The Relationship Between Birds and the Human Psychological Experience of Nature

Dissertation

der Mathematisch-Naturwissenschaftlichen Fakultät

der Eberhard Karls Universität Tübingen

zur Erlangung des Grades eines

Doktors der Naturwissenschaften

(Dr. rer. nat.)

vorgelegt von

Janina Vanhöfen

aus Reutlingen

Tübingen

2026

Gedruckt mit Genehmigung der Mathematisch-Naturwissenschaftlichen Fakultät der Eberhard Karls Universität Tübingen.

Tag der mündlichen Qualifikation:	22.06.2026
Dekan:	Prof. Dr. Thilo Stehle
1. Berichterstatter/-in:	Prof. Dr. Christoph Randler
2. Berichterstatter/-in:	Prof. Dr. Johannes Kamp

Ja, wir könnten jetzt, was gegen den Klimawandel tun, aber wenn wir dann in 50 Jahren feststellen würden, dass sich alle Wissenschaftler doch vertan haben und es gar keine Klimaerwärmung gibt, dann hätten wir völlig ohne Grund dafür gesorgt, dass man selbst in den Städten die Luft wieder atmen kann, dass die Flüsse nicht mehr giftig sind, dass Autos weder Krach machen noch stinken und dass wir nicht mehr abhängig sind von Diktatoren und deren Ölvorkommen. Da würden wir uns schön ärgern.

Marc Uwe Kling

Danksagung

Dieses Dissertationsprojekt wäre ohne die Hilfe und Unterstützung vieler großartiger Menschen niemals möglich gewesen.

Mein erster Dank geht an meine Betreuer, Herrn Prof. Randler und Herrn Prof. Bossdorf. Danke für Ihr Vertrauen in meine Fähigkeiten, Ihre Unterstützung bei all den unterschiedlichen Studien und Ihre wertvollen Ratschläge. Danke auch dafür, dass ich in die Welt der Didaktik hineinschnuppern durfte – wer hätte gedacht, dass mir Umweltbildung einmal Spaß machen würde? Und nicht zuletzt danke ich für das Vertrauen, das Sie mir bei Konferenzen, in der Lehre und auf Exkursionen entgegengebracht haben.

Ein großes Dankeschön geht auch an meine wunderbaren Kolleginnen Talia Härtel, Nadine Kalb und Naomi Staller. Danke für euren Beistand, eure klugen Ratschläge, eure geduldigen Anmerkungen zu meinen Manuskripten und all die vielen Stunden, in denen wir Ideen, Daten und manchmal auch einfach nur Lebensweisheiten diskutiert haben. Mit euch war die Zeit im Büro nicht nur produktiv, sondern auch lustig und lebendig. Danke auch an die vielen Abschlusskandidat: innen in den Projekten – ohne eure Arbeit und euer Engagement hätte es diese Datensätze schlicht nicht gegeben.

Von Herzen danke ich auch meinen Eltern und meinem Bruder. Ihr habt mich immer unterstützt, an mich geglaubt und mich motiviert, auch dann weiterzumachen, wenn ich selbst nicht mehr daran geglaubt habe. Danke für euren Rückhalt, eure Geduld und dafür, dass ihr einfach immer da seid.

Und schließlich, Niklas – danke, dass du in den letzten Jahren alle Höhen und Tiefen mit mir durchgestanden hast. Danke, dass du meine Launen und meine endlosen To-do-Listen ertragen hast. Für deine Geduld und deine Hilfe bei allem. Und auch dafür, dass du einfach immer an meiner Seite bist, bin ich dir unendlich dankbar.

Table of Contents

Summary

Ongoing urbanization and climate change threaten not only biodiversity but also human health, since being in nature is beneficial to human well-being - physically and mentally. However, the underlying mechanisms linking nature experiences and mental well-being are difficult to pinpoint. Many factors are theorized to play a role, which is why investigating the potential contribution of bird diversity to the mental well-being benefits of being in nature, is one of the key questions this dissertation aims to understand.

In the first part of this dissertation, human mental well-being was surveyed and connected to local bird diversity, habitat heterogeneity, and landscape features. Results showed that participants' perception of bird diversity in the study areas was relatively accurate. Positive determinants of mental well-being included perceived naturalness and perceived bird diversity, whereas a highly visible human impact and infrastructure were associated with lower mental well-being, place attachment, and perception. The perceived naturalness of study areas was positively related to present bird diversity and negatively to the human impact. Individual traits, such as positive perception of birds, a high birding specialization, and bird species knowledge were connected to a positive nature experience.

For the second half of the dissertation, two experimental studies were designed. In a controlled, park-like environment, participants undertook an unguided 30-minute walk-through, with mental well-being and physiological stress parameters measured in a pre-post-test design. The treatment groups were designed to enhance the exposure to and/or awareness of birdsong. All groups experienced improved well-being and reduced physiological stress parameters. Increased awareness of participants' surroundings led to improved mental well-being, while additional birdsong did not. The group that was prompted visually to stop regularly on their walk and listen attentively reported the highest benefits, indicating a higher perceived restorativeness of ambient sound and birdsong compared to the group receiving a verbal cue instead. Furthermore, greater bird species knowledge and a positive nature experience led to better mental well-being, as did a positive perception of birds and higher estimated bird diversity.

Finally, bird species characteristics of brightness, visual attractivity, beauty of song, and cuteness were calculated into one value and connected to the mental well-being of recreationists. Species with a high amount of these characteristics lead to a positive effect of satisfaction and place attachment, while birds exhibiting a lower value may even have negative effects. This result could help in understanding why studies on mental well-being and bird diversity often report mixed results. The characteristics of the bird species present in the study areas could have a bigger effect than previously believed. Going forward, this information can help planners improve urban green spaces, not only by creating habitats for birds but also by considering how those same birds may in turn influence the mental well-being of humans. While careful interpretation and further large-scale studies are needed, the present results offer a promising starting point, showing that bird species traits are indeed related to human experience in recreational areas.

Building on these findings, practical implications emerge for designing recreational urban areas: enhancing perceived naturalness and positive nature experiences while reducing visible human impact together can promote human mental well-being. The results also highlight the potential of practical interventions like signage to enhance the nature awareness and mental well-being of recreationists, possibly even leading to more positive attitudes towards nature conservation.

Zusammenfassung

Die fortschreitende Urbanisierung und der Klimawandel bedrohen nicht nur die Artenvielfalt, sondern auch die menschliche Gesundheit, da sich ein Aufenthalt in der Natur positiv auf das körperliche und geistige Wohlbefinden auswirkt. Die zugrunde liegenden Mechanismen, die Naturerlebnisse und geistiges Wohlbefinden miteinander verbinden, sind allerdings schwer festzustellen. Es gibt viele Faktoren, von denen angenommen wird, dass sie eine Rolle spielen, was die Forschung in eine interessante Richtung führt: die Untersuchung des potenziellen Beitrags der Vogelvielfalt zum psychischen Wohlbefinden durch den Aufenthalt in der Natur. Dies ist eine der Hauptfragen dieser Arbeit.

Im ersten Teil dieser Dissertation wurde das psychische Wohlbefinden von Menschen an unterschiedlichen Orten untersucht und mit der lokalen Vogelvielfalt, der Heterogenität der Lebensräume und den vorhandenen Landschaftsmerkmalen in Verbindung gebracht. Die Ergebnisse zeigten, dass die Teilnehmenden die Vogelvielfalt in den Untersuchungsgebieten relativ genau einschätzen konnten. Determinanten des psychischen Wohlbefindens waren die wahrgenommene Natürlichkeit und Vogelvielfalt, während ein starker menschlicher Einfluss und viel Infrastruktur mit einem geringeren psychischen Wohlbefinden und einer geringeren Ortsverbundenheit verbunden waren. Die subjektiv empfundene Natürlichkeit der Gebiete stand in einem positiven Zusammenhang mit der vorhandenen Vogelvielfalt und in einem negativen Zusammenhang mit dem Einfluss des Menschen. Individuelle Merkmale wie eine positive Einstellung zu Vögeln, eine hohe Spezialisierung auf die Vogelbeobachtung und viel vorhandenes Wissen über Vogelarten standen ebenfalls in Zusammenhang mit einer positiven Naturerfahrung.

Für die zweite Hälfte der Dissertation wurden zwei experimentelle Studien konzipiert: In einer kontrollierten, parkähnlichen Umgebung unternahmen die Teilnehmenden allein einen 30-minütigen Spaziergang, wobei psychisches Wohlbefinden und physiologische Stressparameter in einem Vorher-Nachher-Test gemessen wurden. Die Behandlungsgruppen wurden so eingeteilt, dass das Vorhandensein von Vogelgesang und/oder das Bewusstsein für Vogelgesang verstärkt wurde. Alle Gruppen verzeichneten ein verbessertes Wohlbefinden und eine reduzierte physiologische Stressantwort. Ein gesteigertes Bewusstsein für die Umgebung der Teilnehmenden führte zu einem verbesserten psychischen Wohlbefinden, während zusätzlicher Vogelgesang dies nicht bewirkte. Die Gruppe, die visuell dazu aufgefordert wurde, regelmäßig anzuhalten und zu lauschen, schätzte den positiven Effekt am stärksten ein. Dies weist auf eine höhere wahrgenommene Erholungswirkung von Umgebungsgeräuschen und Vogelgesang hin. Darüber hinaus führten höheres ornithologisches Wissen und eine positive Naturerfahrung zu einem besseren psychischen Wohlbefinden, ebenso wie eine positive Wahrnehmung von Vögeln und eine höhere geschätzte Vogelvielfalt.

Zuletzt wurden die Merkmale der Vogelarten hinsichtlich Farbpracht, visueller Attraktivität, Schönheit des Gesangs und Niedlichkeit zu einem Wert zusammengefasst und mit dem psychischen Wohlbefinden der Teilnehmenden der ersten Studie in Verbindung gebracht. Vogelarten mit vielen dieser Merkmale führten zu einem positiven Effekt auf die Zufriedenheit und die Bindung an den Ort, während Vögel mit einem niedrigeren Wert dementsprechend sogar negative Auswirkungen haben könnten. Dieses Ergebnis könnte zur Klärung der Frage beitragen, warum Studien zum psychischen Wohlbefinden und zur Vogelvielfalt oft zu unterschiedlichen Ergebnissen kommen. Die Eigenschaften der in den Untersuchungsgebieten vorkommenden Vogelarten könnten einen größeren Einfluss haben als bisher angenommen. Dies könnte planenden Personen helfen, städtische Grünflächen zu verbessern und nicht nur Lebensräume für Vögel zu schaffen, sondern auch zu verstehen, wie sich Vögel möglicherweise auf das psychische Wohlbefinden des Menschen auswirken. Die vorliegenden Ergebnisse müssen jedoch in weiteren Studien auf eine größere Skala übertragen und zusätzlich im kulturellen Kontext sorgfältig interpretiert werden. Dennoch sind die Ergebnisse ein vielversprechender Anfang, der zeigt, dass die Artenmerkmale von Vögeln tatsächlich mit der menschlichen Erfahrung in Erholungsgebieten zusammenhängen.

Die Erkenntnisse der vorliegenden Dissertation haben praktische Auswirkungen auf die Gestaltung städtischer Erholungsgebiete, da eine Steigerung der wahrgenommenen Natürlichkeit und positiver Naturerlebnisse bei gleichzeitiger Verringerung sichtbarer menschlicher Einflüsse das psychische Wohlbefinden der Menschen in diesen Gebieten fördern kann. Die Ergebnisse unterstreichen auch das Potenzial praktischer Maßnahmen wie Beschilderungen, um das Naturbewusstsein und das psychische Wohlbefinden von Erholungssuchenden zu verbessern, was möglicherweise zu einer positiveren Einstellung gegenüber dem Naturschutz führen kann.

List of Publications[1]

Manuscript Nr. 1.

Vanhöfen, Janina; Schöffski, Nick; Härtel, Talia; Randler, Christoph (2022). Are lay people able to estimate breeding bird diversity?. *Animals*, *12*(22), 3095. https://doi.org/10.3390/ani12223095.

Author Contributions: JV = Conceptualization, Methodology, Validation, Formal analysis, Data curation, Writing – original draft preparation, Writing – review and editing, Visualization. **NS** = Investigation. **TH** = Formal analysis, Investigation, Data curation, Writing – review and editing. **CR** = Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – review and editing, Supervision, Project administration.

Manuscript Nr. 2.

Vanhöfen, Janina; Härtel, Talia; Reichert, Giovanna; Randler, Christoph (2025). The relationship between perception and landscape characteristics of recreational places with human mental well-being. *Scientific Reports* 15, 4245. https://doi.org/10.1038/s41598-025-88414-5.

Author contributions: **JV** = Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing—original draft preparation, Writing—review and editing, Visualization. **TH** = Formal analysis, Investigation, Data curation, Writing—review and editing. **GR** = Methodology, Investigation. **CR** = Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing—review and editing, Supervision, Project administration.

Manuscript Nr. 3.

Vanhöfen, Janina; Stuck, Katharina; Haag, Reimund; Härtel, Talia; Randler, Christoph (2025). Effects of nature experience on mental well-being and physiological stress parameters in an experimental bird walk setting – the role of bird song. *Landscape and Urban Planning* 263, 105456. https://doi.org/10.1016/j.landurbplan.2025.105456.

Author contributions: JV = Conceptualization, Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation. **KS** = Writing – review & editing, Investigation, Formal analysis. **RH** = Writing – review & editing, Investigation, Formal analysis. TH = Methodology, Investigation, Conceptualization. **CR** = Writing – review & editing, Supervision, Resources, Project administration, Methodology, Conceptualization.

Manuscript Nr. 4.

Vanhöfen, Janina; Härtel, Talia; Teufel, Louisa; Schaffer, Laura; Randler, Christoph (2026). Two treatments of birdsong awareness and their influence on human mental well-being in an urban park environment. *Journal of Urban Ecology*, *12*(1), juag013. https://doi.org/10.1093/jue/juag013.

Author contributions: JV = Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft preparation, Writing – review and editing, Visualization. **TH** = Conceptualization, Methodology, Investigation, Writing – review and editing. **LT** = Formal analysis, Investigation, Writing – review and editing. **LS** = Formal analysis, Investigation, Writing – review and editing. **CR** = Conceptualization, Methodology, Resources, Writing – review and editing, Supervision, Project administration.

[1] This thesis includes previously published work (all CC-BY 4.0 licensed https://creativecommons.org/licenses/by/4.0/). Spelling errors identified after publication of the original article have been corrected without altering the content. Figures and tables have been reformatted and numbered consecutively throughout the dissertation for stylistic consistency, without changing their values or the type of graphs.

Manuscript Nr. 5.
Vanhöfen, Janina; Kalb, Nadine; Randler, Christoph (2026). Bird species traits in recreational areas– building a human restoration value of bird species and connecting it to the mental well-being of recreationists in Germany. *Frontiers in Bird Science*, *5*, 1740187. https://doi.org/10.3389/fbirs.2026.1740187.

Author contributions: JV = Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, writing – original draft preparation, writing – review and editing, Visualization. **NK** = Methodology, Investigation, writing - review, and editing. **CR** = Conceptualization, Methodology, Investigation, Resources, Data curation, writing- review and editing, Supervision, Project administration.

Personal contributions

Table 1.
Declaration of the significance of the contribution for Janina Vanhöfen, according to §6,2 of PromO.

Nr.	Accepted publication	List of authors	Scientific ideas by the candidate (%)	Data generation by the candidate (%)	Analysis and Interpretation by the candidate (%)	Paper writing done by the candidate (%)
1	yes	Vanhöfen, Janina Schöffski, Nick Härtel, Talia Randler, Christoph	33	25	80	80
2	yes	Vanhöfen, Janina Härtel, Talia Reichert, Giovanna Randler, Christoph	33	33	80	90
3	yes	Vanhöfen, Janina Stuck, Katharina Haag, Reimund Härtel, Talia Randler, Christoph	70	80	90	90
4	yes	Vanhöfen, Janina Härtel, Talia Teufel, Louisa Schaffer, Laura Randler, Christoph	70	80	90	90
5	yes	Vanhöfen, Janina Kalb, Nadine, Randler, Christoph	50	15	70	90

1. Introduction

As the global human population continues to increase, cities are becoming the primary living environment for an ever-growing number of people. Nowadays, more people live in urban than in rural areas (United Nations, 2018). Urban ecological infrastructure primarily consists of parks, gardens, open spaces, and water catchment areas, which support new, unique ecosystems and biodiversity (Elmqvist et al., 2013; Kowarik, 2011) in regions heavily used by humans for recreational purposes.

In contrast to increasing urbanization, biodiversity is decreasing worldwide at an alarming rate (IPBES, 2019; Isbell et al., 2015). This biodiversity loss presents numerous challenges for both ecosystems and humans (Cardinale et al., 2012). It also poses challenges to people's healthy lifestyle (McDonald et al., 2013). The biodiversity hypothesis in medicine suggests that physical contact with biodiverse environments increases immunoregulatory functioning and protects against allergies and inflammation (Haahtela, 2019). Additionally, recreational areas with diverse bird species have been associated with increased physical activity and lower obesity rates (Knobel et al., 2021), thereby enhancing overall physical health. Biodiversity loss further affects the mental health and well-being of urban dwellers, increasing risks of anxiety and affective symptoms (Xu et al., 2023).

Urbanization is one of the leading causes of biodiversity loss, largely driven by land-use change and habitat transformation (Ladle et al., 2023; McDonald et al., 2020). It is also connected to a decrease in contact with nature – the so-called "extinction of experience"- which contributes to a decline in public well-being, a reduced emotional affinity towards nature and therefore also to a decline in pro-environmental attitudes (Soga & Gaston, 2016). This is significant because many studies propose the idea that human well-being is enhanced by experiencing biodiversity (e.g., Brown & Grant (2005); Irvine & Warber (2002); Maas et al. (2006)). In the face of biodiversity loss, this relationship is part of a rapidly expanding field of research (Houlden et al., 2021) which seeks to explore these connections in greater depth, since being "in nature" has been known to impact human health positively - physically and mentally (de Brito et al., 2019; Fisher et al., 2021; Kaplan & Kaplan, 1989; Marselle et al., 2021b; Sugiyama et al., 2008; Ulrich, 1983; White et al., 2013). It is therefore essential to find solutions for how nature experiences can be provided and preserved in urban areas, thereby fueling positive emotional connections with nature and promoting biodiversity conservation.

To date, there is only limited research on the specific qualities of recreational spaces and biodiversity posing the greatest effects on people's health and well-being. Birds, for example, have been studied as potential contributors to human mental well-being or health, albeit with mixed results (Lovell et al., 2014). This dissertation focuses on the mental well-being of people who spend time outdoors in urban and rural recreational areas, examining the connection with biodiversity, especially bird diversity. To this end, a link is established between bird species diversity, characteristics of recreational areas, and people's psychological experience of nature.

Relevance of mental well-being

Health and well-being are integral to human life. Health, as defined by the World Health Organization (WHO), "*is a state of complete physical, mental, and social wellbeing and not merely the absence of disease or infirmity*" (WHO, 1946). According to the Millennium Ecosystem Assessment Report (WHO, 2005a, 2005b), nature provides various benefits to humans. These ecosystem services are the benefits that people derive from nature (Daily et al., 2009). They are mostly defined by the WHO under the categories "1) provision of resources necessary for human life (e.g., food or fresh water), 2) regulation of natural phenomena such as temperature or the absorption of rainwater, and 3) facilitation of social and cultural interactions and experiences" (WHO, 2005a, 2005b). Green Infrastructure, such as parks, forests, or gardens, is the backbone that provides these ecosystem services. Urban areas face numerous challenges in relation to these ecosystem services, including air and water pollution, increasing energy demands, inadequate waste management, and food shortages, all of which directly impact human health and well-being (UN-Habitat, 2008). These factors also threaten the quality of life, as well as economic and social stability (UN-Habitat, 2011). An estimated 60% of the global population is expected to live in urban areas by 2030 (Montgomery, 2007), which is why such challenges need to be taken seriously. Bratman et al. (2019) even speak of psychological ecosystem services, meaning the positive mental health effects of engaging with nature. They proposed two ecosystem services that could be classified as mental health services: place bonding and restoration (Subiza-Pérez et al., 2020a; Subiza-Pérez et al., 2020b).

