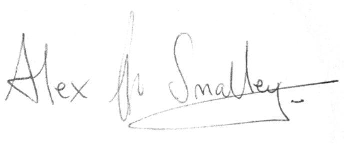
Optimising digital nature for wellbeing

Submitted by Alexander Smalley to the University of Exeter, as a thesis for the degree of Doctor of Philosophy in Medical Studies, September 2023.

I certify that all material in this thesis which is not my own work has been identified and that any material that has previously been submitted and approved for the award of a degree by this or any other university has been acknowledged.



20th September 2023

A brief word on pronouns

This thesis and the research it contains have been conducted and written by Alex Smalley. Yet throughout I will make regular use of the pronouns "*we*" and "*our*" (Pennebaker, 2011). In line with use of the 'editorial we' (Wiktionary, 2023), this inclusive language reflects the fact that whilst I have been the principal architect of each component of every study, I have also worked closely with a diverse range of partners, supervisors, and other academics. Given this deeply collaborative approach, it would not be accurate nor appropriate to, for example, refer to "*my findings*" rather than "*our findings*". Regular use of "*we*" and "*our*" also aims to avoid continual transitioning between singular and plural first-person pronouns. The reader should assume that unless specified, all work and opinions are solely my own. At the end of each (peer-reviewed and published) experimental chapter, a CRediT author statement will identify how different facets of individual projects were assigned (Elsevier, 2023).

Abstract

The global burdens of negative psychological states such as stress, anxiety, and burnout represent a growing public health concern. As the incidence of these conditions has risen so too has awareness that natural environments might provide cognitive and affective benefits.

Yet unrelenting urbanisation, unprecedented species extinction, and rampant ecological degradation are fostering a creeping extinction of experience, straining the links between people and planet. In an increasingly technologically mediated world, growing emphasis is being placed on how digital forms of nature could impact health.

Understanding how simulated contact with the natural world might be optimised for positive wellbeing outcomes is vital if 'virtual nature' is to be used as a therapeutic tool. This thesis consists of three original studies – conducted with large samples and as part of national broadcast initiatives – that aimed to address this burgeoning need.

We first investigated nuances in the way natural soundscapes are experienced. Through an award-winning collaboration with the BBC Natural History Unit, a novel podcast series and experiment generated responses from 7,596 participants. Results indicated how the composition of nature-based soundscapes can affect their restorative potential, demonstrated the crucial role that memories play in these relationships, and suggested that appraisals of restoration can exert an important mediating effect on pro-environmental behaviour.

Next, a similar level of granularity was applied to landscape aesthetics. An online experiment probed how ephemeral features such as sunrise, sunsets, and storms can impact appraisals of virtual environments. Data from 2,509 people supported the familiar urban-nature dichotomy yet revealed substantial momentary and diurnal heterogeneity in measures of beauty and awe. Changes in these metrics also partially mediated participants' willingness to pay to visit these locations in the 'real world'.

Partnering again with the BBC on a multi-platform broadcast initiative called *Soundscapes for Wellbeing*, our third experiment assessed how the visual and acoustic elements of a digital nature experience, including music, might influence viewer emotions. Analyses from 7,636 respondents suggested that whilst music could enhance high arousal feelings such as excitement, natural sounds were integral to eliciting restoration, calmness, awe, and nostalgia. Again, these data revealed a substantial moderating effect of memories, underlining the importance of lived experiences in determining outcomes.

Taken together, these findings reveal important distinctions in the way natural soundscapes are perceived, demonstrate the potential for both ephemeral features and natural sounds to elicit the complex emotions of awe and nostalgia, and highlight the profound moderating effects of personal memories. Future work might focus on expanding understanding of how awe, nostalgia, and memories could represent a hitherto under-recognised depth to the therapeutic potential of encounters with nature in both virtual and real settings.

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Appendix C
Supplementary information for study three, detailed in chapter seven, and published in the *Journal of Environmental Psychology*, https://doi.org/10.1016/j.jenvp.2023.102060.

Data availability
The full dataset for study one (chapter 5) is available on the Open Science Framework at https://osf.io/p3gty.

The full dataset for study two (chapter 6) is available on the Open Science Framework at https://osf.io/d9gc5.

The full dataset for study three (chapter 7) is available on the Open Science Framework at https://osf.io/f3jqb.

Definitions
The terms 'digital' and 'virtual' have been used interchangeably in the extant literature to describe nature portrayed through traditional mediums of picture and video (McAllister et al., 2017), fixed content displayed through virtual reality headsets (Browning et al., 2020a), as well as fully immersive, interactive content (Yeo et al., 2020). This thesis will follow this trend, using 'digital' and 'virtual' as synonymous terms for any digitally mediated experience, with more explicit details (such as 'virtual *reality*') provided where necessary.

Author's declaration

All research presented in this thesis is the author's own work; Alex Smalley has written all chapters of this thesis.

Comments were given by primary supervisors, Dr Mathew White and Prof Lora Fleming. Where other people's data have been used, or advice has been sought, it has been acknowledged in the text.

Chapter 5 details the peer-reviewed study, *Forest 404: Using a BBC drama series to explore the impact of nature's changing soundscapes on human wellbeing and behavior,* published in the journal *Global Environmental Change* doi.org/10.1016/j.gloenvcha.2022.102497.

Alex Smalley was the lead author of this paper, responsible for conceptualization, methodological development, statistical investigation, visualization of results, and paper writing. A CRediT statement at the end of the chapter details co-author contributions.

Chapter 6 details the peer-reviewed study, *Beyond blue-sky thinking: Diurnal patterns and ephemeral meteorological phenomena impact appraisals of beauty, awe, and value in urban and natural landscapes*, published in the *Journal of Environmental Psychology* doi.org/10.1016/j.jenvp.2023.101955.

Alex Smalley was the lead author of this paper, responsible for conceptualization, methodological development, statistical investigation, visualization of results, and paper writing. A CRediT statement at the end of the chapter details co-author contributions.

Chapter 7 details the peer-reviewed study, *Soundscapes, music, and memories: Exploring the factors that influence emotional responses to virtual nature content*, published in the *Journal of Environmental Psychology* doi.org/10.1016/j.jenvp.2023.102060.

Alex Smalley was the lead author of this paper, responsible for conceptualization, methodological development, statistical investigation, visualization of results, and paper writing. A CRediT statement at the end of the chapter details co-author contributions.

Acknowledgements

This PhD has unfolded over five years, two of which represented the upending of our social fabric due to a global pandemic. Much has changed at a personal, political, and institutional level during this time, but the one consistent thread has been this research project.

It has represented polar extremes in many ways, at times being both deeply fulfilling and frustrating, collaborative yet isolating, fast-paced and seemingly never-ending. Several teams contributed to specific research areas, bringing together individuals that were incredibly creative, pragmatic, and united by a singular passion to widen participation in nature-based experiences. Beyond the PhD itself, the colliding of academic and creative worlds has resulted in several shifts in individual directions; three BBC colleagues have gone on to study master's degrees following our research partnerships.

A significant debt is owed to the Wellcome Centre for Cultures and Environments of Health, which both financially and morally supported this research through an unprecedentedly turbulent period. A constantly shifting supervisory team – four supervisors have left the university during the study period – was balanced by the understanding and support of the Wellcome team. Likewise, vital support, advice, and inspiration was provided by friends and colleagues at the European Centre for Environment and Human Health, without whom this PhD would never have started, and certainly would not have been completed.

Similar gratitude must be extended to each of the supervisors, project partners, and organisations who have contributed to this thesis, a roll call of whom is presented below.

But the greatest thanks must be reserved for this PhD's primary supervisors, Dr Mathew White and Prof Lora Fleming. Their support and invaluable guidance have not just been unwavering but transformative, leading to personal and professional growth that has shaped this research, and the many journeys it has encapsulated, in profound ways.
Thank you, Mat and Lora.

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Supervisors

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Project partners

BBC Natural History Unit, BBC Radio Four, BBC Sounds, BBC Radio 3, BBC 6 Music, BBC Winterwatch, BBC Music, BBC Archive Editorial, BBC Research & Development, University of Bristol, The Open University.

1. Introduction

Poor psychological health represents a substantial challenge to populations across the world (Arias et al., 2022). Protecting and nurturing mental wellbeing over the life course has thus been identified as a key component of UK government strategies (UK Government, 2022a).

Positive emotional states and the notion of 'mental capital' are central to these goals, with the latter broadly defined as "*...a person's cognitive and emotional resources [including] their cognitive ability, how flexible and efficient they are at learning, and their…resilience in the face of stress*" (Beddington et al., 2008).

Yet mental capital and its related outcome, 'mental wellbeing' (GO-Science, 2008), are under significant pressure: 17 million working days were lost to stress, depression, or anxiety in Great Britain in 2021/22 (Health and Safety Executive, 2022); and three quarters of UK adults reported feeling overwhelmed by stress at least once in 2018 (Mental Health Foundation, 2018).

Whilst mental health showed signs of a deteriorating trend in the years up to 2020, the onset of the coronavirus pandemic triggered a sudden and substantial decrease in population wellbeing (Daly et al., 2022; Pierce et al., 2020; UK Government, 2022b). Work-related stress increased (Health and Safety Executive, 2022), depression, loneliness, and anxiety in older adults rose (Zaninotto et al., 2021), and mental health declined in young people across numerous metrics (NHS Digital, 2021). According to several indicators, women, those from lower socioeconomic groups, and people with pre-existing mental health conditions reported the greatest falls in wellbeing outcomes (O'Connor et al., 2021; ONS, 2021) exacerbating existing inequalities in health (The Health Foundation, 2022).

Consequently, advancing understanding of the factors and interventions that might support mental wellbeing has never been more crucial (Holmes et al., 2020). The fertility of this research area is embodied by myriad studies exploring a broad range of approaches to varying outcomes (van Agteren et al., 2021): from cognitive behavioural therapy designed to alleviate anxiety and depression (Rezvan et al., 2008; Zhang et al., 2016); to mindfulness exercises aiming to improve stress resilience, subjective wellbeing, and attention (Bhayee et al., 2016; Galante et al., 2018).

Exposure to natural environments has emerged from these efforts as a viable pathway to improved psychological outcomes (Bratman et al., 2012), particularly those that are relevant to public health (Frumkin et al., 2017). Yet this recognition has blossomed at a time when anthropogenic actions are leading to unprecedented environmental degradation (Travis, 2003), humanity's connection to nature is faltering (Soga & Gaston, 2016), and many socio-cultural interactions are increasingly mediated by digital technologies (Levin & Mamlok, 2021).

This is the context within which this thesis is situated. Over three large-scale studies we explored the nexus between natural environments, digital mediation, wellbeing outcomes, and engagement with nature. This programme of research initially intended to focus on virtual reality (VR) as its delivery mechanism. But the emergence of Covid-19 and its effects on face-to-face contact forced a revised approach. Far from leading to impoverished experimental implementations, refocusing on the *design* of digital content rather than the *delivery* allowed us to explore creative and engaged approaches to data collection. By working collaboratively with national broadcasters and experts in the fields of natural history, diverse audiences were involved in the debates surrounding nature and health.

This thesis will first provide a background to the field of nature and wellbeing, highlighting the ways in which therapeutic experiences of nature have been approached, exploring the role that digital encounters might play in these contexts, and identifying areas that have, thus far, been overlooked. Individual studies will then be presented, in their published format, before a general discussion reflects on the overarching implications of this research as a whole and suggests directions for future work.

1.1 A brief word on negative contact with nature

Natural environments have long been associated with hazards and detrimental effects on health (Smith, 2013b). Natural disasters, harmful algal blooms, and severe (often anthropogenic) pollution are among the events that, through much of the 20th century, have framed natural environments as places of *risk* (Galambos, 2005; Grattan et al., 2016; Schwarzenbach et al., 2010). Yet whilst we must recognise the potential for people-nature interactions to result in negative outcomes, from maladies as diverse as microbial infections, animal attacks, allergic reactions, phobias, and mountain falls (Leonard et al., 2015; Soga & Gaston, 2022), interventions seeking to enhance relationships with the natural world overwhelmingly focus on facilitating positive experiences (e.g. Child, 2021; Richardson et al., 2021; Ward Thompson et al., 2008). This PhD builds upon this corpus of work, exploring the beneficial effects of constructive contact with nature, rather than effects arising from negative interactions.

1.2 Aims and objectives

This thesis had several aims and objectives. Specifically, it aimed to:

- Investigate the overlooked factors that might determine how digital forms of nature can impact people's wellbeing.
- Develop collaborative, creative, and engaged methods of enquiry that both stimulate debate and gather large, heterogeneous datasets.
- Extend digital findings to real world settings, where possible.
- Publish outcomes in peer-reviewed journals and in an accessible format in mainstream media.

These aims were achieved by fulfilling the following objectives:

- Reviewing the existing literature on the relationships between nature and wellbeing.
- Identifying the overlooked areas of nature experience, particularly those that might apply to digital experiences.
- Forming creative alliances with transdisciplinary teams and broadcasters to explore how these areas might relate to their practices.
- Co-developing projects that fused academic investigations with national, creative, content production to systematically investigate the factors that might influence the restorative and affective outcomes from digital forms of nature.
- Putting the findings resulting from these collaborations directly into practice via evidence-based programme design.

1.3 Partnerships

Although a broad research focus was determined at the outset of this PhD, specific research questions were developed as part of an engaged, co-created process. Collaborative approaches to research and development created a snowball effect, catalysing the exploration of areas with specific relevance to the creative partners involved.

Whilst the BBC was not an official partner on the project, their input has substantially helped to define its research and impact: an emerging relationship with the BBC Natural History Unit led to the creation of study one, which was innately intertwined with BBC Radio 4's *Forest 404* podcast series; creative and editorial discussions concerning ephemeral features in nature were left unresolved as part of the development of *Forest 404*, and directly informed the evolution of study two; the partnerships forged during these collaborations led to the BBC Four series *Mindful Escapes*, which in turn created editorial questions regarding the pairing of nature and music; we sought to address this lacuna in study three, which was embedded in *Soundscapes for Wellbeing*, a multi-partner arts and science endeavour led by BBC Music.

Thus, a focus on natural sounds, ephemeral features, and music was as much driven by creative and commercial imperatives, as it was the need to address overlooked areas in the academic literature. Comprehensive details of how each study led to the next are provided in chapter 4.

2. Literature review

Before beginning, we must first reflect on the different approaches that exist to tackle ill-health. For example, 'Western' medicine adopts practices that compartmentalise disease, leverage scientific approaches and technological advances, and commonly treat environment and body as separate entities (Silvano, 2021). In contrast, 'Eastern' medicine, and traditional Chinese medicine in particular, relies on ancient records, traditional practices, and considers body and environment to be spiritually intertwined (Chan et al., 2002; Tian, 2011). Although these approaches began to tentatively overlap several decades ago (Tseui, 1978), much of the literature focused on people-nature-health interactions and outcomes has been grounded in Western theories. This research is situated within a Western framework, yet it must be acknowledged that this is just one possible approach to understanding the ways in which natural environments can impact health and wellbeing.

This review begins by first defining some key terms, before then exploring the proposed mechanisms underpinning relationships between nature and psychological wellbeing. Next, three key areas of environmental experience are explored: natural sounds, ephemeral phenomena, and the intersection between nature and music. The possible effects of moderating variables such as memories are then outlined, and finally, research questions arising from lacunas in the existing literature are specified.

2.1 Defining 'health'

How do we define 'health' and 'wellbeing'? In a literal sense, adequate health may be considered a 'neutral' homeostatic state, in which the body is free from disease and functioning routinely – whereas wellbeing implies a more holistic and positive set of outcomes (Faculty of Public Health, 2023; WHO, 1986).

Wellbeing can further be segmented into 'objective' wellbeing, based on a set of economic and welfare indicators, and 'subjective' wellbeing, usually captured through statements that assess levels of cognitive, hedonic, and emotional satisfaction with life (Angner, 2010). Subjective wellbeing has been much debated – see (Angner, 2010) for a thorough review – and in some cases may be equated with happiness, with researchers simply asking "*Taking all things together, how happy are you?*" (Layard, 2010).

Yet in practice, many studies and organisations use phrases such as 'health', 'mental health', and 'wellbeing' interchangeably (Mind, 2023; New Economics Foundation, 2011; NHS, 2022, 2023).

In nature and health research specifically, Herchet et al. (2022) referenced the World Health Organisation (2023) in their recognition that good health is not simply determined by a lack of disease, but also "*a state of complete physical, mental and social well-being*" and factors that "*promote health in a holistic manner.*"

In a comprehensive review of the relationship between nature and health, Frumkin et al. (2017) applied a similarly broad interpretation that included outcomes such as 'physical health', 'mental wellbeing', and 'happiness'. Whilst Bratman et al. (2012) considered 'mental health' (or 'psychological wellbeing'), specifically focusing on "*cognitive capacities (including attention, memory, and impulse inhibition), emotional states (mood), and stress.*"

To avoid possible confusion between terms, this review will focus on 'mental wellbeing'. Under this umbrella it will predominantly consider factors that might contribute to a positive psychological state, among them restoration from cognitive fatigue and the promotion of positive emotions. (Use of the term 'wellness' and its various incarnations will be avoided, see (Kirkland, 2014).)

2.2 Defining 'nature'

Used interchangeably and synonymously, the terms 'nature' and 'natural environment' tend to follow broad definitions within wellbeing research that encompass a wide range of natural elements (Hartig et al., 2014). For example, Kaplan and Kaplan (1989) recognise that "*Nature connotes many settings*" and their use of the word is "*intended to be broad and inclusive*". Considering the range of places that might feature nature, they refer to "*parks and open spaces, meadows and abandoned fields, street trees and backyard gardens…places near and far, common and unusual, managed and unkempt, big, small and in between, where plants grow by human design or even despite it.*"

Whilst terms such as 'green space' (Conedera et al., 2015; POST, 2016) and 'blue space' (White et al., 2020b) denote a more specific focus on environments with certain characteristics, 'nature' and 'natural environment' are often intentionally used as inclusive umbrella terms in policy contexts; the UK government's Monitor of Engagement with the Natural Environment study (MENE, 2019) describes natural environments as "*all green, blue and open spaces in and around towns and cities as well as the wider countryside and coastline*".

These definitions include urban and built areas, recognising the existence of a spectrum in what might constitute a 'natural' setting. There is slightly less consensus on the addition of fauna to these descriptions, yet animals and their behaviour can play a central role in experiences of nature (Bell, 2019; White et al., 2017b). Acknowledging this, Hartig et al. (2014) and Frumkin et al. (2017) add flora and fauna to their criteria, with the latter also specifically mentioning scenic qualities. It is this comprehensive definition that will be used in this research, considering nature as:

"*Areas containing elements of living systems that include plants and nonhuman animals across a range of scales and degrees of human management, from a small urban park through to relatively 'pristine wilderness'...together with abiotic elements such as sunset or mountain views*."

Beyond the geographical, structural, and organic features of nature, a similar spectrum exists to describe the ways in which humans can experience natural environments. Types of contact have been viewed as a continuum from passive to active, with simply viewing an image of nature at one end of this scale and actively engaging with an environment – through gardening for example – at the other (Irvine & Warber, 2002). Others have considered the effects of more intimate and immersive forms of direct contact, through activities such as barefoot walking and swimming (Foley, 2015; Rickard & White, 2021).

Whilst useful, this two-dimensional hierarchy can be enhanced by considering the element of intent; people may choose to directly engage with nature by taking a walk through a forest, or might experience nature incidentally, by travelling along a river on their commute to work (Pretty, 2004). Creating a typology of experiences, Keniger et al. (2013) embraced this notion of purpose by categorising interactions with nature as 'indirect', 'incidental', and 'intentional'. However, by collapsing all indirect exposure into a single group, this model overlooks the agency involved in indirect encounters. For instance, many people may choose to watch a nature documentary on the television at home, making this form of exposure both *indirect* and *intentional*.

When 9.2 million people – 7% of the UK population (ONS, 2017) – tuned into the first episode of the BBC's Planet Earth II series (The Guardian, 2016), they were experiencing nature through this kind of intentional, indirect, and digital medium. Digital experiences of nature then, might represent an important way that people engage with the natural world. Following Spangenberger et al. (2022) we can thus add "*...images of nature in the form of videos, films*" to our definition of nature. This thesis is largely concerned with encounters that fit this indirect, digital, yet intentional description.

2.3 Digital experiences

Delineating nature-based contact according to exposure type can help to enhance the specificity of research findings (Browning et al., 2020b). Yet there is also significant overlap between responses to digital forms of nature and those based on physical, in situ encounters.

For example, both VR and real-life experiences of lakeside environments have proven comparable, with participants reporting similar affective responses following each exposure type (Chirico & Gaggioli, 2019; Newman et al., 2022). Indoor biophilic environments can also trigger analogous physiological and cognitive responses, whether experienced in VR or in reality (Mostajeran et al., 2023; Yin et al., 2018).

The assumption of this 'experimental isomorphism' has underpinned many studies that use simulated forms of nature, providing researchers with a proxy to equate findings observed in the lab with those arising in real-world scenarios (Kjellgren & Buhrkall, 2010), and facilitating experimental manipulations that would be untenable through direct encounters (e.g. Kuper, 2018). Indeed, recent reviews identified 185 published research articles that demonstrated how simulated forms of nature can impact factors associated with psychological and physiological recovery from stress and cognitive fatigue (Browning et al., 2020b; Jo et al., 2019).

Yet there is also evidence to suggest that digital surrogates may form a poor simulacrum for experiencing the real, unfettered, natural world (Huang, 2009). A meta-analysis of 32 studies focusing on affective responses to natural environments, suggested larger effect sizes in groups directly exposed to natural environments ($r = 0.37$) compared to those experiencing simulated nature ($r = 0.26$) (McMahan & Estes, 2015). An even starker picture was painted by Browning et al. (2020c), who reviewed six diverse types of simulation and found that actual nature-based settings led to increases in positive affect, whilst exposure to their digital equivalents did not. Similarly, a review of 21 quantitative studies suggested that immersion in VR nature delivered conflicting and inconsistent effects on psychological and physiological indices of wellbeing (Frost et al., 2022).

Recognition of the possible deficiencies of virtual nature have emerged at a time when people's daily experiences are becoming increasingly digitally mediated. These trends have led to concerns about the ways in which virtual environments might relate to real nature, with some fearing that simulated experiences could diminish the importance of *in situ* encounters and the protection of natural habitats (Levi & Kocher, 1999). These debates overlap with those centred on people's expectations of what nature 'should' look, sound, and feel like: whether it is appropriate to provide a *son et lumière* as in the case of Niagara Falls, or whether for many, 'plastic trees' might be just as acceptable as the real thing (Krieger, 1973).

Indeed, it is easy to see how experiments that digitally enhance biodiversity to promote wellbeing outcomes may stoke fears that degraded environments could one day be 'replaced' by virtual proxies (Cerwén, 2016; Ferraro et al., 2020). Some have even posited that for successive generations, simulated nature may gradually become the norm, leading to a shifting baseline (Pauly, 1995) for what is considered a 'normal' nature experience and an acceptance of subsequently impoverished wellbeing outcomes (Kahn et al., 2008).

However, these conversations overlook the possibility that digital experiences may be most appropriately viewed as a unique form of contact. For example, in their investigation of how natural soundscapes can relate to wellbeing, Bates et al. (2020) adopted the position that in situ sounds and field recordings should *not* be compared. Following in depth interviews with participants, they also suggested that digitally mediated encounters "*should be judged on their own terms, rather than simply dismissed as inauthentic or 'lesser than' the real experience of being outdoors.*"

This approach aligns with that taken by the emerging field of digital ecology, where remote and digitally enabled experiences with nature are viewed as a distinct set of human-nature interactions. For example, 'webcam-travel' blossomed during the Covid-19 pandemic yet represented a very different mode of tourism compared to physical visits (Jarratt, 2021). The resurgence of peregrine falcons in British cities has stimulated the rise of internet-based 'nest cams' and a human-animal relationship with what Searle et al. (2022) referred to as the 'digital peregrine' – a distinct incarnation of their *in vivo* selves. Turnbull et al. (2020) considered the 'liveness' of this form of access as unique, since interactions with animals in the real world rarely take on this level of intimacy. Essen et al. suggested (2021) that wild animals and their digital personas can become entangled, creating encounters that are "*more-than-real*".

In other particularly abstract examples, Spangenberger et al. (2022) used immersive techniques to enable participants to digitally embody and empathise with a tree, whilst Forestry Commission England's immersive installation *In the eyes of the animal* gave users a first person perspective as a dragonfly, owl, and frog (Marshmallow Laser Feast, 2023).

In each of these cases, it is clear that people's digitally-enabled engagement is intimately, sensorily, and creatively different to a typical nature-based encounter (such as simply walking through a forest) and so may reasonably be considered a different type of experience altogether.

This research takes a pragmatic approach to accommodating these contrasting perspectives. Across each study, digital stimuli have been used to prompt emotional responses in participants. In some cases, we asked participants to consider the digital experience itself, in others we asked them to reflect on how a digital stimulus might relate to *in situ* experiences. Findings are related to both interwoven typologies of contact, and implications explored for simulated and real-world interactions. Where appropriate, the limitations of these comparisons are acknowledged.

2.4 Nature and health in history

The potential for natural landscapes to refresh and restore the human constitution has deep roots in global culture. From the Quran and Bible, to Mesopotamian temples and the Hanging Gardens of Babylon, lush and vegetated environments have been seen as vital to human health and wellbeing for millennia. The Greek philosopher Hippocrates extolled the health benefits of a change of environment, which was to include "*bathing, perspiration, walking, and massages*" whilst the Romans took advantage of the therapeutic benefits of spas connected to thermal springs (Robinson & Breed, 2019b). In the UK, monastic traditions carried the idea of the healing garden into the common era, and the landscape garden, picturesque, and pastoral movements ensured these notions survived the industrial revolution (Ward Thompson, 2011).

More recently, the influence of 19th century naturalists, such as Aldo Leopold and John Muir, stimulated a cultural movement that saw Western societies embracing the increasingly safe and desirable idea of 'wilderness', driven by a "*natural inherited wildness in our blood*" (Worster, 2005). Muir recognised the ability of nature to "*give strength to the body and the soul*" (McMahan & Estes, 2015), and the emerging field of landscape architecture –

pioneered by designers like Frederick Law Olmsted – led to the creation of iconic urban green spaces, such as Central Park in New York (Fisher, 2011). Resurrecting the Roman concept of *rus en urbe* (literally 'country in the city'), the designers of city parks hoped their "*beautiful sylvan scenes*" would solve problems of metropolitan inequality and poor health caused by residents who "*were out of touch with external nature*" (Fisher, 2011; Young, 1995, quotes respectively).

In the UK, this trend also embraced the restorative properties of what are now termed 'blue spaces' (White et al., 2020b), with "*the long coast-line of the British Islands…recognised as the greatest of the natural health assets of the country*" (Fortescue Fox & Lloyd, 1938). Beyond the physical benefits of cleaner air and water, it is striking that from ancient civilisations to the pre-war era, the restorative properties of nature proposed by scholars, clergymen, and artists bear a notable resemblance to those posited by today's environmental psychologists (Ward Thompson, 2011).

2.5 Pathways to health

Natural environments have the potential to positively impact health through multiple mechanisms. At a broad scale, a catalogue of 'ecosystem services' (section 2.8) are provided by a healthy and functioning biosphere, such as fresh water, climate regulation, and food production, each of which are vital to healthy human populations (Millennium Ecosystem Assessment, 2005).

At a more localised level, metropolitan trees and vegetation can regulate the temperature of urban fabric (Bowler et al., 2010), and mitigate the health effects of poor air quality by reducing pollution (Beckett et al., 2000; Nowak et al., 2006). Frumkin et al. (2017) elaborated on these pathways, also identifying enhanced immune function, social contact, and physical activity as mechanisms by which nature contact can positively influence health.

Substantial evidence suggests that 'neighbourhood' nature, such as parks and gardens, is associated with a diverse range of benefits, from improved sleep quality (Stenfors et al., 2023) to greater levels of physical activity (Bancroft et al., 2015; Bize et al., 2007). Indeed, so-called 'green exercise' might deliver additional benefits to indoor exercise (Thompson Coon et al., 2011) and lead to concomitant improvements in self-esteem and mood (Barton & Pretty, 2010).

Spending time in, near, or watching nature can also have demonstrable effects on psychophysiological wellbeing (Sudimac et al., 2022; Yao et al., 2021). Research into the Japanese concept of Shinrin-yoku represents a systematic (and well-branded) attempt to develop an evidence base for the physiologically restorative potential of natural environments. This body of research has provided support for physiological stress reduction after sitting in and walking through Japan's forest environments, with notable outcomes including reductions in salivary amylase (an indicator for sympathetic nervous system activity), cortisol levels, heart rate, and blood pressure – each markers of physiological stress (Lee et al., 2009; Park et al., 2008; Park et al., 2007; Park et al., 2010; Tsunetsugu et al., 2007; Yamaguchi et al., 2006). Hansen et al. (2017) and Kotera et al. (2022) reviewed Shinrin-yoku studies from across Asia and Europe, demonstrating further evidence for the reduction of physiological stress in forest environments.

Beyond these direct relationships, natural settings can also impact health and wellbeing through indirect pathways (Hartig et al., 2014). For example, the quality of social relationships can affect mental health and morbidity outcomes (Holt-Lunstad et al., 2010) and positive relationships exist between social cohesion and nearby nature (Hartig et al., 2014), with green spaces associated with an increased sense of community (Francis et al., 2012) and reduced loneliness (Maas et al., 2009).

The effects of natural environments on specific mental wellbeing outcomes have been approached from several disciplinary and methodological perspectives. Bratman et al. (2012) reviewed these "*psychological ecosystem services*", finding evidence for positive relationships between nature contact and outcomes such as attention, memory, impulse inhibition, stress, and mood. Indeed, numerous epidemiological studies have suggested correlational links between proximity to natural environments and mental wellbeing in both children and adults (Herchet et al., 2022).

Bratman et al. (2012) also considered durations of exposure, from minutes to days (as well as longitudinal studies) and types of contact, from wilderness experiences to virtual forms of nature. With a focus on digital experiences, more detailed consideration of the physical and social benefits of nature exposure are beyond the scope of the research reviewed here. Instead, greater detail will be explored regarding the positive psychological effects arising from people-nature interactions.

2.6 Psychological mechanisms

Several mechanisms have been proposed to explain the impacts of natural environments on psychological wellbeing.

2.6.1 Stress recovery

One of the seminal efforts to explain the links between environmental aesthetics and emotions was proposed by Roger Ulrich and his *stress recovery theory* (Ulrich, 1983). In contrast to prevailing wisdom, Ulrich embraced emerging research that highlighted how affect could often precede cognition. He suggested an immediate feeling of happiness or fear could dictate responses to nature-based environments, and these would occur with minimal cognitive burden.

One of the central pillars of stress recovery theory suggests that there were adaptive, and therefore selective, advantages to feeling emotions in response to specific environmental compositions. Instant avoidance behaviour, elicited by fear at the sudden appearance of a snake, is a basic yet powerful way to visualise this mechanism at work. However, in some cases advantages may be more subtle than the need to reduce risks of mortality. For example, if an early hominin was stressed or physically exhausted, experiencing a pleasing emotion when encountering a setting that might provide opportunities for restoration could have encouraged the individual to linger and benefit from reductions in stress and arousal (Ulrich, 1983).

Under this theory, the broad concept of 'stress' is identified by psychological markers such as negative emotions, physiological outcomes such as increased heart rate, and behavioural hallmarks such as irritability, all of which can lead to fatigue if left unchecked (Ulrich et al., 1991). Natural environments are posited to alleviate this stress by "*sustaining non vigilant attention*" and "*restricting negative thoughts*" (de Kort et al., 2006) to create a "*broad shift in feelings towards a more positively-toned emotional state*" where activity of the sympathetic nervous system is reduced, and the parasympathetic system is activated (Korpela & Hartig, 1996).

Settings that can trigger the process of stress reduction feature elements that might have contributed to survival in humans' early development, including water, vegetation, and expansive views (McMahan & Estes, 2015). Thus, an important hallmark of this biological preparedness is its absence when people experience modern urban settings; since they were not part of our evolutionary past, towns and cities should exhibit lower restorative capabilities than unthreatening natural environments (Ulrich et al., 1991), a dichotomy emphasised by several decades of investigation (Meuwese et al., 2021).

2.6.2 Biophilia

The adaptive underpinning of stress recovery theory overlaps substantially with a second influential thesis for explaining human-nature interactions, 'biophilia'. In his 1984 treatise, E.O. Wilson defined biophilia as humans' "*innate tendency to focus on life and lifelike processes*" (Wilson, 1984). A decade later, he expanded this dictum to become the 'Biophilia Hypothesis', which suggested "*a human dependence on nature that extends far beyond the simple issues of material and physical sustenance to encompass as well the human craving for aesthetic, intellectual, cognitive, and even spiritual meaning and satisfaction*" (Kellert & Wilson, 1995).

Kellert and Wilson's hypothesis covered several theoretical avenues, including 'biophobic' responses to environmental threats and implications for human-animal relationships. Of particular relevance here are the arguments proposed to explain landscape preferences and their restorative properties:

- Early humans' responses to certain natural elements and settings contributed to their chances for survival, both for approach and avoidance responses.
- Being able to benefit from stress reduction and mental restoration in appropriate environments was selective.
- Aesthetic preferences for natural environments are therefore governed by this genetic learning.
- Consequently, natural scenes are overwhelmingly preferred to urban scenes.

These areas echo the framework outlined by stress recovery theory (Ulrich, 1983; Ulrich et al., 1991) and have been updated to fit an evolving evidence base. For example, whilst biophilia's adaptive origins suggest its effects should transcend geographical and cultural boundaries, it has recently been proposed as an innate rather than instinctive trait; humans have a disposition to become emotionally connected to nature, but this trait does not result in uniform or fixed behaviours (Barbiero & Berto, 2021).

Nonetheless, its key tenets have drawn sharp criticism in recent years. In a wide-ranging critical review, Joye and De Block (2011) took specific aim at the rationale for evolved preferences for natural environments. They argued that if much of human evolution had taken place in one environment, little selective pressures would have been applied to develop preferences for it, reasoning that since "*restorative effects have been observed in response to almost any kind of non threatening nature, from single plants and plain grasslands to idyllic waterfalls and dense forests*" there is little evidence (or need) to evoke evolutionary arguments.

Although it predates biophilia as a concept (Hartig, 2021), a reliance on adaptive origins (among other criticisms levelled by Joye and De Block) also poses trouble for the mechanisms underlying stress recovery theory. Indeed, stress recovery is posited to have been prompted by environments that would have offered food or protection from predation (Ulrich et al., 1991). Yet Joye and van den Berg (2011) highlighted how Ulrich's use of categories such as 'unthreatening nature', lack the specificity to be testable or attributable to a specific psycho-physical function. Moreover, the supposition of an affinity for "*vegetated settings*" falls victim to the same broadness, since "*not every piece of vegetation or any kind of vegetated setting provides equal opportunities for refuge/safety and not all trees, bushes or plants constantly bear fruit or signal that they can supply such resources in the future*" (Joye & van den Berg, 2011).

Since vegetation would have been obvious in its appearance and was neither fast moving, fleeting, nor subject to rampant competition, Joye and van den Berg (2011) cite the need for further clarity on "*why there should have been a selection pressure to evolve very rapid affective responses toward greenery*".

However, an alternate theory, one that does not rely so heavily on evolutionary origins, also exists to explain the positive psychological effects of natural environments.

2.6.3 Attention restoration

In their pioneering work from 1989, Rachel and Stephen Kaplan outlined the theoretical framework for attention restoration theory (Kaplan & Kaplan, 1989). They proposed that humans' ability to sustain focused or 'directed' attention is finite, periods of 'involuntary' attention are required to replenish cognitive resources, and the qualities that facilitate involuntary attention are abundant in natural settings.

The concept of directed attention is central to attention restoration theory; in order to "*do the important while resisting distraction from the interesting*" people must voluntarily employ effort to maintain focus, a process which is familiarly susceptible to fatigue (Kaplan, 1995). Indeed, the use of directed attention may be most noticeable when it is exhausted, often manifesting as an inability to concentrate, increased likelihood of making errors, and ensuing irritability (Kaplan, 1995; Korpela & Hartig, 1996).

Kaplan and Kaplan (1989) suggested that depletion in the ability to engage directed attention might be recovered by 'switching off' the need for focused attention, replacing it instead with a mode of 'involuntary' attention that does not require effort or consume cognitive resources. Whereas Ulrich's psychophysiological approach relies on a rapid and initial affective response to the aesthetic composition of an environment, attention restoration theory suggests a stepwise progression to recovery. In this model, 'restoration' first involves the removal of immediate thoughts, the capacity for directed attention is then gradually restored, followed by the stimulation of mental reflection (Korpela & Hartig, 1996).

To avoid nomenclature issues, Kaplan renamed involuntary or effortless attention as 'fascination', describing a continuum of fascination types (Kaplan, 1995). 'Hard' fascination grabs attention forcefully, it consumes mental processes, and can be difficult to resist, such as when a snake lunges from the undergrowth. In contrast, 'soft' fascination captures attention gently and effortlessly, also allowing space for contemplation and reflection, a mode elicited by calm ocean waves or clouds traversing the sky for example (Basu et al., 2018). Crucially, whilst directed attention requires effort, soft fascination is effort*less* (Hartig et al., 1997a).

Beyond fascination, attention restoration theory identifies several other factors that can contribute to the recovery of directed attention (Kaplan & Kaplan, 1989; Kaplan, 1995; Korpela & Hartig, 1996):

- *Being away* – an environment should provide a feeling of being away from everyday concerns, manifested as either a physical or perceptual distance.

- *Compatibility* – a person's inclinations should be matched or fulfilled by the environment, "*one carries out one's activities smoothly and without struggle*".

- *Extent* – an environment must provide sufficient stimuli to explore and engage the mind, achieved through richness of experience or physical scale (also referred to as 'scope').

- *Coherence* – a setting should be congruent, ordered, and organised.

The definitions of these factors have evolved following development of the theory and scales used to measure attention restoration, resulting in both supporting and contrasting views on how much they overlap and support restorative outcomes, see (Pasini et al., 2014; Purcell et al., 2001) for more detailed discussion.

Although the Kaplans viewed fascination as the key driver in direct attention recovery, Hartig et al. (1997a) considered 'being away' as the fundamental ingredient of a restorative environment, noting that if a person is "*away from everyday routines and demands on directed attention, fascination can more readily come into function.*"

A significant body of work provides evidence for attention restoration in natural environments (Stevenson et al., 2018), and the factors listed above have been successfully resolved in a scale designed to capture 'perceived restorative potential' (section 2.4.2), a subjective measure of how likely attention restoration is to occur, used when the actual measurement of cognitive fatigue and recovery is unfeasible (Hartig et al., 1997b). Yet despite this progress, the theory has not escaped criticism of its own.

Exercising a similarly forensic approach to their previous theoretical appraisals, Joye and Dewitte (2018) took particular aim at the notion of soft fascination central to attention restoration. They contended that the specific elements which may make a scene 'softly fascinating' remain under-explained and evidenced; elements that should be fascinating, such as moving clouds and sunsets, have rarely been present in experimental stimuli, which instead rely on mundane settings such as parks, gardens, and woodland. Among other conceptual misgivings, Joye and Dewitte (2018) returned to problems of an evolutionary underpinning, suggesting that attention restoration theory has "*posited the existence of an adaptive response, but this response also appears to occur for environments that do not evidently solve the problem for which this adaptation presumably has been designed for by natural selection.*"

However, whilst the theory may have initially invoked adaptive mechanisms as its basis (Hartig, 2021), it loses little potency by moving beyond them. Moreover, although both Ulrich's and the Kaplans' frameworks predict that nature-based settings will provide greater opportunities for restoration than urban environments, stress recovery theory invokes an evolutionary grounding that *a priori* restricts urban environments from being restorative. In contrast, attention restoration theory does not require the qualities of a restorative environment to be confined to nature, and evidence suggests there is scope for metropolitan areas to also foster positive affective responses (Karmanov & Hamel, 2008). Nonetheless, despite centring on different outcomes and mechanisms, there are also several reasons to view these frameworks as complementary.

2.6.4 Complementary constructs

Early development of the theories of stress recovery and attention restoration was marked by ideational sparring:

"*A theoretical position which contends that 'involuntary' attention is the basis for restorative effects of nature is inadequate*" (Ulrich et al., 1991).

"*Ulrich and his colleagues have apparently misinterpreted the other three components [of a restorative experience] as alternative sources of fascination*" (Kaplan, 1995).

However, there is significant overlap between the concepts underlying both hypotheses. For example, Ulrich (1983) postulated that a pleasant natural environment which provokes mild interest, calm, and peacefulness is likely to lead to "*non-vigilant"* attention and subsequent psychophysiological restoration – a seemingly analogous mechanism to the soft fascination posited by attention restoration theory. Moreover, Ulrich considered factors such as complexity, biodiversity, curiosity, and depth as crucial to the restorative potential of an environment; characteristics which accord well with attention restoration theory's components of fascination, being away, and extent.

Importantly, the distinct pathways through which each mechanism operates need not be in conflict. Kaplan (1995) noted that the depletion of attentional resources can be a common antecedent to stress, and that "*under a wide range of circumstances one would expect resource deficiencies and stress responses to occur together*". Kaplan considers the interlinking of these processes so intimate as to pose methodological issues for studies attempting to focus on one outcome "*a resource decline can lead to stress and a stress response can lead to a resource decline…the duration of the [experimental] manipulation must be carefully chosen to keep the attentional fatigue from becoming stressful or vice versa*" (Kaplan, 1995).

Teasing out these differences, Hartig et al. (2003) demonstrated how both processes can occur concurrently "*manifesting in different kinds of outcomes that emerge at different rates and persist to differing degrees.*" Indeed, Hartig (2021) contended that much like other prominent theories in the life sciences, such as evolution, 'restorative environments theory' may best be described as multiple contrasting, complementary, and coexisting frameworks within a larger body of theory. Hartig noted that within the field of environmental psychology, the dominance of a "*two theories*" approach forms the "*conventional narrative*" on restorative environments.

But there have also been calls to create a unified theory. For example, Han (2007) urged for a holistic and multi-perspective approach to understanding landscape preferences, one which incorporates evolutionary, cultural, and informational theories to explain aesthetic and restorative responses. Ratcliffe et al. (2018) went even further, noting that with their predominant focus on the visual modality, the frameworks proposed by Kaplan and Ulrich may be quite inadequate for describing the pathways that link multisensory nature-based experiences with psychological wellbeing. Although through the development of a scale based on attention restoration theory, Payne (2013) successfully included soundscapes in the Kaplan and Kaplan's schema.

2.6.5 Other frameworks

Beyond the 'conventional narrative' (Hartig, 2021), several other approaches to understanding people-nature interactions have also been proposed.

Following the evolutionary arguments underpinning theories of biophilia and stress recovery (Kellert & Wilson, 1995; Ulrich et al., 1991), the savanna hypothesis suggested that since much of human evolution likely took place in the savanna environments of East Africa (Kahn, 1997), people will have favourable affective reactions in settings which mimic their typically open, grassy plains, and scattered trees (Falk & Balling, 2009; Lohr & Pearson-Mims, 2006). However, Joye and De Block (2011) challenged this theory with the contention that if much of human evolution took place in these environments, there would have been little selective pressure to develop preferences for them.

Joye and van den Berg (2011) submitted similar criticisms, instead suggesting that adaptive benefits for preferring certain landscape features are better explained by 'prospect-refuge' theory. Under this model, certain features of an environment that permitted developing hominids to 'see without being seen' would have offered greater opportunities for rest and "*satisfaction of their biological needs*" (Appleton, 1996; Pheasant et al., 2010). An apparent preference for savannas could thus be explained as a by-product of these underlying drivers, a position also endorsed by others (Han, 2007).

Joye and van den Berg (2011) found more value in the notion of 'perceptual fluency' (Reber et al., 2004), positing that natural scenes are more easily processed than urban equivalents and thus demand less cognitive resources. Under this model, restoration is "*the result of an 'undoing process' initiated by positive affect*" that does not require an evolutionary explanation, a stance which early evidence supports (Menzel & Reese, 2021). Joye et al. (2022) offered another alternative in their theory of hedonic value, which suggests that positive nature experiences can enhance performance by providing emotional rewards that prevent people from being distracted while undertaking non-rewarding work. This account also overlaps with the idea of 'instoration', which outlines how nature can deliver psychological benefits without the need for antecedents of stress and fatigue (Korpela & Ratcliffe, 2021).

Instoration and ideas that natural landscapes might "*act as a prophylactic against illness*" (Ward Thompson, 2011) also have commonalities with the field of 'salutogenesis', which focuses on the notion of 'coping' (Hartig, 2021) and promoting factors that might improve people's abilities to navigate stressors and bolster positive health outcomes over the life course (Mittelmark & Bauer, 2022). Despite restorative environments research tending to focus on (often) short-term recovery from stress and fatigue, there is clear overlap between attention restoration and instoration, particularly with respect to possible cumulative effects revealed by epidemiological studies (Alcock et al., 2014) and there have been calls to unite these considerable yet disparate bodies of work: see von Lindern et al. (2022) for a detailed account.

In a similar vein, several authors have recognised how the divergent approaches of meditation and nature restoration might complement one another. At first glance, the effort*ful* processes of discipline, practice, and focus common in meditation might seem at odds with the effort*less* notion of fascination central to attention restoration theory. Yet, several underlying constructs overlap between the two frameworks. For example, a major theme in meditative techniques is the avoidance of active control of typical thought processes, analogous to the relief of directed attention central to restorative environments (Kaplan, 2001b). There is also growing evidence that performing mindfulness in natural environments can enhance wellbeing outcomes compared to other non-natural settings (Choe et al., 2020; Djernis et al., 2019; Lymeus et al., 2018), perhaps due in part to greater restoration from the initial demands of mindfulness training (Lymeus et al., 2019).

The idea of complementarity also lies at the heart of Hartig's relational restoration theory (Hartig, 2021). With a focus on the mutual exchange of emotional support provided between individuals, relational restoration considers how natural (and other) environments can facilitate conversation, bonding, and problem solving between couples, families, and larger groups. Hartig considers these processes as concomitant with stress reduction and attention restoration, and cites an established body of supporting literature that highlights the importance of social interactions in nature (Ashbullby et al., 2013; Coplan & Bowker, 2014; Home et al., 2012).

A further flurry of mechanisms for unpacking nature-health relationships has also recently emerged, that may too be considered complementary to the 'conventional narrative'. These include a conditioned restoration theory (Egner et al., 2020), an affect-based model of benefits (Bratman et al., 2021), a framework for self-determination (Yang et al., 2022), and mechanisms centring on goal-discrepancy reductions (Joye et al., 2023). However, given their embryonic status, each of these accounts has yet to garner empirical support.

2.6.6 A focus on attention restoration

Although each of these frameworks may have implications for the research presented in this thesis, it has been chiefly informed by attention restoration theory. Several considerations made this approach suitable: Covid-19 restrictions precluded *in situ* experimental work and use of physiological measures necessary to explore psychophysiological stress reduction; soundscapes were a key focus of our research and measures of attention restoration have been expanded to relate to natural sounds (Payne, 2013; Ratcliffe, 2021a); cognitive restoration is considered possible and valuable in urban environments – another factor under consideration (Hartig & Kahn, 2016); and perceived restorative potential can be reliably assessed remotely (Hartig et al., 1997b), an essential part of online study designs. Moreover, since a large proportion of studies in the field of environmental psychology are grounded in attention restoration theory, situating the present work within this framework allowed for important comparisons with existing experimental outcomes.

2.7 Attention restoration in practice

The need for a *restorative* environment implies the de facto antecedent condition of degraded or exhausted resources that require *recovery*. As detailed in section 2.6.3, attention restoration theory focuses on the need to replenish diminished cognitive resources, particularly those related to directed attention and the ability to focus on complex tasks.

2.7.1 Experimental manipulations

Whilst there has been some debate about the quality of evidence underpinning attention restoration, in part hampered by heterogeneity among methods and measures used across studies (Ohly et al., 2016), reasonable support exists to suggest factors such as working memory, attentional control, and cognitive flexibility can each be improved by exposure to *in situ* and virtual natural stimuli (Stevenson et al., 2018).

Bratman et al. (2012) highlighted how various experimental manipulations have been employed to induce and measure distinct aspects of cognitive fatigue. For example, concentration and memory have been assessed via the Necker cube pattern control test (See Fig 1, Tennessen & Cimprich, 1995), backward digit span test (Berman et al., 2008), sustained attention to response test (Berto, 2005; Hicks et al., 2020), and proofreading tasks (Hartig et al., 2003). Whilst impulse inhibition has been tested via the Stroop colour word test (Taylor et al., 2002).

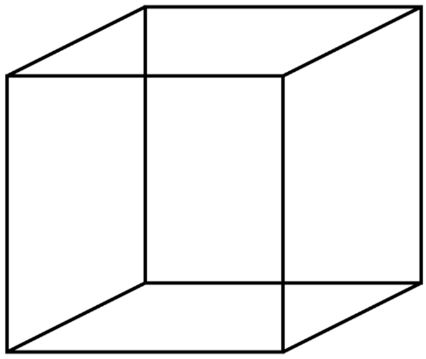


Figure 1. The Necker cube visualisation presents a three-dimensional wireframe cube that can be seen in one of two orientations. Preventing a 'switch' between each orientation is assumed to require attentional effort. Image © Wikipedia.

However, in several experimental designs, such as in online studies, inducing attentional fatigue and measuring its recovery is often unfeasible. In such cases, assessing people's perceptions of environmental qualities, as well as their *expectation* of restoration, have been considered useful proxies.

2.7.2 Perceived restorative potential

To aid the appraisal of likely restoration in the absence of actual resource depletion, Hartig et al. (1997a) developed the perceived restorativeness scale. Successfully parsing out a four-factor model for the constructs of being away, fascination, coherence, and compatibility, the scale comprised 26 items each rated on a seven-point scale. This measure was further developed to include the additional item of 'scope' (also sometimes referred to as extent), resulting in a 29 item scale (Purcell et al., 2001).

In their parallel development of a restoration scale, Laumann et al. (2001) resolved a five factor structure for novelty and escape (identified as separate constructs of 'being away'), extent, fascination, and compatibility. However, this 22-item measure has seen less use in the extant literature.

Significant participant input makes these scales comprehensive yet unwieldy, and they have subsequently been adapted to form shorter instruments. For example, Pasini et al. (2014) developed and validated an 11-item scale that reliably resolved four factors, whilst Berto (2005) employed single items for each of the five factors identified by Purcell et al. (2001). To reduce participant burden and explore a larger range of stimuli in their work, Herzog et al. (2003) also used single item measures of the four restoration components fascination, being away, extent, and compatibility. Felsten (2009) extended this approach through the use of a four factor measure, comparing this outcome with a single item capturing generalised restorative potential and finding a strong correlation between both.

Others have focused solely on the factors of fascination and being away through single item measures (Nordh et al., 2009), with Lindal and Hartig (2013) assuming these factors are most "*influenced by physical attributes of the environment*" and therefore most suited to studies that use digital stimuli. Favouring brevity still further, the use of single-item measures to capture the criterion outcome of perceived restorative potential has gained substantial traction. For example, Herzog et al. (1997) used single experimental questions to capture the effectiveness of environments for reflection and restoration, an approach adopted by numerous others (Herzog et al., 2002; Herzog et al., 2003; Staats et al., 2003; Twedt et al., 2019).

These studies typically involved a scenario-setting procedure, where participants were asked to imagine a narrative in which they were cognitively fatigued and needed to recover. Each employed a variation on that initially used by Herzog et al. (2002) and Staats et al. (2003), such as:

"*You've been working very hard recently. Now, after a long day, you really have had it. You have difficulty concentrating and are very irritable. To top it all off, you have had an upsetting argument with a friend and are feeling very stressed out about it. You sit down somewhere to take a break*" (Ratcliffe et al., 2016).

Whilst it may possess dimensional restrictions, the use of a single measure of perceived restorative potential can reduce burden on participants and suit the use of a high volume of experimental stimuli (Herzog et al., 2003). Indeed, single measures of perceived restorative potential have also been used where study design prohibits a multiple dimension approach; because several questions per item would conflict with the expectations or availability of participants (Stigsdotter et al., 2017; Twedt et al., 2019), and it is in this vein that others have embraced their use (Cracknell et al., 2016; White et al., 2017b).

2.8 Affective outcomes

In tandem with the recovery of attentional resources, positive affective outcomes in the form of improved mood, reductions in negative emotions, and increases in positive emotions are also important consequences of restorative experiences (Hartig & Staats, 2003). These outcomes are considered both antecedent to the theories of stress recovery and attention restoration (Bratman et al., 2012) but also concurrent and reinforcing; once initial affective responses have triggered these mechanisms, continued positive emotions can form place attachment, build emotional bonds, and stimulate further salutary outcomes, a proposition supported by substantial evidence (see Bratman et al., 2021 for a comprehensive review).

2.8.1 Positive and negative affect

Although the affective impacts of nature exposure have sometimes proved difficult to detect in individual experiments (e.g. Berman et al., 2008; Berman et al., 2012), meta-analysis by McMahan and Estes (2015) indicated that, across 32 studies, even brief exposure to natural environments was associated with increases in positive affect and, to a lesser degree, reductions in negative affect. Others have also considered how greater granularity in discernible environmental qualities, such as levels of biodiversity (Cameron et al., 2020), or prevalence of water (White et al., 2010), can influence emotional responses.

Bratman et al. (2021) noted how natural environments can form a central role in emotional regulation, with nature forming a common theme in places people might 'escape' to in order to satisfy emotional outcomes. People may seek out nature they believe to have positive 'emotional potential' when in both happy and sad moods (Johnsen & Rydstedt, 2013), although these pathways to affect regulation remain underexplored (Korpela et al., 2018).

Changes in affect are commonly captured through self-assessment instruments such as the Positive and Negative Affect Schedule, a 20-item scale with robust temporal stability capable of capturing momentary as well as longer term fluctuations in mood (Watson et al., 1988a). Complementary scales include the Zuckerman Inventory of Personal Reactions (Zuckerman, 1977a), and the Profile of Mood States questionnaire (McNair et al., 1989), each used in people-nature research (e.g. van den Berg et al., 2003). Others have considered people's broader emotional wellbeing from the perspective of Russell's circumplex model of affect, which assumes four general affective quadrants marked by degrees of valence and arousal (Russell, 1980). Under this model, emotional states can be either positively or negatively toned, and either low or high in arousal, leading to the two-dimensional spectrum of emotions shown in Fig 2.

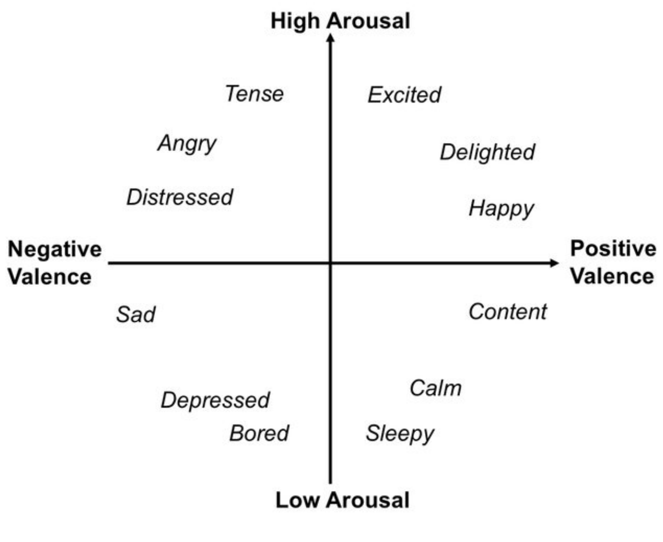


Figure 2. Russell's circumplex model of affect. Image from (Du et al., 2020).

Dimensions of valence and arousal have been successfully employed to measure affective responses to natural stimuli (e.g. White et al., 2017b), with an analogous permutation based on Thayer's model of mood and arousal also sometimes used (Hull & Michael, 1995; Thayer, 1989). This approach has been extended to the study of emotional reactions to soundscapes, marking a bridge between sensory inputs (Axelsson et al., 2010).

Circumplex models can capture a range of emotional states, but have their roots in the notion of 'basic' emotions (Scarantino & Griffiths, 2011). Indeed, broad changes in positive and negative affect, such as happiness and sadness, might reasonably be considered as 'simple' emotional responses (Brechet et al., 2009). Yet a range of more complex affective states could also be important in people-nature exchanges.

2.8.2 Awe

Over the last 20 years, awe has emerged as an emotional response that may offer particular benefits for psychological wellbeing.

Keltner and Haidt (2003) detailed how feelings of awe, and its overlapping and related emotions of wonder and amazement, might be triggered by several diverse types of experience. For example, awe is a familiar response to religious encounters, routinely depicted in religious texts, and experienced by congregations attending powerful sermons. Similarly, charismatic and heroic leaders can elicit awe in their followers through actions that overturn the status quo, change people's attitudes, and provide inspiration. And various artistic formats, such as paintings, theatre, and music, can instil feelings of awe by conveying power, artistic prowess, and aesthetic appreciation; a potential embodied by the sublime movement (Clewis, 2021).

Awe has also been considered as a transcendent emotion related to peak experiences that incorporate feelings of "*wonder, surprise, awe, amazement, reverence, humility, and surrender*" (from Bethelmy & Corraliza, 2019 who quoted; Maslow, 1959). Keltner and Haidt (2003) suggested the experience of 'vastness' and the need for mental 'accommodation' were central features necessary for the stimulation of awe. Vastness might involve physical size, but can relate to many factors that are outside of the "*self's ordinary level of experience or frame of reference*" (Keltner & Haidt, 2003). Accommodation requires a person's established mental structures to expand in order to make sense of the aforementioned vastness, a need that may or may not ultimately be achieved.

Both of these factors are abundant in natural environments, which for many, may represent the prototypical trigger of awe (Piff et al., 2015). For example, Anderson et al. (2018) found that watching sunset and seeing blooming flowers were effective elicitors of awe, and that links between nature experiences and awe were stronger than for other emotions. In their comprehensive review of the literature, Bethelmy and Corraliza (2019) noted how relationships between awe and nature have been approached from several perspectives, including spirituality and mysticism. Their development of a scale to measure 'sublime emotion toward nature' revealed two components: awe and inspiring energy, with awe partly triggered by experiences that are "*so much larger than oneself*."

Indeed, Collado and Manrique (2019) demonstrated that both natural and manmade scenes described as '*extraordinary*' – such as the Grand Canyon or Egyptian Pyramids – were those most likely to elicit feelings of awe. They also linked restorative outcomes with awe-inspiring scenes, which were associated with increases in both perceived and attentional measures of restoration (Collado & Manrique, 2019). However, the authors also suggested that participant improvements in their cognitive task, the Digit Span Test (Hilbert et al., 2014), may be due to awe-evoking scenes heightening arousal and attention, rather than mechanisms consistent with an attention restoration framework. Yet they also posited that the novelty of their awe-inspiring stimuli could play a role in restoration; via a heightened feeling of 'being away' from usual routines and stressors. Novelty has been highlighted by others as a key facet of awe-inspiring experiences, with Sturm et al. (2020) informing participants who took part in 'awe walks' that the emotion "*is most likely to occur in places that involve two key features: physical vastness and novelty*."

Across four iterative studies, Shiota et al. (2007) revealed that awe experienced in natural environments was a largely positive and distinct emotion from happiness that could lead to "*some disengagement from awareness of the self*". The notion of the 'small self' may be a particularly important outcome related to feelings of awe, and is characterised by the diminished importance of personal concerns and goals (Piff et al., 2015). The small self might lead to positive emotions associated with pro-sociality, such as compassion and admiration (Sturm et al., 2020), or enhance pro-social behaviour directly (Piff et al., 2015). These effects may also accumulate over time (Sturm et al., 2020), providing the exciting prospect that beyond a focus on an individual's cognitive state, exposure to natural environments could have wider societal impacts.

Intriguingly, despite awe being described as an infrequent emotion that is difficult to elicit (Keltner & Haidt, 2003), it has been stimulated in numerous studies through the use of static and relatively simple visual methods (Collado & Manrique, 2019; Gordon et al., 2017; Joye & Bolderdijk, 2015; Joye & Dewitte, 2016, see Fig. 3). If these digital forms of nature can trigger feelings of awe, how might these effects be optimised? For example, Joye and Bolderdijk (2015) used images of sunrise, sunset, rainbows, and thunderstorms to elicit awe, but how such ephemeral features might have differentially contributed to participant responses was unexplored (see section 2.11).

Figure 3. Still images used by Gordon et al. (2017) to define threat-based and positively valenced feelings of awe.

Moreover, much of the literature mentioned above considers the primary triggers of awe as visual. Could other sensory modalities augment the way awe is experienced in nature? (A question also posed, but left unanswered, by Chirico et al., 2017.) For example, Gordon et al. (2017) included thunderstorms in their study of negatively-valenced awe, yet did not feature the deep, resonant, rolling sounds of thunder. They also used video footage from the BBC's Planet Earth series that included "*mountains, plains, forests, waterfalls, and canyons, accompanied by uplifting music.*" How might the addition of music to this experience have impacted participant feelings of awe? Music can elicit a range of emotions, including awe (Pilgrim et al., 2017; Silvia et al., 2015), however the ways in which music and nature might combine to influence affective outcomes remains largely unknown (see section 2.12).

2.8.3 Nostalgia

These questions are also relevant for other complex emotions, such as nostalgia. Long overlooked by social scientists, nostalgia has undergone a recent resurgence in research interest, perhaps driven by romanticised perspectives of the 20th century triggered by current issues such as climate change, global conflict, and political upheaval, that have led to a 'nostalgia boom' (Jacobsen, 2020).

Nostalgia has developed substantially from its early pathological roots, where it was identified in 17th century soldiers and initially regarded as a "*sickness primarily related to the heart, a heart aching for that which is lost*" and later "*an affliction of the brain manifested as 'the quite continuous vibration of animal spirits through those fibres of the middle brain*'" (Jacobsen, 2020). As recently as the 1980s, nostalgia was still regarded by some as a psychological disorder typified by "*a regressive manifestation closely related to the issue of loss, grief, incomplete mourning, and, finally, depression*" (Wildschut & Sedikides, 2020).

Although beyond the scope of this review, the concept of 'solastalgia' has also gained recent traction in the environmental literature. Defined as the "*pain or distress caused by the loss of, or inability to derive, solace connected to the negatively perceived state of one's home environment*" (Albrecht et al., 2007), solastalgia is related to terms such as 'eco-anxiety' and can be triggered by environmental maladies such as prolonged drought or climate change (Hickman, 2020; Stanley et al., 2021). See also Galway et al. (2019) for a recent review.

Morphing from a medical term to an emotion over the 20th century, nostalgia came to represent an affective state associated with personal and cultural loss, with typologies that can be both private and individual, or collective and cultural. Yet it can also be characterised by ambivalence: "*full of fond, happy and heart-warming memories*" as well as "*tormenting, frustrating, painful and invaliding*", ultimately forming a mixed-valence emotion that "*encapsulates and embodies the diametrical opposites of the bitter and the sweet, happiness and distress, joy and sadness, pleasure and pain*" (Jacobsen, 2020).

However, recent years have seen a 'rehabilitation' of nostalgia, which is now regarded as a largely positive emotion (Wildschut & Sedikides, 2020). For example, nostalgia is closely related to personal memories, physical settings, shared experiences, and significant events, and when associated with negative outcomes, can rose-tint these experiences towards a feeling that "*it was all for the best*" (Wildschut et al., 2006). Indeed, nostalgia is commonly rated as 'pleasant' and has been closely related to feelings of pride and gratitude (van Tilburg et al., 2018; cited by Wildschut & Sedikides, 2020).

A review of the nostalgia literature provided by Wildschut and Sedikides (2020) identified several functional outcomes of this emotion. Across a range of studies, the authors detailed how nostalgia can positively impact feelings of being 'loved' and 'protected', increase perceptions of social support and social competence, lead to demonstrable improvements in prosocial behaviour, enhance appraisals of positive self-attributes, boost self-esteem, increase meaning in life, and develop personal identities by connecting people to their past. These connections may also be an important precursor to feelings of optimism (Cheung et al., 2013), inspiration (Stephan et al., 2015), and creativity (van Tilburg et al., 2015), and can help to foster meaningfulness in people's lives (van Tilburg et al., 2013).

Nostalgia, then, has emerged as a largely positive emotion with a host of associated benefits for wellbeing. Could this emotion be relevant to nature-based encounters?

From a tourism perspective, both autobiographical and cultural forms of nostalgia can be important factors in visitor experiences to museums (Goulding, 1999), sporting attractions (Fairley & Gammon, 2005), and coastal locations (Severin et al., 2022), with a prevalence that might be most pronounced in older adults with "*more years behind than there are ahead*" (Jarratt & Gammon, 2016). Goulding (1999) found that in this demographic, nostalgia formed a kind of escapism that could be "*heightened by sharing memories with others*". Memories, whether created through direct experiences or related to broader social conditions, are considered a key antecedent to nostalgia. Fairley and Gammon (2005) placed memories at the heart of their definition of nostalgia, which they regarded as "*a preference (general liking, positive attitude or favourable affect) towards objects (people, places, experiences or things) from when one was younger or from times about which one has learned vicariously, perhaps through socialization or the media*."

Indeed, the reminiscence of memories formed at the coast has been highlighted as a key reason for people to revisit these locations, with socially-orientated and bittersweet memories indicating how nostalgia might play a central role in seaside experiences (Severin et al., 2022). Moreover, Jarratt and Gammon (2016) noted how these environments may hold particular value because of their "*timeless*" qualities, allowing visitors to escape their "*everyday perception of time*" and connect with slower natural rhythms that can appear "*permanent in contrast to our life spans and so [put] them into perspective*".

Longing for an era when 'time moved more slowly' is also prominent in reflections on the role of nature in American identity. McDermott (1972) noted how "*The primary meaning of nature for America was the presence of open space, with its corollary, a sense of time as prospective and fruitful.*" Whilst McDermott focused on the cultural nostalgia for a bucolic nature he contends never really existed, Ladino (2012) highlighted the central role that nostalgia has played in North American environmental literature. Landino regarded nostalgia as a "*central affective means through which humans relate to the past and to the natural world…sustaining connections with each other and with the nonhuman world around them*" (DeJong, 2014).

Others have identified the importance of shared experiences in positive forms of nostalgia. Using hospital settings as their case study, Wood et al. (2015) outlined how memory can reinforce a collective and shared identity that, through nostalgia, can influence how people engage with specific environments. Crucially, they suggested that understanding nostalgic cues might help to design spaces that trigger beneficial connections to past experiences (Wood et al., 2015).

Yet despite nostalgia receiving reasonable attention in this body of qualitative people-nature literature, it remains largely overlooked in quantitative assessments of emotional experiences in nature (Jarratt & Gammon, 2016). Could feelings of nostalgia be triggered by digital forms of nature? And if so, what factors might moderate these responses?

2.9 Aesthetic appraisals

Affective responses to natural environments can also play a role in perceptions of their aesthetic value (Brady & Prior, 2020), with the beauty perceived in nature often considered a vital component of its non-material worth (Hirons et al., 2016).

Philosophical discussions of the aesthetics of nature, from wild settings to formal gardens, developed alongside those governing artistic experiences (Brady & Prior, 2020). Indeed, in his *Critique of Judgment*, Kant (1790) considered natural beauty as the archetypal aesthetic experience – one that also embodied the notion of 'disinterestedness'; beauty appreciated from an objective perspective (Carlson, 2020 – see here for extensive detail on the development of environmental aesthetics over the last 300 years). Carlson (2020) outlined how, throughout much of the eighteenth-century, the parameters for what constituted 'natural beauty' were heavily influenced by art: the 'sublime' depicted "*powerful, vast, intense, terrifying*" scenes; whilst the 'picturesque' presented nature tamed, with explicit intervention from humans and implicit rules for scenic composition. As the 19th and 20th centuries progressed however, North American environmental aesthetics placed increasing importance on the idea of wilderness, where figures such as John Muir came to define a beauty that "*eschews humanity's marks on the natural environment*" (Carlson, 2020).

Carlson (1977) suggested that modern interest in what would become 'landscape aesthetics' was largely driven by increasing public concern for the ways natural environments were managed and experienced. Referred to as "*environmental intangibles*" by early theorists, much work has attempted to quantify, and therefore adequately value, how factors such as beauty might contribute to "*an environment's total worth*" (Carlson, 1977). Carlson proposed several key approaches to evaluating environmental aesthetics: objectivity and the related concept of quantifying "*scenic resources*" should allow aesthetic value to be considered alongside other resource management policies; and public opinion should be factored into decision making, such that approaches "*take into account the public concern for aesthetic quality*" (Carlson, 1977). Carlson's final theme invoked ideas of 'formalism', proposing that design elements such as form, contrast, colour, and light might have a role to play in the objective evaluation of aesthetic quality.

The notion that natural beauty might be parsed, compartmentalised, and decoded was also embraced by environmental psychologists seeking to understand the processes underlying preferences for natural environments (see van der Jagt et al., 2014 for extensive literature in this vein). First proposed by Kaplan and Kaplan (1989), the 'preference matrix' sought to explain how evolutionary and adaptive traits could govern habitat selection. Under this model, the coherence, complexity, legibility, and mystery of a scene each contribute to how a person understands and seeks to explore it, enticing early hominids to "*continuously build upon and extend their mental map of the environment, yet [preventing] them from wandering off to potentially unsafe settings*" (van der Jagt et al., 2014). Each of these factors can be effective predictors of landscape beauty, although substantial heterogeneity exists across studies (Stamps, 2004).

Yet not all scholars have been persuaded by these reductionist methods. In a measured critique of landscape evaluation methods, Lothian (1999) contrasted 'objectivist' and 'subjectivist' perspectives: the former based on the notion that landscape quality is "*an intrinsic attribute of the physical landscape, just as landform, water bodies and hue are physical qualities*"; whilst the latter considers landscape beauty as "*solely a human construct, based on the interpretation of what is perceived through…memories, associations, imagination*". Although both approaches have deep philosophical roots, for Lothian "*the future lies in the use of the subjectivist paradigm*" which he contends is both more statistically rigorous and can accurately reflect the preferences of communities (Lothian, 1999).

Bourassa (1988) took a more balanced perspective, highlighting how aesthetics had progressed beyond theories concerning artistic appreciation and the notion of inherent beauty (see Adorno et al., 1997; Shimamura & Palmer, 2011 for much more on aesthetic theorising), but still finding a role for overarching aesthetic rules. His theory of landscape beauty focused on two central pillars: the 'biological' and the 'cultural'.

At the heart of the biological tenet lay evolved preferences that stemmed from Appleton's prospect refuge theory (Appleton, 1996), which posited that human attraction to an environment is driven in part by its ability to satisfy biological needs, promote survival through "*hide-and seek-aesthetics*" that permit the ability to "*see without being seen*", and thus form an agreeable habitat – with clear parallels to Kaplan and Kaplan's preference matrix (Kaplan & Kaplan, 1989). Due to the implicit assumption that these adaptive preferences are ubiquitous in all humans, Bourassa reinforced the notion of formalism – albeit under an evolutionary guise. As previously mentioned, Balling and Falk (1982) famously found some of the first evidence underpinning evolved aesthetics, demonstrating how people tend to prefer savannah-like environments and negating the confounding role of learned associations by including children in their study. Their findings have been supported in part by subsequent research (e.g. Falk & Balling, 2009; Lohr & Pearson-Mims, 2006; Townsend & Barton, 2018) but have also been contested (Joye & De Block, 2011). Indeed, Joye and De Block (2011) suggested that *social* selection might have exerted greater evolutionary pressures than habitat, and that culturally significant environments, "*shaped by architecture, agriculture, and other technologies*" have existed for long enough to influence genetic development.

