammal	**6.** Grey squirrel	y	Species	2	0.5
Wild Mammal	**7.** Hare	y	Species	1	0.2
Wild Mammal	**8.** Hedgehog	y	Species	79	19.7
Wild Mammal	**9.** Hippo	y	Species	1	0.2
Wild Mammal	**10.** Lion	y	Species	1	0.2
Wild Mammal	**11.** Mole	y	Species	20	5.0
Wild Mammal	**12.** Mouse	y	Genus	25	6.2
Wild Mammal	**13.** Muntjac deer	y	Genus	6	1.5
Wild Mammal	**14.** Rat	y	Genus	16	4.0
Wild Mammal	**15.** Red squirrel	y	Species	1	0.2
Wild Mammal	**16.** Shrew	y	Order	1	0.2
Wild Mammal	**17.** Squirrel	y	Genus	120	29.9
Wild Mammal	**18.** Tiger	y	Species	1	0.2
Wild Mammal	**19.** Wildcat	y	Species	3	0.7
Garden Bird *(24.9%)*	**1.** Blackbird	y	Species	24	6.0

Garden Bird	**2.** Blue tit	y	Species	27	6.7
Garden Bird	**3.** Chaffinch	y	Species	1	0.2
Garden Bird	**4.** Collared dove	y	Species	1	0.2
Garden Bird	**5.** Crow	y	Species	15	3.7
Garden Bird	**6.** Dove	y	Family	2	0.5
Garden Bird	**7.** Dunnock	y	Species	1	0.2
Garden Bird	**8.** Goldfinch	y	Species	4	1.0
Garden Bird	**9.** Great tit	y	Species	4	1.0
Garden Bird	**10.** Greenfinch	y	Species	2	0.5
Garden Bird	**11.** Green woodpecker	y	Genus	1	0.2
Garden Bird	**12.** Jackdaw	y	Species	1	0.2
Garden Bird	**13.** Jay	y	Species	2	0.5
Garden Bird	**14.** Long-tailed tit	y	Species	2	0.5
Garden Bird	**15.** Magpie	y	Species	9	2.2
Garden Bird	**16.** Pigeon	y	Family	53	13.2
Garden Bird	**17.** Robin	y	Species	39	9.7
Garden Bird	**18.** Sparrow	y	Genus	6	1.5
Garden Bird	**19.** Starling	y	Species	1	0.2
Garden Bird	**20.** Thrush	y	Genus	1	0.2
Garden Bird	**21.** Wagtail	y	Genus	1	0.2
Garden Bird	**22.** Woodpecker	y	Family	4	1.0
Garden Bird	**23.** Wren	y	Species	2	0.5
Other Bird *(13.7%)*	**1.** Barn owl	y	Species	1	0.2
Other Bird	**2.** Bird of prey	y	Class	4	1.0
Other Bird	**3.** Chicken	y	Species	9	2.2
Other Bird	**4.** Duck	y	Family	15	3.7
Other Bird	**5.** Eagle	y	Family	1	0.2
Other Bird	**6.** Goose	y	Family	1	0.2
Other Bird	**7.** Gull	y	Family	1	0.2
Other Bird	**8.** Heron	y	Family	1	0.2
Other Bird	**9.** House martin	y	Species	1	0.2
Other Bird	**10.** Kestrel	y	Species	1	0.2
Other Bird	**11.** Moorhen	y	Species	2	0.5
Other Bird	**12.** Owl	y	Order	11	2.7
Other Bird	**13.** Parrot	y	Order	1	0.2
Other Bird	**14.** Partridge	y	Family	6	1.5
Other Bird	**15.** Peacock	y	Species	2	0.5
Other Bird	**16.** Peregrine falcon	y	Species	1	0.2
Other Bird	**17.** Pheasant	y	Species	10	2.5
Other Bird	**18.** Red kite	y	Species	2	0.5
Other Bird	**19.** Skylark	y	Species	1	0.2
Other Bird	**20.** Swallow	y	Species	1	0.2
Other Bird	**21.** Swan	y	Genus	2	0.5
Other Bird	**22.** Swift	y	Species	3	0.7
Herpetofauna *(15.7%)*	**1.** Frog	y	Order	51	12.7
Herpetofauna	**2.** Grass snake	y	Species	9	2.2
Herpetofauna	**3.** Newt	y	Family	1	0.2
Herpetofauna	**4.** Snake	y	Order	3	0.7
Herpetofauna	**5.** Tadpole	y	Class	4	1.0