Well-being is often broadly defined as the "quality and state of a person's life" (Maggino, 2015). Therefore, the line between well-being and health is blurred. Linton et al. (2016) categorize the existing literature into six domains of well-being: mental, social, physical, and spiritual well-being, activities and functioning, as well as personal circumstances. Since being healthy does not guarantee a person's sense of well-being, the explicit measurement and improvement of subjective well-being have become key research, policy, and government objectives (Prilleltensky et al., 2015; Steptoe et al., 2015; Stewart et al., 2015).

There are many different theories behind mental well-being as a general concept. Mental well-being measures try to assess the psychological, cognitive, and emotional quality of a person's life (Linton et al., 2016). This component of well-being has been consistently divided into an "affective" component concerned with emotions, and a "cognitive" part, concerned with people's evaluation of their own life (Nieboer et al., 2005; Şimşek, 2011). It is important to note that mental well-being is not the same as the absence of mental illness, even though it refers to optimal psychological functioning and experience (Ryan & Deci, 2001). According to Ryan & Deci (2001), the concept of subjective well-being, which is commonly used in hedonic research, consists of three elements: life satisfaction, presence of positive mood, and absence of negative mood. In contrast, the concept of eudaimonia or self-realization includes the psychological well-being as distinct from subjective well-being with six aspects of human actualization: autonomy, personal growth, self-acceptance, life purpose, mastery, and positive relatedness (Deci & Ryan, 2000, 2012; Ryan & Deci, 2001; Ryff & Keyes, 1995). In the present dissertation, mental well-being references the positive situational state of a person. It is based on positive emotions (White et al., 2020; Wyles et al., 2019) as well as feelings of restoration (White et al., 2017; Young et al., 2020) and satisfaction (Arlinghaus, 2006).

Mental well-being and nature

Being "in nature" – defined here as outdoor green or natural spaces - has been shown to be beneficial to human health and mental well-being, linking nature experiences to increased positive affect (Berman et al., 2012; Hartig et al., 2003), happiness, and subjective well-being (White et al., 2013). Opportunities for contact with nature vary across contexts. According to Hartig et al. (2014), "nature" as a concept often "*refers to physical features and processes of nonhuman origin that people ordinarily can perceive, including the living nature of flora and fauna, together with still and running water, qualities of air and weather, and the landscapes that comprise these and show the influence of geological processes*". They also noted the problem that most natural environments used in well-being research do not exclude human presence or intervention. The natural environments studied are often located in cities or are in many other ways influenced by human activity, representing real-life possibilities for contact with nature. Going with Kaplan & Kaplan (1989), in this dissertation, the term "nature" or "natural environment" is not meant to exclude built or urban environments, it also includes natural features of built environments, e.g., urban parks. These terms are often used interchangeably, even in city contexts. This is also why the term "nature experience" is often used to emphasize the subjective perception of relevant environmental features (Hartig et al., 2014; Kaplan & Kaplan, 1989), irrespective of the kind of natural aspects that can be experienced.

White et al. (2013) summarized the many possible pathways and mechanisms in which green space (and other outdoor areas facilitating the experience of nature) could improve mental well-being: encouraging physical activity (Maas et al., 2008), reducing stress (Grahn & Stigsdotter, 2003), helping with cognitive restoration (Berman et al., 2008), and promoting positive social interactions (Kuo et al., 1998). Shanahan et al. (2015b) differentiate between direct pathways to human health, which are specific ecological properties reducing risks for health problems, e.g., better air quality, and indirect pathways promoting healthy habits like physical activity. But how these pathways are connected to nature and nature experience is difficult to determine. It is also seemingly difficult to pinpoint effects: Mavoa et al. (2019) found no associations between animal richness, plant richness and well-being but in the same study a higher vegetation density correlated positively with increased subjective well-being.

Recreational areas and landscape features

Urban recreational nature areas are critical spaces for urban residents to experience natural environments or features (Felappi et al., 2024). They include “green” spaces, such as parks and forests, and “blue” spaces, such as lakes and rivers. For a significant portion of the urban population, these areas are the primary opportunities for connecting with nature. They are generally associated with mental health benefits for people (Jimenez et al., 2021; White et al., 2013). Being in nature seems to not only help humans' physical health and stress reduction (Berman et al., 2008; Grahn & Stigsdotter, 2003; Maas et al., 2009), but also psychological restoration (Fisher et al., 2021; Kaplan & Kaplan, 1989; Marselle et al., 2021a).

Different areas exhibit distinct landscape characteristics, which may in turn affect recreationists in various ways. The physical features of a region, its topography, geology, climate, vegetation, and human activity are generally referred to as landscape (Kühne, 2019). It is shaped by biodiversity, influencing the distribution and frequency of plant and animal species (Cardinale et al., 2012), which in turn affects the physical and chemical properties of the environment. A landscape with high biological diversity can contain more complex and productive ecosystems with a larger number of pollinators and decomposers, which can improve the functioning and stability of the ecosystems (Van Der Plas, 2019). On the flipside, the landscape affects biodiversity since it provides the conditions in which plants and animals live, and it can change the odds for survival and reproduction. A landscape providing more diverse habitat opportunities (biotopes) also often leads to higher species diversity. Human activities, in contrast, can change landscapes and lead to a decline in biodiversity (Aronson et al., 2014). Biodiversity and landscape features are therefore defining components of recreational areas. According to Pejchar et al. (2025), assessing ecosystem services across diverse land uses and neighborhoods is necessary to gain a broader understanding.

Urban green spaces (like parks, forests, and gardens) and blue spaces (consisting of large water bodies) are both beneficial for well-being. They provide valuable ecosystem services and benefit human health since they can help soften the negative impacts of air, noise, and light pollution (Sarkar et al., 2018). They are associated positively with physical (de Brito et al., 2019) and mental health (Jimenez et al., 2021) of people. This is the reason why a lot of literature focuses on differences between green spaces, in contrast to urban blue spaces (Duke & Soulsbury, 2021). Blue spaces, including oceans and rivers, are shown to reduce depression and stress, and to boost attentional capacities (White et al., 2020; Wyles et al., 2019). Green spaces have been shown to do the same (Hartig et al., 2014). Other health benefits of nature include reduced stress, anxiety, and depression (Beyer et al., 2014; Marselle et al., 2019; Randler et al., 2023a; Randler et al., 2023c). The view of plants or water has been known to be vital for human well-being (Ulrich, 1979; 1983). Especially biodiverse landscapes enhance feelings of restorativeness and have been shown to increase positive affect as well as reduce negative affect, with higher bird species richness particularly influencing perceptions of naturalness (Chang et al., 2024). A high perceived species richness was positively related to better mental well-being in earlier studies (Meng et al., 2024). Locations with higher perceived biodiversity are associated with greater restorativeness, which itself promotes well-being (Fisher et al., 2021; Nghiem et al., 2021). However, perceptions of biodiversity are not uniform and seemingly not always dependent on actual biodiversity. For example, large green spaces with tall and colorful plants are more likely to be perceived as biodiverse, independent of their actual diversity levels (Gonçalves et al., 2021; Hoyle et al., 2017; Southon et al., 2018).

Theories on the effects of natural environments

Stress is an individual´s psychological, physiological, and/or behavioral response to a situation that challenges or threatens well-being (Ulrich et al., 1991). As already mentioned, visiting recreational nature areas is generally associated with lower stress, depression, and anxiety (Beyer et al., 2014) as well as with other mental health benefits (Jimenez et al., 2021). The environment in which people live plays an important role in this. Some earlier studies theorized that biodiversity as a part of the natural environment is one of the main drivers that lead to increased mental well-being among recreationists (Adjei & Agyei, 2015; De Vries & Snep, 2019; Houlden et al., 2021). There are also several hypotheses regarding the underlying reasons/mechanisms for the benefits derived from experiencing nature and biodiversity.

In 1975, the idea was proposed that environmental preferences are derived from our evolutionary origins (Forster, 2010). This theory states that humans tend to prefer environments where they can see prey and predators from a long distance and that they have lived in for much of our evolutionary history. A few years later, Wilson (1986) proposed his **Biophilia hypothesis**, suggesting that humans have evolved to respond positively to environments that enhance the odds of survival and that we are inherently attracted to such settings. Essential to the biophilia hypothesis is the position of a direct emotional connection between nature and humans (Joye & De Block, 2011).

This was then developed further by Kaplan & Kaplan (1989), who theorized that humans have positive aesthetic reactions to environments in which we have functioned effectively as a species. This is probably one of the reasons why many studies find a preference for urban instead of rural areas, even though this is changing in recent times (Subiza-Pérez et al., 2020b). Kaplan & Kaplan (1989) and Kaplan (1995) went on to postulate the **Attention Restoration Theory (ART)**, which suggests that exposure to nature replenishes cognitive resources such as attention. For this, it is assumed that there are two types of attention: focused concentration, which is tiring, and indirect attention, which is restorative (Forster, 2010). The mechanisms that are proposed to be behind this effect have been discussed critically (Joye & Dewitte, 2018), even though the positive effect of nature on affection and attention itself has been shown many times (Joye et al., 2013).

Around the same time, Ulrich (1983) studied two groups of hospital patients: one looking at a wall and one looking at a nature scene. He found that patients with a view of nature recovered quicker with fewer problems than their counterparts. This concept was further developed into the psycho-physiological **Stress Reduction Theory (SRT)** by Ulrich (1979, 1983) and Ulrich et al. (1991), who proposed that natural settings are restorative because they possess evolutionary survival-related advantages and therefore have stress-reducing capabilities (Forster, 2010). Psychological restoration in the sense of both ART and SRT means replenishing cognitive resources and reducing stress (Kaplan & Kaplan, 1989; Ulrich et al., 1991). Some of the following frameworks link biodiversity itself to human mental health and well-being, including the ability to restore and build attentional capacity (e.g., by Marselle et al. (2021a); Marselle et al. (2021b)).

The **self-determination theory** by Deci & Ryan (2000) argues that the satisfaction of basic psychological needs typically fosters subjective well-being as well as self-realization, using subjective well-being as one of many indicators of general well-being. In the present dissertation, subjective well-being is based on this theory, meaning that the subjective well-being tested is about the presence of positive emotions, feelings of satisfaction, and restoration. These measures have been asked for as a momentary assessment, therefore not giving insight into an individual's lifelong well-being. This is in line with the mental well-being/health definition used in most earlier studies looking at the effects of nature or similar environments. Many of these effects can be seen as subjective, since they are often self-reported.

Most research in restorative areas shows that a broadly defined biodiversity has a positive association with human mental health and well-being (Marselle et al., 2019; Randler et al., 2023a; Randler et al., 2023c), but some also find no significant association between species richness, affective states and well-being (Wu et al., 2024). Evidence has been found that species-rich natural areas can promote the (short-term) well-being of visitors. For example, vegetation cover in urban areas has been positively associated with a lower prevalence of depression, anxiety, and stress (Cox et al., 2017b). Increased plant and animal diversity, particularly in green spaces, has also been positively associated with mood enhancement (Cameron et al., 2020; Methorst et al., 2021a; Wei et al., 2022), stress reduction (Schebella et al., 2019b), and increased attention restoration (Fisher et al., 2021; Randler et al., 2023c). However, there are mixed findings on the influence of, e.g., bird species richness on mental health. It appears that having more bird species in the environment and being able to observe them has a positive effect on mental well-being (Cox & Gaston, 2015; Fuller et al., 2007), while listening to their songs can help to restore alertness and recover from stress (Ratcliffe et al., 2013). It is not entirely clear whether these results depend on actual or perceived biodiversity. People's inability to sense and detect biodiversity may lead to a disconnect between biodiversity and their mental well-being (Marselle et al., 2020; Wu et al., 2024).

Restoration

Psychological restoration is based on the suggestion that cognitive and emotional systems of humans can be depleted by stress or urban environments among other factors (Kaplan & Berman, 2010; Wyles et al., 2019). For that reason, the two influential theoretical concepts of ART and SRT argue that exposure to non-threatening natural environments can help restore these depleted resources, leading to **restoration**.

The perceived restorativeness scale (PRS) by Korpela & Hartig (1996) identifies the restorative characteristics of a space, distinguishing between different dimensions of restorativeness (being away/fascination/compatibility) – adapted by Berto (2005). The PRS has been expanded for perceived restorativeness of sound (Payne, 2013; Uebel et al., 2021; Uebel et al., 2022), since it is an important part of restoration, especially in outdoor environments (Coensel et al., 2011; Fisher et al., 2021; Ratcliffe et al., 2013). Restoration is also a very subjective feeling, which is why items such as self-reported restoration (von Lindern, 2017; Young et al., 2020) are a valuable tool.

Emotions

Mental well-being is more than the absence of mental distress and includes positive feelings, including joy, interest, commitment, and love, broadening an individual's situational thought–action repertoire (Fredrickson, 1998). Positive emotions play a crucial role in situational mental well-being (Ryan & Deci, 2001), since stress is not only demanding for cognitive systems in the body, but also for emotional ones (Ulrich, 1979). Being in nature is theorized to increase positive emotions and replenish these emotional systems (Ulrich et al., 2023), increasing the ability of reflection after a nature visit (Mayer et al., 2009). An attentional bias has been observed with individuals focusing more on natural rather than urban environments, particularly when these natural environments elicit positive affective responses (Joye et al., 2013).

Many individuals are happier when living in urban areas with greater amounts of green and blue spaces, as mental distress is reduced and life satisfaction improves (White et al., 2013; White et al., 2020). Additionally, exposure to natural environments has been associated not only with a reduction in negative but also with an increase in positive emotions (McMahan & Estes, 2015). Following the idea of restoring emotional capacity, we used the definition of positive emotions (also called self-reported restoration) by White et al. (2013) and Wyles et al. (2019), asking for feelings of being calm/relaxed, refreshed/revitalized, and peaceful as conceptual matches for emotional restoration.

Satisfaction

The feeling of satisfaction is linked to motivation and goal fulfilment, helping with feelings of self-actualization and vitality (Deci & Ryan, 2000). Additionally, visit satisfaction in tourists also influenced emotional place attachment in earlier studies (Prayag & Ryan, 2011). This is why we asked people about their satisfaction with the visit to the recreational area afterwards (Arlinghaus, 2006).

Place attachment

Many people go to their favorite places to feel better or to self-regulate their emotions (Korpela et al., 2020; Korpela et al., 2010): they exhibit so-called **place attachment,** which is an emotional bond of humans with a place. Scannell & Gifford (2010) theorized three dimensions of place attachment: person, psychological process, and place. According to them, place attachment can vary in terms of spatial level, degree of specificity, and social or physical features of place and is manifested through affective, cognitive, and behavioral psychological responses (Scannell & Gifford, 2010).

The constructs of place attachment and place identity describe the emotional and cognitive attachments that people form to a particular place they like (Boley et al., 2021). Place attachment has also been strongly associated with restoration (Subiza-Pérez et al., 2020b) and the perceived recreational potential of an area (Menatti et al., 2019), influencing people's well-being (Menatti et al., 2019; Subiza-Pérez et al., 2021). Since place attachment allows for enhanced positive emotions and cognitive freedom, it helps to regulate emotions and reduce cognitive load (Scannell & Gifford, 2010), leading to favorite places having restorative qualities (Korpela & Hartig, 1996).

Bryce et al. (2016) identified constructs of **place identity** and **therapeutic value** as cultural ecosystem services, benefitting people´s well-being. According to them, place identity refers to the significance a place holds for an individual, as part of their identity built through attachment and a sense of belonging. Place identity has been condensed on an abbreviated scale by Boley et al. (2021), unifying the many differing scales used in research. Many benefits commonly associated with nature depend on the specific habitats and landscapes people visit (Bryce et al., 2016).

Connectedness to nature

Connectedness to nature as a concept relates to the emotional cognitive bond to nature (Mayer & Frantz, 2004). It is a stable individual personality trait, developing over time (Nisbet et al., 2019; Nisbet et al., 2011) as well as a situational emotional response depending on the context (Nisbet & Zelenski, 2011). Higher levels of connectedness to nature have been linked to improved human health and well-being (Mayer et al., 2009; Tam, 2013) greater happiness (Tam, 2013; Zelenski & Nisbet, 2014) as well as increased engagement in pro-environmental behaviors (Mayer & Frantz, 2004). The two psychological benefits of connectedness to nature and psychological restoration are suggested not to be independent from each other - restorative effects happen *because* of people's connectedness to nature (Wyles et al., 2019).

Bird diversity

Germany's avifauna is typical for this region of the world, situated in the heart of western Europe. The country hosts a total of 527 bird species, approximately 245 of which breed regularly in Germany (Gerlach et al., 2025). Roughly 43% of German bird species are listed on the IUCN Red List (Ryslavy et al., 2020), in addition to 15 globally threatened ones (BirdLife International, 2026). Birds are often used as an indicator of biodiversity present in an area due to their dependency on certain habitats/landscapes/biotopes (Gregory & Van Strien, 2010). They are well studied and trends in bird populations tend to correlate with those of other taxa, which is why wild birds have been adopted by many European countries and by the European Union as indicators of biodiversity (Gregory et al., 2008), making them valuable indicators of biological diversity, ecological conditions, and environmental status (Randler & Koch, 2025). Additionally, many earlier studies concerning biodiversity and its effect on people used birds as a proxy for actual biodiversity (Cameron et al., 2020; Celis-Diez et al., 2017; Dallimer et al., 2012; Farinha-Marques et al., 2011; Wheeler et al., 2015; Williams & Gaston, 1994).

Birds also provide ecosystem services to people, including seed dispersal and the provision of resources like food or feathers (Wenny et al., 2011). Their species characteristics are closely linked to their habitat and provisioned ecosystem services (Sekercioglu, 2006). They have also been associated with increased joy (White et al., 2023), strong connections to a place (Luck et al., 2011), and improved mental health (Methorst et al., 2021a; Xie et al., 2023) in humans. Additionally, human interactions with birds, such as birdwatching and listening to birdsongs, provide educational (Askerlund et al., 2024), motivational as well as psychological benefits to people (Randler et al., 2023a; Randler et al., 2023c). Birds are often used for studying the effects of biodiversity on the mental well-being of people due to their visibility, acoustic presence, and general popularity (Cox & Gaston, 2015), having a unique capacity to draw attention and fascinate people (Woods, 1998). Some species are very abundant, being commonly found in human-dominated environments. Several species thrive, tolerate, or even adapt to human activity (McDonnell & Hahs, 2015). Birds are also a taxonomic group that is generally preferred by lay people and whose species are easily distinguished compared to other taxonomic groups such as insects (Cox & Gaston, 2015). As a result, birds are well-suited to connect people with nature (Belaire et al., 2015).

The evidence on the role of bird species richness for mental health benefits, their perception, and awareness is mixed (Lovell et al., 2014). Some studies show positive associations (Dallimer et al., 2012; Fisher et al., 2021; Huby et al., 2006; Meng et al., 2024; Methorst et al., 2021a) and others find no relationship (Cox et al., 2017b; Taylor et al., 2018). This makes it difficult to measure if and how conservation efforts for bird diversity could boost mental well-being.

Greater bird diversity has not only been associated with physical activity and lower obesity rates (Knobel et al., 2021), but also with more positive moods and feelings of restoration (Douglas & Evans, 2021; Schebella et al., 2019b) as well as improved overall well-being and life satisfaction (Chen et al., 2022; Methorst et al., 2021b; Taylor et al., 2018). Generally, having more birds around and observing them seems to contribute positively to mental well-being (Cox & Gaston, 2015; Fuller et al., 2007). People have reported enjoyment of high bird diversity (presented by birdsong) but not always increased perceived restoration or attentional capacity (Douglas & Evans, 2021). Birdsong is recognized as a calming and restorative natural sound (Ratcliffe et al., 2013), further supporting the inclusion of avian diversity in biodiversity-well-being research. In contrast, some species can be perceived as aggressive or a nuisance (Cox et al., 2018a) and these adverse attitudes can diminish the positive effects of nature on health and well-being (Wu et al., 2024).

Bird diversity is dependent on plant and habitat diversity (Paker et al., 2014), which in turn are also helpful for human well-being (Lindemann-Matthies & Matthies, 2018). In their review, Wu et al. (2024) found a more positive relationship between bird diversity and human health than any other animal taxa. They argue that birds and humans share similar needs for urban green spaces, though human well-being appears to stem from the shared habitats as opposed to direct interactions with wildlife.