Following that theme, the second, cultural component of Bourassa's theory placed greater emphasis on the non-sensory, symbolic aspects of a landscape that might imbue it with meaning and significance, "*we do not so much* discover *aesthetically compelling properties in the environment…as* ascribe *them to it on the basis of our individual and cultural beliefs, values, and needs*" (Costonis, 1982, quoted by Bourassa, 1988 p.248). In acknowledging the vital role of culture in how people experience landscapes, Bourassa's ideas overlapped with the emerging field of 'therapeutic landscapes'. Informed by the work of cultural geographers, this perspective considers how people might derive value from various settings through symbolism and a sense of place, and explored issues such as hegemony and marginalisation (Gesler, 1992). Although beyond the scope of the work presented here, these deeply qualitative investigations have revealed much about how environments can be "*imbued with symbolic meaning*" (Gesler, 1992).

It is also worth noting that Gobster (1999) and Gobster et al. (2007) went a significant step further, reasoning that if scenic aesthetic preferences are pliable cultural artefacts, then 'ecological aesthetics' based on thriving and biodiverse ecosystems could and should be promoted in their place. Although see Parsons and Daniel (2002) for a critical appraisal of this perspective.

Aesthetic appreciation of a landscape then, whether urban or natural, might reasonably be considered a combination of both innate, adaptive mechanisms, and semiotic conditioning: framed as a series of subjective perceptions informed by emotion, knowledge, and culture; viewed with an emphasis on common and intrinsic notions of beauty; or conceptualised through a mix of these both objective and subjective processes (Brady & Prior, 2020; Gobster et al., 2007; Lothian, 1999). And as Bourassa neatly summarised, "*it is not relevant to speak of the aesthetics of individual objects in the landscape (e.g. buildings) without asking how those objects contribute to the wholes…of which they are only parts*" (Bourassa, 1988).

Significant value exists in understanding the factors that underpin perceptions of a setting's aesthetic value, often measured by simple scalar appraisals of 'beauty' (e.g. Han, 2007). This is particularly true for digital representations of nature, where even compositional choices, such as aligning features according to the 'rule of thirds' might influence appraisals (Svobodova et al., 2014). More importantly, if producers of digital nature content must make choices about which scenes to portray, either through live-action filming or via computer generated graphics, clues governing which visual elements should be included might help tailor these encounters for specific outcomes (e.g. BBC Four, 2020).

For example, among the features identified as high in aesthetic value are bodies of water (Herzog, 1985; Howley, 2011; Nordh et al., 2009; White et al., 2010) with reflective properties (Nasar & Li, 2004), high levels of complexity and openness (Han, 2007), leafy green foliage (Pheasant et al., 2010), and mountains (Howley & O'Donoghue, 2011). Recent research has also revealed how novelty in landscape views can augment aesthetic preferences (Wang et al., 2019), particularly for tourists (Kirillova et al., 2014).

Yet several gaps also remain in understanding the myriad factors that might impact how a (digital) landscape is aesthetically appraised. Which areas might have been overlooked?

2.10 Soundscapes

The efforts described thus far to estimate the restorativeness of an environment have a clear drawback: they were developed to focus on the visual modality. Despite the early acknowledgement that contact with nature is a multi-sensory experience (Ulrich, 1983) and that sounds can augment landscape preferences (Anderson et al., 1983), it was some 30 years before a concerted effort was made to include sounds in the assessment of restorative potential.

The major advance in this area was made by Payne (2013), who built on the work of Hartig et al. (1997b) to develop a multi-item perceived restorativeness soundscape scale. Whilst failing to resolve a four-factor structure, the scale was sensitive to differentiations between the restorativeness of soundscapes from urban and rural settings, and within the same environment. Echoing the progression of the original vision-based scale, Ratcliffe et al.

(2016) and Ratcliffe et al. (2018) extended this work by using a single-item measure of restorative potential in their assessment of bird song.

In doing so, both Payne and Ratcliffe brought much needed attention to the role of sound in therapeutic nature-based experiences, a vital component of both real and digitally mediated nature encounters, and a burgeoning seam of research which has gained momentum since the turn of the millennium.

2.10.1 Nature-based soundscapes

An exploration of sound must first acknowledge the many ways in which terms such as 'sound' and 'soundscape' can be interpreted. In its series of standards on acoustics, the International Organization for Standardization (ISO, 2014) makes several definitions useful to this discussion:

- *Sound sources* are considered sounds generated by nature or human activity.
- The *acoustic environment* is represented by all sound sources in an environment (actual or simulated, outdoor or indoor, as experienced or in memory).
- *Soundscape* is defined as the acoustic environment when perceived, experienced, and understood by a person or people, in context.

Whilst there are several other definitions of the term soundscape – and frustration at frivolous use of the term (Kelman, 2010) – as Kang et al. (2016) noted, the key difference between an acoustic environment and a soundscape is the role of subjective interpretation in the latter. Payne et al. (2009) elaborated more explicitly on this nuance in their description, defining soundscape as the "*totality of all sounds within a location with an emphasis on the relationship between individual's or society's perception of, understanding of and interaction with the sonic environment.*"

It is this definition that will be used in this review, acknowledging the many factors which can influence the therapeutic potential of the acoustic environment.

2.10.2 Deleterious sounds

A significant body of work has been dedicated to understanding the impacts of environmental sound, yet much of this work has been viewed from the perspective of unwanted sounds, now ubiquitously termed 'noise' and 'noise pollution'.

The concept of noise is not a contemporary nor a purely urban phenomenon. Whilst the term has been used in both a positive and negative context over time, its use to describe unwanted sound can be dated as far back as 1225 (Schafer, 1977). Indeed, before the advent of mechanised travel, the inhabited world was far from quiet. In the UK for example, villages echoed with the rattling passage of the horse and cart and the hammering sounds of cottage industries (Coates, 2005).

As industrial processes began to replace rustic ways of life and urban sounds encroached on the pastoral acoustic environment, Coates (2005) noted how this change spoke of modernity, "*Quiet was synonymous with indolence, backwardness, and stagnation...a place where you could hear the grass grow (or only the cartwright's mallet and the horse's whinny) was not somewhere you wanted to be*." Schafer (1977) also recognised the subjective nature of defining noise as "*unwanted sound*" observing that "*one man's music may be another man's noise*."

Nonetheless, an overwhelming body of evidence has established noise as a significant environmental and public health issue that contributes to numerous negative psychological and physiological health effects including stress, annoyance, sleep disturbance, and cardiovascular disease (WHO, 2019). Accordingly, much of the soundscape-health related work in recent decades has focused on how to measure and mitigate the issues of noise pollution from transport, industry, construction, and the nighttime economy (Murphy & King, 2014).

This focus on the negative impacts of various acoustic environments is both necessary and ongoing. Indeed, measures designed to control deleterious sounds such as sound barriers, new road surfaces, and sound crystals (Berge et al., 2017; Martínez-Sala et al., 2006; Martínez-Sala et al., 1995) are increasingly relevant as urban settings continue to grow. But an emphasis on the suppression of negative acoustic stimuli has occurred to the detriment of a second, complementary approach: the promotion of positive sounds.

2.10.3 Sounds as resources

Efforts to redress this balance have been made in recent governmental policy. For example, the European Commission's Environmental Noise Directive aimed to prevent and reduce unwanted environmental noise, yet also placed an emphasis on "*preserving environmental noise quality where it is good*" (European Commission, 2020). Highlighting the importance of positive sound sources in 'good noise quality', this sentiment was expanded by the Mayor of London's Ambient Noise Strategy, which recognised the "*counterpoint to urban noise offered by natural sounds*" and the wellbeing potential of aquatic corridors that can be "*explored in terms of their changing sound environments*" and might provide "*places for tranquil enjoyment*" (Mayor of London, 2004). Both of these acknowledgements have paved the way for the positive potential of aural landscapes to be included in policy and planning, but what represents an *ideal* soundscape?

In some cases, favourable soundscapes in urban and rural areas have been seen as synonymous with 'quiet', although the definition of what constitutes an adequate level of 'quietness' has attracted fervent discussion (Memoli et al., 2008). However, Brown (2015) contended that absolute quiet is not a key component of acoustic preference in the outdoor environment, and the term ‘natural quiet’ may offer a more useful definition. Brown described natural quiet as “*the absence of mechanical noise, but containing the sounds of nature, such as wind, streams, and wildlife, as well as visitor-generated self-noise*” (Brown, 2012). De Coensel and Botteldooren (2006) endorsed this idea with their suggestion that silence should be defined as “*the ambience of a soundscape*”, phraseology also used by Mace et al. (2004) who considered the preservation of ‘ambient silence’ (used synonymously with natural quiet) as a vital strategy in US national park management.

Indeed, it is this perspective that has informed much of the investigation into the positive potential of nature-based soundscapes, where natural elements of the acoustic environment (rather than the lack thereof) are seen as valued resources (Brown, 2012; Kang et al., 2016; Mace et al., 2004).

2.10.4 Soundscape models

Given the broad range of disciplines involved in natural soundscape research, numerous and varied attempts have been made to unpick and understand how the constituent components of a soundscape might be perceived (comprehensively reviewed by Payne et al., 2009).

Schafer (1977) wrote the original treatise on soundscape, and has been credited with popularising the term (Kelman, 2010). With a background in composing, Schafer took a highly musical view of the way soundscapes are constructed, defining sound types as “*keynotes*”, “*sound signals*”, and “*soundmarks*”. Under this schema, the keynote of a coastal soundscape might be the sound of waves breaking on the beach, its sound signal might be the calls of an oystercatcher, and its soundmark might be the drone of a fog horn. Schafer also referred to “*hi-fi*” soundscapes as those which have a high signal to noise ratio and therefore allow the determination of individual sounds. He contrasted these with “*lo-fi*” acoustic environments where a cacophony of sounds become noise and individual sounds can no longer be easily distinguished.

Andringa and van den Bosch (2013) and Andringa and Lanser (2013) adopted a more biophysical perspective, arguing that the primary evolutionary role of hearing was to estimate the level of danger an environment presented. They suggested that soundscape quality is judged by safety-based evaluations, with evolutionarily ‘normal’ background and foreground sounds, such as a river and bird song respectively, requiring little attentional resources. In their model, Schafer’s hi-fi environments allow a user to determine normalcy, safety, and derive restorativeness. In contrast, lo-fi soundscapes require constant analysis of threats and consume cognitive resources. They predicted that pleasant sounds will often be those which allow a person to make a positive assessment of safety.

In line with this adaptive narrative, Pheasant et al. (2010) built on the principles of prospect refuge theory (Appleton, 1996) to suggest that due to their importance for survival, reacting favourably to acoustic signatures such as rivers, waterfalls, and prey animals would have conferred selective advantages. To emphasise the importance of sound in humans' evolutionary history, they also cited work from Jaśkowski et al. (1990) that demonstrated how auditory reaction times are ~50ms quicker than those related to the visual modality.

Attempting to create a "*cognitive*" sound map, Matsinos et al. (2008) delineated sound sources according to their geophysical, biological, and anthropogenic origins, a theme which is echoed in the field of soundscape ecology where sounds from these sources are labelled as geophony, biophony, and anthrophony respectively (Pijanowski et al., 2011). These approaches highlight how spatial and temporal variations in sound sources can influence a soundscape (Miller, 2008). For example, geophony at a given location will vary according to weather, biophony according to the time of day or season, and anthrophony due to cultural and economic factors.

Across each of these perspectives, it is clear that soundscapes are composed of distinct elements that can vary temporally, spatially, and in the ways they are interpreted by listeners. This variability inherent in the 'real world' provides significant challenges to achieving an 'optimum' acoustic configuration for any given outcome, such as restoration. Yet investigations into natural and urban soundscapes have also revealed several consistent trends.

2.10.5 Natural sounds and restoration

In their development of an "*affective auditory stimulus database*" Yang et al. (2018) accumulated valence, arousal, and basic emotional ratings for over 900 sounds. Of most relevance here, they found abiotic sounds and particularly those featuring water to generally be considered low in arousal, and the sounds of birds to be rated highly for happiness. Indeed, at a broad scale, listening to the soundscape of the natural world is almost always preferred to that of the urban world (Alvarsson et al., 2010; Benfield et al., 2014; Schafer, 1977), with elements such as bird song (Buckley, 2023; Hedblom et al., 2014; Ratcliffe et al., 2013, 2016) and flowing water (Alvarsson et al., 2010; Carles et al., 1999; Yang & Kang, 2005) repeatedly receiving high preference ratings (Brown, 2012). Supporting the notion that environmental preferences are closely related to restoration (van den Berg et al., 2003; Wilkie & Clouston, 2015), a growing body of research has also demonstrated how these favoured soundscape elements are associated with restorative benefits.

In a narrative review of the state of the art in nature soundscape and restoration research, Ratcliffe (2021a) emphasised the early body of qualitative work in this field. This review identified natural sounds as vital components of environmental encounters, and highlighted how many people notice when sounds are *missing* from an experience, particularly one that is digitally mediated (Fredrickson & Anderson, 1999; Kjellgren & Buhrkall, 2010). Other investigations cited by Ratcliffe (2021a) also demonstrated how natural sounds can lead to both positive affective outcomes and feelings of restoration (e.g. Curtin, 2009) in a range of environments, including coastal locations (Nicolosi et al., 2021).

Ratcliffe's own experimental work echoes these themes, with qualitative interviews and quantitative data demonstrating bird songs and flowing water as highly rated restorative sounds (Ratcliffe et al., 2013, 2016), and highlighting the importance of lived experience in participant responses, with highly restorative sounds more likely to conjure memories of verdant environments, home and gardens, and warm weather (Ratcliffe et al., 2016). Ratcliffe et al. (2018) took a more compartmental approach, focusing instead on the acoustic and aesthetic properties of individual bird sounds. They found that subjective ratings of familiarity and complexity were the most significant predictors of perceived restorative potential, whilst bird sounds exhibiting harmonic, high frequency, and low sound level characteristics were also rated as highly restorative. Their analysis also suggested familiar bird sounds were more likely to be restorative than unfamiliar sounds.

In a systematic review and meta-analysis of 18 studies focused on the health benefits of natural soundscapes, Buxton et al. (2021) revealed positive changes in affect, stress, annoyance, and cognitive performance across a range of studies. They also found a negative association between visits to US national parks and soundscape quality, a trend that could be partly explained by busy parks being close to urban centres.

This theme extends a long history of valuing the importance of soundscape quality in protected US wilderness areas, where the suppression of anthropogenic noise, and the promotion of natural quiet has been a policy focus since the mid-20th century (Levenhagen et al., 2021; Mace et al., 2004; Miller, 2008; Stack et al., 2011; Taff et al., 2014). This sentiment has been mirrored in studies of urban soundscapes, which highlight the competing effects of anthropogenic and natural sounds (Uebel et al., 2021; Uebel et al., 2022).

However, others have taken a more positive perspective and considered how natural stimuli might enhance experiences in urban environments. These studies suggest natural sounds can mask traffic noise (Coensel et al., 2011; Hao et al., 2016; Nilsson et al., 2010; Rådsten-Ekman et al., 2013; Van Renterghem et al., 2020) and improve evaluations of urban soundscapes more generally (Hedblom et al., 2014), with even artificial natural sounds improving urban soundscape perceptions (Cerwén, 2016). Although see Hedblom et al. (2019) who found that birdsong did not reduce skin conductance levels, a proxy measure for psychophysiological stress, in a virtual urban park.

In another, more tangential area, natural sounds have also been explored in relation to eating behaviour, with early studies linking nature-based soundscapes with intentions to buy organic food (Spendrup et al., 2016) and differential perceptions of taste (Lin et al., 2019).

2.10.6 Soundscape ecology

Acoustic characteristics are increasingly being explored in the field of soundscape ecology, which considers the implications of spectral, spatial, and temporal changes to the aural markers of a landscape (Pijanowski et al., 2011). By measuring changes in soundscape composition, soundscape ecology offers a novel way to assess changes in biodiversity that may not be revealed through visual surveys (Krause & Farina, 2016).

These approaches often consider variations in aural complexity as indices of 'acoustic biodiversity', and are commonly used to monitor changes in species richness and ecosystem health (Sueur et al., 2021). The application of these techniques is largely deployed in natural environments such as forests, with particular emphasis on revealing the impacts of industrial processes such as deforestation (Burivalova et al., 2019).

With its focus on non-human ecosystems however, little work in this field has considered how changes to natural soundscapes, such as those observed in pandemic lockdowns (Derryberry et al., 2020), may impact human experience. However, when it comes to avian species, population decline, extirpation, and even extinction can threaten natural soundscapes (Rosenberg et al., 2019). But can non-specialists notice these changes and how might they impact people's experiences in natural environments? Moreover, the contrasting sound sources identified by soundscape ecologists, such as geophony and biophony, are often haphazardly combined in restoration research (e.g. Alvarsson et al., 2010), highlighting a gap between these two fields.

Some efforts have been made to unite these approaches. Ferraro et al. (2020) increased perceived acoustic biodiversity by playing birdsong through hidden speakers, demonstrating enhanced feelings of restoration in hikers. And Buxton et al. (2021) characterised sounds according to geophony and biophony (water and birds respectively), finding that water exerted the greatest positive effect on health and affective outcomes, whilst bird sounds were associated with reductions in stress and annoyance.

In his introduction to *The Great Animal Orchestra*, Bernie Krause vividly described soundscapes from biomes as diverse as a boreal forest and the Gulf of St Lawrence (Krause, 2012). It has previously been suggested that sounds from varying sources may confer differential restorative benefits (Ratcliffe et al., 2013), and it is clear that sounds such as a babbling brook or singing blackbird differ in origin, distribution, temporality, and meaning. Yet so far, there has been no systematic attempt to unpack how contrasting sound types, across a range of biomes, might complement or compete with one another to provide restorative outcomes.

2.10.7 Anthropogenic sound reframed

Another area that has been largely overlooked by soundscape ecologists and nature-restoration researchers is the role of anthropogenic sounds in restoration.

As detailed in section 2.10.2, sounds from human sources are overwhelmingly associated with negative impacts on soundscape ratings (Miller, 2008). However, some studies have noted positive ratings for 'culturally approved' sounds such as church bells and music (Yang & Kang, 2005), and used nature-based sounds 'enhanced' with classical music as restorative stimuli (Goel & Etwaroo, 2006 – the role of music in nature-based experiences is considered in more detail in section 2.12). Moreover, the natural world does not exist in isolation from humankind, which shares a strong cultural connection with nature-rich environments, particularly with respect to health (Ward Thompson, 2011). Whilst human voices can negatively impact appraisals of natural soundscapes (De Coensel & Botteldooren, 2006) and intrusions of speech are often viewed as negatively valenced 'noise events', they may be more favourable in urban soundscapes (Guastavino, 2006). Thus, in the right context, soothing and culturally appropriate voices may form complementary additions to a soundscape.

For example, Karmanov and Hamel (2008) used cultural additions to experimental stimuli to explore the impact of knowledge and culture on people's experience of place. They wrote a story to accompany videos of natural and built environments, leading to significant increases in interest and attractiveness between scenes with and without this narrative. The therapeutic potential of written and spoken word has been extensively investigated in the field of bibliotherapy, where both fictional and non-fictional materials have been used to treat a range of psychological issues (McKenna et al., 2010).

Poetry in particular has demonstrated the potential to induce positive emotions (Obermeier et al., 2013; Wassiliwizky et al., 2017), reduce feelings of loneliness (Xiang & Yi, 2020), and form an effective intervention for pain management (Arruda et al., 2016). The sounds of nature are increasingly being paired with spoken word in commercially available relaxation tools (e.g. headspace.com and calm.com), with videos of this content amassing many millions of online views (e.g. https://youtu.be/5mGifCwig8I). Moreover, both 'nature poetry' and 'green poetry' (Gifford, 1995) have a history of motivating social movements to protect the natural environment (Elder, 1996; Felstiner, 2009).

Yet despite their frequent pairing, very little is known about the potential role that 'culturally approved' spoken word might have on nature-based soundscapes and their subsequent restorative potential.

In this vein, it has been suggested that knowing listeners "*and their cultural heritage is a key factor in deciding what sounds give the desired meaning*" (Kang et al., 2016). The importance of this approach is exemplified in evidence suggesting lived experience and cultural connotations are responsible for contrasting responses to bird species, with the robin highly favoured in the UK (Cox & Gaston, 2015) yet owls associated with negative symbolism and superstition (Ratcliffe et al., 2016). Moreover, although the squawking of crows is generally considered to be unpleasant (Ratcliffe, 2021a), others have found that people can form positive relationships with corvids and their behaviour (Bell, 2019).

The role of meaning and associations in the interpretation of sounds has been highlighted by several innovative studies. Haga et al. (2016) successfully manipulated responses to white noise by attributing its source to a waterfall, or industrial machinery. Participants in the waterfall group reported higher levels of psychological recovery than those in the industrial group, suggesting positive associations with nature, rather than purely adaptive preferences, were helping to shape responses. Supporting this finding, Van Hedger et al. (2019) demonstrated that ratings of urban and natural soundscapes were almost entirely dependent on the associations ascribed to each sound, rather than their acoustic properties.
And focusing on neurological markers, Hunter et al. (2010) paired a white noise soundscape with either images of a freeway or beach, demonstrating changes in brain activity between conditions that suggested subjective experience may be important in the neurological construct of tranquillity.

2.10.8 Conservation outcomes

A multitude of influences might impact a person's feelings about the natural world. Indeed, the overarching trend of declining links between people and nature – exemplified by shifting baselines, environmental generational amnesia, and the extinction of experience (section 2.13.4) – can also impede a broader set of outcomes, including the development of pro-environmental attitudes (Gaston & Soga, 2020; Soga & Gaston, 2016; Soga & Gaston, 2018).

Gifford and Nilsson (2014) identified 17 factors that can affect environmental concerns. Among these, childhood contact with nature was highlighted as a vital pathway to pro-environmental actions later in life, echoing the importance of lived experience in people-nature interactions (section 2.13.1). Place-attachment and cultural factors were also included in this list, as were demographic descriptors such as education, ethnicity, gender, and age.

It must be noted that whilst environmental concern and environmental behaviour are closely linked concepts, they are not directly analogous. For example, Gifford and Nilsson (2014) suggested that although pro-environmental consumer behaviours have been most associated with older people, younger age groups tend to report higher levels of concern about the environment. Two contrasting mechanisms might underlie these differences: older generations, influenced by post-war scarcity, may have adopted less wasteful consumer practices that stayed with them until later life – their environmental behaviour may be a *by-product* of self-interested motivations to save money; in contrast, younger generations' environmental concerns may be driven by more altruistic worries about ecosystem health and leaving a positive environmental legacy for future generations (Gifford & Nilsson, 2014).

Bamberg and Moser (2007) outlined how pro-environmental behaviour is often a mix of each of these processes, with the 'self-interest' model aligning most closely with Azjen's theory of planned behaviour (Ajzen, 1991), whereas more altruistic, pro-social motivations can be best explained by the norm-activation model (Schwartz, 1977). Whilst a detailed consideration of the theoretical underpinnings of environmental concern and behaviour are beyond the scope of this thesis, it may be of merit to explore how they might overlap with a restoration-based framework: how might nature restoration and pro-environmental behaviour be linked?

For example, would people be more motivated to preserve natural environments if they believed they could provide relief from stress and fatigue? This self-interested, 'egoistic' perspective would suggest that people might value an environment's restorative potential and wish to conserve those properties for their own gains. Alternatively, how might more top-down influences, such as lived-experience in the form of memories or a connection to nature, impact pro-environmental motivations? This more altruistic behaviour could be best explained by the activation of personal norms (Stern & Dietz, 1994).

Moreover, could these questions be applied to an exploration of natural soundscapes? Nature-based sounds are increasingly viewed as resources that must be protected (Buxton et al., 2017a) for both human and ecosystem outcomes – a task that is one focus of soundscape ecology (Dumyahn & Pijanowski, 2011). Yet little is currently understood about how changes to an ecosystem's soundscape might be experienced, or even noticed, by human non-specialists. How willing would people be to preserve these sounds?

2.10.9 Valuing ecosystems

Societal efforts to preserve both natural and socio-cultural heritage are big business, and this 'preservation motivation' is often underpinned by desires to convey the meaning and value of a place to human wellbeing (Prince, 1989). This trend has been expanded in recent decades under the banner of ecosystem services, a broad framework that considers the numerous ways that natural environments can support human functions (Millennium Ecosystem Assessment, 2005). This perspective considers how interlinked communities of plants and animals, as well as geophysical processes, can benefit humans. These 'services' include big ticket material functions such as: the provision of water, food, and fuel; the regulation of air quality, climate, and nutrients; and ancillary factors such as pollination, photosynthesis, and carbon sequestration (Millennium Ecosystem Assessment, 2005).

There has also been growing recognition of the need to acknowledge the multitude of aesthetic, spiritual, and social relations that natural ecosystems support. These nonmaterial 'cultural ecosystem services' can be difficult to value and integrate into policy and planning decisions due to their often entangled, intangible, and invisible character (Cheng et al., 2019). Assessing and accurately reflecting the cognitive, stress-related, and affective benefits of spending time in natural environments encapsulates this problem, especially given the complexity of interactions between nature, health, and culture (Hirons et al., 2016). Yet incorporating these factors into ecosystem analyses is vital given their potential to lessen the burden of mental illness in global populations, and they might best be considered a distinct typology of "*psychological ecosystem services*" (Bratman et al., 2019).

What factors should be considered in models that identify these psychological ecosystem services? Bratman et al. (2019) identified several areas that could delineate the wellbeing effects of people-nature experiences, including types of natural features, length of contact, kind of interaction, and expected outcomes. But the authors also noted that deepening granularity in these areas is a "*key research frontier*" where reductionist principles will help to parse out the contributions of individual factors, for example Bratman et al. (2019) asked "*are some tree species more beneficial than others?*"

In searching for areas that have been underexplored in the current literature, and identified in this review, we could also ask "*are some natural soundscapes more restorative than others?*" And acknowledging the role that personal connections and culture can also play in these relationships (Russell et al., 2013), we might add "*what is the mediating role of lived experience in such encounters?*"

In 1962, Rachel Carson used the portent of a 'silent spring' (Carson, 1962) to encapsulate the threat of catastrophic defaunation and launch the modern conservation movement (Davis, 2012). In 1971, recordings of humpback whale songs (Payne & McVay, 1971) helped to galvanise support for an international moratorium on whaling (Schneider & Pearce, 2004). Today, understanding responses to natural soundscapes may prove central to gaining a holistic insight into people's evolving relationship with nature.

If sound represents an under-researched part of environmental sensing, which other areas may have been overlooked?

2.11 Ephemeral phenomena

In 1983, Roger Ulrich noted that "*One issue that has received virtually no attention is responsiveness to natural settings containing prominent ephemeral phenomena. The intuitive literature is replete with accounts of emotional reactions to, for instance, sunsets, cloud formations, and freshly fallen snow…some ephemeral conditions probably elicit strong affective reactions and therefore are important factors in many memorable experiences in the natural environment. This topic has been so neglected that even responses to common ephemeral conditions associated with seasonal changes, such as the absence of foliage on deciduous vegetation in winter, have not been empirically evaluated*" (Ulrich, 1983).

However, over the last forty years, it has become routine for studies attempting to unpick the therapeutic components of nature to focus on visual, structural, landscape factors. For example, in both urban and natural environments, researchers have identified preferences for: water (Herzog, 1985; Howley, 2011; Nordh et al., 2009; White et al., 2010); 'greenness' (Fong et al., 2018; James et al., 2015); trees and flowers (Weber & Trojan, 2018; Wolf et al., 2020); mountains (Howley, 2011); building design (Chen et al., 2015; Lindal & Hartig, 2013; Nasar, 1994); transport infrastructure (Evangelinos & Tscharaktschiew, 2021); and historical and cultural sites (Galindo & Hidalgo, 2005). A recent review by Li et al. (2023) also attempted to acknowledge the importance of less-researched structural features, such as snow, sand and soil, caves, and volcanoes.

Each of these elements tends to be relatively fixed and unchanging, at least on yearly or decadal timescales, and continue to be fervently investigated (e.g. Wang et al., 2020). Yet landscape experience can also be significantly influenced by features that might vary on finer temporal scales, a process recognised over 90 years ago when Finnish geographer J.G. Granö asserted that a complete picture of a site could only be achieved with repeated and frequent observations (Palang et al., 2005).

For example, seasonal shifts can change the color or form of a landscape and exert a substantial effect on aesthetic appraisals (Buhyoff & Wellman, 1979). Autumnal and floriferous periods are often particularly valued (Junge et al., 2015; Kuper, 2018), as are increases in factors such as crop diversity (Häfner et al., 2018). Livestock presence can influence preferences for agrarian settings (van Zanten et al., 2014), and the wider presence of wildlife and its behavior might impact evaluations of scenic quality (White et al., 2017b), especially for landscapes judged to be less beautiful than others (Hull & McCarthy, 1988). In the US, cyclically variable factors such as temperature and tidal state have also been associated with the perceived restorativeness of Californian beaches (Hipp & Ogunseitan, 2011).

These kinds of variations tend to be recurring and rhythmical (Palang et al., 2005), and in the same vein as more structural features, have garnered reasonable attention in landscape research (see Junge et al., 2015; Stobbelaar & Hendriks, 2007). But what about changes that might occur on still finer timescales?

Tveit et al. (2006) identified short-term ‘ephemera’ as one of nine visual characteristics that should be factored into landscape assessment. They cited Litton (1973) who noted the possible impacts of “*natural phenomena occurring at a given point in time, producing a visual product that is characteristic of that moment*”. Tveit et al. (2006) also highlighted how ephemeral features have been described as ‘special effects’ and noted how others (e.g. Trent et al., 1987) had identified the potential for changes in flowering plants, seasonal colours, and weather to impact the ‘aesthetic potential’ of an environment. And in their assessment of landscape experiences while hiking, Hull and Stewart (1995) revealed that "*ephemeral features seemed to attract a disproportionate amount of a hiker's attention…In fact snow, flowers and wildlife were the focus of attention almost 12% of the time, although they comprised much less than 12% of the total landscape.*”

But it was Paul Brassley who, in 1998, wrote *the* comprehensive treatise on what he termed “*landscape ephemera*” (Brassley, 1998). Acknowledging the possible significance of seasonal change under this banner, Brassley’s most striking contribution came with his recognition of how the appearance of landscape might “*change from minute to minute, or through the day*”. He highlighted how the “*momentary effects of sun and cloud*” could briefly alter how a place is experienced and suggested that in flatter landscapes, “*changes in the sky* *are especially important*". Crucially, Brassley observed how a "*landscape seen on a sunny day obviously looks different from the same landscape seen under cloud or in rain or mist*" (Brassley, 1998). Brassley's use of the word "*obviously*" in the latter statement is pertinent; everyone will be familiar with the effects he describes.

Yet despite this recognition, the field of environmental psychology, and quantitative analyses in particular, have remained largely silent on the topic of unexpected, fleeting, and diurnal intra-landscape changes. Instead, the majority of studies have investigated landscape appraisals using experimental stimuli that represent bright, midday, cloudless, 'blue-sky' conditions (e.g. Collado & Manrique, 2019; Herzog et al., 2003; Ode et al., 2009; Pheasant et al., 2010; van Esch et al., 2019). We consequently know very little about how diurnal features, such as sunrise and sunset, or less frequent meteorological events, such as thunderstorms and rainbows, might impact environmental experiences. What could the effects of these 'ephemeral phenomena' be?

2.11.1 Valuing a view

A clue to the importance of ephemeral phenomena lies in the value attributed to open and expansive views. For example, hotel rooms with a sea view are an average of 10% more expensive than those without a view (Fleischer, 2012), urban settings with panoramic views are considered highly attractive (Galindo & Hidalgo, 2005), and large amounts of sky can increase assessments of preference and restorative potential in metropolitan areas (Masoudinejad & Hartig, 2018). Indeed, large proportions of water and sky are highly preferred in views from urban windows, with views of the sky considered one of the most attractive components of the urban landscape (Mirza & Byrd, 2020). The dynamism inherent in these backdrops might be a vital contributor to their wellbeing potential; watching "*sunrise or sunset*", "*the sky*" or "*the weather*" from a city window has been associated with small increases in participants' effective functioning, satisfaction with nature, and satisfaction with their immediate neighbourhood (Kaplan, 2001a).

Other factors associated with window views, such as sunlight and luminosity, have also demonstrated the potential to impact viewing experiences (Leather et al., 1998; Rodriguez et al., 2021), as has the distance to the focus of a view, which has been linked with higher levels of visual satisfaction, particularly for urban scenes (Kent & Schiavon, 2020). Yet across this work, which focuses predominantly on views that incorporate large tracts of sky, researchers have continued a focus on structural factors such as 'naturalness', 'greenness', and 'vegetation' (Sharam et al., 2023; van Esch et al., 2019).

2.11.2 Weather

Windows provide a view to the vast canvas of the atmosphere, where meteorological changes are constantly unfolding. Indeed, the physical effects of weather, such as higher temperatures, lower wind speed, and longer days, have been linked with activity levels in natural environments (Elliott et al., 2019), and associated with changes in mood and cognition (Keller et al., 2005) under the rubric of seasonal affective disorder (Harmatz et al., 2000). Meteorological vagaries can also play a vital part in the lives of those with visual impairments, changing the experience of being in nature – both positively and negatively – from one moment to the next (Bell et al., 2019b).

But it is the aesthetic effects of weather that are inextricably linked with the generation and appearance of ephemeral phenomena (Vannini et al., 2011). For example, meteorological events may obscure the sky, or emphasise its colours and vibrancy (Freeman, 2014), and atmospheric processes can create brief chromatic artefacts such as crepuscular rays, parhelia ('sundogs'), and exotic clouds like the bulging mammatus (Schultz et al., 2006). These unusual events are routinely recorded and discussed (Pedgley, 2009), and are often captivating enough to be considered newsworthy (BBC Weather, 2021).

Indeed, specific events can hold particular relevance. For example, thunderstorms commonly garner widespread attention (e.g. BBC News, 2020c) and might even have the potential to induce both anxiety (Tomczyk et al., 2021) and awe (Joye & Bolderdijk, 2015). Likewise, the symbolism of rainbows has been associated with both malevolence and benevolence across cultures for millennia (Lee & Fraser, 2001). The Hawaiian language has over 20 words to describe the various forms a rainbow might take, signifying their importance in local culture and the frequency with which they appear on the archipelago (Businger, 2021). But for most, rainbows and thunderstorms remain relatively uncommon and fleeting occurrences.

2.11.3 Sunrise and sunset

In contrast, diurnal changes in solar altitude, manifesting in the sun rising above and setting below the horizon, occur on a daily basis. These events represent perhaps the archetypal ephemeral phenomena, and their importance on landscape experience has been suggested from several quarters.

The 19th century 'luminism' style of landscape painting prized and attempted to capture "*the shimmering quality of atmospheric light*" resulting from the low angle of the sun, and the feeling that in these moments "*time and motion are immobilized*" (Hartel, 2002).

In 1988, Hull and McCarthy noted that "*sunsets are generally agreed upon as having significant scenic impacts, although we have no empirical support of this claim, other than observation of people who go out of their way to observe sunsets*" (Hull & McCarthy, 1988).

In their seminal work on attention restoration theory, Kaplan and Kaplan (1989) suggested that sunsets might be one of the many "*fascinations afforded by the natural setting*".

And in 1998, Paul Brassley pondered how the "*numerous tourists gathering to photograph sunset over the Grand Canyon or the African veld suggest that the landscape experience is in* *some way intensified by the colour changes produced in those brief periods*" (Brassley, 1998).

More recently, Lengen (2015) observed how "*Solar altitude and its effect on visual perception of hue, brightness and colours, also plays an important role in well-being*" and cited a participant for whom these moments held particular value:

"*Yes, the sky… it is reddish coloured… pastel colours…a fine pink shade… yes, I like the sunrise and sunset, it is a metamorphosis, getting calm or still not awake… still, calmness and quietness.*"

In their study of virtual and real-life representations of nature, Chirico and Gagglio (2019) asked "*Is a real-life sunset more emotionally engaging than a virtual sunset?*" They suggested that "*Intuitively, the answer is obvious: gazing at a natural sunset should elicit more intense emotional responses than its virtual counterpart*" but disappointingly, then went on to use a panoramic view without this phenomenon in their experimental stimulus.

Landscapes that feature sunrise and sunset can also capture popular attention depending how they appear on any given day (BBC News, 2020b). And although never explicitly mentioned, a broad set of ephemeral phenomena, from sunsets, rainbows, and thunderstorms, feature heavily in the landscape images used in the development of the Open Affective Standardized Image Set (Kurdi et al., 2017), and score relatively highly in aesthetic judgements (Brielmann & Pelli, 2019). Moreover, the combination of meteorological phenomena and changing solar altitude can produce particularly striking events; high clouds at dusk might create noctilucence (Gadsden & Schröder, 1989) and a brilliant twilight (Corfidi, 2014).

2.11.4 Nighttime

Indeed, the importance of ephemeral phenomena may not end when the sun has set. For example, the allure of the night sky was famously captured by Van Gogh (1888), whilst the presence of a full moon can carry substantial cultural significance (Hua, 2015) and has long been associated with impacts on mental health (Rotton & Kelly, 1985), even if these theories have been largely debunked (Launer, 2021). Moreover, the prevalence of "*night skies drenched in stars*" has been described as an "*inalienable inheritance of humanity*" (Feathers, 2022), with others suggesting "*our search for introspection amidst what we see overhead must have started when the first human eyes looked up at night*" (Moore et al., 2011).

These experiences are becoming rarer due to factors such as light pollution, "*the Milky Way is hidden from more than one-third of humanity*" (Falchi et al.). In this vein the relevance of the night sky to environmental encounters has also been viewed from the perspective of environmental generational amnesia (section 2.6.3), with Kahn and Weiss (2017) lamenting a diminishing interest in "*lying under the summer night stars on cool ground and looking up with awe at that infinity of starlit emptiness*". Whilst the possible impact of the night sky on landscape experience has been largely overlooked in nature-based settings, it has attracted some attention in urban environments.

Nasar and Terzarno (2010) found that participants would rather have a print of a city skyline at night than a natural environment, finding the nighttime cityscape to be more attractive and exciting. Focusing on tourist perceptions, Huang and Wang (2018) found that Hong Kong's cityscape was perceived as more lively, trendy, glamorous, mysterious, and feminine at night compared to during the day. And Zhao et al. (2023) compared the restorative potential of 12 urban green spaces between day and night, finding that day time scenes were consistently preferred. Rockstroh et al. (2019) also included the moon and stars in their experiment using biofeedback in virtual reality, although these elements were not the focus of their study (Fig. 4).

(A)

(B)

(C)

Figure 4. (A) Starry skies and a crescent moon featured in Rockstroh et al. (2019); (B) an example image from Nasar and Terzano (2010); (C) Hong Kong's skyline viewed at night from Huang and Wang (2018).

2.11.5 The importance of ephemera

If ephemeral phenomena can alter experiences of a place from one moment to the next, their effects on landscape encounters might be profound (Brassley, 1998). Yet as Joye and Bolderdijk (2015) lamented, "*In most research on human—nature interactions there has been a tendency to investigate the beneficial psychological effects of fairly mundane natural landscapes…with relatively little attention to the potentially beneficial psychological effects of exposure to more extraordinary kinds of natural environments and phenomena.*"

Thus, despite consistent recognition of the importance of ephemeral phenomena, such as rainbows, sunrises, sunsets, sudden storms, and starry skies, we know very little about how they might impact affective reactions to various landscape views. These effects could be of particular merit in digital environments, where ephemeral features could be included to prompt specific emotional outcomes, and allow people to experience otherwise rare and elusive events.

Moreover, as Brassley noted, "*if people are prepared to part with disposable income to watch the sunset over the Grand Canyon…they are presumably indicating a desire to experience these ephemeral effects*" (Brassley, 1998). Ocean views can increase property prices by 60% and people are willing to pay more for houses with views of water, mountains, and valleys (Benson et al., 1998). Might the potential to witness ephemeral phenomena also impact the perceived value of an environmental view?

If these effects could be detected, they might be included in the modelling of cultural ecosystem services (see section 2.10.9). These models are capable of dealing with ever finer granularity in the factors they include and are being broadened to feature the effects of nature exposure on psychological health (Bratman et al., 2019). Could the effects of ephemeral phenomena be added to these analyses (Fig. 5)?

Indeed, there have been calls for greater research "*at a scale fine enough to assess which components or characteristics of specific landscapes constitute the most important drivers of human health benefits*" (Velarde et al., 2007), an approach that is becoming increasingly relevant in urban settings.

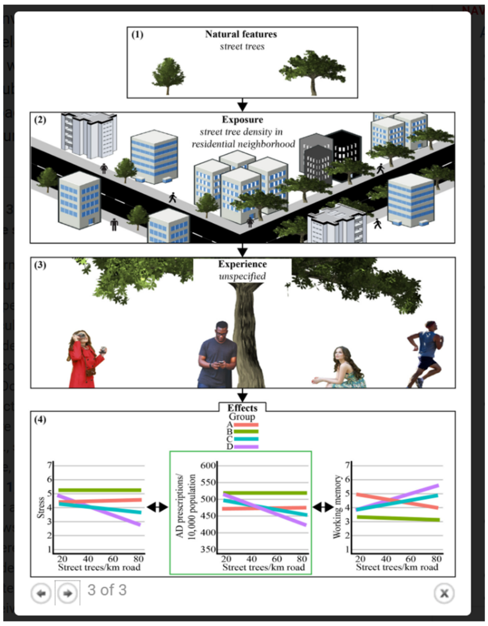


Figure 5. A schematic from Bratman et al. (2019) demonstrating how features such as trees can be built into an ecosystem services model. If the effects of ephemeral phenomena could be identified, they might also be included in a similar way.

2.11.6 Urban nature

In his treatise on North Americans' nostalgia for wilderness, McDermott (1972) lamented how US society was convinced that "*the city is a trap*", would "*seem to give the city credence only to the extent that we are able to import nature, to 'green' it*", and had "*failed to diagnose the limitations and strengths of our present urban context on its own terms, rather than as a function of the absence of nature.*"

McDermot's observations capture a trend prevalent amongst environmentalists throughout the western world; that urban environments are predominantly places of aesthetic and ecological "*disvalue*" (Brady & Prior, 2020). Indeed, Light (2001) noted how in the field of environmental ethics, many authors "*appear outright hostile to the potential of finding value in humanly produced cultural landscapes.*" This theme has been echoed by environmental psychologists, with coarse, dichotomous approaches often pitting verdant natural scenes against busy, grey, and unappealing urban settings (Staats et al., 2003; Tennessen & Cimprich, 1995; Velarde et al., 2007).

Yet a significant body of work has focused on how urban fabric might be 'improved' by including elements of nature, through approaches that often rely on physical interventions to increase the presence of elements such as green spaces, street trees, gardens, and bodies of water (Alvarado et al., 2023; Andersson et al., 2019; Hartig & Kahn, 2016). Evidence abound for how these forms of urban nature can impact resident wellbeing. For example, studies have demonstrated links between natural spaces in cities and increased attention and mood (Kondo et al., 2018), improved eudaimonic wellbeing (de Bell et al., 2020), and greater psychological wellbeing in general (Garrett et al., 2019; Weber & Schneider, 2021; White et al., 2017a).

At a finer granularity, biodiversity and species richness of flora and fauna (Carrus et al., 2015; Southon et al., 2017, 2018), perceptions of 'naturalness' (Hoyle et al., 2019), floriferous planting (Hoyle et al., 2017), the act of "*seeing trees*" (Bakolis et al., 2018), and appraisals of 'wildness' (Allard-Poesi et al., 2022) have emerged as specific elements that might contribute value to the urban experience.

However, opportunities to experience these elements rely on either substantial structural interventions (which in 'compact' cities can be difficult to achieve), or the movement of residents to suburban settings where the grass is, both metaphorically and quite literally, greener (Van Den Berg et al., 2007). It must also be noted that urban greening represents just one approach to metropolitan design that might impact resident wellbeing, for other examples see (Lee & Sener, 2016; Olsen et al., 2019; Sallis et al., 2009).

To what extent might the presence of ephemeral phenomena in the skies above towns and cities provide a frictionless way to enhance the urban environmental experience? In their novel digital study of metropolitan residents, Bakolis et al. (2018) identified "*seeing the sky*" as a key predictor of positive momentary wellbeing, an effect that also lasted several hours after the initial event. And as highlighted in section 2.11.1, panoramic views of the sky have been identified as valued components of urban aesthetics (Galindo & Hidalgo, 2005; Kaplan, 2001a; Masoudinejad & Hartig, 2018; Mirza & Byrd, 2020). People may even prefer urban skylines at night (section 2.11.4) compared to attractive nature-based vistas during the day, and consider the former more exciting in general (Nasar & Terzano, 2010). Nighttime cityscapes have even been considered by some as a new form of 'nocturnal sublime' (Stone, 2021).

2.11.7 Contingent valuation

In line with the arguments made in section 2.10.9, capturing the potential of ephemeral phenomena to augment landscape experience may be an important cultural ecosystem service to include in planning policies.

One method that has proved successful in this endeavour is hedonic pricing (ONS, 2018), which is increasingly employed to determine the effects of environmental externalities on property values (Nicholls, 2019). These studies have allowed estimations of the market rates for factors such as air quality, water standards, and pollution (Boyle & Kiel, 2001). Hedonic pricing has also begun to tackle the economic appraisal of inherently aesthetic factors, such as the view from a property. Efforts to place monetary values on these aesthetic externalities have typically concerned the impact of visible water (in the form of an ocean, river, or lake), with panoramic views adding up to 60% to the price of waterfront housing and 6% to landlocked properties, with the bulk of this premium purely attributable to increases in aesthetic value (Benson et al., 1998; Bourassa et al., 2004). Although not dealt with explicitly, implicit in the descriptions of views considered in this work is a commensurately large tract of sky, from which weather dependent, dynamic, and ephemeral features can also be observed (Kaplan, 2001a). Yet including this kind of variable aesthetic experience in regression models, that are dependent upon relatively coarse and quantifiable parameters, remains elusive.

In lieu of a market-based, hedonic pricing model for determining the value of natural capital, contingent valuation methods are often employed instead (Haab et al., 2020). These approaches ask survey participants how much they are willing to pay for a specific outcome and despite methodological criticisms (Diamond & Hausman, 1994; Hausman, 2012), are regarded as a suitable way to determine the 'existence value' for a public good when there is no revealed preference method or market comparison (Hanemann, 1994; Perni et al., 2021; Venkatachalam, 2004). Estimating the economic value of natural capital is a vital underpinning for decision-making that aims to preserve ecological processes and the myriad services they provide (Daily et al., 2000). Thus, contingent valuation is increasingly being used to quantify the impacts of ecosystem degradation (Zambrano-Monserrate & Ruano, 2020) and has also been applied to the valuation of aesthetic change (Dupras et al., 2018).

Meaningfully integrating these components into models that attempt to capture ecosystem services is likely to prove challenging, not least because of the difficulties presented by moving from stated preference values to the monetary quantification of qualities such as 'scenic beauty' (Daniel et al., 2012). Nevertheless, identifying areas that populations care most about and believe should be prioritised must be a fundamental part of modern planning policies (Chan et al., 2012).

How then, might ephemeral meteorological phenomena and diurnal rhythms affect people's experiences in towns and cities? And if ephemeral phenomena form an intrinsic part of the aesthetic value of an environment, could this value be very cautiously quantified?

In furthering these lines of inquiry, particularly in urban settings, we might also address another conundrum posed by Brassley (1998), asking if "*the relative importance of the ephemeral is itself one of the defining characteristics of rurality*"?

Whilst ephemeral phenomena might represent a hitherto overlooked component of nature-based experiences, another, equally as ubiquitous presence has also evaded attention, music.

2.12 Music

"*The public, I must say, went completely mad over the nightingale, the experiment touched a chord in their love of music, nature and loveliness.*"

Beatrice Harrison, edited by Cleveland-Peck, 1985, p133, in (Baird, 2015).

In 1924, the sounds of nature, and of a nightingale specifically, were heard live for the first time on BBC radio. The nightingale's song was not alone, however, but accompanied by music played by cellist Beatrice Harrison (Baird, 2015). A staggering one million people tuned into the broadcast and although it was recently revealed that in that inaugural performance, the nightingale had suffered from stage fright and a human impressionist had to stand in at the last minute (The Guardian, 2022), successful 'duets' between Harrison and the nightingales would become an annual tradition lasting many years (Baird, 2015).

2.12.1 A history of nature and music

Yet Harrison was not the first to highlight the synergy between natural sounds and music. The recent discovery of 50,000 year old neanderthal flutes, made from bone, suggests that much like the songs of birds and whales, communicating via melody might have been a central part of hominin development – when humans might have been considered more recognisable as *a part*, rather than *a master*, of nature (Gray et al., 2001). Indeed, relationships between music and nature were considered by the ancient Greeks (Allen, 2011) and East African tribes have included the low frequency sounds of elephants in their music for centuries (Gray et al., 2001).

In the middle ages, birds and imitated birdsong routinely featured in musical compositions, with species such as the European cuckoo and nightingale receiving particular attention (Jensen, 1985). However, the prevailing consensus in the middle ages was one that contrasted animal sounds from human produced music, due to the scientific and artistic underpinnings of the latter, as Elizabeth Leach described, "*that which makes music an art is that which separates it from nature and the natural voices of birds*" (Leach, 2007).

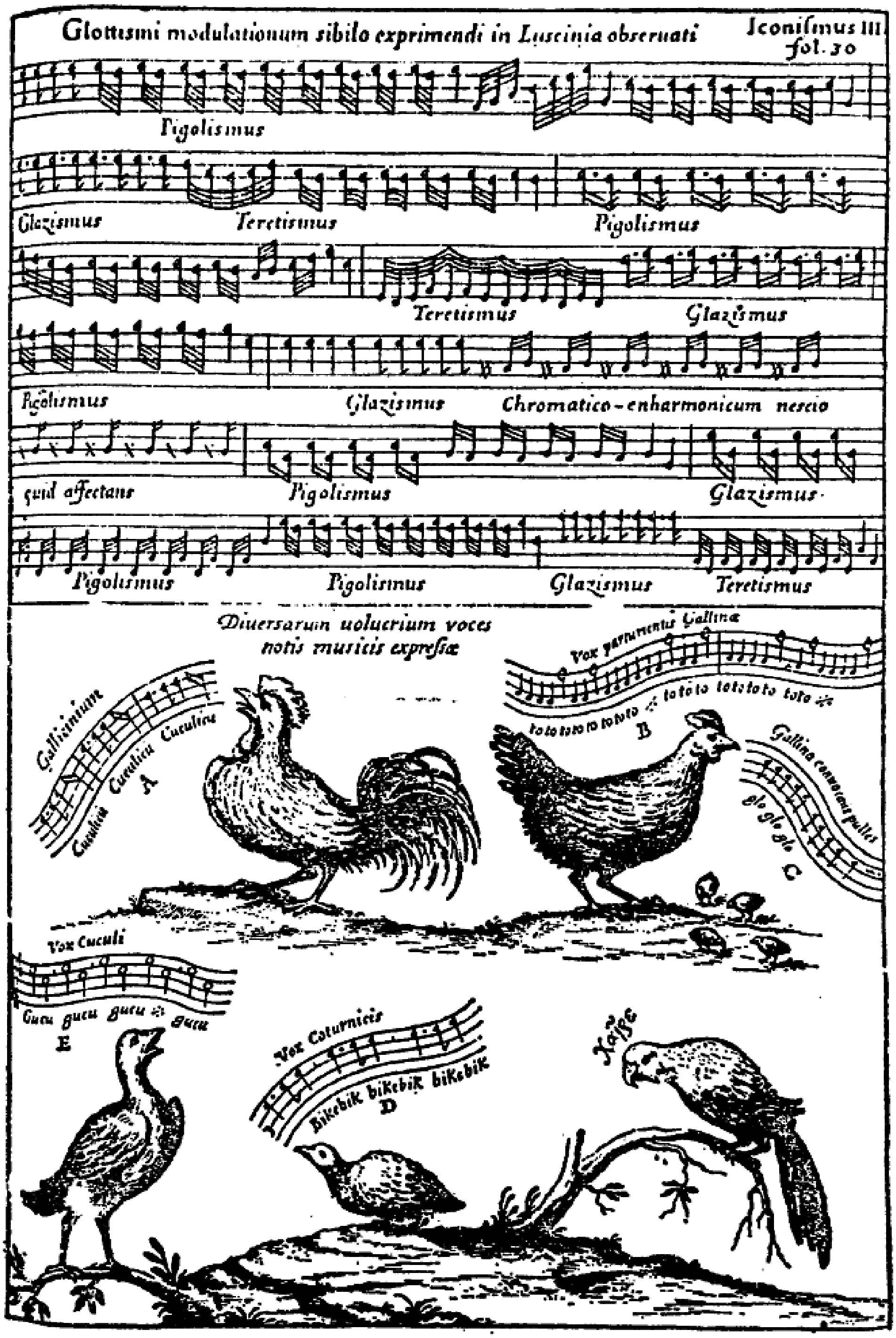
Yet in his treatise on *The Music of Nature*, William Gardiner prefaced the edition with the assertion that "*the instances here recorded are a faithful transcript of the voice of Nature, and it will strike everyone, that music has had its origin in these simple and immutable expressions*" (Gadiner, 1841). Amongst an extensive treatment on the many ways human and non-human sounds are produced, Gardiner created musical notations for bird song and reflected on their similarities with the human register:

"*The song of the cuckoo I have invariably found in Leicestershire to be in the key of D. If the cuckoos in other countries should be found to accord with this curious fact, as nature is pretty much the same, we may take these notes as a standard of pitch. White of Selborne* *observes, 'I have tried all the owls in this neighborhood with a pitch-pipe, and found them to hoot in B flat, and the cuckoos to sing in the key of D'"* (Gadiner, 1841).

In 1879, Xenos Clark also highlighted how passerine bird song was perfectly tuned to human standards of musicality "*as tested by trained ears, a dozen singing birds of different kinds in the same room made no disagreeable dissonance*" (Clark, 1879). This comparison has also been made for humpback whale songs, which use rhythms, scales, tones, and structures remarkably similar to those found in human compositions (Gray et al., 2001). In his thesis on "*animal music*", Clark invoked inherited and adaptive traits for these similarities, citing Darwin's still recent work on the theory of evolution (Clark, 1879). These ideas also have modern day analogues, see (Fitch, 2006; and Mithen, 2006) for comprehensive comparisons between human and animal 'music', and evolutionary mechanisms in their development.

Clark's principles contrasted with aesthetic considerations of music at the time, where scholars prized the seemingly transcendent qualities of 'nature music'. Emily Dolan (2008) suggested that "*instruments were not simply devices designed to harness the most perfect tone, but rather attempts to create portals through which humans could experience nature's sublime and ethereal voice*" and highlighted how "*the difficulty of mechanically reproducing the sounds of nature imparted the aura of authenticity to the idea of those sounds: it confirmed that they were indeed ideal, untameable by man, and that music was not wholly of this world.*" Indeed, in her description of the Aeolian harp, Dolan (2008) noted how this ancient instrument embodied the idea that "*music was an organic part of nature…By coaxing [haunting sonorities] from wind, the Aeolian harp seemed to whisper nature's secrets to the enchanted listener.*"

Composers such as Beethoven agreed. His *Pastoral Symphony* aimed to mimic the sounds of birds, running water, and thunder, reflecting both the importance of natural sounds to the composer and also "*the inherent musicality of those sounds"* (Turner & Freedman, 2004). In other examples, Vivaldi's *Goldfinch* concerto prompted flautists to recreate the songs of these iconic birds, Olivier Messiaen 'transcribed' birdsongs with the hope that an orchestra could replicate them note by note (see Fig. 6 for an even earlier example), and Benjamin Britten's *Spring Symphony* captured the "*progress of Winter to Spring and the reawakening of the earth*" (Britten, 1949; Rothenberg & Ulvaeus, 2001).



Example 2. Songs of the nightingale, rooster, hen, cuckoo, and quail as represented in Athanasius Kircher's *Musurgia universalis.* The song of the nightingale is notated in the upper portion of the example. Published in 1650, this is one of the earliest examples of notated birdsong in a nonmusical context.

Figure 6. Notated birdsong from Mursurgua universalis, 1650, and reproduced by Jensen, (1985).

2.12.2 Ecomusicology

Moreover, music can often reflect ecological issues, and even act as an agent of change in ecological thinking (Hawitt, 2020). This intertwining of music and nature is a theme embraced by the field of 'ecomusicology', defined as "*the study of music, culture, and nature in all the complexities of those terms*" and the "*coming together of music/sound studies with environmental/ecological studies and sciences*" (Allen & Dawe, 2015). Titon (2013) suggested "*how a holistic relational epistemology of interconnectedness, based in ecology and fundamentally different from that arising from scientific reductionism and economic rationality, offers an epistemological pathway to a more sustainable concept of nature, music, and the environment*", and in doing so, took the discussion down a humanistic route that is beyond the perspective of this thesis. Nonetheless, ecomusicology warrants more than a cursory mention.

Allen and Dawe noted how one avenue of ecomusicology represents "*the mutual interests of music psychology and ecological psychology*", and reflected on how binaries such as 'music' and 'sound' or 'environment' and 'human' can be both unnecessary and unhelpful: these descriptors might be better employed to represent how such topics are inextricably entangled (Allen & Dawe, 2015). In an example of this approach, Boyle and Waterman (2015) took an ecological perspective of music, referring to facets of bird song as the "*music that birds make*", and sounds that are "*performed*", for their "*audience*", in order to describe human and non-human music under the same framework.

This approach may hold particular relevance here. In section 2.10 natural soundscapes were largely described as *separate* to anthropogenic sounds. Yet ecomusicology does not make this distinction. Instead, we might consider music and soundscape as interchangeable descriptors for the totality of sound experienced, whether from human or more than human origins. Indeed, in their introduction to the 'Book of Music and Nature', Rothenberg and Ulvaeus (2001) noted how "*With only a little effort, the whole world can be heard as music*" and highlighted how contributors to their volume "*found music in natural sounds*" and reported "*wild sound-gatherings, and tales where music and nature surprisingly converge*" (see this volume for several fascinating perspectives on the intertwining of music and nature).

Similarly, in *The Great Animal Orchestra*, Bernie Krause described how "*Every place, with its vast populations of plants and animals, becomes a concert hall, and everywhere a unique orchestra performs an unmatched symphony, with each species' sound fitting into a specific part of the score. It is a highly evolved, naturally wrought masterpiece*" (Krause, 2012). Krause went on to reiterate the point made by Rothenberg and Ulvaeus (2001), "*it is likely that the origins of every piece of music we enjoy and word we speak come, at some point, from this collective voice. At one time, there was no other acoustic inspiration*."

A lack of separation between music and soundscape has also been suggested in research on music and emotions, where the assumption that psychophysiological responses to *all* sounds are underpinned by the same framework (Juslin, 2013 and see section 2.12.4).

2.12.3 Music and nature today

Given these symbolic, cultural, and adaptive overlaps between nature and music, we might reasonably assume that listening to music would accord well with modern-day experiences in natural environments, a proposition supported by several examples.

People commonly listen to music while running in natural environments, and a vibrant field of research (139 studies were reviewed by Terry et al., 2020) has demonstrated how music can help to improve the emotions and performance of a broad range of exercisers and athletes, and promote "*experiences that are pleasant and enjoyable*" (Terry et al., 2020). This relationship was even recognised as far back as 1911, with Ayres reporting that "*contestants in the recent New York six-day bicycle race made better time when the band played than they did when it was silent, according to a series of tests conducted during the races held in Madison Square Garden*" (Ayres, 1911).

In 1968, Krause and Beaver produced *In a Wild Sanctuary*; the first musical album that fused natural sound recordings with electronic instruments (Krause, 2012). Composers such as R Murray Schafer have written scores specifically intended to be performed outside in nature (Turner & Freedman, 2004). And in his search to produce a new kind of 'ambient music' that would "*induce calm and a space to think*", Brian Eno turned to the ambient sounds of nature, "*I sometimes found myself…sitting out on the patio in the evenings with the microphone placed to pick up the widest possible catchment of ambient sounds from all directions, and listening to the result on my headphones. The effect of this simple technological system was to cluster all the disparate sounds into one aural frame; they became music*" (Eno, 1986).

These fusions of music and natural sounds are commonly combined with practices such as yoga, massage, and meditation (Turner & Freedman, 2004), and have amassed a staggering number of plays on media platforms such as YouTube – the first result in a cursory search for "*meditation music and nature sounds*" has 55 million plays (YouTube, 2023b) whilst another video featuring piano music and bird song has had over 225 million plays (YouTube, 2023a).

But perhaps the most familiar way people encounter music and nature in modern settings is via natural history documentaries, where composers such as George Fenton pair bold orchestral scores with nature footage, as in the BBC's Blue Planet series (Wheatley, 2004). Here we find a pervasive example – 9.2 million people in the UK watched the opening episode of the BBC's Planet Earth II series (The Guardian, 2016) – of music accompanying, and anecdotally enriching digital nature experiences (BBC, 2017).

Indeed, this pairing has become so *de rigueur* that music and nature are often unquestioningly combined in research probing responses to digital forms of nature. For instance, music has been added to natural stimuli in studies based in clinical settings (Bauer et al., 2011; Gerber et al., 2017), the workplace (Ahmaniemi et al., 2017), and classrooms (Anderson et al., 2017), and further used in explorations of biofeedback (Rockstroh et al., 2019) and sensory stimulation (Serrano et al., 2016).

Music has been included in these experiences based on the assumption that it will enhance positive affective responses. However, evidence suggests this relationship may not be so straightforward. For example, Largo-Wight et al. (2016) found that those who listened to the sounds of ocean waves experienced a decrease in stress markers (muscle tension, heart rate, and self-reported stress), but those who listened to classical music did not. Thoma et al. (2013) found that natural sounds (unintentionally) outperformed 'relaxing' music at aiding stress recovery across a series of physiological measures, although a follow up study suggested that natural sounds may not produce such effects in those suffering from somatic complaints (Thoma et al., 2018).

Thus, a central question remains unanswered: how does the addition of music to nature-based stimuli specifically impact participant outcomes?

2.12.4 Music and emotions

A substantial body of evidence has investigated how music can influence listener emotions (Zentner et al., 2008), attempting to answer the question of how, as Juslin (2013) puts it, "*music – an abstract form of art, which appears removed from our concerns in everyday life – can arouse emotions – biologically evolved reactions related to human survival*"?

Despite theoretical wrangling over the characteristics of emotions induced by music, it is generally accepted that music evokes the same emotions as other affective stimuli (Juslin & Västfjäll, 2008) and music is commonly used as a mood induction tool (Lamont, 2011) – see also Lamont and Eerola (2011) for a detailed review of the field. In another comprehensive overview, Juslin (2013) highlighted how 'everyday' and 'aesthetic emotions' might be triggered by music. Juslin considered everyday emotions as the "*ordinary emotions experienced in life*", such as happiness, sadness, excitement, and calmness, whilst aesthetic emotions might be more complex yet less common – particularly with respect to music. They include feelings such as admiration, awe, and nostalgia.

Awe and nostalgia may be important emotions to consider in nature-based encounters (section 2.8.2 and section 2.8.3). Awe can be elicited by both nature and music (Silvia et al., 2015), and has been associated with mixed valence musical encounters (Pilgrim et al., 2017), whilst nostalgia triggered by music can offer a range of affective benefits, including a 'buffering' effect from psychological discomfort (Sedikides et al., 2022).

Juslin (2013) detailed how the activation of one (or more) of eight mechanisms can lead to emotional responses to music. These mechanisms are based on adaptive processing that would have aided the perception of threat or survival to early hominids, tapping into diverse brain functions from simple sensations to syntactic processing (Juslin, 2013).

However, Juslin (2013) did not remove the role of the listener in invoking these bottom-up processes, affirming that "*each mechanism may respond in its own manner to information in the music, the listener, and the situation…they involve psychophysical relationships between 'external' features of the environment (i.e., the music and the context) and 'internal' features of the perceiver"*, a point that hints at the significance of top-down processing discussed in section 2.13.2. Briefly, Juslin's eight mechanisms are:

- **Brain stem reflex**
  Acoustic characteristics of the music, such as sudden, loud features, are taken by the brain stem to signal an important event that requires immediate attention. Emotions are likely to be high in arousal, such as surprise.

- **Rhythmic entrainment**
  A bodily rhythm, such as heart rate or breathing, adjusts and aligns to the rhythm of the music. Through proprioceptive feedback, this may then affect emotional outcomes, either through modulating arousal, or "*feelings of communion*".

- **Evaluative conditioning**
  Learned associations with music, formed when hearing a particular song in positive or negative situations, can cause a listener to re-experience those emotions when the music is heard again at a later date.

- **Contagion**
  Emotions such as sadness and happiness are expressed by and perceived in the music, which is then mimicked by the listener. This mechanism may be most relevant to music that contains voices, or with instruments that mirror the human voice such as the oboe and cello.

- **Visual Imagery**
  A visual image is triggered by the music in the listener's mind's eye, perhaps because the music suggests certain affordances. Responses may be related to previous experiences and include feelings of pleasure and relaxation.

- **Episodic Memory**
  Music triggers recall of a memory, with the emotion associated with that memory also re-experienced. This mechanism is linked to feelings of nostalgia in particular (see section 2.8.3).

- **Musical Expectancy**
  Features of the music confound a listener's expectation of how it should progress. A prerequisite for this mechanism is familiarity with a specific song or genre, and it is most associated with surprise and anxiety.

- **Aesthetic Judgement**
  Music may be assessed for its inherent artistic qualities, according to factors such as beauty, meaning, novelty, and skill. Appraisals of these elements may lead listeners to feel pleasure, awe, amazement, and satisfaction – although Liljestrom et al. (2012) also noted how "*everyday emotions to music rarely, if ever, arise out of a de-contextualized aesthetic relationship to the music as 'object.' All musical emotions occur in complex interactions between the listener, the music, and the situation.*"

Indeed, it is clear that these mechanisms involve adaptive, informational, and learned processes, and as such may occur over differing time scales, with varying intensity, and under various levels of control (Juslin, 2013). They can also occur concurrently, leading to emotional responses that might be competing or complementary.

Further work from Juslin's stable (Juslin et al., 2015; Juslin et al., 2013) tested four of these mechanisms, using adjective scales to demonstrate how "*basic*" emotions – those that occupy each quadrant of the circumplex model of affect (Russell, 1980, see section 2.8.1) – and more complex feelings such as awe and nostalgia, could be triggered by different musical features (bipolar self-reported measures represent the accepted standard for capturing affective response to music, (Eerola & Vuoskoski, 2013; Lamont & Eerola, 2011; van der Zwaag et al., 2011)). As well as providing evidence for the mechanisms of brain stem reflex, contagion, episodic memory, and musical expectancy, a key outcome of these studies was confirmation that listeners actually *experienced* the emotions reported, rather than simply *perceived* them in the music.

Lamont and Eerola (2011) reiterated this perspective, noting that whilst it may not be explicitly defined, "*all research on the impact of music contains some element of emotion*." They also drew attention to how personal associations can substantially moderate emotional responses to music, and highlighted the need for findings that were ecologically valid. Juslin et al. (2015) underscored the importance of ecological validity and the need to understand responses to "*real*" music, rather than simple, highly manipulated, experimental stimuli – or classical music, which is commonly used but not representative of most people's musical experience (Eerola & Vuoskoski, 2013).

Van der Zwaag et al. (2011) embraced this approach, using common pop and rock music to demonstrate how structural features such as tempo and mode (minor or major) correlate well with both emotional and physiological responses in listeners. The neurological pathways linking music to emotion have also been explored, revealing how music can stimulate the brain regions commonly associated with affective responses, such as the amygdala and hippocampal formation (Koelsch, 2014).

2.12.5 Sounds on screen

The potential for music to augment mood and emotion, along with ever sophisticated equipment to record and playback sound, has made it a ubiquitous presence in the digital age: it pervades consumer settings, television, radio, and media consumed via portable devices. As such, audiences have come to expect its inclusion in a range of creative and factual experiences, to both enhance narratives and guide emotional experiences (Rogers, 2014).

However, others have suggested that the omnipresence of music on the small and big screen has reached its peak. Fahlenbrach (2008) contended that each time people and environments are experienced by audiovisual media "*we are unconsciously guided by acoustic cues*" that move beyond music. Indeed, greater emphasis is now being placed on capturing the ambience of a scene, particularly through the sounds of the natural world, where the primacy of the soundscape may even dictate how a scene should be visually depicted (Kulezic-Wilson, 2008). Natural sounds have been considered vital to the emotions conveyed by documentaries too, where audible natural processes both complement and stand alone from dialogue and music (Strachan & Leonard, 2014). Indeed, both natural sights and sounds are particularly important in nature-based documentaries, where even the footsteps of millipedes can now be 'heard' (Collins, 2018).

In their attempts to depict reality, documentaries tread a line between authenticity and narrative persuasion, often using diegetic sound (that created by events seen on screen) and music to guide audience emotions (Rogers, 2014). However, Rogers (2014) refuted cinematographer Michel Brault's notion that documentary is "*realism, and [non-diegetic] music has no place there*". She noted how audiences have become familiar and adept at interpreting the combination of moving images and music, drawing particular attention to the ways that music is used in natural history programming to "*familiarise the otherness of the filmed wilderness for an audience located on warm sofas many miles away*" and "*enable a greater flow in programmes that frequently jump between terrains and activities*" (Rogers, 2014). Collins (2018) suggested these scores have been informed by big-budget Hollywood productions, "*the immense popularity in recent years of action and superhero films…along with the accompanying 'loudness wars' has forged an audience that expects and in fact demands this type of sonic aesthetic.*"

Cooke (2014) also highlighted how, for ocean-related documentaries at least, the tropes now familiar in these scores originated in early feature films. For example, 1953's *Beneath the 12-Mile Reef* employed musical patterns to represent its underwater world that have since been used by natural history composers, and the score for Jack Cousteau's 1956 epic *Le monde du silence* accompanied underwater fauna with waltzes, a style that has been mimicked numerous times since (Cooke, 2014). These scores aimed to take audiences on a journey; from tension to release and from despair to warmth.

In the present day, scoring nature documentaries has certainly become a lucrative endeavour. Ahead of the BBC's American release of Blue Planet II, the corporation's media team focused heavily on a collaboration between Radiohead and Hans Zimmer (BBC Studios, 2017), and for the release of *Frozen Planet II*, a similar fanfare was made for a partnership between Hans Zimmer and Camila Cabello (BBC Media Centre, 2022). The popularity of these pairings has also led to performances that place even greater emphasis on the music. For example, the orchestral score accompanying the 2003 documentary *Deep Blue* has been performed alongside live screenings of the film with orchestras as prolific as the Berlin Philharmonic (Cooke, 2014), whilst George Fenton's score for the 2001 series *The Blue Planet* was performed in a special 'Blue Planet Prom in the Park' event as part of the BBC Proms (Wheatley, 2004).