Herpetofauna	**6.** Toad	y	Order	3	0.7
Herpetofauna	**7.** Tortoise	y	Order	3	0.7
Insect *(52.9%)*	**1.** Ant	y	Family	116	28.9
Insect	**2.** Aphid	y	Order	1	0.2
Insect	**3.** Bee	y	Family	102	25.4
Insect	**4.** Beetle	y	Order	11	2.7
Insect	**5.** Blackfly	y	Family	1	0.2
Insect	**6.** Black garden ant	y	Species	1	0.2
Insect	**7.** Bumblebee	y	Genus	5	1.2
Insect	**8.** Butterfly	y	Order	64	16.0
Insect	**9.** Caterpillar	y	Order	23	5.7
Insect	**10.** Cricket	y	Order	1	0.2
Insect	**11.** Dragonfly	y	Order	10	2.5
Insect	**12.** Fly	y	Order	23	5.7
Insect	**13.** Grasshopper	y	Order	7	1.7
Insect	**14.** Greenfly	y	Species	3	0.7
Insect	**15.** Hornet	y	Genus	1	0.2
Insect	**16.** Ladybird	y	Family	35	8.7
Insect	**17.** Larvae	y	Class	1	0.2
Insect	**18.** Mayfly	y	Order	2	0.5
Insect	**19.** Midge	y	Order	1	0.2
Insect	**20.** Mosquito	y	Family	1	0.2
Insect	**21.** Moth	y	Order	5	1.2
Insect	**22.** Red ant	y	Species	1	0.2
Insect	**23.** Shield bug	y	Order	1	0.2
Insect	**24.** Stag beetle	y	Family	3	0.7
Insect	**25.** Violet ground beetle	y	Species	1	0.2
Insect	**26.** Wasp	y	Order	30	7.5
Insect	**27.** Yellow meadow ant	y	Species	1	0.2
Other Invertebrate *(50.9%)*	**1.** Arachnids	y	Class	2	0.5
Other Invertebrate	**2.** Centipede	y	Class	9	2.2
Other Invertebrate	**3.** Millipede	y	Class	6	1.5
Other Invertebrate	**4.** Slug	y	Class	51	12.7
Other Invertebrate	**5.** Snail	y	Class	94	23.4
Other Invertebrate	**6.** Spider	y	Order	97	24.2
Other Invertebrate	**7.** Woodlouse	y	Order	37	9.2
Other Invertebrate	**8.** Worm	y	Phylum	103	25.7
Plants *(Total: 56 terms)*					
General *(79.6%)*	**1.** Berries	n	None	1	0.2
General	**2.** Blossom	n	None	1	0.2
General	**3.** Bush/Shrub/Hedge	n	None	93	23.2
General	**4.** Evergreen tree	n	None	1	0.2
General	**5.** Flower	n	None	112	27.9
General	**6.** Fruit tree	n	None	12	3.0
General	**7.** Plant	n	None	49	12.2
General	**8.** Tree	n	None	247	61.6
General	**9.** Weed	n	None	2	0.5
Tree *(6.5%)*	**1.** Apple tree	y	Species	12	3.0
Tree	**2.** Cherry tree	y	Genus	6	1.5