The impact of perception and awareness

Even though research into the relationship between mental well-being and actual /perceived biodiversity has shown conflicting results, being outside undoubtedly has some form of positive effect on the well-being of people. It is often suggested that greater biodiversity in an area also leads to improved well-being of people (Luck et al., 2011; Wood et al., 2018). Species-rich areas, particularly those with diverse vegetation, are linked to lower rates of depression, anxiety, and stress (Cox et al., 2017b; Wheeler et al., 2015). While having more birds around and observing them generally contributes positively to mental well-being (Cox & Gaston, 2015; Fuller et al., 2007), studies about the connection between biodiversity and the mental well-being of people have used differing approaches to assess biodiversity. While some studies based on real counts of plants (Marselle et al., 2016) or bird diversity (Dallimer et al., 2012) report positive associations with mental well-being (Dallimer et al., 2012; Huby et al., 2006; Methorst et al., 2021a; Wolf et al., 2017), others found no such relationship (Cox et al., 2017b; Taylor et al., 2018). In contrast, studies accounting for participants perceived biodiversity presented more robust associations with mental well-being: Perceived plant and bird diversity, for example, was associated with a greater ability to concentrate, positive moods, and lower stress levels (Cameron et al., 2020; Schebella et al., 2019b). Fisher et al. (2021) showed that people perceived biodiverse locations as more restful, which in turn leads to improved well-being. Nghiem et al. (2021) found that perceived animal diversity contributes to perceived (psychological) restfulness. Again, other studies found no association between perceived biodiversity and restoration, general health, or well-being (Douglas & Evans, 2021; Fisher et al., 2022; Nghiem et al., 2021; Southon et al., 2018). This discrepancy in the effectiveness of actual and perceived species' richness suggests that cognitive and sensory impressions - rather than objective measures - often drive psychological benefits (Zumhof, 2019).

In humans, perception plays a key role in how individuals experience biodiversity. Although this perception is often not accurate, people's mental representation of their environment remains important to their mental health (Gifford, 2009; Moser, 2009). Earlier studies have shown that lay people often either over- or underestimate species richness (Belaire et al., 2015; Dallimer et al., 2012). Some studies have found positive relationships between perceived biodiversity, bird counts (Cameron et al., 2020), and plant diversity (Fisher et al., 2022). Douglas & Evans (2021) demonstrated that lay people were able to accurately identify that certain green spaces have a higher bird diversity than others but did not associate this with enhanced well-being. Other studies only report weak or no associations, often reporting diverging perceptions from objective measures (Fisher et al., 2022; Ha & Kim, 2021; Hoyle et al., 2017; Southon et al., 2018). Dallimer et al. (2012) found that there was no consistent relationship between the actual and perceived species richness of plants, birds, and butterflies. People underestimate species' richness and there has been no correlation between observed and estimated species richness in the study by Shwartz et al. (2014).

It seems that landscape characteristics of green spaces, like vegetational height and variety, act as cues for perceived species richness (Schebella et al., 2019a, 2019b). Even though people do not always accurately perceive biodiversity, factors such as nature connectedness and knowledge improve accuracy (Southon et al., 2018). Therefore, the mixed evidence on people's ability to perceive biodiversity could be due to their lack of awareness of the surrounding wildlife (Methorst et al., 2021a; Methorst et al., 2021b). Perception in itself does not need to happen consciously, but awareness, defined as the conscious understanding and processing of impressions (Merikle et al., 2001), can be cultivated through interventions such as mindfulness or informational cues, thereby potentially enhancing nature-related experiences. According to Graziano & Kastner (2011), awareness is a reconstruction of the attentional state of mind, but not the same thing as attention. They argue that awareness is about perceiving the focus of attention.

Colléony et al. (2020) used cues to enhance interaction with nature and positive affect. Mindfulness leads to greater awareness and stronger connectedness with nature as well as less negative emotions (Nisbet et al., 2019). In the study by Breitschopf & Bråthen (2023), the appreciation of biodiversity correlated more strongly with perceived biodiversity than with actual plant diversity. Therefore, active perception is the foundation on which awareness can be built (Graziano & Kastner, 2011). It also plays a role in the positive effects on mental well-being. People who report benefits from nature also tend to feel more strongly connected to it (Mayer et al., 2009). Moreover, paying attention to natural surroundings increases awareness, strengthens this connection, and reduces negative emotions (Nisbet et al., 2019). Attention is not only a passive feature but can be directed. Colléony et al. (2020) used cues to enhance interaction with nature and subsequently also increased positive affect. When tasked with photographing their surroundings, people in natural environments experienced increased well-being and a heightened sense of connectedness to nature (Passmore & Holder, 2017).

Soundscapes

The environment is not only composed of visual elements but also integrates many different sounds. So-called "soundscapes" are integrating all the sounds of a landscape, building scenes of ambient sound characterizing a place (Pijanowski et al., 2011a; Pijanowski et al., 2011b). They significantly influence human emotional states. Pleasant soundscapes have been positively associated with psychological well-being (Erfanian et al., 2021). Natural acoustic environments, dominated by birdsong, water, and wind, are often rated as more restorative than anthropogenic soundscapes (Payne, 2013). Urban settings can achieve similar benefits when birdsong is present, especially when more than one species is singing (Hedblom et al., 2014). Exposure to natural sounds has also been shown to lower blood pressure, heart rate, depression, anxiety levels, and other negative mood states (Ha & Kim, 2021; Stobbe et al., 2022; Zhu et al., 2024). Urban Park soundscapes, characterized by a variety of birdsong and minimal traffic noise, appear to offer the greatest perceived restorative benefits (Uebel et al., 2021). The pleasantness of birdsong in a soundscape even seems to buffer the negative effects of traffic noise (Uebel et al., 2022). Birdsong has been suggested as the natural sound most associated with stress recovery and restoration (Ratcliffe et al., 2013) and it is also able to enhance the pleasantness of an area's soundscape (Coensel et al., 2011).

As a major component of natural soundscapes, birds contribute significantly to the acoustic environment of the northern hemisphere (Farina et al., 2011), especially during springtime (Whelan et al., 2016). They are often perceived by humans in the form of birdsong either consciously or subconsciously (Ferraro et al., 2020). Moreover, the number of bird species perceived by visitors is higher in areas with lower anthropogenic noise pollution (Levenhagen et al., 2020). Most people share some kind of preference for birdsong (Chen et al., 2022), but some songs and calls can also annoy urban residents (Belaire et al., 2015; Pejchar et al., 2025), making not all bird sounds helpful for restoration purposes (Ratcliffe et al., 2013). The calls of gulls, for example, are often not perceived as pleasant. Personal associations with different birds and their sounds, as well as personal relationships with nature, might strongly influence restorative benefits (Ratcliffe et al., 2013). Furthermore, some virtual reality treatments showed differing results, finding no difference in stress recovery between birdsong and traffic noise treatments (Hedblom et al., 2019).

Bird Species traits

The role of bird diversity on human mental well-being is still unclear, with mixed evidence regarding its effects. As explained above, not all birdsong is helpful for restoration (Ratcliffe et al., 2013). This is why it is important to look beyond general assessments of bird diversity and to focus on the composition of bird species in an area. Finding the species traits important for human mental well-being may explain the discrepancies between studies, since not all species are present to the same extent in the study areas. Only a few studies have considered that not all bird species affect people equally (see, for example, Fisher et al. (2023); Garnett et al. (2018); Randler & Koch (2025); Randler et al. (2023b); Ratcliffe et al. (2013)). But this could be an important part of the nature experience and the positive effects a visit to green spaces has, as there is a large variation in the perception, likeability, and preferences (Albert et al., 2018; Veríssimo et al., 2014; White et al., 2023) as well as in the bird species themselves. This is why we think that the human perception of birds is strongly linked to mental well-being, and therefore, the species composition in an area may determine the mental well-being benefits received when visiting.

Species perceived as charismatic, being strongly appealing to humans, are often aesthetically pleasing and perceived as beautiful (Prokop et al., 2025; Veríssimo et al., 2014), which in birds are mostly small and colorful species (Haukka et al., 2023; Santangeli et al., 2023). Earlier studies on flagship species have suggested certain species characteristics of liked animal species to be high body mass (Santarém et al., 2019; Smith et al., 2012) and a large body size (Albert et al., 2018; Callaghan et al., 2021). In the study by Garnett et al. (2018), participants nominated mostly large and well-known species as most attractive, even though they earlier noted a preference for small colorful birds with melodious songs. Da Silva et al. (2022) found that complex and melodious songs are among the most preferred by people. Additionally, many liked species exhibit a bright appearance, colors, or color patterns (Santarém et al., 2019; Veríssimo et al., 2014), making them visually attractive. In the study by Lišková & Frynta (2013), preferences for beautiful birds were mostly affected by morphology as well as the colors blue and yellow and overall brightness. Aesthetic attraction is dependent on a set of features that make something interesting or likeable, usually composed of visual and emotional cues (Haukka et al., 2023). This effect seems to be strongest for smaller birds, with vivid colors and extreme ornaments (Santangeli et al., 2023). Other factors which have been suggested to influence attractivity or likeability are visibility, rarity, familiarity, or encounter rate (Santangeli et al., 2023; Schlegel & Rupf, 2010; Veríssimo et al., 2014).

Some species are also considered “cute” (Albert et al., 2018; Borgi et al., 2014), drawing the viewers’ attention. The concept of cuteness is often based on the baby schema by Lorenz (1943), which sums up characteristics that are supposed to trigger innate caring behavior in humans. These characteristics include a relatively large head, short and thick extremities, large eyes, a rounded forehead, and protruding, chubby cheeks (Lorenz, 1943). On the other hand, some birds, such as the hooded crow, are associated with problems like trash scattering, noise disturbance, and aggressive behavior (Kövér et al., 2022), possibly influencing nature experiences negatively. In conclusion, bird species traits can and do have positive or negative effects on people’s mental well-being.

Physiological stress parameters

Stress is not only a subjective feeling but also a physiological response of the body. The physiological stress response involves the sympathetic adrenomedullary (SAM) and hypothalamic-pituitary-adrenal (HPA) systems working together to achieve stability inside the body (Gunnar & Quevedo, 2007; Sheridan et al., 1994). Activation of the SAM leads to increased heart rate and blood volume, ensuring blood supply to the brain and muscles, enabling a fast fight/flight response (Gunnar & Quevedo, 2007). Activation of the HPA leads to the release of the stress hormone cortisol, which is a steroid hormone (Gunnar & Quevedo, 2007; Kondo et al., 2018). Frequent or prolonged stress responses lead to allostatic load. Over long periods of time, a chronic activation of these systems can have deleterious effects on physical and mental health. A physiological stress response can therefore be measured through physiological biomarkers such as heart rate (for the SAM system), blood pressure (for the cardiovascular system, Whelton & Carey (2017)) and cortisol levels (for the HPA system, Kondo et al. (2018)).

The stress hormone cortisol, built and secreted by the adrenal gland, plays a crucial role in supporting emotion-appropriate behavior (Sheridan et al., 1994). Negative emotions and high stress levels are generally associated with higher cortisol concentrations (Polk et al., 2005). Its levels tend to follow a specific diurnal secretion pattern, the Cortisol awakening response (= CAR; Hellhammer et al. (2009); Kirschbaum & Hellhammer (1994)). Salivary cortisol samples are a convenient and painless sampling method for participants and have been used extensively as a stress biomarker in research settings (Inder et al., 2012; Kirschbaum & Hellhammer, 1994), since they accurately reflect serum-free cortisol levels without needing to take blood samples (Aardal-Eriksson et al., 1998; Aardal & Holm, 1995). Additionally, measurements of blood pressure and heart rate are also easy, non-invasive, common methods used in studies on health effects (see, for example, Li et al. (2021); Park et al. (2010); Polk et al. (2005)). According to the SRT and ART

(Kaplan & Kaplan, 1989; Kaplan, 1995; Ulrich et al., 1991), mental well-being is connected to stress reduction. Therefore, there should also be a connection to physiological stress parameters spending time outdoors (Lindemann-Matthies & Matthies, 2018; Schebella et al., 2020). Negative emotions and high stress levels have already been associated with higher cortisol concentrations in earlier studies (Polk et al., 2005). Walking in nature improved cortisol levels and mood more than walking indoors or looking at nature scenes (Olafsdottir et al., 2020). People exposed to more natural settings also showed a decrease in blood pressure in combination with stress reduction (Hartig et al., 2003). More plant species and greater habitat richness have been linked to reduced blood pressure (Lindemann-Matthies & Matthies, 2018; Wu et al., 2024). In earlier studies, greener environments also offered better opportunities for coping with stress (Ward Thompson et al., 2012). Experiencing a forest environment promoted lower cortisol concentration, lower heart rate, and lower blood pressure than in an urban environment (Ideno et al., 2017; Park et al., 2010; Song et al., 2016). Generally, blood pressure (BP) and heart rates (HR) seem to be lower in green environments (Kondo et al., 2018) than in urban environments. Opdahl et al. (2021) were able to show that spending time in species-rich areas and areas with high perceived aesthetic values correlates with a reduction in salivary cortisol and improved subjective well-being. It was also found that natural sounds lead to a greater sense of comfort and relaxation, while street sounds drive up the heart rate (Li et al., 2021).

2. Research Objectives

Being outside in nature is beneficial not only to humans' physical fitness but also to their psychological well-being (de Brito et al., 2019; Jimenez et al., 2021). However, the underlying mechanisms linking nature experiences and mental well-being outcomes are difficult to pinpoint. Research suggests that certain characteristics of natural environments, (Ulrich, 1983; Cox et al., 2017b), and/or increased plant or animal diversity (Cameron et al., 2020; Wei et al., 2022), may play a key role in fostering mental well-being. The role of avian diversity is also often considered but with mixed results (Lovell et al., 2014). These insights lead to the idea of investigating the potential contribution of birds to the mental well-being benefits of being in nature.

This thesis primarily examines the impact of characteristics of nature, such as bird species richness and different landscape characteristics on the mental well-being of individuals who spend time outdoors. By focusing on birds as both ecologically important and highly visible elements of biodiversity, this research aims to shed light on the nuanced ways in which nature may support human well-being. Since the evidence on benefits of bird species richness in recreational areas is mixed, this dissertation project aims to connect the mental well-being of recreationists not only with bird species richness but also with other landscape characteristics like soundscapes and biotope types. Additionally, characteristics of different bird species are to be connected to mental well-being outcomes, as not all species may be influencing people in the same way. Finding which parts of bird diversity, species traits, and nature experience lead to improved mental well-being of people also provides additional arguments in favor of nature conservation efforts.

In detail, this thesis aims to address the questions:

1. Can people accurately perceive bird diversity (**Manuscript 1**)? And what are the effects of actual and perceived bird species richness on human mental well-being and nature experience?
2. How is bird species richness across different recreational areas related to human mental well-being, and to what extent do landscape characteristics like differing biotope types influence this relationship (**Manuscript 2**)?
3. Which factors can be manipulated or varied to enhance mental health?
    a. How does an artificial increase in bird species richness through soundscapes influence mental well-being and experience of nature (**Manuscript 3**)?
    b. How does heightened awareness through verbal or visual cues affect mental well-being and experience of nature (**Manuscript 4**)?
4. Is there an effect of certain bird species traits on human mental well-being (**Manuscript 5**)?

3. Studies

Overview of studies

Biodiversity and health – field survey

This study is the core of the dissertation project. In summer 2022, 40 recreational areas between Rottenburg am Neckar and Stuttgart (Baden-Württemberg, Germany) were selected, which differ in their landscape features, such as urbanization, bird species richness, and the presence of green and blue spaces. Biological characteristics (e.g. bird diversity and biotope types) and landscape characteristics (e.g., infrastructure, structures, and incivilities) were recorded in field surveys using standardized methods. A total of 1184 recreationists participated in a pen-and-paper survey about their current psychological state, assessing their mental well-being and their subjective nature experience after spending some time in the respective study area. Participants' assessment of bird diversity was compared with that of professional ornithologists (**Manuscript 1**). Results show that lay people estimated bird species richness consistently lower than professionals, but proportionally similar. On average, their estimates were between professional morning and afternoon counts. Since most people were surveyed in the afternoon, their assessment of bird diversity is possibly influenced by factors other than direct observation. Still, perceived bird diversity in the areas was relatively accurate.

Beauty of areas – online survey

The second study was conducted in winter 2022/2023 using photographs of the 40 study areas taken earlier in summer. Using SoSciSurvey, they were shown to 49 participants who were asked to rate the study areas based on estimated biodiversity, beauty, restorativeness, and naturalness. This study was analyzed together with the biodiversity and health study as outlined in **Manuscript 2** of the dissertation. Using a two-level multivariate GLM, results revealed perceived naturalness and bird diversity to be significant predictors of mental well-being. On the other hand, high human impact is correlated with worse mental well-being. Perceived naturalness is positively related to actual bird diversity and negatively to human impact. A positive perception of birds improved mental well-being, whereas a high birding specialization was linked to lower recalled restoration. Additionally, ratings from the online survey (restoration and beauty) correlated with positive emotions experienced on-site, suggesting that virtual perception corresponds with real-world experiences. These findings have practical implications for designing recreational urban areas. Increasing perceived bird diversity and naturalness while lowering human impact can promote mental well-being in recreational areas.

Bird diversity and well-being in the Arboretum – experimental studies

Two experimental studies were conducted in the Arboretum of the University of Tübingen to assess psychological and physiological responses to nature exposure in a controlled outdoor environment. Participants were sent on an unguided 30-minute walk, with subjective well-being (satisfaction, emotions and restoration) and objective physiological stress parameters (cortisol, blood pressure and heart rate) being assessed before and after.

The first study (**Manuscript 3**, summer 2023, N = 233) manipulated the bird soundscape to analyze the influence of perceived bird diversity. Participants were divided into groups in a 2x2+1 design: one group received instructions to listen to birdsong, another heard additional birdsong and a third was given active noise-cancelling headphones. All groups experienced improved well-being and reduced stress after the walk. While playing additional birdsong had no effect, raising awareness about the natural birdsong did lead to a better nature experience, which in turn was the primary influence for mental well-being. Perceived bird diversity did not differ between groups and did not impact either mental well-being or nature experience. This implies that awareness of, and not the actual species' richness, is important for feeling benefits.

Due to the impracticability of direct personal instructions in public spaces, the follow-up study tested the effectiveness of signage (**Manuscript 4**, summer 2024, N = 47**)**. Participants received either a verbal or visual (by way of signage) prompt to stop and listen to the birdsong. Both treatments once again improved mental well-being and physiological stress parameters. However, the group receiving a visual prompt reported higher perceived restorativeness of ambient sound and birdsong than the group receiving a verbal cue. Furthermore, better bird species knowledge and a positive nature experience led to better mental well-being, as did a positive perception of birds and higher estimated bird diversity. Therefore, such individual factors are very important for the benefits to mental well-being a person receives. The results also highlight the potential of practical interventions like signage to possibly enhance the nature awareness and mental well-being of recreationists.

Bird species traits

Since not all bird species are expected to influence people similarly, the last study tried to analyze the effects of certain bird species traits on human mental well-being (**Manuscript 5**). For this, we combined pre-existing data on cuteness, brightness, visual attractivity and beauty of song from earlier studies into one factor per bird species. Then, a value per place was calculated using the species frequencies as noted for the biodiversity and health study. This per-place-value was then related to the mental well-being of participants in the 40 study areas of the biodiversity and well-being study.

Manuscript 1

Are Lay People Able to Estimate Breeding Bird Diversity?

Vanhöfen, Janina; Schöffski, Nick; Härtel, Talia & Randler, Christoph (2022). Are lay people able to estimate breeding bird diversity?. *Animals*, *12*(22), 3095.

Simple Summary

The experience of nature is different for everybody. Some studies used perceived biodiversity as an approach to measure the biodiversity of a location. This present study assessed if lay people could estimate bird species richness at specific places in southwest Germany. We compared their assessment with bird counts of professional ornithologists and data from the citizen science platform Ornitho (Germany). With a survey, lay people were asked about the bird diversity they perceived at a given place. About 30 people were surveyed per place, summing up a total of 1184 respondents. The results show that lay people have a generally good assessment of the bird species richness in recreational areas, correlating with the data of professionals. But since the surveys were often done in the afternoon and their assessment coincided with the professional data of morning and total counts, lay people seem to make their assessment of biodiversity due to other factors than actual birds seen. The counts of professional ornithologists and citizen science data did not correlate; therefore, we suggest carrying out own professional surveys if possible.