But beyond audience figures and creative tradition, what evidence can we draw on to understand the ways in which music might affect these, largely digital, experiences of nature? Despite numerous studies exploring the impacts of music on activities as diverse as office working, banking, socialising, eating out, and shopping (Haake, 2011; North et al., 2000; Wilson, 2003; Yi & Kang, 2019) little systematic attention has been paid to the pairing of music and nature-based encounters. What does the scant research in this area tell us about how these common bedfellows might interact?

2.12.6 Music in natural settings

Yamasaki et al. (2013) assessed how music with varying valence and arousal characteristics affected people's in situ perceptions of several urban settings. They found that high arousal music could increase an environment's 'activation' ratings, whilst calming music had the opposite effect. However, these effects were most pronounced when the music was at odds with the environment; calming music made stressful environments less so, and arousing music had the greatest impact in calm environments (such as an urban park). Crucially for our discussion here, Yamasaki et al. (2013) found that whilst music could increase the valence of their settings, it led to *diminished* ratings in their park environment, which was *already* highly rated for valence.

In contrast, Franěk et al. (2020) found that listening to pop music in urban green spaces had no effect on evaluations, with environmental features instead playing a significant role. In another direct comparison of music and natural settings, Iwamiya (1997) assessed how music influenced perceptions of landscapes viewed from a moving vehicle. Their natural environment featured a river, which was paired with nine musical excerpts. Although only 10 participants took part in the study, results suggested that music could substantially augment how each environment was appraised, with calming music increasing landscape ratings for relaxation, and high arousal music increasing ratings for 'power'.

The field of music therapy has also begun to recognise how experiences of silence can form an important component of music-based interventions that may not need to be preceded by music to foster relaxation (Pfeifer et al., 2019). In this context, 'outdoor silence' featuring the sounds of nature has been associated with increased improvements in self-reported relaxation and boredom when compared to ‘indoor silence’, and may help to reduce rumination and mind-wandering (Pfeifer et al., 2020). Thus, conducting music therapy in outdoor settings has been suggested as a way to bring the complimentary effects of music and nature together (Pfeifer et al., 2019).

And in a somewhat tangential example, Steel et al. (2019) demonstrated how music could mask traffic sounds and improve perceptions of urban squares. However, the authors also noted how their specific music intervention could promote both fascination and the formation of memories in these spaces. Indeed, the film composer Joel Douek also highlighted the role of memories on screen, noting how “*Much of the work of the film composer is a kind of musical alchemy, pouring rarified ingredients (and more than a drop of our own blood) into a bubbling cocktail of pitches, patterns, modes and* ***memories***” (Douek, 2013).

2.12.7 Music and memories

Music can be a powerful cue for memory recall, stimulating memories that might be particularly vivid compared to those surfaced by other mnemonic triggers (Belfi et al., 2016). These memories can be semantic, or autobiographical, with the latter relating to specific events or broader periods in a person’s life (Jäncke, 2008). Although familiarity with a specific song does not guarantee that it will trigger a memory, when a memory is retrieved it is likely to be associated with strong, predominantly positive emotions (Janata et al., 2007).

Memories triggered by music could, therefore, reasonably exert a significant moderating effect on responses to virtual forms of nature (see section 2.13.2). However, as the handful of studies mentioned in section 2.12.6 demonstrate, not only is little known about how music can impact restorative and affective experiences in nature, but the role that memories might play in this relationship has, so far, been largely neglected. Crucially, both memories and music are potent triggers of feelings of nostalgia (Holak & Havlena, 1998; Janata et al., 2007, and see section 2.8.3). If nostalgia can be triggered by virtual nature experiences, how might music and memories affect this relationship?

Thus, despite the diverse and interwoven links between music and nature, we currently have very little steer on how they might combine to influence experiences in the natural world. This is particularly true for digital forms of nature; although music routinely accompanies natural history documentaries, nature videos on YouTube, and stimuli used in restoration research, the rationale underpinning these pairings have not been driven by quantitative evidence.

2.13 Moderating factors

Outcomes from nature interactions can vary substantially between people, and quantitative studies assessing environmental experiences should take these individual differences into account wherever possible. What might be the most important factors driving this heterogeneity?

2.13.1 The importance of lived experience

Restorative environments research is commonly approached from a 'bottom-up' perspective, with researchers tending to focus on the perceptual (visual, spatial, and acoustic) properties of natural environments (Kaplan & Kaplan, 1989). However, a considerable body of qualitative work has, for several decades, highlighted the vital role of personal experiences in people-nature interactions. Often situated in the field of health geography, these humanist approaches place value on the subjectivity and meaning associated with landscape experiences, and stem in part from reactions to deterministic efforts to quantify nature-based encounters (Gesler, 1992).

Conceptualised under the previously mentioned rubric of therapeutic landscapes, this corpus of research rejects the idea that environments can be intrinsically therapeutic and often employs in-depth narrative methods (e.g. Conradson, 2005) to reveal people's complex and evolving relationships with nature (see Bell et al., 2018; Williams, 2017 for comprehensive reviews). Despite this established field continuing to demonstrate how positive wellbeing outcomes can "*emerge through interactions between a person and a socio-material setting…within broader cultural and historical geographies of health*" (Doughty et al., 2023), these factors are rarely incorporated into the quantitative work common in environmental psychology.

Yet personal experiences can impose a strong influence on reactions to both real and virtual natural environments (Chin et al., 2022; Martin et al., 2020). Such 'top-down' mechanisms place emphasis on the values, memories, and cultural symbolism of environment-people interactions that might augment wellbeing outcomes (Ratcliffe & Korpela, 2016). In this context, a top-down framework assumes that people interpret life experiences as broadly positive or negative, and these associations go on to influence how environments are perceived and experienced (Korpela et al., 2008).

2.13.2 Memories

There are many cognitive pathways through which life experience can augment responses to real and virtual forms of nature. Factors such as societal expectations, personal values, and nature connectedness can each impact psychological outcomes (Chin et al., 2022; Martin et al., 2020). Of these factors, memories represent a potent mechanism through which lived experience can be retained, recalled, and referenced, with notable effects on emotion (Mills & D'Mello, 2014).

A large body of research has explored the relationships between memory and emotions (Holland & Kensinger, 2010). This work has revealed how experiences that evoke strong emotions are most likely to be recalled, and suggests that an individual's goals at the time of retrieval can substantially impact which elements of a memory are surfaced (Kensinger & Ford, 2020). Indeed, episodic recall has demonstrated the ability to stimulate the re-experiencing of affective states, with the valence of recalled memories central to desirable outcomes (Gillihan et al., 2007). Evidence suggests people tend to self-regulate emotions through the preferential retrieval of memories that foster positive and reduce negative emotions (Buchanan, 2007; Pillemer, 2009), a hedonic process that has been associated with increases in optimism, creativity, and resilience to stressful situations (Kensinger & Ford, 2020).

Beyond specific, episodic events, autobiographical memory can also manifest as broader feelings of knowing and familiarity, a more nebulous mnemonic typology that might be relevant to nature-based encounters; since most experiences in nature may not be sufficiently "*imbued with emotion*" necessary for strong memory formation (Holland & Kensinger, 2010), a more cumulative and semantic process may be important. This form of memory recall can also have a substantial effect on emotional responses to videos (Dudzik et al., 2020).

Involuntary memories – those which occur without a specific prompt – are commonly triggered whilst experiencing multimedia content, particularly when the viewer is relaxed and using a low level of attention (McDonald et al., 2012). Involuntary memory stimulation may have additional benefits; it can encourage attentional drift (Dudzik et al., 2020), a positive end-state that is similarly posited by attention restoration theory (Kaplan, 1995). However, whilst limited evidence suggests memories may be more important than specific features in moderating emotional responses to both visual and acoustic stimuli (Maksimainen et al., 2018), how they might augment affective or restorative outcomes in nature is currently under-explored.

The first steps were taken to address this gap by Ratcliffe and Korpela (2016), who considered how autobiographical memories might impact restorative experiences. They noted that Roger Ulrich (1983) first identified a role for encounters that have been "*crystallised in memory*" and highlighted research that demonstrated how the valence of memories can impact mood (Gillihan et al., 2007, see fig 7), yet lamented how these processes had gained little traction in restorative environments research.

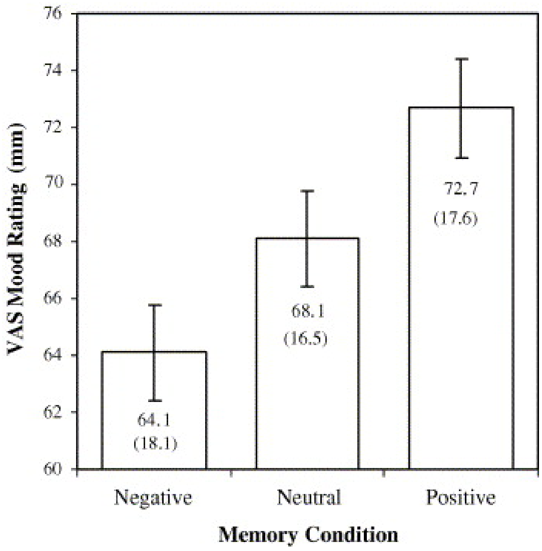


Figure 7. The impact of differently valenced memory recall on mood ratings, from Gillihan et al. (2007).

According to Ratcliffe and Korpela (2016), both memory content and the process of recall are important, suggesting that the "*recall of positively valenced, place-based memories may be able to generate positive affective states towards places evaluated in the present moment.*" They noted how the impacts of lived experience on restorative outcomes have been most thoroughly explored through research that focuses on people's experiences in favourite places (Korpela & Hartig, 1996; Korpela et al., 2008), where the role of memories is implied if not explored directly.

Although place attachment is not the focus of the studies presented here (for a detailed account of this research seam, see Lewicka, 2011), Ratcliffe and Korpela (2016) suggested the affective properties of place-based memories "*may predict restorative perceptions with place attachment as a mediating variable.*" Importantly, their mixed-methods study found evidence for this hypothesis, showing that positively valenced memories were an effective predictor of a place's perceived restorativeness, mediated by place attachment, and quantitatively identifying the role of lived experience in restoration research for the first time.

The role of positive memories in determining restorative outcomes was further highlighted in a comprehensive review of the literature by Ratcliffe and Korpela (2017), who detailed how memories have been related to restorative experiences in both visual and acoustic settings (Ratcliffe et al., 2016; Shaw et al., 2015). The authors also highlighted childhood as a key time to form associations with natural environments. This proposition is supported by research that shows a strong link between childhood experiences in nature and wellbeing in adulthood (Asah et al., 2011; Pamela et al., 2016; Ward Thompson et al., 2008), an effect that may be mediated by enhanced visits to natural spaces later in life (Vitale et al., 2022).

Of particular relevance to interventions using digital exposures, Dudzik et al. (2020) drew vital attention to the role that memories can play in emotional responses to video content. Grounded in the field of Video Affective Content Analysis, their study identified memories triggered by audio-visual content as a substantial predictor of affective outcomes. When memory valence was included in their analyses, model fit was even greater. These effects were larger than those associated with both characteristics of the video and participant demographics. Dudzik et al. (2020) emphasised the significance of their findings with the conclusion that "*without accounting for dynamic influences like personal memories in computational models, accurate predictions of video-induced emotions in real-life applications will remain out of reach.*"

Thus, nascent evidence suggests memories could be a vital moderator of people's responses to environmental encounters, especially those that are digitally mediated. However, the extent to which memories might impact the restorative potential of specific visual and acoustic stimuli, and augment emotional outcomes from these experiences, has yet to be robustly quantified; how might memories moderate responses to digital forms of nature?

2.13.3 Nature connectedness

Beyond the impact of specific memories, people can form strong bonds with nature even after minimal contact earlier in life (van Heezik et al., 2021). Commonly referred to as 'nature connectedness', this trait-based construct reflects a feeling of belonging to the natural world (Mayer & Frantz, 2004) that tends to be stable over time (Capaldi et al., 2014).

These "*personal relationships with nature*" (Nisbet et al., 2008) are commonly assessed via one of several scales, each attempting to capture dimensions of nature connectedness from affective and cognitive perspectives and represent a person's feelings of "*oneness*" (Mayer & Frantz, 2004) with the natural world (Wesley Schultz, 2001). Of relevance to UK populations in particular, the Nature Connection Index developed by Richardson et al. (2019) has been validated against a representative UK population (MENE, 2019). This scale taps into six emotional components of nature connectedness such as happiness and amazement, aesthetic appraisals of beauty, personal meanings, compassion towards the natural world, and a sense of belonging. These components are weighted and collapsed to form a single measure on a 100-point scale, with higher ratings demonstrating increased connection to nature (Richardson et al., 2019).

Nature connectedness may be an important factor to consider in people-nature interactions and has been associated with several general wellbeing outcomes, such as increased happiness (Zelenski & Nisbet, 2012), improved psychological resilience (Ingulli & Lindbloom, 2013), reduced anxiety (Martyn & Brymer, 2014), and greater eudaimonic and hedonic wellbeing (Capaldi et al., 2014; Pritchard et al., 2020). Whilst short term changes in momentary nature connectedness have been investigated as a mediator between nature experience and wellbeing outcomes (Mayer et al., 2008), connection to nature as a stable trait may be more suitably interpreted as a possible moderator. Under this implementation, it has been found to moderate how experiences in nature relate to wellbeing, suggesting that nature exposure may be more effective in promoting positive outcomes for those who already feel connected to the natural world (Martin et al., 2020) and should be considered as a covariate in analyses seeking to examine these associations.

The extent to which people seek and experience natural environments is also heavily influenced by a feedback loop of personal factors; those who spend time in nature are more likely to become emotionally connected to nature, and those emotionally connected to nature are more likely to spend time in it (Hatty et al., 2022). This trend has been reinforced by evidence suggesting that an affinity for nature may be learned, with young American children actually exhibiting a preference for urban environments that shifts to natural settings as their childhood progresses (Meidenbauer et al., 2019).

2.13.4 The extinction of experience

Whilst life experience manifesting as memories and connectedness to nature might enhance responses to natural environments, a more pessimistic framing of this relationship also exists: what might be the impacts of *not* having these experiences?

Reduced contact with nature, particularly that featuring 'meaningful contact' (Richardson et al., 2021) might arise for several reasons. Often first on this list is environmental degradation. Indeed, mounting evidence suggests that environmental decline is accelerating at an unprecedented rate: climate change is increasing the destruction of natural habitats (Travis, 2003); anthropogenic materials now contaminate the land, freshwaters, seas, and air (Rochman & Hoellein, 2020); and global reductions in biodiversity (Dirzo et al., 2014; Newbold et al., 2016) are unfolding at rates fast enough to herald a sixth mass extinction event (Ceballos et al., 2015). These trends are exceeding earth's planetary boundaries (Rockstrom et al., 2009), catalysing the development of global pandemics (IPBES, 2020), and causing the widespread collapse of natural ecosystems (Bergstrom et al., 2021).

Robert Pyle suggested these negative environmental changes could lead to a gradual loss of knowledge about, and connection to, natural environments – a trend he called the 'extinction of experience' (Pyle, 1993; Soga & Gaston, 2016). With the natural world in an increasingly ailing state (Ceballos et al., 2015; Newbold et al., 2016; Travis, 2003), both logic and evidence suggest that opportunities for spending time in 'high quality' nature may be diminishing (Imai et al., 2019) – although recent evidence suggests this assumption may be unfounded in some cases (Novotný et al., 2020; Oh et al., 2020).

Extinction of experiences can also result from other external factors, including increases in urbanisation (Soga & Gaston, 2016). Over 55% of the world's human inhabitants currently reside in urban environments – a figure projected to reach 68% by 2050 and which has already risen as high as 82% in upper-income regions such as North America (United

Nations, 2019). Metropolitan residents may have limited opportunities for contact with nature (Cox et al., 2017) and typically experience diminished levels of biodiversity or "*biological poverty*" that can lead to a 'shifting baseline' of what is considered a normal and healthy environment (Turner et al., 2004).

Daniel Pauly (1995) coined the term "*shifting baseline syndrome*" in his despairing commentary of the state of global fish stocks. Pauly contended that:

"*each generation of fisheries scientists accepts as a baseline the stock size and species composition that occurred at the beginning of their careers, and uses this to evaluate changes. When the next generation starts its career, the stocks have further declined, but it is the stocks at that time that serve as a new baseline. The result obviously is a gradual shift of the baseline, a gradual accommodation of the creeping disappearance of resource species, and inappropriate reference points for evaluating economic losses resulting from overfishing, or for identifying targets for rehabilitation measures*" (Pauly, 1995).

It is clear how this trend might apply to various forms of environmental destruction, and Peter Kahn (2002) extended this logic to experiences in nature. Khan described "*environmental generational amnesia"* as the process by which successive generations accept their level of environmental quality as 'normal' and fail to notice the longer-term trend of declining health of, and contact with, natural systems.

Generational amnesia is particularly relevant when it comes to the extirpation and extinction of local species (Soga & Gaston, 2016). Beyond a decline in charismatic megafauna (Amir et al.; Dirzo et al., 2014), localised extinction events can have negative effects on people's ecological knowledge, causing the loss of nature experience not just from individual but also cultural memory (Kai et al., 2014). Yet complex patterns in biodiversity change can obscure the insidious rise of these trends (Sax & Gaines, 2003). For example, suburban development can reduce native species richness but increase overall populations due to rises in invasive fauna (Blair & Johnson, 2008), part of a wider trend of biotic 'homogenization' (McKinney & Lockwood, 1999) that is particularly relevant for reductions in the diversity of plant species (Sutton & Morgan, 2009), which may go unnoticed by local residents due to factors such as 'plant blindness' (Allen, 2003; Balding & Williams, 2016).

Perhaps most worryingly, a 'societal extinction of species' can occur even without the process of biological eradication or extirpation (Jarić et al., 2022). Jaric and his co-authors define this trend as "*the loss of collective memory, attention, knowledge, representations, and cultural products associated with species from cultures and/or societies*" and note that it can take place at both global and regional spatial scales. A lack of direct experiences in nature can lead to the societal extinction of a species, as can a gradual decline in population numbers. Indeed, as a species becomes rarer, people's awareness of their existence, traits, and symbolism may increasingly be maintained through digital representations (Jarić et al., 2022).

If people lose direct contact with nature, it is clear that they will also lose the wellbeing benefits associated with this contact, outlined in sections 2.5 and 2.6. Indeed, a growing reliance on digital forms of nature may represent a covert progression of the extinction of environmental experience via the transference of in situ experiences to digital surrogates (Gaston & Soga, 2020). However, this viewpoint overlooks the benefits that virtual encounters may also present for environmental knowledge, emotional connection, and wellbeing. Perhaps a more relevant question here is: if people lose direct contact with nature and the *memories* and *emotional connections* this can foster, will they suffer impoverished outcomes when they interact with nature later in life, particularly if this contact is digitally mediated?

2.13.5 Individual characteristics

Demographic factors such as age, gender, ethnicity, working status, and socio-economic grouping have been associated with diverse nature-based experiences (or lack thereof, see Boyd et al., 2018), and are commonly controlled for in large-scale quantitative analyses (Barbosa et al., 2007; Cervinka et al., 2011; Dallimer et al., 2014; de Bell et al., 2020; White et al., 2016; White et al., 2013; White et al., 2014b).

These factors have also been included in several studies as covariates of specific interest. For example: Luck et al. (2011) revealed that demographic factors were more effective predictors of wellbeing than environmental features; Buijs et al. (2009) found that immigrant status was a very strong predictor of landscape preference in a large Dutch sample; Wyles et al. (2017) found that females and older people tended to experience greater feelings of restoration in nature compared to males and younger people; Howley (2011) found that older people tended to prefer farmed landscapes but not blue spaces, when compared to younger people; and McMahan and Estes (2015) found older age was associated with greater positive affect in their meta-analysis of 32 studies.

However, in many cases samples are restricted to specific demographic segments; McMahan and Estes (2015) only included those aged between 20 and 28.5 years in their review. Moreover, research investigating responses to natural sounds, landscape changes, and music has often relied on sample sizes that do not permit meaningful statistical interrogation of individual characteristics, for example: n = 45 (Medvedev et al., 2015); n = 40 (Alvarsson et al., 2010); n = 40 (Van den Berg et al., 2016); n = 120 (Pazhouhanfar & Kamal, 2014); n = 60 (Juslin et al., 2015). It is also common for these studies to use convenience samples composed of university students (e.g. Medvedev et al., 2015; Pazhouhanfar & Kamal, 2014; Van den Berg et al., 2016), limiting generalisation of findings to wider groups.

2.14 Digital stimuli

Investigating responses to digitally-mediated forms of nature can deepen knowledge about the processes underlying experiences in 'real' environments (section 2.3). But digital encounters are also becoming increasingly important and distinct forms of contact in their own right (Bates et al., 2020).

Moreover, for centuries humans have attempted to recreate and relive the experience of being in nature; intricate frescoes adorned the walls of Roman villas (Amery et al., 2002), medieval music imitated birdsong (Jensen, 1985), and composers such as Beethoven sought to mimic the sounds of nature (section 2.12.1).

As technology developed, the first recordings of birdsong were made in the late 19th and early 20th centuries (British Library, 2023a, 2023b), and whilst commercially released to a market of eager gramophone owners, were designed to educate listeners rather than "*provide comforting atmospherics or bucolic montages*" (Bud et al., 2018). However, the leading sound recordist of the early 1900s, Ludwig Koch, later advocated the calming properties of birdsong during the second world war "*I would like to advise everybody in a position to do so, to relax his nerves, in listening to the songs, now so beautiful, of the British birds*", and in doing so brought nature into towns and cities like never before (Bud et al., 2018). In a similar vein, the first recordings of whale song (Payne & McVay, 1971) not only catalysed a conservation movement, but have subsequently been used alongside complementary therapies (The Guardian, 2007).

Further technical advances continued these trends. In 1973, Martin Krieger suggested that "*what we experience in natural environments may actually be more controllable than we imagine*" and foretold a future in which "*we shall want to apply our technology to the creation of artificial environments... by means of substitution and simulation*" (Krieger, 1973). Slater and Wilbur (1997) imagined technological advances in fidelity and immersion that would allow users to "*roll down the window*" and create virtual environments that conveyed a very real feeling of "*being there*".

Around the same time (and in a prescient piece of horizon scanning), Levi and Kocher (1999) discussed the restorative possibilities of VR, "*in the future, virtual reality technology will allow people to experience nature in a simulated environment – virtual nature.*" They posited that digital experiences might one day produce 'hyper-real' nature encounters that excite the senses with their brilliance, richness and pliability. Others imagined a future where virtual nature might help people recover from workplace stress, negative life events, post-operative malaise, and invasive medical treatments (de Kort et al., 2006).

The emergence of affordable and consumer-ready VR technology in 2016 (HTC, 2016) seemed to herald the realisation of these prophecies, with renewed attention on the restorative possibilities that might be presented by increasingly immersive forms of virtual nature (Nukarinen et al., 2022; Spano et al., 2023). Commonly viewed through head mounted displays, VR nature has been associated with reductions in heart rate, breathing frequency, and blood pressure in intensive care settings (Gerber et al., 2017) and linked with improvements in negative emotions, self-reported stress, anxiety, happiness, creativity, and vitality (Palanica et al., 2019; Schebella et al., 2020; Theodorou et al., 2023; Yu et al., 2018).

Seeking to capitalise on these effects, a growing number of VR relaxation tools have been developed by the private sector (Lindner et al., 2019). Whilst popular with their early-adopter user base (Fagernäs et al., 2021), these applications have yet to demonstrate sustained engagement (Lindner et al., 2019), marking a wider trend of faltering large scale domestic uptake of VR platforms (Green et al., 2021) and reflecting fears that fervour surrounding the current iteration of this technology has collapsed (The Guardian, 2023; The Insider, 2023).

Indeed, the wellbeing benefits delivered by virtual reality may only represent marginal gains above those provided by more traditional, 2D, content (Yeo et al., 2020) and in some cases, no advantages at all (Li et al., 2021b). With 'VR sickness' still a significant problem for many users (Howard & Van Zandt, 2021) and evidence that the increased agency available in VR can be detrimental to people's experiences in some settings (Mostajeran et al., 2021; Reese et al., 2021), when it comes to wellbeing outcomes, the *design* of digital content may be more important than the *delivery* (Depledge et al., 2011; Ludden et al., 2019).

The unrelenting ubiquity of non-VR, screen-based, and audible nature content certainly makes these mediums stubbornly relevant: UK viewing figures for the launch of the 2021 BBC series *A Perfect Planet* were in excess of six million (Royal Television Society, 2021); YouTube nature videos routinely amass tens of millions of views (YouTube, 2023b); narrative nature games such as *Walden, a game* sit in best seller lists (itch.io, 2018); and media platforms such as Spotify are increasingly marketing nature content under the banner of 'wellness' (Spotify, 2023).

Building on this demand, world-leading television and radio broadcasters are seeking to better understand the wellbeing potential of their nature-based broadcasts (Keltner et al., 2017) and leverage these outcomes in new multi-platform outputs (BBC Archive, 2020) aimed squarely at a 'wellness' market (BBC Four, 2020). The private sector is also hurriedly creating digital nature experiences that seek to engage, educate, and reconnect people with the natural world (Litleskare et al., 2020) as well as harness its therapeutic potential (Portal.app, 2022) – an approach that might be most beneficial for those with reduced access or mobility (Van Houwelingen-Snippe et al., 2021).

An evidence-based approach is thus vital to the development of this burgeoning field, particularly since digital forms of nature can now replicate *any* kind of experience. Understanding how people respond to elements such as natural sounds, ephemeral features, and music may help to create encounters that can be tailored to elicit certain emotional outcomes – based on the specific needs of users (Chirico et al., 2018).

We must also recognise that rather than viewing virtual nature as a possible panacea for the stresses of modern life, or a way to democratise nature-based experiences, many scholars have questioned what digitised encounters might mean for natural environments in *reality*.

Levi and Kocher (1999) warned how hyper-reality might lead to the devaluation of 'ordinary' natural environments, suggesting people would become tired with the mediocrity of 'neighbourhood' nature when they could be continuously awed by virtual nature. Peter Kahn lamented the ways that "*actual nature is being replaced with technological nature*" (Kahn et al., 2009) and cautioned how adapting to these forms of nature raises "*the issue of whether such adaptations are not just different but impoverished from the standpoint of human functioning and flourishing*" (Kahn et al., 2008).

Likewise, although in their discussion of environmental experiences and conservation, Clayton et al. (2017) took a positive stance to the integration of nature and technology, suggesting that "*rather than dismissing these forms as inauthentic, conservation scholars and practitioners should examine the ways in which they help to construct people's attitudes and behaviors toward nature*", this sentiment was short lived. Just three years later, Truong and Clayton (2020) expressed concerns that 'screen-mediated' forms of nature were reducing sensory and embodied experiences, and ultimately creating homogenised and impoverished encounters with the natural world.

Yet Truong and Clayton (2020) also acknowledged that whilst direct contact with nature might be declining, digital technologies, in their many guises, offer a rich diversity of opportunities for people to experience natural settings – as well as providing a potential bridge between simulated and real worlds. In this regard, virtual nature could be a vital way to connect Generation Z and successive generations of digital natives with ecosystems, particularly via compelling new forms of digital field trip (McCauley, 2017). Indeed, McCauley (2017) noted how these interactions open up new possibilities for engagement:

"*I involuntarily ducked when a humpback whale swam over my head during a sample virtual reality SCUBA dive…I have vivid memories of standing enraptured in front of wildlife dioramas in the Smithsonian's Museum of Natural History as a child—but none of them ever made me duck.*"

A natural synergy may therefore exist where digital experiences designed to foster positive wellbeing outcomes might also help to educate and connect users with the natural world, and in turn stimulate pro-environmental behaviours.

2.15 Creative approaches

Any attempt to achieve this triple bottom line of positive changes in wellbeing, knowledge, and behaviour change must foster academic and creative alliances that engage broad populations with scientific findings (Pietrzak et al., 2018), develop public attitudes that support positive environmental outcomes (Curtis et al., 2013), reconnect urban communities to the natural world (Ives et al., 2018), and increase the desire to protect planetary ecosystems (DeFries et al., 2012).

Achieving these goals certainly requires new creative and transdisciplinary ways of working (Clayton et al., 2017), and an understanding of the ways in which information is curated and shared in a digital world where the personalised algorithms of social media feeds have led to a "*tectonic shift in the balance of power in science information ecologies*" (Brossard & Scheufele, 2013). With these factors in mind, how might we integrate scientific research with creative outputs, raise awareness of environmental challenges, and enable audiences to contribute to data collection?

We might learn from existing approaches. For example, The Wildlife Trusts annual *30 days Wild* campaign encourages people to "*do one 'wild' thing a day every day throughout June*" (The Wildlife Trusts, 2023). The campaign has been featured on mainstream media programmes, participants are encouraged to share their activities on social media, and invited to provide data as part of ongoing academic study (Richardson et al., 2016; Richardson & McEwan, 2018).

Public participation in data collection, often described under the banner of 'citizen science', has been successfully employed across a range of fields, from astronomy to ornithology, and might aim to either further scientific findings, influence decision making, or contribute to participant knowledge (Shirk et al., 2012). That last point is embodied by citizen science projects at the Cornell Lab of Ornithology, where as well as collecting data, participants have learned about subject matter and gained experience of the scientific process (Bonney et al., 2009).

Shirk et al. (2012) delineated public participation in research according to levels of collaboration: 'contributory' projects are designed by academics and the public provide data; 'collaborative' projects involve a small level of feedback from public members; and 'co-created' projects involve participants in the entire research process, from design to data collection and dissemination. Across this spectrum of engagement, it is clear that involving broad publics in scientific research can have profound impacts (Bonney et al., 2014).

These successes are set amongst a backdrop where public messaging designed to raise awareness of the consequences of an ailing natural environment (WWF, 2020) is failing to mobilise collective action (Hess et al., 2020). Recent evidence suggests people may respond more favourably to positive messaging about the environment (White et al., 2020a), and creative ways of communicating environmental issues might prove successful in this domain. In one example of this approach, *Lightning Birds: An Aeroecology of the Airwaves* (Smith, 2021), employed several communication devices in the form of a "*podcast-style audiobook, a curatorial essay, and a bibliography*" to explore the intersection between birds and the media across outputs that combine "*traditional forms of text-based scholarship with sound art, music, and audio storytelling.*"

Both typical forms of broadcast radio and now ubiquitous audio podcasts (Fox et al., 2021) can disseminate accessible scientific messaging to specialists, non-specialists, and foreign language speakers alike (Barrios-O'Neill, 2018; Quintana & Heathers, 2021; Ye, 2021). The reach and flexibility of these formats, and the benefits of "*borrowing communication strategies from the arts and humanities*" (Martinez-Conde & Macknik, 2017), mean that academics are increasingly employing innovative storytelling devices to widen the reach of academic outputs (Dahlstrom, 2014).

3. In summary

Relationships between nature and health have held deep cultural significance for humans for millenia. But it is in the last 40 years that substantial evidence has been generated to support the proposition that contact with natural environments can confer a diverse range of therapeutic benefits. Amongst these positive outcomes, exposure to nature has been associated with physiological stress reduction, recovery from cognitive fatigue, alleviation of negative moods, and the stimulation of positive emotions.

Evidence for these effects has stemmed from several disciplinary perspectives employing contrasting approaches, including epidemiological studies, in situ interventions, qualitative methods, and laboratory experiments. These diverse investigations have given rise to several theoretical frameworks seeking to explain the mechanisms underpinning nature-health relations. Initially rooted in evolutionary development and increasingly recognising cultural conditioning, Kaplan and Kaplan's concept of attention restoration has emerged as a prominent theory in this domain.

With its focus on indirect attention, or ' soft fascination', and feelings of 'being away', attention restoration is commonly measured alongside affective outcomes that include appraisals of 'simple' emotions such as happiness and sadness. More complex emotions are also beginning to garner interest, among them feelings of awe and nostalgia, pioneered by Keltner and Sedikides respectively. Eliciting these responses may confer specific benefits and represent a complexity to environmental experiences that is still to be fully explored.

In this regard, several other important facets of human-nature interactions have, thus far, been largely overlooked. Chief among them is the role that natural soundscapes might play in restorative experiences. Moving beyond a narrow focus on noise pollution, the sounds of nature are increasingly considered as positive aural resources, and emerging research led by researchers such as Payne and Ratcliffe suggests this sensory modality is a vital component of interactions with the natural world. Yet how people might respond to diverse natural soundscapes is an area requiring greater analytical attention.

Soundscape research marks a needed departure from the well-established domain of visual preferences. Yet within the visual realm, we also find a neglected seam of research hiding in plain sight. Embodied by diurnal and meteorological processes, Brassley's 'ephemeral phenomena' represent significant intra-landscape aesthetic changes with hitherto unexplored effects on the ways both natural and urban settings are experienced. Anecdotal evidence abound for the importance of fleeting moments such as a sunrise and sunset, but quantification of these impacts on psychological indicators has, so far, remained elusive.

The effects of both natural sounds and ephemeral phenomena are particularly relevant to digital encounters of nature, where *any* kind of experience can be created. Natural history content, whether on TV or through wellbeing apps, routinely engages millions of viewers across the UK, and this kind of digital content is increasingly being designed to support health outcomes. Generating evidence that underpins editorial decisions may well be the cornerstone of these developments, but the ubiquitous presence of ‘virtual nature’ also presents a third, unexplored, area of enquiry.

Since the very first days of nature programming, natural sights and sounds have been accompanied by music. This pairing continues today and is perhaps most familiar in the striking orchestral scores of flagship BBC series. Indeed, adding music to natural scenes has become so commonplace that it has crept into numerous studies attempting to assess the therapeutic effects of nature contact. But how, specifically, might music impact the emotional and restorative potential of nature? Although a large field of research has considered the psychophysiological effects of listening to music, we currently have scant evidence to answer this fundamental question.

Equally as important, what role might lived experience play in these relationships? Top-down processes – those that rely on cognition and in turn, memories and meaning – have the potential to substantially augment nature-based encounters. Long recognised by cultural geographers and the field of ‘therapeutic landscapes’, we know little about how to quantify the effects of personal experience on restorative outcomes. Likewise, experiments with large, heterogeneous samples are still the exception rather than the rule in most studies; and generating samples from a diverse set of participants remains a priority.

If factors such as natural sounds, ephemeral phenomena, music, and memories can affect encounters with digital forms of nature, how might we inform practice in the ‘real world’? Translating findings into a format that might fit with the modelling of cultural ecosystem services, by including contingent valuation measures for example, could help to ensure these overlooked areas are considered in planning and policy. These applications may be crucial at a point in history when global environments are suffering from wholesale destruction, and the connections between humans and nature are faltering.

If science is to make a difference in these endeavours, it must use novel and creative methods to engage with broad audiences. This research aimed to do just that. Across three collaborative studies, this PhD integrated transdisciplinary teams from the arts and sciences, and engaged with national and international audiences to investigate how natural sounds, ephemeral landscape aesthetics, and music can each impact the experience of digital, and by extension, real, encounters with nature.

3.1 Research questions

Specific research questions for each experiment are detailed in chapters 5-7, an overview of those questions is provided here.

3.1.1 Natural sounds

Study one sought to understand how various combinations of sound and people's personal memories might impact the restorative potential of natural soundscapes. This study was intertwined with the narrative of *Forest 404*, inviting audience members to reflect on the value of both natural sounds and poetry. We attempted to answer four key research questions:

1. How might the perceived restorative potential of a natural soundscape be influenced by the sound types from which it is composed? We anticipated that the presence of landscape elements such as flowing water and audible fauna such as bird song would be perceived to enhance restoration. How the addition of 'culturally approved' spoken word, and differing combinations of abiotic, biotic, and 'cultural' sound types, might impact these appraisals was highly exploratory.

2. How might participants' motivation to preserve a natural soundscape be influenced by the sound types from which it is composed? This question replicated the approach of question #1 and whilst we expected natural sounds from biological sources to increase listeners' desires to preserve the soundscapes they heard, the inclusion of poetry was again exploratory.

3. How might the patterns emerging from research questions #1 and #2 be moderated by lived experience. We anticipated that positive memories of a soundscape would be associated with increases in restorative potential. The scale of this effect and whether it would be mirrored in ratings for preservation motivation, were novel areas of investigation.

4. If soundscape composition and lived experience are associated with appraisals of restorative potential and preservation motivation (questions 1-3), might restorative potential mediate preservation motivation? We suspected participants may be more motivated to preserve soundscapes they believed would provide therapeutic outcomes, but the scant literature in this area of environmental sensing meant we could not hypothesise about the magnitude and consistency of this relationship.

3.1.2 Ephemeral phenomena

Building on the approach of study one, study two aimed to apply a similar level of granularity to landscape aesthetic appraisals, tackling four key research questions:

1. How might six relatively common ephemeral phenomena affect assessments of landscape beauty? Are these effects moderated by urban and natural environment types?

2. Can ephemeral phenomena also impact participants' feelings of awe? Are these effects also moderated by urban and natural environment types?

3. Do our phenomena impact participants' willingness to pay to visit a location? And are these effects again moderated by urban and natural environment types?

4. If the answers to research questions 1-3 is 'yes', to what extent might beauty and awe mediate willingness to pay valuations?

3.1.3 Music and nature

Study three combined the approaches applied in studies one and two, building upon the stimuli used in these experiments to untangle the possible interactions between nature, music, and memories. Specifically, we asked:

1. How might the addition of natural sounds, music, and the combination of both natural sounds and music to a digital nature experience, influence perceptions of restoration?

2. Could the addition of natural sounds, music, and the combination of both natural sounds and music to a digital nature experience affect the elicitation of emotions such as calmness and excitement?

3. Could the addition of natural sounds, music, and the combination of both natural sounds and music to a digital nature experience impact the more complex affective responses of awe and nostalgia?

4. How might the triggering of memories in response to our experimental manipulation moderate any relationships identified in research questions 1-3?

4. Methods

The specific methodological approaches used to answer our research questions are detailed in the published studies presented in chapters 5-7. Contextual information that was not included in these published papers (due to both word limits and formatting constraints) is presented here, along with a narrative that explains how each study was intertwined.

4.1 Co-created and collaborative design

A unique opportunity arose to position two studies at the heart of large-scale BBC broadcast initiatives (section 4.3.1 and 4.6). These projects were highly collaborative and involved transdisciplinary teams with experience across a range of creative perspectives.

Although a broad research focus was determined at the outset of the PhD, specific research questions were developed with project partners as part of an engaged, co-created process. For example, the restorative potential of natural sounds had been identified as an area in need of further research, but the decision to focus on soundscape composition, preservation motivation, and memories in study one evolved with input from all partners and represented a symbiosis with the *Forest 404* drama series. This process was highly responsive, allowing the development of research questions that would not just address gaps in the existing literature, but also inform future broadcasts (see *Mindful Escapes*, section 9.1).

4.2 Commonalities

Each study employed online experimental approaches. Participants were randomly assigned to multiple (studies one and two) or single (study three) conditions. They were asked to focus on an experimentally manipulated digital nature experience either by listening, watching, or both listening and watching, and to (self) report how the encounter affected them according to our metrics of interest.

All three projects recruited sample sizes that are uncommon in this type of research. Study one captured responses from ~7,600 participants, study two from ~2,500 panel members, and study three from ~8,700 people. Although the use of online methods precluded us from capturing qualitative context or physiological measures, the scale of these data provided the sensitivity to reveal trends that might be obscured by the inherent variability of smaller samples (see section 2.13.5).

Working with world-renowned creative teams also meant that we could develop experimental stimuli that mirrored the quality of real-world digital nature experiences, and thus possessed a high degree of ecological validity. It is routine for researchers in the fields of environmental psychology and landscape aesthetics to develop their own experimental conditions, often with low levels of fidelity and quality (e.g. Felnhofer et al., 2015). In each of our three studies, we sought to move beyond these approaches by working with leading script writers, actors, sound recordists, composers, and visual artists to produce experiences that paralleled those encountered in everyday life.

Beyond these project partners, the University of Exeter's Health and Environment Public Engagement group (HEPE) provided vital guidance in the development of each study. Composed of volunteers with a diverse range of lived experiences, HEPE provided a 'common sense' perspective as each project progressed. They offered critical feedback on every aspect of the process, from research questions and methodologies, to experimental wording and results reporting.

Participation from automated bots and problems such as 'ballot stuffing' are becoming increasing issues in online research (Griffin et al., 2022). To mitigate the potential of these practices several steps were taken in each study: where possible, data collection platforms prevented multiple submissions from the same participant; experiments were not indexed by search engines (Xu et al., 2022); in two studies no remuneration was provided to respondents; where remuneration was provided, it was offered as part of a strictly managed consumer panel. As an additional measure, and where responses could be timed, those who completed the experiment in times faster or appreciably slower than those deemed acceptable by pilot testing were excluded from analyses.

Ethical approval for study one was provided by the partner institution in that project, the University of Bristol Arts Faculty Research Ethics Committee, #76582. Ethical approval for studies two and three was granted by the University of Exeter's College of Medicine and Health Research Ethics Committee, application numbers 20/01/236 and 20/11/267 respectively.

4.3 Beginning with *Forest 404*, Study 1

Since 2016, the research team at the European Centre for Environment and Human Health (ecehh.org) had been fostering a research relationship with the BBC Natural History Unit, the program-making team responsible for nature series such as *Planet Earth* and *Blue Planet*. This partnership had contributed to a successful study assessing how delivery mode can impact digital nature experiences (Yeo et al., 2020), and as 2018 began, conversations centred on how to develop a deeper level of collaboration.

Funding for this PhD was confirmed in March 2018. As the year progressed, an AHRC-funded collaboration between the BBC and the University of Bristol neared its end with substantial monies left for a 'creative output' (grant number AH/P504622/1). Peter Coates was the principal investigator on this grant, a professor of American and environmental history, who had previously written about the history of natural and human sound (Coates, 2005).

Throughout the summer of 2018, discussions began with producers at the Natural History Unit, Peter Coates at the University of Bristol, commissioners at BBC Radio 4, and developers of a new citizen science tool at The Open University, to explore how we might pool our resources, interests, and expertise to produce a creative, public-facing piece of nature programming, that placed scientific approaches at its heart. These discussions led to the creation of *Forest 404*, a novel, multi-stranded drama series and sound experiment.

4.3.1 Development and launch of *Forest 404*

The series and experiment were developed very quickly. Funding for this PhD began in October 2018 with a planned launch date for *Forest 404* of 15th January 2019. However, the new *BBC Sounds* mobile app, which was a replacement for the *iPlayer Radio* app, had suffered a maligned launch in late 2018. A relaunch of *BBC Sounds* was proposed at the start of April 2019, and *Forest 404* was selected to be one of its flagship pieces of original content. This development meant that the full institutional might of the BBC geared up to promote the series and by extension our experiment.

The series was named after the '404' error message displayed when trying to follow a link to web content that has been removed. Set some 300 years from now and following a catastrophic event called 'The Cataclysm', *Forest 404* imagined a world in which ecological destruction, technological intervention, and the extinction of experience have reached their ultimate end points. The result was a society in which both the 'messiness' and memory of nature had been removed: ecological processes were performed by machines; cultural links between people and nature had been broken; and the concept of the natural world as we know it had been all but forgotten.

The drama was written by Timothy X Atack and placed scientific trends at the heart of its narrative, which followed main protagonist, Pan (played by Pearl Mackie), as she uncovered sounds from a tropical rainforest in her role as a data archivist. In a world short on digital storage, Pan had to decide which sounds to preserve and which to irretrievably delete. With no experience of nature, she could not decipher the 'noises' she heard but was innately beguiled by them. She began a quest to understand their origin and meaning, bartering with sound files as she slowly uncovered the horror of her dystopian society. Following several rounds of creative discussion, the series intentionally yet implicitly asked if people had an innate affinity for natural soundscapes, and if so, how would they feel when they listened to them and what lengths would they go to preserve them?

Working closely with the creative teams developing the podcast allowed us to both underpin these questions with academic understanding, and accurately reflect them in our study design. The result was a soundscape experiment that was interconnected with the storyline of the drama, providing a seamless route to participation; listeners were encouraged to tell us how *they* felt about natural sounds.

Forest 404 also marked a unique four-part offering from the BBC: launched as a multi-platform podcast, the drama (part 1) aimed to confront environmental degradation, loss of cultural heritage, and explored links between nature and health; a series of 'pod-talks' (part 2) accompanied each episode and aimed to explain the science behind the drama; part 3 took the form of an accompanying set of soundscapes to provide audiences with an immersive experience of the *Forest 404* world; this creative and performance-based framework placed audience participation at its heart, allowing listeners to take part in the *Forest 404 experiment* (part 4). Visit http://bbc.co.uk/forest to listen in full.

Forest 404 launched on April 4th 2019 at a special event at the Barbican Conservatory (Fig. 8). It was advertised across almost all BBC television and radio channels, with an iconic theme song produced by Bonobo. Between April 2019 and March 2020, episode downloads had exceeded 2.5 million. The series went on to win accolades from Prix Europa, the UK Writers' Guild, and the Audio and Radio Industry Awards.

Figure 8. The Forest 404 cast and production team at the series' launch in April 2019.

4.3.2 Creation of the experimental instrument

During early conversations about how to build, host, and deliver the *Forest 404 experiment*, The Open University joined the team. Professor Mike Sharples was leading the development of a new platform designed to enable 'citizen science' and 'enquiry-based learning'. Called *nQuire*, the tool was in an embryonic state and not yet open to the public (https://nquire.org.uk). As part of an ongoing partnership with the BBC, The Open University agreed to expedite development of this platform, ensuring it would be suitable to host the *Forest 404* experiment.

Significant collaboration was required to enhance *nQuire* and bring its functionality up to a standard suitable for running a large-scale, nationally promoted, online experiment. Working closely with the *nQuire* technical team, substantial feedback was provided to guide and test a series of new features, namely: the creation of highly visual and intuitive sliding scale Likert responses; an accessible embedded audio player with options for file formatting and hosting; a new randomisation algorithm with options for 'binning'; redesign of the user interface and experience, including changes to user journey and wording of navigation options; a new informed consent module to replace the existing passive consent form; and bug and compatibility testing across multiple browsers and devices.

Based on feedback and evaluations from four rounds of piloting, the user experience of the experiment went through several design and formatting iterations. Richer descriptive feedback was also elicited from the Health and Environment Public Engagement group.

The launch of *Forest 404* represented a substantial stress test for the *nQuire* system, which had previously experienced low rates of participation; our experiment generated 7,596 completed responses, a large proportion of which occurred within the first few weeks of launch (Fig. 9).

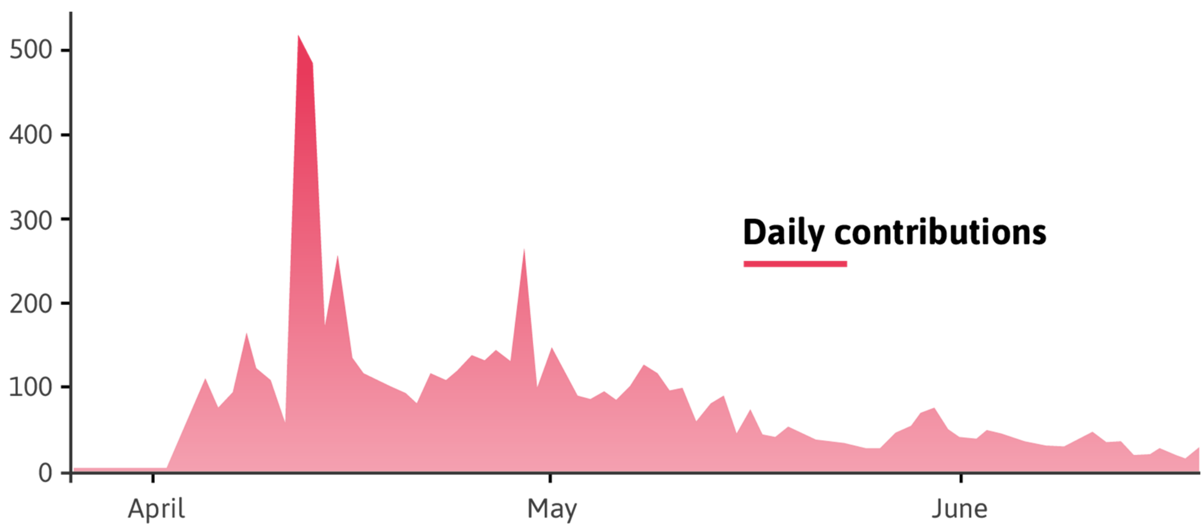


Figure 9. Daily participation rates in the *Forest 404* experiment during the first ten weeks of its launch.

In addition to the quantitative data collected as part of this study (comprehensively presented in chapter 5), over one hundred individual communications were received. These correspondences were overwhelmingly positive, with people sometimes even reporting a demonstrable change in their behaviour because of listening to *Forest 404*. Some provided extra information related to their responses in the experiment (although all data were anonymised, so emailed feedback could not be linked with completed responses), whilst others wanted to know more about the series and plans for what might come next. The following quotes provide an insight into the types of response received:

"*This is SUCH a cool project + podcast! I have enjoyed both tremendously. Please will you share the findings with me when you publish them?*"

"*My ears seem more attuned to nature now. On my morning dog walk I could hear nothing but birdsong, I don't think this is any different than before I think I've just noticed it now.*"

"*I have just been listening to the Forest 404 podcast / the experiment and was absolutely blown away by the creativity of the story, and the science / soundscape podcasts were really interesting!*"

"*I've been listening to forest 404...It's amazing and I wish that everyone would listen to this to connect with nature. This experiment and the information connected to it is so new and makes me yearn to be outside more. Thankyou for doing this :)*"

4.3.3 Identifying a gap

As part of the extensive conversations that created *Forest 404*, we initially explored several areas of environmental experience that might fit within the series' narrative. One theme that was partially developed related to Pan's obsession with images of sunset. For example, early versions of the script read "*yes she got some sky light, her days were influenced by solar rhythms, but it doesn't explain her sudden infatuation with pictures of sunsets.*"

They also referenced the way that sunsets had captured people's attention across cultures:

"*a sunset in the slow times was very very different. It involved colours. Quite a few colours. The skies ran differently to the way they do now…their sunsets were appallingly unpredictable. Humans from the old times were obsessed with their cracked and refracting skies. The evidence suggests they were desperate to document all of them. Even today, we keep discovering multiple digital images of the setting sun, with ancient people dancing and smiling in front of it, possibly making an offering of themselves.*"

Yet with the desire to ground *Forest 404* in robust academic findings, it became clear that there was little quantitative steer to explain the cognitive and affective processes unfolding when people responded to ephemeral features such as sunsets, and the idea was subsequently dropped from the narrative. However, the creative and scholarly desire to address this gap led to the development of our next study.

4.4 The inception of ephemeral phenomena, Study 2.

Following the success of *Forest 404*, the BBC was eager to continue our academic and creative partnership and develop further understanding that might ultimately inform their natural history programming. To that end, they committed funds for an exploratory study investigating the attraction of visual ephemeral features in the natural world and we sought to answer several of the questions posed by Brassley's (1998) treatise "*On the unrecognized significance of the ephemeral landscape*" (section 2.11).

4.4.1 Development and data collection

The BBC contributed £3,500 to the study. With no associated broadcast initiative to catalyse participation, and with the desire to maximise the size and representativeness of our sample, the entirety of that budget was allocated to paid participation through a consumer panel.

The success of our creative partnership in *Forest 404* placed an emphasis on designing visual stimuli with both high fidelity and high levels of control. However, following several conversations with design teams at the BBC and external organisations, it became clear that we did not have the budget to pay for the required amount of design time. At this point, Nick Smalley, an award-winning 3D animator, agreed to step in and help create the visual conditions.

Input to the study was also sought from our growing network of creative partners. Marshmallow Laser Feast (marshmallowlaserfeast.com), a leading producer of VR experiences, Floris Koet, a pioneer in natural 'cinemagraphs' (livingstills.nl), designers at 3Dctrl (3dctrl.com), as well as the wider team at the BBC Natural History Unit, each provided thoughts and direction on the metrics they would be interested in understanding, and how they might feed results into their practice.

Outcomes from these conversations, along with precedents and gaps in the existing literature, helped to determine the type and format of questions posed. They also placed emphasis on a fluid user experience, and the innovative use of cinemagraphs as experimental conditions, formatted as looping .gifs.

Based on prior experience, a good working relationship, and competitive pricing, Cint (cint.com) were selected to run the study. Cint applied census quotas to the recruitment of the sample based on Euromonitor data. Respondents were charged at £1.40 per completed response, with speeders and 'flatliners' identified during the data collection phase and replaced with new entrants. We aimed to achieve 2,500 participants who each received a ~£1 incentive for taking part in the experiment, with the exact type of remuneration (cash or voucher) dependent on the specific panel the participant had signed up to.

Although The Open University's *nQuire* platform had been used to run the *Forest 404 experiment,* it was not capable of presenting animating gifs or employing adequate randomisation for this project. Qualtrics was used instead, a much more powerful and adaptable survey tool (qualtrics.com/uk). A web developer was also employed to finesse the look and feel of the final experiment, and ensure it worked equally well across devices.

Creating and financing this study required a substantial amount of financial agility: BBC funding secured the participant sample; the Qualtrics licence was 'gifted' by collaborators on the EU-funded Smartline project (smartline.org.uk); bespoke development work was paid for by the Wellcome Trust's research allowance; and stimuli design work was paid for by collaborators at Plymouth University.

In addition to the industry input outlined above, two special sessions were held with the Health and Environment Public Engagement group. They helped to refine the aims and objectives of the study, and further ensured its research questions would have relevance to non-academics. They also participated in two rounds of piloting, ironing out problems with legibility and technical execution. An epilepsy expert was also consulted to ensure our conditions would not trigger any photosensitive reactions (particularly the thunderstorm).

As the study developed, the BBC became increasingly interested in its public interest potential and began to explore how it might be integrated more deeply with their natural history output. One viable option involved running the study with two samples, one captured through Cint, and a second generated through a concerted program of social media promotions across BBC channels. But in March 2020, the UK entered its first, total, Covid-19 related lockdown. As a result, these plans were shelved and data collection began, via Cint only, on 6th May 2020.

However, as the Covid-19 pandemic deepened, new conversations were sparked with the BBC about creating a form of nature-based 'slow TV' that might reach people confined at home and provide an opportunity to put the findings generated from our *Forest 404* and *Ephemeral Phenomena* studies into practice.

4.5 Mindful Escapes

The BBC Natural History Unit had been approached by Headspace (headspace.com), a smartphone-based mindfulness tool that aims to "*improve the health and happiness of the world*" (Headspace, 2023). They had substantial budget to produce a short TV series (see section 9.1 for full details), and hoped to fuse meditative prose with restorative scenes of the natural world, aiming to improve the wellbeing of audiences at a time when mental health was faltering, particularly in those from lower socio-demographic groups (O'Connor et al., 2021).

Early findings from both our *Forest 404* and *Ephemeral Phenomena* studies provided steers on how to blend spoken word with natural sounds, and how ephemeral visual features might influence audience experiences. However, particularly pertinent to this narrative was the recurring question regarding music.

Editorial conversations repeatedly centred on the inclusion of music. Confidentiality agreements mean that specific details cannot be divulged, but several members of the production team wanted to create slower experiences that featured only the sounds of natural ambience (akin to encounters in the 'real world'), whilst others pushed for a faster pace with music throughout (more aligned with typical natural history content). Ultimately one producer suggested "*a scientific take on the situation would help.*" Yet almost no quantitative or qualitative evidence existed that had examined how combining music with nature-based experiences might influence therapeutic outcomes – particularly for digital encounters. There was thus a clear academic and commercial need to address this lacuna.

4.6 The inception of *soundscapes for wellbeing*, Study 3

As part of the editorial conversations concerning music and *Mindful Escapes*, introductions were made to Rebecca Sandiford, a commissioning executive at BBC Music. Rebecca was working with the BBC Archive and BBC Sounds to launch a digital collection of soundscapes and orchestral performances, aiming to alleviate anxiety in people with Covid-19.

As part of a building relationship, preliminary findings from *Forest 404* were offered to help shape this final offering. Called the *Mindful Mix – Critical Care Special*, it launched on BBC Sounds during Mental Health Awareness Week (May 18th 2020) and featured: a blend of natural soundscapes and calming music; an introduction from Sir David Attenborough; and a curated collection of recordings from Chris Watson, a renowned nature sound recordist (BBC Archive, 2020).

The collection was well received both within the BBC and with audiences, and with debates about the inclusion of music in *Mindful Escapes* still ongoing, developmental conversations subsequently progressed about how to create a multi-platform programme of content and investigative science that might explore the intersection of music, nature, and wellbeing more deeply.

4.6.1 Development of *Soundscapes for wellbeing*

Embryonic ideas centred on a project with several strands – part documentary, part podcast, part Mindful Mix, part academic research project. Teams from BBC Radio 3, BBC Radio 4, BBC Archive, and the BBC Natural History Unit were involved in initial ideas generation, providing a level of internal collaboration that is relatively uncommon within the BBC. Concepts such as 'sound walks' with famous voices, seasonally varying soundscape recordings in the same locations, unique musical compositions from famous musicians, and short films for BBC Three (targeting a younger audience) were all explored as possible formats.

Once again, funding a possible collaboration required significant financial dexterity. Within the BBC, a potential route involving the launch of the new BBC Sound Effects (SFX) site appeared to present a budgetary opportunity (the SFX team were subsequently included in discussions), as did a small pot of funds from BBC Radio 3. Internal support from the Wellcome Trust at the University of Exeter designed to "*seed projects and to help develop connections to community and engaged partners…up to £5,000*" was also leveraged.

With funding amounts largely determined, ideas and timelines began to crystallise throughout the summer of 2020. From a theoretical perspective, we also saw an elegant opportunity to create an experiment that combined and built on learning from our *Forest 404* and *Ephemeral Phenomena* studies, blending natural sounds and sights with music in a strictly controlled way to understand the contribution each factor might make to audience experiences (Fig. 10).

At the end of August 2020, the project was confirmed with a structure that included an experiment investigating the roles of nature and music in virtual experiences; BBC Radio 3 exploring music, natural soundscapes, and mixing the two via a special *Slow Radio* episode; the launch of the new BBC SFX website (sound-effects.bbcrewind.co.uk), with a huge tranche of new and freely available nature recordings; a special edition of Music Matters on BBC Radio 3 reporting on the experiment; and multiple opportunities for connected content across the BBC. Exemplifying that final point, the BBC Winterwatch team were eager to make the experiment a core part of their series and the final launch date was set for January 2021 to coincide with their schedule. The project was given the working title '*Soundscapes for wellbeing*'.

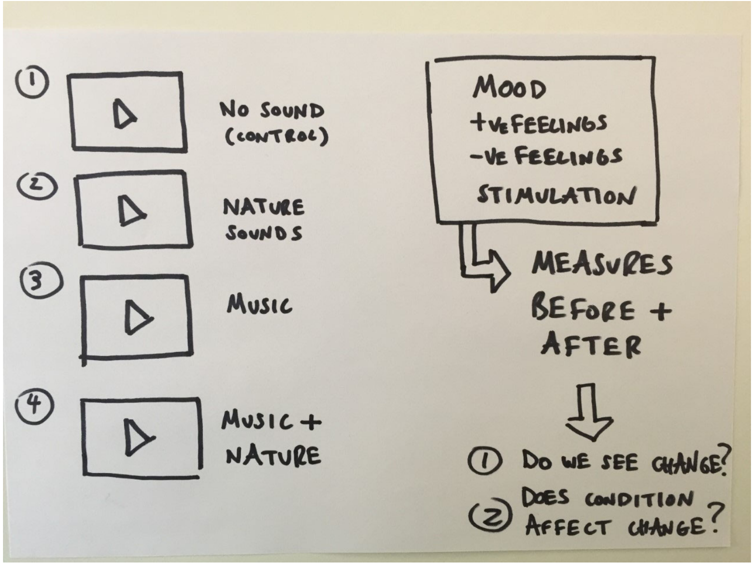


Figure 10. The first sketched outline of the music and nature study.

Continuing the transdisciplinary and collaborative approaches embraced by this PhD, the project team was further expanded to incorporate specific areas of expertise. We were joined by: Nainita Desai, a composer with a wealth of experience in scoring for television programmes and nature documentaries; Chris Watson, the UK's leading nature sound recordist; Dr Laura Sakka, music and emotion researcher at Uppsala University, Sweden; and Nick Smalley, award winning 3D animator and architect of the visuals used in our *Ephemeral Phenomena* study. Far from simply being included in the project for their technical abilities, these team members contributed to every aspect of the project's design, lending opinions and insights based on their broad and diverse experience.

For example, to enhance ecological validity of the experience and experiment, the whole team were keen to try and replicate the acoustic design typical in natural history programming, where natural soundscapes (often recorded separately) are carefully matched to visual cues, and bold scores fuse a mix of ambient, electronic, and orchestral styles. Acoustic and visual conditions were thus created with input from all project partners, in an iterative process that considered academic evidence, creative experience, and an understanding of audience expectations. Each condition used the same visual component, which was created by enhancing scenes from our *Ephemeral Phenomena* experiment, allowing us to create a journey in audience emotions similar to the 'highs and lows' typical in narrative nature content.

As the creation of the experimental stimuli progressed, a major area of debate became our fourth condition – in which the natural soundscape and musical score were mixed together. Although both tracks had been developed separately by Nainita Desai (composer) and Chris Watson (nature sound recordist), they had also involved a high degree of collaboration to ensure they would work well when mixed together. One of BBC Radio 3's foremost music balancers, Michael Bacon, was brought onboard to create the mix, which underwent several changes before the final version was signed off.

In tandem with this process, two special sessions were run with the Health and Environment Public Engagement group (HEPE). As with studies one and two, they provided crucial feedback on the ethics application, study design, experiment piloting, and project descriptions. Following the success of using Qualtrics in *Ephemeral Phenomena*, it was again selected to host the study, with a licence gifted by the University of Exeter's Clinical Trials Unit. HEPE suggested several important changes following piloting, including wording, signposting, a reduced consent process, and refined user experience. Bespoke coding was commissioned to finesse the aesthetic and ensure the experiment worked seamlessly across devices.

A key strand to this project also considered how the methods and outcomes might inform the BBC's digital wellbeing framework (bbc.co.uk/rd/projects/digital-wellbeing). This initiative was being led by BBC Research & Development and hoped to "*create experiences that are relevant to audiences across…changing situations and contexts.*" The project team thus expanded further to include representatives from BBC R&D, opening a dialogue that hoped to allow the *Soundscapes for Wellbeing* project to have a direct influence on the BBC's wellbeing developments.

4.6.2 Programme launch

Soundscapes for Wellbeing launched on 25th January 2021, when the UK was in its third and only full winter lockdown. It was widely promoted by numerous BBC TV, radio, and online channels, with dedicated features on the BBC home page, BBC News, BBC World News, BBC R4, BBC Radio 3 , *Morning Live* on BBC One, *Winterwatch* on BBC Two (Fig. 11), BBC World service, BBC Radio 2, BBC 6 Music, BBC Radio Scotland, BBC Asian Network, numerous BBC social media channels, and the BBC Science Focus magazine.

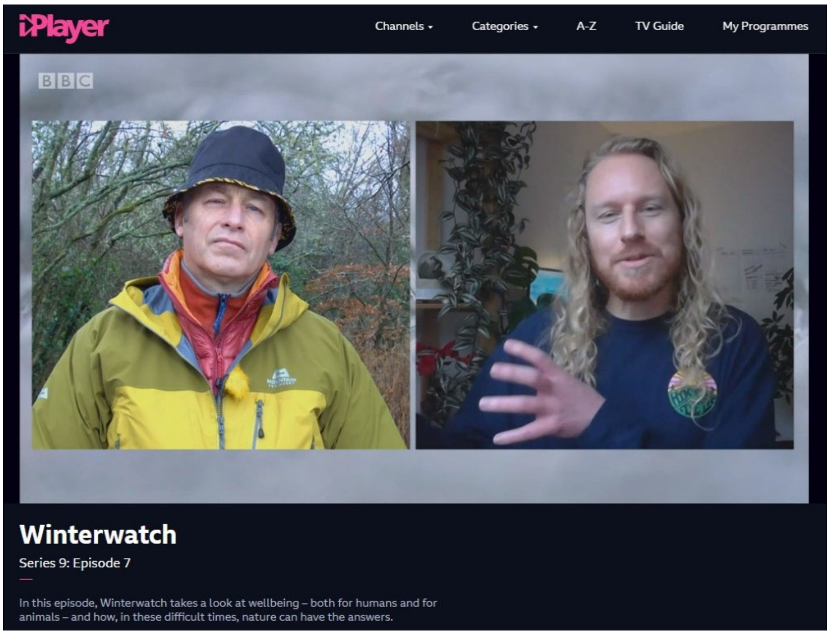


Figure 11. Alex Smalley speaks with Chris Packham, presenter of BBC Winterwatch, as part of a dedicated episode focused on nature and mental health.

This coordinated promotion stimulated substantial engagement in the *Soundscapes for Wellbeing* content. By 16th Feb 2021, 7,800 people had taken part in the experiment, and by 19th April 2021, we had reached 8,700 participants.

Data collection closed at the end of April 2021, with an episode of BBC Radio 3's Music Matters programme dedicating a special package to the success of the project and providing a 'sneak peek' at participant demographics and top-level trends in the data.

In addition, several hundred people got in touch via email to provide extra detail on their experiences. This feedback ranged from overwhelmingly positive:

"*I came across your experiment quite by accident, and took part. I find it absolutely fascinating* 🙂 *I'm going to encourage my Mum to take part, she is 85 and unfortunately lost the ability to walk last year.*"

"*I took part in the study, that was fun to do, and the sunrise, and sunset, had the most emotive/calming effect on me, esp. sunset with the sound of the blackbird singing.*"

To particularly critical:

"*I am writing to say how I was disappointed to find the video was dominated by the sound track. I would have preferred no music and just sounds of nature.*"

But perhaps the most insightful comments were those that elaborated on how people were already using digital forms of nature for therapeutic gains:

"*I have only ever tried a small amount of meditation and not very successfully, I feel with this [virtual nature] I might be able to 'chill out' much easier*."

"*I have for the last couple years been listening and watching quite a few different videos on YouTube as the amount of all kinds of videos have been posted and the range is amazing. It is certainly helping me in so many ways especially as due to physical emotional and mental health issues that impacts me I have not been able to get out into the natural world for the past few years*."

"*My children are 13 year old identical twin boys with autism and a host of comorbid behaviours, difficulties and needs. My mum has dementia. For each of us, sounds and images from the natural world engage us in ways that other looking and listening activities do not.*"

4.7 Data collection complete

The culmination of *Soundscapes for Wellbeing* marked a significant milestone in the PhD: three large datasets (ns ≈ 7,600, 2,500 and 8,700) now had to be unpacked, analysed, and published, ultimately producing the three peer-reviewed papers that are presented in the following chapters.

The full text from these published manuscripts is provided in chapters 5,6,7. Whilst this format will result in some repetition from the literature review in chapter 2, it will provide a complete, contextual overview of each experimental component for the reader. Repetition has been minimised in the discussion section by refraining from simply restating results, instead discussing findings in context with the existing literature, and offering additional perspectives that could not be included in the published papers.

We turn first to a consideration of the restorative potential of natural soundscapes which, when this PhD began in 2018, still represented a much-understudied facet of environmental encounters.

5. Study one, *Forest 404*

Title

Forest 404: Using a BBC drama series to explore the impact of nature's changing soundscapes on human wellbeing and behavior.

Published in *Global Environmental Change*
doi.org/10.1016/j.gloenvcha.2022.102497

Abstract

Extensive ecosystem degradation and increasing urbanization are altering human relationships with nature. To explore these trends, we created a transdisciplinary, narrative-led podcast series produced by the BBC, called *Forest 404*. The series explored the implications of a world without nature. An online experimental component mobilized audience participation (n = 7,596) to assess responses to natural soundscapes with and without abiotic, biotic, and poetic elements across five biomes. Conditions featuring the sounds of wildlife, such as bird song, were perceived to be more psychologically restorative than those without. Participants' personal lived experiences were strongly related to these outcomes; those who had memories triggered by the sounds were more likely to find them psychologically restorative and exhibited a greater motivation to preserve them. Moreover, the effects of both soundscape composition and memories on preservation behavior were partially mediated by restorative potential; respondents were more likely to want to protect the sounds they heard if they thought they might offer therapeutic outcomes. Our findings highlight the value of art-science collaborations and demonstrate how maintaining contact with the natural world can promote wellbeing and foster behaviors that protect planetary health.

5.1 Introduction

The planet is undergoing wholesale ecological degradation, with estimates of accelerating environmental decline abound: climate change is increasing the destruction of natural habitats (Travis, 2003); anthropogenic materials now contaminate the land, freshwaters, seas, and air (Rochman & Hoellein, 2020); and global reductions in biodiversity (Newbold et al., 2016) are unfolding at rates fast enough to herald a sixth mass extinction event (Ceballos et al., 2015). These trends are exceeding earth's planetary boundaries (Rockstrom et al., 2009), catalyzing the development of global pandemics (IPBES, 2020), and causing the widespread collapse of natural systems (Bergstrom et al., 2021).

This trajectory clearly matters if human populations are to not just survive but thrive. Robust and functioning ecosystems provide many services vital for human health, such as clean air, fresh water, and climate regulation (Millennium Ecosystem Assessment, 2005). A significant body of evidence also suggests that safe, constructive contact with the natural world is important for a wide range of positive physical and mental health outcomes (Frumkin et al., 2017). In particular, exposure to nature can reduce stress (Ward Thompson et al., 2012), help people cope with challenging situations (Lederbogen et al., 2011), support cognitive functioning and emotional wellbeing (Bratman et al., 2019), and reduce negative rumination, a key risk factor in depression (Bratman et al., 2015).

However, despite public messaging designed to raise awareness of the consequences of an ailing natural environment (WWF, 2020), collective action to redress global trends has been slow to materialize. This inertia may in part stem from the fact that increasingly few people are present to witness environmental crises firsthand; over 55% of the world's human inhabitants now reside in urban environments – a figure projected to reach 68% by 2050 and which is already above 81% in higher-income regions such as North America (United Nations, 2019). These demographic shifts are reducing opportunities for direct contact with natural settings and biodiverse settings in particular (Turner et al., 2004), leading to worries about how an 'extinction of experience' might affect public health and influence societal attitudes towards environmental protection (Soga & Gaston, 2016). Moreover, visualizing the consequences of ecological change can be challenging for people (Pahl & Bauer, 2011), limiting the effectiveness of scientific approaches designed to communicate potential environmental futures (Sheppard, 2012).

To address these shortcomings, there have been increasing calls for the formation of academic and creative alliances that engage wide audiences with scientific findings (Hess et al., 2020) and reconnect urban communities to the natural world (Ives et al., 2018). Fictional literature has emerged as an encouraging tool in this endeavor, employing creative storytelling as a successful way to involve the public in modern ecological issues (Schneider-Mayerson et al., 2020). Here we extend upon these methods, embracing the scientific communication potential of Web 2.0 (Brossard & Scheufele, 2013) via the medium of audio podcasting.

Through a multi-institution arts and science collaboration we developed a podcast series, titled *Forest 404*, that engaged audiences with environmental issues and mobilized their participation in a large online experiment (n = 7,596). The premise of the series suggested that humans have an intrinsic and hard-wired affective response to the sounds of nature (Wilson, 1984). Our experimental approach probed the assumption that all participants would respond the same to differing environmental sounds, and we present findings that challenge this hypothesis. We first introduce the *Forest 404* series, outline the key elements of our study design, then present our results and conclusions.