Tree	**3.** Crab apple tree	y	Genus	2	0.5
Tree	**4.** Cypress	y	Family	1	0.2
Tree	**5.** Olive tree	y	Species	3	0.7
Tree	**6.** Palm tree	y	Family	1	0.2
Tree	**7.** Pear tree	y	Genus	7	1.7
Tree	**8.** Plum tree	y	Genus	2	0.5
Flower *(2.7%)*	**1.** Daffodil	y	Genus	1	0.2
Flower	**2.** Dandelion	y	Genus	1	0.2
Flower	**3.** Lavender	y	Genus	2	0.5
Flower	**4.** Lily	y	Genus	1	0.2
Flower	**5.** Poppy	y	Family	1	0.2
Flower	**6.** Rose	y	Genus	5	1.2
Flower	**7.** Snowdrop	y	Genus	1	0.2
Flower	**8.** Sunflower	y	Genus	1	0.2
Flower	**9.** Tulip	y	Genus	1	0.2
Crop *(5.2%)*	**1.** Blackberries	y	Genus	2	0.5
Crop	**2.** Blueberries	y	Genus	1	0.2
Crop	**3.** Broccoli	y	Species	1	0.2
Crop	**4.** Carrots	y	Species	4	1.0
Crop	**5.** Chilli	y	Genus	1	0.2
Crop	**6.** Grapes	y	Genus	1	0.2
Crop	**7.** Green beans	y	Species	1	0.2
Crop	**8.** Herbs	n	None	3	0.7
Crop	**9.** Lettuce	y	Species	1	0.2
Crop	**10.** Mint	y	Genus	1	0.2
Crop	**11.** Peas	y	Species	1	0.2
Crop	**12.** Potatoes	y	Species	1	0.2
Crop	**13.** Raspberries	y	Genus	2	0.5
Crop	**14.** Rhubarb	y	Species	1	0.2
Crop	**15.** Rosemary	y	Species	1	0.2
Crop	**16.** Strawberries	y	Species	7	1.7
Crop	**17.** Thyme	y	Genus	1	0.2
Crop	**18.** Tomatoes	y	Species	1	0.2
Crop	**19.** Vegetables	n	None	5	1.2
Other Plants *(60.6%)*	**1.** Bamboo	y	Family	1	0.2
Other Plants	**2.** Bramble	y	Genus	1	0.2
Other Plants	**3.** Fern	y	Class	1	0.2
Other Plants	**4.** Grass	y	Family	237	59.1
Other Plants	**5.** Heather	y	Family	1	0.2
Other Plants	**6.** Holly	y	Genus	1	0.2
Other Plants	**7.** Ivy	y	Genus	2	0.5
Other Plants	**8.** Mushroom	y	Kingdom	3	0.7
Other Plants	**9.** Pampas grass	y	Family	1	0.2
Other Plants	**10.** Reeds	y	None	1	0.2
Other Plants	**11.** Rhododendron	y	Genus	1	0.2

Table S4.6. Table showing the numbers and proportions of children's drawings (*n* = 401) that contained at least one representative of each group (see Table S4.5 for a full list of terms and categories).

Group ***(List of categories and extra terms included)***	**No. drawings (*n* = 401) containing at least one mention**	**% drawings containing at least one mention**
Mammal *(incl. all terms in the categories 'Domestic Mammals' and 'Wild Mammals', and the 'General' term 'Mammal')*	323	80.5
Bird *(incl. all terms in the categories 'Garden Birds' and 'Other Birds', and the 'General' term 'Bird')*	275	68.6
Herpetofauna *(incl. all terms in the category 'Herpetofauna')*	63	15.7
Insect *(incl. all terms in the category 'Insects' and the 'General' terms 'Bug' and 'Insect')*	219	54.6
Other invertebrate *(incl. all terms in the category 'Other Invertebrates' and the 'General' terms 'Creepy crawlies' and 'Minibeasts')*	206	51.4
'General' animal term(s) only	11	2.7
Tree *(incl. all terms in the category 'Trees' and the 'General' terms 'Evergreen tree', 'Fruit tree' and 'Tree')*	269	67.1
Flower *(incl. all terms in the category 'Flowers' and the 'General' terms 'Blossom' and 'Flower')*	121	30.2
Crop *(incl. all terms in the category 'Crops' and the 'General' term 'Berries')*	21	5.2
Other plant *(incl. all terms in the category 'Other Plants' and the 'General' terms 'Bush', 'Plant' and 'Weed')*	290	72.3
'General' plant term(s) only	106	26.4

Table S4.7. Table showing results of post-hoc analyses following a significant effect of school type in the parent model. For plant species richness, *p* values are the results of Tukey all-pair comparisons, adjusted via the Bonferroni correction, following a significant effect of school type in the GLMM. State school drawings had higher species richness than private school drawings. For animal community composition, *p* values are the results of pairwise comparisons via an analysis of deviance for the mGLM, adjusted for multiple comparisons via a free step-down resampling procedure. State school drawings contained more terms for invertebrates other than insects, and private school drawings contained more terms for garden birds. Significant *p* values are shown in bold.