Abstract

Studies about biodiversity and well-being used different approaches to assess biodiversity, e.g., scientific counts and censuses or perceived biodiversity estimated by the respondents. Here, we assessed whether lay people could estimate the breeding bird diversity or species richness at specific places. For comparison, we carried out bird censuses with standard methods of professional ornithologists and used citizen science data from the internet platform Ornitho (Germany). Lay people from the public (1184 respondents) were surveyed between May and July 2022 at 40 different places in southwest Germany between Rottenburg/Tübingen and Stuttgart, following the catchment of the river Neckar (30 people surveyed per place). People were asked to estimate the bird species richness/diversity at this current place. Here, we show that the data from the citizen science platform does not correlate with the professional census counts nor with the perceived species richness of lay people. Lay people have a generally good assessment of the bird species richness, correlating with the data of professionals ($r = 0.325$, $p = 0.041$). On average, the number of species assessed by lay people lies between the values of the professional morning and afternoon census. People were most often surveyed in the afternoon; therefore, their assessment must be done on factors other than actual birds present. This result is valuable for future studies on the connection between biodiversity and well-being.

Keywords: biodiversity; citizen science; green space; ornithologist; species richness

Introduction

As soon as people go outside, they experience nature and biodiversity, even in small urban green spaces (White et al., 2013; Wyles et al., 2019). Being in contact with nature and biodiversity helps people to restore psychologically, additionally to widely being recognized for having positive effects on human health and well-being (Fisher et al., 2021; Kaplan & Kaplan, 1989; Kaplan, 1995; Ulrich, 1983; White et al., 2013). Psychological restorativeness means replenishing cognitive resources and reducing stress (Kaplan & Kaplan, 1989; Ulrich, 1983). The attention restoration theory (ART) states that spending time in nature allows recovery from attention fatigue (Kaplan & Kaplan, 1989; Kaplan, 1995). Meanwhile, the stress reduction theory (SRT) proposes that a high biodiversity level benefits psychophysiological stress recovery (Ulrich, 1983). Moreover, the specific knowledge of people is not related to beneficial rewards from nature (Randler et al., 2022); thus, people at all levels of biodiversity knowledge may benefit from being in nature.

Evaluation of biodiversity may depend on the condition of lay people and not on their knowledge. Although the benefit of biodiversity on psychological restoration, well-being, and positive emotions is unquestioned, it is still unclear which specific measures of diversity may be responsible for this relationship. Studies about biodiversity and well-being used different approaches to assess biodiversity, e.g., real counts or censuses (Dallimer et al., 2012), perceived biodiversity estimated by the respondents (Fisher et al., 2021) or even virtual experience of green spaces (Douglas & Evans, 2021). But different studies revealed inconsistencies in the relationship between actual biodiversity (measured as species richness), perceived biodiversity, and well-being. Some studies found psychological benefits with higher actual biodiversity (Dallimer et al., 2012; Wolf et al., 2017). In contrast, there was a strong positive relationship between well-being and perceived biodiversity in some studies. Fisher et al. (2021) showed that if sites were perceived as species-rich, they were perceived as more restorative, resulting in the improved well-being of citizens. Nghiem et al. (2021) assessed perceived biodiversity and found that perceived animal diversity contributes to perceived (psychological) restorativeness. In general, perceived biodiversity has been more consistently related positively to well-being, highlighting the importance of psychological benefits.

Moreover, some studies took the biodiversity knowledge of the respondents into account when assessing the value of nature (van Riper et al., 2017). However, many people are unfamiliar with the biodiversity in their environment (Hooykaas et al., 2019). Most people have inaccurate ideas about the number of species in their country or worldwide. For example, in Switzerland, plant species richness was strongly overestimated (Lindemann-Matthies & Matthies, 2018). Even though lay people appreciate species richness, they do not seem to be able to accurately perceive it in their local green space. Dallimer et al. (2012) found that there was no consistent association between the actual and perceived species richness of plants, birds, and butterflies. The degree of mismatch even grew as the participants' species knowledge declined. Shwartz et al. (2014) concluded that people underestimate species richness and that there is no correlation between observed and estimated species richness. Other studies found no relationship between bird diversity and perception by park visitors. Visitors underestimated avian diversity in city parks, and public knowledge did not relate to species richness (Celis-Diez et al., 2017). In contrast, Fisher et al. (2021) found that participants accurately estimated bird species richness around them and perceived sites with greater proportions of vegetation and water as more natural. Fuller et al. (2007) identified that participants could detect plant species richness fairly accurately.

Many studies concerning biodiversity and the effect on people used birds as a proxy for actual biodiversity (Butler et al., 2010; Cameron et al., 2020; Celis-Diez et al., 2017; Dallimer et al., 2012; Farinha-Marques et al., 2011; Wheeler et al., 2015; Williams & Gaston, 1994). In addition, other than being used in previous studies, birds are used for various reasons, for example, their capacity to draw attention and fascinate due to color, movement, or song (Woods, 1998). Additionally, birds are generally preferred by lay people and more easily distinguished as different species compared to other taxonomic groups, for example, insects (Cox & Gaston, 2015). Therefore, we used the estimate of bird diversity as an estimate for biodiversity to compare the assessments of lay people, professional ornithologists, and citizen science data.

Citizen Science (CS) makes it possible to involve anyone with curiosity and access to the internet to contribute to scientific questions and databases. This facilitates the collection and distribution of all kinds of taxonomic data with a wide geographic distribution at minimal cost and could even possibly replace museums' roles in the future for supplying a biodiversity baseline (Boakes et al., 2010). With regards to birdwatching, there is a large [birding] community, and contributions to CS are manifold. Birdwatchers are a quite heterogeneous group (Randler, 2021a), ranging from novices up to professionals. Randler (2021b) showed that users of the CS platform Ornitho showed higher skill and competence, more investment, and higher personal commitment to birdwatching than birdwatchers not using the CS platform. This suggests that the data quality of such platforms is comparatively high. Most lists of CS data have also been found to be mostly complete at the family level when compared to professional data and provide prompt records for new emerging species (Ding et al., 2022). Since most species are correctly identified as well (Gorleri et al., 2022), this means CS data can be a good predictor for species richness (Williams & Gaston, 1994). Robinson et al. (2021) showed a count difference biased toward undercounts of contributors to the CS platform eBird compared to a professional ornithologist. They also concluded that species misidentification was unlikely to be an important factor in the counting errors.

We here compare bird diversity among professional ornithologist counts, CS data, and lay people's assessments. For the CS data, we used the large German platform Ornitho and aimed to check if the results of this platform were consistent with the professional census and could be used for our surveys. Many professional ornithologists also contribute to many different CS platforms, making these possibly easy solutions for scientific questions that are difficult to solve for one or two professionals alone.

Since the ability of lay people to detect the actual level of species richness in an area varies on an individual level, it is important to know to which degree lay people can accurately estimate the bird diversity at a given place. This knowledge not only translates to the well-being of people but also to their connectedness to nature. If lay people can estimate species richness, this knowledge can be used for future environmental measures and activities. Therefore, we here asked the questions: (1) whether lay people could correctly estimate actual occurring species numbers of birds in recreational areas and (2) whether the results of CS projects match with professional bird censusing of breeding birds. Further, we study this question on the individual level of the respondents and on the place level, following the concept of swarm intelligence (Krause et al., 2010).

Measurements and Methods

Study Area

We conducted the study at 40 locations between Rottenburg am Neckar and Stuttgart along the Neckar River in southwest Germany. The places differ in degree of urbanization and include blue spaces as well as green spaces for a well-rounded picture of the diversity this area has to offer. All of them are recreational areas that are easily accessible for people, either by foot, car, or public transportation.

Professional Bird Censuses

Bird species richness was surveyed at each site by trained ornithologists (authors NS, CR). Using standard protocols (Bibby et al., 2000), bird counts were carried out two times in the morning and once in the afternoon, with each morning survey having at least three weeks in between. In a 250 m radius on footpaths, which visitors also experience, all bird species and individuals seen and heard in a time span of 15 min were recorded. Since estimated bird densities increase with time (Matsuoka et al., 2012), we expect this method to cover most of the bird species available in these locations. Data were collected between March and June 2022. We compiled three species lists per location of these bird surveys: professional morning count, professional afternoon count, and professional total count. The professional total count compiled all encountered bird species of all recordings at one location; thus, each species contributed once to the dataset.

Citizen Science—Ornitho Data

Approximately 33,000 people use the German-based birding platform Ornitho (www.ornitho.de, accessed on 10 July 2022) to submit bird observations to CS projects. Ornitho comprises the countries Germany, Switzerland, Austria, Liechtenstein, and Luxembourg, but is also widely used in other parts of Europe. The data are incorporated into a lot of different scientific and conservational evaluations, making it a valuable dataset of bird species of central Europe. Our CS Data was compiled following Ding et al. (2022). The Ornitho website featured data from 31 out of our 40 locations, which has been kindly provided to us by the Ornithologische Gesellschaft Baden-Württemberg (OGBW). We used the data from March to June of 2022, with permission from the Steuerungsgruppe of the OGBW. The number of bird species was compiled into one count per place, summing up all species recorded. The sampling periods between the professional count and the CS were identical to guarantee a fair comparison.

Lay People Surveys

A survey study was carried out with pedestrians in all 40 study areas. The surveys were carried out by a PhD student (TH) and some Master's students at the University of Tübingen. Master's students received course credits. People over the age of 18 were recruited to participate in the questionnaire if they had already been in the respective area for a while. They were asked to participate in the study and given the questionnaire on paper with a ballpoint pen as a participation gift. In total, 1184 people participated in the survey. The study has been granted ethical permission by the ethics committee of the Faculty of Social Sciences and Economics of the University of Tübingen.

The questionnaire included 24 questions about location and biodiversity parameters, and emotional and well-being items. The question of estimated bird species rich- ness at the respective place was based on a categorical scale containing nine categories (0–5; 6–10; 11–20; 21–30; 31–40; 41–50; 51–60; 61–70; over 70 species present; scale adapted after Ferraro et al. (2020) and Southon et al. (2018)). We also asked about birding specialization based on how many bird species participants can recognize by appearance without help from books or apps (Randler & Heil, 2021). In addition, some demographic variables were asked for: age in years, gender (male, female, diverse), and graduation (university degree, coded dichotomously "yes or no" with "yes" meaning at least a bachelor's degree).

Statistical Analysis

Due to the structure of the data sets, we did a nonparametric correlation analysis with Spearman-rho as the correlation coefficient and a two-sided significance testing. Additionally, we did a Wilcoxon test to compare the categories within the same places. Demographic differences were assessed using Mann–Whitney U tests. For statistical analysis, the program SPSS (Version 28.0.0.0) was used.

We used the following variables: The number of species in total from three census counts (two mornings, one afternoon) = *professional total count*; the number of species from two census counts in the morning (morning bird diversity) = *professional morning count*; the number of species from census counts in the afternoon = *professional afternoon count*; the total number of species in ornitho.de for March to July 2022 = *Ornitho*. As the data were collected in absolute numbers for the professional count and in categories for the pedestrian assessment (see above), we also transformed the precise counts into categories to make the data comparable for the Wilcoxon tests. Since we had only one item per professional count and CS data, we first analyzed the lay people's assessment on the place level, summarizing all their assessments together as a mean score per place based on the concept of swarm intelligence (Krause et al., 2010). Thus, we considered the 30 respondents per place as an aggregated expert. After that, we checked if the results kept consistent when analyzed on an individual level.

As demographic effects may have an influence on bird species knowledge (Randler & Heil, 2021), we analyzed the estimated species richness with respect to age, gender, self-reported birding skill level, and university degree.

Results

The professional morning count strongly correlated with the professional afternoon count (r = 0.396, p = 0.011) and the professional total count (r = 0.960, p < 0.001), making the surveys of the ornithologists inherently consistent, and the morning and the total count nearly identical. The professional afternoon count and the professional total count also correlated significantly (r = 0.525, p < 0.001).

The CS data provided by Ornitho did not correlate with any of the professional censuses (Professional Morning Count: r = 0.278, p = 0.131; Professional Afternoon Count: r = 0.165, p = 0.375; Professional Total Count r = 0.307, p = 0.093).

The survey had a slight surplus of women (1184 participants: 54.9% female and 44.1% male and participants, 0.2% identified as diverse, 0.8% did not answer). Over half (55.7%) of the participants reported a university degree. The survey covered a broad age range, with the age of participants ranging from 18 to 89 years old (1.9% did not answer the question of age). The mean age was 43.34 years, with an SD of 17.75 years.

Age correlated negatively with the estimated number of species (r = −0.076, p = 0.011). A Mann–Whitney U-test showed a slightly significant difference among gender (Z = −1.996, p = 0.046), with males estimating species richness slightly higher. University degree had no impact on estimated species richness (Mann–Whitney U-Test Z = −0.803, p = 0.422), but self-reported bird knowledge significantly correlated positively with the estimated number of species (r = 0.102, p < 0.001). Thus, higher skilled pedestrians estimated the species richness higher. The perceived species richness of lay people correlated weakly with the professional total count (r_s = 0.085, p = 0.004) but not with the CS data (r_s = −0.020, p = 0.551).

Aggregated on the place level, the perceived species richness of lay people correlated with the professional total count (Table 2, Figure 1) even when they were recoded into the same categories, but it did not correlate with the CS data. However, the correlation coefficient was higher in the aggregated data based on the place level (r_s = 0.3) following the approach of swarm intelligence compared with the individual level correlation (r_s = 0.085).

Table 2.
Spearman-Rho correlation analysis results of the different bird count sources with the estimation of species present by lay people. We repeated the analysis with the variables (absolute species richness) converted into the same categories as the lay people's assessment: 1 = 0–5; 2 = 6–10; 3 = 11–20; 4 = 21–30; 5 = 31–40; 6 = 41–50; 7 = 51–60; 8 = 61–70; 9 = over 70. * $p < 0.05$.

Measured Species Richness (Absolute and in Corresponding Categories)	Perceived Species Richness
Professional Morning Count (absolute)	0.353 *
Professional Morning Count (category)	0.297
Professional Afternoon Count (absolute)	0.158
Professional Afternoon Count (category)	0.098
Professional Total Count (absolute)	0.325 *
Professional Total Count (category)	0.312 *
Ornitho (absolute)	−0.126
Ornitho (category)	−0.097

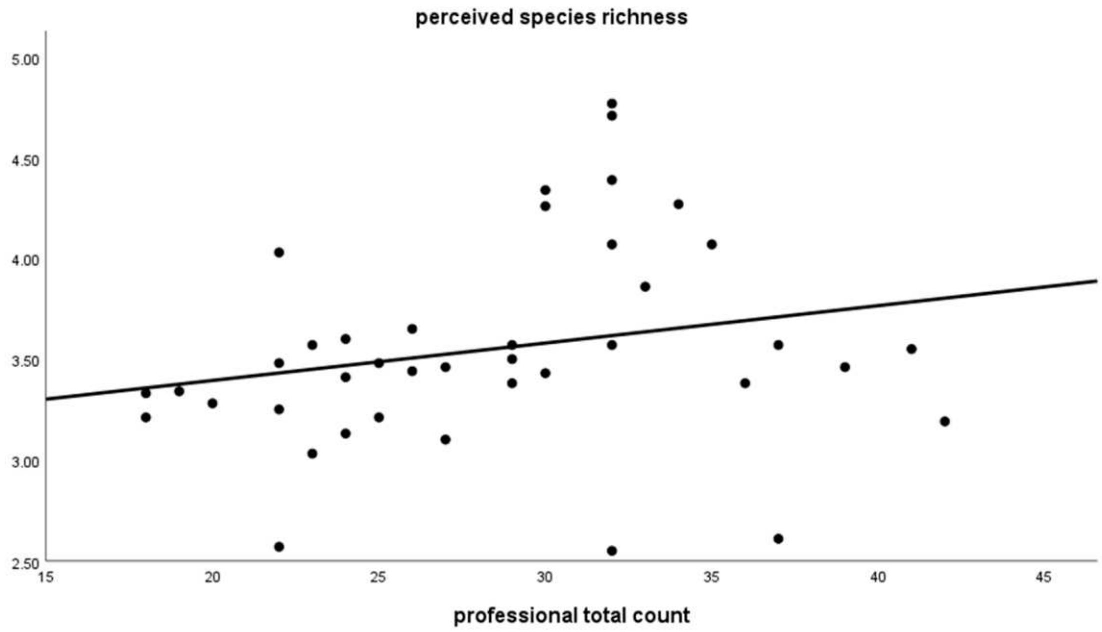


Figure 1.
Perceived species richness of lay people (measured in categories, averaged per place) correlated with the professional total count (measured in absolute numbers).

Using the converted variables (absolute bird species richness recoded in similar categories as the perceived species richness estimates), a Wilcoxon test of the professional counts with the perceived species richness of lay people (place level) was done as a follow-up (Figure 2). This analysis showed that lay people's assessment in categorical terms is lower compared to the professional morning or total count, but higher than the professional afternoon count. This suggests that the lay people underestimated the morning but overestimated the afternoon species richness.

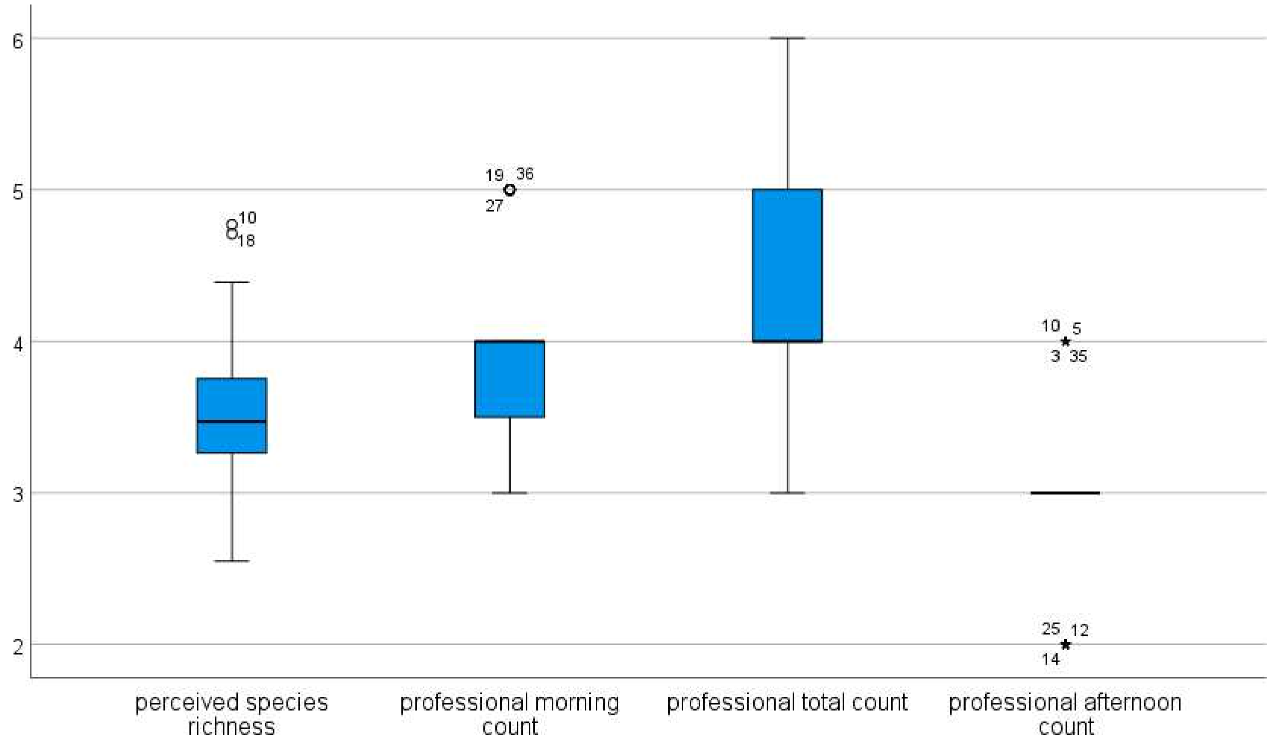


Figure 2.
Boxplot of the results of the Wilcoxon test of the recoded variables into the same categories as the lay people's assessment: 1 = 0–5; 2 = 6–10; 3 = 11–20; 4 = 21–30; 5 = 31–40; 6 = 41–50; 7 = 51–60; 8 = 61–70; 9 = over 70. Professional total count: $Z = -5.028$, $p < 0.001$ (negative ranks); professional morning count: $Z = -3.166$; $p = 0.002$ (negative ranks); professional afternoon count: $Z = -4.382$, $p < 0.001$ (positive ranks). The circles indicate outliers (numbers are respective case numbers), the * indicate extreme outliers. Numbers represent the places.