5.1.1 The Forest 404 series

Named after the error message encountered when searching for a web page that no longer exists, *Forest 404* was written by Timothy X Atack and produced by the UK's national broadcaster, the British Broadcasting Corporation (BBC). The series was based around a nine-part 'eco-thriller', set in a not-too-distant future, where ecological trends have resulted in the eradication of natural environments, the technological replacement of ecosystem services, and an elimination of nature from cultural history.

Episode one introduced Pan, the series' protagonist played by Pearl Mackie, at her job in a data archiving facility. Data storage was at a premium in this future society and Pan was charged with prioritizing 'ancient' audio files for preservation or deletion; a task she had little trouble negotiating until she was presented with the soundscape of a tropical rainforest. Pan was beguiled by the audio but unable to relate it to the world in which she lived. *Forest 404* followed Pan's reaction to the sounds of nature and explored how losing a connection to natural environments could impact both planetary and human health (visit http://bbc.co.uk/forest to listen in full).

5.1.2 Series engagement

The *Forest 404* series sought to harness the capacity of landmark BBC nature programs to engage large audiences in environmental issues (BBC News, 2018). Each episode of the drama was accompanied by an interview-based talk that explored issues covered in the fiction with topic experts; an immersive natural soundscape for listeners to engage with; and a statement encouraging participation in the online experiment. This novel cross-genre format created 27 podcast episodes that were released in April 2019 through internet browsers, the BBC Sounds smartphone app, and international podcast services (such as iTunes and Spotify). Between April 2019 and March 2020, episode downloads exceeded 2.5 million. The series won accolades from Prix Europa, the UK Writers' Guild, and the Audio and Radio Industry Awards.

5.1.3 Research focus

In synergy with the narrative and audio-based format of *Forest 404*, our experiment used sound to probe participant responses to natural environments. Our primary focus was on how varying natural soundscapes might provide 'perceived restorative potential', an indirect measure of the bottom-up recovery of positive attentional and affective states posited by Attention Restoration Theory (Kaplan, 1995). This multifaceted construct captures assessments of how restorative an environment is believed to be (Hartig et al., 1997b; Payne, 2013) and is commonly used alongside scenarios that ask participants to imagine a time of diminished cognitive resources, such as after a long day at work, or following time spent in a busy, noisy, urban environment (Ratcliffe et al., 2016; Staats & Hartig, 2004). Our second focus was a simulation of participant behavior. We asked respondents to imagine they were Pan, *Forest 404's* lead character, and make decisions to 'keep' the sounds they were presented with in an archive, or 'delete' them to make space for other data. The question was a direct analogue for the choices Pan faces in the drama, worded so those who had not listened to the series could also respond effectively. We refer to this behavior here as 'preservation motivation' (Prince, 1989), and concentrate on incentives to conserve natural capital that reflect nature-first priorities (e.g. protection of rare species), or human-first priorities (e.g. wellbeing benefits); factors that strongly overlap with the motives underpinning pro-environmental behaviors (Dearborn & Kark, 2010; Gifford & Nilsson, 2014) and align with the broad notion of soundscape conservation (Dumyahn & Pijanowski, 2011).

5.1.4 The importance of sound

Our emphasis on soundscapes addressed a gap in the existing literature, which has overwhelmingly centered on the visual perception of natural settings. For example, studies of psychological restoration have often relied upon still and moving images as their exposure conditions (Korpela, 2013); focused on aesthetic properties such as view and composition (Gatersleben & Andrews, 2013; Kaplan, 2001a); or assessed contrasts between urban and natural scenes (Van den Berg et al., 2016). However, sound represents an intrinsic mechanism through which nature is sensed and experienced (Conniff & Craig, 2016; Fisher, 1999).

The impacts of anthropogenic sound have been extensively studied under the rubric of noise pollution (Murphy & King, 2014) with the presence of audible factors such as mechanized industry and transport demonstrating detrimental effects on landscape experience (Miller, 2008). Nevertheless, mitigating unwanted acoustic elements to achieve a state of 'quiet' may not automatically lead to the positive appraisal of a soundscape (Brown, 2015). Attention has instead turned to how nature-based sounds might contribute to the idea of 'natural quiet' (Brown, 2012), a shift in focus that values natural soundscape components (rather than the lack thereof) as positive resources (Kang et al., 2016). In this vein, research across several disciplines has identified a consistent set of preferences for acoustic sources (see Ratcliffe (2021a) for a comprehensive review). For example, listening to the soundscape of the natural world is almost always preferred to that of urban environments (Alvarsson et al., 2010; Benfield et al., 2014; Schafer, 1977; Uebel et al., 2021), with elements such as flowing water (Carles et al., 1999; Yang & Kang, 2005) and passerine birdsong (Hedblom et al., 2014; Ratcliffe et al., 2016) commonly receiving high appraisal ratings.

Soundscapes featuring these components have also demonstrated the potential to reduce the physiological and psychological indices of stress, facilitate recovery from cognitive fatigue, and increase positive emotional states (Buxton et al., 2021; Ratcliffe, 2021a). This therapeutic potential has been attributed to several theoretical mechanisms that may operate concurrently, most notably: adaptive, evolutionary processes where natural quiet might signify a place suitable to 'rest and digest' (Andringa & Bosch, 2013; Gould van Praag et al., 2017); an extension of Attention Restoration Theory (Kaplan, 1995), in which natural sounds stimulate feelings of fascination and 'being away' that might facilitate the recovery of attentional resources (Payne, 2013); and also top-down mechanisms through which acoustic stimuli might trigger memories and associations capable of encouraging psychological restoration (Gould van Praag et al., 2017; Haga et al., 2016; Ratcliffe et al., 2016).

Sound is thus emerging as an essential ingredient in restorative nature-based experiences (Annerstedt et al., 2013). Yet sound sources such as a singing blackbird or babbling brook clearly differ in origin, distribution, temporality, and meaning. Could these kinds of contrasting sound types confer differential restorative advantages, and how might their combinations produce additive or competing effects?

The dissection of soundscapes according to their constituent components has been expanded by the field of acoustic ecology, which commonly distinguishes between geophysical, biological, and anthropogenic sources (Pijanowski et al., 2011). These approaches have presented novel ways to assess fluxes in audible fauna through sonic techniques (Sueur et al., 2021) and might hold particular value for monitoring biodiversity (Burivalova et al., 2019). 'Acoustic biodiversity' has been suggested as an important contributor to wellbeing outcomes in natural environments (Ferraro et al., 2020; Sueur et al., 2021) but with current methods of soundscape analysis relying on complex computational techniques (Pijanowski et al., 2011), little is currently understood about how changes to an ecosystem's soundscape might be experienced, or even noticed, by human non-specialists. Moreover, with increasing importance being placed on preserving pristine natural soundscapes (Buxton et al., 2017b), how a change in acoustic composition might impact people's motivations to conserve these environments remains unclear (Dumyahn & Pijanowski, 2011).

Concern for natural environments is, in part, influenced by socio-cultural factors (Gifford & Nilsson, 2014), reflecting the deep civilizational connections between nature and health (Ward Thompson, 2011). These interrelations are increasingly being explored through the use of creative prose, which is now often paired with natural sounds in commercially available relaxation tools (Headspace, 2021) and employed as a way to reconnect people with nature (National Trust, 2021). Although the presence of human voices can diminish the perceived tranquility of natural environments (Benfield et al., 2010), a narrow focus on these negative effects might obscure a possible synergy between nature and the use of spoken word in creative forms such as poetry. For example, in the right context, 'culturally valued' narratives can form positive compliments to a nature-based experience (Karmanov & Hamel, 2008) and poetry has demonstrated the potential to induce positive emotions in people (Obermeier et al., 2013). Recognizing their possible overlap, the unique format of *Forest 404* provided a platform to explore the interplay between nature-based poetry and natural soundscapes.

5.1.5 Possible moderating and mediating factors

To understand differential patterns in restorative potential and preservation motivation across changing soundscapes, we centered on a key moderator: lived experience. Memories of prior encounters with nature may be important for both increasing people's wellbeing (Ratcliffe & Korpela, 2016) and stimulating pro-environmental behavior (Evans et al., 2018), with a reduction in nature-based experiences expected to have negative impacts on each of these outcomes (Kahn Jr & Kellert, 2002). Research has suggested the importance of lived experience in soundscape appraisals (Medvedev et al., 2015; Ratcliffe et al., 2016; Yang &

Kang, 2005) and we sought to detect and quantify this moderating effect. Our experimental approach also made it possible to explore how psychological restoration might play a role in mediating pro-environmental behavior (Hartig et al., 2007): would participants demonstrate 'human-first' priorities by exhibiting higher motivations to preserve natural sounds if they thought they would be good for recovering depleted affective and cognitive resources?

Characteristics such as sex, age, and trait-based connection to nature can also impact responses to natural stimuli. For example, women and older people have reported greater feelings of calmness when listening to bird song (Hedblom et al., 2017), and women, younger people, and those more connected to nature have reported increased happiness and demonstrated a higher propensity for pro-environmental attitudes (Capaldi et al., 2014; Gifford & Nilsson, 2014; Whitburn et al., 2020; Zelezny et al., 2000). Detailed exploration of these individual differences was beyond the scope of the current paper but given their importance in previous studies, we also sought to account for their possible effects by including them as covariates in our analyses.

5.1.6 Research questions

Our research questions were intertwined with the narrative of *Forest 404*, inviting participants to make their own appraisals of varying natural soundscapes.

- Research question #1 asked how the perceived restorative potential of a natural soundscape might be influenced by the sound types from which it is comprised. We anticipated that the presence of landscape elements such as flowing water (Yang & Kang, 2005) and audible fauna such as bird song (Ferraro et al., 2020) would be perceived to enhance restoration. However, we had little steer on how the addition of poetry might impact these appraisals. Similarly, how differing combinations of these sound types might impact restorative potential was highly exploratory.

- Research question #2 probed the same areas as question #1, asking how preservation motivation might be influenced by soundscape composition. We expected the presence of natural sounds from biological sources to increase participants' desires to preserve the soundscapes they heard. But once again, how the inclusion of poetry might affect these ratings, and how varying sound combinations would be perceived, was unclear given the lack of relevant prior research.

- Research question #3 assessed how the patterns emerging from research questions #1 and #2 might be moderated by lived experience. Based on prior studies (Ratcliffe & Korpela, 2016) we expected positive memories of a soundscape to be associated with increases in restorative potential. The scale of this effect and whether it would be mirrored in ratings for preservation motivation, were novel areas of investigation.

- Research question #4 was partly contingent on the outcomes of questions 1-3; if soundscape composition and lived experience were associated with appraisals of restorative potential and preservation motivation, might restorative potential mediate preservation motivation? We suspected participants may be more motivated to preserve soundscapes they believed would provide therapeutic outcomes (Hartig et al., 2007), but the scant literature in this area of environmental sensing meant we could not hypothesize about the magnitude and consistency of this relationship.

Across each of these research questions we also included sex, age and connectedness to nature as covariates.

5.2 Methods

Our experimental approach presented respondents with three natural soundscapes, randomly selected and ordered, and asked them to appraise the sounds they heard according to several dependent measures. To facilitate a between-participant design and prevent possible ordering effects, we only considered data from respondents' first sound in the analyses presented here.

5.2.1 Participants

We hoped to collect a minimum of 50 responses per stimulus (50 x 36 conditions = 1,800 in total) based on previous soundscape studies where between 30 and 50 participants per condition have been sufficient to detect inter-stimulus differences in restoration and affect (Alvarsson et al., 2010; Medvedev et al., 2015; Payne, 2013). Participants were recruited via a call-to-action in the credits of each *Forest 404* episode. Those who were interested in taking part followed an online link to the experiment. Participation was open for seven months, from 4th April to 31st October 2019. Most respondents (94%) took part within the first 3 months of study recruitment. No remuneration was provided in return for participation and respondents were informed that the study aimed to improve "*Understanding of people's feelings about nature-based sounds and poetry*". No additional information about hypotheses and methods was provided.

Between 4th April and 31st October 2019, 7,596 participants completed the experiment, four times the required sample size. Only finalized responses were recorded, we do not know how many people started but did not complete the experiment. Modal age range was 46-55, 30% of our sample was aged 35 or under, 63% were female, 35% male, 0.7% identified as 'Another sex or gender'. Most participants (87%) were UK residents, we did not record the location of international respondents. Two-thirds of participants (67%) reported visiting nature at least once in the last week and mean self-reported connectedness to nature was 7.02 on a 10-point scale (Table S1, Appendix A). Compared to UK averages (ONS, 2019; Richardson et al., 2019; White et al., 2017a), our sample was slightly biased towards females, those who were older, and people more interested in the natural world, but not excessively so compared with similar studies (Richardson & McEwan, 2018).

5.2.2 Experimental design

We employed the acoustic categories ‘geophony’, ‘biophony’, and ‘anthrophony’ used in soundscape ecology (Pijanowski et al., 2011) but renamed our sound types to provide a succinct labelling structure. Abiotic sounds (A) represented the aural signature of the landscape, such as waves breaking and water flowing; whilst Biotic sounds (B) stemmed from fauna within an environment, including the sounds of birds, livestock, and, in our underwater biome, whale song. Our ‘Culturally valued’ poems (C) each depicted their respective environment and, to enhance integration with the wider series, were read by *Forest 404* actor, Pippa Haywood.

To create soundscapes of differing composition and increasing complexity, stimuli were arranged in the 2x2x2 factorial design (A = Yes/No; B = Yes/No; C = Yes/No) depicted in Fig. 12A. To broaden the applicability of the study beyond responses to a single environment, this design was repeated across five biomes: UK woodland; UK coastal; UK pastoral; tropical rainforest; and underwater. The three UK-based environments were chosen because they reflected common Eurasian soundscapes likely to be familiar to much of the *Forest 404* listenership, and therefore elicit mixed valence memories. The fourth biome, a tropical rainforest, was more exotic in origin and closely resembled the soundscape Pan encountered in the *Forest 404* series. The final biome, an underwater ocean soundscape, was selected because of its frequent use in relaxation settings (Lin et al., 2011). This design resulted in a total of 36 conditions (Fig. 12B) and aimed to reduce the chance that results might reflect reactions to a specific sound, instead revealing more generalizable patterns across contexts. Since the focus of the analyses reported here was on changing soundscape composition, responses to sound types were collapsed across biomes resulting in eight conditions: seven soundscapes and our silent control.

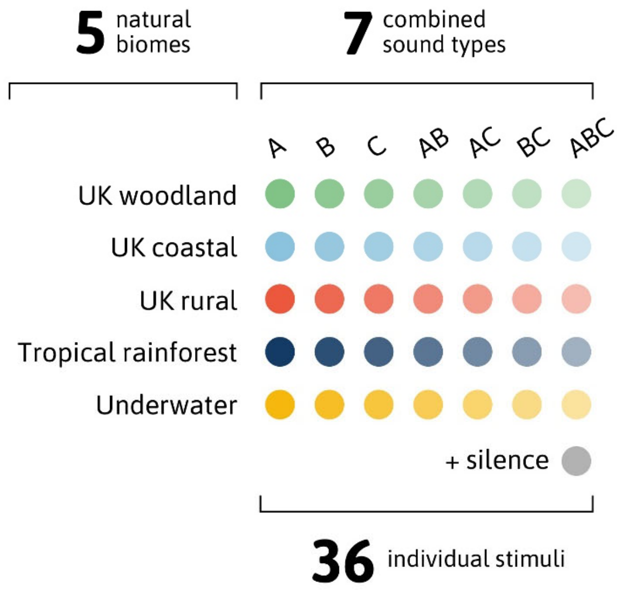
Figure 12. Arrangement of stimuli in study design.

(**A**) Factorial arrangement of sound types within a single biome. (**B**) Total stimuli arising from factorial design applied across five biomes. **Example stimulus:** Using this structure, the ABC stimulus in our tropical rainforest biome was created by combining (A) the abiotic sound of rain falling on leaves, with (B) the biotic sounds of indigenous New Guinea birds, and (C) a spoken extract from 'Savage Grace: A Journey in Wildness' by Jay Griffiths (read by *Forest 404* actor, Pippa Haywood).

(A)

		Abiotic No	Abiotic Yes
Cultural (poem) No	Biotic No	Silence	A
	Biotic Yes	B	AB
Cultural (poem) Yes	Biotic No	C	AC
	Biotic Yes	BC	ABC

(B)



5.2.3 Experimental stimuli

The abiotic and biotic sounds chosen to represent each of our auditory biomes were intended to be broadly calming. Drawing on archival recordings at the BBC, specific sounds were selected based on preferences already established in the literature (Buxton et al., 2021; Carles et al., 1999; Hedblom et al., 2014; Ratcliffe et al., 2016; Yang & Kang, 2005). Nature-based poems ('C' sounds) were selected to match their corresponding biome with significant input from producers at BBC Radio 4's 'Poetry Please' program. For example, 'Dover Beach' by Matthew Arnold was chosen for the coastal soundscape, whilst 'Woods' by Wendell Berry was paired with sounds in the woodland biome. Rights to all sounds were obtained by the BBC, with explicit consent received from artists where necessary. The specific list of sounds is shown in Table 1. Based on previous studies (Hedblom et al., 2014) and following extensive piloting, stimulus duration was set at 40 seconds.

Table 1. Description of specific sounds used in experimental conditions. As shown in Figure 1, sounds were arranged in a 2x2x2 design within biomes. For example, an AB sound in the UK coastal biome would feature both 'calm waves lapping on the beach' and 'oystercatchers chirping'; an ABC sound would add the poem 'Dover Beach' by Matthew Arnold to this mix.

Biome	Sound A	Sound B	Sound C
UK woodland	Swirling wind with leaves rustling	Woodland birdsong with blackbird	'Woods' by Wendell Berry
UK coastal	Calm waves lapping on the beach	Oystercatchers chirping	'Dover beach' by Matthew Arnold
UK rural	Gentle stream flowing	Hedgerow birds with distant sheep bleating	'Spring' by Gerard Manley Hopkins
Tropical rainforest	Heavy rain with distant thunder	Various bird calls from the New Guinea rainforest	Extract from 'Savage Grace: A Journey in Wildness' by Jay Griffiths
Underwater	Underwater waves crashing and sloshing	Humpback whale calls	'Underwater' by Michael Schmidt

5.2.4 Experimental instrument

Ethical approval for the present study was granted by the University of Bristol Research Ethics Committee, Ref: 76582.

The experiment was hosted online via The Open University's nQuire platform (The Open University, 2021). Following a brief introduction, participants had to provide informed consent before taking part. They then listened to a test sound to ensure their speakers were working and set to a comfortable volume. Respondents then read a stress-inducing vignette. This approach was used due to the online nature of the experiment, which did not allow real stress inducement and measurement of recovery. The narrative was adapted in accordance with previous studies (Ratcliffe et al., 2016; Staats & Hartig, 2004) and asked participants to imagine a situation in a typical urban setting that had led them to feel stressed and cognitively fatigued. To enhance immersion in the story, participants were asked to listen to a busy city soundscape, featuring traffic and construction noise, while they read the vignette. Given wide potential heterogeneity in aural experiences before taking part in the experiment, the vignette and soundscape were designed to harmonize the immediate experiences of all participants (to be unpleasant and mildly stressful) before exposure to the experimental conditions.

Participants then listened to one of our nature-based soundscapes, randomly chosen from the pool of 36. They were instructed to listen to the sound in full first, with their eyes closed if possible. When the sound had finished playing, they were asked to scroll down and respond to a series of questions (detailed in section 5.2.5). Participants could play the sound again or answer questions before having heard all of it. We could not record the time spent listening to each sound. After their first stimulus, participants repeated this process for another two soundscapes, randomly chosen and ordered by the nQuire software. The 40-second duration of stimuli and use of relatively few response scales aimed to keep average completion time below ten minutes (determined from pilot testing), maintain participant interest, and encourage full completion. The experiment ended with a series of demographic items. An overview of the experimental procedure is available in Appendix A and full wording, including an example of the user-interface, is available on the Open Science Framework (https://osf.io/p3gty). As previously mentioned, to maximize relevance to the initial vignette and to avoid possible ordering effects, we only consider data from respondents' first sound in the analyses presented here (between 199 and 218 participants per condition and ~1000 responses per condition collapsed across biomes).

5.2.5 Measures

The need for a short online experiment precluded the use of multi-item psychometric measures. In line with other creative data gathering exercises (Richardson & McEwan, 2018), short-version scales and single item metrics were thus used for several dependent variables. Given the reach of our unique recruitment opportunity, the experiment included a wide variety of questions. Measures not included in the present study captured appraisals of valence, arousal, and generalized preference.

5.2.5.1 Perceived restorative potential

Our composite measure of therapeutic potential comprised three items each measured on a ten-point scale: perceived restorative potential, fascination, and being away. The single item measure of restorative potential used wording adapted from several other studies (Herzog et al., 2003; Ratcliffe et al., 2016) and asked "*Thinking about your stressful scenario, to what extent do you think listening to this sound would help you recover and feel better in that moment?*"

Items for 'fascination' and 'being away' – two core components of a restorative experience (Kaplan, 1995) – were adapted from several permutations which exist in the current literature (Hartig et al., 1997b; Payne, 2013). The fascination item asked "*To what extent do you agree with this statement? 'Listening to this soundscape is fascinating; it holds my interest and awakens my curiosity.'*" The 'being away' item asked "*To what extent do you agree with this statement? 'Listening to this soundscape allows me to feel far away from everyday thoughts and concerns.'*"

The personal pronoun ("my" or "me") was included to ensure respondents were considering the restorative potential for themselves, rather than via a more objective perspective (Payne & Guastavino, 2018). Each item was rated on a 10-point scale, from "*Not at all*" (1) to "*Completely*" (10). Inter-item correlations for these measures were high ($0.64 < r < 0.75$) and they were subsequently collapsed into a combined measure of perceived restorative potential ($\alpha = 0.88$).

5.2.5.2 Preservation motivation

Preservation motivation was measured using a novel item designed to prompt a hypothetical decision to 'keep' or 'delete' a soundscape, with the latter action removing the sound from recorded history. It required participants to appraise the severity of irreversible loss of their sound, for themselves and wider society. It was deliberately analogous to the choices Pan faces in *Forest 404*, both in the data archive and when she is forced to trade her soundscapes in place of financial payment (*Episode two: The Fumetown Priest*). Although links to the experiment were only available via the podcast, we could not rule out that some participants may not have listened to the drama. The experiment information sheet thus provided background on Pan's role and the question was worded to make sense to those who could have found the experiment via alternative routes. Specifically, it asked "*Imagine you are Pan from the Forest 404 podcast. You are working in the data library and this is the file you have just been asked to process. What do you think you would do with this sound?*" Responses were captured on a 10-point scale from "*Definitely delete*" (1) to "*Definitely keep*" (10). A higher rating indicated a greater desire to keep rather than discard the stimulus.

5.2.5.3 Memories

Following previous research demonstrating the importance of lived experience in soundscape appraisals (Dumyahn & Pijanowski, 2011; Medvedev et al., 2015) we asked if participants had memories triggered by the soundscape they were listening to, and if so, to state the valence of these memories. The question was "*Do you have any memories associated with this kind of sound? If so, are they mostly positive, negative or mixed?*" Participants could answer with one of the following responses: *No memories; Mostly positive memories; Mostly negative memories; A mix of positive and negative memories*.

5.2.5.4 Individual difference covariates

Respondents were asked to state their sex and could identify as: *Female; Male; Another sex or gender*. 'Another sex or gender' was included as a factor level in all analyses, but low prevalence (0.7%) in our sample precluded the statistical power necessary to identify significant trends and this group is subsequently omitted from descriptions of findings.

Age was captured in groups spanning ten-year bands (e.g. 36-45). All age groups were included as covariates in analyses with consistent positive associations for those aged 36 and over. To simplify reporting, and based on observed patterns in the different groups, age was collapsed into two categories, with those aged between 18 and 35 in one group, and those aged 36 and over in the second group.

To reduce participant burden from longer scales (Richardson et al., 2019), connectedness to nature was measured using a single item adapted from the Inclusion of Nature in Self scale (Schultz, 2002). Participants were asked "*Thinking about your place in the world, to what extent do you feel 'part of nature'?*" Responses were registered on a 10-point scale from "*Not at all*" (1) to "*Completely*" (10).

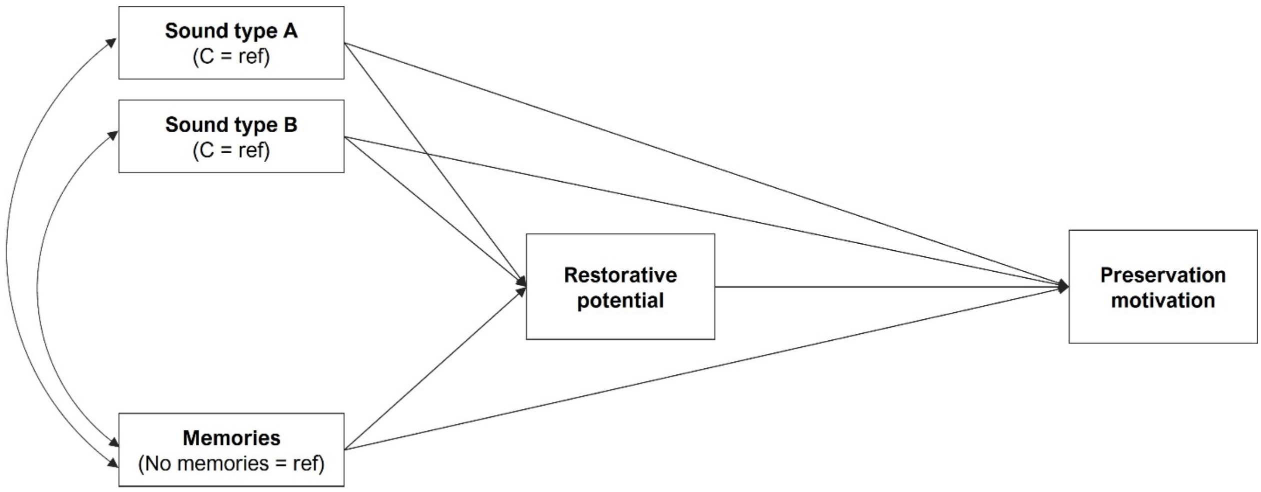
The full list of demographic items captured in this study is presented in the 'Demographic questions' section of Appendix A.

5.2.6 Statistical analysis

All analyses were conducted using the statistical software R (R Core Team, 2021). To answer research questions 1-3, outcomes were analyzed using a between-subjects ordinary least squares linear regression, with main effects for all factors included. To explore research question 4, a mediation analysis was conducted using the structural equation modelling package 'Lavaan' (Rosseel, 2012). We constructed a simplified path model (Hayes, 2017) with sound type (A, B, C) and memories (any vs none) as predictors, preservation motivation as outcome, and perceived restorative potential as mediator, as depicted in figure 13. The model ran 1,000 resamples. Sex, age, and connectedness to nature were included as covariates in all models. Since all dependent variables used the same ten-point scales, we present the unstandardized coefficients in each figure to aid comparisons between analyses. We also initially report mean appraisals of sounds collapsed according to biome, with differences between groups assessed via a one-way ANOVA. Related post hoc tests have been Bonferroni adjusted. Although briefly presented in section 5.3, further expansion of these analyses is beyond the scope of the current research. Full tabular outputs are presented in Appendix A. The full dataset is available on the Open Science Framework (https://osf.io/p3gty).

Figure 13. Mediation pathways

The planned mediation model used to explore research question 4, with sound type (A, B, C) and memories (any vs none) as predictors, preservation motivation as outcome, and restorative potential as mediator. Covariances of residuals depicted by double headed arrows.



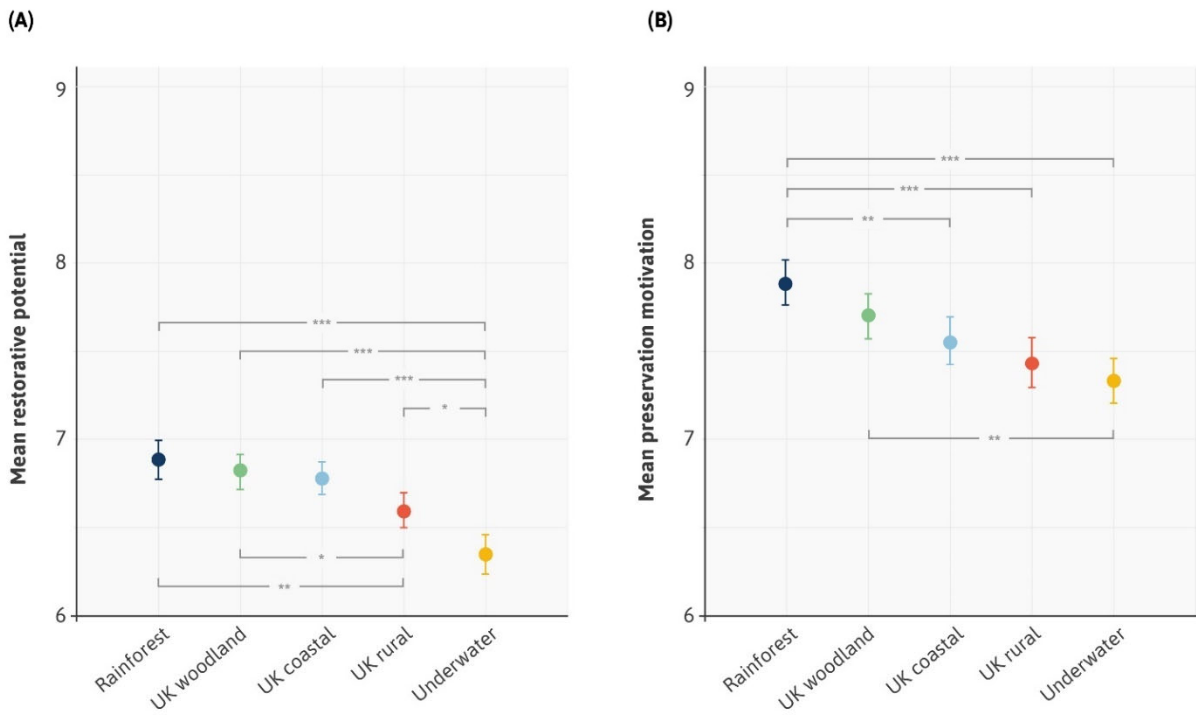
5.3 Results

5.3.1 Preliminary results across biomes

Aggregating responses for all sound types, appraisals for our key metrics varied by less than a scale point across the five biomes (Fig. 14). However, small but significant differences existed for both perceived restorative potential ($F(4, 7249) = 16.38$, $P < 0.001$) and preservation motivation ($F(4, 7289) = 9.54$, $P < 0.001$). Broadly speaking, soundscapes from the tropical rainforest, the signature soundscape of the *Forest 404* series, were rated highest for both restorative potential (Fig. 14A) and preservation motivation (Fig. 14B). Sounds from our underwater biome were rated the least positively on both outcomes. Appraisals for sound types were highly similar across environments (see Fig. S1 and S2 in Appendix A), so for the remainder of the paper we have collapsed analyses across biomes to focus on our primary research questions.

Figure 14. Soundscape appraisals according to biome.

Mean scores for (**A**) perceived restorative potential and (**B**) preservation motivation, for all sound types (excluding silence) collapsed according to biome. Asterisks highlight significant differences, * denotes $p < 0.05$, ** denotes $p < 0.01$, and *** denotes $p < 0.001$. Pairwise comparisons have been Bonferroni corrected. Confidence intervals (95%) are also displayed.



5.3.2 Hierarchies between soundscapes

Starting with research question #1, we began with an examination of variations in the perceived restorative potential of our stimuli (Fig. 15A, see table S2 and S3 in Appendix A for tabular outputs). Compared to the silent control condition, soundscapes that combined abiotic and biotic elements ('AB') were perceived as most restorative (B = 3.41, SE = 0.15, t(7133) = 18.63, P < 0.001). Biotic sounds alone ('B') were rated as significantly more restorative than silence (B = 3.26, SE = 0.15, t(7133) = 17.02, P < 0.001) with no significant difference between these and our combined AB sounds (B = - 0.16, SE = 0.09, t(7133) = -1.79, P = 0.074). Abiotic sounds ('A') were rated as more restorative than silence (B = 2.63, SE = 0.15, t(7133) = 17.02, P < 0.001), but significantly lower than our combined AB sounds (B = - 0.78, SE = 0.09, t(7133) = -8.92, P < 0.001). Put simply, our most acoustically rich natural soundscapes – containing both abiotic and biotic sounds – were the most restorative. When we removed biotic sounds (such as birdsong) from these soundscapes, to leave only the abiotic sounds of the landscape (such as flowing water), we observed a clear reduction in perceived restorative potential.

On their own, our 'culturally valued' poems ('C') were rated as more restorative than silence (B = 1.92, SE = 0.15, t(7133) = 21.05, P < 0.001), but significantly less so than the nature-only sound types described above (Table S4). However, adding nature-based sounds to our poems had a consistent positive effect. For example, the inclusion of abiotic and biotic sounds ('ABC') significantly increased ratings of restorative potential compared to poetry alone (B = 0.78, SE = 0.09, t(7133) = 8.85, P < 0.001).

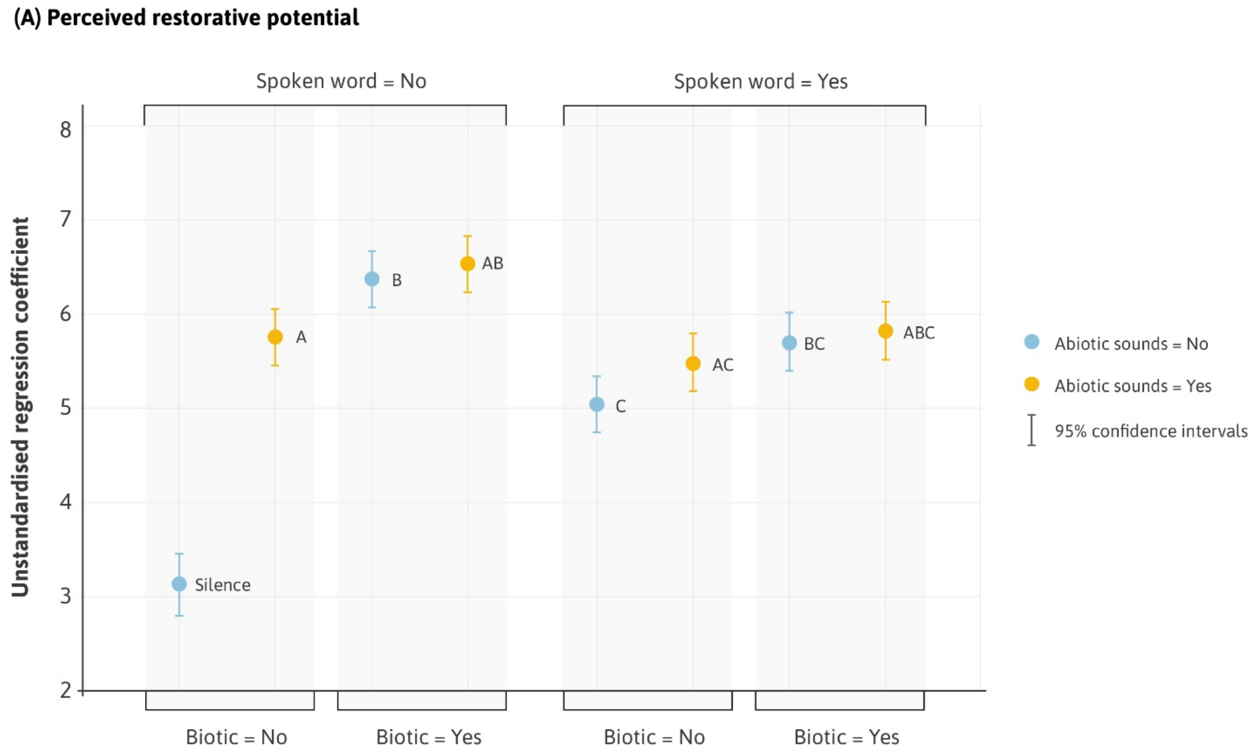
Addressing research question #2, patterns in participant motivations to preserve their soundscapes were very similar (Fig. 15B, tables S5-7 in Appendix A for tabular outputs). Compared to silence, combined abiotic and biotic soundscapes ('AB') had the highest preservation ratings (B = 4.81, SE = 0.20, t(7173) = 23.80, P < 0.001). Again, biotic sounds alone ('B') were no less likely to be preserved than AB sounds (B = -0.10, SE = 0.11, t(7173) = -0.90, P = 0.37). However, removing biotic sounds to leave only abiotic elements ('A'), significantly decreased preservation motivation (B = -0.99, SE = 0.11, t(7173) = -8.65, P < 0.001). Poetry was more likely to be preserved than silence (B = 2.33, SE = 0.20, t(7173) = 11.51, P < 0.001), but less so than our nature-only sounds. Once again, combining nature-based sounds with poetry had a positive effect. For example, the addition of abiotic and biotic sounds ('ABC') significantly increased preservation motivation compared to poetry alone (B = 1.37, SE = 0.12, t(7133) = 11.87, P < 0.001).

With respect to our covariates, we observed a positive association between perceived restorative potential and connection to nature across all sound types; participants who felt more connected to the natural world rated their sounds as more restorative (B = 0.13, SE = 0.01, t(7133) = 11.19, P < 0.001). We detected no relationship with age or sex for perceived restorative potential. However, for preservation motivation greater individual differences existed. Females exhibited higher preservation motivation ratings than males (B = 0.19, SE =

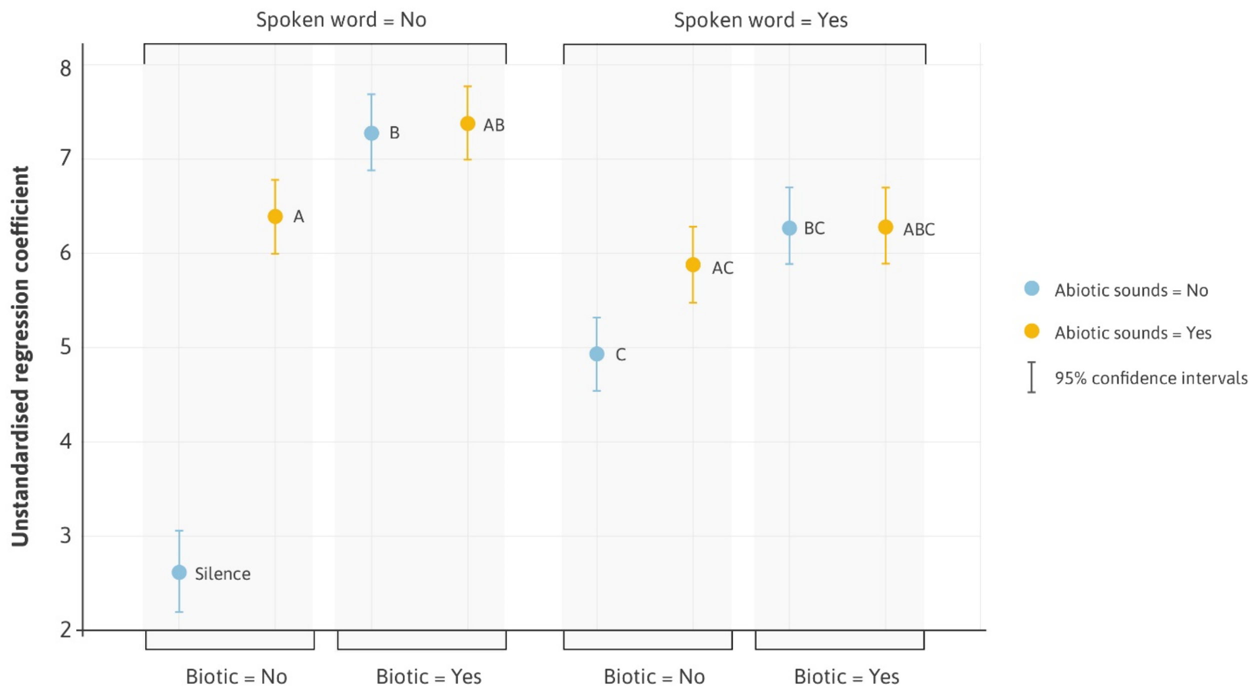
0.06, t(7173) = 3.00, *P* = 0.003); and participants aged 36 and over returned higher average ratings than those aged between 18 and 35 (*B* = 0.24, SE = 0.07, t(7173) = 3.62, *P* < 0.001). Those reporting higher connectedness to nature were also more likely to want to keep the soundscapes they listened to (*B* = 0.13, SE = 0.02, t(7173) = 8.68, *P* < 0.001).

Figure 15. Delineating according to sound types.

Unstandardised coefficients for (A) perceived restorative potential and (B) preservation motivation. The y-axis represents a range that captures all the variation in responses. To aid visualization, regression coefficients have been added to the intercept (Silence). Confidence intervals (95%) are also displayed.



(B) Preservation motivation



5.3.3 The moderating role of memories

Next, we considered research question #3 and explored how participants' memories might moderate responses to our stimuli. The format of our memory-based question prevented us from interpreting memories for our combined soundscapes (we could not determine which component the memory related to), so for these analyses we focused on single component soundscapes only (A, B, or C). The silent condition was also not considered here.

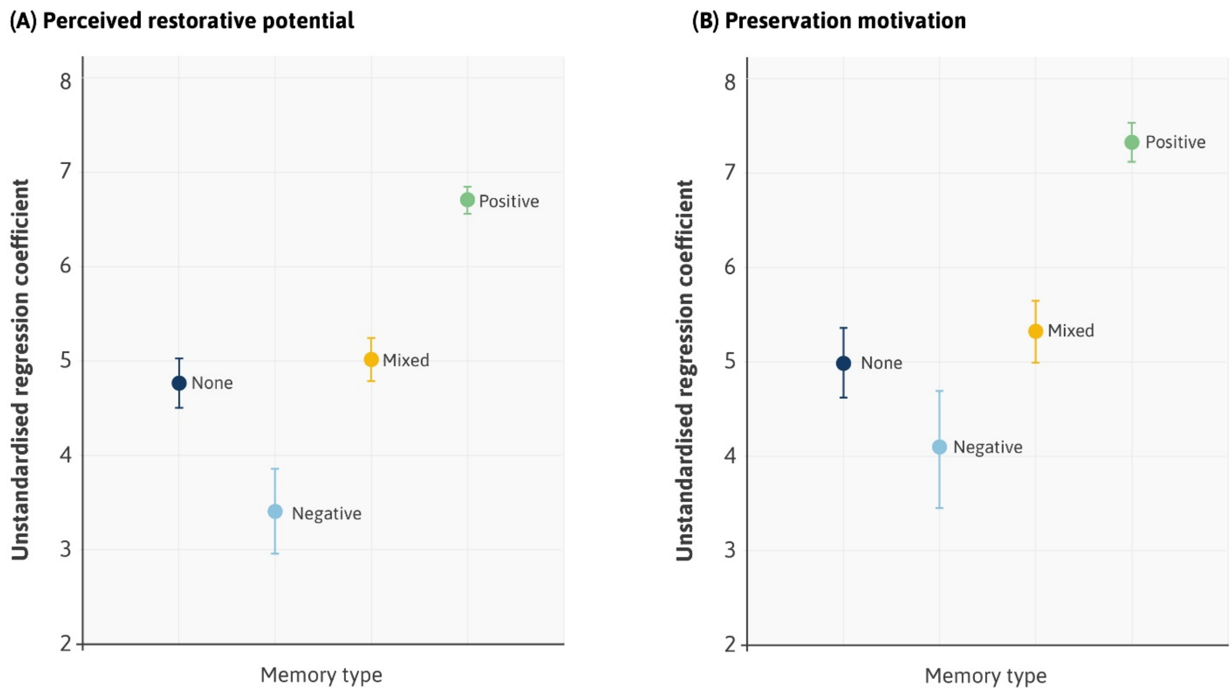
Collapsing our soundscapes together, we observed a significant main effect of memory type on perceived restorative potential (Fig. 16A, Table S8). Compared to those with no prior memories of their sounds, negative memories had a significant detrimental effect on ratings of restorative potential (B = -1.36, SE = 0.22, t(2987) = -6.11, $P < 0.001$). Positive memories exerted the opposite effect, increasing ratings by nearly 2 scale points (B = 1.94, SE = 0.08, t(2987) = 25.02, $P < 0.001$). Mixed memories led to a small yet still significant increase (B = 0.25, SE = 0.12, t(2987) = 2.09, P = 0.037).

The same pattern existed in participants' motivation to preserve their sounds (Fig. 16B, Table S9). Compared to those with no memories, negative memories reduced ratings (B = -0.90, SE = 0.31, t(3002) = -2.89 P = 0.004) whilst positive memories substantially increased them (B = 2.33, SE = 0.11, t(3002) = 21.44, $P < 0.001$). Mixed memories led to a slight increase in preservation motivation (B = 0.34, SE = 0.17, t(3002) = 2.03, P = 0.043).

Once again, females (B = 0.37, SE = 0.10, t(3002) = 3.83, $P < 0.001$), those aged 36 and over (B = 0.33, SE = 0.10, t(3002) = 3.21, P = 0.001), and those who were more connected to nature (B = 0.08, SE = 0.02, t(3002) = 3.54, $P < 0.001$) had higher preservation motivation ratings. Only connection to nature was a significant covariate for restorative potential (B = 0.08, SE = 0.02, t(2987) = 4.73, $P < 0.001$).

Figure 16. Soundscape ratings grouped by participant memories.

The relationships between memory type and (**A**) perceived restorative potential and (**B**) preservation motivation, across abiotic, biotic and poetry-based sound types collapsed together. The y-axis represents a range that captures all variation in responses. To aid visualization, regression coefficients have been added to the intercept (memories = none). Confidence intervals (95%) are also displayed.



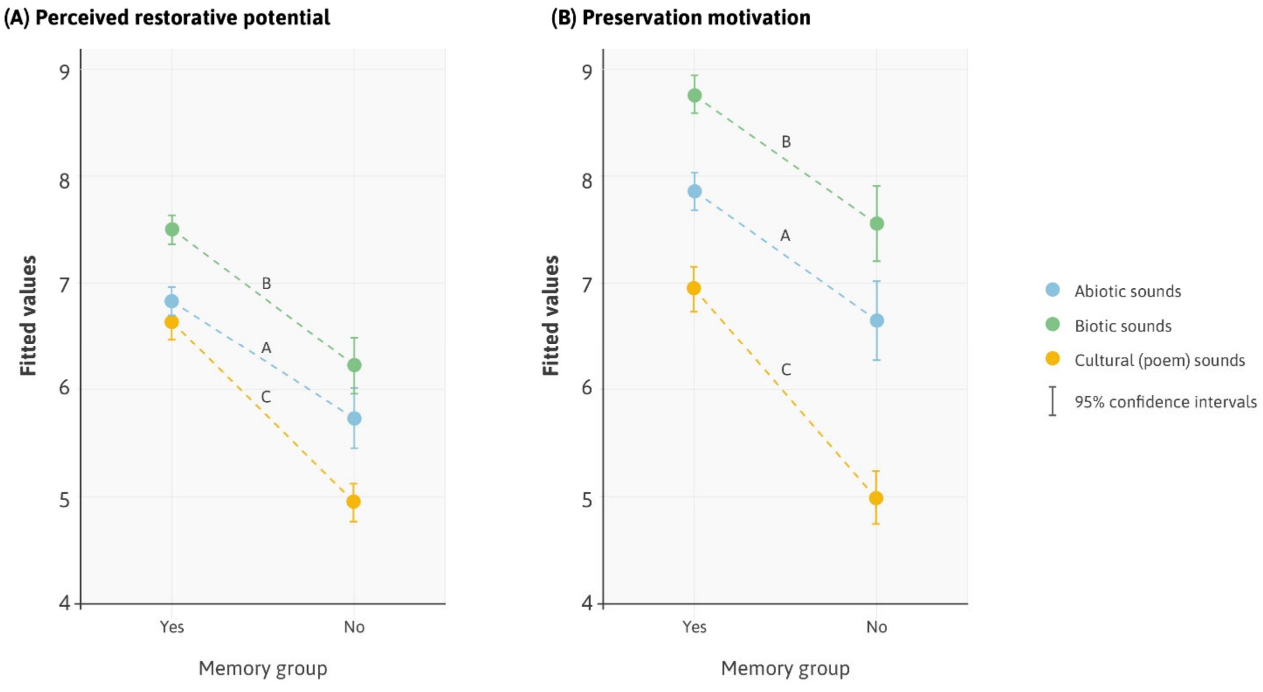
5.3.4 The effects of memories on individual sound types

We might reasonably assume that participants without memories of our sounds had interacted less with natural environments over their lives than those with memories, regardless of whether those memories were positive or negative. To explore the possible impact of this extinction of experience on our individual sound types (Soga & Gaston, 2016), we collapsed our negative, mixed, and positive memory categories together to form a single group of participants with memories of the sounds they heard (n = 2244), and compared this subset to those without (n = 808).

Fitting estimated marginal means to our model, Fig. 17 depicts a significant main effect of memories. Each of our sound types received higher ratings of perceived restorative potential (Fig. 17A, tables S10 and S11) from those who had memories triggered by the experience compared to those who did not (B = 1.11, SE = 0.16, t(2985) = 7.11, $P < 0.001$). The pattern for preservation motivation was similar yet even more pronounced (Fig. 17B, tables S12 and S13). Those reporting memories were much more likely to preserve each sound type than those with no memories (B = 1.21, SE = 0.21, t(3000) = 5.84, $P < 0.001$). Significant interaction terms also suggested that for both perceived restorative potential (B = 0.58, SE = 0.20, t(2985) = 2.92, P = 0.003) and preservation motivation (B = 0.74, SE = 0.26, t(3000) = 2.83, P = 0.005), a lack of memories had a disproportionately larger impact on responses to poetry (C) than either abiotic (A) or biotic (B) sounds, as reflected in the steeper downward sloping lines in Fig. 17.

Figure 17. The effect of memories on specific sound types.

Fitted model values for A, B, C sound types and memory group for (**A**) perceived restorative potential and (**B**) preservation motivation.

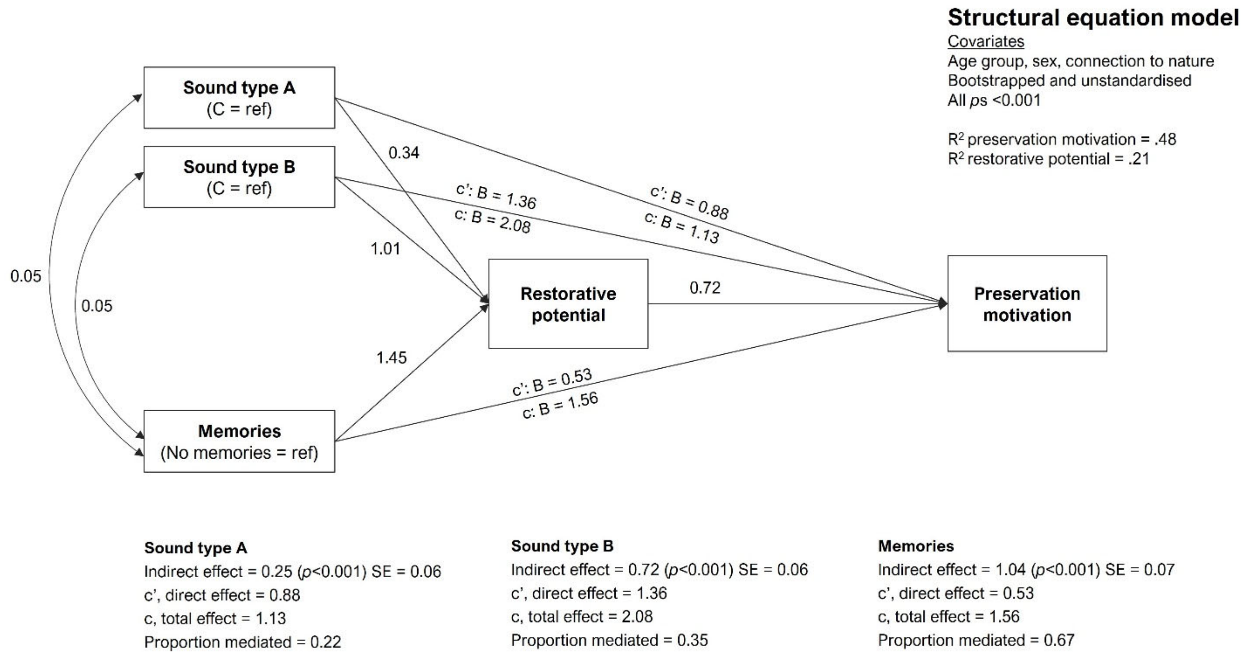


5.3.5 Restorative potential as a mediator of preservation motivation

The similarity between patterns for perceived restorative potential and preservation motivation described above reflects their strong association ($r = 0.64$, $P < 0.01$, Table S14) and is indicative of potential mediation; the reason why participants may want to ‘keep’ certain soundscapes from being deleted may be because they present the opportunity for psychological restoration (Hartig et al., 2007), rather than holding intrinsic value in their own right (Dearborn & Kark, 2010). To address research question #4, we therefore examined the extent to which the restorative potential of our soundscapes might mediate preservation motivation, and the role memories may play in this relationship. We constructed a simplified path model (Hayes, 2017) with sound type (A, B, C) and memories (any *vs* none) as predictors, preservation motivation as outcome, and perceived restorative potential as mediator. Results indicated that restorative potential partially mediated the effects of sound type and memories on preservation motivation (Fig. 18). The bootstrapped (samples = 1000) and unadjusted indirect effects via restorative potential accounted for 22% and 35% of the total effects of abiotic and biotic sounds on preservation motivation, respectively (compared to poetry, the reference category). The unadjusted, indirect effect of memories via restorative potential on preservation motivation was 67% ($B = 1.04$, $SE = 0.07$, $P < 0.001$) of the total effect. In other words, a fifth of the effect of abiotic sounds, a third of the effect of biotic sounds, and two thirds of the effects of lived experience on participant decisions to preserve their stimuli were mediated by the restorative potential they might offer (see Fig. 18 and Table S15).

Figure 18. Mediation model.

Structural equation model with sound type (A, B, C) and memories (any vs none) as predictors, preservation motivation as outcome, and restorative potential as mediator. Covariances depicted by double-headed arrows. Tabular outputs can be found in Table S15, Appendix A.



5.4 Discussion

The potential for the arts and sciences to co-develop novel methods that engage people in ecological issues is receiving increasing attention (Sommer et al., 2019). The *Forest 404* podcast embraced these principles, inviting listeners to imagine themselves as the series' protagonist, who exhibited an intrinsic positive reaction to natural sounds – even though she had never experienced them before. Did our participants' responses support the assumptions underpinning the *Forest 404* narrative?

5.4.1 Findings

Results demonstrate that nature-based soundscapes were valued differently according to their composition. Participants were more motivated to preserve sounds that featured biotic elements, such as bird song or pastoral fauna, and believed they would find these soundscapes to be most restorative in times of stress and cognitive fatigue. When we removed biotic sound sources to simulate the kind of impoverished environmental experience portrayed in *Forest 404*, perceived restorative potential and preservation motivation both fell. To put it another way, as the soundscape appeared to reflect a decline in environmental quality, participants' sense that the environment would offer psychological benefits also fell and their motivation to protect those environments appeared to follow suit.

Crucially, our findings demonstrate that when it comes to nature, memories matter. Without memories of the soundscapes they heard, participants were significantly less likely to find them restorative and were less motivated to preserve them. These findings challenge the *Forest 404* narrative and suggest reduced environmental experience may have a significant effect on responses to nature-based stimuli. Moreover, our results highlight the potential importance of psychological restoration in appraisals of natural capital. Two-thirds of the total effect of memories on participant motivations to preserve natural sounds was mediated by the restorative potential they might offer. Interactions with nature can foster pro-environmental attitudes (Alcock et al., 2020) and our results suggest that psychological restoration could be an important pathway through which this mechanism operates.

When listened to on its own, nature-inspired poetry received lower ratings of restorative potential and preservation motivation than natural soundscapes. The addition of abiotic and biotic sounds increased these ratings, suggesting context-specific natural soundscapes might enhance both the evaluation and therapeutic potential of poetry. However, this relationship can also be viewed more pessimistically; adding poetry to our nature-based sounds led to a significant drop in positive appraisals compared to natural sounds alone.

The effects of age and sex were relatively consistent across our results. Females and those aged 36 and over were, on average, more likely to preserve their soundscapes compared to males and younger people. Participants who felt more connected to nature also exhibited a higher tendency to want to 'keep' their soundscapes. In contrast to the cynical motivations described above, these patterns provide support for the effects of 'nature-first' conservation priorities among these groups (Dearborn & Kark, 2010), and underline the positive links between connectedness to nature and environmental behavior (Whitburn et al., 2020). Consistent with previous findings (Capaldi et al., 2014), increased ratings of restorative potential were also positively associated with connection to nature.

5.4.2 Limitations

Despite the large size and diversity of our study population, some limitations must also be acknowledged. Our sample was self-selecting, and participants tended to be older, more connected to nature, and more likely to be female than UK averages. Recruitment to the experiment was almost exclusively via the *Forest 404* series. We do not know how much of the podcast participants had listened to, nor the degree to which its narrative might have influenced their responses. Our experimental design simulated ecosystem degradation by removing all wildlife sounds from the acoustic environment. This kind of severe change in soundscape composition has previously been considered a portent of environmental damage, embodied by the notion of a ‘silent spring’ (Carson, 1962). Yet real biodiversity loss tends to happen at a more gradual rate, and most species do not contribute to the soundscape. Future work might look at the impacts of more nuanced changes, particularly with respect to the impact of ‘shifting baselines’ and the notion that people readily adapt to slow shifts in reference states (Pauly, 1995).

To reduce participant burden, we used soundscapes that were 40-seconds long. We do not know how outcomes may have varied for longer exposures, particularly for our poem-based sounds. Our preservation motivation question asked respondents to imagine a situation in which they had to ‘keep’ or ‘delete’ the sounds they were hearing. Since this behavior was hypothetical and did not have demonstrable consequences, we must be careful when drawing parallels with actions in real-world situations. Our measure of lived experience captured a general sense of participant memories, but we could not determine at what point in the life course these memories occurred or whether they were truly autobiographical. Respondents reported having memories of our more exotic soundscapes, suggesting that responses might also reflect associations assembled from a broad mix of experiences, including natural history programming. The diversity of what people consider to be ‘lived experiences’ of nature could be a beneficial focus of future research (Ballouard et al., 2011).

5.4.3 Implications

The restorative potential of varying acoustic sources has often been considered interchangeably under the broad banner of ‘natural sounds’ (Alvarsson et al., 2010; Gould van Praag et al., 2017). Yet emerging evidence suggests these approaches may have overlooked differential contributions of specific sound types (Buxton et al., 2021). Through the systematic manipulation of soundscapes from five contrasting biomes, our results suggest that significant heterogeneity exists in the appraisal of environmental stimuli already broadly defined as therapeutic, and reveal nuance in the notion of ‘tranquil space’ (Pheasant et al., 2010).

We find that abiotic sounds explored by other studies, such as wind and flowing water (Ratcliffe, 2021a), are significantly enhanced by the addition of sounds from biotic sources, such as bird songs and calls. Acoustic ecologists have recently begun to consider ‘biophony’ as a vital marker of ecosystem health (Pijanowski et al., 2011) and our findings suggest that non-specialists may also detect when audible components of biodiversity are missing. These outcomes are particularly striking because participants were not making a comparison between soundscapes with and without wildlife (due to our between-participant design), yet they reacted differently when it was missing. The presence of bird song might form an important contributor to wellbeing outcomes in natural settings (Ferraro et al., 2020) and we demonstrate how this trend may extend to a wider range of acoustic biodiversity (Sueur et al., 2021).

How might these findings inform practice? One pathway could be through the inclusion of specific natural soundscapes – and their subsequent restorative potential – in psychological ecosystem services (Bratman et al., 2019), recognizing biodiverse soundscapes as natural capital and incorporating them into existing models designed to map and quantify these services (Paulin et al., 2020). Our results might also feed into the design of restorative public spaces (Yang & Kang, 2005) by promoting efforts to protect and create habitats that feature wildlife and its associated aural markers (Levenhagen et al., 2021). Soundscape appraisals can play a considerable role in determining landscape preferences (Gan et al., 2014) yet acoustic environments are in constant temporal flux (Matsinos et al., 2008). Sonic signatures such as breaking waves and falling rain can vary with sporadic shifts in the weather, whilst the sounds of bird song and other fauna are likely to follow diurnal and seasonal patterns. Our data provide evidence to suggest these variations might also be considered alongside visual ephemeral features in landscape assessments (Brassley, 1998).

Supporting early theorizing (Kaplan, 1995; Ulrich, 1983) and more recent extensions (Ratcliffe & Korpela, 2016), our findings further validate the importance of top-down processes such as memories in environmental appraisals. Although more often explored in qualitative studies (Conradson, 2005), the relatively large effects of prior memories on our results suggests that these and other top-down processes should be more prominent in future quantitative soundscape investigations. Moreover, the effects of memories extended to participant motivations to preserve their sounds. Engagement with the natural world in early life can lead to positive environmental attitudes later on (Nancy & Kristi, 2006) and our results provide further support for this effect.

Viewed in reverse, this relationship paints a stark picture of the impacts stemming from the potential extinction of nature-based experiences. People who had no previous memories of their soundscapes were less likely to believe they could gain wellbeing benefits from listening to them and were less motivated to protect them. *Forest 404* implicitly asked audiences "*Can you feel loss for something you have never known?*" The profound effects of memories in our results suggest the answer to this question might, worryingly, be "*no*". If societal trends continue to demonstrate a disconnection of populations from the natural world (Hunt, 2016), a negative feedback loop for both wellbeing and environmental preservation may ensue (Soga & Gaston, 2018) – although also see (Novotný et al., 2020; Oh et al., 2020).

Questions have been raised about the pathways through which nature experience might impact the valuing of natural environments (Neuteleers & Deliège, 2019). We present evidence to suggest that appraisals of therapeutic potential could be a viable mediating mechanism in this relationship. This outcome is consistent with an 'egoistic' motivation for environmental protection, in which a person makes decisions based on outcomes likely to affect them personally (Stern & Dietz, 1994). Repercussions for the extinction of experience are once again writ large, but these findings could also have implications for conservation messaging. The use of shock and fear to motivate behaviors which address trends such as biodiversity loss is increasingly ineffective in a world where people have a limited 'pool of worry' (White et al., 2020a). By making it clear that individual wellbeing could stand to benefit from nature protection, a reciprocal relationship might motivate people to preserve natural ecosystems (Soga & Gaston, 2016).

Existing research suggests that poetry can contribute to a range of positive wellbeing outcomes (Obermeier et al., 2013) and we find, for nature poetry at least, that the addition of natural sounds may enhance these effects. These outcomes might be particularly useful for those aiming to connect people to the natural world through creative endeavors (National Trust, 2021), or harness the restorative power of literature and nature through bibliotherapy (McKenna et al., 2010) and emerging digital interventions (Headspace, 2021).

5.4.4 Conclusions

As global environmental changes continue to alter acoustic experiences, our results contribute to efforts to improve understanding of how soundscapes might impact human wellbeing and behavior (Smith & Pijanowski, 2014). They also take on new meaning following responses to the COVID-19 pandemic. In western societies at least, strict lockdowns re-focused attention on the relationships between nature and health (BBC News, 2020a). As reductions in anthropogenic noise resulted in a quieting of both urban and rural environments, natural sounds were highlighted as a crucial component of the aural experience (Derryberry et al., 2020). With many people confined to their homes for prolonged periods, an interest in how digitally-mediated nature experiences might shape wellbeing also entered public discourse, reigniting debates surrounding the potential value of 'virtual nature'(Depledge et al., 2011). How sound and nature-based narratives might fit into this conversation could be an important focus of future work.

This study represents just one part of the BBC *Forest 404* project, a collaborative and award-winning public engagement initiative. This transdisciplinary series merged fictional, factual, immersive, and experimental elements, and encouraged audiences to contribute to scientific understanding. *Forest 404* demonstrated the power of creative alliances and provides a further exemplar for partnerships aiming to develop novel methods that enrich engagement in, and understanding of, environmental futures.

5.4.5 CRediT author contributions

Conceptualization: AJS, TXA, RR, PAC, MPW, NG, AG.
Resources (production): TXA, RR, EL, AH.
Methodology: AJS, MPW, MS.
Investigation: AJS, MPW.
Visualization: AJS.
Supervision: MPW, NG, AG, LEF.
Writing—original draft: AJS, MPW.
Writing—review & editing: MHD, LEF, PAC, NG, AG, RR, MPW, AJS.

[Published content ends]

As highlighted in sections 2.11 and 4.3.4, the desire to apply a similarly systematic level of exploration to visual, ephemeral landscape (rather than soundscape) features directly resulted from both lacunae identified in the existing literature and editorial conversations arising from the development of *Forest 404*. Thus, we next considered how ephemeral features, such as sunrise and sunset, might impact (digital) landscape experiences.

6. Study two, *Beyond blue-sky thinking*

Title
Beyond blue-sky thinking: Diurnal patterns and ephemeral meteorological phenomena impact appraisals of beauty, awe, and value in urban and natural landscapes

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Abstract
Landscape views can be dynamic; many of the elements within an environmental vista may change from one moment to the next. Features such as a vibrant sunrise or sudden storm are often brief and unexpected, they are ephemeral, and might significantly alter the way an environment is perceived and experienced. Yet existing research has tended to focus on appraisals of urban and rural scenes under uniformly clement, 'blue-sky' conditions, with few studies considering how diurnal rhythms and fleeting meteorological processes might impact landscape appraisals. To address this gap, we conducted an online experiment that presented participants (n = 2,509) with either an urban or natural virtual setting, strictly matched in terms of scenic structure, within which six 'ephemeral phenomena' were applied. We assessed ratings of beauty, awe, and willingness-to-pay to visit in each condition. Supporting existing findings, results demonstrated the natural setting was generally rated more positively than the urban setting. However, ephemeral phenomena substantially moderated this effect, with rainbows, storms, and nightfall each reducing the divergence. Sunrise and sunset were the most valued conditions within both environments, outcomes that were partially mediated through increased ratings of beauty and awe. We find that whilst an urban-nature dichotomy exists in landscape appraisals, acknowledging the effects of ephemeral, non-structural phenomena could have important implications for landscape research and design.

6.1 Introduction

Few would argue against the power of a sudden rainbow to arrest and delight those within view (Haußmann, 2016). Photographers prize the liminal 'golden hours' of morning and evening (Raphael, 2018). Tourists flock to beaches and hill tops to capture the setting sun (Hull & McCarthy, 1988). From dawn to dusk and through myriad fleeting changes in between, landscape views are in constant flux. Yet the quantitative research literature reveals surprisingly little about the potential impacts of this dynamic and diurnal variability on place-based experiences. Here we attempt to address this lacuna.

Temporary changes can occur *within* an environment for numerous reasons. For example, seasonal shifts can change the color or form of a landscape and exert a substantial effect on aesthetic appraisals (Buhyoff & Wellman, 1979). Autumnal and floriferous periods are often particularly valued (Junge et al., 2015; Kuper, 2018), as are increases in factors such as crop diversity (Häfner et al., 2018). Livestock presence can influence preferences for agrarian settings (van Zanten et al., 2014), and the wider presence of wildlife and its behavior might impact evaluations of scenic quality (White et al., 2017b), especially for landscapes judged to be less beautiful than others (Hull & McCarthy, 1988).

These kinds of variations tend to be recurring and rhythmical (Palang et al., 2005), even if they rarely follow the rigid order of the astronomical calendar (Olwig, 2005). They have garnered reasonable attention in landscape aesthetics (see Stobbelaar and Hendriks (2007) and Junge et al. (2015)) and are *not* the focus of this paper. We are instead interested in the temporal variations superimposed on these seasonal phases. These unpredictable and often brief changes occur *within* the diurnal cycle and can alter landscape experience from one moment to the next. After Brassley (1998), we refer to these temporary occurrences as 'ephemeral phenomena'.

Changing patterns of weather are inextricably linked with the generation and appearance of ephemeral phenomena (Vannini et al., 2011). For example, meteorological events may obscure the sky, or emphasize its colors and vibrancy (Freeman, 2014). Atmospheric processes can create brief chromatic artifacts such as crepuscular rays or parhelia ('sundogs') and produce exotic clouds like the bulging mammatus (Schultz et al., 2006). These unusual events are often captivating enough to warrant documentation (BBC Weather, 2021), but more common and cyclical phenomena, such as sunrise and sunset, can also garner attention depending how they appear on any given day (BBC News, 2020b). Indeed, the combination of meteorological phenomena and changing solar altitude can produce particularly memorable events; high clouds at dusk might create noctilucence (Gadsden & Schröder, 1989) and a brilliant twilight (Corfidi, 2014).

These moments clearly matter to people: the rhythm of the day held notable significance for ancient civilizations (Robinson, 1970); ephemeral phenomena feature in accounts of modern history (Jones, 1932); and the term 'sunset' has over 300 million tags on image sharing platform Instagram (2022). These intra-landscape changes have been acknowledged in the existing literature and even described as "*special effects*" by some (Tveit et al., 2006), but little quantitative evidence exists to suggest how these changes might augment the experience of place, with existing work instead focusing on how structural properties might affect landscape preferences, investigating factors such as aquatic features, levels of agriculture, or 'naturalness' (Howley, 2011; Ode et al., 2009; White et al., 2010).

In his comprehensive treatise on the topic, Paul Brassley (1998) highlighted this omission and called for systematic research to improve understanding in the area. Over the last twenty years however, many landscape studies have employed experimental stimuli that only represent bright, midday, blue-sky conditions (Collado & Manrique, 2019; Ode et al., 2009; van Esch et al., 2019). The present paper is, in large part, a response to several of the questions posed in Brassley's work that remain unanswered. How then might we explain the possible impact of ephemeral phenomena on landscape appraisals?

6.1.1 Landscape aesthetics

One arm of aesthetic theory grounds environmental preferences in evolved and adaptive processes, explaining affective reactions to natural environments by their ability to satisfy biological needs or benefit survival (Appleton, 1996; Bourassa, 1988). Ancient civilizations certainly used environmental clues to predict impending meteorological changes (Fishman & Kalish, 1994). For example, the saying "*Red sky at night, shepherd's delight*" refers to clement conditions following a vibrant sunset. This proverb first appeared in the Bible and its veracity is partly supported by empirical observation (Met Office, 2022), perhaps helping early humans to decide when to travel, seek shelter, or manage livestock. These kinds of learnings, enshrined in folklore over generations, also have clear overlap with the second pillar of aesthetics, which considers the importance of learned, semiotic, and cultural attachments in landscape experience (Brady & Prior, 2020; Gobster et al., 2007; Lothian, 1999). Here we find a natural fit with appraisals of fleeting phenomena. For instance, the symbolism of rainbows has been recognized across cultures for millennia (Lee & Fraser, 2001), and the Hawaiian language has over 20 words to describe the various forms a rainbow might take, highlighting both their frequency and importance in local traditions (Businger, 2021). Could these kinds of ephemeral phenomena in turn augment the beauty perceived in landscape scenes?