Pairwise comparison	**Adjusted *p* value**
Plant species richness	
State—Academy	1
State—Private	**0.00611**
Private—Academy	0.06489
Animal community composition	
State—Academy	**0.005**
State—Private	**0.006**
Private—Academy	**0.006**

Table S4.8. Results of chi-square tests of independence on differences in taxonomic resolution of animal terms in each category by school type.

Category	χ^2	***df***	***p* value**
Domestic mammal	0.052458	2	0.9741
Wild mammal	0.54349	2	0.7621
Garden bird	0.054229	2	0.9732
Other bird	0.25421	2	0.8806
Herpetofauna	0.092517	2	0.9548
Insect	2.8187	2	0.2443
Other invertebrate	NaN	2	NA

Table S4.9. Results of chi-square tests of independence on differences in taxonomic resolution of plant terms in each category by school type.

Category	χ^2	***df***	***p* value**
Tree	0.66349	2	0.7177
Flower	NaN	2	NA
Crop	0.91926	2	0.6315
Other	NaN	2	NA

Chapter Five: Supplementary material

Table S5.1. Table showing details of wildlife documentaries sampled in the study, together with start time of the five-minute sample period within each documentary. All documentaries were identified through the *Internet Movie Database* website (*IMDb*, 2021).

Title	**Year Released**	**Time Period**	**Production Country**	**Anglophone**	**Series**	**Episode**	**Start Time**
Nature's Half Acre	1951	pre-1970s	USA	yes	na	na	00:08:01
Beaver Valley	1950	pre-1970s	USA	yes	na	na	00:22:52
Grand Canyon	1958	pre-1970s	USA	yes	na	na	00:12:18
White Wilderness	1958	pre-1970s	USA	yes	na	na	00:01:57
Water Birds	1952	pre-1970s	USA	yes	na	na	00:12:03
The Struggle for existence	1925	pre-1970s	USA	yes	na	na	00:00:00
The Animal World	1956	pre-1970s	USA	yes	na	na	00:01:03
The Private Life of the Gannets	1934	pre-1970s	UK	yes	na	na	00:03:23
National Geographic: Miss Goodall and the Wild Chimpanzees	1965	pre-1970s	USA	yes	na	na	00:21:29
The Undersea World of Jacques Cousteau: Savage World of the Coral Jungle	1968	pre-1970s	USA	yes	na	na	00:32:53
Mutual of Omaha's Wild Kingdom: El Tigre	1966	pre-1970s	USA	yes	5	10	00:05:45
Le Monde Sans Soleil (World Without Sun)	1964	pre-1970s	France	no	na	na	00:35:45
Jungle Cat	1960	pre-1970s	USA	yes	na	na	00:15:52

National Geographic: Reptiles and Amphibians	1968	pre-1970s	USA	yes	na	na	00:13:29
National Geographic: The Hidden World: A Study of Insects	1966	pre-1970s	USA	yes	na	na	00:08:42
Inner Space: Man Eater	1973	1970s	Australia	yes	1	9	00:04:02
The Hellstrom Chronicle	1971	1970s	USA	yes	na	na	00:45:23
The Living Sands of Namib	1978	1970s	USA	yes	na	na	00:44:53
Wonder of It All	1974	1970s	USA	yes	na	na	00:13:03
Monkeys, Apes & Man	1971	1970s	USA	yes	na	na	00:26:24
Vive la Baleine (Three Cheers for the Whale)	1972	1970s	France	no	na	na	05:42:00
Wildlife on One: Squirrel on my shoulder	1979	1970s	UK	yes	4	1	00:05:23
National Geographic Specials: The Great Mojave Desert	1971	1970s	USA	yes	na	na	00:00:31
Life on Earth: Lords of the Air	1979	1970s	UK	yes	1	8	00:44:53
Obitateli (Inhabitants)	1970	1970s	Soviet Union	no	na	na	00:03:00
Cry of the Wild	1973	1970s	Canada	yes	na	na	00:48:58
National Geographic Specials: Search for the Great Apes, Part 2: Gorillas	1976	1970s	USA	yes	na	na	00:16:08