To check this assumption further, we subtracted the perceived species richness on an individual level from the categorized professional counts. The result confirms the hypothesis that people underestimate the professional total and morning count. Figure 3 shows the deviance of the species richness estimates of the people from the professional counts. On the individual level, respondents underestimated the morning and total count by about one category (Figure 3).

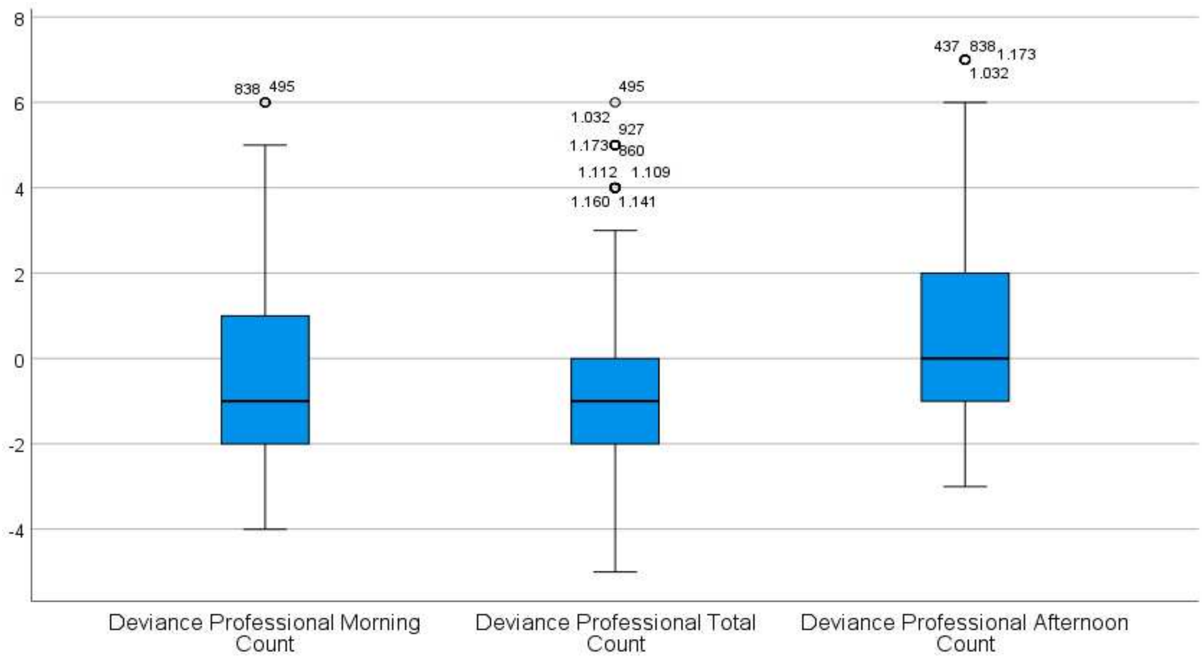


Figure 3.
Boxplot of the deviance of the species richness estimates of the people from the professional counts. On the individual level, respondents underestimated the morning and total count by about one category. The circles indicate outliers (the numbers are the respective case numbers).

Discussion

This study compared bird diversity among professional ornithologist counts, CS data, and lay people's assessment of perceived species richness. We asked whether the results of the CS projects match with professional bird censusing and whether lay people could correctly estimate the actual numbers of birds in recreational areas.

Professional Counts

Even though the professional afternoon count showed lower values, it is strongly correlated with the other two counts. Looking at the species numbers, the afternoon count does not add much to the total. Total and morning species richness are nearly identical, meaning that the professional morning count could be sufficient in future study designs. Even though afternoon bird abundances were previously positively associated with a lower prevalence of depression, anxiety, and stress (Cox et al., 2017b), fewer birds are present to experience during this time of day. However, it is also the time of day when people experience nature most. Depending on the study design, morning counts at the peak of the breeding season may be suitable, but afternoon counts may provide additional data for specific research questions (Cox et al., 2017b), especially when social questions and human dimensions are in the focus of a study.

The method used in the professional ornithologist's assessment of bird species is useful because it is easy to apply and provides consistent results. Since estimated bird densities increase with time (Matsuoka et al., 2012), this method should cover most species. Other studies also used a comparable amount of time but walked transects off trails (Cameron et al., 2020). This was considered not useful for the present study since we wanted to compare our data with lay people's assessments, and the pedestrians stayed on walkways. Since all counts were carried out in the same time span from March to July, most breeding birds in southwest Germany should be covered. The assessments of professional ornithologists are also consistent with each other.

Citizen Science

The CS data are best compared with the professional total count since both contain multiple counts independent of the time of day. Still, the data from the platform Ornitho did not correlate with any of the professional data. Across platforms, the species checklists of different sources do often have considerable discrepancies, even among expert-curated lists, although CS data seem to be mostly complete at the family level when compared to professional data (Ding et al., 2022). Even though this is a surprise, it can be sufficiently explained by the differences in data acquisition. The vast majority of data available at Ornitho was collected by the observers during their field trips by chance. As a rule, the data are not the result of systematic studies and are made by an array of observants of different skill levels. Callaghan et al. (2021) showed that CS data are usually biased towards larger and more common species, which are mostly correctly identified (Gorleri et al., 2022). Therefore, for specific scientific questions, CS data may be sufficient. Depending on the research objective, a professional and, most importantly, a systematic count may still be warranted. However, as a cautionary note, our data failed the significance marginally, meaning that a higher sample size may have produced a significant correlation between the CS data and the professional total counts. Therefore, it may be useful relying on CS data, especially when own counts are not feasible.

Lay People's Estimation of Species Richness

Hooykaas et al. (2019) found that lay people's species knowledge increased with age and educational level. Further, Randler & Heil (2021) showed that older people scored higher in bird species knowledge tests, meaning that older people can probably better estimate the number of species present at the moment. In our study, age correlated negatively with the perceived species richness estimates, meaning that younger people estimate the species diversity higher than older ones. However, both Hooykaas et al. (2019) and Randler et al. (2007), as well as Randler & Heil (2021), explicitly applied a test of species knowledge, while in this current study, we asked the pedestrians for their species richness estimates. This may explain the differing results.

Meanwhile, gender was slightly related to the estimated number of species, with men tending to have a higher assessment of the bird species richness. This is in line with other studies concluding that men are more interested in birding (Moore et al., 2008; Randler, 2021a). Graduation or university degree did not impact the estimated species count, which is not surprising since everyone can experience nature independently of education.

Self-reported bird knowledge strongly correlated positively with the estimated number of species, meaning that people who think of themselves as having more knowledge of birds make a higher estimate of the occurring bird diversity. Dallimer et al. (2012) could also show that people with higher identification skills are more likely to perceive species richness accurately. But can self-assessments of knowledge be considered a reliable measure? Especially, recent studies clearly showed that the self-assessment of bird species knowledge measured by birding specialization (encompassing visual competence, acoustic competence, and self-assessment from novice to expert) based on Lee & Scott (2004) correlated with scores from a knowledge test (about 0.7; Randler & Heil (2021); Rögele et al. (2022)). These studies suggest that using a simple self-classification item rather than a detailed test may make such surveys easier and more convenient.

Our study showed that lay people could roughly estimate bird species richness in relative terms. Their assessment correlated with the professional morning count and professional total count. Even though they generally underestimated species richness, they did this in a consistent manner. This coincides with Fisher et al. (2021), who found that participants could accurately estimate bird species richness around them. Participants in this study generally assessed the bird diversity lower than the professional morning and total census. This difference probably exists because of the higher number of counts provided by professional ornithologists. People were surveyed only once, while the professional total count consisted of three censuses. Moreover, professional ornithologists went out to specifically look for birds; meanwhile, lay people did not. They mostly went for relaxation purposes. The pedestrian surveys were mostly done in the afternoon, but participants estimated bird diversity higher than the actual afternoon count and lower than the morning and total count. If people went outside looking specifically for birds, their assessment could possibly be even closer to the professional counts.

As people seem to be able to relatively assess total species richness at a time of day when it is not fully experienceable, they may base their assessment on other cues, such as tree cover or perceived diversity of the area in general, rather than on actual bird diversity. Perceived richness was previously positively associated with vegetation height, evenness, and colorfulness, suggesting that these are cues for estimating species richness (Southon et al., 2018). In a study in South America, people estimated bird diversity as lower because they perceived only a small fraction of the overall diversity. Their awareness is especially biased toward the most abundant species (Celis-Diez et al., 2017). Accordingly, people seem to be biased in their perception of biodiversity, looking only at what grabs their attention. Ishibashi et al. (2020) suggest that both the individual's personal characteristics and the species' ecological traits determine park users' recognition of local biodiversity. Other studies indicate that residents' valuations of ecosystem services are linked to their perceptions of bird species richness rather than the actual species richness. People may perceive only a subset of the birds in their neighborhoods (Belaire et al., 2015). Cameron et al. (2020) found that avian biodiversity was closely correlated with the participants' perception of biodiversity, even though participants rated biodiversity as the number of types of plants/trees/animals in general. People probably perceive biodiversity as high or low, independent of their specific knowledge of birds.

According to our studies, lay people’s assessment of bird diversity coincides with professional counts, meaning it can be used for further studies. Since biodiversity and well-being are linked, and access to public green spaces and bird species richness are expected to decline in the future (Sushinsky et al., 2017), it is more important than ever to find ways to preserve the link between people's perception, experience, and biodiversity.

Conclusions

The assessment of bird species diversity by professional ornithologists and CS Data did not correlate, meaning professional biodiversity censuses are not replaceable. Therefore, we suggest conducting professional surveys for studies based on bird diversity and well-being. Even though CS data may not be useful for biodiversity assessments as in this study, they could still be useful to assess more large-scale distribution of birds, as well as monitoring of alien species and rare species.

Lay people can roughly estimate the species richness of birds in recreational areas. But since they often went to the area in the afternoon, but their assessment coincided with the professional data of morning and total counts on the aggregated place level, lay people seem to make that assessment due to other factors than actual birds seen. Therefore, their assessment of biodiversity is subjective and useful for studies on perception, well-being, and others, but not so much as a replacement for actual biodiversity counts. Therefore, it is important to know how lay people perceive their surroundings when studying in this area.

Manuscript 2

The relationship between perception and landscape characteristics of recreational places with human mental well-being.

Vanhöfen, Janina; Härtel, Talia; Reichert, Giovanna & Randler, Christoph (2025). The relationship between perception and landscape characteristics of recreational places with human mental well-being. *Scientific Reports*, *15*(1), 4245.

Abstract

Being outdoors benefits both humans' physical and mental well-being, but the reasons for this connection are difficult to pinpoint. This study examines 40 recreational areas to understand their individual characteristics' impact on mental well-being. We interviewed 1184 visitors on their perception of the place and feeling of mental well-being. In a second survey, 49 participants were shown images of the areas to assess whether they perceived them in the same way as people on-site did. Biologists then evaluated the areas through bird and biotope surveys, also assessing various other landscape characteristics of the study areas. Analysis using a two-level multivariate GLM revealed that perceived naturalness and perceived bird diversity are significant predictors of improved mental well-being. On the flip side, mental well-being declines with increased human impact, as indicated by the amount of infrastructure and the Human Footprint Index value. Notably, perceived naturalness positively correlates with actual bird diversity ($p = 0.005$) and negatively with human impact ($p = 0.006$). A strong perception of birds enhances the mental well-being of greenspace visitors ($p < 0.001$), while a high birding specialization negatively affects recalled restoration ($p = 0.014$). The estimated restoration value ($p = 0.001$) and estimated beauty ($p < 0.001$) from the online survey correlate positively with emotions experienced on-site. The perception of naturalness in images aligns with on-site perception, suggesting pathways for future research and the design of recreational areas.

Keywords: Recreational places, Perceived naturalness, Landscape characteristics, Mental well-being, Place attachment, Biodiversity

Introduction

Mental health and well-being are an important part of human life. According to the Constitution of the World Health Organization (WHO), health "*is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*" (WHO, 2002). Health is strongly related to the quality of life and, therefore, to areas frequented and lived in by people. Another important part of human life is the living situation. By 2030, approximately 60% of humanity will live in towns or cities (Montgomery, 2007). In 2020, 77.5% of Germans lived in cities, a rising trend (United Nations, 2019). This urbanization is not only a challenge for quality of life, but also one of the presumed leading causes for biodiversity loss (McDonald et al., 2020). Biodiversity, being the variety of life on earth, provides not only environmental services like air purification, temperature regulation and groundwater recharge, it's loss is also a challenge to a healthier lifestyle of people (McDonald et al., 2013). In the face of biodiversity loss and climate change, the relationship between human health, mental well-being, and biodiversity is a rapidly expanding field of research (Houlden et al., 2021).

The importance of biodiversity on mental well-being

Recently, evidence has emerged that biodiversity may support (short-term) well-being, possibly through the provision of ecosystem services (Aerts et al., 2018). Or by exposure to pleasant surroundings, or by encouraging health-promoting behaviors (Lovell et al., 2014). "Well-being" is a very broad term, which can be further divided into physical, mental, and social well-being (Linton et al., 2016). In the present study, we focus on mental well-being. According to Linton et al. (2016), mental well-being is connected to the psychological, cognitive and emotional quality of a person's life, their thoughts and feelings about the state of their life and their experience of happiness. As it is an important aspect of human health, it is important to understand its predictors. In earlier studies, there even seemed to be an association between the presence of biodiversity and mental well-being (Houlden et al., 2021; Korpela et al., 2018; Marselle et al., 2019). For example, the experience of urban green spaces has increasingly been associated with greater mental well-being (White et al., 2013) and lower levels of stress, depression and anxiety (Beyer et al., 2014) in people. People also smile more in parks with diverse shrubs and herbs (Wei et al., 2022).

There are two important theoretical frameworks on the underlying mechanisms connecting natural environments to human mental well-being: attention restoration and stress reduction. The attention restoration theory (ART) by Kaplan & Kaplan (1989) indicates that spending time in nature allows recovery from attentional fatigue and restores the capacity to direct attention (Kaplan, 1995). The stress reduction theory (SRT) suggests that natural environments benefit psychophysiological stress recovery due to people's evolutionary connection to nature (Ulrich, 1983 and Ulrich et al., 1991).

Going further, Marselle et al. (2021b) described pathways by which biodiversity is possibly linked to human mental well-being. One of them is by restoring capacities, adding the biodiversity dimension to the SRT and

ART mentioned above. However, earlier research on the benefits of nature on human mental well-being often lacks specifics on ecological characteristics (Collins et al., 2020) and the specifics of the biodiversity involved (Sandifer et al., 2015). Regularly there is a focus on either flora or fauna, often missing the connection to landscape characteristics. Vegetational cover in urban areas has been positively associated with a lower prevalence of depression, anxiety and stress (Cox et al., 2017b). Generally, higher plant diversity in green spaces has been related to better mental well-being (Marselle et al., 2021b; Marselle et al., 2019). More varied and species-rich vegetation is also generally seen as aesthetically pleasing (Lindemann-Matthies et al., 2010) even though it does not always directly translate into preference (Qiu et al., 2013). Plant species richness may additionally aid in stress recovery (Lindemann-Matthies & Matthies, 2018) and improve mental health (Methorst et al., 2021a). Other studies focused on animal-related biodiversity. For example, many studies on biodiversity and well-being used bird species as an easily experienceable part of nature (Butler et al., 2010; Cameron et al., 2020; Dallimer et al., 2012; Wheeler et al., 2015), caused by birds being easily observed due to their behavioral characteristics (Woods, 1998). In addition, people even seem to generally be happier in more wildlife-rich environments (Cameron et al., 2020).

But, beyond these simplifications of biodiversity, there is more to “nature” than just numbers of plants and animal species, namely, the experience and perception of it. Every person is different and even though the ability to estimate the bird species richness seems to be roughly in line with actual bird species richness (Vanhöfen et al., 2022), species knowledge and perception are often inaccurate (Hooykaas et al., 2019). Knowledge of bird species has also not been related to self- reported well-being in Chilean parks (Parra-Saldívar et al., 2020). Hence, for experiencing nature, biodiversity and its benefits for mental well-being, accurate species knowledge is possibly not of high importance (Shwartz et al., 2023). We aim to deepen the understanding of the effects of actual and perceived biodiversity of vegetation and animals (namely birds) on the mental well-being of visitors of recreational areas.

The importance of recreational spaces for restoration and place attachment

People often develop emotional and cognitive bonds with a particular place they like—so-called “place attachment” (Boley et al., 2021; Bryce et al., 2016; Droseltis & Vignoles, 2010; Lewicka, 2011; Randler et al., 2023a; Scannell & Gifford, 2010). The constructs of place attachment and place identity are strongly linked to the perceived restorativeness (Subiza-Pérez et al., 2020b) and the perceived restorative potential of an area (Menatti et al., 2019). Young et al. (2020) reported a greater connectedness of people to nature and greater restoration when visiting areas with higher environmental quality. Areas with a higher number of bird species nearby are unconsciously more satisfying to live in (Hepburn et al., 2021). Animal diversity and nature-relatedness are also positively linked to perceived restorativeness which in turn increases positive affect and decreases negative affect (Nghiem et al., 2021). Additionally, perceived restorativeness mediates the relationship between actual biodiversity and self-reported psychological and physical benefits, with participants in high biodiversity environments perceiving their environment as more restorative than those in low biodiversity environments (Carrus et al., 2015). Landscapes were also perceived as more natural and with higher restorativeness whenever they were objectively more diverse and natural (Chang et al., 2024), with bird species richness influencing the perception of naturalness (Schebella et al., 2019b).

Landscape characteristics

Interaction with nature for urban dwellers mostly happens in recreational areas. These are areas or spaces of differing nature, often in the city, but also in rural areas, which are intended and designed for recreational use, like parks. Often, the terms recreational areas and green spaces are used interchangeably since a lot of parks are mostly dominated by vegetation ("green"). According to the WHO (2016) "green spaces" are defined as "land covered by vegetation of any kind". However, recreational areas are not limited to green spaces. A lot of recreational areas inside and outside of cities include bodies of water of differing sizes. If the body of water dominates the area, it is generally called a "blue" space. These can be just as beneficial, perhaps even more so, than green spaces for humans (White et al., 2020). While green spaces mainly include urban parks, forests, and gardens (Young et al., 2020), blue spaces include the ocean, rivers, lakes, etc. (White et al., 2020; Wyles et al., 2019). Their recreational use has been shown to improve mood and attention, reducing depression, stress and anxiety (Barton & Pretty, 2010; Cox et al., 2017b; Grahn & Stigsdotter, 2003; Hartig et al., 2003; Maas et al., 2009; Maas et al., 2006; Ottosson & Grahn, 2005; Roe & Aspinall, 2011; Ulrich et al., 1991). Restoration in blue spaces was mostly related positively to landscape characteristics like beautiful views, bodies of water and greenery, but also to perceived restorativeness (Subiza-Pérez et al., 2021). Still, the comparison between blue and green spaces and their connection to the effects of biodiversity on mental well-being is lacking in the literature.

Even though biodiversity as a concept is hard to grasp for a lot of people, naturalness, being the proportion of anthropic versus natural elements, is an easily understood concept (Schebella et al., 2019b). Recreational areas are not only different in their amount of blue and green space but also in the physical elements present, like the amount of man-made structures or infrastructure. Human impact on the environment is ubiquitous. The Human Footprint Index (HFI), first published in 2022 and further developed by Venter et al. (2016), shows human impact at a spatial resolution of ~ 1 km. It uses data inputs on built environments, population density, electric power infrastructure, crop lands, pasture lands, roads, railways, and navigable waterways. To measure human pressure on the environment, remotely sensed and bottom-up surveyed information was compiled. The HFI is therefore a quantitative analysis of human influence across the globe. Human impact and other landscape characteristics may not only influence actual biodiversity in the areas (Stein et al., 2014) but also the perception and experience of people existing in it.