6.1.2 Ephemera in art

Artistic representations of nature have long recognized how ephemeral phenomena might enhance the appeal and gravitas of environmental settings (Brassley, 1998). Romantic era paintings famously exemplified these trends through works such as J.M.W. Turner's *Sun Rising through Vapour* (1807) and *The Fighting Temeraire* (1839). Although a move toward the sublime harnessed the dramatic, powerful, and sometimes terrifying might of natural scenes (Morley, 2010), here too ephemera featured heavily; Frederic Edwin Church's *Cotopaxi* (1862) depicted the sun rising beneath a volcanic ash cloud, whilst *Dew-Drenched Furze* by John Everett Millais imagined a gentle sunrise penetrating morning mist (Millais, 1889; Smith, 2013a). By leveraging the potential for nature to exhibit beautiful vastness and power, the experience of the sublime has been interpreted as a form of 'aesthetic awe' (Clewis, 2021). If ephemeral phenomena were important for artistic representations of the sublime, could they also have an impact on the elicitation of awe?

6.1.3 Awe in nature

Natural environments are particularly good at facilitating awe-inspiring experiences (Anderson et al., 2018), which are often triggered by epic and overwhelming scenes, and marked by increases in amazement, wonder, and joy (Keltner & Haidt, 2003; Shiota et al., 2007). Awe is increasingly considered an important affective response to place-based experiences, with these encounters demonstrating the potential to improve mood (Joye & Bolderdijk, 2015), enhance prosocial behavior (Piff et al., 2015), and increase positive emotions (Sturm et al., 2020). Grand natural environments, such as waterfalls and canyons, are commonly used to elicit feelings of awe (Gordon et al., 2017) but everyday settings can also instill feelings of wonder, particularly if they possess qualities of vastness or novelty (Sturm et al., 2020). By moderating landscape aesthetics, might the presence of ephemeral phenomena lead to variations in awe *within* a landscape view, and thus make this emotional response and its consequences more readily accessible? Moreover, if feelings of awe can exist in urban environments (Collado & Manrique, 2019; Joye & Dewitte, 2016), could ephemeral phenomena also augment the experience of awe for city-dwellers?

6.1.4 Urban environments

There are increasing calls to change how highly anthropogenic landscapes are assessed (Light, 2001), develop a deeper understanding of the factors affecting people's responses to urban environments (Barros et al., 2021), and frame these settings as more than places of 'disvalue' (Brady & Prior, 2020). Indeed, with urban populations continuing to grow, understanding how best to create and promote opportunities for positive experiences in towns and cities is rapidly gaining importance (Hartig & Kahn, 2016). Whilst these efforts might focus on 'big ticket' issues such as sustainability (Newman, 1999), the promotion of physical activity (Sallis et al., 2016), or improvements in environmental factors like air quality (Vos et al., 2013), it might also be relevant to understand how aesthetic features can impact urban experiences and factors related to wellbeing. For example, preferences have been detected for certain structural features in metropolitan areas such as tree height, building design, and green space (Chen et al., 2015). Of particular relevance to the present study, urban areas that afford panoramic views are also regarded as highly attractive (Galindo & Hidalgo, 2005). Favored views often contain large proportions of sky and water (Masoudinejad & Hartig, 2018; Mirza & Byrd, 2020) and dynamic features such as "*sunrise or sunset*", "*the sky*" or "*the weather*" have been associated with small increases in effective functioning and neighborhood satisfaction (Kaplan, 2001a). Might ephemeral phenomena also impact how urban aesthetics are appraised? And if so, could this outcome be tentatively translated into a format fit for consideration in decision-making?

6.1.5 Ecosystem services

Nature's potential to positively impact human experience is often operationalized through an ecosystem services framework, providing a way to factor both the monetary and non-monetary value of ecological functions into planning decisions (Chan et al., 2012; Millennium Ecosystem Assessment, 2005). These models are particularly suited for utilities such as clean water and climate regulation yet can fail to reflect intangible benefits that are more social, cultural, and psychological (Bratman et al., 2019; Chan et al., 2012). Aesthetic experiences certainly fall into this kind of 'cultural ecosystem service' (Gobster et al., 2007) and hedonic pricing methods (ONS, 2018) have estimated the value of aesthetic factors such as waterside views, which can add up to 60% to property prices (Benson et al., 1998; Bourassa et al., 2004). However, a revealed preference mechanism or market comparison does not exist for most visual features. Methodological criticisms notwithstanding (Hausman, 2012), contingent valuation methods (Haab et al., 2020) have previously been used to determine the 'existence value' of landscape aesthetics (Dupras et al., 2018) and typically ask survey participants how much they are willing to pay for a specific outcome (Perni et al., 2021; Venkatachalam, 2004). There is growing evidence that 'willingness to pay' values for travelling to recreational sites are related to subsequent emotional experiences and might be used to cautiously estimate the value of these experiences (Börger et al., 2022). The current work aimed to extend this logic; could equally exploratory estimates be made about people's willingness to experience certain ephemeral phenomena?

6.1.6 Research questions

To explore each of these areas and move beyond a consideration of 'blue-sky' landscapes, this paper attempts to answer four key questions:

1. How might six relatively common ephemeral phenomena affect landscape beauty? Are these effects moderated by environment (urban vs natural) type?
2. Can these ephemeral phenomena also impact participants' feelings of awe? And are these effects moderated by environment type?
3. Do our phenomena impact participants' willingness to pay to visit a location, and is this relationship moderated by environment type?
4. If so, to what extent might beauty and awe mediate these valuations?

Individual characteristics such as age, sex, and nature connectedness can also have a demonstrable effect on responses to landscape attributes (Häfner et al., 2018; Howley, 2011; van Zanten et al., 2014). Whilst detailed exploration of these factors was beyond the scope of this study, given their possible importance they were included as covariates in all analyses and associations with dependent variables are reported alongside main effects.

6.2 Methods

To examine each of these areas, we constructed an online experiment that presented a large and diverse sample of participants with a series of carefully constructed landscape images.

6.2.1 Participants

Recruitment of our UK-based participants was conducted in April 2020 via Cint (cint.com), a global online panel of consumers widely used in academic research in this area (White et al., 2017b). Sampling quotas allowed us to minimize bias in respondent characteristics and achieve a cohort that reflected national patterns in age and sex. Previous studies investigating responses to urban and natural scenes have found between 16 and 50 responses per condition sufficient to detect inter-stimulus differences in participant appraisals (Collado & Manrique, 2019; Lindal & Hartig, 2013; Pazhouhanfar & Kamal, 2014; Van den Berg et al., 2016). However, due to the exploratory nature of our research questions and since our stimuli featured scenes that might all be considered favorable, we elected to attain as many participants as possible within our recruitment budget. A total of 2,867 people took part in the study, evenly split between our experimental groups. Those who completed the experiment in less than three minutes (n = 140) or more than twenty minutes (n = 198) were excluded from analyses based on feasible boundaries for attention and accessibility determined from pilot testing. This provided a final sample of 2,509 participants (Table 2). 35% of respondents were aged 18–35, 37% were aged 36–55, and 28% were aged 56 or over. Just over half (51%) of our sample was female, the mean score for all sexes on the Nature Connectedness Index (Richardson et al., 2019) was 63 out of 100. Just under half of participants (45%) used a smartphone to take part, and an equal amount used either a laptop or desktop computer. There were no systematic differences in sampling between conditions.

6.2.2 Experimental design

Experimental conditions reflected two contrasting landscapes: one urban and one natural. Six ephemeral phenomena were then applied within each of these settings to create a 2 x 6 study design. Respondents were randomly assigned to either the urban or natural setting, and viewed all six images, randomly ordered, within that setting. Landscape was thus a between-participants factor (urban *vs.* nature), and ephemeral phenomena a within-participants factor (e.g., blue-sky *vs.* rainbow).

Table 2. Descriptive statistics for study participants, split by urban and nature conditions.

Variable	N	Urban, N = 1,255[1]	Nature, N = 1,254[1]	p-value[2]
Sex	2,509			0.9
Male		616 (49%)	620 (49%)	
Female		639 (51%)	634 (51%)	
Age	2,505			0.3
18 – 25		180 (14%)	159 (13%)	
26 – 35		262 (21%)	283 (23%)	
36 – 45		264 (21%)	257 (21%)	
46 – 55		204 (16%)	204 (16%)	
56 – 65		230 (18%)	223 (18%)	
66 – 75		97 (7.7%)	120 (9.6%)	
76+		15 (1.2%)	7 (0.6%)	
Nature connection	2,509	63 (42, 90)	62 (42, 88)	0.8
Device	2,509			0.9
Smartphone		559 (45%)	561 (45%)	
Laptop		388 (31%)	390 (31%)	
Desktop computer		184 (15%)	172 (14%)	
Tablet		123 (9.8%)	128 (10%)	
Other		1 (<0.1%)	3 (0.2%)	

[1]n (%); Median (IQR)

[2]Pearson's Chi-squared test; Wilcoxon rank sum test; Fisher's exact test

Differing ns are due to missing or 'prefer not to answer' data. Nature Connection Index is on a 0-100 point scale. Only one respondent identified as "Another sex or gender", they were 26–35 years old, scored 69 on the NCI, and used a smartphone.

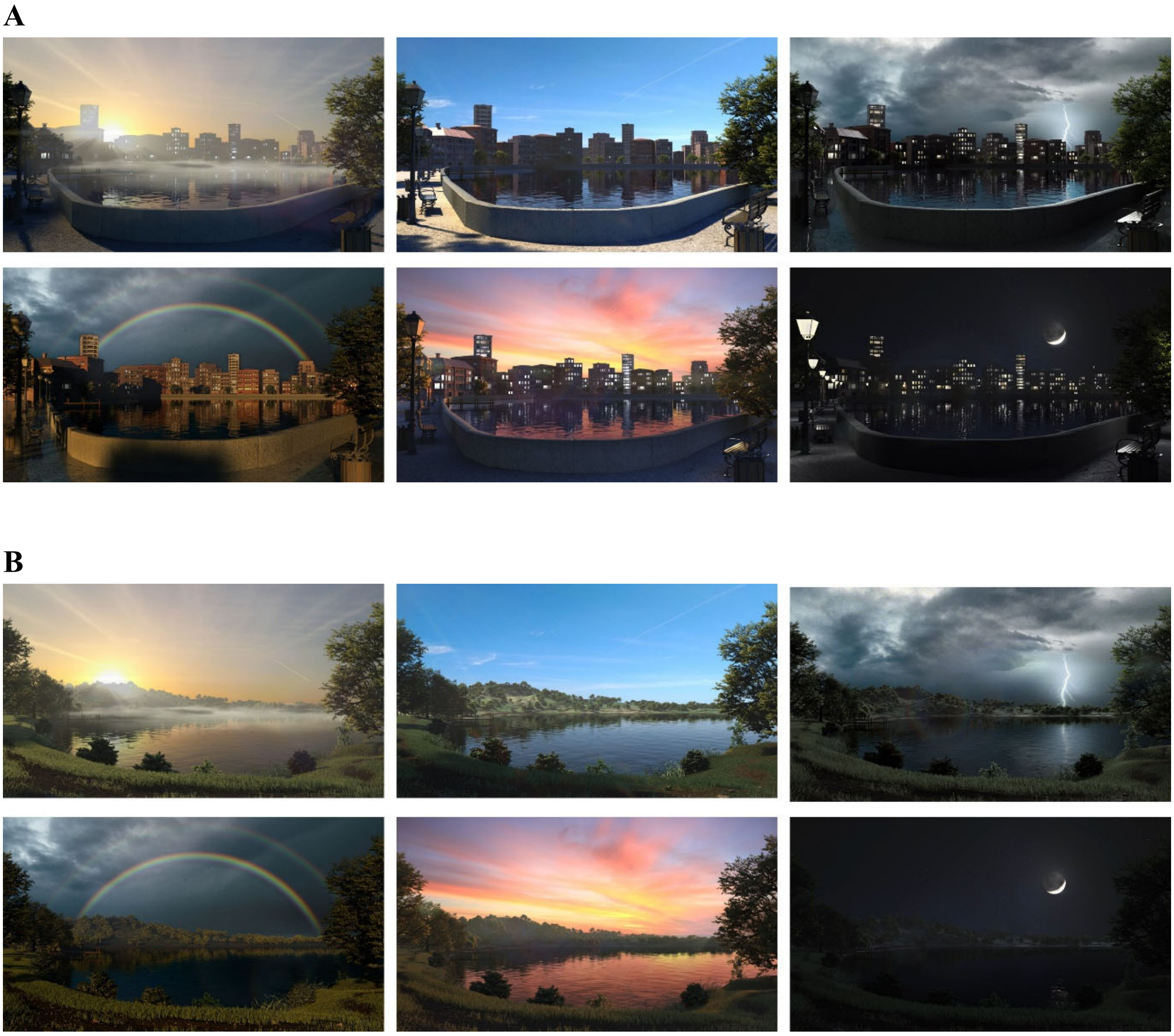
6.2.3 Stimuli

Previous research has often compared verdant, tranquil scenes of nature with busy, grey urban environments (e.g.Valtchanov & Ellard, 2015). However, these comparisons likely reflect very different moments in a person's routine; the former may be associated with recreation away from work, whilst the latter might represent a busy commute. (For example, this contrast could easily be reversed by comparing a crowded beach or overflowing forest car park with an empty, leafy urban street). Thus, to avoid 'stacking the deck' against either environment, our urban and natural scenes were both designed to be broadly favorable. This approach aimed to enhance the ecological validity of the experiment by representing places that people might willingly seek out for rest and relaxation, a framing that was also important for our willingness to pay measure. Each setting included features already identified as highly preferred in the existing literature such as a prominent body of water (Herzog, 1985; Howley, 2011; Nordh et al., 2009; White et al., 2010), favorable reflective properties (Nasar & Li, 2004), high levels of complexity and openness (Han, 2007), large amounts of sky (Masoudinejad & Hartig, 2018), leafy green foliage (Pheasant et al., 2010), and in the natural scene, a distant geological massif (Howley, 2011). All scenes were constructed using the 3D animation software Nuke and Houdini (Foundry, 2022; SideFX, 2022). Structural proportions were closely matched between the urban and natural setting, and the same lighting was applied across views (Fig. 19).

Figure 19. Urban and natural landscapes at sunrise.

Ephemeral phenomena were selected to reflect a range of changes possible in a typical day, progressing from sunrise through to midday blue-skies (our control condition), on to a thunderstorm with visible lightning, followed by a rainbow, sunset, and then night-time with prominent moon and stars. This mix of diurnal changes and ephemeral phenomena were applied to each landscape to produce a series of 'digitally calibrated images' (Arnberger & Eder, 2011). This technique allowed us to keep landscape components uniform *within* the urban and nature groups, and apply identical ephemeral phenomena *across* these groups (Fig. 20). Such strict control of our stimuli aimed to prevent possible confounding factors arising from changes in scene or view (Häfner et al., 2018). The use of fictional digital settings minimized the possibility that participants would have memories triggered by the images, a possible moderator of nature-based experiences (Ratcliffe & Korpela, 2016).

Figure 20. Six conditions in (A) the urban and (B) the natural setting. Stimulus comparisons can also be viewed in this short video https://youtu.be/lWmjUKqiiuY.



Landscape preferences derived from photographs correlate highly with those from in situ ratings (Hartig et al., 1996; Shafer et al., 1969) and elements of motion may also be important in these assessments (Hetherington et al., 1993). We thus sought to increase realism through the use of 'cinemagraphs', a form of animating image that represents a fixed scene with some elements of motion (Bai et al., 2013). Images were encoded in the *.gif* format and automatically started playing once loaded to reveal rippling water, gently swaying foliage, and for our thunderstorm, recurring lightning.

6.2.4 Procedure

Ethical approval was provided by the main author's host university research ethics committee, application number 20/01/236. The experiment was hosted by the data collection platform Qualtrics (qualtrics.com/uk). Once recruited via the consumer panel, respondents clicked an online link that directed them to the experiment. They could access the study using any internet-enabled digital device. Participants received a small fee from panel administrators that could be redeemed in varying forms, depending on the panel they signed up to. No personally identifiable information was collected as part of this study. The full experimental procedure, consent form, and instrument wording is presented in Appendix B.

6.2.5 Measures

Participants were asked to rate each image according to 8 dependent measures. They could scroll through and answer these questions while the image remained in view. We were unable to monitor time spent on each stimulus. Assessments of several items are beyond the scope of the current paper and will be published elsewhere (see Appendix B for the full list of items used). The length of our experiment and use of multiple dependent measures precluded the use of multi-item scales for some constructs (e.g. Yaden et al., 2019).

6.2.5.1 Beauty

To assess aesthetic appraisals of our landscape scenes, we used a single item measure of beauty common in the existing literature (Han, 2007; Latimer et al., 1981). Participants were asked: "*To what extent do you find this place beautiful?*" Responses were measured on a 10-point scale from "*Not beautiful at all*" to "*Very beautiful*".

6.2.5.2 Awe

To measure feelings of awe, respondents were asked "*To what extent do you agree with the following statement? This scene is awe-inspiring and fills me with wonder.*" Responses were measured on a 10-point scale (Chirico et al., 2017; Shiota et al., 2007; Sturm et al., 2020).

6.2.5.3 Willingness to pay (to visit)

Our valuation item assessed participants' willingness-to-pay to experience our scenes in the real world. Whilst only an approximation of participant behavior, the question sought to depict a specific and realistic situation and used a categorical scale approach (Donaldson et al., 1997). Participants were asked: "*Imagine you are on holiday and this location is a short journey from where you are staying. How much would you be willing to pay to visit this place and experience the moment depicted?*" Response options ranged from £0 to £100; a scale refined through pilot testing to create bounds deemed large enough to minimize range bias.

6.2.5.4 Covariates

Participants were asked to state their sex and could identify as: "*Female*"; "*Male*"; "*Another sex or gender*". Only one respondent answered "*Another sex or gender*", precluding the statistical power needed for meaningful inclusion of this category in our analyses.

Respondents recorded their age according to broad groupings, such as 18-25, 26-35, 36-45 and so on, up to the final group of 76+. Preliminary analysis suggested comparable responses from age bands between 18 and 45, and for those aged 46 and above. To simplify reporting across our variables of interest, age was thus collapsed into a binary variable, with those aged 45 and under in one group, and those aged 46 and over in the second group.

Trait-based connectedness to nature was assessed using the six-item Nature Connection Index, a metric validated against a large UK population sample (Richardson et al., 2019). Items were weighted and collapsed to form a single measure on a 100-point scale. Higher ratings demonstrated increased connection to nature.

To capture potential differences in participant experience, we recorded the type of device respondents used, including "*smartphone*", "*laptop*", "*desktop computer*", and "*tablet*". Only four people reported using an "*Other*" device, and this category has not been included in descriptions of results.

6.2.6 Statistical analyses

To answer research questions 1-3, we fitted moderation models that reflected our 2 (environment) by 6 (phenomena) design with ephemeral phenomena as predictors, environment (urban vs natural) as our key moderator, and beauty, awe, and willingness to pay as our outcome variables. A series of linear mixed effects models were constructed in the statistical software R (R Core Team, 2021) using the 'nlme' package and 'lmer' function (Pinheiro et al., 2022). Environment was the between-groups factor and phenomena the within-groups factor, with random intercepts specified to account for variability across participants. Because of the exploratory nature of the comparisons between settings and phenomena, a large number of contrasts were run. To control for a potentially high family-wise error rate, the Tukey method was applied across pairwise comparisons. In order to test research question #4 we selected the most highly valued phenomena in each landscape and created a simplified path model (Hayes, 2017) using the lavaan package in R (Rosseel, 2012), with ephemeral phenomena as predictors, beauty and awe as parallel mediators, and willingness-to-pay as outcome variable. To retain relevance to the original scales, unstandardised coefficients have been presented throughout. All data are available on the Open Science Framework here https://doi.org/10.17605/osf.io/d9gc5.

6.3 Results

Table 3 reports the fixed effects coefficients from each mixed model, revealing significant heterogeneity in assessments of our experimental conditions (see Tables S1 and S2 in Appendix B for correlations and mixed models without covariates, respectively).

6.3.1 Beauty

With respect to research question #1, we first focused on aesthetic appraisals. On average, our nature-based setting was considered substantially more beautiful than our urban scene (*B* = 1.90, CIs = 1.74, 2.06), yet ephemeral phenomena significantly affected ratings within these groups. For our urban landscape, the ephemera sunrise (*B* = 0.58, CIs = 0.46, 0.69), rainbow (*B* = 0.63, CIs = 0.52, 0.74), and sunset (*B* = 0.65, CIs = 0.53, 0.76) each led to significant increases in beauty ratings, compared to the blue-skies control. The presence of a storm decreased beauty ratings (*B* = -0.47, CIs = -0.58, -0.36), whilst night-time was considered equally as beautiful as the control (*B* = 0.04, CIs = -0.07, 0.16).

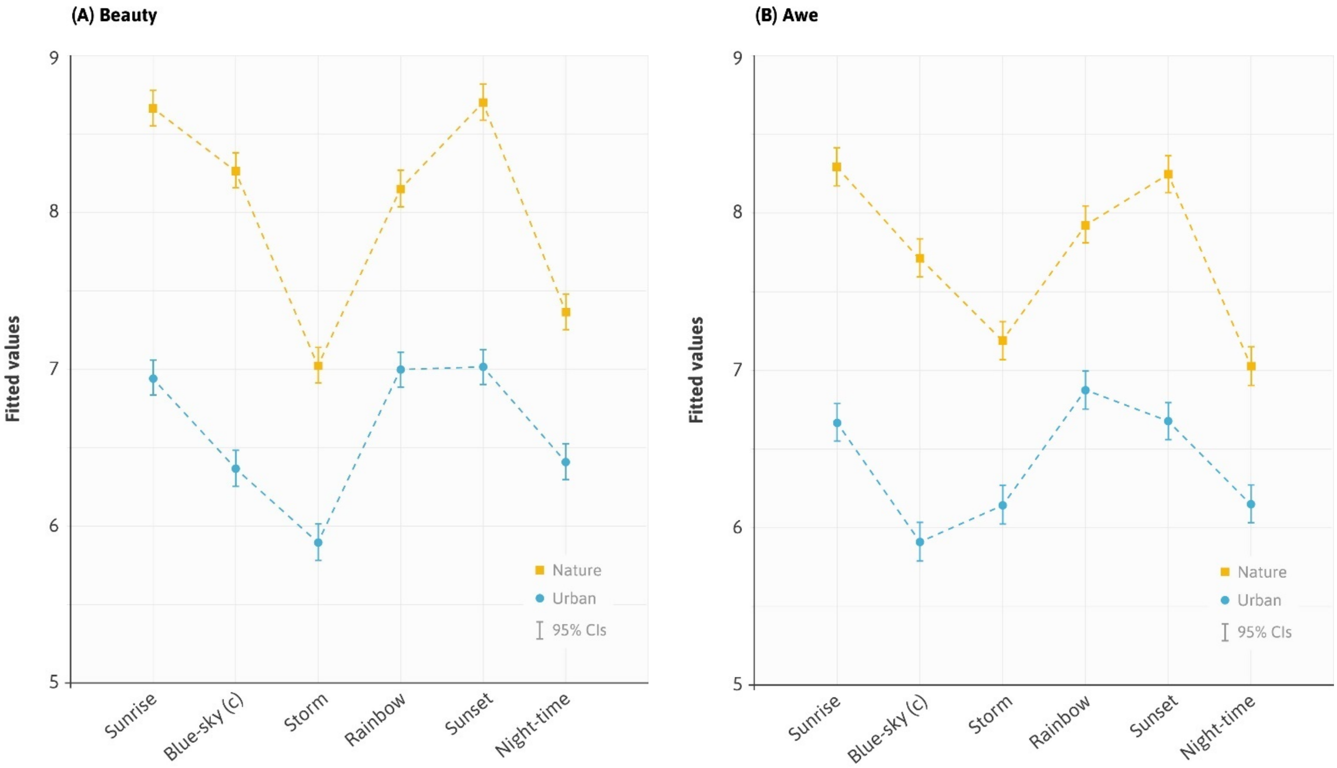
Significant interaction terms indicated the impacts of ephemeral phenomena also varied according to landscape type. Extracting fitted values from our model, Figure 21A demonstrates these effects (see Appendix B Table S3 for values and Table S8 for contrasts). For example, in our urban condition the presence of a rainbow increased beauty ratings compared to our blue-sky condition (M_{DIFF} = -0.63, CIs = -0.82, -0.44), but in our natural scene a rainbow led to no significant change (M_{DIFF} = 0.11, CIs = -0.08, 0.30). The thunderstorm led to a marked decrease in beauty for our natural landscape (M_{DIFF} = 1.24, CIs = 1.05, 1.42), yet in our urban scene this drop was almost two-thirds smaller (M_{DIFF} = 0.47, CIs = 0.28, 0.66). The negative sign of the interaction terms indicated that each ephemeral phenomena reduced the difference between environments, and importantly, exerted a modulating effect on the size of the urban-nature disparity. Pairwise comparisons revealed a mean difference of nearly two scale points between our urban and natural environments at sunrise (M_{DIFF} = -1.72, CIs = -1.99, -1.45) yet less than one scale point at night-time (M_{DIFF} = -0.95, CIs = -1.22, -0.68). Perhaps most strikingly, when we compared contrasting ephemeral phenomena across our urban and natural scenes, we found the main effect of environment type could disappear completely. For instance, the urban condition was rated equally as beautiful at sunset as our nature-based condition was during the storm (M_{DIFF} = -0.02, CIs = -0.29, 0.25). Despite these differences, similarities also existed. Sunrise and sunset emerged as particularly beautiful times to experience each environment, with sunset in our natural scene receiving the highest aesthetic ratings overall (M = 8.70, CIs = 8.59, 8.82).

In general, females found our conditions more beautiful than males (*B* = 0.14, CIs = 0.01, 0.26), whilst those aged 46 and above rated them considerably less beautiful than younger people (*B* = -0.64, CIs = -0.77, -0.51). Increasing connection to nature was associated with higher beauty ratings (*B* = 0.02, CIs = 0.02, 0.03) and those using a desktop computer (*B* = -0.32, CIs = -0.52, -0.12) or tablet (*B* = -0.27, CIs = -0.49, -0.05) found our experimental scenes slightly less beautiful than participants who used a smartphone.

Table 3. Unadjusted coefficients for our three mixed models with beauty, awe, and willingness-to-pay to visit as the dependent variables. 'Blue-sky' was the reference ephemeral condition, and 'urban' the reference landscape group. [1]CI = Confidence Interval, * = significant at p < .05 level. Note that a negative interaction term indicates a narrowing of the gap between environments, compared to the blue-sky control.

	DV = Beauty		DV = Awe		DV = Willingness to pay	
Characteristic	Beta	95% CI[1]	Beta	95% CI[1]	Beta	95% CI[1]
(Intercept)	5.24*	5.03, 5.45	4.51*	4.29, 4.73	7.30*	6.59, 8.00
Landscape						
Urban	—	—	—	—	—	—
Nature	1.90*	1.74, 2.06	1.80*	1.63, 1.97	2.41*	1.92, 2.91
Condition						
Sunrise	0.58*	0.46, 0.69	0.75*	0.63, 0.87	0.83*	0.58, 1.08
Blue-sky (control)	—	—	—	—	—	—
Storm	-0.47*	-0.58, -0.36	0.23*	0.11, 0.35	-1.04*	-1.29, -0.79
Rainbow	0.63*	0.52, 0.74	0.96*	0.84, 1.08	0.77*	0.52, 1.02
Sunset	0.65*	0.53, 0.76	0.76*	0.64, 0.88	0.93*	0.68, 1.18
Night-time	0.04	-0.07, 0.16	0.24*	0.11, 0.36	0.01	-0.24, 0.26
Sex						
Male	—	—	—	—	—	—
Female	0.14*	0.01, 0.26	0.08	-0.05, 0.21	-0.16	-0.60, 0.29
Age group						
18-45	—	—	—	—	—	—
46+	-0.64*	-0.77, -0.51	-0.60*	-0.74, -0.46	-2.04*	-2.51, -1.57
Nature connection	0.02*	0.02, 0.03	0.03*	0.03, 0.03	0.04*	0.03, 0.05
Device						
Smartphone	—	—	—	—	—	—
Desktop	-0.32*	-0.52, -0.12	-0.40*	-0.61, -0.19	-2.16*	-2.86, -1.46
Laptop	-0.06	-0.20, 0.09	-0.13	-0.28, 0.03	-1.44*	-1.96, -0.92
Tablet	-0.27*	-0.49, -0.05	-0.30*	-0.53, -0.06	-0.68	-1.47, 0.11
Condition * group						
Sunrise * Nature	-0.18*	-0.34, -0.02	-0.18*	-0.35, -0.01	0.14	-0.21, 0.49
Storm * Nature	-0.77*	-0.93, -0.61	-0.76*	-0.93, -0.58	-1.34*	-1.69, -0.99
Rainbow * Nature	-0.74*	-0.90, -0.58	-0.75*	-0.92, -0.58	-0.84*	-1.20, -0.49
Sunset * Nature	-0.21*	-0.37, -0.05	-0.23*	-0.40, -0.06	-0.19	-0.55, 0.16
Night-time * Nature	-0.95*	-1.11, -0.79	-0.92*	-1.09, -0.75	-1.35*	-1.70, -0.99

Figure 21. Fitted values from our mixed effects models, with (**A**) beauty ratings as the outcome variable and (**B**) awe ratings as the outcome variable. The y-axis represents a range that captures all variation in responses. See Appendix B for tabulated values.



Put simply, results showed that the presence of ephemeral phenomena had a substantial and significant impact on the aesthetic appraisal of our landscape scenes. On average, the natural environment was considered more beautiful than the urban, yet the effects of ephemeral phenomena dramatically altered the scale of this advantage. Each condition made the gap between environments smaller, with the rainbow, storm, and night-time having the greatest effect. Sunrise and sunset emerged as particularly beautiful times to experience both scenes.

6.3.2 Awe

Regarding research question #2 and consistent with ratings for beauty, our nature-based scene was, overall, considered significantly more awe-inspiring than our urban scene (B = 1.80, CIs = 1.63, 1.97). Yet once again, the presence of ephemeral phenomena substantially modified these ratings. For our urban setting, all phenomena were associated with an increase in awe when compared to the blue-sky condition, but to varying degrees. For example, whilst the presence of a thunderstorm led to a small but significant increase (B = 0.23, CIs = 0.11, 0.35), a rainbow enhanced ratings by almost a whole scale point (B = 0.96, CIs = 0.84, 1.08).

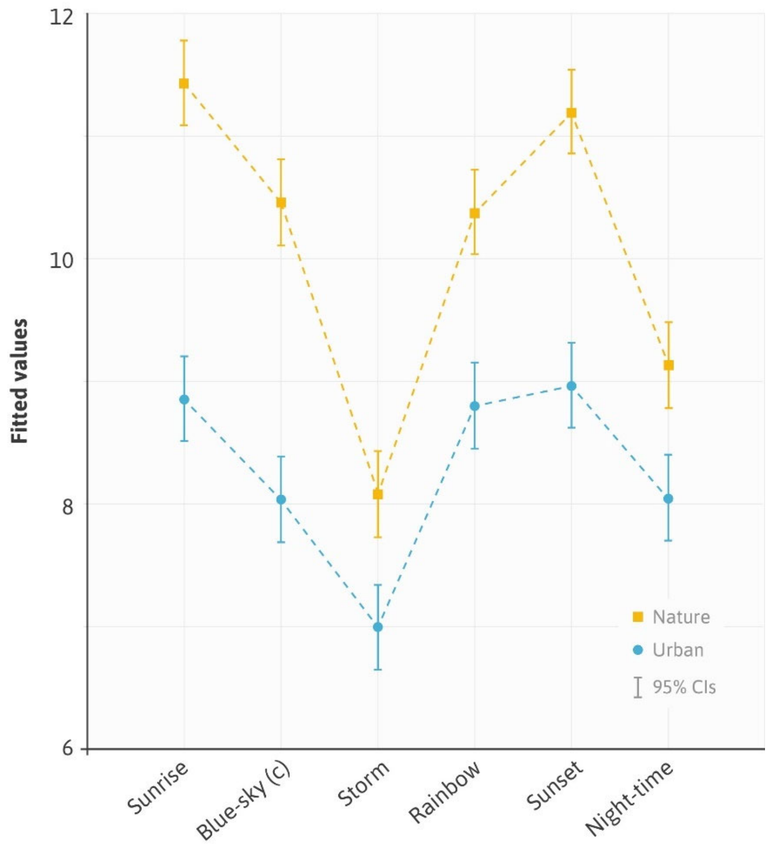
As with aesthetic appraisals, varying interaction terms demonstrated differential effects of ephemera according to landscape. Figure 21B plots fitted values from our model to reveal commonalities and conflicting patterns between our urban and natural environments (see Appendix B Table S4 for values and Table S9 for contrasts). For example, although all ephemeral phenomena increased ratings of awe in our urban condition compared to the control, in our nature-based landscape both the storm (M_{DIFF} = 0.52, CIs = 0.32, 0.73) and night-time (M_{DIFF} = 0.69, CIs = 0.48, 0.89) led to significant *decreases*. Sunset and sunrise were again rated highly, with sunrise in the natural environment considered most awe-inspiring overall (M = 8.29, CIs = 8.17, 8.41). Once more, significant negative interactions suggested each ephemeral phenomena reduced the size of the urban-nature disparity, yet differential effects also remained. At sunrise the difference was over 1.5 scale points (M_{DIFF} = -1.62, CIs = -1.91, -1.33), whilst at night-time this gap was almost halved (M_{DIFF} = -0.88, CIs = -1.16, -0.59). When considering contrasting configurations of ephemeral phenomena across our scenes, the natural landscape was always rated as more awe-inspiring than the urban landscape, except when comparing the urban rainbow with natural night-time, where there was no significant difference (M_{DIFF} = -0.15, CIs = -0.44, 0.14).

We detected no association with sex and awe (*B* = 0.08, CIs = -0.05, 0.21). But again, those aged 46 and over were more indifferent, rating our conditions considerably less awe-inspiring than younger people (*B* = -0.60, CIs = -0.74, -0.46). A higher connection to nature was associated with increased feelings of awe (*B* = 0.03, CIs = 0.03, 0.03) and those using a desktop computer (*B* = -0.40, CIs = -0.61, -0.19) or tablet (*B* = -0.30, CIs = -0.53, -0.06) rated the stimuli lower than participants who used a smartphone.

6.3.3 Willingness to pay

With respect to research question #3, the natural scene attracted a higher willingness-to-pay premium than the urban scene on average (*B* = 2.41, CIs = 1.92, 2.91). But again, ephemeral phenomena led to significant variations within environments. For example, experiencing the urban environment at sunset was valued almost £1 higher than under blue-sky conditions (*B* = 0.93, CIs = 0.68, 1.18), whilst the storm was valued over £1 less (*B* = -1.04, CIs = -1.29, -0.79). Interaction effects were also significant, although not this time for sunrise (*B* = 0.14, CIs = -0.21, 0.49) and sunset (*B* = -0.19, CIs = -0.55, 0.16). Interactions were greatest for the storm (*B* = -1.34, CIs = -1.69, -0.99) and night-time (*B* = -1.35, CIs = -1.70, -0.99), which both had a notably larger negative effect on willingness-to-pay to visit the natural landscape. Fitted values (Figure 22 and Table S5) demonstrated that sunrise in the natural environment was the most valued combination of landscape type and ephemeral phenomenon, with a mean willingness-to-pay to visit of £11.43 (M = 11.43, SE = 0.18, CIs = 11.08, 11.78). This premium was 9% above our natural blue-sky condition (M = 10.46, SE = 0.18, CIs = 10.11, 10.81) and 41% higher than the natural storm condition (M = 8.08, SE = 0.18, CIs = 7.73, 8.43).

Figure 22. Fitted values from our mixed effects model with willingness-to-pay ratings (in British pounds) as the outcome variable. The y-axis represents a range that captures all the variation in responses. See Appendix B for tabulated values.



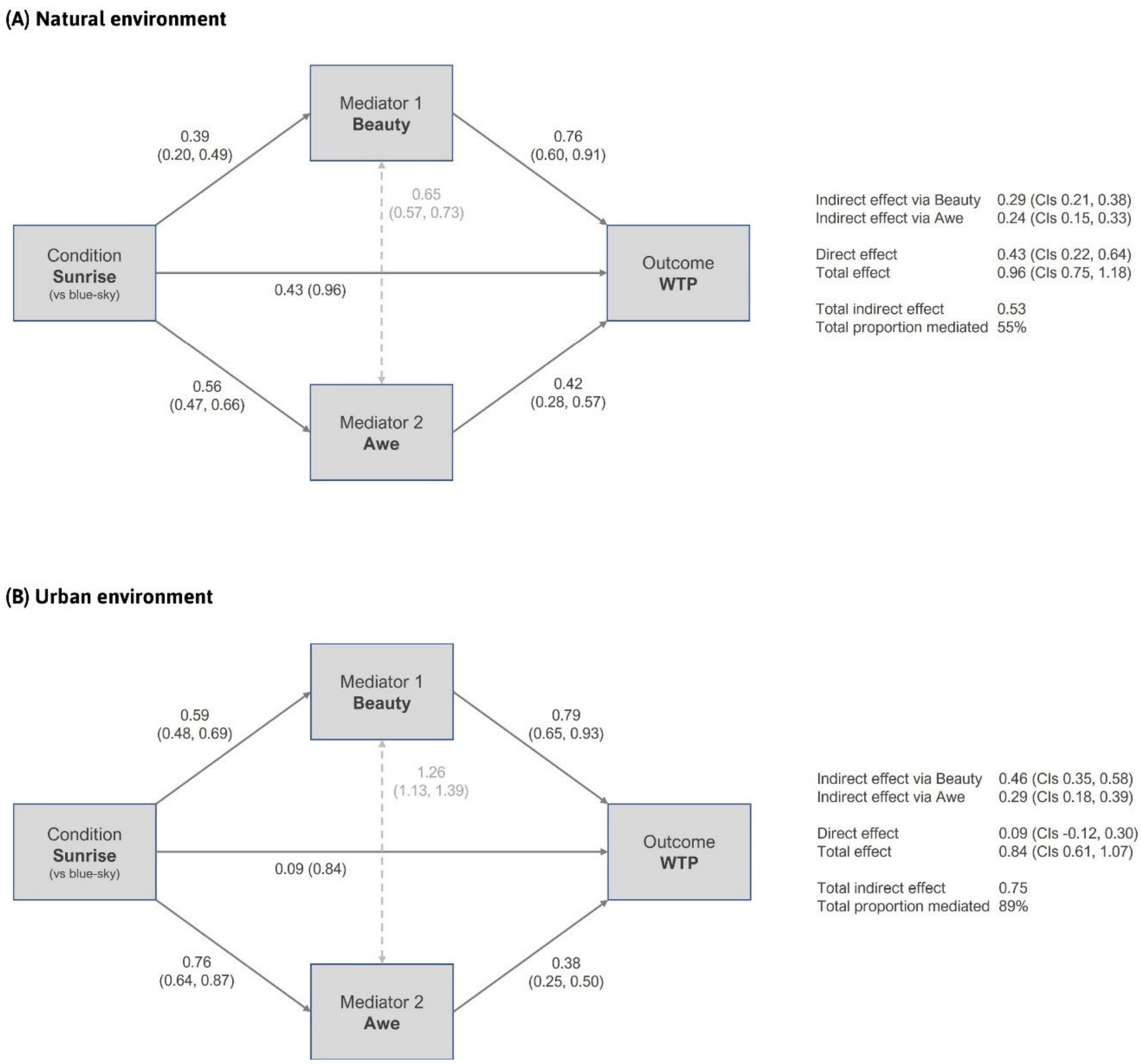
6.3.4 Mediation analyses

The similarity in appraisal patterns for beauty, awe, and willingness-to-pay reflects their interrelation and could be indicative of mediation; the reason people may be willing to pay a premium to visit a landscape at certain points in the day might be because they believe they would find the experience more aesthetically pleasing and awe-inspiring. To test this hypothesis, we created a simplified path model (Hayes, 2017) with ephemeral phenomena as predictors, beauty and awe as parallel mediators, and willingness-to-pay as the outcome variable. To simplify reporting and highlight patterns in our pathways of interest, we focused on the ephemeral phenomenon that attracted some of the largest increases in valuation in both settings: sunrise. Since these relatively simple models are 'saturated' (where all predictors have paths to all mediators and outcome variables), no fit statistics are reported.

First, we considered the extent to which beauty and awe mediated the effect of sunrise on the valuation of our nature-based scene. Results are presented in Figure 23A and Table S6 in Appendix B. Unadjusted indirect effects via beauty accounted for 30% of the total effects of sunrise on willingness to pay (B = 0.29, SE = 0.04, CIs = 0.21, 0.38). The indirect effects of awe accounted for 25% of the total effects (B = 0.24, SE = 0.05, CIs = 0.15, 0.33); despite their high shared variance, the two variables showed separate yet similar mediation effects. In sum, over half the premium (55%) people were prepared to pay to visit our natural scene at sunrise (compared to blue-sky conditions) was mediated by the enhanced beauty and awe likely to be experienced.

These effects were even more pronounced in our urban scene (Figure 23B, Table S7 Appendix B). Unadjusted indirect effects via beauty accounted for 55% of the total effects of sunrise on willingness-to-pay (B = 0.46, SE = 0.06, CIs = 0.35, 0.58). Indirect effects of awe accounted for 35% (B = 0.29, SE = 0.05, CIs = 0.18, 0.39), combining with beauty to mediate 89% of the total effects of sunrise on willingness to pay, and rendering the direct effects insignificant (B = 0.09, SE = 0.11, CIs = -0.12, 0.30).

Figure 23. Structural equation model with condition as predictor (sunrise *vs*. blue-sky), willingness-to-pay as outcome, and beauty and awe as parallel mediators. 95% confidence intervals are also depicted. Tabular outputs can be found in Tables S4 and S5 of Appendix B.



6.4 Discussion

In his pioneering paper on ephemeral phenomena, Paul Brassley suggested "*...if it could be demonstrated that changes in landscape ephemera affected perception and evaluation in the same way as changes in permanent landscape components...the implications could be far-reaching*" (Brassley, 1998, p. 129). Our results provide some of the first quantitative evidence to support this proposition.

6.4.1 Findings

Overall, nature was rated more highly than urban in the settings we tested. Yet the differential effects of ephemeral phenomena acted to widen and close this disparity, even eliminating it completely under specific conditions. Participants particularly valued sunrise and sunset within each landscape, finding these moments more beautiful and awe-inspiring than the blue-sky control conditions. The presence of a rainbow increased ratings of awe in the urban and natural setting, but enhanced beauty only in the urban landscape. The thunderstorm and night-time reduced appraisals of beauty in each landscape, decreased feelings of awe in the natural environment, yet increased awe in the urban scene. For both beauty and awe, the urban-nature divergence was greatest at sunrise and sunset, and smallest at night-time.

These patterns were mirrored in participants' financial valuations of our landscape views, which were at their maximum at sunrise and sunset, and at their minimum at night-time and during the thunderstorm. Participants were prepared to pay a premium of 9% to visit the natural setting at sunrise compared to under blue-sky conditions, and 41% more when comparing sunrise to the thunderstorm. These values should be viewed as highly preliminary but are similar in scale to those attributed to physical and permanent features, such as proportions of visible water or attractive buildings (Bourassa et al., 2004; White et al., 2010).

Crucially, results suggested these premiums were partially mediated by appraisals of beauty and awe. In the natural environment, increases in both metrics accounted for over half the effect of sunrise on willingness-to-pay. In the urban setting they mediated the effect of sunrise completely. Moreover, despite their shared variance, there were separate mediation pathways for both beauty and awe, suggesting they reflect different underlying processes in how landscapes might be valued.

Compared to younger people, those aged 46 and over were less likely to find our environments beautiful and awe-inspiring, and less willing to spend money to visit them in the real world. Sex was only a significant covariate for beauty, where females returned slightly more positive ratings than males. Increasing connection to nature and using a smartphone to view our stimuli were both associated with more positive appraisals in general, a relationship that was consistent across each of our analyses.

6.4.2 Limitations

Our large sample size and strictly controlled stimuli were key strengths of our experimental approach. Nonetheless, several limitations must also be acknowledged. The rich, immersive, multisensory features of landscape can exert an important influence on their aesthetic value (Brady & Prior, 2020). Since our investigation was confined to two-dimensional, unimodal visual scenes, we must exercise caution when seeking to draw parallels with real-world assessments. Perceived realism has been associated with reactions to environmental encounters in digitally mediated settings (Newman et al., 2022) and although we used the latest 3D techniques to create our experimental conditions, some participants may have found it difficult to relate to a computer-generated image. This response could underpin the age-based patterns in our data, with digital stimuli likely to be more familiar and acceptable to younger participants. A similar effect may also explain why participants using smartphones rated our stimuli consistently higher than those using other devices, where larger screens may have placed more emphasis on visual fidelity.

Quantitative investigations form just one way of unpacking how and why people perceive environments differently (Scott et al., 2009). Our focus on positive appraisals may have overlooked the possible negative valence of some participant reactions; inclement weather can reduce subjective wellbeing (Connolly, 2013) and has demonstrated a negative impact on preferences for natural and urban environments (White et al., 2014a), whilst night-time can be associated with a lack of safety (Boyce et al., 2000). Deeper qualitative lines of inquiry might benefit the interpretation of future work in this area (Brady & Prior, 2020).

Although we were able to attain a heterogeneous participant group, we must not assume our results are transferable across geographical locations and cultures (Henrich et al., 2010). Moreover, although they can represent a suitable guide to estimating non-market goods and services (Haab et al., 2020), the use of contingent valuation methods has been contested (Clark et al., 2000; Venkatachalam, 2004). Indeed, reflecting the value participants might place on visiting a location under specific conditions may have been hard to achieve. Although recent evidence suggests an approximately linear relationship between the amount spent to visit a recreational location and satisfaction with the experience, there may be intrinsic biases in these ratings (Börger et al., 2022). We must therefore remain cautious about over-interpreting our results, and instead view them as highly exploratory.

6.4.3 Implications

To date, most studies assessing people's responses to urban and rural settings have used images, videos, or real-world excursions under clement and often 'blue-sky' conditions. Using this standard as our control condition, we found the presence of ephemeral phenomena could substantially change landscape appraisals. What impact could these findings have?

Recognizing that landscape aesthetics are in constant flux could reframe the ways that often-static views are valued by their inhabitants, particularly in urban environments. For example, the UK's national mapping agency already depicts 'Tourist features' and 'Viewpoints' with dedicated symbols on their maps (Ordnance Survey, 2021). Signposting places where ephemeral phenomena can also be observed might highlight the potential to experience dynamic and transient features, challenging typical cartographic representations of landscape that tend to focus on permanent and unchanging morphologies (Qviström & Saltzman, 2006). Moreover, by preserving open skies with eastern or western aspects, planning policies might seek to maximize people's chances of viewing fleeting phenomena. Our results suggest that ephemera should also be incorporated into the myriad ways natural beauty is considered and interpreted in planning legislation (Selman & Swanwick, 2010).

These approaches could have the most impact by eliciting feelings of awe, which under the right conditions can be readily accessed in 'everyday' encounters with nature (Sturm et al., 2020). By highlighting opportunities to experience events such as sunrise or sunset, those in both urban and natural settings could experience a small yet significant increase in this hard-to-elicit emotion. Accompanying rises in awe's associated benefits, such as increased positive affect and higher levels of altruism (Piff et al., 2015; Sturm et al., 2020), may then follow suit. These outcomes might be particularly beneficial for 'green prescriptions' that seek to improve participant wellbeing (Robinson & Breed, 2019a).

We must also reflect on some surprising patterns in our results for this emotion. With its vastness, dynamism, and intensity, we expected the thunderstorm to be a strong elicitor of awe (Keltner & Haidt, 2003). Yet conditions such as sunrise, rainbow, and sunset led to larger increases in awe across both environments, with the storm even leading to an average *decrease* in awe in the natural setting. Awe can represent a mixed-valence emotion (Arcangeli et al., 2020) and this pattern may have been partly due to the potential for stormy weather to trigger threatening feelings (Gordon et al., 2017) and negatively impact preferences (White et al., 2014a). With few visible places for refuge, this effect could have been exacerbated in the natural setting. Moreover, since awe requires a sense of scale and power to be conveyed, this emotion may be much harder to trigger using digital images compared to real life scenarios, an area which might garner further research attention.

Fears that society is rapidly undergoing an 'extinction of experience' (Soga & Gaston, 2016) often center on reduced chances for direct contact with natural settings (Cox et al., 2017). Indeed, attempts to increase the psychological wellbeing of metropolitan residents commonly center on enhanced encounters with natural environments, often through urban greening initiatives (Hartig & Kahn, 2016). Perhaps opportunities to experience ephemeral phenomena could help to address these issues without a reliance on interventions that augment structural factors. They might also serve to highlight the rhythms of the day, seasons, weather, and climate, facilitating an indirect yet valuable part of human-nature interactions and reconnecting people to their surrounding environments (Kahn et al., 2010).

After centuries of awareness about the cultural significance of events such as sunrise and sunset, we provide an initial and very tentative estimate for the premium these experiences might attract. Landscape aesthetics are an important cultural ecosystem service (Häfner et al.,

2018) and our results suggest this aesthetic value could vary throughout the course of a single day. Meaningfully integrating these components into models that attempt to value and protect natural capital is likely to prove challenging (Daily et al., 2000), but their tentative inclusion could broaden model applicability and the granularity at which they reflect environmental externalities (Bratman et al., 2019). Intriguingly, we found that awe and beauty in the urban environment fully mediated the direct effect of sunrise on willingness to pay. Yet in the natural setting, these metrics only accounted for half of this variance, suggesting a more complex set of appraisals may be at play. Natural environments are often associated with positive moods and feelings of restoration, and it is likely that the expectation of deriving therapeutic outcomes from this setting could also be driving increases in value. More in-depth qualitative research might help to unpick the relative importance of these pathways in future work.

From a theoretical perspective, the uncommon and unexpected nature of ephemeral phenomena may play a central role in their appeal, representing minor yet welcome deviations from expected patterns or experiences (Brassley, 1998). Novel landscapes and features often receive high ratings of aesthetic preference (Buhyoff & Wellman, 1979; Hull & Stewart, 1995; Wang et al., 2019) yet personal experience is also considered an important factor in scenic appraisals, with a positive relationship existing between familiarity, preference, and opportunities for cognitive restoration (Korpela & Hartig, 1996; Korpela et al., 2001). By representing the opportunity for novelty *within* a familiar landscape, ephemeral phenomena may provide an elegant way to join these contrasting mechanisms. To what extent could the changes in awe and beauty identified in our results be due to concomitant variations in novelty? These links may be worthy of further investigation.

Differences between urban and natural environments have been extensively covered in the existing literature, and this coarse dichotomy continues to be explored (Keenan et al., 2021; Pasca et al., 2021). However, by examining a deeper level of detail in human-nature experience, our results suggest how positive outcomes in contrasting landscapes might be optimized. These applications may be most relevant in digitally mediated settings, where people can be immersed in *any* kind of experience, and outcomes targeted for specific mental states (Chirico et al., 2018).

6.4.4 Conclusions

Structural landscape components such as rivers and lakes, distant mountains, leafy streets, and historical buildings are each considered favorable and even value-enhancing aesthetic features. Here we provide some of the first evidence to suggest that a similarly significant and quantifiable relationship may also exist with features that are non-structural, meteorological, and diurnal. Acknowledging the impacts from these ‘ephemeral phenomena’ might introduce a vital temporal component to how landscape experience is evaluated in both urban and natural settings, moving beyond a static and uniform model to one in which a complex kaleidoscope of possible daily experiences is also recognized. As Brassley (1998) suggested, the implications of such an approach could indeed be far-reaching.

6.4.5 CRediT author contributions

Conceptualization: AJS, MPW.
Methodology: AJS, MPW.
Investigation: AJS.
Visualization: AJS.
Supervision: MPW.
Writing—original draft: AJS.
Writing—review & editing: MPW, AJS.

[Published content ends]

Studies one and two demonstrated the importance of complete soundscapes (consisting of abiotic and biotic sounds), memories, and ephemeral phenomena (such as sunrise and sunset) on the ways people experienced digitally delivered environmental stimuli. How might these factors combine to 'optimise' restorative and emotional outcomes further? As outlined in sections 4.5 and 4.6, editorial conversations as part of the BBC 4 *Mindful Escapes* series had also identified a need to understand how music might feature in this kind of content, a gap in understanding that was equally reflected in the academic literature described in section 2.12. Subsequently, our final study considered how soundscapes, music, and memories might augment responses to a specifically created digital nature experience.

7. Study three, *Soundscapes, music, and memories*

Title

Soundscapes, music, and memories: Exploring the factors that influence emotional responses to virtual nature content.

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Abstract

From walking through a park to sitting on a beach, much is known about the therapeutic potential of direct contact with natural environments. Yet routinely in the UK, millions of people encounter nature in a completely different way, through their television screens. Despite the ubiquity of natural history programming, little is understood about its impact on the restorative and affective experiences of audiences. Nowhere is this truer than in the bold orchestral scores that accompany almost all nature documentaries. Whilst considerable evidence suggests that separately, both nature and music can provide a range of psychological benefits, how their pairing might affect the wellbeing potential of virtual nature encounters remains largely unknown. Similarly, scant research has considered how viewers' own experiences, recalled through memories, might influence outcomes. To explore these areas, we formed a transdisciplinary broadcast initiative, called BBC Soundscapes for Wellbeing. Part of this project involved a randomized and controlled experiment that presented participants (n = 7,636) with a dynamic nature scene accompanied by one of four acoustic tracks. Results demonstrated that whilst adding music to this scene led to increased feelings of excitement, it led to no other restorative or affective benefits when compared to silence. In contrast, the addition of natural sounds was associated with greater feelings of restorative potential, calmness, and excitement. Natural sounds also drove significant increases in the complex emotions of awe and nostalgia. Crucially, results showed the substantial moderating effects of participant memories. Those with positive memories stimulated by the experience reported significantly greater effects across all conditions and dependent variables. We find that although the acoustic design of virtual nature encounters can affect a range of emotional responses, the memories triggered by these experiences may be far more important for predicting viewer outcomes.

7.1 Introduction

In 1924 the BBC aired its inaugural live outside broadcast, in which the British public heard, for the first time, the digitized sounds of a bird in its natural habitat (Helge, 2019). Yet the nightingale singing over wireless radio sets was not alone; it was accompanied by music in the form of a 'duet' with cellist Beatrice Harrison (Baird, 2015). And so continued a trend established by the ancient Greeks and much remarked upon since: that music and the broad concept of nature are innately, intricately, intertwined (Gray et al., 2001; Levin, 2009).[1]

Music continues to be a familiar companion to diverse nature experiences today (AHRC Press, 2018; The Guardian, 2021). People routinely listen to music whilst exercising in natural environments, a pairing that may enhance both mood and performance (Terry et al., 2020). In modern relaxation settings, nature and music are often combined to complement the delivery of therapies such as yoga and massage (Turner & Freedman, 2004). But perhaps nowhere is the pairing of nature and music more familiar than in the bold orchestral scores of natural history documentaries, such as the BBC's Blue Planet series (Wheatley, 2004).

Amidst growing recognition that nature can play a positive role in people's wellbeing (Frumkin et al., 2017), practitioners and policy makers are seeking to understand how best to develop and deliver nature-based experiences that might provide salutary benefits. This trend is being embraced by television and radio broadcasters in particular, who are hoping to leverage the wellbeing potential of their natural history broadcasts (Keltner et al., 2017) through the delivery of new multi-platform outputs (BBC Archive, 2020; BBC Four, 2020). Yet media producers face a dilemma: how should these novel programs be designed to not just educate and entertain, but also enhance psychological health?

A key question centers on the inclusion of music in this content. Despite evidence that music and nature share a symbiotic relationship (Doolittle & Gingras, 2015), little research exists to suggest how their pairing might influence therapeutic outcomes. Likewise, should program-makers target simple affective responses, such as calmness and excitement, or could their audiences experience more complex emotional states, like awe and nostalgia? Crucially, what role might viewers' individual characteristics, such as personal memories, play in moderating these outcomes? To deepen understanding in these areas, we developed a transdisciplinary project, called *Soundscapes for wellbeing*, that launched across BBC platforms in January 2021 (BBC, 2021). Here we report findings from the experimental part of this endeavor.

7.1.1 Nature and wellbeing

Exposure to natural environments is associated with a long list of positive health outcomes (Bratman et al., 2019; Frumkin et al., 2017). Contact with nature can benefit psychological wellbeing in particular: increasing positive emotions (MacKerron & Mourato, 2013);

[1] The BBC has recently revealed that the real nightingale had actually left the location before recording and was, at the last minute, substituted by an impressionist (The Guardian, 2022). Yet subsequent programs, which ran for many years, featured real nightingales and our point remains; nature and music have been paired since the very earliest days of broadcasting.

decreasing negative emotions (Bowler et al., 2010); improving cognitive functioning (Ohly et al., 2016; Stevenson et al., 2018); and enhancing mental health more generally (White et al., 2021).

These responses are commonly investigated from two bottom-up perspectives: nature's potential to recover depleted cognitive resources via attention restoration theory (Kaplan & Kaplan, 1989); and its ability to reduce the psychological and physiological indices of stress detailed by stress recovery theory (Ulrich et al., 1991). Despite conceptual differences in these frameworks (Joye & van den Berg, 2011), both mechanisms can be considered complementary and might even operate concurrently (Hartig et al., 2003), each invoking subconscious affective reactions to environmental features (Kaplan, 1995).

Crucially, these processes can be triggered by a diverse range of exposures to the natural world (Keniger et al., 2013). These might involve intentional physical contact, by walking barefoot along a beach for example (Rickard & White, 2021), or more indirect experiences, such as looking at woodland from a window (Leather et al., 1998). Within this spectrum, the present study focused on indirect and digital encounters: those that people have chosen to engage in, but which involve no direct contact with the natural world. When 9.2 million people – 7% of the UK population (ONS, 2017) – tuned into the first episode of the BBC's Planet Earth II series (The Guardian, 2016), they were experiencing nature through this kind of intentional, indirect, and digital medium.

7.1.2 Digital nature

Whilst spending time in 'real' natural environments might confer enhanced wellbeing outcomes compared to indirect experiences (Browning et al., 2020c), a substantial proportion of the evidence supporting nature's therapeutic potential stems from studies that have used digital surrogates (McMahan & Estes, 2015). For example, nature-based videos have demonstrated the potential to aid recovery from the physiological and psychological markers of stress across thirty years of research (Meuwese et al., 2021; Ulrich et al., 1991). Even viewing simple still images of nature-based scenes can lead to significant increases in positive affect (Hartig et al., 1996), improvements in mood (van den Berg et al., 2003), recovery of attentional capacity (Berto, 2005), increases in executive attention (Berman et al., 2008), and reductions in impulsivity (Berry et al., 2015).

These benefits also extend to more immersive presentations of digital environments, commonly delivered through virtual reality (VR) technology (Nukarinen et al., 2022; White et al., 2018). VR nature has been associated with improvements in negative emotions, self-reported stress, anxiety, happiness, and creativity (Palanica et al., 2019; Schebella et al., 2020; Yu et al., 2018). Yet evidence suggests these benefits may only represent marginal gains above those provided by the 2D format of typical TV broadcasts (Yeo et al., 2020), and in some cases, no advantages at all (Li et al., 2021b).

With ‘VR sickness’ still a significant problem for many users (Howard & Van Zandt, 2021), when it comes to wellbeing outcomes, the *content* of digital experiences may be more important than the *delivery* (Depledge et al., 2011; Ludden et al., 2019). Indeed, faltering domestic uptake of VR platforms (Green et al., 2021) has underlined how the ubiquity of 2D, screen-based nature programming remains stubbornly relevant. UK viewing figures for the launch of the 2021 BBC series *A Perfect Planet* were in excess of six million (Royal Television Society, 2021), a popularity that may be particularly important for younger age groups (BBC News, 2016). What factors might impact the ‘wellbeing potential’ of these digital encounters?

7.1.3 Restorative design

Assessing the ‘restorative potential’ of a virtual nature experience is central to answering this question (Hartig et al., 1997b; Kaplan & Kaplan, 1989). Much is known about how preferences for natural features can affect this measure. For example, visual elements such as water (Herzog, 1985; Howley, 2011; Nordh et al., 2009; White et al., 2010), leafy green foliage (Pheasant et al., 2010), mountains (Howley & O'Donoghue, 2011), and open tracts of sky (Masoudinejad & Hartig, 2018) are often rated highly for aesthetic value and have been associated with increases in psychological restoration (Korpela, 2013).

Beyond vision, a growing body of work has highlighted the importance of sound in therapeutic outcomes (see Ratcliffe, 2021a for a comprehensive review). For example, numerous studies have used digital stimuli to demonstrate strong preferences for sounds of the natural world compared to those from urban environments (Benfield et al., 2014; Ren et al., 2018). Others have demonstrated the value of individual sound sources, such as bird song (Hedblom et al., 2014; Ratcliffe et al., 2013, 2016) and flowing water (Alvarsson et al., 2010; Carles et al., 1999; Yang & Kang, 2005), and considered how these abiotic and biotic elements might contribute to cognitive restoration (Buxton et al., 2021; Smalley et al., 2022). Moreover, the development of a specific restorativeness scale has allowed natural sounds to be incorporated into a restoration framework (Payne, 2013), recognizing these sounds as positive and valued elements of the auditory environment (Brown, 2012) and extending soundscape research past a narrow focus on noise pollution (Murphy & King, 2014).

Yet whilst anthropogenic sound can have negative impacts on natural soundscapes (e.g. Uebel et al., 2021), ‘designing out’ human elements from nature-based experiences might overlook the possibility that context specific and culturally valued sounds, such as music, can also be positively received (Yang & Kang, 2005). How might music ‘enhance’ the restorative potential of nature-based sounds (Goel & Etwaroo, 2006)?

7.1.4 Nature, music, and emotions

Pioneered by the BBC's 1979 *Life on* Earth series (The Guardian, 2009), music has increasingly been used in 'blue-chip' natural history series as program-makers respond to expectations of acoustic design led by broader trends in television and cinema (Collins, 2018). Indeed, both small and big screen productions have a long history of using music to guide audience emotions, with auditory elements such as rhythm, tension, and release helping to support and even drive visual narratives (Douek, 2013). This trend is especially true for natural history programming, where an original orchestral score is considered an implicit marker of quality (Wheatley, 2004) used to stimulate engagement, empathy, and emotions in response to the many forms of nature depicted (Rogers, 2014).

The reason many people engage in experiences that feature music is because of their expected emotional effects, which can occur via several psychological mechanisms (see Eerola & Vuoskoski, 2013; Juslin & Sloboda, 2011; Juslin & Västfjäll, 2008 for comprehensive reviews). For example, much attention has been paid to the neurological pathways through which music can induce affective change, revealing how musical stimulation is linked to the brain regions associated with emotion processing, such as the amygdala and hippocampal formation (Koelsch, 2014). Music can also influence physiological markers linked with affect, such as skin conductance and heart rate (van der Zwaag et al., 2011). But it is retrospective and self-reported measures (commonly employed via single-item Likert scales) that have routinely demonstrated how various genres of music, ranging from classical to electronic, can elicit basic emotions such as calmness and excitement, and more complex feelings like awe (Eerola & Vuoskoski, 2013; Juslin, 2013).

Calmness and excitement are located in the positive half of the affect circumplex (Russell, 1980), a schema that considers typical emotions as comprised of two dimensions: 'valence' describes how unpleasant or pleasurable a state is; and 'arousal' how stimulating the experience is. Under this model, calmness and excitement are both pleasurable emotions, representing low and high arousal states respectively. Each can be elicited by music (van der Zwaag et al., 2011) and also by real and digital natural environments (Newman et al., 2022), depending on the type of experience encountered (Cracknell et al., 2016). Aroused states such as excitement may be particularly important to understand, given their potential to alleviate boredom and low mood in participants (Yeo et al., 2020).

In contrast, the emotional experience of awe is a sparsely researched and complex emotion; it can be fleeting, rare, and straddle the boundary between fear and wonder (Keltner & Haidt, 2003; Sturm et al., 2020). Yet it is gaining increasing interest from multiple fields (Keltner, 2023) and may be a valuable emotion to stimulate due to its potential to confer a range of benefits, including prosocial behavior, reduced rumination, and diminished self-focus (Lopes et al., 2020; Monroy & Keltner, 2022; Piff et al., 2015). Separately, both music and visual forms of nature can be effective elicitors of awe (Silvia et al., 2015), particularly if they possess vast, overwhelming, or unusual qualities (Gordon et al., 2017; Pilgrim et al., 2017). How might these factors interact to stimulate awe-inspiring experiences?

Although the pathways underlying reactions to music and nature may differ (Leaver & Rauschecker, 2010), evidence suggests this area is worthy of further study. For example, music can augment responses to landscapes viewed from a car, which may be rated most highly when 'relaxing' music is heard (Iwamiya, 1997). Others have considered how music can change the aesthetic appraisal of urban settings, particularly those characterized by high levels of traffic noise (Steele et al., 2019) and shown that arousal levels perceived in music might alter how 'active' outdoor environments are considered (Yamasaki et al., 2013) (although see Franěk et al., 2020). Crucially, these studies have also hinted at how culture, memories, and sound might interact to influence landscape encounters (Bull, 2007).

7.1.5 Memories and nostalgia

Memories represent a potent mechanism through which personal experiences can be retained and retrieved (Mills & D'Mello, 2014), a process that is also important for emotional regulation. Episodic recall has demonstrated the ability to stimulate the re-experiencing of affective states (Gillihan et al., 2007; Holland & Kensinger, 2010) and people tend to retrieve memories that foster positive and reduce negative emotions (Buchanan, 2007; Pillemer, 2009), a largely hedonic process associated with increases in optimism, creativity, and resilience (Kensinger & Ford, 2020).

Beyond specific, episodic events, autobiographical memory can also manifest as broader feelings of knowing and familiarity, a more nebulous mnemonic typology that might be relevant to nature-based encounters; since most experiences in nature may not be "imbued with the emotion" necessary for strong memory formation (Holland & Kensinger, 2010), a more cumulative and semantic process may be important.

This 'top-down' processing differs from the 'bottom-up' perceptual framework employed by restorative environment research, where characteristics of a landscape are commonly isolated and examined (Kaplan & Kaplan, 1989). Yet although top-down effects have been demonstrated from a 'favorite places' perspective, where positively toned memories have been associated with increased perceptions of restoration (Ratcliffe & Korpela, 2016, 2017), they are rarely factored into experimental studies. How might memories influence a broader set of affective outcomes triggered by digital nature content?

Music has been highlighted as a powerful cue for memory recall (Belfi et al., 2016), a process associated with a range of positive emotions (Janata et al., 2007; Jäncke, 2008; Lamont, 2011) and exemplified by affective responses to music videos (Dudzik et al., 2020). Involuntary memories (those that occur without a specific prompt) are commonly triggered whilst experiencing this kind of multimedia content (McDonald et al., 2012) and may encourage 'attentional drift' (Dudzik et al., 2020), a positive end-state that is similarly posited by attention restoration theory (Kaplan, 1995). Intriguingly, evidence suggests the role of memories in moderating emotional responses to both visual stimuli and music may be more important than stimulus-specific features such as structure or tempo (Maksimainen et al., 2018), a relationship that might be most pronounced for more complex affective outcomes such as nostalgia (Barrett et al., 2010).

Memories, music, and nostalgia are inextricably linked: memories are an important antecedent to invoking nostalgia (Holak & Havlena, 1998); and nostalgia triggered by music can offer a range of benefits, including a 'buffering' effect from psychological discomfort (Sedikides et al., 2022). Although feelings of nostalgia are a common and powerful outcome from hearing music (Janata et al., 2007), it has received little attention in quantitative people-nature research. Despite its bittersweet connotations, nostalgia is now considered a largely positive emotion with the potential to strengthen prosocial actions, enhance self-esteem, foster meaning in life, and boost inspiration and creativity (Wildschut & Sedikides, 2020). Could nostalgic feelings be triggered by virtual nature experiences, and how might music and memories affect this relationship?

7.1.6 Research questions

We sought to untangle the possible interactions between nature, music, and memories. Specifically, we assessed how a virtual nature experience accompanied by one of four soundtracks (silence, nature sounds, music, nature + music) might impact appraisals of perceived restorative potential and the emotional responses of calmness, excitement, awe, and nostalgia. We also probed how memories might moderate these responses. Our research questions asked:

1. How might the inclusion of natural sounds and music influence the perceived restorative potential of a digital nature experience?

2. Could different soundscape combinations affect the elicitation of low and high arousal positive emotions such as calmness and excitement?

3. Can acoustic design impact the more complex affective responses of awe and nostalgia?

4. How might involuntarily-triggered memories moderate any relationships identified in research questions one to three?

7.2 Methods

We formed *Soundscapes for Wellbeing* to explore these questions, a transdisciplinary and cross-platform BBC initiative. The project launched in January 2021 when the UK was under a strict lockdown, limiting contact between people and restricting direct nature-based experiences (UK Government, 2020). During this time, the ability for natural environments to improve psychological wellbeing was a key theme in public discourse (BBC News, 2020a; The Washington Post, 2020), with digital nature emerging as a novel way for audiences to seek therapeutic gains (Xu et al., 2021).

Soundscapes for Wellbeing was co-created with perspectives from several facets of natural history broadcasting, including nature sound recording, music composition, sound design, and digital animation. This broad initiative engaged audiences in conversations focusing on the links between nature, music, and health, and comprised a range of creative and factual content that aired during a two-week period across radio, television, and online platforms (view extracts at bbc.co.uk/soundscapesforwellbeing). With these debates as context, we encouraged audience participation in an anonymous and randomized online experiment that examined responses to digital nature more systematically.

7.2.1 Experimental design

Our study focused on four experimental conditions. Each condition used the same visual elements, which were then accompanied by either natural sounds, music, a combination of natural sounds and music, or no sounds, as depicted in Table 4. The silent condition arising from this configuration acted as our control, to which the other conditions were compared. Participants experienced one stimulus, selected at random, in a between-participants design.

Table 4. Four experimental conditions were created with varying acoustic compositions. All stimuli used identical visual elements.

	Music = No	Music = Yes
Natural sounds = No	1. No sound	3. Music
Natural sounds = Yes	2. Natural sounds	4. Music and natural sounds

7.2.2 Stimuli

The visual components of our experimental conditions were constructed using the 3D animation software, Nuke and Houdini (Foundry, 2022; SideFX, 2022). They depicted a fictional nature-based view comprised of elements identified as restorative in the existing literature, such as water, foliage, and large amounts of sky (Howley, 2011; Masoudinejad & Hartig, 2018; Pheasant et al., 2010; White et al., 2010). To mimic the engaging experience common in natural history content (Collins, 2018), the non-structural elements of this environment evolved to simulate the diurnal cycle. Using ephemeral features known to elicit significant changes in viewer appraisals (Smalley & White, 2023), this dynamic scene progressed from a striking sunrise through to midday blue skies, before an afternoon thunderstorm formed, which finally gave way to a vibrant sunset (Fig. 24). To enhance both interest and acoustic congruency, several birds also crossed the field of view (White et al., 2017b). The scene was three minutes long.

Figure 24. Still frames depicting key scenes from our visual stimulus.

The acoustic compositions shown in Table 4 were then added to these visuals. To increase ecological validity, we worked with award-winning sound designers and composers, with a depth of experience in creating audio for nature-based programs. The natural soundscape reflected British fauna typical of an inland aquatic environment and varied in line with the changing temporal and visual elements. Acoustic sources included calming elements such as gently flowing water, woodland birds, and crickets, as well as more energetic sounds of waterfowl and sudden claps and rumbles of thunder.