Wildlife on One: The Private Life of the Barn Owl	1977	1970s	UK	yes	2	1	00:18:01
The Lion Who Thought He Was People	1971	1970s	UK	yes	na	na	00:25:04
Blue Water, White Death	1971	1970s	USA	yes	na	na	00:26:58
Animal Olympians	1980	1980s	UK	yes	na	na	00:20:37
Natural World: The Coral Triangle	1988	1980s	UK	yes	7	10	00:01:25
Lost Worlds, Vanished Lives: The Rare Glimpses	1989	1980s	UK	yes	1	4	00:26:32
Lions of the African Night	1987	1980s	USA	yes	na	na	00:29:34
Among the Wild Chimpanzees	1984	1980s	USA	yes	na	na	00:47:38
Cane Toads: An Unnatural History	1988	1980s	Australia	yes	na	na	00:39:30
Beavers	1988	1980s	USA	yes	na	na	00:06:17
Wild America: The Beauty of Butterflies	1982	1980s	USA	yes	1	2	00:11:54
Wildlife on One: The Ravening Hordes	1988	1980s	UK	yes	16	5	00:16:53
National Geographic Specials: The Sharks	1982	1980s	USA	yes	na	na	00:48:58
Wildlife on One: Blubber Lovers	1989	1980s	UK	yes	17	1	00:07:31
Rivers to the Sea	1989	1980s	Canada	yes	na	na	00:19:25
Silent Hunter	1988	1980s	South Africa	yes	na	na	00:11:57
National Geographic: White Wolf	1986	1980s	USA	yes	na	na	00:30:53

Realm of the Alligator	1986	1980s	USA	yes	na	na	00:42:18
Natural World: The Millenium Oak	1999	1990s	UK	yes	18	5	00:20
The dragons of Galapagos	1998	1990s	USA	yes	na	na	00:30:51
Natural World: New Guinea an Island Apart: Other Worlds	1992	1990s	UK	yes	10	10	00:36:51
Whales: An Unforgettable Journey	1997	1990s	USA	yes	na	na	00:33:41
Mountain Rivals	1999	1990s	Netherlands	no	na	na	00:03:42
Wildlife on One: March of the Flamebirds	1993	1990s	UK	yes	20	1	00:17:14
Wolves at our Door	1997	1990s	USA	yes	na	na	00:09:45
Odyssey of Life: The Unknown World	1996	1990s	Sweden	no	na	na	00:06:47
Realms of the Russian Bear: Born of Fire	1992	1990s	UK	yes	1	6	00:35:26
The Greatest Places	1998	1990s	USA	yes	na	na	00:31:13
Walking with Dinosaurs: Spirit of the Ice Forest	1999	1990s	UK	yes	1	5	00:02:19
National Geographic Specials: Seasons of the Salmon	1998	1990s	USA	yes	na	na	00:03:26
The Trials of Life: Fighting	1990	1990s	UK	yes	1	8	00:12:23
Galapagos	1999	1990s	USA	yes	na	na	00:25:48
Before It's Too Late: From the	1994	1990s	Australia	yes	na	na	00:38:26

Brink of Eternity							
Uncovering Our Earliest Ancestor: The Link	2009	2000s	UK	yes	na	na	00:16:33
With Beak and Claw	2002	2000s	Poland	no	na	na	00:21:29
Chased by Dinosaurs: The Giant Claw	2002	2000s	UK	yes	1	1	00:07:02
The National Parks: America's Best Idea: Great Nature	2009	2000s	USA	yes	1	5	01:28:53
Wolves of the Rockies	2008	2000s	USA	yes	na	na	00:03:26
Before It's Too Late: Papua New Guinea Land of the Unexpected	2004	2000s	USA	yes	na	na	00:08:53
Natural World: The Falls of Iguacu	2006	2000s	UK	yes	25	5	00:13:04
Life in Cold Blood: Sophisticated Serpents	2008	2000s	UK	yes	1	5	00:18:32
Trek: Spy on the Wildebeest	2007	2000s	UK	yes	1	1	00:44:23
Meerkat Manor: The Story Begins	2008	2000s	USA	yes	na	na	00:51:43
Bob, Huey and Me	2008	2000s	USA	yes	na	na	00:18:04
Jane Goodall's Wild Chimpanzees	2002	2000s	USA	yes	na	na	00:21:59
National Geographic Specials: Whales in Crisis	2004	2000s	USA	yes	na	na	00:05:40