Goal of the current study

It remains unclear how recreational areas with their differing landscape characteristics connect to the mental well-being and nature experience of people using these areas for recreational purposes.

Therefore, we bring together many different aspects of earlier research to be able to paint a broader picture:

- Two different actual biodiversity measures (bird diversity (Dallimer et al., 2012; Fuller et al., 2013; Methorst et al., 2021a; Shwartz et al., 2023) and vegetational biotope types (Shwartz et al., 2014; Shwartz et al., 2023)),
- different landscape characteristics (Gidlow et al., 2018; Schebella et al., 2019a; Voigt et al., 2014),
- experience/perception of biodiversity and naturalness on-site (Dallimer et al., 2012; Meng et al., 2024), and finally, we compare these to the
- perception of biodiversity/naturalness by pictures (Chang et al., 2024).

To achieve this, we examined 40 recreational areas in southwestern Germany regarding their landscape characteristics and their effect on human mental well-being. In detail, we carried out three different surveys: (a) an ecological field survey done by biologists, (b) an on-site survey with recreationists, and finally (c) an online study to gather additional assessments (Figure 4). Since recreational areas are not all built the same, their use and value to people differ tremendously. We would therefore expect different effects on people's mental well-being depending on the area characteristics.

More precisely, we had the following research questions (RQs) and aims in mind:

1. How do the landscape characteristics affect the user's mental well-being?
2. Does perceived bird diversity and/or naturalness on-site influence mental well-being?
3. Do participants assessing the restorative quality of recreational places via images perceive places similarly to people on-site?

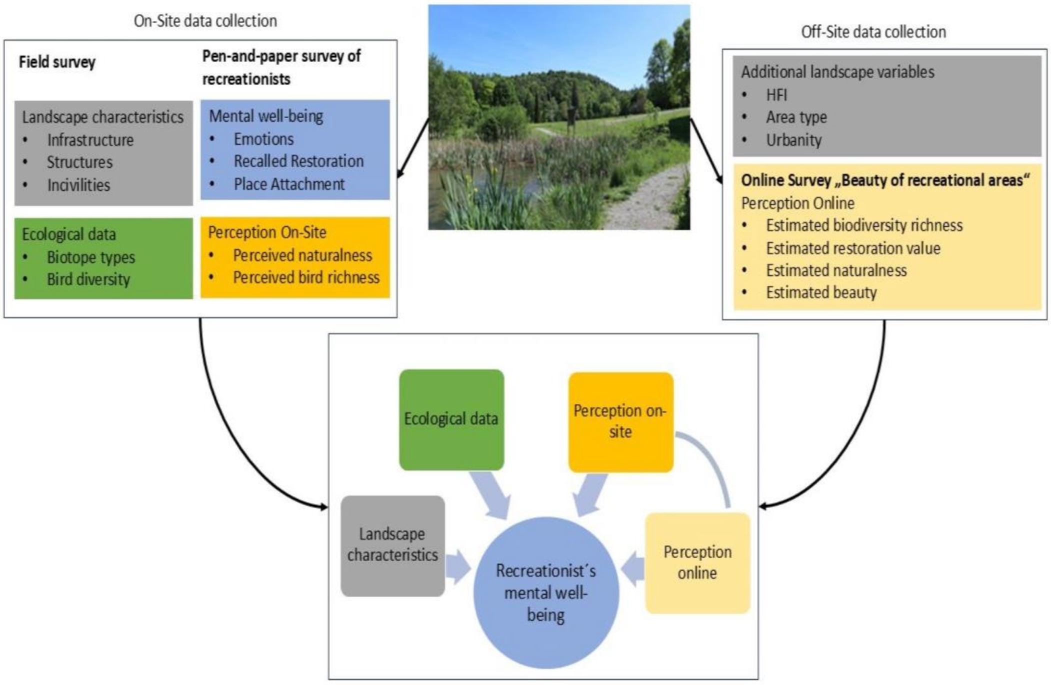


Figure 4.
Scheme of research. 40 study locations in southwestern Germany were assessed on-site with a field survey and a pen-and-paper survey of recreationists. Additionally, off-site data collection regarding further landscape characteristics and online assessment of the areas was done. Variables were used to assess their connection with recreationists' mental well-being, as well as the relationship between perception on-site and perception online.

Materials and methods

To answer our research questions, we collected a variety of area characteristics and did two different surveys on users of recreational areas.

Study locations

Two surveys were carried out in 40 locations between Rottenburg am Neckar and Stuttgart along the Neckar River in Baden-Württemberg, a federal state in southwestern Germany. First, a field survey was conducted by biologists to assess ecological data. Second, recreationists were surveyed on their experience and mental well-being via a pen-and-paper questionnaire. Surveys were carried out in May and June of 2022 on days with fair weather. The sites vary in their degree of urbanization and include both green and blue spaces. All the sites are recreational areas easily accessible to people. These study sites were selected due to their popularity as recreational areas and their being easily accessible either by foot, bike, public transportation or car. See Figure 5 for a map of the locations of the study sites.

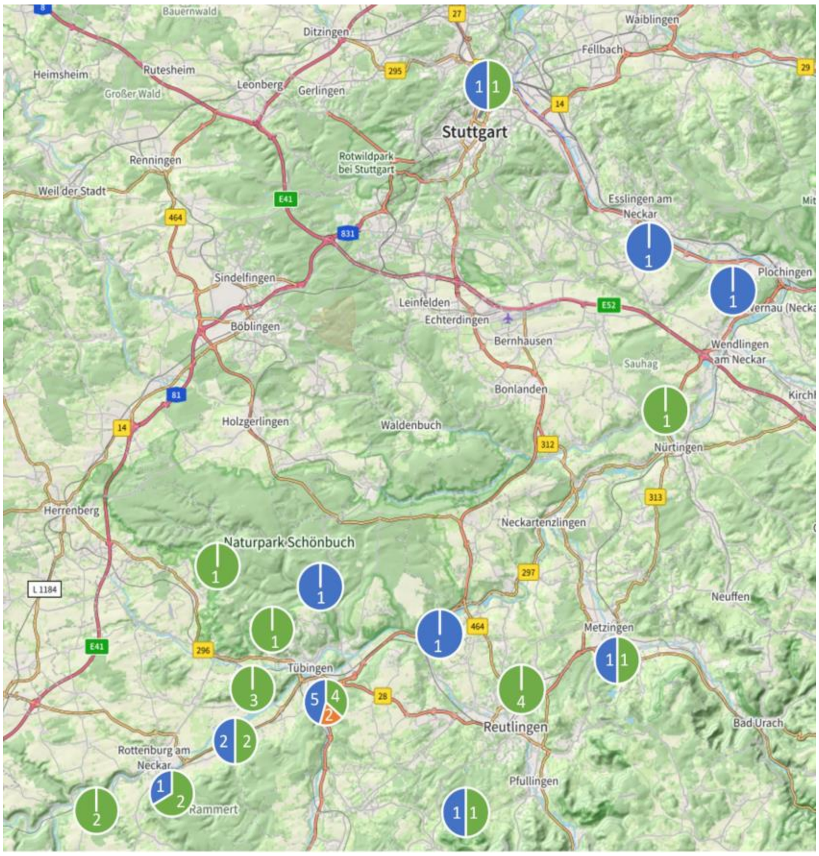


Figure 5.
Map of the communes in which the study sites are located. Starting in the north with the city of Stuttgart, Baden-Württemberg, southwest Germany, going south along the Neckar River until just behind Rottenburg am Neckar. Circles marking the study areas are divided by their portion of present area types: blue spaces in blue, green spaces in green and mixed spaces in orange. Map data is copyrighted by OpenStreetMap contributors and available from https://www.openstreetmap.org. (Thanks to D. Richter for helping with the map design.)

Area perception pen- and paper survey "biodiversity and well-being"

Pedestrians over the age of 18 were invited to participate in the questionnaire if they had already been in the respective area for a while. Participants were given the questionnaire on paper with a ballpoint pen. They were informed that it was anonymous, voluntary, and that they could stop at any time without consequences. This study has been granted ethical permission by the ethics committee of the Faculty of Social Sciences and Economics of the University of Tübingen (AZ: A2.5.4-219_ns) and has been carried out following all relevant guidelines and regulations. Informed consent was obtained from all participants.

Questionnaire

The questionnaire included 24 questions about location, perceived bird diversity, and well-being (Vanhöfen et al., 2022). Demographic variables were age, gender, and the highest level of education. In addition, participants were asked to rate their ornithological skill level (birding specialization from Lee & Scott (2004); Randler (2021a); Randler & Heil (2021) and their perception of birds (Belaire et al., 2015).

We used three **outcome measures** for assessing mental well-being: *recalled restoration*, *emotions* and *place attachment*.

Recalled restoration after the visit was asked with one item, on a categorical scale with 6 categories ("significantly more recovered", "somewhat recovered", "about the same", "less recovered", "significantly less recovered", "cannot say"), adapted from Young et al. (2020). For better comparability between the scales in our study, we recoded the recalled restoration Scale into a 0 ("cannot say") to a 5 ("significantly more recovered") Likert scale, with 0 being considered as missing data.

Emotions or self-reported restoration were measured with three items on a 5-point Likert scale (1 = fully disagree to 5 = fully agree), adapted from White et al. (2020) and Wyles et al. (2019). The scale had a Cronbach's alpha of 0.77 in our study.

Place attachment (full scale with a Cronbach's alpha of 0.88) can be split into two variables after a factor analysis, namely *place attachment-identity* and *place attachment-recovery*. The recovery scale is derived from the therapeutic value by the place attachment assessment of Bryce et al. (2016) and has a Cronbach's alpha of 0.86 in our study. The identity scale is derived from the abbreviated three-item place identity scale of Boley et al. (2021) and has a Cronbach's alpha of 0.87 in our study. Both scales use three items, coded on a Likert scale from 1 ("does not apply at all") to 5 ("completely true").

Additional variables asked for in the questionnaire were: *perceived bird diversity* at the respective places, asked on a categorical scale with nine categories (0–5; 6–10; 11–20; 21–30; 31–40; 41–50; 51–60; 61–70; over 70 species present; adapted after Ferraro et al. (2020), Southon et al. (2018) and *perceived naturalness*, asked on a scale from 1 (unnatural) to 5 (very natural), adapted from Schebella et al. (2019a). For a detailed description of the constructs and items used in the questionnaire, please see Table 21 in the Appendix.

Biodiversity data collection

In a field survey, accompanying the pen-and-paper survey, biologists collected data on actual biodiversity present in the study locations.

Bird diversity

Actual bird species richness on site was recorded by trained ornithologists using standard protocols (Bibby et al., 2000). In a 250 m radius around footpaths which visitors experience, all bird species seen and heard in 15 minutes were noted. Data was collected between March and June 2022, based on three visits at least 4 weeks apart. Here, we used the total bird count of all recorded bird species (see also Dallimer et al. (2012); Vanhöfen et al. (2022)). This list therefore, includes all bird species encountered at one location so that each species contributed to the dataset only once.

Biotope types

Several previous studies tried to assess and categorize areas. Voigt et al. (2014) proposed the three dimensions of the biotic, abiotic, and man-made to assess urban parks. In a further development, Gidlow et al. (2018) developed the natural environment scoring tool, which comprises 47 items in 8 domains: accessibility, recreational facilities, amenities, aesthetics-natural, aesthetics-non-natural, significant natural features, incivilities and usability. This list is comprehensive, but not all domains apply to our study areas. In their assessment, Schebella et al. (2019a) used checklists examining structural elements, habitat types and anthropic elements. They also proposed an urban park naturalness index including biotic elements, artificial elements, input and extraction, dynamics, and general human dependence.

Both tools are not easily applicable to our study areas without modification. Therefore, we adapted the ideas of all three mentioned authors to an area survey more easily applicable to our study areas by trained biologists (for a detailed description, see Table 22 in the Appendix).

The biotic vegetational composition and structure of the areas were recorded using the determining key catalogue "Arten, Biotope, Landschaft" from the nature conservation administration Baden-Württemberg (Höll et al., 2009), which serves as a uniform reference system for biological data collection projects. Using this key, biologists noted all biotope types (out of 64 possible Items) in the respective areas, using the same tours and roads normal visitors would use. The resulting variable *biotope types* includes the number of all different biotope types present in the respective areas, representing the richness of possible habitats for biodiversity and especially the species richness of plants.

Landscape characteristics

Different landscape characteristics were collected, either directly on the study sites or in a second step using map data.

On-Site landscape variables

To assess the abiotic elements, the biologists conducting the field survey also noted all man-made elements present in the areas (see also Table 23 in the Appendix for further information). From this, reasonable categories in adherence to Gidlow et al. (2018); Schebella et al. (2019a); Schebella et al. (2019b) were built. *Structures* (like buildings, roads, bridges, etc.) included the sum of most man-made structures not fitting in with the variable of infrastructure. *Infrastructure* included the sum of factors like accessibility, parking places, hiking routes, signage, benches, toilets, lighting, etc. *Incivilities* included trash and vandalism, among other things.

Off-Site landscape variables

Urbanity

As a further assessment of the area characteristics, we dichotomized areas as either rural or urban to get the variable of *urbanity*. Since most of Germany is very densely populated, this definition is mostly a subjective assessment, influenced by present structures. Areas were defined as rural if they were mostly situated in open farmland, grassland, marsh, or woodland, containing only a few elements like roads, large buildings, and houses (Reichert, 2022). Urban areas in contrast contained a matrix of built-in areas, like roads, houses, or large buildings. The urban recreational areas within this matrix still contained nature-based features such as gardens, parks, or water bodies. According to Reichert (2022), rural sites were coded with a 2, and urban sites were coded with a 1.

Blue and green spaces—area type

To assess further the characteristics of the areas of interest, we also measured the percentage of blue spaces and green spaces using QGIS (3.32.1) and the QuickOSM plugin (2.2.3). Since the federal state of Baden-Württemberg does not participate in the geodata offered by the federal government of Germany, the official database of the federal government uses the Open Street Map Data of Baden-Württemberg, making it sufficient for our use (BKG, 2023). The Open Street Map database is distributed under the Open Database License (ODbL) 1.0 and is available under https://www.openstreetmap.org/ (last assessed on 05.10.2023). Using these percentages, places were then further categorized regarding their features as a blue-, green- or mixed area, creating the variable *area type.*

Since blue spaces are generally outdoor environments with a prominent water feature and accessible to humans either proximally or distally (Grellier et al., 2017), we used the percentage of waterbodies in an area to define them as follows: blue space is composed of at least > 25% water body and is coded as 1, green space is composed of > 50% vegetational area and is coded as 2. If neither nor both apply, the area is labelled as mixed and coded as 3. As our study sites are roughly located along the Neckar River, spaces categorized as blue mainly include the river, large waterbeds, and different forms of large ponds. At the same time, mixed spaces include a high percentage of green space with only small water streams and bodies. As green categorized spaces do not contain much water but cover multiple vegetation types, like woodland, grassland, parks, and gardens. Of the 40 study sites, 37.5% are categorized as blue space, 57.5% as green space and 5% as mixed space (meaning neither blue nor green components predominate). 47.5% are urban and 52.5% are rural areas.

Human footprint index

The Human Footprint Index (HFI), developed by Venter et al. (2016), shows the human impact on a respective area. Pressures are scaled between 0 and 10 and afterwards weighed according to estimates of their relative level and summed together to create the standardized HFI. For each 1 km^2 the HFI can range from 0 to 5, with a lower score indicating less human impact. We assessed this data last on 10.08.2023 (Venter et al., 2018) by using QGIS (Version 3.32.1).

Area perception online-study "beauty of recreational areas"

In a separate but related online survey, the 40 areas used for the on-site assessment were randomly presented to an independent sample of respondents via an online survey. To ensure the quality of responses, the participants were asked to complete the survey task in the presence of working group members. Participants received a book for compensation to increase compliance.

This survey was distributed within the student body of a large German university and was hosted on the German SoSci-Survey server to comply with the European Union's data privacy rules.

Demographic variables asked for were gender, age, and highest level of education, to check for bias in participation. The demographic results were not used directly in this analysis on place level.

Participants were shown images of the same 40 places where the on-site survey took place (photographed by authors JV and TH, Figure 6 shows one example presented to participants). Four pictures were shown per site. For each study area, we asked for the participants' assessment of (see full survey catalogue in Table 24 in the Appendix):

- *Estimated beauty* of the area on a scale from 1 (not at all beautiful) to 5 (very beautiful).
- *Estimated the naturalness* of the area on a scale from 1 (unnatural) to 5 (very natural) which is the same question as in the "biodiversity and well-being" survey and derived from Schebella et al. (2019a); Schebella et al. (2019b).
- *Estimated biodiversity richness* on a scale from 1 (low) to 5 (high), derived and adapted from White et al. (2017).
- *Estimated restoration value* on a scale from 1 (none) to 5 (very high) (White et al., 2017).

Figure 6.
Wernau dredging lake, example for a rural blue space—as shown to participants of the area-perception online study "Beauty of recreational areas". (Pictures by J. Vanhöfen)

Statistical analysis

We did our analysis two ways: (1) on the place level, following previous studies (Dallimer et al., 2012; Fuller et al., 2007; Schebella et al., 2019b), using the means per place calculated from the individual surveys. And (2) in a hierarchical structure, using individual-level data. The program SPSS (Version 29.0.1.1) was used for all statistical analyses.

Before analyzing the research questions, the descriptive statistics of predictor variables and study areas were assessed at the place level. To check if the assessments of biologists and participants are related to the variables of area type and the HFI, we carried out a non-parametric Spearman-rho correlation on the landscape characteristics.

To analyze the research questions 1 and 2, we did a multivariate two-level GLM on the outcome variables (mental well-being: emotions, recalled restoration, place attachment-identity and place attachment—recovery) with the individual data points (N = 1184) as level 1 the place-level (N = 40) as superior level 2. The same model is used to see the effects of landscape characteristics on visitors' mental well-being (RQ1), and if perception on-site (and online) influences the mental well-being of visitors (RQ2). To be able to determine the effect direction, an additional Pearson correlation (p-values Bonferroni–Holm corrected) as well as a graphical inspection was done. For RQ2, a nonparametric Spearman-rho correlation of the perception on-site and the perception online with the landscape characteristics was done to analyze a possible connection between landscape characteristics and the perception.

After, we did a Spearman-rho correlation on the online survey "Beauty of recreational areas" to see if the perception while looking at images during the online study is in line with the results of the pen and paper study "biodiversity and well-being" (RQ3). We checked if participants online had the same outcome in perceived bird diversity and perceived naturalness and wanted to see if this correlated with bird diversity and biotope types. Since two of our predicting variables, area type and urbanity, are nominally coded, we did a Chi^2 to analyze their relationship with the other variables.

In all correlation analyses the p-values were Bonferroni–Holm corrected.

Results

Descriptive statistics

The area perception on-site survey "biodiversity and well-being" had 1184 participants. There were 30 to 31 participants per area, except for two study sites (N = 17 and 24). 54.9% of the participants were female, 44.1% were male (0.2% identified as diverse, 0.8% did not answer the question). A university degree (at least on the bachelor's level) was reported by 55.7% of the participants. Participants` ages ranged from 18 to 89 years old (1.9% did not answer) with the mean age being 43.34 ± 17.75 years.

The area perception online study "beauty of recreational areas" had 49 participants with a surplus of females (34.7% male, 63,3% female, and 2% did not answer the question). The mean age was 32.69 ± 13.63 years (range 19–67). About half of the participants did not have a university degree (55.1%): 16.3% had a secondary school diploma ("Realschulabschluss"), 38.8% had a high school diploma ("Abitur"), meanwhile 40.8% reported some university degree (4% did not answer or selected "different").

Table 3 shows the descriptive statistics of the study areas, depending on the respective area type. The descriptive statistics of all variables are presented in Table 25 in the Appendix.

Table 3.
Descriptive statistical information on the study areas, dependent on their area type (blue/green/ mixed space) (N = 40).