The musical soundscape embraced the ‘wall of sound’ style employed by composers such as Hans Zimmer (Collins, 2018). As with the natural sounds, this bespoke composition was carefully designed to match the visual scene and featured both electronic and classical styles. The score responded to cues in the evolution of the environment: moments of energy and excitement were reflected in a gradually building crescendo as the thunderstorm reached its peak; and these were balanced with moments of calm at sunrise and a gradual diminuendo as the sun set. The score used changing rhythm and dynamics to convey power and release (Douek, 2013) over a relatively short period of time. These kinds of variations can be important precursors to emotional stimulation (Maksimainen et al., 2018), and our music was designed to trigger both high and low arousal responses.

Our natural and musical soundtracks were co-created to stand alone and work together, allowing their seamless integration in the combined nature and music soundscape. This fourth condition featured the exact soundtracks used in conditions two and three, professionally blended to form a single mix.

Since one of our key variables centered on participant memories, the creation of unique visual and acoustic stimuli prevented people referencing direct memories elicited by our experimental stimuli, instead aiming to trigger more generalized associations gained from a broad range of previous experiences. The final conditions were formatted as HD (1080 x 1920) videos and can be watched in full at https://vimeo.com/showcase/9877045.

7.2.3 Experimental procedure

Ethical approval was provided by the University of Exeter's College of Medicine and Health research ethics committee (ref 20/11/267). The experiment was launched in January 2021, hosted by survey platform Qualtrics, and made publicly available. Participation was advertised as part of *Soundscapes for Wellbeing* features on BBC radio, TV, and online platforms. Upon clicking the advertised online link, participants were directed to an information sheet and consent form (Appendix C). Once online consent had been granted, respondents conducted a brief audio-visual check to ensure they could see and hear the experimental content. They were then randomly allocated to one of our four video conditions. They were asked to focus on the content as it played, watch it from start to finish, and reflect on the emotions they felt. Participants then responded to a series of questions about the experience (section 7.2.5), their interests, and demographic characteristics. The full experimental instrument is available on the Open Science Framework, https://doi.org/10.17605/OSF.IO/F3JQB.

7.2.4 Participants

Due to our open recruitment method and the exploratory nature of our research questions, we used precedents in the existing literature to define our recruitment targets, rather than formal power analyses. Previous studies quantifying responses to nature and music-based content have detected inter-stimulus differences in emotions and psychological restoration in samples of between 16 and 50 participants (Juslin et al., 2015; Lindal & Hartig, 2013; White et al., 2010). Since our conditions were all likely to be positively rated, we considered these sample sizes as a lower bound, instead aiming for at least 400 respondents (100 per condition).

Between January and May 2021, a total of 8,752 people completed the experiment, far exceeding our minimum required sample. To minimize the possible impact of participation from automated bots and practices such as ‘ballot stuffing’ (Griffin et al., 2022), we took several steps: the Qualtrics system prevented multiple submissions from the same participant; the experiment was not indexed by search engines (Xu et al., 2022); and no remuneration was provided to respondents. As an additional measure, those who completed the experiment in less than four minutes (n = 593) or more than 30 minutes (n = 470), were excluded from analyses based on feasible completion times determined from pilot testing.

This provided a final sample of 7,636 participants. Two-thirds of respondents were female (67%), just under a third were male (31%), and 0.5% (38) identified as non-binary. Those aged 18 to 35 represented 18% of our sample, whilst people aged 36 to 55 and 56 to 76 accounted for 40% and 38% of participants respectively (additional characteristics are reported in Table S13, Appendix C). There were no systematic differences in age and gender between conditions and these factors were not included as covariates in analyses (Table 5).

Table 5. Characteristics of study participants, split by experimental condition.

		Experimental condition				
Variable	N	Silence, N = 1,864[1]	Nature, N = 1,930[1]	Music, N = 1,889[1]	Combined, N = 1,953[1]	p-value[2]
Age	7,636					0.7
18 - 25		109 (5.8%)	105 (5.4%)	108 (5.7%)	108 (5.5%)	
26 - 35		218 (12%)	266 (14%)	221 (12%)	232 (12%)	
36 - 45		282 (15%)	283 (15%)	302 (16%)	301 (15%)	
46 - 55		474 (25%)	502 (26%)	445 (24%)	506 (26%)	
56 - 65		473 (25%)	458 (24%)	467 (25%)	449 (23%)	
66 - 75		246 (13%)	257 (13%)	272 (14%)	282 (14%)	
76+		49 (2.6%)	45 (2.3%)	61 (3.2%)	59 (3.0%)	
No answer		13 (0.7%)	14 (0.7%)	13 (0.7%)	16 (0.8%)	
Gender	7,550					0.9
Female		1,253 (68%)	1,280 (67%)	1,272 (68%)	1,325 (69%)	
Male		585 (32%)	616 (32%)	584 (31%)	597 (31%)	
Non-binary		12 (0.6%)	9 (0.5%)	7 (0.4%)	10 (0.5%)	

[1]n (%); [2]Pearson's Chi-squared test. Varying Ns are due to missing data; demographic questions were not mandatory.

7.2.5 Measures

Participants were asked to rate their experience according to a series of dependent measures. Question phrasing followed extensive piloting with the University of Exeter's Health and Environment Public Engagement group (see Table S1, Appendix C, for correlations between dependent variables).

7.2.5.1 Perceived restorative potential

Perceived restorative potential requires participants to evaluate how restorative they think an experience would be. It is typically based on several underlying constructs, evaluated through a complex multi-item scale (Hartig et al., 1997a). To reduce participant burden in our brief online experiment, we adapted existing single-item measures of these constructs (Hartig et al., 1997b; Pasini et al., 2014; Payne, 2013). Each item, listed in Table 6, focused on the specific video experience, with responses measured on a 10-point scale from "Not at all" to "Completely". Items were collapsed to form a single measure of perceived restorative potential ($\alpha = 0.79$).

Table 6. Items and phrasing for the components of perceived restorative potential.

Item	**Item phrasing**
Fascination	*The video was fascinating; it had interesting features and held my attention.*
Being away	*The video gave me a break from my routine and helped me feel away from everyday thoughts and concerns.*
Coherence	*There was too much going on in the video.* (Reverse coded before collapsing.)
Extent	*The video gave me a feeling of scale and showed a place large enough to be explored.*
Compatibility	*The video suited my personality and preferences.*

7.2.5.2 Emotional responses

Measures for calmness and excitement (Russell, 1980), as well as the more complex emotions of awe and nostalgia were adapted from nature-based (Bowler et al., 2010), music-based (Juslin et al., 2015), and broader psychological research (Pollock et al., 1979; Watson et al., 1988b; Zuckerman, 1977b). To accommodate variations in these emotions across the experience, participants were primed with the text "*First, we would like to ask you about your emotions during the video, which could have varied at different points.*" Items were worded so that respondents reflected on the emotions they personally experienced, rather than those they might have perceived in the music (Eerola & Vuoskoski, 2013). Participants were asked "*How much did you experience the following emotions?*" with "*Calm*", "*Excited*", "*Awe*" and "*Nostalgic*" provided as specific emotional states. Responses were measured on a 10-point scale from "*Not at all*" to "*A lot*".

7.2.5.3 Memories

Autobiographical memories are commonly elicited in laboratory studies by asking individuals to report specific personal episodes or narratives (Holland & Kensinger, 2010). However, these approaches lead to the *intentional* recall of a memory. Since our investigation was focused on involuntary memories and their valence, our approach captured participant memories *after* the video, asking:

"*Did the video trigger any memories? If so, were they positive, negative, or mixed?*"
Response options were: "*No memories*"; "*Mostly positive memories*"; "*Mostly negative memories*"; "*A mix of positive and negative memories*".

This method aimed to prevent 'priming' respondents to retrieve a specific experience, instead capturing memories related to broader, semantic recall; an approach used in other studies assessing the influence of memories on emotional responses to online videos (Dudzik et al., 2020).

7.2.5.4 Items not explored here

Additional measures beyond the scope of the current paper included aesthetic appraisals and self-reported physiological reactions (see the full experimental instrument for all items, available at https://doi.org/10.17605/OSF.IO/F3JQB). Negative emotions were also captured in this list and included the low and high arousal responses of boredom and anxiety, and a generalized feeling of sadness. Preliminary analyses suggested low stimulation of these emotions, with little variance and floor effects resulting in poor model fit (Table S2, Appendix C). Consequently, these items were not explored further.

7.2.6 Statistical analyses

To answer research questions one, two, and three, we created a series of linear regression models in the statistical software R (R Core Team, 2021), with our 'silent' stimulus set as the reference condition. To address research question four, we first assessed the main effects of memories by combining responses from all four experimental conditions and setting memory type (none, positive, negative, mixed) as our independent variable. Since positive memories tend to be those most often recalled and used for affect regulation (Buchanan, 2007; Kensinger & Ford, 2020; Pillemer, 2009), we then focused solely on those who had positive memories triggered by our stimuli compared to those reporting no memories. This binary memory variable was added as a moderator to the models used in research questions one, two, and three.

To retain relevance to the original scales, unstandardised coefficients have been reported throughout. Data for our dependent variables were slightly skewed but our methodologies were robust to minor deviations in normality and our large sample size enabled multivariate analysis to remain appropriate (Lumley et al., 2002), an approach taken by studies with similar sample sizes (e.g. Martin et al., 2020). Where fitted values and pairwise comparisons are presented, the Tukey method was applied to control for a potentially high family-wise error rate. The full dataset is available at https://doi.org/10.17605/OSF.IO/F3JQB.

7.3 Results

7.3.1 Restoration and simple affective responses

Starting with research questions one and two, adding natural sounds to our digital nature experience led to consistent increases in feelings of perceived restorative potential (B = 0.47, CIs = 0.35, 0.59, p <0.001), calmness (B = 0.70, CIs = 0.57, 0.83, p <0.001), and excitement (B = 0.53, CIs = 0.38, 0.68, p <0.001) compared to the silent control condition. However, the addition of music led to contrasting outcomes. Compared to silence, the music condition led to no change in appraisals of restorative potential (B = -0.09, CIs = -0.21, 0.03, p = 0.13), *decreased* feelings of calmness (B = -0.20, CIs = -0.33, -0.07, p = 0.003), and *increased* feelings of excitement (B = 0.80, CIs = 0.65, 0.95, p <0.001).

In general, ratings for our combined condition (featuring both natural sounds and music) were between those for the natural sounds-only and music-only conditions. Compared to silence, the combined condition led to a significant yet smaller increase in perceived restorative potential (B = 0.25, CIs = 0.13, 0.37, p <0.001) than for natural sounds alone. Feelings of calmness were greater (B = 0.33, CIs = 0.20, 0.47, p <0.001) but less so than for natural sounds alone, and excitement also increased compared to silence (B = 0.74, CIs = 0.60, 0.89, p <0.001) but to a lesser extent than in the music-only condition. Table 7 reports the unstandardised coefficients from each baseline model with our three dependent variables sequentially set as target outcomes, results are visualized in Fig. 25.

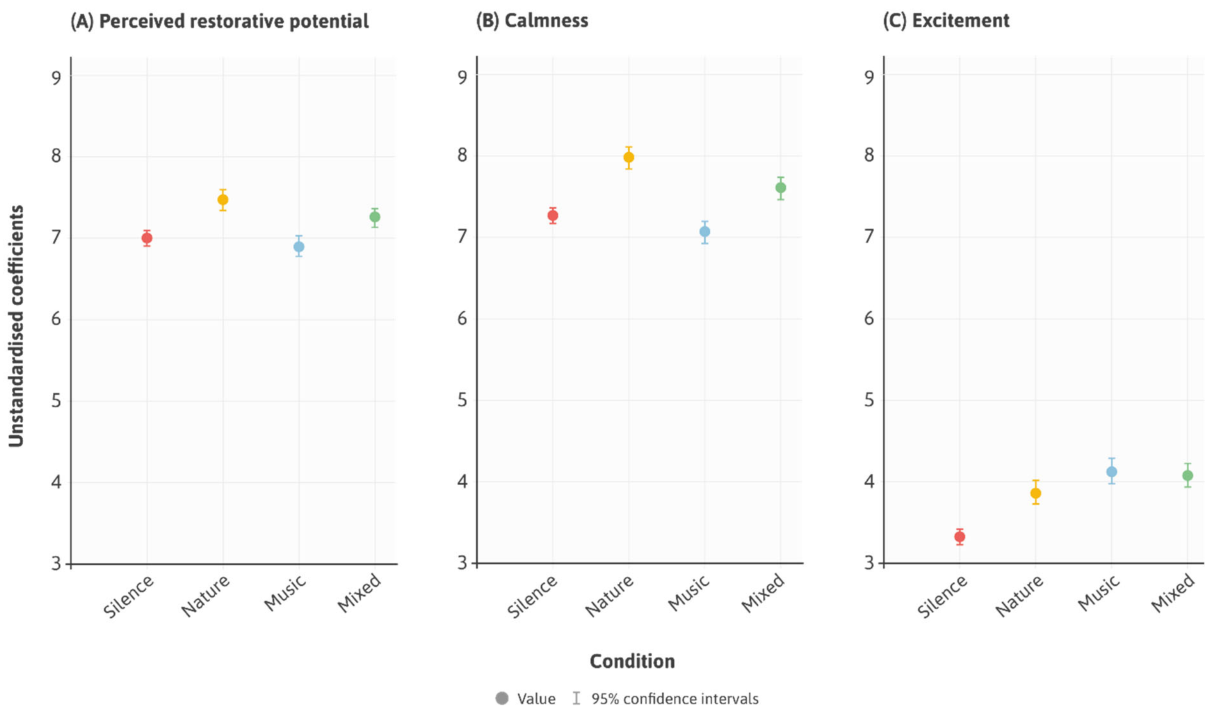
Table 7. Unstandardised coefficients from our baseline models with perceived restorative potential, calmness, and excitement as dependent variables and the silent condition as reference. Adjusted R^2 is also shown.

	DV = PRP[1]			DV = Calmness			DV = Excitement		
Characteristic	**Beta**	**95% CI[2]**	**p-value**	**Beta**	**95% CI[2]**	**p-value**	**Beta**	**95% CI[2]**	**p-value**
(Intercept)	6.99	6.91, 7.08	<0.001	7.27	7.18, 7.37	<0.001	3.32	3.22, 3.43	<0.001
Condition									
Silence	—	—	—	—	—	—	—	—	—
Nature	0.47	0.35, 0.59	<0.001	0.70	0.57, 0.83	<0.001	0.53	0.38, 0.68	<0.001
Music	-0.09	-0.21, 0.03	0.13	-0.20	-0.33, -0.07	0.003	0.80	0.65, 0.95	<0.001
Combined	0.25	0.13, 0.37	<0.001	0.33	0.20, 0.47	<0.001	0.74	0.60, 0.89	<0.001
Model fit	$R^2 = 0.013$ $F(3, 7632) = 35.29$, $p = <0.001$			$R^2 = 0.026$ $F(3, 7632) = 69.47$, $p = <0.001$			$R^2 = 0.017$ $F(3, 7632) = 46.08$, p = <0.001		

[1]PRP = Perceived restorative potential

[2]CI = Confidence Interval

Figure 25. Coefficients from Table 7 plotted according to the dependent variable. Betas have been added to the intercept to aid interpretation. The y-axes represent a range capturing all variation across conditions. 95% confidence intervals are also shown.



7.3.2 Awe and nostalgia

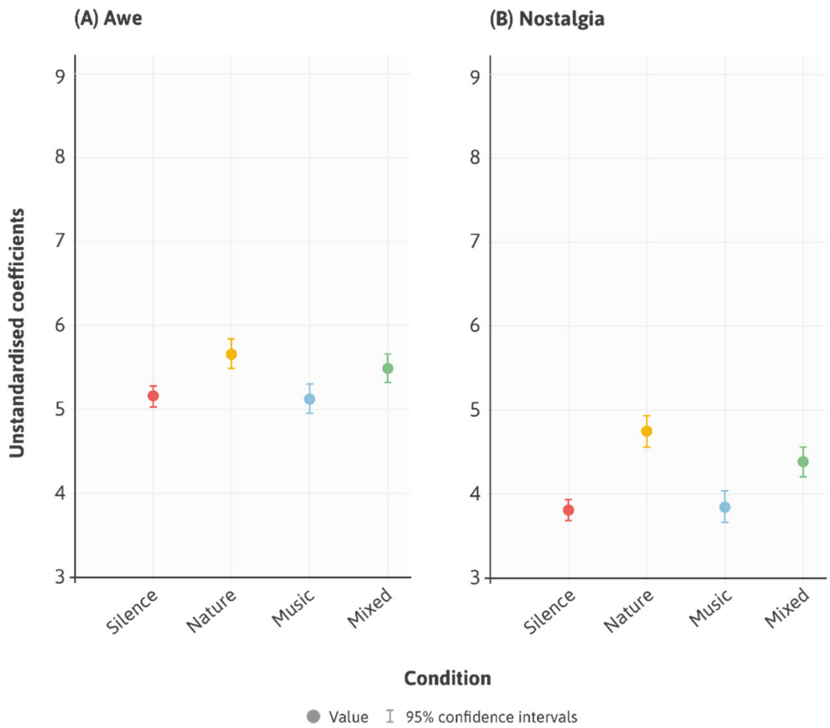
To address research question three, awe and nostalgia were set as dependent variables in our baseline model (Table 8 and Fig. 26). Compared to silence, the natural sounds condition increased feelings of both awe (B = 0.50, CIs = 0.32, 0.67, p <0.001) and nostalgia (B = 0.93, CIs = 0.75, 1.12, p <0.001), with the latter increase representing a gain of almost one scale point. Adding music to our experience led to no increase in either outcome. But again, the combined nature and music condition was associated with modest positive effects for awe (B = 0.32, CIs = 0.14, 0.50, p <0.001) and nostalgia (B = 0.57, CIs = 0.39, 0.75, p <0.001).

Table 8. Unstandardised coefficients from our baseline models with awe and nostalgia as dependent variables and the silent condition as reference. Adjusted R^2 is also shown.

	DV = Awe			DV = Nostalgia		
Characteristic	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**
(Intercept)	5.17	5.04, 5.29	<0.001	3.81	3.68, 3.94	<0.001
Condition						
Silence	—	—		—	—	
Nature	0.50	0.32, 0.67	<0.001	0.93	0.75, 1.12	<0.001
Music	-0.04	-0.21, 0.14	0.7	0.04	-0.15, 0.22	0.7
Combined	0.32	0.14, 0.50	<0.001	0.57	0.39, 0.75	<0.001
Model fit	R^2 = 0.006 F(3, 7632) = 16.21, p = <0.001			R^2 = 0.017 F(3, 7632) = 47.05, p = <0.001		

[1]CI = Confidence Interval

Figure 26. Coefficients from Table 8 plotted according to the dependent variable. Betas have been added to the intercept to aid interpretation. The y-axes represent a range capturing all variation across conditions. 95% confidence intervals are also shown.



7.3.3 Main effect of memories

To explore our fourth research question, we began by focusing on the main effect of memories, collapsing responses across conditions to assess how the valence of recalled experiences might impact our dependent variables (Table 9 and Fig. 27).

Positive memories were associated with universal increases across all dependent variables, compared to no memories. At roughly one scale point, this effect was smallest for feelings of excitement (B = 1.05, CIs = 0.93, 1.17, p <0.001), and at almost three scale points, largest for nostalgia (B = 2.77, CIs = 2.63, 2.90, p <0.001).

Those with negative memories triggered by our digital encounters reported substantially lower appraisals of perceived restorative potential (B = -1.42, CIs = -1.96, -0.89, p <0.001), calmness (B = -2.33, CIs = -2.93, -1.72, p <0.001), and awe (B = -0.83, CIs = -1.64, -0.01, p = 0.047), compared to those with no memories. In contrast, participants with negative memories tended to report *higher* levels of nostalgia (B = 1.39, CIs = 0.60, 2.18, p <0.001), than those with no memories. No significant trend existed for feelings of excitement (B = -0.53, CIs = -1.23, 0.16, p = 0.13).

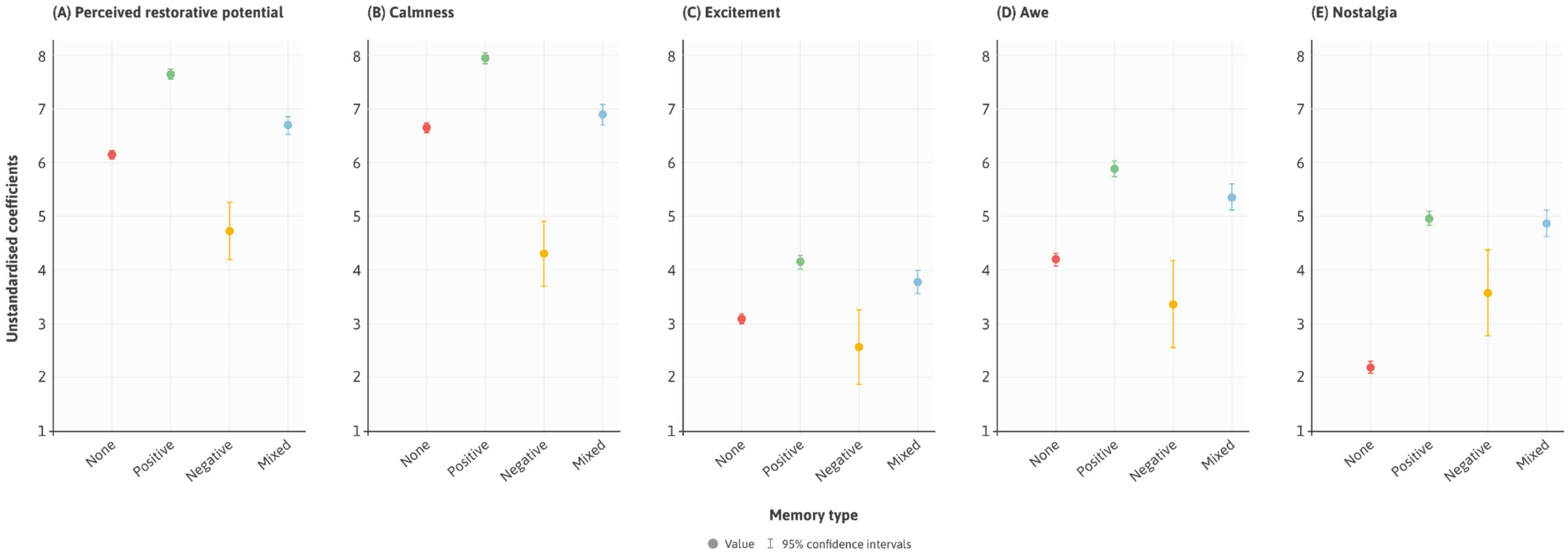
Mixed memories were associated with increases across each of our outcome variables, but consistent with effects arising from experiences with conflicting valence, these were not as large as for positive memories alone. Once again, the exception was for feelings of nostalgia, where mixed memories led to an increase in this emotion (B = 2.68, CIs = 2.44, 2.91, p <0.001) similar to that for positive memories (B = 2.77, CIs = 2.63, 2.90, p <0.001).

Table 9. Unstandardised coefficients from each baseline model collapsed across experimental conditions, with memories = "none" set as the reference condition. Participant numbers for each memory group are also shown.

	DV = PRP			DV = Calmness			DV = Excitement			DV = Awe			DV = Nostalgia		
Characteristic	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**
(Intercept)	6.16	6.08, 6.23	<0.001	6.65	6.57, 6.74	<0.001	3.11	3.02, 3.21	<0.001	4.20	4.08, 4.31	<0.001	2.19	2.08, 2.31	<0.001
Memories															
None (n = 2068)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Positive (n = 4916)	1.50	1.41, 1.59	<0.001	1.29	1.18, 1.39	<0.001	1.05	0.93, 1.17	<0.001	1.68	1.54, 1.82	<0.001	2.77	2.63, 2.90	<0.001
Negative (n =43)	-1.42	-1.96, -0.89	<0.001	-2.33	-2.93, -1.72	<0.001	-0.53	-1.23, 0.16	0.13	-0.83	-1.64, -0.01	0.047	1.39	0.60, 2.18	<0.001
Mixed (n = 609)	0.54	0.38, 0.69	<0.001	0.24	0.06, 0.42	0.009	0.68	0.48, 0.89	<0.001	1.16	0.92, 1.40	<0.001	2.68	2.44, 2.91	<0.001
Model fit	$R^2 = 0.135$ F(3, 7632) = 396.8, *p* <0.001			$R^2 = 0.090$ F(3, 7632) = 255.7, *p* <0.001			$R^2 = 0.040$ F(3, 7632) = 106.2, *p* <0.001			$R^2 = 0.071$ F(3, 7632) = 195.9, *p* <0.001			$R^2 = 0.180$ F(3, 7632) = 559.9, *p* <0.001		

[1]CI = Confidence Interval

Figure 27. Coefficients from Table 9 plotted according to the dependent variable. Betas have been added to the intercept to aid interpretation. The y-axis represents a range capturing all variation across conditions. 95% confidence intervals are also shown.



7.3.4 Moderation by memories

Next, we considered how memories might moderate the relationships between experimental conditions and dependent variables. As outlined in section 7.2.6, we focused our analyses on those who had positive memories triggered by our stimuli (n = 4916) and compared this group to those reporting no memories (n = 2068).

As detailed in section 7.3.3, the main effect of positive memories was evident across all conditions and dependent variables (Table 10). Interactions were significant between memories and condition for restorative potential, where positive memories were associated with a divergence in ratings in the music (*B* = 0.33, CIs = 0.08, 0.57, *p* = 0.009) and combined conditions (*B* = 0.40, CIs = 0.15, 0.65, *p* = 0.002) compared to those not reporting any memories. No interaction effects existed for calmness and awe, but positive memories in the music condition were associated with a pronounced increase in ratings of excitement (*B* = 0.46, CIs = 0.14, 0.78, *p* = 0.005), and greater feelings of nostalgia in the combined condition (*B* = 0.37, CIs = 0.00, 0.75, *p* = 0.050).

In short, positive memories did not affect all outcomes equally across conditions and fitting estimated marginal means revealed further differences (Fig. 28 and Fig. 29, see Tables S3-S12 in Appendix C for tabulated values and contrasts). For example, when considering feelings of excitement, those with positive memories in the nature sounds condition rated their experience close to one scale point higher than those with no memories (M_{DIFF} = 0.84, CIs = 0.44, 1.24, *p* <0.001). Yet in the music condition, this increase was 60% greater (M_{DIFF} = 1.35, CIs = 1.00, 1.69, *p* <0.001). Focusing on awe, those with no memories experienced a drop in this emotion between the nature and music conditions of 0.64 scale points (M_{DIFF} = 0.64, CIs = 0.11, 1.16, *p* = 0.006), whilst those with positive memories experienced no significant fall (M_{DIFF} = 0.21, CIs = 0.54, 1.90, *p* = 0.554).

Table 10. Unstandardised coefficients for all outcome models according to condition and memories, the latter grouping was based on a subset of our sample and included those reporting either no memories or positive memories. Interactions are depicted by *Condition*Memories*.

	DV = PRP			DV = Calmness			DV = Excitement			DV = Awe			DV = Nostalgia		
Characteristic	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**
(Intercept)	6.22	6.08, 6.37	<0.001	6.56	6.40, 6.72	<0.001	2.72	2.53, 2.91	<0.001	4.12	3.90, 4.34	<0.001	2.06	1.85, 2.27	<0.001
Condition															
Silence	—	—		—	—		—	—		—	—		—	—	
Nature	0.22	0.00, 0.45	0.049	0.66	0.41, 0.91	<0.001	0.49	0.20, 0.79	0.001	0.53	0.18, 0.87	0.003	0.40	0.07, 0.73	0.019
Music	-0.27	-0.47, -0.07	0.007	-0.25	-0.47, -0.03	0.028	0.56	0.30, 0.81	<0.001	-0.11	-0.42, 0.19	0.5	0.12	-0.17, 0.41	0.4
Combined	-0.12	-0.33, 0.09	0.3	0.21	-0.03, 0.45	0.085	0.57	0.30, 0.85	<0.001	0.07	-0.26, 0.40	0.7	0.12	-0.20, 0.43	0.5
Memories															
None (n = 2068)	—	—		—	—		—	—		—	—		—	—	
Positive (n = 4916)	1.25	1.08, 1.43	<0.001	1.20	1.00, 1.39	<0.001	0.88	0.65, 1.11	<0.001	1.59	1.32, 1.86	<0.001	2.56	2.30, 2.82	<0.001
Condition * Memories															
Nature * Positive	0.11	-0.15, 0.37	0.4	-0.12	-0.42, 0.17	0.4	-0.05	-0.39, 0.30	0.8	-0.26	-0.67, 0.14	0.2	0.28	-0.11, 0.67	0.2
Music * Positive	0.33	0.08, 0.57	0.009	0.12	-0.16, 0.39	0.4	0.46	0.14, 0.78	0.005	0.17	-0.21, 0.55	0.4	-0.03	-0.39, 0.34	0.9
Combined * Positive	0.40	0.15, 0.65	0.002	0.03	-0.25, 0.31	0.8	0.22	-0.11, 0.55	0.2	0.25	-0.14, 0.64	0.2	0.37	0.00, 0.75	0.050
Model fit	R^2 = 0.140 F(7, 6976) = 163.6, *p* = <0.001			R^2 = 0.098 F(7, 6976) = 109.5, *p* = <0.001			R^2 = 0.061 F(7, 6976) = 66.36, *p* = <0.001			R^2 = 0.077 F(7, 6976) = 85.04, *p* = <0.001			R^2 = 0.199 F(7, 6976) = 249.0, *p* = <0.001		

[1]CI = Confidence Interval

Figure 28. Fitted values for the models listed in Table 10. Tabulated values can be found in Appendix C. Confidence intervals (95%) are also shown.

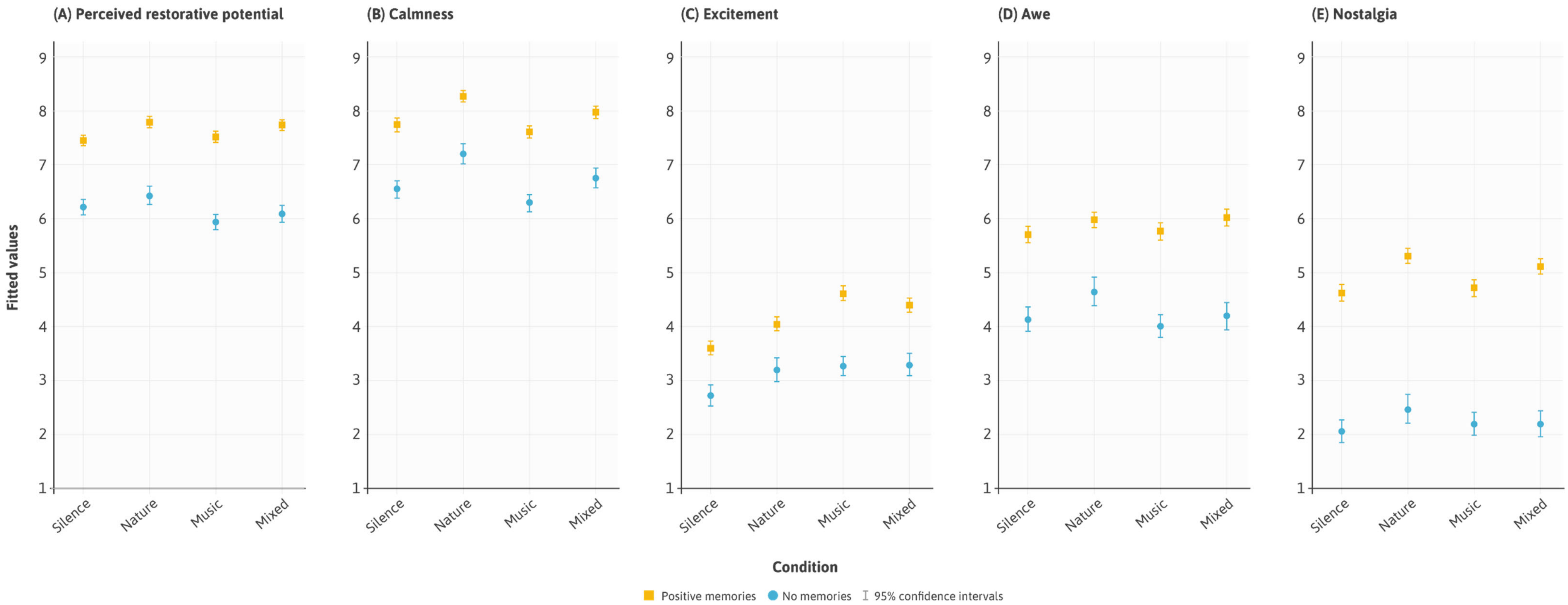
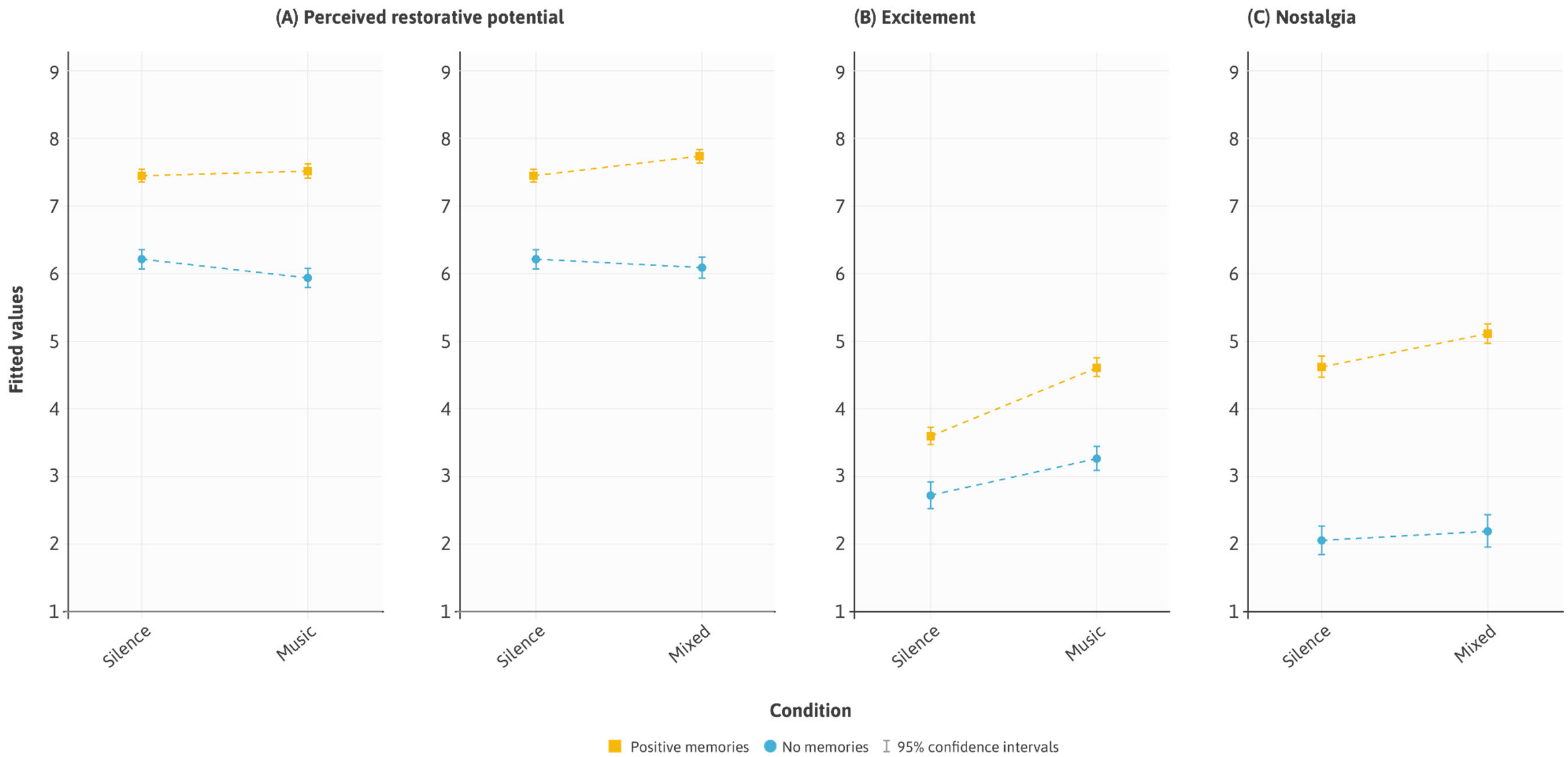


Figure 29. Fitted values for the models listed in Table 10, but with only values displayed where a significant interaction existed between condition and memory. Confidence intervals (95%) are also shown.



7.4 Discussion

Millions of people regularly experience nature through digital content that features a mix of natural sights, sounds, and music. We explored how the acoustic design of these encounters can affect several psychological outcomes. We also sought to quantify how participant memories could moderate these relationships.

7.4.1 Findings

Supporting previous research (Ferraro et al., 2020; Gan et al., 2014; Ratcliffe, 2021a), adding natural sounds to our digital scene enhanced participant evaluations of calmness, excitement, and perceived restorative potential, compared to the same scene without any sound. Our results also revealed the novel finding that natural sounds could impact feelings of awe and nostalgia, with their addition leading to significant increases in these emotions compared to the same visual stimulus with no sounds.

The inclusion of music in our scene was associated with greater feelings of excitement (where it was the highest rated condition for this outcome), lower levels of calmness, and no significant change in restorative potential, awe, or nostalgia, compared to the silent control. Our combined condition, created by blending both natural sounds and music, demonstrated moderately positive effects: it was rated roughly midway between the nature-only and music-only conditions for each dependent variable.

Participant memories were associated with substantial changes in how our stimuli were appraised. In general, those with negative memories experienced lower levels of perceived restoration, calmness, and awe, compared to those with no memories. Yet negative memories led to *increases* in nostalgia, reflecting the bittersweet connotations of this complex emotion. Positive memories were the most common form of memory triggered in participants and were associated with substantially higher ratings for all outcome variables, compared to those with no memories. This relationship was remarkably consistent across each of our experimental conditions. However, we did detect some modest interaction effects. Compared to those with no memories, positive memories enhanced feelings of excitement to a greater extent in the music condition and led to greater feelings of nostalgia in the combined condition. For restorative potential, interactions widened the gap between memory groups in the music and mixed condition.

Importantly, the effects of memories on our dependent variables were substantially greater than those arising from changes in experimental condition. In our complex model (in which both condition, positive memories, and their interactions were considered) coefficients for the effects of condition were well under 1 for all outcomes. For memories, they ranged from just under 1 to over 2.5.

7.4.2 Implications

Feelings of awe and nostalgia have been associated with a host of positive outcomes, including prosocial behavior, creativity, and self-esteem (Piff et al., 2015; Sturm et al., 2020; Wildschut & Sedikides, 2020). Our analyses are some of the first to demonstrate that adding natural sounds to a virtual environment could enhance these complex emotions.

Whilst nostalgia is recognized as a common response in music and emotion research, it has been largely neglected in the nature restoration literature. Manifesting as a powerful emotion associated with happiness, love, and emotional warmth (Zhou et al., 2012), digital forms of nature, especially those featuring natural sounds, may represent an exciting new pathway through which this emotion can be stimulated. Moreover, the triggers of awe are commonly approached from a visual perspective in person-nature interactions (Chirico et al., 2018), yet our findings suggest natural sounds might also modulate the stimulation of this increasingly researched emotion (Keltner, 2023). In addition to wellbeing outcomes, feelings of awe may contribute to further benefits, perhaps motivating audiences to engage in pro-social behaviors (Piff et al., 2015). These results suggest there may be merit in moving beyond more generalized appraisals of positive and negative affect in virtual nature encounters (McMahan & Estes, 2015). Acknowledging the depth of emotions that can be stimulated by these experiences may add to the value associated with both their production and consumption.

Extending recent findings (Smalley et al., 2022), the moderating effects of memories on our restorative and emotional outcomes were profound. The potential impacts of top-down processing on restoration have previously been identified (Ratcliffe & Korpela, 2016), and we widen these findings to quantify associations across a range of affective indices. Importantly, these effects outweighed those attributable to our experimental design, suggesting that solely bottom-up approaches to nature-based encounters, in which components of an experience external to the individual are compartmentalized and assessed, might only explain a small proportion of the variation seen in participant responses.

Yet we also observed intriguing patterns related to our changing acoustic stimuli. Natural sounds were particularly well received by participants, a finding that corroborates existing work (Ratcliffe, 2021a) and underlines the importance of multi-sensory depictions of nature (Lindquist et al., 2020). In contrast, we did not find the same positive effects for music. Notably, although music can be a powerful trigger of nostalgia, this relationship was absent from our data. However, these effects are commonly attributed to songs that reflect a particular point in a person’s life (Janata et al., 2007) and our use of an original score may have impeded this particular mechanism.

Our music condition did lead to significant increases in feelings of excitement, a relationship that might be explained by the activation of mechanisms proposed by Juslin and Västfjäll (2008). For example, in places our score featured an allegro tempo, which may have caused participants to synchronize their internal bodily rhythm with the music through a process of ‘rhythmic entrainment’. Similarly, as our scene evolved to portray a growing thunderstorm, participants may have experienced ‘emotional contagion’, perceiving energy and excitement expressed by the music and consequently adopting those emotions. Powerful scores are a mainstay of modern nature programming and these effects may help to energize and engage audiences (Wheatley, 2004), an outcome of particular benefit to those who may be suffering from boredom and under stimulation (Yeo et al., 2020).

However, since we included only one type of music in our study, we must be cautious about generalizing these findings to other genres. Compositions featuring a blend of natural sounds and music are immensely popular on digital platforms such as YouTube and Spotify (Endel, 2022a), accumulating well over 100 million plays in some cases (YouTube, 2018). Indeed, moderately positive effects associated with our fourth, combined condition, suggest creative mixes of music and nature may still facilitate increases in affective indicators – but our results also suggest these effects may be more nuanced than previously assumed.

This study was conducted in the middle of a global pandemic, when many public parks were closed (Volenec et al., 2021). Webcams, still images, and virtual reality, became familiar ways to experience nature during this time, an indirect form of contact that was associated with wellbeing gains (Jarratt, 2021; Kaplan Mintz et al., 2021; Kolbe et al., 2021). These encounters represent an increasingly important way in which people interact with the natural world (Searle et al., 2022) and broadcasters are already responding to this demand (BBC Four, 2020). In one recent example, the BBC’s popular *Winterwatch* series launched two-minute ‘Mindfulness Moments’ aiming to help people “*...switch off from the stresses of our busy lives and immerse ourselves in pure nature*” (BBC Two, 2022). Our results might contribute to an evidence-based approach in these endeavors, but they also highlight a point of friction.

Research focusing on virtual representations of nature often seeks to replicate effects seen in ‘real’ experiences (Chirico & Gaggioli, 2019; Newman et al., 2022). But digitally mediated contact with the natural world may be more appropriately considered as a unique typology (Bates et al., 2020). Indeed, our experimental conditions were constructed using computer graphics, digitally conveyed online, and incorporated music, reflecting an increasingly curated version of virtual nature synonymous with ‘Wilderness 2.0’ (Stinson, 2017). Some have voiced concern that this kind of ‘hyper-real’ experience might diminish connections to more ‘normal’, nearby nature (Krieger, 1973; Levi & Kocher, 1999). How expectations derived from virtual nature might promote or detract from direct encounters with natural environments, and how these could relate to other creative interpretations of nature (Ahn et al., 2016; flow-mer.org, 2022; Schonberg, 2019), including those created by artificial intelligence (Endel, 2022b), are areas requiring urgent investigation.

7.4.3 Limitations

Whilst the size of our sample provided the sensitivity necessary to detect small inter-stimulus differences, participants were self-selecting and did not reflect national demographic characteristics (ONS, 2019). Our sample tended to be older, more female, and less ethnically diverse than UK averages, meaning we were unable to generalize our findings to wider population groups and cultures (Henrich et al., 2010). We used the latest digital techniques to create strictly controlled experimental conditions. Yet they did not feature the narrative or innovative camera work common in much natural history content; how findings might apply to other digital forms of nature is thus unknown. Similarly, our musical composition, created specifically for this experiment by an experienced composer, represented just one possible score and in line with those accompanying nature documentaries, varied throughout its duration. We do not know how music with differing characteristics might have been received.

Our use of original audio-visual stimuli aimed to prevent people having direct memories of the scene and sounds depicted, instead eliciting more general recall of memories formed throughout the life course. However, we could not use novel natural sounds and our inclusion of species such as blackbirds and skylarks may have triggered specific memories. Moreover, the online format of our study meant we could not measure actual recovery of attentional resources, instead relying on participant perceptions. As such and given the dearth of literature investigating the combination of nature and music, this study should be viewed as both preliminary and exploratory. Further work might seek to examine how responses to specific acoustic cues vary in real time, using physiological outcomes under laboratory conditions (Johnson et al., 2021), and employ emerging technology, such as spatial audio.

We must also acknowledge that many people feel no emotion at all in response to music, with large differences between individuals (Juslin, 2013). We could not account for this heterogeneity in our analyses, and we do not know how prevalent a lack of emotional response may be to nature-based sounds. Importantly, quantitative analyses can only reveal part of the complex relationships that exist between people and nature. As part of the BBC *Soundscapes for Wellbeing* project, the authors received several hundred emails from participants and audience members containing personal reflections on how digital forms of nature were being used therapeutically. Although ethical constraints prevented their inclusion in the analyses reported here, these insights may provide vital qualitative context to the patterns we observed. Mixed-methods approaches could be an important way to approach further work in this area.

7.4.4 Conclusions

Across a range of devices, digital environments are currently being designed to harness nature's therapeutic potential (e.g. Portal.app, 2022; Sphaeres VR, 2023), as well as engage, educate, and reconnect people with the natural world (Litleskare et al., 2020). Fostering a deeper knowledge of how this burgeoning content can impact audience outcomes is vital to its successful development. In this pursuit, acoustic design has been described as a "*musical alchemy, pouring rarified ingredients…into a bubbling cocktail of pitches, patterns, modes and memories*" (Douek, 2013). When it comes to nature, our findings suggest that memories might be the crucial ingredient in this cocktail, with significant impacts for emotional and restorative experiences alike.

7.4.5 CRediT author contributions

Conceptualization: AJS, MPW, RS, ND, CW, NS, JT, LS.
Methodology: AJS, MPW, LS.
Investigation: AJS.
Visualization: AJS.
Supervision: MPW, LEF.
Writing—original draft: AJS.
Writing—review & editing: MPW, LEF, LS.

[End of published content]

8. General conclusions

In 2018, this PhD set out to understand more about how digital experiences of nature might be optimised for wellbeing outcomes. Its initial, overarching aim was to investigate areas that had been overlooked in the existing literature, but by collaborating with the UK's largest broadcaster and building teams with broad transdisciplinary backgrounds, specific areas of research responded to editorial and academic lacunae alike. Through a series of novel, creative, and multi-format initiatives, we engaged diverse audiences in debates surrounding environmental degradation, wellbeing, and digital mediation, and generated large, heterogeneous datasets. The trajectory of this research was substantially altered by the Covid-19 pandemic, yet responding to this unprecedented event created as many opportunities as it removed, particularly with respect to the partnerships forged.

Since experimental outcomes have already been summarised as part of the published papers presented in chapters 5, 6, 7, to avoid repetition for the reader a summary of results has not been reiterated here. Instead, the following discussion will centre on how findings relate to and build on the existing body of people-nature literature.

8.1 Relevance and implications

A principal focus of this thesis was the unexplored ways in which acoustic factors might augment outcomes from digital nature experiences, and this discussion first explores the relevance of findings relating to natural sounds, poetry, and music. The discussion of results overlaps with those presented in the published versions of each study and therefore avoids simply re-stating the implications presented there, instead offering additional perspectives that were omitted due to word limits. So, following five years of collaborative enquiry, how have we contributed to the field of environmental psychology?

8.1.1 Natural sounds

With repeated demonstrations that 'natural quiet' (Brown, 2012; Mace et al., 2004) is routinely preferred to the sounds of urban environments (e.g. Benfield et al., 2014; Payne, 2010), we focused our efforts on understanding the specific factors that might influence how natural soundscapes are experienced. By adopting the structure commonly employed by soundscape ecology (Pijanowski et al., 2011), our findings are compatible with a framework that considers the effects of sound on human and non-human health alike (Buxton et al., 2017b). This approach also allowed us to systematically explore how sounds from different sources might be perceived and consider their combination in 'ecologically valid' representations of the natural world.

Separately, abiotic sounds such as flowing water (e.g. Yang & Kang, 2005) and biotic sounds such as passerine bird song (e.g. Ratcliffe et al., 2013) have been identified as highly preferred acoustic typologies that might also confer restorative benefits (Ratcliffe et al., 2016). Moving beyond individual sources to reflect soundscapes from five diverse biomes, our data revealed a robust hierarchy in these responses; sounds from biotic sources were considered more restorative than those from abiotic sources.

Intriguingly, our most complete soundscapes, featuring both abiotic and biotic sounds, scored no higher than biotic sounds alone. This finding may be indicative of potential ceiling effects; biotic sounds may have been close to the upper bound of how restorative a natural soundscape can be perceived to be, and so making this soundscape contextually richer – by adding the aural signature of the landscape – could not lead to additional benefits. A more pessimistic framing might start with this complete soundscape as our baseline. Under this scenario our data suggest that removing biotic sounds completely could lead to demonstrable falls in the restorative potential of the acoustic environment.

Is this kind of complete ecosystem collapse likely? Science fiction certainly thought so. A century ago, the prescient novels of E.M. Forster (*The Machine Stops*, 1909) and Yevgeny Zamyatin (*We,* 1924) depicted a global society characterised by unbridled urbanisation: they imagined futures in which populations would be clustered in tightly controlled conurbations, separated from the natural environment (a trope faithfully reimagined by *Forest 404*). Modern evidence has suggested that science fiction may be insidiously morphing into scientific fact. In 1962, Rachel Carson heralded the portent of a 'Silent Spring' (Carson, 1962), foretelling the kind of silent future that would result from the devastation of avian species. Sixty years on, the "*staggering decline of bird populations*" has continued unabated (Rosenberg et al., 2019), making Carson's warnings seemingly closer than ever.

Soundscape ecologists might use sophisticated monitoring and processing equipment to monitor declines in acoustic biodiversity of this kind (Sueur et al., 2021), including those that represent positive changes (Derryberry et al., 2020). Our data suggest that non-specialists may also be able to implicitly detect these changes; participants were not making a comparison between soundscapes with and without wildlife (due to our between-participant design), yet they reacted differently when it was missing. This finding corroborates recent research highlighting how bioacoustic diversity can impact perceptions of restoration (Ferraro et al., 2020; Fisher et al., 2021), and extends it beyond bird species to a wider range of fauna to place greater emphasis on the importance of preserving biodiverse ecosystems and their aural signatures.

Perhaps more forebodingly, participants' desires to protect their soundscapes followed the same pattern as that for restorative potential; respondents particularly valued soundscapes featuring biotic sources and removing these elements – to leave only the abiotic sounds of the landscape – led to demonstrable drops in preservation motivation. Species extirpation and extinction can have a negative impact on people's ecological knowledge (Kai et al., 2014) and the trends in our data suggest that a waning interest in protecting impoverished environments can also be detected through aural sensing.

Moreover, pro-environmental behaviours can be affected by a host of individual, societal, and environmental factors (Gifford & Nilsson, 2014). Our analyses suggested that appraisals of therapeutic potential could partially mediate people's desires to protect the sounds they heard. This trend is indicative of 'egoistic' behaviour, whereby decisions that result in environmental protection are based on outcomes that personally affect an individual (Stern & Dietz, 1994). Drives to promote conservation might apply this finding by expanding messaging to emphasise the ways that wellbeing can benefit from nature protection, and highlighting the reciprocity involved in preserving natural ecosystems (Soga & Gaston, 2016).

Our findings also complement those from recently released studies. In a systematic review of the literature, Buxton et al. (2021) delineated soundscapes according to three types of natural sound: water, birds, and those from a variety of mixed sources. Whilst unable to apply the strict control exercised in our experimental design, the review included studies that assessed a range of physiological and psychological measures across several settings. The authors found that water-based soundscapes exerted the greatest effect on positive affective outcomes, whilst those dominated by bird sounds were associated with greater reductions in stress and annoyance. Michels and Hamers also (2023) compared bird song with the sounds of water, finding both acoustic sources capable of reducing stress and negative affect. However, their control condition featured the sounds of wind, which were also present in their experimental stimuli, making each soundscape a more complicated mix of sound sources akin to our combined abiotic and biotic condition.

Our focus on natural soundscape composition did not consider the well-worn domain of urban noise, which has been explored from numerous perspectives in recent years (Basner et al., 2014). Nonetheless, our findings may complement efforts to protect positive soundscapes in metropolitan surroundings (e.g. Project DeStress, https://destress.hw.ac.uk). Although Ratcliffe (2021b) highlighted how a typical urban soundscape can include many desirable socio-cultural sounds, the need for 'quiet areas' in towns and cities remains (Payne & Bruce, 2019). The importance of these spaces has been recognised in government legislation, where areas that are "*quiet or relatively quiet*" and create "*significant benefits (in terms of health, wellbeing, and quality of life) for the communities they serve because of their quietness*" can now be protected in policy and planning decisions (DEFRA, 2019).

Beyond simply shielding these spaces from the incursion of anthropogenic noise, our results suggest that we might seek to maximise the wellbeing potential of these areas by (re) establishing healthy ecosystems that also promote audible fauna. This approach might also help to deepen the creation of 'green' infrastructure projects aimed at reducing factors such as noise pollution, by ensuring they also create habitats that contribute to a positive natural soundscape (Liu et al., 2023).

Indeed, adding natural sounds to several settings in the hope of improving emotional and restorative outcomes has become very much *en vogue* in recent years. For example, nature-based sounds have been trialled in hospital settings for both patients (Busch-Vishniac &

Ryherd, 2023) and clinicians (Suko et al., 2022), applied to vehicle acoustics (Podwinska et al., 2023), included in tools for sleep (https://uk.kokoon.io), deployed via mobile applications to enhance restoration (Luo et al., 2021) and focus (Haruvi et al., 2022), and incorporated into 'wellness hubs' (Spotify, 2023). Natural sounds may also play a central role in 'micro-breaks' designed to foster stress recovery (Largo-Wight et al., 2016). Our findings contribute to furthering the evidence base these applications are leveraging, an approach we were also able to put directly into practice in the development of *Mindful Escapes* (section 9.1).

8.1.2 Poetry

Our experimental approaches also sought to move beyond a consideration of natural sounds in isolation, including a focus on the cultural acoustic features that often accompany many digital nature experiences, but which have been overlooked in the people-nature literature.

Part of our *Forest 404 experiment* examined how people responded to biome-specific poems. Selected from the canons of literary greats such as Wendell Berry and Gerald Manley Hopkins, these poems were read by Pippa Haywood, one of the lead actors in *Forest 404.* They subsequently mimicked the style, quality, and diction familiar in the experiences provided by companies such as *Headspace* and *Calm*, where dulcet storytelling often includes descriptions of natural environments along with congruent nature-based soundscapes (Calm, 2020; Headspace, 2021). These 'interventions' are immensely popular; just one teaser example narrated by actor Stephen Fry has accumulated over 15 million plays on YouTube (https://youtu.be/5mGifCwig8I).

Yet in our experiment, participants perceived these poems to be substantially less restorative than our nature-based soundscapes, and when poems were added to our natural sounds, ratings also dropped significantly. These findings accord well with research in US national parks, where the incursion of human voices can have negative impacts on visitor experiences (Marin et al., 2011; Pilcher et al., 2009).

Yet context may also be an important factor to consider. For example, De Coensel and Botteldooren (2006) found that human voices were "*somewhat unfitting and annoying in [a] quiet rural setting*" yet Guastavino's (2006) participants described human voices in a busy urban setting in largely positive terms. The case could certainly be made that effects observed in our data may be partly due to respondents' context and expectations; the *Forest 404 experiment* was launched as part of a series that focused on the unadulterated sounds of the natural world, and participants may have been expecting to hear these sounds without the intrusion of spoken word, no matter how poetic its content and delivery.

Moreover, although we controlled for people's feelings of nature connectedness, our sample was more connected to nature than population averages, and so may have been particularly sensitive to anthropogenic additions to the sounds they heard. Likewise, memories had a greater effect on the ways our poems were perceived, indicating that familiarity with this material might have played an important role in participant responses. We must also not conflate findings for outcomes such as restorative potential and preservation motivation with a general 'dislike' for our poems; they may have been well received but not considered restorative.

Indeed, as highlighted in section 2.10.7, poetry may exert a more beneficial impact on other outcomes, such as positive emotions and feelings of loneliness (Obermeier et al., 2013; Wassiliwizky et al., 2017; Xiang & Yi, 2020). Thus, there could be value in viewing our results through a more optimistic lens, by taking poetry as our baseline stimulus. Under this scenario, our data suggest that adding congruent natural soundscapes to spoken words could enhance their restorative potential. This approach could offer tangible benefits to those producing narrative content for therapeutic outcomes (McKenna et al., 2010), and contribute to efforts to connect people to the natural world through creative prose (National Trust, 2021, 2023). A possible complementarity between poetry and music has also been considered in therapies aimed at alleviating pain and depression, with findings suggesting that listening to either poetry or music could reduce perceptions of pain and depression in oncology patients (Arruda et al., 2016).

8.1.3 Music

A focus on music laid at the heart of our *Soundscapes for Wellbeing* study. We probed how music might impact outcomes arising from the experiences provided by typical forms of natural history content, where it is both a common and expected feature (Wheatley, 2004).

Given this familiarity, and the rich cultural and historical overlap between nature and music highlighted in section 2.12, we anticipated that music would accord well with our experimental stimuli. Indeed, we went to great lengths to ensure our music was intertwined with the nature-based landscape and soundscape presented in these conditions; working with a leading composer, sound recordist, sound mixer, and digital animator to create each element in a synchronous fashion that, we suspected, would lead to synergistic effects.

However, our results did not conform to expectations. Adding music to our visual scene led to no significant increases in feelings of restoration, awe, and nostalgia, and even led to *lower* feelings of calmness, when compared to our silent condition. This contrasted with the effects observed from adding natural sounds to our visual stimulus, which led to substantial and significant increases across each of our dependent variables.

Although unexpected, our findings echo those of others. Natural sounds have been shown to out-perform music when it comes to stress reduction in different settings (Largo-Wight et al., 2016; Thoma et al., 2013), music has been found to reduce appraisals of urban parks (Yamasaki et al., 2013), and Juslin (2013) highlighted how many people register no emotional response at all when it comes to music. This latter point may be particularly relevant since several of our affective indicators reflected no change between the silent and music-based conditions. These outcomes also challenge the assumption – made in many studies – that music is a naturally calming addition to nature-based scenes (Anderson et al., 2017; Gerber et al., 2017), and suggest that for restorative outcomes at least, the inclusion of music in digital encounters should be very carefully considered.

Although feelings of calmness dropped below those for silence when music was included, this fall was countered by an increase in feelings of excitement, which were highest in the music condition compared to all other conditions. Calmness and excitement might be envisaged as opposite end points of a bipolar scale, representing positively valenced yet low and high arousal affective states respectively, and we might therefore expect them to be somewhat (although not totally) mutually exclusive emotions (Västfjäll et al., 2002).

The pronounced effect of music on feelings of excitement might be explained by the activation of mechanisms proposed by Juslin and Västfjäll (2008) and outlined in section 2.12.4. For example, in places our score featured an allegro tempo, which may have caused participants to synchronise their internal bodily rhythm with the music through a process of 'rhythmic entrainment'. Similarly, as our scene evolved to portray a growing thunderstorm, participants may have experienced 'emotional contagion', perceiving energy and excitement expressed by the music and consequently adopting those emotions. The powerful scores common in modern nature programming are certainly designed to energise and engage audiences (Wheatley, 2004), and our findings provide a quantitative validation of this creative endeavour – an approach that may be of particular benefit to those suffering from boredom and under-stimulation (Yeo et al., 2020).

However, our three-minute experience depicted an evolving scene that sought to instil *both* feelings of calmness and excitement at different points; from a gentle sunrise to an energetic thunderstorm, before a setting sun slowly restored a sense of calm. Whilst the music added to the building crescendo, it also aimed to enhance a final feeling of tranquillity with several slow and concordant string sections.

Why then might participants only have registered increases in feelings of excitement? Excitement might have represented the 'peak' in our stimulus posited by Kahneman's 'peak-end rule' (Do et al., 2008), and since highly arousing emotions are often those that are most readily recalled from an experience (Ochsner, 2000), these might have overawed the calming end to the video. We might also invoke Occam's razor and acknowledge the simple explanation that, although the score was designed to elicit feelings of calmness at certain points, it was, overall, ineffective at doing so.

For the first time, we were able to assess how combining both natural sounds and music influenced outcomes compared to either stimulus-type on its own. Results revealed possible averaging effects; the combined condition was rated roughly midway between the nature-only and music-only conditions for each dependent variable. The fusion of music and nature-based soundscapes has previously been assumed to provide an optimum configuration for therapeutic outcomes (Ahmaniemi et al., 2017; Anderson et al., 2017; Bauer et al., 2011).

Again, our results suggested that across several indicators, this combination may actually lead to diminished affective outcomes compared to natural sounds alone, reinforcing the need to place evidence-based design, rather than intuition, at the heart of these interventions.

How might our results relate to the intertwining of music and nature in historical cultures and the field of ecomusicology (sections 2.12.1 and 2.12.2)? Rothenberg and Ulvaeus (2001) reported numerous "*tales where music and nature surprisingly converge*" but it seems our participants were not in favour of this convergence. Indeed, whilst authors such as William Gardiner (1841) might have asserted that "*music has had its origin in these simple and immutable expressions [of nature]*", the probing eye will have spotted that this relationship appears to be almost entirely one-way.

For example, statements such as:

"*Every place, with its vast populations of plants and animals, becomes a concert hall, and everywhere a unique orchestra performs an unmatched symphony"* (Krause, 2012);

"*The difficulty of mechanically reproducing the sounds of nature imparted the aura of authenticity to the idea of those sounds: it confirmed that they were indeed ideal, untameable by man*" (Dolan, 2008); and

"*That which makes music an art is that which separates it from nature and the natural voices of birds*" (Leach, 2007), not only suggest that natural sounds are the archetypal form of music, but that music may be considered a poor imitator of nature, and even that each entity should be kept separate.

Yet we must also refrain from seeking to apply these findings to all digital experiences. Compositions featuring a blend of natural sounds and music are immensely popular on digital platforms such as YouTube and Spotify, accumulating well over 100 million plays in some cases (e.g. https://youtu.be/Lp6XlsBm_Lw). Moreover, many nature-based productions are designed to educate and entertain, rather than offer cognitive or restorative benefits. But with broadcasters and the wellbeing sector increasingly seeking to enhance the therapeutic potential of their content (BBC Four, 2020; Keltner et al., 2017; Portal.app, 2022; Spotify, 2023), and where music must be included in these efforts for creative and narrative decisions, or to satisfy consumer expectations (Rogers, 2014), we find that combining music with congruent natural sounds could help to bolster positive emotional responses in audiences (Strachan & Leonard, 2014).

It is difficult to ignore the overwhelmingly positive effects of natural sounds in our *Soundscapes for Wellbeing* experiment. Built on the learning from both our *Forest 404* study and the existing literature, this soundscape included abiotic and biotic sounds in the form of evolving aural signatures of flowing water and passerine birds (Alvarsson et al., 2010; Buckley, 2023; Ratcliffe et al., 2016). We therefore expected it to be highly rated in terms of restorative potential. Nonetheless, its strong performance across our other, more complex emotional indicators, was a novel finding.

8.1.4 Nostalgia

Soundscapes for Wellbeing marked one of the first systematic investigations into how a nature-based experience might stimulate feelings of nostalgia. Our analyses suggested that even our silent condition was effective at eliciting low levels of this increasingly valued emotion, and that adding natural sounds to our digital environment could enhance this effect significantly further.

This mechanism may have been due to the surfacing of positive memories in natural environments and the reliving of these experiences, particularly those featuring pleasant nature-based sounds. Intriguingly, there is also some evidence to suggest that the sounds of adverse weather – those that feature rain, wind, and thunder – might also be a significant trigger of nostalgia. Across 4 novel studies, van Tilburg et al. (2018) demonstrated that participants could experience nostalgia in response to weather-induced distress. This reaction may be driven by a need to reestablish psychological homeostasis following (or during) negative experiences, a process that nostalgia may help with by simulating past events that can "*in turn be expected to confer benefits to the individual as if they occurred in the present*" (van Tilburg et al., 2018). Since our experimental conditions featured a dramatic thunderstorm, we may have inadvertently 'tuned' our experience to trigger this mechanism.

Importantly, nostalgia has been associated with a suite of experiential encounters, including visits to museums, sporting events, and the coast (Fairley & Gammon, 2005; Goulding, 1999; Severin et al., 2022), and our findings indicated that digital forms of nature, especially those featuring natural sounds (and even adverse weather), may represent an exciting new pathway through which this emotion can be stimulated.

Indeed, nostalgia could represent a powerful aspect to nature-based experiences that has, thus far, gone largely unnoticed. Acknowledging this 'nostalgic potential' could deepen recognition of the emotional benefits associated with digitally mediated forms of nature, whilst nostalgia's ties to shared experiences could feed into theories of 'relational restoration' that place social interactions at the heart of the restorative process experienced in nature (Hartig, 2021). The tendency for nostalgia to rose-tint past experiences, dampen possible negative reflections (Wildschut et al., 2006), and buffer the effects of psychological discomfort (Sedikides et al., 2022) might also make it an important emotion for theories of instoration and salutogenesis, where positive outcomes (that do not require degraded emotional, cognitive, or stress-related starting points) are emphasised over the maintenance or recovery of an 'adequate' baseline in psychological states (Korpela & Ratcliffe, 2021; Mittelmark & Bauer, 2022).

Moreover, the almost exhaustive litany of positive outcomes associated with nostalgia, from feelings of being loved, to enhanced perceptions of social competence, self-esteem, and increases in prosocial behaviour (Wildschut & Sedikides, 2020, and section 2.8.3), suggest that triggering nostalgia could even be considered an essential *target* of nature-based encounters.

Yet a substantial caveat exists to the success of this approach: people must have had prior experiences in nature to feel nostalgic about them. Nostalgia and memories are inextricably linked (Wildschut et al., 2006) and our *Soundscapes for Wellbeing* data quantified the magnitude of this moderating effect, which was nearly three times greater than that for excitement, and roughly twice as large as that for feelings of restoration, calmness, and awe (see section 8.1.7 for a discussion of our memory-based results).

If worries about a growing 'extinction of experience' prove founded, whether due to changes in behaviour or biospheric breakdown (Soga & Gaston, 2016), the ability for future generations to experience nature-based nostalgia could be greatly diminished. This trend might be mitigated by investment in interventions designed to foster positive encounters with nature earlier in life, particularly those occurring with family and friends.

Notably, we detected no relationship between music and nostalgia. Music can be a powerful trigger of nostalgia (Juslin, 2013), which as outlined above, has been linked with a staggering number of potential benefits (Sedikides et al., 2022). These effects are commonly attributed to songs that reflect a particular point in a person's life (Janata et al., 2007) and thus our use of an original score may have impeded this particular mechanism.

However, this explanation may not be so straightforward. Sedikides et al. (2022) have argued that nostalgia perceived in music can in turn be 'contagious' to a listener. Although we did not detect this effect in our data, the complexity of these mechanisms suggests a closer look is warranted at the ways nature, music, and nostalgia might interact.

8.1.5 Awe

Nostalgia shares several positive outcomes with feelings of awe, among them prosocial behaviour, creativity, and self-esteem (Piff et al., 2015; Sturm et al., 2020; Wildschut & Sedikides, 2020). Yet unlike nostalgia, the triggers of awe have commonly been approached from a visual perspective in people-nature interactions (Anderson et al., 2018; Chirico et al., 2018).

Findings from *Soundscapes for Wellbeing* represented a sensory advance in this area, suggesting that, in addition to visual stimuli, natural sounds might also modulate the stimulation of this increasingly researched emotion (Keltner, 2023). How might our natural soundscape have increased feelings of awe?

Sublime manifestations of awe are often exemplified by fear, vulnerability, and power, and might also be accompanied by positive feelings such as joy, energy and freedom (Bethelmy & Corraliza, 2019). The building energy of our digital scene could have been amplified by the increasing cadence of the natural soundscape, which peaked with the powerful claps and ripples of thunder. Passerine bird song, from species such as the skylark and blackbird, may also have stimulated aesthetic interpretations of awe (Clewis, 2021). Taken together, these sublime and aesthetic appraisals might have led to the need to accommodate a new perspective on nature (Keltner & Haidt, 2003). However, given the sparse literature on how natural sounds and awe might be related, these findings highlight the need for further work aimed at unpicking the mechanisms that might be at play.

In contrast, adding music to our digital scene in the Soundscapes *for Wellbeing* experiment did not contribute to enhanced feelings of awe, compared to our silent condition. This finding was unexpected; music has previously been identified as an effective elicitor of awe, particularly for 'upbeat' and 'complex' genres (Pilgrim et al., 2017). However, personal experiences have also been closely related to "*what makes a piece of music moving*" (Konečni, 2005) and our use of an original score may have suppressed this process.

Similarly, Konečni (2005) suggested that it is the experiential elements of listening to music in live settings that might be most important for stimulating awe, "*to be sublime, music must be 'colossal', and this status it can achieve only by being performed in vast architectural spaces that have not only excellent acoustic qualities, but are also of extraordinary beauty.*"

Perhaps most importantly, people's trait-based 'openness to experience' may be a significant moderator of feeling awe in response to music (Silvia et al., 2015). The musical stimuli used by Silvia et al. (2015), *Hoppípolla* by Icelandic group Sigur Rós, was very similar in style to the music created for our experiment. Yet we have no steer on how participants' openness to experience might have varied, nor how it might have affected their responses. These conflicting outcomes, along with our own findings, highlight the paucity of research into the ways in which awe might be elicited by non-visual means.

8.1.6 Ephemeral features

When it comes to nature, there also remains much to understand about the visual triggers of awe and our focus on ephemeral phenomena considered awe as a central response to unusual and fleeting intra-landscape changes.

We found that, compared to blue-sky conditions, features such as sunrise, sunset, and rainbows could lead to significant increases in awe in both urban and natural settings. Previous studies have demonstrated that landscape views including these phenomena can be effective at eliciting awe (Anderson et al., 2018; Joye & Bolderdijk, 2015), and we extended these findings by quantifying their differential effects both within the same environment, and across settings.

Although commonly discussed in response to vast and 'extraordinary' views of nature (Joye & Bolderdijk, 2015), awe can also be triggered in everyday settings (Sturm et al., 2020) and our findings lend support to the possibility of experiencing this emotion as part of daily routines. As reflected upon in the published version of this study (Smalley & White, 2023), these findings may be most relevant in metropolitan environments, providing a route for residents to experience transcendent experiences of nature (Bethelmy & Corraliza, 2019) without the need for structural interventions.

As with nostalgia, the effects of awe may align well with the processes associated with instoration in nature, improving attentional capacities and affective states without the need for previously depleted psychological resources (Collado & Manrique, 2019; Korpela & Ratcliffe, 2021). Crucially, our findings suggested that an environment's potential to offer these benefits may vary substantially throughout the diurnal cycle, and signposting *when*, rather than simply *where* to facilitate contact with nature could be vital for maximising outcomes.