The Last Mahout	2008	2000s	Australia	yes	na	na	00:12:42
Lions Behaving Badly	2005	2000s	South Africa	yes	na	na	00:14:17
This American Land	2013	2010s	USA	yes	1	3	00:02:54
Rhythms of Nature in the Berycz Valley	2011	2010s	Poland	no	na	na	00:18:08
Natural World: Living with Baboons	2012	2010s	UK	yes	31	1	00:30:31
Wild Arabia	2013	2010s	UK	yes	1	1	00:30:14
The Great British Year: Summer	2013	2010s	UK	yes	1	3	00:42:20
Nature and Life	2018	2010s	Bangladesh	no	1	280	00:15:51
Life Story	2014	2010s	UK	yes	1	1	00:10:48
The Hunt	2015	2010s	UK	yes	1	3	00:35:03
Natural World: France the Wild Side	2014	2010s	UK	yes	33	3	00:24:08
Off the Trail: The Birds and Bees of Spring	2015	2010s	USA	yes	1	2	00:04:43
Pounding Hooves	2015	2010s	UK	yes	na	na	00:01:49
Coral Gardening	2015	2010s	Philippines	yes	na	na	00:11:13
Cantábrico	2017	2010s	Spain	no	na	na	00:14:53
Animals with Cameras	2018	2010s	UK	yes	1	1	00:23:52
Great Bear Rainforest	2019	2010s	USA	yes	na	na	00:31:00
Earth's Tropical Islands	2020	2020s	UK	yes	1	1	00:28:47
Night on Earth	2020	2020s	UK	yes	1	5	00:17:43
To the Ends of the Earth: Birds of East Africa	2020	2020s	USA	yes	na	na	00:02:54
Die Rückkehr der Wildkatze	2020	2020s	Germany	no	na	na	00:24:00

Work on the Wild Side	2020	2020s	UK	yes	1	17	00:39:21
David Attenborough: A Life on Our Planet	2020	2020s	UK	yes	na	na	01:12:25
Whales in a Changing Ocean	2021	2020s	New Zealand	yes	na	na	00:09:25
Cheetah Family & Me	2021	2020s	UK	yes	1	1	00:22:07
Arctic Vets	2020	2020s	Canada	yes	1	1	00:16:03
The Heart of the Elephant	2020	2020s	South Africa	yes	na	na	00:43:41
America's Wild Border	2020	2020s	Canada	yes	na	na	00:06:36
My Octopus Teacher	2020	2020s	South Africa	yes	na	na	00:53:42
Waterhole: Africa's Animal Oasis	2020	2020s	UK	yes	1	2	00:37:06
Earth at Night in Color: Jaguar Jungle	2020	2020s	USA	yes	1	3	00:03:58
Cher and the Loneliest Elephant	2021	2020s	Pakistan	yes	na	na	00:50:46

Chapter Six: Supplementary material

Appendix S6.1. Statements and scale taken from Marteau & Bekker, 1992, 'The development of a six-item short-form of the state scale of the Spielberger State-Trait Anxiety Inventory (STAI)', *British Journal of Clinical Psychology*, 31:301-306, DOI: 10.1111/j.2044-8260.1992.tb00997.x. Date accessed 18/12/2016.

Pre- and post-walk questionnaires

Class:______________

Register number:________________

Location of walk (Circle the correct one): School Corridor/Athletics Track/Orchard

Date:______________

Age:_______________

Number of caffeinated drinks (Coffee, tea, Coca Cola, Red Bull etc.) drunk today, if any:__

Number of hours' sleep last night:_______________

Pre-Walk Questionnaire

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the most appropriate number to the right of the statement to indicate **how you feel right now, at this moment.**

There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

		1	**2**	**3**	**4**
		Not at all	**Somewhat**	**Moderately**	**Very much**
a)	I feel calm	1	2	3	4
b)	I am tense	1	2	3	4
c)	I feel upset	1	2	3	4
d)	I am relaxed	1	2	3	4
e)	I feel content	1	2	3	4
f)	I am worried	1	2	3	4

Pre-Walk Pulse Rate

Take your pulse rate using the finger-tip monitor.
Take three readings and write all three readings below. Then, calculate the average of your three readings.

Pulse rate (Beats/minute):

Reading 1: **Reading 2:** **Reading 3:** **Average:**

Now that you have come back from your walk, rest for five minutes and then fill in the following information.