	Area type	Mean	Std. deviation	Minimum	Maximum	Range
HFI	Blue	35.989 ± 0.396	8.291	13.0	45.0	32.0
	Green	32.239 ± 0.410	10.737	14.0	46.0	32.0
	Mixed	30.000 ± 0.260	2.017	28.0	32.0	4.0
Urbanity	Blue	1.450 ± 0.024	0.498	1.0	2.0	1.0
	Green	1.606 ± 0.019	0.490	1.0	2.0	1.0
	Mixed	1.000 ± 0.000	0.000	1.0	1.0	0.0
Biotope types	Blue	12.547 ± 0.101	2.114	9.0	16.0	7.0
	Green	13.568 ± 0.170	4.449	7.0	22.5	15.5
	Mixed	16.500 ± 0.456	3.530	13.0	20.0	7.0
Structures	Blue	5.521 ± 0.068	1.427	3.0	8.0	5.0
	Green	5.305 ± 0.075	1.957	2.0	10.0	8.0
	Mixed	8.000 ± 0.000	0.000	8.0	8.0	0.0
Infrastructure	Blue	5.487 ± 0.104	2.181	1.5	10.5	9.0
	Green	7.203 ± 0.072	1.887	4.5	11.0	6.5
	Mixed	6.250 ± 0.033	0.252	6.0	6.5	0.5
Incivilities	Blue	1.726 ± 0.041	0.865	0.0	3.0	3.0
	Green	0.920 ± 0.032	0.830	0.0	3.0	3.0
	Mixed	3.000 ± 0.391	3.025	0.0	6.0	6.0
Bird diversity	Blue	29.030 ± 0.251	5.247	22.0	42.0	20.0
	Green	28.250 ± 0.249	6.513	18.0	41.0	23.0
	Mixed	23.500 ± 0.195	1.513	22.0	25.0	3.0

Looking at the landscape characteristics, the biotope types correlate with bird diversity (rho = 0.496, p = 0.006) and HFI (rho = − 0.477, p = 0.012). The bird diversity additionally correlates negatively with the HFI (rho = − 0.472, p = 0.012). This confirms that in areas with a high number of biotope types there are more bird species with the opposite being true for areas with a high human impact factor. See Figure 7 for a presentation of the distribution of actual biodiversity in the 40 study areas. It also confirms the wide variety of recreational areas we used.

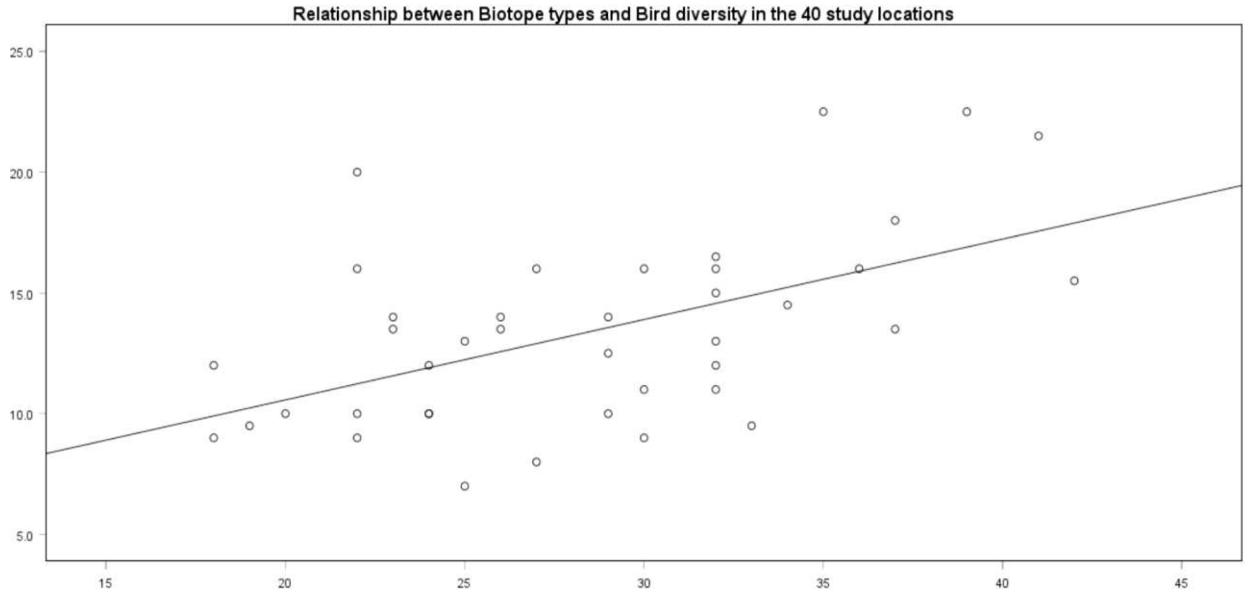


Figure 7.
Point-plot of the actual biodiversity, in the 40 study areas. The relationship between biotope types and bird diversity is shown with a regression line (R2 linear = 0.292).

In addition, area type is related to incivilities (X^2 (8, N = 40) = 31.179, p < 0.001), and urbanity is related to the HFI (X^2 (20, N = 40) = 34.319, p = 0.024). These results are probably related to the usage of the areas, a topic outside the scope of this manuscript. Urbanity being connected to the HFI confirms that more urban areas have a higher HFI. The structures and infrastructure variables do not correlate with any of the other area characteristics assessed.

Effects of landscape characteristics on mental well-being (RQ1)

Mental well-being was measured with the variables recalled restoration, emotions, place attachment-identity, and place attachment-recovery. The two-level GLM (Table 4) shows significant effects of gender, birding specialization, age, HFI, and infrastructure on the mental well-being variables.

Table 4.
Hierarchical 2-level GLM, with individual-level data (N = 1184) as level 1 and study site (N = 40) as level 2, corrected for individual sociodemographic variables. Significant results are written in bold letters.

Source	**Dependent variable**	**Numerator df**	**Denominator df**	**F**	**Sig**
Intercept	**Emotions**	**1**	**1049**	**56.929**	<0.001
	Recalled restoration	**1**	**1044**	**19.144**	<0.001
	Place attachment—identity	**1**	**1050**	**23.890**	<0.001
	Place attachment—recovery	**1**	**1051**	**34.738**	<0.001
Area type	Emotions	2	1049	0.388	0.678
	Recalled restoration	2	1044	0.532	0.588
	Place attachment—identity	2	1050	0.632	0.532
	Place attachment—recovery	2	1051	0.738	0.478
Urbanity	Emotions	1	1049	0.038	0.845
	Recalled restoration	1	1044	0.622	0.430
	Place attachment—identity	1	1050	2.821	0.093
	Place attachment—recovery	1	1051	0.974	0.324
Gender	Emotions	1	1049	1.277	0.259
	Recalled restoration	**1**	**1044**	**4.389**	0.036
	Place attachment—identity	1	1050	0.164	0.686
	Place attachment—recovery	**1**	**1051**	**7.032**	0.008
Graduation	Emotions	1	1049	0.089	0.766
	Recalled restoration	1	1044	0.440	0.508
	Place attachment—identity	1	1050	0.015	0.903
	Place attachment—recovery	1	1051	0.002	0.968
Birding specialization	Emotions	5	1049	0.741	0.593
	Recalled restoration	**5**	**1044**	**2.853**	0.014
	Place attachment—identity	5	1050	1.316	0.255
	Place attachment—recovery	5	1051	1.066	0.377
Age	Emotions	1	1049	0.261	0.610
	Recalled restoration	**1**	**1044**	**5.964**	0.015
	Place attachment—identity	**1**	**1050**	**63.245**	<0.001
	Place attachment—recovery	1	1051	0.027	0.870
HFI	**Emotions**	**1**	**1049**	**11.280**	<0.001
	Recalled restoration	1	1044	1.754	0.186
	Place attachment—identity	**1**	**1050**	**4.830**	0.028

	Place attachment—recovery	1	1051	0.919	0.338
Estimated biodiversity richness	Emotions	1	1049	0.026	0.871
	Recalled restoration	1	1044	1.334	0.248
	Place attachment—identity	1	1050	1.475	0.225
	Place attachment—recovery	1	1051	0.002	0.963
Estimated restoration value	**Emotions**	**1**	**1049**	**10.857**	0.001
	Recalled restoration	1	1044	1.797	0.180
	Place attachment—identity	1	1050	0.017	0.897
	Place attachment—recovery	1	1051	0.589	0.443
Estimated naturalness	Emotions	1	1049	0.014	0.906
	Recalled restoration	1	1044	0.403	0.525
	Place attachment—identity	1	1050	3.031	0.082
	Place attachment—recovery	1	1051	1.331	0.249
Estimated beauty	**Emotions**	**1**	**1049**	**17.841**	<0.001
	Recalled restoration	1	1044	1.354	0.245
	Place attachment—identity	1	1050	0.000	0.990
	Place attachment—recovery	1	1051	0.452	0.501
Biotope types	Emotions	1	1049	0.019	0.892
	Recalled restoration	1	1044	0.488	0.485
	Place attachment—identity	1	1050	0.157	0.692
	Place attachment—recovery	1	1051	0.084	0.772
Structures	Emotions	1	1049	1.687	0.194
	Recalled restoration	1	1044	0.022	0.883
	Place attachment—identity	1	1050	0.015	0.901
	Place attachment—recovery	1	1051	0.491	0.484
Infrastructure	Emotions	1	1049	0.148	0.700
	Recalled restoration	1	1044	1.979	0.160
	Place attachment—identity	**1**	**1050**	**22.971**	<0.001
	Place attachment—recovery	**1**	**1051**	**4.803**	0.029
Incivilities	Emotions	1	1049	1.573	0.210
	Recalled restoration	1	1044	0.542	0.462
	Place attachment—identity	1	1050	0.374	0.541
	Place attachment—recovery	1	1051	0.341	0.560
Bird diversity	Emotions	1	1049	1.256	0.263
	Recalled restoration	1	1044	2.567	0.109

	Place attachment—identity	1	1050	0.091	0.762
	Place attachment—recovery	1	1051	0.092	0.762
Perceived bird diversity	Emotions	1	1049	1.737	0.188
	Recalled restoration	**1**	**1044**	**6.586**	0.010
	Place attachment—identity	1	1050	1.709	0.191
	Place attachment—recovery	1	1051	2.036	0.154
Perceived naturalness	**Emotions**	**1**	**1049**	**61.288**	< 0.001
	Recalled restoration	**1**	**1044**	**4.591**	0.032
	Place attachment—identity	**1**	**1050**	**18.370**	< 0.001
	Place attachment—recovery	**1**	**1051**	**33.438**	< 0.001
Perception of birds	**Emotions**	**1**	**1049**	**95.565**	< 0.001
	Recalled restoration	**1**	**1044**	**20.914**	< 0.001
	Place attachment—identity	**1**	**1050**	**68.720**	< 0.001
	Place attachment—recovery	1	1051	60.693	< 0.001

The sociodemographic variables have various impacts on the mental well-being of participants. Female participants report higher recalled restoration and higher place attachment–recovery values than male participants. The older the participants, the higher they rate their recalled restoration and place attachment—identity. Participants with higher self-reported ornithological skill rate their recalled restoration lower than participants with less birding specialization.

The landscape characteristics only impacted participants negatively: in places with higher HFI the emotions and place attachment-identity ratings were lower. Additionally, more infrastructure led to lower place attachment-identity and place attachment-recovery.

Effects of perception on mental well-being (RQ2)

Landscape characteristics and perception

The perceived naturalness on-site correlates positively with bird diversity and negatively with the HFI (Table 5). Thus, people perceive places as more natural if they present a higher bird diversity with a small human impact.

The number of biotope types is correlated with the estimated biodiversity richness and estimated beauty of the area perception online study. The HFI, in addition to perceived naturalness, correlates negatively with all variables of the area perception online study. From this, we confer that people looking at images are negatively influenced in their perception of biodiversity, naturalness, beauty, and restoration value by a high human impact. Structures, infrastructure, and incivilities do not play a role since they do not correlate with the perception variables. Area type and urbanity are not related to any of the perception values according to the chi^2 test we did.

Bird diversity additionally correlates with the estimated biodiversity richness and estimated naturalness of the online study. Therefore, if there are a lot of bird species present, people looking at areas per images perceive them as higher in biodiversity and naturalness.

Table 5.
Nonparametric spearman-rho correlation of the perception on-site and the perception online with the landscape characteristics (N = 40). p values were Bonferroni–Holm corrected. Significant values are written in bold letters.

	Perceived bird diversity		**Perceived naturalness**		**Estimated biodiversity richness**		**Estimated restoration value**		**Estimated naturalness**		**Estimated beauty**	
	rho	**cor. p**	**rho**	**cor. p**	**rho**	**cor. p**	**rho**	**cor. p**	**rho**	**cor.p**	**rho**	cor. p
Biotope types	0.333	0.186	0.347	0.168	**0.449****	**0.024**	0.359	0.138	0.368	0.114	**0.422***	0.042
Structures	− 0.231	0.456	− 0.310	0.306	− 0.100	> 0.999	− 0.123	> 0.999	− 0.198	> 0.999	− 0.033	> 0.999
Infrastructure	− 0.111	0.594	0.040	> 0.999	− 0.054	> 0.999	0.058	> 0.999	− 0.101	> 0.999	0.023	> 0.999
Incivilities	− 0.169	0.594	− 0.218	> 0.999	− 0.156	> 0.999	− 0.098	> 0.999	− 0.100	> 0.999	0.006	> 0.999
HFI	− 0.343	0.186	**– 0.558****	**0.006**	**− 0.678****	**0.006**	**− 0.616****	**0.006**	**− 0.592****	**0.006**	**− 0.559****	0.006
Bird diversity	0.325	0.186	0.517**	0.005	0.492**	0.006	0.349	0.162	0.487**	0.006	0.403	0.06

Perception and mental well-being

The two-level GLM (Table 4) shows the effects of estimated restoration value, estimated beauty, perceived bird diversity, perceived naturalness and perception of birds on the mental well-being of participants.

Participants with a more positive perception of birds reported more positive emotions, higher recalled restoration, place attachment-identity and place attachment-recovery.

Places with higher perceived bird diversity led to higher recalled restoration ratings of participants.

High perceived naturalness led to more positive emotions (Figure 8, right), higher recalled restoration, place attachment-identity and place attachment-recovery. The HFI has a negative relationship with emotions and recalled restoration (Figure 8 left)

The online perception of the areas is also connected to mental well-being on-site: higher estimated restoration value and estimated beauty online are connected to more positive emotions on-site.

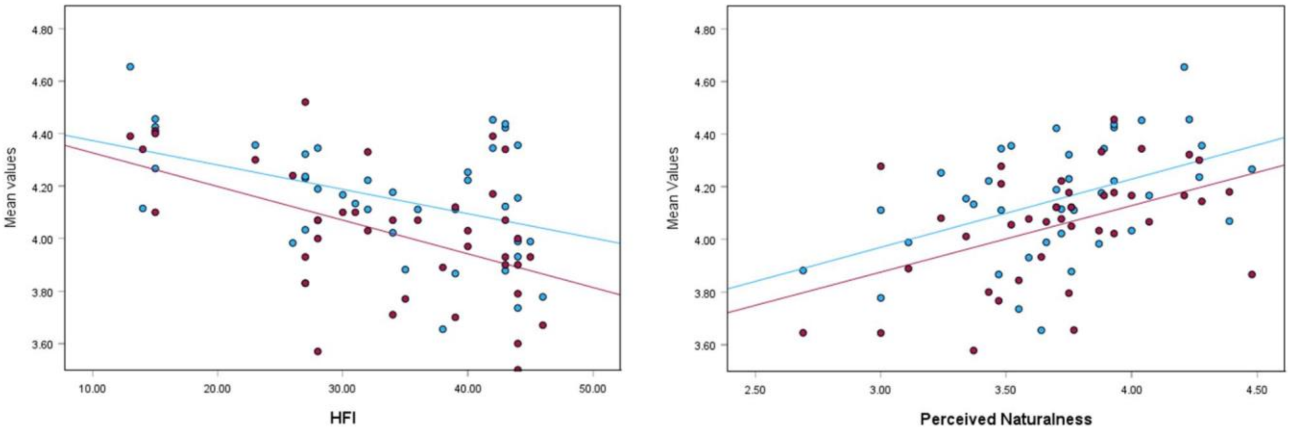


Figure 8.
(Left) The negative relationship between the HFI and emotions respectively recalled restoration. Blue = emotions, red = recalled restoration. R2 linear (emotions, blue line) = 0.175, R2 linear (recalled restoration, red line) = 0.245).
(Right) The positive relationship between place attachment—recovery, emotions and perceived naturalness. Blue = emotions, red = place attachment—recovery. R2 linear (both lines) = 0.215.

Perception on-site and online (RQ3)

All four variables for the area perception online study correlate with the perceived naturalness of a place (Table 6). In contrast, they are not related to the perceived bird diversity by people asked in the area. Therefore, if a place is perceived as natural by people on-site, people looking at images also find it to be more biodiverse, natural, beautiful and of a higher restoration value.

Table 6.
Non-parametric spearman-rho correlations (N = 40) comparing the area perception online study with the area perception on-site survey. Significant results are written in bold letters.

	Perceived bird diversity			**Perceived naturalness**		
	rho	***p***	**cor. p**	**rho**	***p***	cor. p
Estimated biodiversity richness	0.378	0.016	0.056	**0.610****	**< 0.001**	0.004
Estimated naturalness	0.386	0.014	0.056	**0.607****	**< 0.001**	0.004
Estimated restoration value	0.21	0.194	0.38	**0.534****	**< 0.001**	0.004
Estimated beauty	0.212	0.19	0.38	0.472**	0.002	0.004

Discussion

In this paper, we compare two different survey studies and use different area characteristics to assess the impact on visitors' mental well-being in recreational areas.

Results of the GLM show that sociodemographic are also connected to the mental well-being of recreationists in the study areas. Female participants have a higher recalled restoration and higher place attachment-recovery than male participants. This is probably due to individual differences predisposing some females to higher restoration benefits from green space (Feng et al., 2022).

In addition, older participants rate their recalled restoration and place attachment-identity higher than younger participants.

Additionally, participants with a high perception of birds reported more positive emotions, higher recalled restoration, place attachment-identity, and place attachment-recovery. These are probably people with a stronger connection to nature benefitting from being outside. Connectedness to nature is the emotional connection to living animals and nature (Mayer et al., 2009). This emotional connectedness to nature can influence participation in nature-based activities (Cheng & Monroe, 2012) and probably also does so in our study.

Interestingly, participants with higher ornithological skills rate their recalled restoration lower. These participants could have been on a birding trip or similar and might have been frustrated by not meeting their goals. In earlier studies, Randler et al. (2023a) found that non-birders have higher satisfaction and restoration than specialized birders after a birding trip since the feeling of success arrives more quickly for them.

How do the landscape characteristics affect the user's mental well-being? (RQ1)

The different biotope types and the actual bird diversity were not connected to mental well-being variables according to the model (Table 4). Even though some large-scale survey studies like Methorst et al. (2021a) found a significant positive relationship between bird species richness and mental health in Germany using panel surveys of private households, our result is in line with other on-site studies, which found no relationship between mental well-being and actual bird species richness (Cox et al., 2017b; Dallimer et al., 2012; Taylor et al., 2018). Bird species richness, therefore, seems not to improve mental well-being directly on-site, but still could have an indirect and/or delayed positive impact on people. Generally, having more species in a neighborhood has been shown to have a positive effect on well-being (Cox & Gaston, 2015; Fuller et al., 2013; Fuller et al., 2007; Methorst et al., 2021a). In our study, it is not the actual bird diversity per se which impacts people's mental well-being on-site. Rather, the experience in the area is the decisive factor, as discussed regarding the RQ2 and RQ3. Even though we did not find a direct connection between our biodiversity measures and mental well-being, it could be that places promoting high bird diversity have beneficial landscape properties, which also benefit people's well-being (Methorst et al., 2021b). This is probably partly due to aesthetic reasons (Lindemann-Matthies et al., 2010), since the number of different biotope types in an area does not affect visitors' mental well-being according to our results. People may either differentiate or experience biotope types in terms of vegetation in general leading to stress reduction (Cox et al., 2017b). And more varied green spaces were related to better mental well-being in previous studies (Marselle et al., 2021b; Marselle et al., 2019; Methorst et al., 2021a). Or recreationists also could only find the "larger picture" of the landscape to be beneficial to their mental health (Ward Thompson et al., 2012).