Experiences of awe could also offer important reciprocal potential. Awe's ability to generate feelings of the 'small self' and subsequent increases in prosociality (Piff et al., 2015; Sturm et al., 2020) could be important for cohesive and compassionate societies, effects that might extend to pro-environmental behaviours and be most valuable in ever-crowded cities.

As previously highlighted in section 8.1.5, sublime interpretations of awe also infer a mixed valence response that can be "*tinged with elements of fear and threat*" (Gordon et al., 2017). Indeed, in our simulated natural environment, a thunderstorm decreased ratings of awe, yet increased these ratings in the urban setting (compared to our blue-sky control). Konečni (2005) contended that sublime experiences require safety to be experienced as beautiful; "*existential well-being is considered a* sine qua non *for experiencing a potentially sublime stimulus as indeed sublime.*" In Smalley et al. (2023) we embraced this argument, suggesting that the storm might have been poorly received in our natural setting due to fewer places to seek refuge.

However, since digital experiences offer this *sine qua non* of safety via remote viewing, it is also difficult to rationalise our findings with this mechanism. Moreover, participants who feel more "*captivated and engrossed in their surroundings*" have demonstrated a greater propensity to experience awe (Ballew & Omoto, 2018), highlighting the need for further evidence of how virtual triggers of this emotion might relate to those experienced *in situ* (Quesnel & Riecke, 2018).

Ephemeral phenomena were also associated with concomitant variations in beauty, supporting Brassley's (1998) proposition that substantial variations in aesthetic value might occur at previously unexplored temporal scales. Positive patterns were again most notable for sunrise, sunset, and rainbows compared to sunny conditions in both natural and urban settings.

These effects fit well with those described by preference matrix theory (Kaplan & Kaplan, 1989); by introducing higher levels of complexity and mystery to a landscape, ephemeral phenomena might make it more innately attractive and appealing for exploration (van der Jagt et al., 2014). Ephemera also offer opportunities for changing experiences within familiar landscapes, providing a viable way to join mechanisms that suggest both novelty (Buhyoff & Wellman, 1979; Hull & Stewart, 1995; Wang et al., 2019) and familiarity are important for aesthetic preferences and restoration (Korpela & Hartig, 1996; Ratcliffe & Korpela, 2016).

Brassley considered ephemeral phenomena a central issue in landscape aesthetics "*because the existence of ephemera makes it difficult to produce a reliable evaluation of a landscape at a single point in time; and…because ephemera are not normally subject to the landscape planning process*" (Brassley, 1998). Our data provide quantitative support for the importance of these issues and suggest that landscape aesthetics could benefit from the consideration of attributes that are in constant flux.

Reframing evaluations to account for these changes could shift the aesthetic focus from permanent and unchanging morphologies and bolster the ways both urban and natural environments are perceived by inhabitants (Qviström & Saltzman, 2006). Indeed, recognising that nature and natural processes are 'always going on above us' may help to advance nature and health conversations beyond the well-worn urban-nature dichotomy that is still the focus of much research (e.g. Pasca et al., 2021).

Our results allowed us to place, for the first time, a very tentative estimate on the ways diurnal and meteorological events can affect landscape values, with people most willing to pay to visit landscapes that featured sunrise and sunset. For example, experiencing our urban environment at sunset was valued almost £1 higher than under blue-sky conditions (which attracted a figure of roughly £8): a relative price difference that is comparable to that found between hotel rooms with and without a sea view (Fleischer, 2012).

These exploratory figures suggest that momentary differences in the 'value of a view' (Benson et al., 1998) might be discernible, depending on the presence of ephemeral features. Whilst windows, particularly in high rise buildings (Masoudinejad & Hartig, 2018), can offer a way to leverage this utility, existing work has primarily focused on the structural and natural features that might be observed from workplace and residential windows (Kaplan, 1993; Sop Shin, 2007; Tennessen & Cimprich, 1995). Our findings suggest that the effects of these views, especially those that feature large proportions of sky, may have been significantly undervalued.

Should ephemera be incorporated into the myriad ways natural beauty is considered and interpreted in planning legislation (Selman & Swanwick, 2010)? Whilst building such momentary considerations into pricing models is likely to be unrealistically granular, an uplift in potential value might be considered for views that facilitate the experiencing of specific phenomena, such as an elevated, west-facing, aspect that might provide views of sunset throughout the year.

Although nighttime in the natural setting was associated with substantially lower ratings of beauty and awe than our blue-sky condition, our urban environment was considered just as beautiful at night as during the day, and rated significantly more awe-inspiring at night. These findings echo those of Zhao et al. (2023), who found that urban green spaces were perceived as more restorative during the day, but that improved lighting could reduce this disparity completely. Indeed, our nature-based scene featured no additional lighting at night, whilst our urban scene featured numerous lit windows and streetlights that shimmered in the large water feature. This aesthetic mirrored that of stimuli used in previous studies that have revealed positive appraisals for urban landscapes at night (Huang & Wang, 2018; Nasar & Terzano, 2010).

Perhaps of most relevance, increases in feelings of awe in our urban setting at night support notions of an "*urban nocturnal sublime*" and the need to create nightscapes that are "*aesthetically powerful*" (Stone, 2021). Much like early preferences for urban sounds that heralded modernity (Coates, 2005), public lighting in cities, from oil lamps to electrification, has been associated with positive values such as safety and progress that still exist today (Stone, 2021).

Indeed Stone (2021) referenced Nye (1996) and Dewdney (2005) who defined "*a nightscape of different lighting intensities, types, colours*" that together form an "*electrical sublime*" (Nye) and "*one of the most fantastic sights of our times*" (Dewdney).

Stone noted how lighting "*effectively creates the city at night, carving space and time out of darkness*" and reflected on how these experiences can feel in busy cities, "*there is a reverence and excitement when entering a metropolitan city at night, with its innumerable lights creating a vibrant atmosphere*" (Stone, 2021).

Finally, quoting Nye again (Nye, 2010), Stone (2021) also acknowledged the parallel of this experience with what he called the 'astronomical sublime', "*city nights create a sort of human-made constellation, erasing the heavens in favour of 'man-made stars'*".

The effects of light pollution for astronomical, ecological, financial, and human health-related outcomes notwithstanding (Cupertino et al., 2023; Falchi et al.; Gallaway et al., 2010; Longcore & Rich, 2004), our findings support these efforts to recognise the cultural importance of the urban aesthetic (Light, 2001). Crucially, the impacts of ephemeral phenomena highlight the importance of subjectivity, meaning, and memories on landscape experience, a thread that ran across each of our studies.

8.1.7 Memories

In both our *Forest 404* and *Soundscapes for Wellbeing* data, we found that participant memories exerted a moderating effect on restorative and affective outcomes that, in some cases, substantially outweighed the effects of our experimental manipulations.

Compared to those who recalled no memories, respondents in our *Forest 404* experiment were significantly more likely to find their soundscapes restorative and more inclined to preserve them if they had memories triggered by the sounds they heard. These effects were most pronounced for nature-based poetry.

Likewise, our *Soundscapes for Wellbeing* analyses revealed that those with memories stimulated by the experience (compared to those reporting no memories) appraised greater levels of restorative potential, calmness, excitement, awe, and nostalgia across all conditions. Crucially, the effects of memories on our dependent variables in these data were substantially greater than those arising from changes in experimental conditions. In our complex model (in which both condition, positive memories, and their interactions were considered) coefficients for the effects of condition were well under 1 for all outcomes. For memories, they ranged from just under 1 to over 2.5.

Across both of these studies, the patterns in our results bear a striking resemblance to those of Gillihan et al. (2007), who demonstrated how negative, neutral, and positive memory recall could affect participant mood (Fig 7.). We extend these findings to the field of environmental psychology by identifying that memories *involuntarily* triggered by nature-based stimuli can have the same effect as those *intentionally* recalled from a wider range of lived experiences.

These top-down mechanisms were first posited by early theorists in the field (Kaplan, 1995; Ulrich, 1983), yet had received little critical attention until relatively recently (Ratcliffe & Korpela, 2016). Ratcliffe and Korpela's (2017) work explored how the effects of memories might be mediated by place identity, and highlighted memorable experiences as a vital ingredient in restorative outcomes. They suggested that feelings of 'being away' – one of the central pillars of attention restoration theory (Kaplan & Kaplan, 1989) – might be particularly relevant to memory–mediated restoration since the past "*can be "visited" in the mind's eye as a source of escape*" (Ratcliffe & Korpela, 2017). Our data indicate that this mechanism could be especially potent for natural soundscapes: with a lack of visual stimuli, the mind might be allowed to return to any congruent visual scene.

Ratcliffe and Korpela (2017) also noted how relationships with certain settings were likely to develop over time, rather than relate to a "*single-exposure event*". Indeed, whilst this semantic form of memory does not rule out the effects of specific episodic recall, it is likely to be more relevant to nature-based experiences that might reflect the accumulation of broadly positive events, rather than a single, defining moment (Holland & Kensinger, 2010). This process is likely to be particularly pertinent to our *Soundscapes for Wellbeing* study, since participants were viewing a fictional virtual scene that they could not have had direct memories of. Instead, it might have triggered a more general feeling of 'knowing' that reflected previous places and experiences.

Indeed, although we do not know how the specific contents of participant memories could have influenced the magnitude of their effects, it is likely that they involved the recall of shared experiences. In this way, memories triggered by nature-based stimuli may relate to the creation of resources central to relational restoration theory, such that "*even when seemingly alone in some setting, a person may through their memories and anticipation remain engaged with other people, activities, and settings in ways that enhance or degrade the restorative quality of their experience*" (Hartig, 2021).

Whilst the role of life experience and relational factors in restoration will be of little surprise to those concerned with the notion of 'therapeutic landscapes' (Bell et al., 2018), our findings represent an initial attempt to quantify the effects of these factors on a diverse set of indicators. The scale and consistency of our findings across these metrics and via differing visuo-acoustic presentation methods, suggest they could be a substantial and hitherto overlooked confounding factor in studies that take a compartmental approach to nature contact. For example, how might the results of Ferraro et al.'s (2020) study into the effects of acoustic biodiversity have differed if participant memories had been considered? Perhaps more importantly, could the null results reported in Hedblom et al.'s (2019) investigation into the stress-reducing effects of bird song have been explained by memory-based biases in their relatively small sample?

The identification of a clear quantitative association between nature-based experiences, memories, and positive wellbeing outcomes could also underscore the importance of fostering relationships capable of nurturing these connections. Indeed, if digital forms of nature are to be used therapeutically, our data suggest they will, to some extent, be reliant upon these memories *already* being in place.

What could this mean for future generations? If the portent of a growing extinction of environmental experience becomes reality (Gaston & Soga, 2020; Soga & Gaston, 2016), and people do not create positive memories of interacting with the natural world, our data suggest the wellbeing potential of digital forms of nature might be significantly diminished. As detailed in section 2.13.4, degraded encounters with healthy ecosystems can occur via numerous mechanisms and this insidious process can lead to a "*forgetting that crosses generations*" (Kahn Jr, 2002), such that following a century or so of decline, people may accept a very low level of nature-based memories as normal. Our *Forest 404* narrative imagined such a world, which Khan (2002, pp110) perhaps described best with the following analogy:

"*Imagine that your favourite food item is the only source of an essential nutrient and that without it everyone suffers from low-grade asthma and increased stress. Now imagine a generation of people who grow up in a world where this food item does not exist. In such a world, it would seem likely that people would not feel deprived by the absence of this tasty food (it was never in their minds to begin with) and that they would accept low-grade asthma and increased stress as the normal human condition. Nature is like that food.*"

If we hope to leverage the benefits of virtual nature, especially for those who may be in situations that limit their access to the outside world, we must ensure that childhood awareness of, and experiences in, nature are facilitated (Ward Thompson et al., 2008), as well as those that foster a connection to natural systems throughout the life course (Li et al., 2021a). The clear links between memories and complex yet rich and powerful emotions such as nostalgia, highlight the breadth of benefits that might arise from these efforts.

There may also be considerable value in exploring the ways that digitally-mediated encounters could maintain cultural memories of those flora, fauna, and people-environment traditions that are under threat (Jarić et al., 2022). Moreover, in a world where people's everyday lives are increasingly managed in virtual and online environments, introducing nature experiences to digital settings may represent a surreptitious way to reach those who have already disconnected from environmental realities (e.g. Portal.app).

8.2 Limitations

Our studies recruited unusually large samples to take part in controlled and randomised experiments that focused on the restorative potential of nature-based encounters. Yet these studies also represented a surprisingly low relative participation rate.

For example, Between April 2019 and March 2020, episode downloads for *Forest 404* exceeded 2.5 million. The BBC's best estimate for the total number of individuals engaged with the series during the seven months the experiment was open, was just over 1 million. However, just 7,596 of these completed the experiment, producing a practical conversion rate of ~0.76% (MailChimp, 2023).

At first glance, *Soundscapes for Wellbeing* saw much improved engagement. Over 141,000 people visited the programme website, leading to 8,752 respondents completing the experiment and a conversion rate of ~6.2%. However, the *Soundscapes for Wellbeing* study was publicised on primetime television slots across BBC One, BBC Two, BBC World News, and BBC Radio 4, leading to tens of millions of impressions (Adobe, 2022). When accounting for this level of exposure, participation in our *Soundscapes for Wellbeing* experiment could be viewed as even more disappointing.

Are these conversion rates unusual? In their analysis of people taking part in The Wildlife Trust's *30 days wild* campaign, Richardson and McEwan (2018) noted that of the 49,000 people taking part in the initiative, 8,442 completed the baseline survey as part of the sign-up process. Yet just 308 responded to post-participation data collection, representing a conversion rate of ~0.63% and very similar to that for *Forest 404.*

Several reasons may explain these high levels of attrition. Whilst participation in the *Forest 404* experiment was encouraged at the end of every podcast episode, potential respondents had to exit their podcast app, enter the web url on their browser, and then navigate to the experiment. This process was the same for *Soundscapes for Wellbeing* and likely represented several major opportunities for drop-off. The length and wording of consent forms, largely dictated by research ethics committees, could have acted as a further barrier to entry.

Moreover, each study required substantial commitment from participants, who had to find a quiet and distraction-free place to take part, were encouraged to use headphones, and had to remain engaged for ~10 minutes to complete each experiment. Whilst these factors were largely unavoidable, future experiments could be considerably streamlined by placing user experience at the heart of their design.

Whilst we were able to employ nationally representative demographic quotas through our consumer panel, Cint, in our ephemeral phenomena study, both our *Forest 404* and *Soundscapes for Wellbeing* samples were susceptible to self-selection bias. However, in their analyses of 32,800 respondents recruited via a BBC Radio 4 study, Morrissey et al. (2016) found no significant differences between survey participants and non-participants. These results suggest the benefits of generating large samples via mainstream broadcast efforts may outweigh possible bias-based drawbacks, but substantial caveats remain. Participants in our self-selecting samples were more likely to be white, female, older, and more highly connected to nature than national averages. We must therefore be very careful when seeking to generalise our findings to more diverse groups (Henrich et al., 2010), and continue to find ways that encourage participation from those who are currently underrepresented (Byrne, 2012).

Moreover, both *Forest 404* and *Soundscapes for Wellbeing* stimulated debate around the roles that nature, and natural sounds in particular, can play in wellbeing outcomes. We do not know whether these narratives might have 'primed' participants to respond in certain ways or made them more sensitive to specific elements of our experimental conditions.

Across each experiment, we employed stimulus durations of varying lengths: from 40 seconds in *Forest 404* to three minutes in *Soundscapes for Wellbeing*, and an open-ended viewing experience for our ephemeral phenomena. These durations were derived from and consistent with those in the existing literature, yet might have presented limitations of their own. For example, we do not know how longer, more immersive soundscapes might have influenced outcomes in *Forest 404*, nor how more carefully constructed mixes of prose and natural sounds could have been received. The same goes for *Soundscapes for Wellbeing*, where the music had to achieve dramatic shifts in pace and timbre that would normally evolve over much longer time frames.

All experimental manipulations also involved degrees of creative augmentation. This was most obvious in the digitally designed visual scenes used in studies two and three, but the soundscapes in studies one and three underwent similar levels of manipulation. Our stimuli therefore aimed to portray nature in an 'optimised' state and did not represent the real-world messiness that characterises most outdoor settings (Michael, 2011). This level of control allowed us to isolate specific factors in our experimental manipulation, but equally presented several drawbacks.

For example, in *Forest 404* we simulated ecosystem degradation by removing all wildlife sounds from the acoustic environment. This kind of severe change in soundscape composition has previously been considered a portent of environmental damage, embodied by the notion of a 'silent spring' (Carson, 1962). Yet real biodiversity loss tends to happen at a more gradual rate, and most species do not contribute to the soundscape. Future work might look at the impacts of more nuanced changes, particularly with respect to the impact of 'shifting baselines' and the notion that people readily adapt to slow shifts in reference states (Pauly, 1995).

The use of two-dimensional and unimodal computer generated imagery in our ephemeral phenomena study meant we could not replicate the rich, immersive, multisensory features of landscape that are known to have an important influence on aesthetic value (Brady & Prior, 2020). We must therefore exercise caution when seeking to draw parallels with real-world assessments. Perceived realism has been associated with reactions to environmental encounters in digitally mediated settings (Newman et al., 2022) and although we used the latest 3D techniques to create our experimental conditions, some participants may have found it difficult to relate to a computer-generated image. This response could underpin the age-based patterns in our data, with digital stimuli likely to be more familiar and acceptable to younger participants. A similar effect may also explain why participants using smartphones rated our stimuli consistently higher than those using other devices, where larger screens may have placed more emphasis on visual fidelity.

Likewise, our *Soundscapes for Wellbeing* stimuli built on those used in studies one and two, employing the latest digital techniques to create strictly controlled experimental conditions. Yet they did not feature the narrative or innovative camera work common in much natural history content; how findings might apply to other digital forms of nature is thus unknown. Similarly, our musical composition, created specifically for this experiment by an experienced composer, was designed to mimic the 'wall of sound' style that accompanies flagship nature documentaries. Yet this represented just one possible score and we do not know how music with differing characteristics might have been received.

To alleviate participant burden and maximise the capture of information across numerous outcome variables, we used single-item measures for several metrics. Although validated and extrapolated from the rich corpus of literature on nature and health, these measures may have lacked the dimensional insights offered by more detailed, longer-form scales. The deficiencies of single-item measures were highlighted in *Soundscapes for Wellbeing*; although many people feel no emotion at all in response to music, with large differences between individuals (Juslin, 2013) we could not capture or account for this heterogeneity in our analyses, and we do not know how prevalent a lack of emotional response may be to nature-based sounds.

Indeed, the online format of our studies (which was largely dictated by Covid-19 restrictions) meant we could not measure actual recovery of attentional resources, instead relying on participant evaluations of *perceived restorative potential* (Hartig et al., 1997a). Further work might seek to examine how responses to specific acoustic cues vary in real time, using physiological outcomes under laboratory conditions (Johnson et al., 2021), and employing emerging technology, such as spatial audio. Equally, our preservation motivation question (*Forest 404*) asked respondents to imagine a situation in which they had to 'keep' or 'delete' the sounds they were hearing, as if they were the main character in the Forest 404 narrative. Since this behaviour was hypothetical and did not have demonstrable consequences, we must be careful when drawing parallels with actions in real-world situations.

In a similar vein, although they can represent a suitable guide to estimating non-market goods and services (Haab et al., 2020), the use of contingent valuation methods has been contested (Clark et al., 2000; Venkatachalam, 2004). Thus, in our ephemeral phenomena study, reflecting the value participants might place on visiting a location under specific conditions may have been hard to achieve. Although recent evidence suggests an approximately linear relationship between the amount spent to visit a recreational location and satisfaction with the experience (Börger et al., 2022), there may be intrinsic biases in these ratings. We must therefore remain cautious about over-interpreting our results, and instead view them as highly exploratory.

In both study one and two, our memory measures captured a general sense of participants' lived experiences, but we could not determine at what point in the life course these memories occurred or whether they were truly autobiographical. In our *Forest 404* data, respondents reported having memories of our more exotic soundscapes, suggesting that responses might also reflect associations assembled from a broad mix of experiences, including natural history programming. In *Soundscapes for Wellbeing*, our use of original audio-visual stimuli aimed to prevent people having direct memories of the scene and sounds depicted, instead eliciting more general recall of memories formed throughout the life course. However, we could not use novel natural sounds and our inclusion of species such as blackbirds and skylarks may have triggered specific memories, something we could not account for in our analyses. The diversity of what people consider to be 'lived experiences' of nature could be a beneficial focus of future research (Ballouard et al., 2011).

Crucially, quantitative investigations form just one way of unpacking how and why people perceive environments differently (Scott et al., 2009). As part of *Forest 404* and *Soundscapes for Wellbeing*, we received several hundred emails from participants and audience members containing personal reflections on how digital forms of nature were being used therapeutically. Although ethical constraints prevented their inclusion in the analyses reported here, these insights may provide vital qualitative context to the patterns we observed. Mixed-methods approaches should form a central part of further work in this area.

8.3 Recommendations

This thesis has illustrated how the composition of natural soundscapes can impact how they are perceived, and suggested natural sounds might be effective elicitors of powerful emotions such as awe and nostalgia. We have identified significant nuance in how cultural acoustic factors, such as poetry and music, might complement or detract from virtual experiences of nature, and for the first time, revealed findings that indicate the substantial ways in which ephemeral features can augment landscape experience. Across these outcomes we have also highlighted the crucial and often overlooked importance of memories. Where might our investigative gaze turn next?

Since each of our studies was conducted online, there would be considerable value in attempting to replicate our findings in more strictly controlled, laboratory settings. Beyond merely validating our results, this approach could extend mechanistic understanding by permitting the use of physiological measures, cognitively depleting tasks, temporal monitoring, and highly immersive experiences. Indeed, our experimental stimuli are already being used in research attempting to unpick how virtual experiences of nature can impact the neural pathways associated with pain in laboratory settings (Eder et al., in preparation), and furthering these lines of investigation would mark an exciting extension to the work presented here.

Whilst we probed how the ephemerality of visual features might impact environmental perceptions, soundscapes are also in a constant state of flux (Payne, 2010). Indeed, diurnal variations in acoustic sources might occur for several reasons: geophony can vary according to weather; biophony due to the time of day or season; and anthrophony because of cultural and economic factors (Pijanowski et al., 2011). Our *Forest 404* data hinted at how changes in the abiotic and biotic compositions of a soundscape can influence outcomes such as cognitive restoration. Recognising the ephemerality of aural features – such as the dawn chorus, a sudden downpour, or the hooting of owls at night – could have equally significant implications for how these moments are incorporated into nature-based experiences, whether situated in digital or real environments.

Similarly, there remains much to be understood about how nature-based encounters might be enriched by a broader range of acoustic influences. The beginning paragraph of chapter two acknowledged how this thesis employs a western perspective and this tack prevented the consideration of eastern practices that are steadily growing in popularity.

Often typified by the resonance of gongs, so-called 'sound baths' represent one richly immersive example from this domain. Whilst some have asserted the ability of sound baths to "*transform consciousness*" (Auster & Orkin, 2019) and proclaimed that "*everything is vibration. When you find harmony, you allow sound health*" (Longdon, 2020), the mysticism and pseudo-scientific vernacular associated with these experiences may have diverted attention from the positive impacts they can have on wellbeing (Caballero, 2013). Indeed, initial evidence suggests that gong 'therapy' may be more effective at reducing anxiety than natural sounds (Singh Khalsa, 2021). How this, and other forms of complementary therapy, might interact to form 'healing' encounters with nature would be a valuable focus of future work.

In a similar vein, the significance of numerous nature-*related* experiences – those that can occur as part of the tapestry of activities undertaken in natural environments – have yet to be fully acknowledged. For example, with their soft, dancing hues, evocative pops and crackles, and opportunities for warmth, outdoor campfires represent beguiling nature-related experiences that can transcend cultural boundaries (Mechling, 1980). Mechling (1980) detailed the ways that fireside settings can promote the learning of nature-based skills, social bonding, and storytelling. Whilst Dana Lynn (2014) noted that for early humans "*fire likely extended the day, provided heat, helped with hunting, warded off predators and insects, illuminated dark places, and facilitated cooking. Campfires also may have provided social nexus and relaxation effects that could have enhanced prosocial behavior.*"

We have touched on ideas of relational restoration and the positive social interactions that nature can foster (Hartig, 2021), and in the campfire we might find a powerful forum for holding communion with both nature and others. Crucially, Dana Lynn's (2014) evocative study of fire suggested that "*the hypnotic influence of watching campfires*" is dependent upon the combination of visual and acoustic cues, which can act through absorption and prosociality to increase feelings of relaxation. As with notions for a broader affinity with natural settings, we might invoke adaptive mechanisms to underpin positive affective responses to fire (Clark & Harris, 1985; Gowlett, 2016; Twomey, 2013). Acknowledging these processes and the ways that campfire experiences might enhance both digital and *in situ* encounters with nature could represent a fertile seam of research.

It is also clear from these examples that sound presents open and accessible opportunities for immersive experiences that do not rely on vision. The 2024 release of Apple's Vision Pro headset may herald a new era in virtual living (Apple Inc, 2023), and nature-based environments are likely to feature heavily in this new world of 'spatial computing' (Fig. 30). The role of immersive sound in these experiences, delivered through technologies such as binaural and spatial audio, must continue to be researched and implemented if outcomes are to be optimised for wellbeing gains.

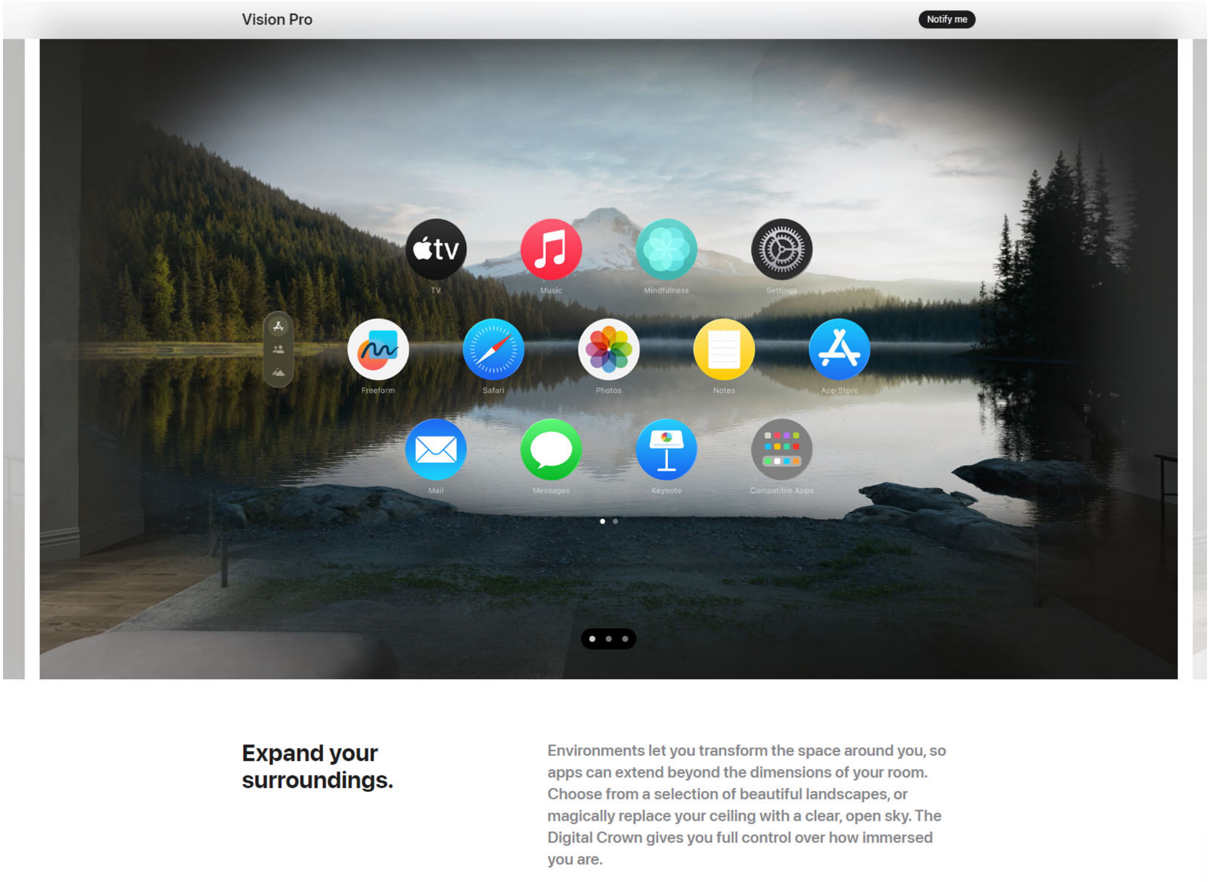


Figure 30. Promotional feature for ‘environments’ on the Apple Vision PRO (Apple Inc, 2023).

Moreover, identifying mechanisms to ensure academic findings are used to promote an evidence-based approach to virtual nature experiences remains pressing. This PhD has, in several domains, put findings directly into practice, but the success of these efforts relied on personal relationships and opportunism, rather than an established interface between creative, technical, and environmental disciplines. Formalising a ‘route to market’ for the deluge of people-nature-wellbeing research published each month, the majority of which still resides behind journal paywalls, would be as valuable to progressing the field of environmental psychology as it would commercial entities.

This might be particularly true for performance-related outcomes. Emerging evidence suggests that beyond restoration, virtual experiences of nature can enhance productive states such as ‘flow’ (Ruvimova et al., 2020). Yet if people begin to spend increasingly more time in virtual settings, a more important challenge may concern how to best highlight and foster the reciprocity that exists between nature and people. How could digital nature experiences be designed to not just improve wellbeing and increase productivity, but also represent part of a ‘personalised ecology’ (Gaston et al., 2023), ‘nudging’ users into developing a greater empathy for the natural world and concomitant pro-environmental actions (Nelson et al., 2019)?

When it comes to real-world interactions, the value of examining an urban-nature dichotomy is leading to ever-diminishing returns, as McDermott (1972) dryly observed, "*turning wilderness into a park is, after all, a gentle form of urbanization.*" As populations increase and urban densities rise, we must continue efforts to understand how best to 'live in cities naturally' (Hartig & Kahn, 2016). Our exploration of ephemeral phenomena highlighted how the awe-inspiring experience of nature might be readily accessed even in the most metropolitan of settings. Examining how to sign-post these opportunities through collaborative community-based interventions, such as the incredibly powerful *Green Space Dark Skies* project (greenspacedarkskies.uk), could mark a step change in the way urban landscapes are perceived and experienced.

Crucially, environmental psychologists can no longer ignore the role of lived experience and memories in their experimental work. Qualitative researchers have long asserted that experimental approaches to nature and health may be "*illusory*" if they do not account for the myriad individual factors that shape a person's responses to the natural world (Bell et al., 2019a). Whilst such a partisan stance might be unhelpful, the profound moderating role of memories in our data suggest that these factors must be incorporated into future studies hoping to dig deeper into the subtleties of people-nature interactions.

Rather than presenting a barrier to developments in the field, understanding the role of memories in stimulating powerful outcomes such as nostalgia could acknowledge a new breadth and depth in the 'affective potential' of natural settings. Perhaps more importantly still, the ability for positive memories to be repeatedly relived might lead to a process of 'mnemonic accumulation', whereby the positive affective components of nature-based experiences aggregate over a lifetime of repeated recall, leading to hitherto unquantified benefits. Exploratory work in this area should begin without delay.

8.4 Concluding remarks

Finally, it is with great regret that over the course of this PhD, societies across the world have continued to witness and participate in the reckless, egregious, wanton decimation of ecological systems (Marske et al., 2023). Far from being confined to those countries still undergoing rapid economic development, these acts of environmental vandalism are taking place in plain sight and on home turf (UK Parliament, 2022). This PhD has aimed, in a small way, to highlight the inextricable interconnectedness of human and natural systems, and digital forms of nature might continue to help in this endeavour. But it is only with concerted governmental and societal change that the future imagined by *Forest 404* will be averted.

We must all act now if we are to avoid the experience of healthy, thriving, biodiverse natural environments becoming the preserve of antiquity (Ring, 2020).

9. A note on impact

UK Research and Innovation define impact as "*an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia*" (UKRI, 2022). As part of the new wave of scientific studies that aim to integrate impact throughout their life cycle – rather than simply as an add-on at the project's end (UKRI, 2023) – this PhD embraced collaborative ways of working that might lead to demonstrable change both beyond and within academic boundaries.

As outlined in chapter 4, the notion of co-creation and reciprocity were central to these methods, which aimed to follow the blueprint for engaged research outlined by the Wellcome Centre for Cultures and Environments of Health (the funder of this PhD), which should begin with "*the articulation of the nature of the problem, the co-identification of issues to be researched and the co-creation of research questions, and leads on to collaborative research and the delivery of research outcomes that are beneficial for all partners*" (WCCEH, 2018).

Thus, whilst the broad area of enquiry for this thesis was established at its inception, the co-creation of its foci followed a participatory process that ensured the focus of its research addressed questions with real-world relevance. Collaborations with the BBC also led to atypical levels of publicity about, and interest in, this PhD. These snowballed to provide further opportunities for partnerships and engagement.

9.1 Mindful Escapes

The development of *Mindful Escapes* was hinted at in section 4.5, which arose following editorial and creative discussions between the BBC Natural History Unit and Headspace, a smartphone-based mindfulness tool that aims to "*improve the health and happiness of the world*" (Headspace, 2023). Following success with other BBC 'slow TV' programmes (bbc.co.uk/programmes/p02q34z8), which had included an hour long feature on the dawn chorus (bbc.co.uk/programmes/b05ttkx2), and with the country in the grip of the Covid-19 pandemic, *Mindful Escapes* aimed to blend archival footage of the natural world with meditative prose. The four-part series hoped to offer bespoke outcomes to audiences, such as enhanced calmness, positivity, and feelings of 'being in the moment' (BBC Four, 2020).

I was invited to participate as scientific consultant on the series (Fig. 31), providing a unique opportunity to put findings from this PhD, and the wider literature on nature and health, into practice. I was able to feed preliminary findings from our *Forest 404* and ephemeral phenomena studies into the programme's development, provide substantial desk research on the interactions between mindfulness and nature (e.g. Lymeus et al., 2018, 2019), and use the creative discussions surrounding music (section 4.5) as a catalyst for our *Soundscapes for Wellbeing* initiative. This process represented an archetypal example of digital nature being used for therapeutic outcomes, evidence-based design, and responsive, co-created research development.

A video outlining the science behind the series (bbc.co.uk/programmes/p08qqx4d) attracted over 157,000 views on Facebook (facebook.com/bbcearth/videos). Reviews were also positive, with The Guardian referring to its ability to encourage "*viewers to consider their breathing and imagine a 'deeper feeling of peace*'" (The Guardian, 2020b) and the Financial Times describing the series as "*soothing and light-as-air*" (The Financial Times, 2020). Although others were less convinced; "*this is a completely new and innovative way of using the format of "television", but the result is like a motivational quote that happens to move*" (The Guardian, 2020a).

BBC Four audience statistics showed that the series beat channel averages, achieving an average audience of 165,000, which was 66% higher than the 7pm slot average. The series was a particular success with females, a notable result on a channel that typically skews male, exceeding the channel slot average by 150%. The title was also popular with Black and minority ethnic audiences, who represented 13% of the audience, a figure that was substantially greater than the channel's slot average profile of 2%.

Deeper audience panel feedback mentioned both the escape the series offered, and its contrast to the typical format of natural history programming:

"*Fantastic. More Please. Great reminder that we need more time in today's rather seriously frightening world*" – Female, 65

"*A lovely escape for 30 minutes, the photography was stunning and very peaceful*" – Female, 67

"*It was so nice to be able to watch a programme about the natural world that I didn't have to turn away from because it involved killings or animals in pursuit of others*" – Female, 54

Mindful Escapes overtly placed the notion that virtual forms of nature can be good for wellbeing into the homes of many thousands of people. But throughout this PhD we also sought to stimulate debate about the interactions between people and nature in a diverse range of forums.

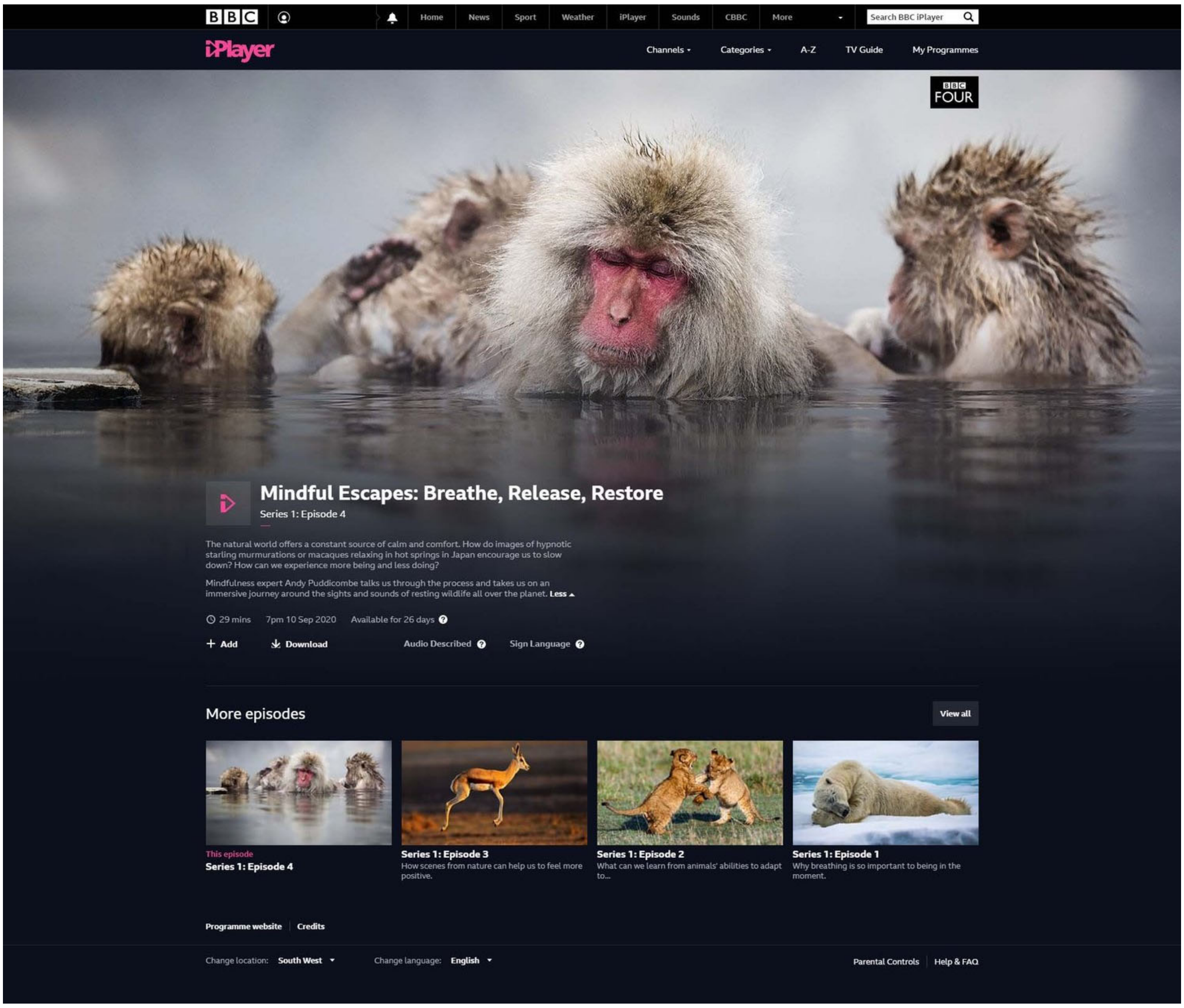


Figure 31. The BBC iPlayer page for the Mindful Escapes series and Alex Smalley, thrilled with his end credit.

9.2 Broader project reach

This PhD attracted a great deal of publicity and public interest throughout its duration, a trend that was initiated by the promotions surrounding *Forest 404*, reinvigorated by *Mindful Escapes*, and supercharged by *Soundscapes for Wellbeing*. The ebb and flow of this interest is neatly encapsulated by the traffic to the project website, shown in Fig. 32.

As a result of the promotions surrounding the PhD and its research, we were able to contribute to public discourse concerning the intersection of nature and health in several ways. Below are links to some of the highlights.

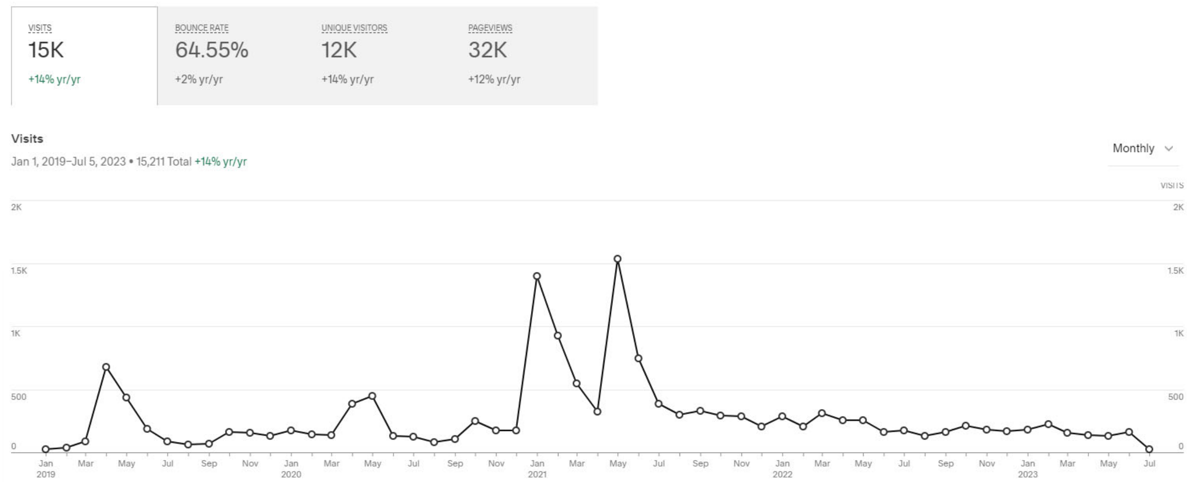


Figure 32. Monthly user traffic to the project website (virtual-nature.com) since January 2019.

9.2.1 Audio appearances

Forest 404, episode T1, "*Why should I listen to trees?*"
bbc.co.uk/sounds/play/p074m272

BBC Radio 4, Farming Today
https://youtu.be/B5EEwJdcVB8

BBC Radio 4, Today programme
https://vimeo.com/513853493

BBC Radio 3, Music Matters
https://vimeo.com/513850858

Eden Project podcast
https://apple.co/3NAERud

Curious cast, Canada
https://youtu.be/PgWUXNBMtJ0

BBC Radio Cornwall, James Dundon
https://youtu.be/IH-H3f1oNV0

Radio Adelaide, Australia
radioadelaide.org.au/2021/04/22/why-we-should-listen-to-trees

9.2.2 Television appearances

BBC World News
https://vimeo.com/543094210

BBC Two, Winterwatch
https://youtu.be/trsbBAafmG4

BBC One, Breakfast Live
(Link unavailable)

BBC Four online
bbc.co.uk/programmes/p08qqx4d

9.2.3 In print

BBC News (1)
https://www.bbc.co.uk/news/entertainment-arts-55746288

BBC News (2)
https://www.bbc.co.uk/news/health-52479763

BBC Culture
bbc.com/culture/article/20210609-the-sounds-that-make-us-calmer

Forbes
https://bit.ly/3NEY7qv

Washington Post (1)
https://wapo.st/3dc7b1X

Washington Post (2)
https://wapo.st/43coB8r

Süddeutsche Zeitung
https://bit.ly/3r7WV7c

Return to Nature (book)
https://bit.ly/3NYmqAS (and access pp58 here)

9.2.4 In person

House of Lords, Science and Technology Committee
https://bit.ly/3JKD30v

British Academy
https://bit.ly/3XLBF3t

BBC Academy
https://bit.ly/3rkGZyu

10. Appendix A

Supplementary information for study one, detailed in chapter five, and published in the journal *Global Environmental Change,* https://doi.org/10.1016/j.gloenvcha.2022.102497:

Forest 404: Using a BBC drama series to explore the impact of nature's changing soundscapes on human wellbeing and behavior

This file includes:

- Supplementary Text
- Figs. S1 to S2
- Tables S1 to S15
- Full experimental wording and consent form

Note that figure numbering is specific to each appendix, rather than part of the global document numbering.

Supplementary Text

Online implementation
The full wording of the experimental instrument is available at the end of this appendix. Here we provide an overview of the participant experience.

Information and consent
The experiment was hosted on the Open University's nQuire platform, an inquiry-based learning toolkit designed to support citizen-led science investigations. Calls to take part in the experiment were present at the end of every *Forest 404* podcast episode, which directed listeners to the *Forest 404* website. From there, participants were directed to the experiment page on nQuire. Respondents were initially presented with an information sheet detailing the experimental procedure, data handling, and process for withdrawal. They were asked to provide explicit online consent before being allowed to take part. Beyond the confirmation of consent, no questions within the experiment were mandatory.

Sound test
Upon beginning the experiment, participants were asked to complete a short sound test. This was designed to ensure their audio setup was optimized, they could hear the sounds they were about to play, and to familiarize them with the way the nQuire platform registers responses. Peak audio levels were normalized between conditions.

Vignette
Before listening to our nature-based experimental conditions, participants were asked to imagine a situation in which they felt stressed and cognitively fatigued. This approach was used due to the online nature of the experiment, which did not allow the measurement of actual stress inducement and recovery. A vignette-style mood induction was adapted in accordance with previous studies (Staats and Hartig, 2004) and participants were asked to imagine a stressful situation by reading the following paragraph:

"*Please imagine it's been a difficult time for you lately. There's been a lot going on and you've been feeling overstretched and on edge. You've also had trouble sleeping, found it difficult to concentrate, and feel irritable for no obvious reason. Now, to top it all off, you've just had an upsetting argument with a friend and feel very stressed out about it. You find yourself walking down a busy street and decide to sit on a bench and put your headphones on while you wait for a bus home."*

To enhance immersion in this narrative, participants were asked to listen to a busy urban soundscape while reading the above passage. This soundscape lasted for 40 seconds and consisted of traffic and construction noise, with passing vehicles, jackhammers, and clanking scaffold poles also audible.

Stimuli and exposure
Following the mood induction, participants were asked to listen to one of our 40-second nature-based stimuli, randomly chosen from the pool of 36. They were instructed to listen to the sound in full first, with their eyes closed if possible. When the sound had finished playing, they were then asked to scroll down and answer the 8 questions which followed (detailed in 'Measures development' below). They were told they could play the sound again whilst answering the questions if they found it helpful. Participants then repeated this process for two more sounds, again chosen at random. To maximize relevance to the stressful

vignette and to avoid possible ordering effects, we only considered data from respondents' first sound in our analyses, creating a between-participant design.

Demographics and debrief

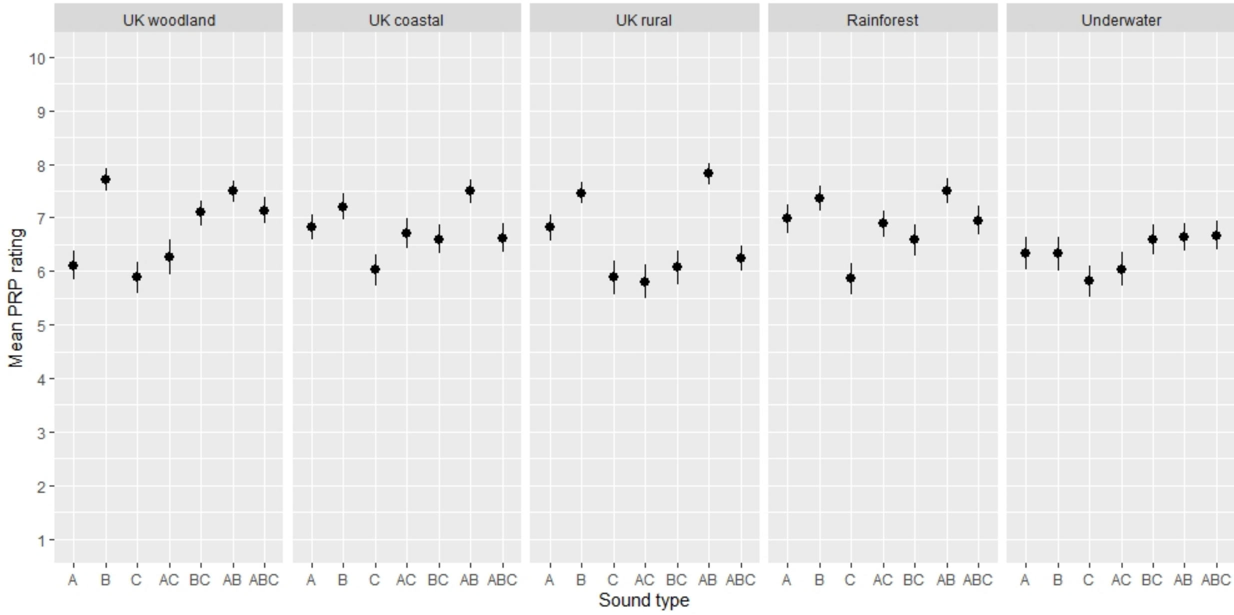
The experiment concluded with a series of demographic items. Upon completion of these sections, participants viewed a debrief screen which explained what would happen next in terms of analysis and publishing, and provided links to further information about the study.

Demographic questions

As highlighted in the main text, we included three demographic factors deemed to be important covariates in nature-health relationships in these analyses: sex, gender, and connection to nature. In addition, and in line with the UK's Monitoring Engagement with the Natural Environment (MENE) survey, we also collected data on a further series of classification questions. Relationships with these factors and our questions of interest were inconsistent and they will be explored in further analyses beyond the scope of the current paper. The full list of demographic and behavior-based questions were:

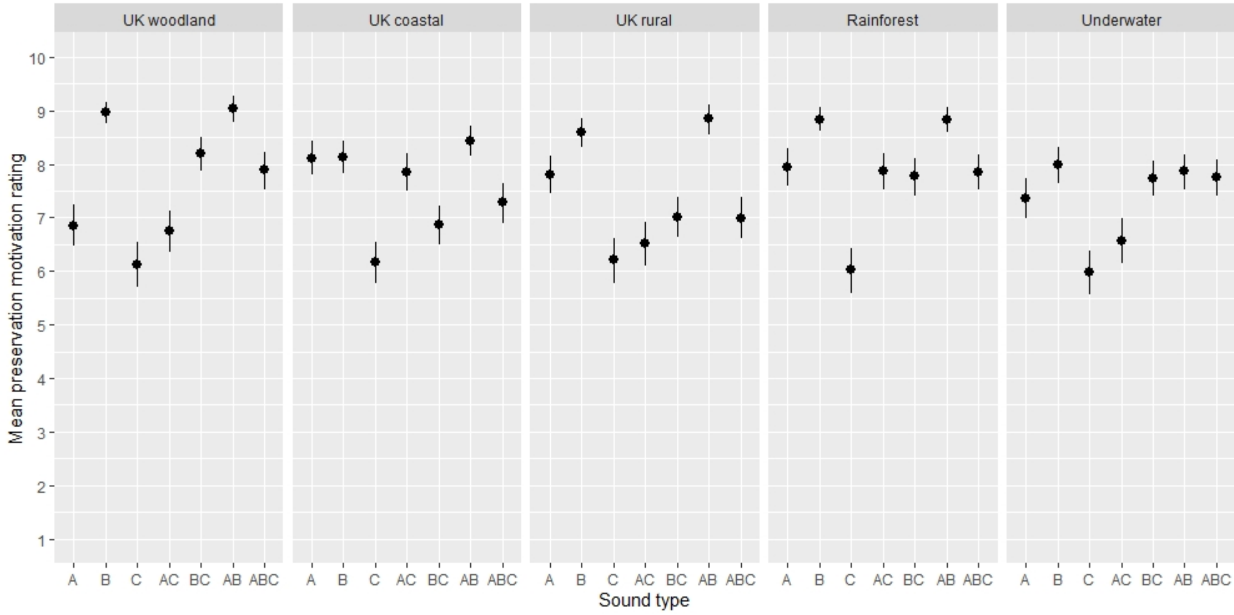
1. What is your age?
2. Do you consider yourself to be: Female; Male; Another sex or gender?
3. Which of the following regions do you live in?
4. How would you characterize the surroundings in which you currently live?
5. How would you characterize the surroundings in which you grew up as a child?
6. Thinking about your place in the world, to what extent do you feel 'part of nature'?
7. How often do you watch or listen to nature programs on the TV or radio?
8. How often do you spend time in nature-based environments?
9. Are you a member of any nature-based organizations, such as the National Trust or RSPB for example?

Figure S1.



Responses within biomes. Mean perceived restorative potential ratings for individual sounds, displayed according to biome of origin. Confidence intervals (95%) are also displayed. Patterns for sound types were highly similar across biomes and were thus collapsed together for analyses presented in the main text. Inter-biome comparisons are beyond the scope of the current paper but will be explored in a subsequent publication.

Figure S2.



Responses within biomes. Mean preservation motivation ratings for individual sounds, displayed according to biome of origin. Confidence intervals (95%) are also displayed. Patterns for sound types were highly similar across biomes and were thus collapsed together for analyses presented in the main text. Inter-biome comparisons are beyond the scope of the current paper but will be explored in a subsequent publication.

Table S1.

Variable	N	Male, N = 2618[1]	Female, N = 4798[1]	Another sex or gender, N = 53[1]
Age	7347			
18-25		221 (8.6%)	599 (13%)	22 (42%)
26-35		460 (18%)	936 (20%)	13 (25%)
36-45		420 (16%)	798 (17%)	10 (19%)
46-55		654 (25%)	1084 (23%)	4 (7.7%)
56-65		528 (21%)	931 (20%)	3 (5.8%)
66-75		240 (9.3%)	319 (6.8%)	0 (0%)
76+		34 (1.3%)	37 (0.8%)	0 (0%)
Prefer not to answer		13 (0.5%)	21 (0.4%)	0 (0%)
Connection to nature	7425	7 (6, 8)	7 (6, 9)	7 (5, 8)

[1]Statistics presented: n (%); median (IQR)

Participant characteristics. Note the relatively low prevalence of those reporting their sex as ‘Another sex or gender’. Total sample size = 7,596. Varying Ns are due to missing data for specific questions (no questions within the experiment were mandatory).

Table S2.

Characteristic	Beta	95% CI[1]	p-value	Fit
(Intercept)	3.12	2.79, 3.44	<0.001	
Sound type				
Silence	–	–		
A	2.63	2.33, 2.93	<0.001	
B	3.26	2.95, 3.56	<0.001	
C	1.92	1.62, 2.23	<0.001	
AC	2.36	2.06, 2.67	<0.001	
BC	2.59	2.29, 2.89	<0.001	
AB	3.41	3.11, 3.72	<0.001	
ABC	2.71	2.40, 3.01	<0.001	
Connection to nature	0.13	0.11, 0.16	<0.001	
Age group				
18-35	–	–		
36+	-0.01	-0.11, 0.09	0.847	
Sex				
Male	–	–		
Female	-0.06	-0.15, 0.04	0.250	
Another sex or gender	-0.29	-0.85, 0.26	0.299	
				R^2 = 0.110** 95% CI [0.10, 0.12]

[1]CI = Confidence Interval

Hierarchies between soundscapes. Multiple linear regression with perceived restorative potential as dependent variable. Silent sound type as reference condition. Beta represents unstandardized regression coefficients.

Table S3.

Characteristic	**Beta**	**95% CI[1]**	**p-value**	**Fit**
(Intercept)	6.53	6.32, 6.74	<0.001	
Sound type				
AB	—	—		
A	-0.78	-0.95, -0.61	<0.001	
B	-0.16	-0.33, 0.02	0.074	
C	-1.49	-1.66, -1.32	<0.001	
AC	-1.05	-1.22, -0.88	<0.001	
BC	-0.82	-1.00, -0.65	<0.001	
ABC	-0.71	-0.88, -0.53	<0.001	
Silence	-3.41	-3.72, -3.11	<0.001	
Connection to nature	0.13	0.11, 0.16	<0.001	
Age group				
18-35	—	—		
36+	-0.01	-0.11, 0.09	0.847	
Sex				
Male	—	—		
Female	-0.06	-0.15, 0.04	0.250	
Another sex or gender	-0.29	-0.85, 0.26	0.299	
				R^2 = 0.110** 95% CI [0.10, 0.12]

[1]CI = Confidence Interval

Comparisons. Multiple linear regression with perceived restorative potential as dependent variable. AB sound type (abiotic and biotic combined) set as reference condition for sound type comparisons presented in the main text. Beta represents unstandardized regression coefficients.

Table S4.

Characteristic	**Beta**	**95% CI**[1]	**p-value**	**Fit**
(Intercept)	5.04	4.83, 5.25	<0.001	
Sound type				
C	–	–		
A	0.71	0.53, 0.88	<0.001	
B	1.33	1.16, 1.50	<0.001	
AB	1.49	1.32, 1.66	<0.001	
AC	0.44	0.26, 0.61	<0.001	
BC	0.67	0.49, 0.84	<0.001	
ABC	0.78	0.61, 0.96	<0.001	
Silence	-1.92	-2.23, -1.62	<0.001	
Connection to nature	0.13	0.11, 0.16	<0.001	
Age group				
18-35	–	–		
36+	-0.01	-0.11, 0.09	0.847	
Sex				
Male	–	–		
Female	-0.06	-0.15, 0.04	0.250	
Another sex or gender	-0.29	-0.85, 0.26	0.299	
				R^2 = 0.110** 95% CI [0.10, 0.12]

[1]CI = Confidence Interval

Comparisons. Multiple linear regression with perceived restorative potential as dependent variable. C sound type (poem only) set as reference condition for sound type comparisons presented in the main text. Beta represents unstandardized regression coefficients.

Table S5.

Characteristic	Beta	95% CI[1]	p-value	Fit
(Intercept)	2.60	2.17, 3.03	<0.001	
Sound type				
Silence	–	–		
A	3.82	3.42, 4.21	<0.001	
B	4.70	4.31, 5.10	<0.001	
C	2.33	1.93, 2.72	<0.001	
AC	3.30	2.90, 3.70	<0.001	
BC	3.70	3.31, 4.10	<0.001	
AB	4.81	4.41, 5.20	<0.001	
ABC	3.70	3.30, 4.09	<0.001	
Connection to nature	0.13	0.10, 0.16	<0.001	
Age group				
18-35	–	–		
36+	0.24	0.11, 0.38	<0.001	
Sex				
Male	–	–		
Female	0.19	0.07, 0.32	0.003	
Another sex or gender	0.08	-0.63, 0.80	0.819	
				R^2 = 0.139** 95% CI [0.12, 0.15]

[1]CI = Confidence Interval

Preservation motivation. Multiple linear regression with preservation motivation as the dependent variable. Silent sound type as reference condition. Beta represents unstandardized regression coefficients.

Table S6.

Characteristic	**Beta**	**95% CI[1]**	**p-value**	**Fit**
(Intercept)	7.41	7.13, 7.68	<0.001	
Sound type				
AB	–	–		
A	-0.99	-1.22, -0.77	<0.001	
B	-0.10	-0.33, 0.12	0.4	
C	-2.48	-2.71, -2.26	<0.001	
AC	-1.51	-1.74, -1.28	<0.001	
BC	-1.10	-1.33, -0.88	<0.001	
ABC	-1.11	-1.34, -0.88	<0.001	
Silence	-4.81	-5.20, -4.41	<0.001	
Connection to nature	0.13	0.10, 0.16	<0.001	
Age group				
18-35	–	–		
36+	0.24	0.11, 0.38	<0.001	
Sex				
Male	–	–		
Female	0.19	0.07, 0.32	0.003	
Another sex or gender	0.08	-0.63, 0.80	0.819	
				R^2 = 0.139** 95% CI [0.12, 0.15]

[1]CI = Confidence Interval

Comparisons. Multiple linear regression with preservation motivation as dependent variable. AB sound type (abiotic and biotic combined) set as reference condition for sound type comparisons presented in the main text. Beta represents unstandardized regression coefficients.

Table S7.

Characteristic	Beta	95% CI[1]	p-value	Fit
(Intercept)	4.92	4.65, 5.20	<0.001	
Sound type				
C	–	–		
A	1.49	1.26, 1.71	<0.001	
B	2.38	2.15, 2.60	<0.001	
AB	2.48	2.26, 2.71	<0.001	
AC	0.97	0.74, 1.20	<0.001	
BC	1.38	1.15, 1.60	<0.001	
ABC	1.37	1.14, 1.60	<0.001	
Silence	-2.33	-2.72, -1.93	<0.001	
Connection to nature	0.13	0.10, 0.16	<0.001	
Age group				
18-35	–	–		
36+	0.24	0.11, 0.38	<0.001	
Sex				
Male	–	–		
Female	0.19	0.07, 0.32	0.003	
Another sex or gender	0.08	-0.63, 0.80	0.819	
				R^2 = 0.139** 95% CI [0.12, 0.15]

[1]CI = Confidence Interval

Comparisons. Multiple linear regression with preservation motivation as dependent variable. C sound type (poem only) set as the reference condition for sound type comparisons presented in the main text. Beta represents unstandardized regression coefficients.

Table S8.

Characteristic	Beta	95% CI[1]	p-value	Fit
(Intercept)	4.78	4.52, 5.03	<0.001	
Memories				
None	—	—		
Negative	-1.36	-1.79, -0.92	<0.001	
Mixed	0.25	0.02, 0.48	0.037	
Positive	1.94	1.78, 2.09	<0.001	
Connection to nature	0.08	0.05, 0.11	<0.001	
Age group				
18-35	—	—		
36+	0.10	-0.04, 0.24	0.172	
Sex				
Male	—	—		
Female	0.07	-0.06, 0.21	0.284	
Another sex or gender	0.05	-0.64, 0.74	0.890	
				R^2 = 0.240** 95% CI [0.21, 0.26]

[1]CI = Confidence Interval

The moderating role of memories. Multiple linear regression with perceived restorative potential as dependent variable. 'No memories' category as reference condition. Beta represents unstandardized regression coefficients. Note that the format of our memory-based question prevented us from interpreting memories for our combined soundscapes (we could not determine which component the memory related to), so for these analyses we focused on single component soundscapes (A, B, or C) collapsed together.

Table S9.

Characteristic	Beta	95% CI[1]	p-value	Fit
(Intercept)	4.98	4.62, 5.34	<0.001	
Memories				
None	–	–		
Negative	-0.90	-1.51, -0.29	0.004	
Mixed	0.34	0.01, 0.67	0.043	
Positive	2.33	2.12, 2.55	<0.001	
Connection to nature	0.08	0.04, 0.13	<0.001	
Age group				
18-35	–	–		
36+	0.33	0.13, 0.52	0.001	
Sex				
Male	–	–		
Female	0.37	0.18, 0.56	<0.001	
Another sex or gender	0.74	-0.21, 1.70	0.127	
				R^2 = 0.182** 95% CI [0.16, 0.20]

[1]CI = Confidence Interval

Memories and preservation motivation. Multiple linear regression with preservation motivation as dependent variable. 'No memories' category as reference condition. Beta represents unstandardized regression coefficients.

Table S10.

Characteristic	Beta	95% CI[1]	p-value	Fit
(Intercept)	5.08	4.71, 5.44	<0.001	
Memories				
No	–	–		
Yes	1.11	0.80, 1.41	<0.001	
Sound type				
A	–	–		
B	0.51	0.13, 0.89	0.009	
C	-0.78	-1.11, -0.45	<0.001	
Age group				
18-35	–	–		
36+	0.05	-0.09, 0.20	0.471	
Sex				
Male	–	–		
Female	0.00	-0.14, 0.14	0.985	
Another sex or gender	-0.32	-1.04, 0.40	0.386	
Connection to nature	0.09	0.05, 0.12	<0.001	
Memory * sound type interactions				
Memories = Yes * sound type B	0.17	-0.25, 0.59	0.437	
Memories = Yes * sound type C	0.58	0.19, 0.96	0.003	
				R^2 = 0.171** 95% CI [0.15, 0.19]

[1]CI = Confidence Interval

Memory x sound type interactions for restorative potential. Multiple linear regression with perceived restorative potential as dependent variable. ‘No memories’ and sound type ‘A’ (abiotic sounds) as reference categories and memory x sound type interactions included. Beta represents unstandardized regression coefficients.

Table S11.

Memory group	Sound type	Fitted value	SE	CI lower	CI upper
No	A	5.71	0.14	5.44	5.99
Yes	A	6.82	0.07	6.69	6.95
No	B	6.22	0.13	5.96	6.49
Yes	B	7.50	0.07	7.37	7.63
No	C	4.94	0.09	4.76	5.12
Yes	C	6.62	0.08	6.47	6.77

Fitted values. Estimated marginal means from the model described in Table S10 (perceived restorative potential predicted by memory group and sound type) and shown in Figure 5A in the main text.

Table S12.

Characteristic	Beta	95% CI[1]	p-value	Fit
(Intercept)	5.58	5.09, 6.06	<0.001	
Memories				
No	–	–		
Yes	1.21	0.80, 1.61	<0.001	
Sound type				
A	–	–		
B	0.91	0.41, 1.42	<0.001	
C	-1.65	-2.09, -1.21	<0.001	
Age group				
18-35	–	–		
36+	0.29	0.10, 0.49	0.003	
Sex				
Male	–	–		
Female	0.27	0.09, 0.46	0.004	
Another sex or gender	0.35	-0.60, 1.29	0.470	
Connection to nature	0.10	0.05, 0.14	<0.001	
Memory * sound type interactions				
Memories = Yes * sound type B	0.00	-0.56, 0.56	0.994	
Memories = Yes * sound type C	0.74	0.23, 1.26	0.005	
				R^2 = 0.199** 95% CI [0.17, 0.22]

[1]CI = Confidence Interval

Memory x sound type interactions for preservation motivation. Multiple linear regression with preservation motivation as dependent variable. ‘No memories’ and sound type ‘A’ (abiotic sounds) as reference categories and memory x sound type interactions included. Beta represents unstandardized regression coefficients.

Table S13.

Memory group	Sound type	Fitted value	SE	CI lower	CI upper
No	A	6.64	0.19	6.27	7.00
Yes	A	7.84	0.09	7.67	8.01
No	B	7.55	0.18	7.20	7.89
Yes	B	8.76	0.09	8.58	8.93
No	C	4.99	0.12	4.74	5.23
Yes	C	6.94	0.10	6.73	7.14

Fitted values. Estimated marginal means from the model described in Table S12 (preservation motivation predicted by memory group and sound type) shown in Figure 5B in the main text.

Table S14.

Variable	*M*	*SD*	1	2	3	4
1. PRP (combined)	6.61	2.09				
2. PRP (single item)	6.47	2.17	.88** [.87, .88]			
3. Fascination	6.38	2.43	.89** [.88, .89]	.64** [.63, .66]		
4. Being away	6.98	2.39	.92** [.92, .93]	.75** [.74, .76]	.73** [.72, .74]	
5. Preservation motivation	7.48	2.78	.64** [.63, .65]	.55** [.53, .56]	.57** [.56, .59]	.60** [.58, .61]

Note. M and *SD* are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation. ** indicates $p < .01$.

Correlations among our dependent variables. '*PRP (combined)*' is our composite measure of perceived restorative potential described in the main text, created by collapsing our '*PRP (single)*', '*Fascination*', and '*Being away*' items.

Table S15.

Outcome	Predictor	Effects pathway	Estimate	95% CIs[1]
Perceived restorative potential (PRP)	**Sound type A vs C**	Direct (Total)	0.34***	0.20, 0.49
	Sound type B vs C	Direct (Total)	1.01***	0.86, 1.17
	Memories Yes vs. No	Direct (Total)	1.45***	1.27, 1.62
		Total variance explained[2] (R^2)	21%	
Preservation motivation	**Sound type A vs C**	Direct	0.88***	0.71, 1.07
		Indirect via PRP	0.25***	0.14, 0.35
		Total effect	1.13***	0.92, 1.35
		Proportion mediated	**0.22**	
	Sound type B vs C	Direct	1.36***	1.19, 1.54
		Indirect via PRP	0.72***	0.61, 0.86
		Total effect	2.08***	1.89, 2.28
		Proportion mediated	**0.35**	
	Memories ‘yes’ vs ‘no’	Direct	0.53***	0.33, 0.74
		Indirect via PRP	1.04***	0.90, 1.18
		Total effect	1.56***	1.33, 1.80
		Proportion mediated	**0.67**	
	Restorative potential	Direct (total)	0.72***	0.67, 0.76
		Total variance explained[2] (R^2)	48%	
Covariances	**Memories ↔ sound type A**	Direct	0.053***	0.045, 0.061
	Memories ↔ sound type B	Direct	0.049***	0.041, 0.056

[1]CI = Confidence Interval.
[2]Includes age, sex, and connection to nature as covariates.
Coefficients are bootstrapped (1,000 samples).
p-values denoted by asterisks *** $p<0.001$.

Mediation model. Tabular results of mediation analysis shown in Figure 6 in the main text and testing perceived restorative potential as mediator of the effects of memories and sound type on preservation motivation.

Full experimental wording

Survey home page text

[Title]
The Forest 404 Experiment

[Subtitle]
We want to explore how people respond to the sounds of nature.

[Body]
Welcome to the Forest 404 Experiment.

This experiment is linked to the BBC's 'Forest 404' podcast series, set in a distant future where a world without nature is imagined.

The drama's main character, Pan, works in a data library where she archives audio recordings from the 21st century. One day she stumbles upon a recording of a rainforest she is inexplicably drawn to and begins a quest to understand its origin and meaning.

We want to explore the emotions Pan has in more detail, and discover how people respond to the sounds of nature. You can help us by taking part in a short online study.

We'll ask you to listen to several sounds as part of the experiment, so you'll need some headphones or speakers at the ready.

[Scroll down to find out more and get started.]

Information and consent form

Background
Scientific research has shown that spending time in nature can be good for people's wellbeing, and the aim of this experiment is to learn more about how people feel when listening to the sounds of nature.

You'll be asked to listen to several sounds which are chosen at random, such as birds singing or waves washing onto the beach. We are also interested in how people feel about cultural interpretations of nature, so some of the sounds might contain short snippets of nature-based poetry.

Information about taking part

- The experiment should take between 5 and 10 minutes to complete and anyone who is aged 18 or over can take part.

- You can withdraw at any time by closing your browser window. Any data you have provided up until that point will not be saved.

- All the responses you make will be anonymous - you won't be personally identifiable in any way. Once collected, the data will be stored and shared securely.

- After July 2024, all data from the experiment will be made freely accessible for others to use in their own research. Your responses will remain anonymous - you will not be able to be personally identified in this dataset.

Read more about your participation here [text on following page].

The Forest 404 Experiment is a research partnership between BBC Sound, the BBC Natural History Unit, the University of Bristol, the Open University and the University of Exeter.

More information page

This information page is for people wanting to know more about taking part in the BBC Forest 404 Experiment. Please read this information carefully before deciding to participate.

What is the aim of the experiment?
Scientific research has shown that spending time in nature can be good for people's physical and mental health. Some of these effects can even be gained just by watching or listening to the natural environment.

The aim of this experiment is to find out more about how people feel when listening to the sounds of nature. This might include the wind in the trees, birds singing, or waves washing on to the beach.