Post-Walk Questionnaire

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the most appropriate number to the right of the statement to indicate **how you feel right now, at this moment.**

There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

		1	**2**	**3**	**4**
		Not at all	**Somewhat**	**Moderately**	**Very much**
a)	I feel calm	1	2	3	4
b)	I am tense	1	2	3	4
c)	I feel upset	1	2	3	4
d)	I am relaxed	1	2	3	4
e)	I feel content	1	2	3	4
f)	I am worried	1	2	3	4

<u>Post-Walk Pulse Rate</u>

Take your pulse rate using the finger-tip monitor.
Take three readings and write all three readings below. Then, calculate the average of your three readings.

Pulse rate (Beats/minute):

Reading 1: **Reading 2:** **Reading 3:** **Average:**

<u>Spend 2 minutes drawing a picture of yourself on your walk:</u>

Appendix S6.2. Letter with information sent to parents and guardians of school students.

Simon Langton Girls' Grammar School

UNIVERSITY OF CAMBRIDGE
Department of Zoology

Department of Biology
Simon Langton Girls' Grammar School
Old Dover Road
Canterbury
Kent
CT1 3EW

Study title: **The relationship between exposure to biodiversity and children's wellbeing**

Participant Information

Before you decide to give permission for your child to take part in this study, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please contact Sam Goodfellow [redacted] if there is anything that is not clear or if you would like more information. Please take time to decide whether or not you wish to take part.

What is the research about?

We are investigating the effects of green space on children's wellbeing. We are interested in whether exposure to nature affects children's pulse rate or level of anxiety. This study is being carried out as a result of a Partnership Grant awarded to the School by the Royal Society, and it is conducted in partnership with researchers at the University of Cambridge.

Why have I been asked to participate?

We hope to collect responses from as many children at School as possible, so individuals have not been selected on any particular basis.

What does the study entail?

After giving consent for your child to take part, your child will be asked to go for a short, 300m walk within the school grounds. Before and after going on their walk, they will be asked to fill in in a short questionnaire asking them how they are feeling and to record their pulse rate via a finger-tip monitor. The pre- and post-walk questionnaires will then be collected in by their teacher and the change in mental wellbeing and pulse rate will be calculated.

The School's safeguarding lead has been made aware of the study in case there are extreme responses on the anxiety questionnaire, or in case the questionnaire is 'triggering' for a child. In either case, the safeguarding lead will be informed and consulted on the best course of action for the individual child. Most likely, a conversation between the child and the safeguarding lead will be had around the subject matter within the questionnaire.

Will participation be confidential?

Yes. All information collected will remain strictly confidential and will not be shared beyond the research team. Data will be linked to each child an anonymous code, the details of which will be stored in a password-protected file, accessible only by the immediate research team. This is solely for the purposes of being able to withdraw an individual's data from the study at a later date if either they or their parent or guardian wishes to do so.

General guidance on how the University of Cambridge uses personal data can be found at https://www.information-compliance.admin.cam.ac.uk/data-protection/research-participant-data.

Your child will not be identified in any report or publication. Results will be presented at conferences and written up in peer-reviewed journal papers. Results will usually be presented in terms of groups of individuals. If data from any individual are presented, the data will be totally anonymous, without any means of identifying the individual(s) involved.

What happens if I change my mind?

Taking part is entirely voluntary, and refusal or withdrawal will involve no penalty or loss, either now or at any point in the future. You are free to contact the research team at [redacted] to withdraw your consent at any point in the future, up until three months after taking part.

This research is funded by the Royal Society via a Partnership Grant, and the study protocol has been reviewed by the Psychology Research Ethics Committee of the University of Cambridge.

Consent Form

Please tick each box below to acknowledge that you have read, understood and agreed to the following statements, then sign and date below.

☐ I confirm that I have read and understood the Participant Information.

☐ I understand that I can contact the research team via [redacted] at any point to ask for more information.

☐ I understand that all information collected will remain confidential and that all efforts will be made to ensure my child cannot be identified.

☐ I agree that data gathered in this study may be stored anonymously and securely and may be used for future research.

☐ I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason, up until three months after taking part, by contacting [redacted]

☐ I give permission for my child to take part.

Name: ________________________________

Signed: ________________________________

Date:_____________