Because we are also interested in how poems and stories about nature may affect these experiences, some of the sounds you will be asked to listen to might contain short snippets of nature-based poetry.

The results will help us to better understand the value of natural soundscapes for human wellbeing and inform efforts to protect them.

This survey is being undertaken as part of a collaboration between the BBC, the University of Bristol, the Open University and the University of Exeter.

Who can take part?
Anyone who is aged 18 or over can take part. You will be asked to listen to several different sounds and so must have either headphones or speakers at the ready.

What will I be asked to do?
The experiment should take between 5 and 10 minutes to complete. It consists of four main sections:

1. Sound test – to make sure you can hear the audio correctly;
2. Mood setting – asking you to imagine a certain scenario;
3. Soundscapes – listening to three 30 second clips, and answering several short questions about how they made you feel;
4. Background – questions to help us understand how soundscapes affect people with different characteristics. For example, *where did you grow up?*

There are no right or wrong answers - we are genuinely interested in your views. For some of the questions you may indicate that you "prefer not to answer" if you wish.

Can I change my mind and withdraw from the survey?
You can withdraw from the survey at any time (without giving a reason) by closing your browser window. Any data you have provided up until that point will not be saved.

What data or information is collected and what use will be made of it?
All the responses you make to the questions in this survey will be recorded by the Open University nQuire platform. All responses you provide will be anonymous - you won't be personally identifiable in any way. Once collected, the data will be stored on an offline server and only shared securely between selected people at the Open University, the University of Bristol, and the University of Exeter.

We aim to report the results of the experiment on a future radio programme, via project partner websites, academic publications, and press releases. As we are not collecting any personal data from you, you will not be personally identifiable in any research output. After July 2024, all data from the experiment will be made freely accessible to the public. This means anyone could apply to use it for their own research or commercial purposes. Your responses will however, remain anonymous - you will not be able to be personally identified in this dataset.

If you have any questions about this project or wish to know the results of the project please contact: Prof Peter Coates on P.A.Coates@bristol.ac.uk or Alex Smalley on A.J.Smalley@exeter.ac.uk.

[Click here to return to the experiment.]

Confirm and consent form
I have read and understand the information about this experiment. I know that:

1. My participation in the project is entirely voluntary.
2. I am free to withdraw from the survey at any time by closing my browser window.
3. The data will be retained in secure storage.
4. The results of the project may be published but my contribution will be anonymous.
5. A fully anonymised dataset including my responses will be made publicly accessible after July 2024.

By checking the box below, I agree to take part in this experiment and confirm that I am aged 18 or above.

▢ I confirm and consent

<u>Experiment section 1</u>

[Title]
Sound Test

Thank you for agreeing to take part!

Before we can start, we need to check you can hear the sounds we're going to use. (Headphones provide the best experience but if you don't have these, speakers will be fine too.)

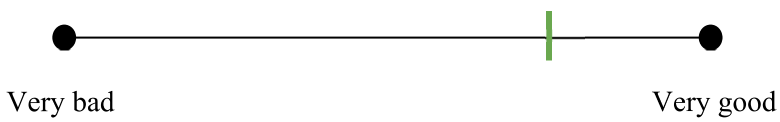
Please make sure your speakers or headphones are connected to your device and then click 'play' on the sound below.

How good is your listening experience?

Adjust your speakers, headphones, or the volume of your device until you can hear the sound comfortably. You can replay it as many times as necessary until you find the correct level.

When you are happy, please use the sliding scale below to rate the quality of your listening experience.

(We are only asking you to rate how good your audio setup is here, not to rate the sound itself.)



How are you listening to the sounds in this experiment?

- ▢ Headphones
- ▢ External speakers
- ▢ Inbuilt phone or tablet speaker
- ▢ Other

Section 2

[Title]
Setting the mood

Before listening to some nature-based sounds, we'd like you to imagine a situation in which you feel stressed.

Please press play on the following sound while you read the passage below:

[Accompanying 40 second urban soundscape]

Please imagine it's been a difficult time for you lately. There's been a lot going on and you've been feeling overstretched and on edge.

You've also had trouble sleeping, found it difficult to concentrate, and feel irritable for no obvious reason.

Now, to top it all off, you've just had an upsetting argument with a friend and feel very stressed out about it.

You find yourself walking down a busy street and decide to sit on a bench and put your headphones on while you wait for a bus home.

When you're ready, press the arrow below to listen to your next sound.

<u>Section 3</u> [repeated 3 times]

[Title]
Nature sound

Please play the sound below and listen to it with your eyes closed. Try to immerse yourself in what you hear.

Once it has finished, please answer the following questions – you can replay the sound as you answer if you like.

1. Thinking about your stressful scenario, to what extent do you think listening to this sound would help you recover and feel better in that moment?

Not all — Completely

2. How pleasant do you find the experience of listening to this sound?

Very unpleasant — Very pleasant

3. Do you find this sound boring or exciting?

Very boring — Very exciting

4. Do you find this sound chaotic or calm?

Very chaotic　　　　　　　　　　　　　　Very calm

5. To what extent do you agree with this statement?

"Listening to this sound is fascinating; it holds my interest and awakens my curiosity."

Not all　　　　　　　　　　　　　　Completely

6. To what extent do you agree with this statement?

"Listening to this sound allows me to feel far away from everyday thoughts and concerns."

Not all　　　　　　　　　　　　　　Completely

7. Do you have any memories associated with this kind of sound? If so, are they mostly positive, negative or mixed?

▢ No memories
▢ Mostly positive memories
▢ Mostly negative memories
▢ A mix of positive and negative

8. Imagine you are Pan from the Forest 404 podcast. You are working in the data library and this is the file you have just been asked to process. What do you think you would do with this sound?

Definitely delete　　　　　　　　　　　　　　Definitely keep

Section 6

[Title]
About you

Now we'd like to ask some questions about you. These will help us understand how different types of people feel about the sounds of nature.

1. What is your age?

▢ 18-25
▢ 26-35
▢ 36-45
▢ 46-55
▢ 56-65
▢ 66-75
▢ 76+
▢ Prefer not to answer

2. Do you consider yourself to be:

▢ Female
▢ Male
▢ Another sex or gender
▢ Prefer not to answer

3. Which of the following regions do you live in?

▢ London
▢ South West
▢ South East
▢ West Midlands
▢ East Midlands
▢ East England
▢ Yorkshire and the Humber
▢ North West
▢ North East
▢ Wales
▢ Scotland
▢ Northern Ireland

▢ Another country
▢ Other region/don't know
▢ Prefer not to answer

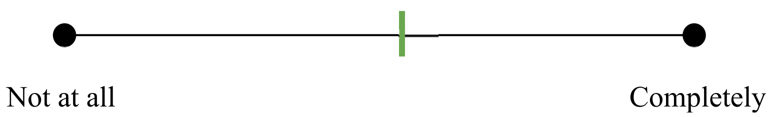
4. How would you characterise the surroundings in which you currently live? (Tick all that apply.)

▢ Urban
▢ Suburban
▢ Rural
▢ Coastal
▢ Other
▢ Prefer not to answer

5. How would you characterise the surroundings in which you grew up as a child? (tick all that apply)

▢ Urban
▢ Suburban
▢ Rural
▢ Coastal
▢ Other
▢ Prefer not to answer

6. Thinking about your place in the world, to what extent do you feel 'part of nature'?



7. How often do you watch or listen to nature programmes on the TV or radio?

□ Once a week or more often
□ Once every 2 or 3 weeks
□ Once a month
□ Once every 2 or 3 months
□ Once or twice a year
□ Never
□Prefer not to answer

8. How often do you spend time in nature-based environments?

These would be places you consider to be natural environments. They might feature plants and animals, and could include a garden, park, forest, or beach for example.

□ Once a week or more often
□ Once every 2 or 3 weeks
□ Once a month
□ Once every 2 or 3 months
□ Once or twice a year
□ Never
□Prefer not to answer

9. Are you a member of any nature-based organisations, such as the National Trust or RSPB for example?

▢ Yes
▢ No

Thank you page

Thank you for taking part in this study!

We're testing a total of 36 soundscapes in this experiment and responses like yours will help us to understand how the sounds of nature might affect wellbeing.

Our analysis will allow us to see if patterns exist in the way people rate and respond to the audio we have tested, and will form the first stages in exploring how sound could be used in a therapeutic intervention to improve people's mental health.

More information about the project can be found at www.bbc.co.uk/forest and https://virtual-nature.com.

As soon as we have analysed the data you have helped us to collect, we will be publishing our findings as widely as possible. Look out for them appearing on social media, on the project website, and across the BBC.

Alternatively, you can email Peter Coates on P.A.Coates@bristol.ac.uk, or Alex Smalley on a.j.smalley@exeter.ac.uk for more information on the outcomes of this project.

11. Appendix B

Supplementary information for study two, detailed in chapter six, and published in the *Journal of Environmental Psychology*, https://doi.org/10.1016/j.jenvp.2023.101955:

Beyond blue-sky thinking: Diurnal patterns and ephemeral meteorological phenomena impact appraisals of beauty, awe, and value in urban and natural landscapes

This file includes:

- Experimental procedure outline
- Tables S1 to S9
- Full experimental wording and consent form

Note that figure numbering is specific to each appendix, rather than part of the global document numbering.

Experimental procedure
After following the link provided by the consumer panel (Cint), potential participants were first asked to read an information sheet and then required to agree to a series of consent conditions. Once consent had been granted, participants entered the online experiment and were initially asked to complete the six-item Nature Connection Index (Richardson et al., 2019). Respondents were then randomly allocated to either the urban or nature-based landscape group. They were presented with 6 animating images in a randomized order, each showing the same landscape with a different ephemeral phenomenon. Images were viewed one at a time, anchored to the top of the screen, and our dependent measures were presented beneath.

Participants could scroll through and answer these questions while the image remained in view. Based on adaptive approach or avoidance processing, a significant amount of information can be acquired from very short (<100ms) exposures to landscape imagery (Greene and Oliva, 2009). However, in order to capture a complete picture of perceptual reactions to our scenes, participants could view the image for as long as needed to make their assessments. We could not monitor time spent on each stimulus.

Following the final image, participants were invited to share their own memorable experiences via a free text response (not analyzed here). Respondents then provided demographic data previously shown to be important covariates in landscape preferences such as age and sex (Howley, 2011; Häfner et al., 2017). Finally, participants were prompted to submit their answers and exited the experiment to a debrief page.

Table S1. Means, standard deviations, and correlations for the dependent variables considered in analyses presented in the main paper.

Variable	*M*	*SD*	1	2
1. Beauty	7.32	2.35		
2. Awe	7.07	2.46	.84** [.83, .84]	
3. Willingness to pay	9.20	6.67	.57** [.56, .58]	.56** [.55, .57]

M and *SD* represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. * indicates $p < .05$. ** indicates $p < .01$.

Table S2. Unadjusted coefficients for our three mixed models with beauty, awe, and willingness-to-pay to visit as the dependent variables, and covariates excluded. 'Blue-sky' was the reference ephemeral condition, and 'urban' the reference landscape group.

	DV = Beauty		**DV = Awe**		**DV = Willingness to pay**	
Characteristic	Beta	95% CI[1]	Beta	95% CI[1]	Beta	95% CI[1]
(Intercept)	6.38	6.26, 6.50	5.92	5.79, 6.05	8.04	7.68, 8.40
Landscape						
Urban	—	—	—	—	—	—
Nature	1.89	1.72, 2.06	1.79	1.61, 1.97	2.40	1.89, 2.92
Condition						
Sunrise	0.58	0.46, 0.69	0.75	0.63, 0.87	0.82	0.57, 1.07
Blue-sky (control)	—	—	—	—	—	—
Storm	-0.47	-0.59, -0.36	0.23	0.11, 0.35	-1.03	-1.28, -0.78
Rainbow	0.63	0.51, 0.74	0.96	0.84, 1.08	0.77	0.52, 1.02
Sunset	0.64	0.53, 0.75	0.76	0.64, 0.88	0.93	0.68, 1.18
Night-time	0.04	-0.07, 0.15	0.24	0.12, 0.36	0.02	-0.23, 0.27
Condition*Landscape						
Sunrise * Nature	-0.18	-0.34, -0.02	-0.18	-0.35, -0.01	0.15	-0.21, 0.50
Storm * Nature	-0.77	-0.93, -0.61	-0.76	-0.93, -0.59	-1.34	-1.69, -0.99
Rainbow * Nature	-0.74	-0.90, -0.58	-0.75	-0.92, -0.58	-0.85	-1.20, -0.49
Sunset * Nature	-0.21	-0.37, -0.05	-0.23	-0.40, -0.06	-0.19	-0.54, 0.16
Night-time * Nature	-0.94	-1.10, -0.79	-0.92	-1.10, -0.75	-1.35	-1.70, -0.99

[1]CI = Confidence Interval

Table S3. Fitted values for the model shown in Table 3 and depicted in Figure 3A in the main paper, with **beauty** as the dependent variable.

Landscape	Phenomena	Fitted value	SE	95% CI lower	95% CI upper
Urban	Blue-sky (control)	6.37	0.06	6.26	6.49
	Sunrise	6.95	0.06	6.84	7.07
	Storm	5.90	0.06	5.79	6.02
	Rainbow	7.00	0.06	6.89	7.12
	Sunset	7.02	0.06	6.90	7.13
	Night-time	6.42	0.06	6.30	6.53
Nature	Blue-sky (control)	8.27	0.06	8.16	8.39
	Sunrise	8.67	0.06	8.56	8.78
	Storm	7.04	0.06	6.92	7.15
	Rainbow	8.16	0.06	8.04	8.27
	Sunset	8.70	0.06	8.59	8.82
	Night-time	7.37	0.06	7.25	7.48

[1]CI = Confidence Interval

Table S4. Fitted values for the model shown in Table 3 and depicted in Figure 3B in the main paper, with **awe** as the dependent variable.

Landscape	Phenomena	Fitted value	SE	95% CI lower	95% CI upper
Urban	Blue-sky (control)	5.92	0.06	5.80	6.04
	Sunrise	6.67	0.06	6.55	6.79
	Storm	6.15	0.06	6.03	6.27
	Rainbow	6.88	0.06	6.76	7.00
	Sunset	6.68	0.06	6.56	6.80
	Night-time	6.15	0.06	6.03	6.27
Nature	Blue-sky (control)	7.72	0.06	7.59	7.84
	Sunrise	8.29	0.06	8.17	8.41
	Storm	7.19	0.06	7.07	7.31
	Rainbow	7.93	0.06	7.81	8.05
	Sunset	8.25	0.06	8.13	8.37
	Night-time	7.03	0.06	6.91	7.15

[1]CI = Confidence Interval

Table S5. Fitted values for the model shown in Table 3 and depicted in Figure 4 in the main paper, with **willingness-to-pay** as the dependent variable.

Landscape	Phenomena	Fitted value	SE	95% CI lower	95% CI upper
Urban	Blue-sky (control)	8.05	0.18	7.70	8.40
	Sunrise	8.88	0.18	8.53	9.23
	Storm	7.01	0.18	6.66	7.36
	Rainbow	8.82	0.18	8.47	9.17
	Sunset	8.98	0.18	8.63	9.33
	Night-time	8.06	0.18	7.71	8.41
Nature	Blue-sky (control)	10.46	0.18	10.11	10.81
	Sunrise	11.43	0.18	11.08	11.78
	Storm	8.08	0.18	7.73	8.43
	Rainbow	10.39	0.18	10.04	10.74
	Sunset	11.20	0.18	10.85	11.55
	Night-time	9.13	0.18	8.78	9.48

[1]CI = Confidence Interval

Table S6. Multilevel (within-participant) mediation model for sunrise vs blue-sky in the **nature-based** condition.

Outcome	Predictor	Effects pathway	Estimate	SE	95% CIs[1]
Beauty	**Sunrise vs blue-sky**	Direct	0.39	0.04	0.20, 0.49
Awe	**Sunrise vs blue-sky**	Direct	0.56	0.05	0.47, 0.66
Covariances	**Beauty ↔ awe**	Direct	0.65	0.04	0.57, 0.73
WTP	**Beauty**	Direct	0.76	0.08	0.60, 0.91
	Awe	Direct	0.42	0.07	0.28, 0.57
	Sunrise vs blue-sky	Direct	0.43	0.11	0.22, 0.64
		Indirect via beauty	0.29	0.04	0.21, 0.38
		Indirect via awe	0.24	0.05	0.15, 0.33
		Total effect	**0.96**	**0.11**	**0.75, 1.18**
		Proportion mediated via beauty	0.30		
		Proportion mediated via awe	0.25		
		Total proportion mediated	**0.55**		

[1]CI = Confidence Interval.
Includes age, sex, and connection to nature as covariates.

Table S7. Multilevel (within-participant) mediation model for sunrise vs blue-sky in the **urban** condition.

Outcome	Predictor	Effects pathway	Estimate	SE	95% CIs[1]
Beauty	**Sunrise vs blue-sky**	Direct	0.59	0.05	0.48, 0.69
Awe	**Sunrise vs blue-sky**	Direct	0.76	0.06	0.64, 0.87
Covariances	**Beauty ↔ awe**	Direct	1.26	0.07	1.13, 1.39
WTP	**Beauty**	Direct	0.79	0.07	0.65, 0.93
	Awe	Direct	0.38	0.06	0.25, 0.50
	Sunrise vs blue-sky	Direct	0.09	0.11	-0.12, 0.30
		Indirect via beauty	0.46	0.06	0.35, 0.58
		Indirect via awe	0.29	0.05	0.18, 0.39
		Total effect	**0.84**	**0.12**	**0.61, 1.07**
		Proportion mediated via beauty	0.55		
		Proportion mediated via awe	0.35		
		Total proportion mediated	**0.89**		

[1]CI = Confidence Interval.
Includes age, sex, and connection to nature as covariates.

Table S8. Tukey adjusted pairwise comparisons for all possible contrasts of landscape and phenomena type, derived from the model specified in Table 3 in the main text with **beauty** set as the dependent variable. 'CO' denotes the blue-sky control, 'SR' sunrise, 'ST' storm, 'RB' rainbow, 'SS' sunset, and 'NT' night-time. 'CI' = 95% confidence interval.

Contrast	Estimate	SE	Lower CI	Upper CI
CO Urban - SR Urban	-0.578	0.058	-0.766	-0.390
CO Urban - ST Urban	0.469	0.058	0.281	0.658
CO Urban - RB Urban	-0.631	0.058	-0.820	-0.443
CO Urban - SS Urban	-0.646	0.058	-0.834	-0.458
CO Urban - NT Urban	-0.043	0.058	-0.232	0.145
CO Urban - CO Nature	-1.898	0.083	-2.168	-1.628
CO Urban - SR Nature	-2.297	0.083	-2.567	-2.027
CO Urban - ST Nature	-0.662	0.083	-0.933	-0.392
CO Urban - RB Nature	-1.786	0.083	-2.056	-1.516
CO Urban - SS Nature	-2.330	0.083	-2.600	-2.060
CO Urban - NT Nature	-0.994	0.083	-1.264	-0.724
SR Urban - ST Urban	1.047	0.058	0.859	1.236
SR Urban - RB Urban	-0.054	0.058	-0.242	0.135
SR Urban - SS Urban	-0.068	0.058	-0.256	0.120
SR Urban - NT Urban	0.535	0.058	0.346	0.723
SR Urban - CO Nature	-1.320	0.083	-1.590	-1.050
SR Urban - SR Nature	-1.719	0.083	-1.989	-1.449
SR Urban - ST Nature	-0.085	0.083	-0.355	0.186
SR Urban - RB Nature	-1.208	0.083	-1.478	-0.938
SR Urban - SS Nature	-1.752	0.083	-2.022	-1.482
SR Urban - NT Nature	-0.416	0.083	-0.686	-0.146
ST Urban - RB Urban	-1.101	0.058	-1.289	-0.912
ST Urban - SS Urban	-1.115	0.058	-1.303	-0.927
ST Urban - NT Urban	-0.512	0.058	-0.701	-0.324
ST Urban - CO Nature	-2.367	0.083	-2.637	-2.097
ST Urban - SR Nature	-2.766	0.083	-3.036	-2.496
ST Urban - ST Nature	-1.132	0.083	-1.402	-0.862
ST Urban - RB Nature	-2.255	0.083	-2.525	-1.985
ST Urban - SS Nature	-2.799	0.083	-3.069	-2.529
ST Urban - NT Nature	-1.463	0.083	-1.733	-1.193
RB Urban - SS Urban	-0.014	0.058	-0.203	0.174
RB Urban - NT Urban	0.588	0.058	0.400	0.777
RB Urban - CO Nature	-1.266	0.083	-1.536	-0.996
RB Urban - SR Nature	-1.665	0.083	-1.936	-1.395
RB Urban - ST Nature	-0.031	0.083	-0.301	0.239
RB Urban - RB Nature	-1.154	0.083	-1.424	-0.884

Contrast	Estimate	SE	Lower CI	Upper CI
RB Urban - SS Nature	-1.698	0.083	-1.968	-1.428
RB Urban - NT Nature	-0.362	0.083	-0.632	-0.092
SS Urban - NT Urban	0.603	0.058	0.414	0.791
SS Urban - CO Nature	-1.252	0.083	-1.522	-0.982
SS Urban - SR Nature	-1.651	0.083	-1.921	-1.381
SS Urban - ST Nature	-0.017	0.083	-0.287	0.254
SS Urban - RB Nature	-1.140	0.083	-1.410	-0.870
SS Urban - SS Nature	-1.684	0.083	-1.954	-1.414
SS Urban - NT Nature	-0.348	0.083	-0.618	-0.078
NT Urban - CO Nature	-1.855	0.083	-2.125	-1.584
NT Urban - SR Nature	-2.254	0.083	-2.524	-1.984
NT Urban - ST Nature	-0.619	0.083	-0.889	-0.349
NT Urban - RB Nature	-1.743	0.083	-2.013	-1.472
NT Urban - SS Nature	-2.287	0.083	-2.557	-2.016
NT Urban - NT Nature	-0.951	0.083	-1.221	-0.680
CO Nature - SR Nature	-0.399	0.058	-0.588	-0.211
CO Nature - ST Nature	1.235	0.058	1.047	1.424
CO Nature - RB Nature	0.112	0.058	-0.076	0.300
CO Nature - SS Nature	-0.432	0.058	-0.620	-0.244
CO Nature - NT Nature	0.904	0.058	0.716	1.092
SR Nature - ST Nature	1.634	0.058	1.446	1.823
SR Nature - RB Nature	0.511	0.058	0.323	0.700
SR Nature - SS Nature	-0.033	0.058	-0.221	0.156
SR Nature - NT Nature	1.303	0.058	1.115	1.492
ST Nature - RB Nature	-1.123	0.058	-1.312	-0.935
ST Nature - SS Nature	-1.667	0.058	-1.856	-1.479
ST Nature - NT Nature	-0.331	0.058	-0.520	-0.143
RB Nature - SS Nature	-0.544	0.058	-0.732	-0.356
RB Nature - NT Nature	0.792	0.058	0.604	0.980
SS Nature - NT Nature	1.336	0.058	1.148	1.524

Table S9. Tukey adjusted pairwise comparisons for all possible contrasts of landscape and phenomena type, derived from the model specified in Table 3 in the main text with **awe** set as the dependent variable. 'CO' denotes the blue-sky control, 'SR' sunrise, 'ST' storm, 'RB' rainbow, 'SS' sunset, and 'NT' night-time. 'CI' = 95% confidence interval.

Contrast	Estimate	SE	Lower CI	Upper CI
CO Urban - SR Urban	-0.752	0.062	-0.954	-0.551
CO Urban - ST Urban	-0.232	0.062	-0.433	-0.030
CO Urban - RB Urban	-0.962	0.062	-1.164	-0.761
CO Urban - SS Urban	-0.759	0.062	-0.960	-0.557
CO Urban - NT Urban	-0.235	0.062	-0.436	-0.034
CO Urban - CO Nature	-1.798	0.088	-2.084	-1.511
CO Urban - SR Nature	-2.371	0.088	-2.658	-2.085
CO Urban - ST Nature	-1.275	0.088	-1.561	-0.988
CO Urban - RB Nature	-2.011	0.088	-2.297	-1.724
CO Urban - SS Nature	-2.328	0.088	-2.615	-2.042
CO Urban - NT Nature	-1.112	0.088	-1.399	-0.826
SR Urban - ST Urban	0.520	0.062	0.319	0.722
SR Urban - RB Urban	-0.210	0.062	-0.412	-0.009
SR Urban - SS Urban	-0.006	0.062	-0.208	0.195
SR Urban - NT Urban	0.517	0.062	0.316	0.719
SR Urban - CO Nature	-1.046	0.088	-1.332	-0.759
SR Urban - SR Nature	-1.619	0.088	-1.906	-1.333
SR Urban - ST Nature	-0.522	0.088	-0.809	-0.236
SR Urban - RB Nature	-1.258	0.088	-1.545	-0.972
SR Urban - SS Nature	-1.576	0.088	-1.863	-1.289
SR Urban - NT Nature	-0.360	0.088	-0.647	-0.073
ST Urban - RB Urban	-0.731	0.062	-0.932	-0.529
ST Urban - SS Urban	-0.527	0.062	-0.728	-0.325
ST Urban - NT Urban	-0.003	0.062	-0.205	0.198
ST Urban - CO Nature	-1.566	0.088	-1.853	-1.279
ST Urban - SR Nature	-2.140	0.088	-2.426	-1.853
ST Urban - ST Nature	-1.043	0.088	-1.329	-0.756
ST Urban - RB Nature	-1.779	0.088	-2.065	-1.492
ST Urban - SS Nature	-2.096	0.088	-2.383	-1.810
ST Urban - NT Nature	-0.880	0.088	-1.167	-0.594
RB Urban - SS Urban	0.204	0.062	0.002	0.405
RB Urban - NT Urban	0.727	0.062	0.526	0.929
RB Urban - CO Nature	-0.835	0.088	-1.122	-0.549
RB Urban - SR Nature	-1.409	0.088	-1.696	-1.122
RB Urban - ST Nature	-0.312	0.088	-0.599	-0.026
RB Urban - RB Nature	-1.048	0.088	-1.335	-0.762

Contrast	Estimate	SE	Lower CI	Upper CI
RB Urban - SS Nature	-1.366	0.088	-1.652	-1.079
RB Urban - NT Nature	-0.150	0.088	-0.436	0.137
SS Urban - NT Urban	0.524	0.062	0.322	0.725
SS Urban - CO Nature	-1.039	0.088	-1.326	-0.753
SS Urban - SR Nature	-1.613	0.088	-1.899	-1.326
SS Urban - ST Nature	-0.516	0.088	-0.803	-0.229
SS Urban - RB Nature	-1.252	0.088	-1.539	-0.965
SS Urban - SS Nature	-1.570	0.088	-1.856	-1.283
SS Urban - NT Nature	-0.354	0.088	-0.640	-0.067
NT Urban - CO Nature	-1.563	0.088	-1.849	-1.276
NT Urban - SR Nature	-2.136	0.088	-2.423	-1.850
NT Urban - ST Nature	-1.040	0.088	-1.326	-0.753
NT Urban - RB Nature	-1.776	0.088	-2.062	-1.489
NT Urban - SS Nature	-2.093	0.088	-2.380	-1.807
NT Urban - NT Nature	-0.877	0.088	-1.164	-0.591
CO Nature - SR Nature	-0.574	0.062	-0.775	-0.372
CO Nature - ST Nature	0.523	0.062	0.322	0.725
CO Nature - RB Nature	-0.213	0.062	-0.414	-0.011
CO Nature - SS Nature	-0.530	0.062	-0.732	-0.329
CO Nature - NT Nature	0.686	0.062	0.484	0.887
SR Nature - ST Nature	1.097	0.062	0.895	1.298
SR Nature - RB Nature	0.361	0.062	0.159	0.562
SR Nature - SS Nature	0.043	0.062	-0.158	0.245
SR Nature - NT Nature	1.259	0.062	1.058	1.461
ST Nature - RB Nature	-0.736	0.062	-0.937	-0.535
ST Nature - SS Nature	-1.054	0.062	-1.255	-0.852
ST Nature - NT Nature	0.162	0.062	-0.039	0.364
RB Nature - SS Nature	-0.318	0.062	-0.519	-0.116
RB Nature - NT Nature	0.898	0.062	0.697	1.100
SS Nature - NT Nature	1.216	0.062	1.015	1.417

The memorable moments experiment

Full instrument wording

Participant consent form

I agree to take part in this experiment and confirm that:

- I have read the information sheet for this experiment

- I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily

- I understand that my participation is voluntary and that I am free to withdraw at any time by closing my browser window without giving any reason and without my legal rights being affected

- I understand that the data collected during the study will be analysed by individuals at the University of Exeter and regulatory authorities for audit purposes. I give permission for these individuals to use this data as necessary in their analyses

- I understand that taking part involves providing anonymised survey responses to be used for the purposes of:
    - Reports published in academic publications, the project website, and media publications
    - Inclusion in a digital archive
    - Shared with other researchers for use in future research projects
    - Teaching or training materials for use in university activities.

- I understand that the data collected during the study will be anonymised and retained in offline secure storage

- I understand that a fully anonymised dataset (all information gathered by the experiment) including my responses will be made publicly accessible after June 2024

- I am aged 18 or above

- I am a UK resident

By checking this box, I confirm that I have understood and agree with the above statements and I consent to taking part in this experiment. ☐

Footnote
This project has been reviewed and approved by the University of Exeter Medical School Ethics Committee, reference number (20/01/236).

The memorable moments experiment
Full experiment

Thank you for agreeing to take part in this experiment.

We will now ask you several sets of questions, some of which will capture your responses to a series of images.

Section 1 | Your feelings towards nature

First, we'd like you to think about your relationship with nature.

Please select the option which best describes how much you agree or disagree with each sentence. (There are no right or wrong answers.)

Q1. Being in nature makes me very happy

Q2. I find being in nature really amazing

Q3. I always find beauty in nature

Q4. Spending time in nature is very important to me

Q5. I always treat nature with respect

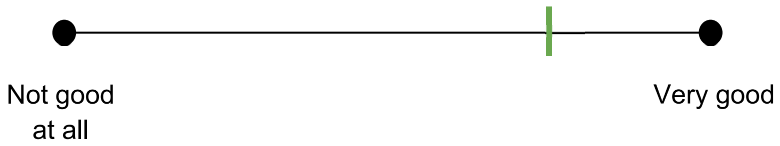
Q6. I feel part of nature

<A seven-point scale (example below) placed beneath each item>

Section 2 | Condition 1

Please take a few moments to view the following image. Try and imagine you are in this setting looking out from a safe and comfortable place.

Q1 Thinking about a time when you might have been tired and unable to concentrate, to what extent do you think this setting would be good for taking a break?



<All scales in section 2, with the exception of question 8, use a ten-point response system>

Q2 How much do you agree with this statement?

"*This place has interesting features and holds my attention.*"

Not at all — Completely

Q3 How much do you agree with this statement?

"*This place would allow me to feel far away from everyday thoughts and concerns.*"

Not at all — Completely

Q4 Do you find this place boring or exciting?

Very boring — Very exciting

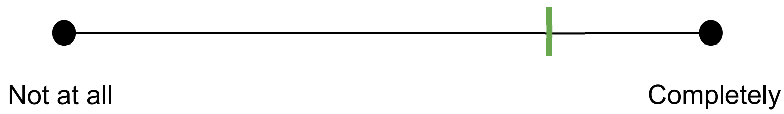
Q5 Do you find this place chaotic or calm?

Very chaotic — Very calm

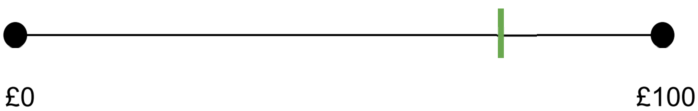
Q6 To what extent do you find this place beautiful?

Q7 To what extent do you agree with the following statement?

"*This scene is awe-inspiring and fills me with wonder.*"



Q8 Imagine you are on holiday and this location is a short journey from where you are staying. How much would you be willing to pay to visit this place and experience the moment depicted?



Section 2 was then repeated identically for a further 5 stimulus conditions (only the image changed, image order was randomised for each participant). These conditions represent **sections 3-7**.

Section 8 | Tell us about a memorable moment in nature that is important to you.

Q1 Now we'd like you to think about a time when you have experienced a change in your surroundings that was brief or unexpected. Please describe this memorable experience and its effect on you.

(This might have been in a natural environment, in a city, close to home, or further afield. For example, you might recall "*surprise as a rainbow appeared over my local bus station"* or "*relaxing as the sun set over the fields*".)

<Free text response>

Section 9 | Some questions about you

This final section will ask you to provide some background information about yourself. We are interested in your answers here because some factors might influence how different people evaluate environments.

We will not collect any personal data here; your responses are anonymous, and you will not be identified from the answers you provide.

Q1 What is your age?

▢ 18-25
▢ 26-35
▢ 36-45
▢ 46-55
▢ 56-65
▢ 66-75
▢ 76+
▢ Prefer not to answer

Q2 Do you consider yourself to be:

▢ Female
▢ Male
▢ Another sex or gender
▢ Prefer not to answer

Q3 Your income
Which of the following describes your household's total annual income after tax and compulsory deductions, from all sources? If you don't know the exact figure, please give an estimate.

□ Less than £10,858

□ £10,858 to under £14,548

□ £14,548 to under £18,132

□ £18,132 to under £21,715

□ £21,715 to under £25,994

□ £25,994 to under £30,754

□ £30,754 to under £36,691

□ £36,691 to under £44,714

□ £44,714 to under £58,620

□ £58,620 or more

□ Don't know

□ Prefer not to answer

Q4 Which of the following regions do you live in?

▢ London
▢ South West
▢ South East
▢ West Midlands
▢ East Midlands
▢ East England
▢ Yorkshire and the Humber
▢ North West
▢ North East
▢ Wales
▢ Scotland
▢ Northern Ireland
▢ Other region/don't know
▢ Prefer not to answer

Q5 How often do you spend time in nature-based environments?

(These would be places you consider to be natural environments. They might feature plants and animals, and could include a garden, park, forest or beach for example.)

□ Once a week or more often
□ Once every 2 or 3 weeks
□ Once a month
□ Once every 2 or 3 months
□ Once or twice a year
□ Never
□ Prefer not to answer

Q6 Are you a member of any nature-based organizations, such as the National Trust or RSPB for example?

▢ Yes
▢ No
□ Prefer not to answer

Q7 What device are you using to take part in this experiment?

☐ Smartphone
☐ Tablet
☐ Laptop
☐ Desktop computer

Thank you for your answers. That marks the end of this experiment, please click the button below to submit your responses and find out what happens next.

12. Appendix C

Supplementary information for study three, detailed in chapter seven, and published in the *Journal of Environmental Psychology*, https://doi.org/10.1016/j.jenvp.2023.102060:

Soundscapes, music, and memories: Exploring the factors that influence emotional responses to virtual nature content

This file includes:

- Information sheet for participants
- Tables S1 to S13
- Full experimental wording

Note that figure numbering is specific to each appendix, rather than part of the global document numbering.

Experiment information sheet for participants
Version #4 | 18th December 2020

Thank you for showing an interest in this experiment. Please read this information sheet carefully before deciding to take part.

What is the aim of the project?
We want to understand how online and digital scenes of nature might affect people's wellbeing.

This study is part of a larger project aiming to bring virtual experiences of nature to those who can't get outside. Our data will be used in research funded by The Wellcome Trust.

What will you be asked to do?
If you would like to participate, you must be aged 18 or over. You will be asked to play one of several short videos and answer a series of questions. The experiment takes around 8–10 minutes to complete and consists of several sections:

1. The first will check your browser can play online videos.
2. We'll then ask you to watch a 3-minute video.
3. Next, we will ask you a series of questions about the experience.
4. Finally, we'll ask you to provide some basic background information.

☆ Please note that you may see some flashing images ☆
If you have a photosensitive condition such as epilepsy and are worried or unsure about the risk of viewing moving images on screen, you should not take part.

How will your data be stored and used?
Your participation is entirely voluntary. All responses will be anonymous, and you will not be identifiable in any way. We will not be collecting any personal data (such as your name, date of birth, or address).

Data will be stored on a secure server until Dec 2022, when the current research project ends. After this, the anonymised data will be made freely available online. This allows other people to use the data and answer questions of their own.

The results from this study will be communicated on the project website (link available at the end of the experiment), in academic publications, at meetings and conferences, and via the media. The results may also be used in teaching or training materials at the University of Exeter.

Can you change your mind?
You can withdraw from the study at any point before you have submitted your responses, without giving a reason. To withdraw, simply close your internet browser. Any data you have given up to that point will not be stored. Because your participation is anonymous you will not be able to withdraw once your responses have been submitted.

What if you have any questions?
If you have any questions about our project, either now or in the future, please contact:

BLINDED FOR PUBLICATION

We will aim to reply within 48hrs. Because we are not collecting any personal information, will be unable to identify and provide feedback on your data from the experiment.

Complaints
This project has been reviewed and approved by the University of Exeter Medical School ethics committee, reference number: Dec20/B/267. If you have any complaints, please contact:

BLINDED FOR PUBLICATION

☐ I have read and understood the information above, I am aged 18 or over, and consent to take part.
☐ I do not consent to take part.

Please click the blue arrow below to continue.

⇨

Table S1. Means, standard deviations, and correlations (with confidence intervals) for our key dependent variables.

Variable	***M***	***SD***	**1**	**2**	**3**	**4**
1. Perceived restorative potential	7.16	1.89				
2. Calmness	7.49	2.11	.63** [.62, .64]			
3. Excitement	3.84	2.34	.38** [.36, .40]	.30** [.28, .32]		
4. Awe	5.37	2.80	.62** [.60, .63]	.47** [.45, .49]	.45** [.43, .46]	
5. Nostalgia	4.20	2.89	.37** [.35, .39]	.27** [.25, .29]	.24** [.22, .26]	.35** [.33, .37]

Note. M and *SD* are used to represent mean and standard deviation, respectively. Bracketed values indicate the 95% confidence interval for each correlation. ** indicates $p < 0.01$.

Table S2. Unstandardised coefficients from our baseline models with negative emotions as dependent variables and the silent condition as reference. Adjusted R^2 is also shown.

	DV = Boredom			DV = Anxiety			DV = Sadness		
Characteristic	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**
(Intercept)	2.84	2.75, 2.94	<0.001	1.99	1.91, 2.07	<0.001	1.97	1.90, 2.05	<0.001
Condition									
Silence	—	—		—	—		—	—	
Nature	-0.88	-1.01, -0.75	<0.001	-0.11	-0.22, 0.00	0.060	-0.12	-0.23, -0.02	0.023
Music	-0.32	-0.45, -0.19	<0.001	0.23	0.11, 0.34	<0.001	0.03	-0.07, 0.14	0.5
Mixed	-0.72	-0.86, -0.59	<0.001	0.09	-0.02, 0.20	0.12	0.03	-0.08, 0.14	0.6
Model fit	$R^2 = 0.026$ $F(3, 7632) = 68.52$, $p = <0.001$			$R^2 = 0.004$ $F(3, 7632) = 12.13$, $p = <0.001$			$R^2 = 0.001$ $F(3, 7632) = 3.79$, $p = 0.01$		

[1]CI = Confidence Interval

Table S3. Fitted values for the model shown in Table 7 and depicted in Figure 5A in the main paper, with **perceived restorative potential** set as the dependent variable. 'CI' = 95% confidence interval.

Condition	Memory type	Fitted value	SE	Lower CI	Upper CI
Silence	None	6.22	0.07	6.08	6.37
Nature	None	6.45	0.09	6.28	6.62
Music	None	5.95	0.07	5.82	6.09
Mixed	None	6.10	0.08	5.95	6.26
Silence	Positive	7.47	0.05	7.37	7.58
Nature	Positive	7.81	0.05	7.72	7.90
Music	Positive	7.53	0.05	7.43	7.64
Mixed	Positive	7.75	0.05	7.66	7.84

Table S4. Tukey adjusted pairwise comparisons for all possible contrasts of condition and memory type, derived from the model specified in Table 7 in the main text with **perceived restorative potential** set as the dependent variable. 'Silence', 'Nature', 'Music', and 'Mixed' refer to experimental conditions. 'None' and 'Positive' denote memory type. 'CI' = 95% confidence interval.

Contrast	Estimate	SE	DF	Lower CI	Upper CI	T ratio	P value
Silence None - Nature None	-0.225	0.114	6,976.000	-0.571	0.121	-1.968	0.504
Silence None - Music None	0.269	0.100	6,976.000	-0.034	0.573	2.688	0.126
Silence None - Mixed None	0.122	0.107	6,976.000	-0.203	0.447	1.137	0.949
Silence None - Silence Positive	-1.251	0.089	6,976.000	-1.521	-0.982	-14.077	0.000
Silence None - Nature Positive	-1.588	0.086	6,976.000	-1.849	-1.327	-18.447	0.000
Silence None - Music Positive	-1.309	0.090	6,976.000	-1.580	-1.037	-14.608	0.000
Silence None - Mixed Positive	-1.527	0.087	6,976.000	-1.790	-1.263	-17.566	0.000
Nature None - Music None	0.494	0.112	6,976.000	0.154	0.834	4.407	0.000
Nature None - Mixed None	0.347	0.118	6,976.000	-0.012	0.706	2.927	0.067
Nature None - Silence Positive	-1.027	0.102	6,976.000	-1.336	-0.717	-10.050	0.000
Nature None - Nature Positive	-1.364	0.100	6,976.000	-1.666	-1.061	-13.673	0.000
Nature None - Music Positive	-1.084	0.103	6,976.000	-1.395	-0.772	-10.549	0.000
Nature None - Mixed Positive	-1.302	0.100	6,976.000	-1.607	-0.998	-12.965	0.000
Music None - Mixed None	-0.147	0.105	6,976.000	-0.466	0.171	-1.402	0.857
Music None - Silence Positive	-1.521	0.086	6,976.000	-1.782	-1.259	-17.645	0.000
Music None - Nature Positive	-1.858	0.083	6,976.000	-2.110	-1.605	-22.301	0.000
Music None - Music Positive	-1.578	0.087	6,976.000	-1.841	-1.314	-18.160	0.000
Music None - Mixed Positive	-1.796	0.084	6,976.000	-2.051	-1.541	-21.347	0.000
Mixed None - Silence Positive	-1.373	0.094	6,976.000	-1.659	-1.087	-14.560	0.000
Mixed None - Nature Positive	-1.710	0.092	6,976.000	-1.988	-1.432	-18.652	0.000
Mixed None - Music Positive	-1.431	0.095	6,976.000	-1.719	-1.143	-15.064	0.000
Mixed None - Mixed Positive	-1.649	0.092	6,976.000	-1.929	-1.368	-17.833	0.000
Silence Positive - Nature Positive	-0.337	0.069	6,976.000	-0.547	-0.127	-4.861	0.000
Silence Positive - Music Positive	-0.057	0.074	6,976.000	-0.281	0.166	-0.780	0.994
Silence Positive - Mixed Positive	-0.276	0.070	6,976.000	-0.489	-0.062	-3.917	0.002
Nature Positive - Music Positive	0.280	0.070	6,976.000	0.067	0.493	3.982	0.002
Nature Positive - Mixed Positive	0.062	0.067	6,976.000	-0.141	0.264	0.922	0.984
Music Positive - Mixed Positive	-0.218	0.071	6,976.000	-0.434	-0.002	-3.062	0.046

Table S5. Fitted values for the model shown in Table 7 and depicted in Figure 5B in the main paper, with **calmness** set as the dependent variable. 'CI' = 95% confidence interval.

Condition	Memory type	Fitted value	SE	Lower CI	Upper CI
Silence	None	6.56	0.08	6.40	6.72
Nature	None	7.22	0.10	7.02	7.41
Music	None	6.31	0.08	6.15	6.46
Mixed	None	6.77	0.09	6.59	6.94
Silence	Positive	7.75	0.06	7.64	7.87
Nature	Positive	8.29	0.05	8.18	8.39
Music	Positive	7.62	0.06	7.51	7.74
Mixed	Positive	7.99	0.05	7.89	8.10

Table S6. Tukey adjusted pairwise comparisons for all possible contrasts of condition and memory type, derived from the model specified in Table 7 in the main text with **calmness** set as the dependent variable. 'Silence', 'Nature', 'Music', and 'Mixed' refer to experimental conditions. 'None' and 'Positive' denote memory type. 'CI' = 95% confidence interval.

Contrast	Estimate	SE	DF	Lower CI	Upper CI	T ratio	P value
Silence None - Nature None	-0.659	0.129	6,976.000	-1.050	-0.268	-5.107	0.000
Silence None - Music None	0.249	0.113	6,976.000	-0.094	0.592	2.200	0.351
Silence None - Mixed None	-0.209	0.121	6,976.000	-0.577	0.158	-1.725	0.671
Silence None - Silence Positive	-1.197	0.100	6,976.000	-1.502	-0.893	-11.917	0.000
Silence None - Nature Positive	-1.732	0.097	6,976.000	-2.027	-1.437	-17.792	0.000
Silence None - Music Positive	-1.066	0.101	6,976.000	-1.373	-0.759	-10.526	0.000
Silence None - Mixed Positive	-1.437	0.098	6,976.000	-1.735	-1.139	-14.629	0.000
Nature None - Music None	0.908	0.127	6,976.000	0.524	1.292	7.169	0.000
Nature None - Mixed None	0.450	0.134	6,976.000	0.044	0.856	3.360	0.018
Nature None - Silence Positive	-0.538	0.115	6,976.000	-0.888	-0.188	-4.662	0.000
Nature None - Nature Positive	-1.073	0.113	6,976.000	-1.414	-0.731	-9.515	0.000
Nature None - Music Positive	-0.407	0.116	6,976.000	-0.759	-0.055	-3.502	0.011
Nature None - Mixed Positive	-0.778	0.114	6,976.000	-1.122	-0.434	-6.854	0.000
Music None - Mixed None	-0.458	0.119	6,976.000	-0.818	-0.098	-3.861	0.003
Music None - Silence Positive	-1.446	0.097	6,976.000	-1.742	-1.151	-14.851	0.000
Music None - Nature Positive	-1.981	0.094	6,976.000	-2.266	-1.695	-21.039	0.000
Music None - Music Positive	-1.315	0.098	6,976.000	-1.613	-1.017	-13.389	0.000
Music None - Mixed Positive	-1.686	0.095	6,976.000	-1.975	-1.398	-17.732	0.000
Mixed None - Silence Positive	-0.988	0.107	6,976.000	-1.311	-0.665	-9.270	0.000
Mixed None - Nature Positive	-1.522	0.104	6,976.000	-1.837	-1.208	-14.690	0.000
Mixed None - Music Positive	-0.857	0.107	6,976.000	-1.182	-0.531	-7.981	0.000
Mixed None - Mixed Positive	-1.228	0.105	6,976.000	-1.545	-0.911	-11.751	0.000
Silence Positive - Nature Positive	-0.534	0.078	6,976.000	-0.772	-0.297	-6.817	0.000
Silence Positive - Music Positive	0.132	0.083	6,976.000	-0.121	0.384	1.581	0.762
Silence Positive - Mixed Positive	-0.240	0.080	6,976.000	-0.481	0.001	-3.016	0.052
Nature Positive - Music Positive	0.666	0.079	6,976.000	0.425	0.906	8.387	0.000
Nature Positive - Mixed Positive	0.294	0.075	6,976.000	0.066	0.523	3.900	0.002
Music Positive - Mixed Positive	-0.371	0.081	6,976.000	-0.615	-0.127	-4.612	0.000

Table S7. Fitted values for the model shown in Table 7 and depicted in Figure 5C in the main paper, with **excitement** set as the dependent variable. 'CI' = 95% confidence interval.

Condition	Memory type	Fitted value	SE	Lower CI	Upper CI
Silence	None	2.72	0.10	2.53	2.91
Nature	None	3.21	0.12	2.99	3.44
Music	None	3.28	0.09	3.10	3.45
Mixed	None	3.29	0.10	3.09	3.50
Silence	Positive	3.60	0.07	3.47	3.74
Nature	Positive	4.05	0.06	3.93	4.17
Music	Positive	4.62	0.07	4.49	4.76
Mixed	Positive	4.40	0.06	4.28	4.52

Table S8. Tukey adjusted pairwise comparisons for all possible contrasts of condition and memory type, derived from the model specified in Table 7 in the main text with **excitement** set as the dependent variable. 'Silence', 'Nature', 'Music', and 'Mixed' refer to experimental conditions. 'None' and 'Positive' denote memory type. 'CI' = 95% confidence interval.

Contrast	Estimate	SE	DF	Lower CI	Upper CI	T ratio	P value
Silence None - Nature None	-0.492	0.150	6,976.000	-0.947	-0.037	-3.281	0.023
Silence None - Music None	-0.556	0.132	6,976.000	-0.955	-0.157	-4.229	0.001
Silence None - Mixed None	-0.573	0.141	6,976.000	-1.000	-0.146	-4.066	0.001
Silence None - Silence Positive	-0.883	0.117	6,976.000	-1.237	-0.529	-7.564	0.000
Silence None - Nature Positive	-1.330	0.113	6,976.000	-1.673	-0.987	-11.759	0.000
Silence None - Music Positive	-1.901	0.118	6,976.000	-2.258	-1.545	-16.157	0.000
Silence None - Mixed Positive	-1.680	0.114	6,976.000	-2.026	-1.334	-14.715	0.000
Nature None - Music None	-0.064	0.147	6,976.000	-0.511	0.382	-0.436	1.000
Nature None - Mixed None	-0.081	0.156	6,976.000	-0.552	0.391	-0.519	1.000
Nature None - Silence Positive	-0.391	0.134	6,976.000	-0.798	0.016	-2.915	0.070
Nature None - Nature Positive	-0.838	0.131	6,976.000	-1.235	-0.441	-6.396	0.000
Nature None - Music Positive	-1.409	0.135	6,976.000	-1.819	-1.000	-10.441	0.000
Nature None - Mixed Positive	-1.188	0.132	6,976.000	-1.588	-0.788	-9.005	0.000
Music None - Mixed None	-0.017	0.138	6,976.000	-0.435	0.402	-0.120	1.000
Music None - Silence Positive	-0.327	0.113	6,976.000	-0.670	0.016	-2.888	0.075
Music None - Nature Positive	-0.774	0.109	6,976.000	-1.105	-0.442	-7.071	0.000
Music None - Music Positive	-1.345	0.114	6,976.000	-1.691	-0.999	-11.785	0.000
Music None - Mixed Positive	-1.124	0.111	6,976.000	-1.459	-0.789	-10.168	0.000
Mixed None - Silence Positive	-0.310	0.124	6,976.000	-0.686	0.065	-2.505	0.193
Mixed None - Nature Positive	-0.757	0.120	6,976.000	-1.122	-0.392	-6.286	0.000
Mixed None - Music Positive	-1.329	0.125	6,976.000	-1.707	-0.950	-10.649	0.000
Mixed None - Mixed Positive	-1.107	0.121	6,976.000	-1.476	-0.739	-9.117	0.000
Silence Positive - Nature Positive	-0.447	0.091	6,976.000	-0.723	-0.171	-4.905	0.000
Silence Positive - Music Positive	-1.018	0.097	6,976.000	-1.311	-0.725	-10.529	0.000
Silence Positive - Mixed Positive	-0.797	0.092	6,976.000	-1.077	-0.517	-8.624	0.000
Nature Positive - Music Positive	-0.571	0.092	6,976.000	-0.851	-0.292	-6.194	0.000
Nature Positive - Mixed Positive	-0.350	0.088	6,976.000	-0.616	-0.084	-3.990	0.002
Music Positive - Mixed Positive	0.221	0.094	6,976.000	-0.062	0.505	2.365	0.259

Table S9. Fitted values for the model shown in Table 7 and depicted in Figure 5D in the main paper, with **awe** set as the dependent variable. 'CI' = 95% confidence interval.

Condition	Memory type	Fitted value	SE	Lower CI	Upper CI
Silence	None	4.12	0.11	3.90	4.34
Nature	None	4.64	0.14	4.37	4.91
Music	None	4.00	0.11	3.79	4.21
Mixed	None	4.19	0.12	3.95	4.43
Silence	Positive	5.71	0.08	5.55	5.86
Nature	Positive	5.97	0.07	5.83	6.11
Music	Positive	5.76	0.08	5.60	5.92
Mixed	Positive	6.02	0.07	5.88	6.17

Table S10. Tukey adjusted pairwise comparisons for all possible contrasts of condition and memory type, derived from the model specified in Table 7 in the main text with **awe** set as the dependent variable. 'Silence', 'Nature', 'Music', and 'Mixed' refer to experimental conditions. 'None' and 'Positive' denote memory type. 'CI' = 95% confidence interval.

Contrast	Estimate	SE	DF	Lower CI	Upper CI	T ratio	P value
Silence None - Nature None	-0.525	0.177	6,976.000	-1.062	0.011	-2.969	0.060
Silence None - Music None	0.112	0.155	6,976.000	-0.358	0.583	0.724	0.996
Silence None - Mixed None	-0.070	0.166	6,976.000	-0.574	0.434	-0.421	1.000
Silence None - Silence Positive	-1.589	0.138	6,976.000	-2.006	-1.171	-11.532	0.000
Silence None - Nature Positive	-1.851	0.133	6,976.000	-2.256	-1.447	-13.873	0.000
Silence None - Music Positive	-1.645	0.139	6,976.000	-2.066	-1.224	-11.847	0.000
Silence None - Mixed Positive	-1.906	0.135	6,976.000	-2.314	-1.497	-14.149	0.000
Nature None - Music None	0.638	0.174	6,976.000	0.111	1.164	3.671	0.006
Nature None - Mixed None	0.455	0.184	6,976.000	-0.101	1.012	2.480	0.204
Nature None - Silence Positive	-1.063	0.158	6,976.000	-1.543	-0.583	-6.717	0.000
Nature None - Nature Positive	-1.326	0.155	6,976.000	-1.794	-0.857	-8.579	0.000
Nature None - Music Positive	-1.120	0.159	6,976.000	-1.602	-0.637	-7.031	0.000
Nature None - Mixed Positive	-1.380	0.156	6,976.000	-1.852	-0.909	-8.870	0.000
Music None - Mixed None	-0.182	0.163	6,976.000	-0.676	0.311	-1.121	0.953
Music None - Silence Positive	-1.701	0.134	6,976.000	-2.106	-1.296	-12.737	0.000
Music None - Nature Positive	-1.964	0.129	6,976.000	-2.355	-1.572	-15.212	0.000
Music None - Music Positive	-1.757	0.135	6,976.000	-2.165	-1.349	-13.050	0.000
Music None - Mixed Positive	-2.018	0.130	6,976.000	-2.414	-1.623	-15.479	0.000
Mixed None - Silence Positive	-1.519	0.146	6,976.000	-1.962	-1.075	-10.390	0.000
Mixed None - Nature Positive	-1.781	0.142	6,976.000	-2.212	-1.350	-12.535	0.000
Mixed None - Music Positive	-1.575	0.147	6,976.000	-2.021	-1.129	-10.700	0.000
Mixed None - Mixed Positive	-1.836	0.143	6,976.000	-2.270	-1.401	-12.812	0.000
Silence Positive - Nature Positive	-0.263	0.107	6,976.000	-0.588	0.063	-2.444	0.220
Silence Positive - Music Positive	-0.056	0.114	6,976.000	-0.402	0.290	-0.493	1.000
Silence Positive - Mixed Positive	-0.317	0.109	6,976.000	-0.648	0.013	-2.910	0.071
Nature Positive - Music Positive	0.206	0.109	6,976.000	-0.124	0.536	1.896	0.554
Nature Positive - Mixed Positive	-0.055	0.104	6,976.000	-0.368	0.259	-0.527	1.000
Music Positive - Mixed Positive	-0.261	0.110	6,976.000	-0.596	0.074	-2.364	0.259

Table S11. Fitted values for the model shown in Table 7 and depicted in Figure 5E in the main paper, with **nostalgia** set as the dependent variable. 'CI' = 95% confidence interval.

Condition	Memory type	Fitted value	SE	Lower CI	Upper CI
Silence	None	2.06	0.11	1.85	2.27
Nature	None	2.46	0.13	2.20	2.71
Music	None	2.17	0.10	1.97	2.38
Mixed	None	2.17	0.12	1.94	2.41
Silence	Positive	4.62	0.08	4.47	4.77
Nature	Positive	5.30	0.07	5.17	5.44
Music	Positive	4.71	0.08	4.56	4.86
Mixed	Positive	5.11	0.07	4.97	5.25

Table S12. Tukey adjusted pairwise comparisons for all possible contrasts of condition and memory type, derived from the model specified in Table 7 in the main text with **nostalgia** set as the dependent variable. 'Silence', 'Nature', 'Music', and 'Mixed' refer to experimental conditions. 'None' and 'Positive' denote memory type. 'CI' = 95% confidence interval.

Contrast	Estimate	SE	DF	Lower CI	Upper CI	T ratio	P value
Silence None - Nature None	-0.398	0.170	6,976.000	-0.913	0.117	-2.345	0.269
Silence None - Music None	-0.117	0.149	6,976.000	-0.569	0.334	-0.787	0.994
Silence None - Mixed None	-0.117	0.159	6,976.000	-0.600	0.367	-0.733	0.996
Silence None - Silence Positive	-2.563	0.132	6,976.000	-2.963	-2.162	-19.385	0.000
Silence None - Nature Positive	-3.244	0.128	6,976.000	-3.632	-2.855	-25.329	0.000
Silence None - Music Positive	-2.653	0.133	6,976.000	-3.057	-2.249	-19.910	0.000
Silence None - Mixed Positive	-3.054	0.129	6,976.000	-3.446	-2.662	-23.627	0.000
Nature None - Music None	0.281	0.167	6,976.000	-0.224	0.786	1.686	0.696
Nature None - Mixed None	0.281	0.176	6,976.000	-0.253	0.815	1.597	0.752
Nature None - Silence Positive	-2.164	0.152	6,976.000	-2.625	-1.704	-14.248	0.000
Nature None - Nature Positive	-2.845	0.148	6,976.000	-3.295	-2.396	-19.184	0.000
Nature None - Music Positive	-2.254	0.153	6,976.000	-2.718	-1.791	-14.753	0.000
Nature None - Mixed Positive	-2.656	0.149	6,976.000	-3.109	-2.203	-17.782	0.000
Music None - Mixed None	0.000	0.156	6,976.000	-0.473	0.474	0.002	1.000
Music None - Silence Positive	-2.445	0.128	6,976.000	-2.834	-2.057	-19.082	0.000
Music None - Nature Positive	-3.126	0.124	6,976.000	-3.502	-2.751	-25.238	0.000
Music None - Music Positive	-2.535	0.129	6,976.000	-2.927	-2.144	-19.621	0.000
Music None - Mixed Positive	-2.937	0.125	6,976.000	-3.316	-2.558	-23.472	0.000
Mixed None - Silence Positive	-2.446	0.140	6,976.000	-2.871	-2.020	-17.436	0.000
Mixed None - Nature Positive	-3.127	0.136	6,976.000	-3.540	-2.713	-22.928	0.000
Mixed None - Music Positive	-2.536	0.141	6,976.000	-2.964	-2.107	-17.953	0.000
Mixed None - Mixed Positive	-2.937	0.138	6,976.000	-3.354	-2.520	-21.361	0.000
Silence Positive - Nature Positive	-0.681	0.103	6,976.000	-0.994	-0.368	-6.603	0.000
Silence Positive - Music Positive	-0.090	0.109	6,976.000	-0.422	0.242	-0.823	0.992
Silence Positive - Mixed Positive	-0.492	0.105	6,976.000	-0.809	-0.174	-4.698	0.000
Nature Positive - Music Positive	0.591	0.104	6,976.000	0.274	0.908	5.657	0.000
Nature Positive - Mixed Positive	0.189	0.099	6,976.000	-0.112	0.491	1.907	0.546
Music Positive - Mixed Positive	-0.401	0.106	6,976.000	-0.723	-0.080	-3.790	0.004

Table S13. Additional participant characteristic according to ethnicity, UK residency, and UK region (if applicable).

Characteristic	N = 7,636[1]
Ethnicity	
White	6,997 (92%)
Arab	9 (0.1%)
Asian	150 (2.0%)
Black	33 (0.4%)
Chinese	35 (0.5%)
Mixed	161 (2.1%)
Other ethnicity	68 (0.9%)
Prefer not to answer	183 (2.4%)
UK resident	
Yes	6,648 (87%)
No	950 (12%)
Prefer not to answer	38 (0.5%)
UK region	
Another region	33 (0.5%)
East England	541 (8.1%)
East Midlands	444 (6.7%)
London	805 (12%)
North East	197 (3.0%)
North West	527 (7.9%)
Nothern Ireland	56 (0.8%)
Scotland	391 (5.9%)
South East	1,199 (18%)
South West	1,268 (19%)
Wales	280 (4.2%)
West Midlands	413 (6.2%)
Yorkshire and the Humber	460 (6.9%)
Prefer not to answer	30 (0.5%)

[1]n (%)

Full experimental wording

Thank you for agreeing to take part in this experiment.

Before we begin, we would like to check your internet browser can play videos correctly.

A few of the experiences we're testing feature sound, and this is best heard through headphones. If you have these available, please connect them now.

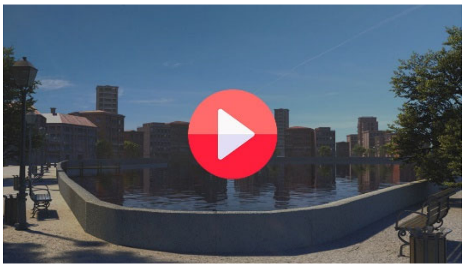
Section 1 | Sound and vision check

Next, press play on the video below and adjust the volume to a comfortable level.

If you are viewing on a laptop or desktop computer, once you have pressed play you can make the video full-screen by pressing 'F' on your keyboard.

Pressing the 'Esc' button will exit full-screen.

When you are ready, please answer the questions below. You can replay the video and make further adjustments if needed.



Q1. Is the video playing without interruption or buffering?

☐ Yes
☐ No

Q2. Can you hear the sounds clearly?

☐ Yes
☐ No

When you are ready, please click the arrow below to continue.

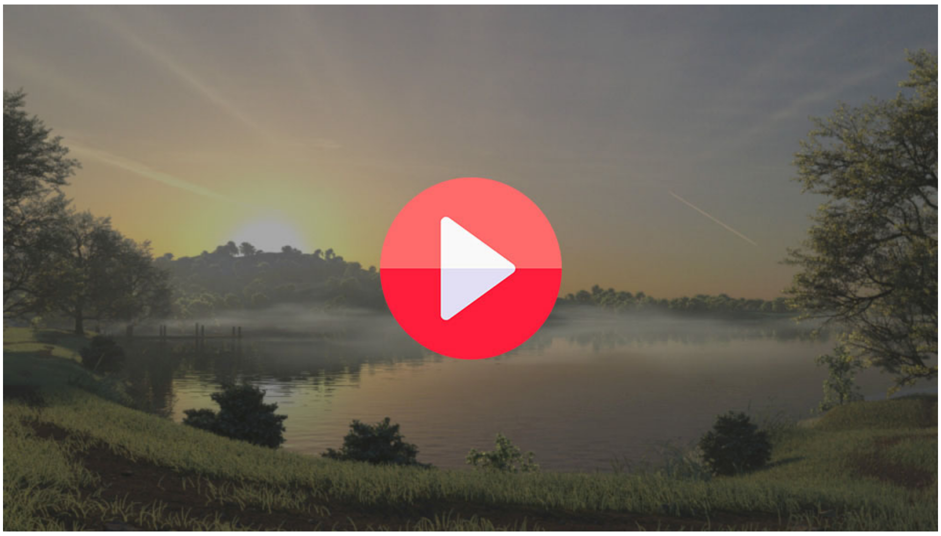
Section 2 | Randomised condition

We would now like you to play the video below. The video is three minutes long and we would like you to view it in one go and right to the end.

Try to focus on the experience without distraction. Please think about how it makes you feel and whether these feelings change as the video progresses.

If you are viewing on a laptop or desktop computer, once you have pressed play please make the video fullscreen by pressing 'F' on your keyboard.

Press 'Esc' when the video has finished to return to this screen.



When the video has finished, please press the arrow below to continue.

Section 3 | Condition-based measures

Now we would like to ask you some questions about the video. There are no right or wrong answers.

First, we would like to ask you about your emotions during the video, which could have varied at different points.

How much did you experience the following emotions?

Q1. Calm

Q2. Excited

Q3. Happy

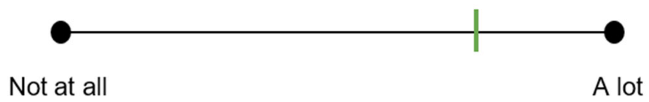
Q4. Awe

Q5. Bored

Q6. Anxious

Q7. Sad

Q8. Nostalgic



[Scale placed beneath each item]

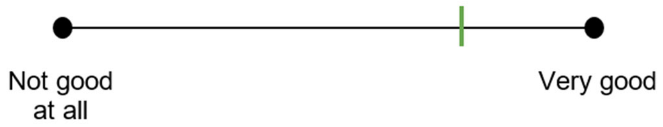
Q9. Did you get goose bumps or feel ‘chills’ down your spine during the experience?

☐Yes
☐No

[Music and restoration questions split into distinct sections in the user interface.]

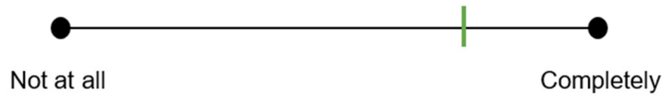
Q10. Now we'd like you to think about a time when you were tired and couldn't concentrate.

To what extent do you think watching this video would be good for taking a short break and recovering?



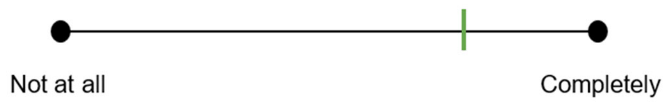
Q11. How much do you agree with this statement?

"The video was fascinating, it had interesting features and held my attention."



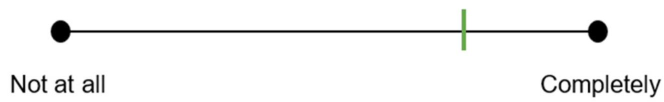
Q12. How much do you agree with this statement?

"The video gave me a break from my routine and helped me feel away from everyday thoughts and concerns."



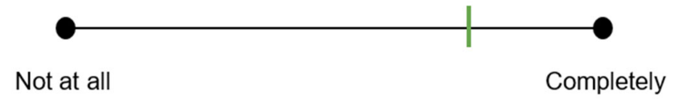
Q13. How much do you agree with this statement?

"There was too much going on in the video."



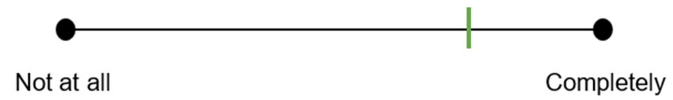
Q14. How much do you agree with this statement?

"The video showed a place which felt large and could be explored."



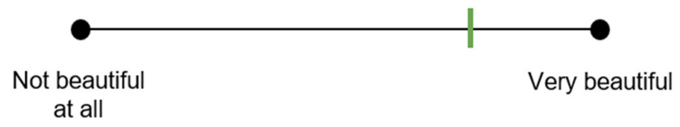
Q15. How much do you agree with this statement?

"The place shown in the film is an ideal setting for me."



Q16. "How much do you agree with this statement?"

"The video was really beautiful"



Q17. Did the video trigger any memories? If so, were they positive or negative?

☐ No memories
☐ Mostly positive memories
☐ Mostly negative memories
☐ A mix of positive and negative memories

Please click the blue arrow below to continue.

Section 4 | Your relationship with nature and music

Please indicate how much you agree or disagree with each sentence below. (There are no right or wrong answers.)

Q1. Being in nature makes me very happy

Q2. I find being in nature really amazing

Q3. I always find beauty in nature

Q4. Spending time in nature is very important to me

Q5. I always treat nature with respect

Q6. I feel part of nature

[Seven-point scale (example below) placed beneath each item.]

In the following three questions, we would like you to think about activities you undertake deliberately.

Q7. How often do you spend time in nature-based environments?

These could include a garden, park, forest, or beach for example.

- ▢ Most days
- ▢ Once or twice a week
- ▢ Once or twice a month
- ▢ Once every 2 or 3 months
- ▢ Once or twice a year
- ▢ Never

Q8. How often do you take time to the sounds of nature?
Such as bird song, the wind in the trees, or waves breaking, for example.

- ▢ Most days
- ▢ Once or twice a week
- ▢ Once or twice a month
- ▢ Once every 2 or 3 months
- ▢ Once or twice a year
- ▢ Never

Q9. How often do you listen to music?

▢ Most days
▢ Once or twice a week
▢ Once or twice a month
▢ Once every 2 or 3 months
▢ Once or twice a year
▢ Never

Q10. Do you play a musical instrument?

▢ Yes
▢ No

Q11. Do you have any musical education?

▢ Yes
▢ No

Q12.

Do you sing, either on your own or as part of a group?
▢ Yes
▢ No

Please click the blue arrow below to continue.

Section 5 | Demographic items

In this final section we will ask you to provide some background information about yourself.

We will not collect any personal data here; your responses are anonymous and you will not be identified from the information you provide.

Q1. What device are you using to take part in this experiment?

☐ Smartphone
☐ Tablet
☐ Laptop
☐ Desktop computer

Q2. How did you listen to the sounds in this experiment? (We are still interested in your answer if you received the silent condition.)

▢ Headphones
▢ External speakers
▢ Inbuilt phone or tablet speaker
▢ Other

Q3. What is your age?

▢ 18-25
▢ 26-35
▢ 36-45
▢ 46-55
▢ 56-65
▢ 66-75
▢ 76+
▢ Prefer not to answer

Q4. What is your gender?

▢ Woman
▢ Man
▢ Non-binary
▢ Another gender
▢ Prefer not to answer

Q5. What is your ethnic group?
[Taken from ONS best practice guidance here https://bit.ly/3n4Xx77.]

Please choose one option that best describes your ethnic group or background

☐ Arab
☐ Asian/Asian British
☐ Black/African/Caribbean/Black British
☐ Chinese
☐ White
☐ Mixed/Multiple ethnic groups
☐ Other ethnic group
☐ Prefer not to answer

Q6. Do you live in the United Kingdom?

☐ Yes
☐ No

Q7. Have you experienced COVID-19 restrictions in the last 4 weeks (government enforced, quarantine related, or due to shielding) which mean your usual access to natural environments has been reduced?

☐ Yes
☐ No
☐ Prefer not to answer

Thank you for your answers. That marks the end of this experiment, please click the blue arrow below to submit your responses and find out what happens next.

Participant debrief sheet

Thank you for taking part in this study!

We're testing a total of 4 different videos in this experiment and responses like yours will help us to understand how digital experiences of nature might affect people's wellbeing.

Our analyses will allow us to see if patterns exist in the way people respond to the conditions we have tested, and will form the first stages in exploring how we might create virtual experiences of nature which enhance positive emotions.

More information about the project can be found at virtual-nature.com and outcomes of this study will be available on this website as soon as possible.

We will also be publishing our findings in academic journals and sharing them on social media, follow @ExeterMed on Twitter to stay in touch.

Alternatively, you can email the study lead, Alex Smalley, on a.j.smalley@exeter.ac.uk for more information on the outcomes of this project.

If you have any complaints about the way this study has been carried out, please contact the Chair of the University of Exeter Medical School Ethics Committee:

Email address blinded for publication.

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