In addition to biodiversity, as recorded by biologists, we collected data on existing infrastructure, structures, and incivilities. A higher presence of infrastructure led to lower place attachment-identity and place attachment-recovery. Infrastructure in our study means connections, accessibility, car parks, hiking routes, signposting, benches, playgrounds, etc. These are mainly well-developed areas that are likely to be visited by many people. They may be perceived as noisier, deprived, and polluted. Earlier, perceived traffic was negatively related to restoration in a study by Subiza-Pérez et al. (2021).

In our study areas, incivilities such as trash or graffiti did not affect place attachment—recovery. Incivilities were only present with a mean score of 1.33 ± 1.21 out of 6; their rare presence had seemingly no impact on visitors. Structures, on the other hand, are present with a mean of 5.51 ± 1.83 out of 10. Structures in our study are man-made things like buildings, roads, bridges etc., which are necessary for access to the areas and a common sight for people. It follows that these are perceived as neutral, especially for urban dwellers, and do not have a direct strong impact on our assessments of mental well-being or place attachment.

We also measured urbanity, area type and the HFI of the areas and tried to relate them to the people's mental well-being.

Area type and urbanity do not affect our outcome variables—it does not matter to people if an area is a green or blue space, the most important thing is that it is an outside or natural area (Li et al., 2021). It has to be kept in mind that most landscapes are not always one type or the other as most consist of many different characteristics which in turn can influence mental well-being and/or perception.

In study areas with a higher HFI, the emotions and place attachment—identity were lower than in areas with lower HFI (Table 4). From this we conclude that more important than the type of an area is the human impact present in it. Areas with greater human impact elicit more negative emotions and may even be harmful to restoration since restoration as a concept is seen as an evolutionary-based response to certain landscapes (Kaplan & Kaplan, 1989; Ulrich et al., 1991).

Participants in our study felt more attached to areas with fewer buildings, infrastructure, and other developments. The HFI is negatively connected to mental well-being in our study, meaning that areas with a high human impact are not as beneficial to visitors´ mental health. People express more positive emotions in more rural places even though urbanity as a variable does not predict mental well-being. Perception of a place is therefore perhaps the most important predictor of mental well-being.

Does perceived biodiversity and or naturalness on-site influence mental well-being? (RQ2)

High perceived naturalness led to more positive emotions, higher recalled restoration, place attachment—identity and place attachment- recovery, according to the model (Table 4). Additionally, a higher perceived bird diversity led to higher recalled restoration of participants.

The results also show that the estimated restoration value and estimated beauty when looking at pictures are also related to emotional and restorational outcomes on-site.

This adds to the growing evidence that it is the perception of a place that is important when experiencing it. Previous studies (Dallimer et al., 2012; Fuller et al., 2007; Marselle et al., 2019) showed that perception of species richness is important for human mental well-being. However, we have also shown that the perceived naturalness of an area is important. As in the study by Schebella et al. (2019b), the perceived measures of biodiversity are impacting well-being instead of actual/objective measures (e.g. actual bird diversity).

This matches the results mentioned in the first part of this discussion: areas with less infrastructure and human impact are perceived as more natural and therefore also affect mental well-being. Since the perceived naturalness of a place is negatively correlated with the HFI (Table 5), people can correctly associate areas with a high human impact as less "natural". The definition of "nature" is not clear, but Hartig et al. (2014) defined it as "physical features and processes of non-human origin", which suits the general perception of the public seeing "natural" as the counterpart of "human". However, due to the subjectivity of the definition, it is difficult to determine what people perceive as natural. Some management seems desirable, as sites left completely untouched are often perceived as less aesthetic than extensively managed sites (Martens et al., 2011). For example, managed meadows have a more positive impact on stress reduction than abandoned meadows in the Alps (Hussain et al., 2019). Since people seem to perceive naturalness/biodiversity visually (Gonçalves et al., 2021), mostly concentrating on vegetation (Meng et al., 2024) and especially noticing trees (McEwan et al., 2020), the personal definition of "natural" could be quite different and depend strongly on the socialization of participants. However, according to our findings, this perception of naturalness is of particular importance when it comes to promoting mental well-being in recreational areas. Wilson (1986, 2017)'s theory of biophilia states humans feel most at home and are best able to flourish in places that mimic the natural spaces in which the species evolved. More natural areas with less infrastructure and a lower HFI fit this description probably best for most people.

Do participants assessing the restorative quality of recreational places via images perceive places similarly to people on-site? (RQ3)

In a related online survey, we showed participants pictures of the areas surveyed in the on-site study and asked for their perception of these places. The estimated biodiversity richness, estimated naturalness, estimated restoration value, and estimated beauty of this survey are correlated with the perceived naturalness of the on-site survey (Table 6). Therefore, people's perceptions of areas are similar if not the same, no matter if asked on-site or shown pictures. The estimated restoration value is additionally connected to emotions and recalled restoration on-site. The perception of an area as restorative could well be the subjective landscape characteristic important for improving mental well-being. The effect on the mental well-being of online participants was not tested in this study, but other studies found positive results (Luo et al., 2022).

Areas perceived as more restorative are probably landscapes with greater naturalness and ecological diversity, as areas like this were assessed as more natural and positively associated with greater perceived restorativeness in the study by Chang et al. (2024). Areas with a greater presence of biotope types and higher bird diversity are perceived to be more biodiverse and beautiful (Table 5). Areas perceived to be more natural have higher bird diversity, just as the perceived naturalness of participants on-site. As already shown by Vanhöfen et al. (2022), people on-site can roughly estimate the bird diversity as recorded by biologists. People online were seemingly just as good at estimating species richness as the people on-site. Estimated biodiversity richness and estimated beauty are also related to the number of biotope types. This strengthens the idea that people estimate biodiversity independently of their experience of it. However, it is unknown which variables and impressions lead to the assessment of a biodiversity-rich area. This could be studied further using qualitative interviews.

Additionally, the HFI was related to perceived naturalness on-site as well as estimated biodiversity richness, naturalness, restoration value and beauty, giving further evidence that people can perceive a place similarly, regardless of experience. They do not need to be there physically to estimate naturalness and species richness. This also means that people use measures other than experiencing a species or biodiversity itself in their evaluation of a place.

Conclusion

The present studies assessed various area characteristics and different biodiversity and landscape measures to relate them to the mental well-being of people on-site. They also connect the mental well-being of people on-site to an evaluation with an online study. In this, mental well-being did not depend on actual bird diversity or biotope types, but recalled restoration was positively influenced by perceived bird diversity. The perceived naturalness of an area positively influenced all mental well-being variables, while infrastructure and human impact in an area had a negative impact. Participants with a more positive perception of birds benefit in terms of mental well-being, possibly due to better connectedness to nature. Therefore, to increase the positive impact on the mental well-being of visitors to recreational areas, the perceived naturalness and perceived bird diversity of an area should be increased.

Perception of an area can also be retrieved by showing pictures and is not dependent on the experience on-site. More research needs to be done on the effect of mental well-being when looking at pictures. These results would be useful as a proxy for people who cannot easily access these areas, as well as for reducing the impact on these areas.

Implications and limitations

Mental well-being depends mostly on the perception of the area, mainly perceived naturalness and perceived bird diversity, and is therefore indirectly connected to the infrastructure and human impact in an area. Positive perception of birds—and therefore probably a higher connectedness to nature—also benefits the mental well-being of participants. This has a plethora of implications for future studies and the planning of recreational areas in accordance with nature conservation. People express more positive emotions in places with less human impact, so recreational places should take this into account when planning, renovating, or advertising places. Coincidentally, places with less human impact are often areas where biodiversity thrives and are therefore important for nature conservation. Especially in cities, these natural and biodiverse places need to be established and preserved for the future, for the sake of nature and people's mental well-being.

A few limitations need to be addressed on behalf of this study. Our results of people feeling better in areas with less human impact are statistically true for the study sites in this study. It may not be true for other areas, since the range of our study sites is quite limited to a small region inside of southwestern Germany. In other countries, this may be different not only due to ecological reasons but also due to cultural differences.

In addition, participants were people met by chance at the study sites. They were asked to participate after being in the study area. Therefore, our sample may be made up of people already happy to be outside and more inclined towards nature. But this was not controlled for here. Surveying the effect of being outside in the recreational areas on "city-people" or people with non-nature-related hobbies would be important to get a more complete picture.

The comparison of the online and outdoor studies should also be taken only as an indication since the online sample was mainly made up of university students and in its small sample size is not directly comparable to the outside study.

It would also be interesting to see how people on-site perceive the restorativeness of the areas. This was only asked in the picture survey and its impact therefore needs to be studied further.

Amidst the ever-growing human impact, we think that our results of the impact of perception/experience are an important factor to consider when designing recreational areas in the future. To be able to boost mental well-being and positive experiences in outdoor spaces, these areas should be designed to seem natural to recreationists, but still manageable to facilitate usage.

Manuscript 3

Effects of nature experience on mental well-being and physiological stress parameters in an experimental bird walk setting – the role of bird song.

Vanhöfen, Janina; Stuck, Katharina; Haag, Reimund; Härtel, Talia & Randler, Christoph (2025). Effects of nature experience on mental well-being and physiological stress parameters in an experimental bird walk setting–the role of bird song. *Landscape and Urban Planning*, *263*, 105456.

Abstract

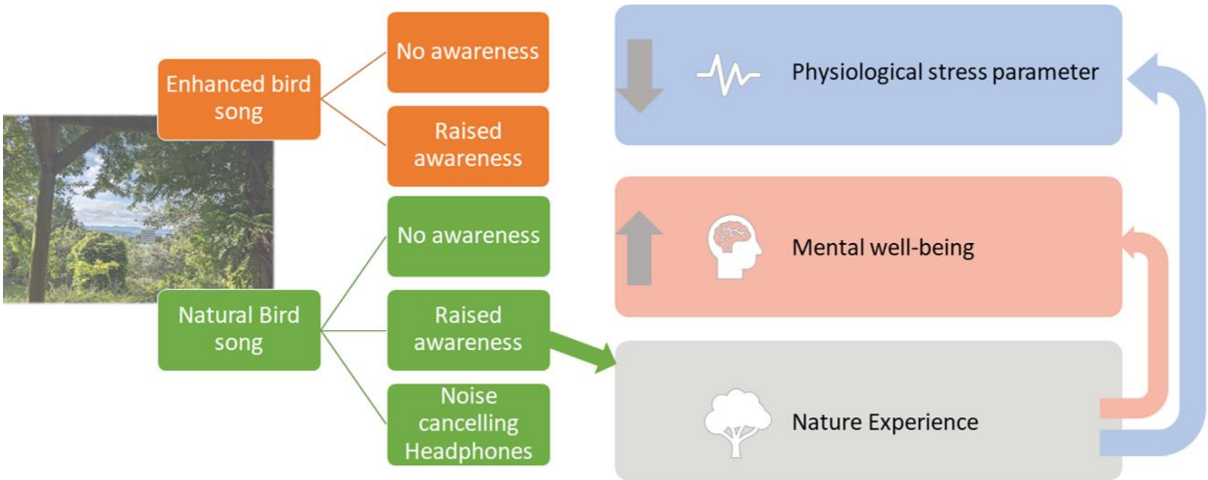
Recreational nature experience in cities is an accessible way for people to receive benefits for their physical and mental health. Recreational walking, for example, is a popular way of stress relief. Further, birdsong has been found to improve well-being. The following study aims to determine if an unguided bird walk through a controlled environment positively affects mental well-being, physiological stress markers and subjective nature experience. For this, an experimental design was developed, with two manipulations being 1) enhanced bird song vs. natural song, 2) raised awareness for bird song vs. no raised awareness, in a 2x2 factorial design, with additional noise-cancelling headphones as control. In a pre-post-test design, measurements of saliva cortisol levels, blood pressure and heart rate were employed to assess physiological stress markers. The unguided bird walk generally positively affects well-being and physiological stress parameters. Physiological stress parameters decreased, and positive emotions increased after a bird walk in a controlled park environment. Playing additional bird songs as playback did not lead to enhanced mental well-being or nature experience compared to natural songs. However, raising awareness about the natural bird song led to a higher nature experience than not raising awareness about the bird song. The results suggest that nature experience plays a significant role in mental well-being. In our analysis, nature experience itself is connected to increased awareness of the environment and also to a positive perception of birds as a trait variable. We conclude that a positive personal nature experience is important to promote mental well-being after an unguided nature or bird walk and is additionally enhanced by verbal awareness cues.

Keywords: Controlled bird walk, Bird song, Nature experience, Mental well-being, Physiological stress markers

Highlights

- An unguided bird walk increases positive emotions and decreases physiological stress parameters.
- Playing additional bird songs as playback did not lead to enhanced mental well-being or nature experience compared to natural bird songs.
- Raising awareness about the natural bird song led to a higher nature experience. Mental well-being was primarily influenced by nature experience.
- The nature experience itself was influenced by an increased awareness of the environment and a positive perception of birds.
- Perceived bird species richness did not impact well-being or nature experience.

Graphical abstract



Introduction

The benefits of being in nature are an increasing field of research, since it not only helps humans in their psychological restoration but also improves physiological health and reduces stress (Fisher et al., 2021; Kaplan & Kaplan, 1989; Marselle et al., 2021a; Ulrich, 1983; White et al., 2013). Aside from promoting physical health through physical activity (Sugiyama et al., 2008), walking in green areas is also very effective at reducing anxiety and increasing positive affect compared to suburban walking (de Brito et al., 2019). But nature comprises many parts, one of them being biodiversity, mainly species richness. Many earlier studies looked at the effect of species richness, especially from birds, on people's mental well-being. Mostly, a high bird species richness was beneficial to the mental well-being, but there are inconsistent results regarding the different effects of actual and perceived bird diversity. And it is still not clear whether increased bird diversity alone is sufficient to enhance mental well-being, or if a raised awareness of bird diversity is also helpful.

Mental well-being.

Suburban and urban blue and green spaces are generally associated with mental health benefits for people (Jimenez et al., 2021; White et al., 2013), as well as lower levels of stress, depression and anxiety (Beyer et al., 2014). Biodiversity as a compound of nature plays a pivotal role in this. Many pathways link biodiversity to human mental health and well-being. Some of them include the ability to restore and build capacity, as proposed by (Marselle et al., 2021a). Therefore, a walk in the park builds capacities by promoting physical activity and restores mental capacities. There are different theoretical frameworks frequently mentioned for how outside experience could cause this restoration. Two of them, the Attention Restoration Theory (ART) by Kaplan & Kaplan (1989) and Kaplan (1995) − which indicates that spending time in nature facilitates recovery from attentional fatigue Kaplan (1995) - and the stress reduction theory (SRT) − which indicates that psychophysiological stress recovery benefits from high levels of biodiversity (Ulrich, 1983; Ulrich et al., 1991), argue that exposure to natural environments help restore psychological resources. Therefore, psychological restoration in the sense of ART and SRT means replenishing cognitive resources (like attention) and reducing stress (Kaplan & Kaplan, 1989; Ulrich et al., 1991). Even though these frameworks have been discussed critically (Joye & Dewitte, 2018), earlier research in restorative green spaces was able to show a relationship with better mental well-being (Marselle et al., 2019; Randler et al., 2023c). Similarly, people seem to be happier when they spend time in places with higher biodiversity (Cameron et al., 2020). The following study used both these frameworks as a basis for item selection for restoration and stress reduction.

Physiological stress parameters.

If, according to the SRT (Ulrich, 1983; Ulrich et al., 1991), mental well-being is connected to stress reduction, there can also be a connection to physiological stress parameters be expected. The physiological stress response is the product of the sympathetic adrenomedullary (SAM) system and the hypothalamic-pituitary-adrenocortical (HPA) system working together to achieve stability inside the body (Gunnar & Quevedo, 2007; Sheridan et al., 1994). The activation of these systems can be measured through markers like heart rate (HR, for the SAM system), cortisol levels (for the HPA system) or blood pressure (BP, for the cardiovascular system, Kondo et al. (2018)). Blood pressure during contraction (systolic) and relaxation (diastolic) of the heart is a reliable marker of the state of the cardiovascular system (Whelton & Carey, 2017). The heart rate (= heartbeats/minute) is not only an indicator of physical effort but also reacts to the secretion of different neurohormones (Kondo et al., 2018).

One crucial role in the physiological stress response is played by cortisol, a stress hormone, built and secreted by the adrenal gland, which supports emotion-appropriate behavior (Sheridan et al., 1994) and exhibits a specific diurnal secretion pattern (Hellhammer et al., 2009; Kirschbaum & Hellhammer, 1994). Salivary cortisol samples are a convenient and painless sample method for participants and have been used extensively as a stress biomarker in research settings (Inder et al., 2012; Kirschbaum & Hellhammer, 1994). They accurately reflect serum-free cortisol without the hassle of taking blood samples (Aardal-Eriksson et al., 1998; Aardal & Holm, 1995). Measurements of saliva cortisol levels, blood pressure, and heart rate are all non-invasive common measurement methods used in studies on health effects (see, for example, Li et al. (2021), Park et al. (2010), and Polk et al. (2005)).

Negative emotions and high-stress levels are generally associated with higher cortisol concentrations (Polk et al., 2005). Greener environments may offer better opportunities for coping with stress, as shown by the relationship to diurnal cortisol patterns by Ward Thompson et al. (2012). For example, Opdahl et al. (2021) were able to show in hikers that spending time in species-rich areas and areas with high perceived aesthetic values correlates with a reduction in salivary cortisol and improved well-being. It was also found that experiencing a forest environment promotes lower cortisol concentration, lower heart rate and lower blood pressure than an urban environment (Ideno et al., 2017; Park et al., 2010; Song et al., 2016). Generally, blood pressure and HR seem to be significantly lower in green environments than in urban environments (Kondo et al., 2018). That natural sounds lead to a greater sense of comfort and relaxation, with street sounds driving up the heart rate, was confirmed in the study by Li et al. (2021).

Bird diversity.

Earlier studies often showed a positive relationship between mental well-being and perceived biodiversity, meaning species richness, as in the study by Meng et al. (2024). Fisher et al. (2021) showed that locations that are perceived as biodiverse are also perceived as more restful, which in turn leads to improved well-being. Nghiem et al. (2021) found that perceived animal diversity contributes to perceived (psychological) restfulness.

Many studies on biodiversity and mental well-being were based on birds because they are easy to observe in nature (see, for example, but not exhaustively, Butler et al. (2010); Cameron et al. (2020); Celis-Diez et al. (2017); Dallimer et al. (2012); Marselle et al. (2019); Wheeler et al. (2015)). They can be viewed throughout the year and are mostly diurnal. Additionally, birds get the attention of humans through their coloration, movement, and song and are generally liked by lay people since they are easier to distinguish and observe in comparison to other taxonomic groups (Cox & Gaston, 2015).

While having more birds around and observing them generally contributes positively to mental well-being (Cox & Gaston, 2015; Fuller et al., 2007), the influence of actual bird species richness on human mental health remains inconclusive due to mixed evidence (Lovell et al., 2014). Some studies have shown positive associations with mental well-being (Huby et al., 2006; Methorst et al., 2021a), while others found no relationship (Cox et al., 2017b; Taylor et al., 2018). In the study by Douglas & Evans (2021), people reported greater enjoyment of high bird diversity, which was indicated by bird song, but not greater perceived restoration or attentional capacity.

The reasons behind this disparity are not entirely clear, suggesting a mismatch between the effects of actual biodiversity and perceived biodiversity.

Soundscapes.

Due to their song, birds are the main contributors to natural soundscapes in the Northern Hemisphere (Farina et al., 2011), and bird diversity is often perceived by humans in the form of bird song (Ferraro et al., 2020). Soundscapes are scenes of sound experienced by visitors. They integrate all sounds of a landscape – sounds produced by animals, water, vehicles and humans (Pijanowski et al., 2011a; Pijanowski et al., 2011b). Urban soundscapes are perceived as less relaxing than the soundscapes of a city park, while a rural soundscape is considered more relaxing (Payne, 2013). Listening to natural sounds also resulted in reduced anxiety, heart rate and blood pressure (Zhu et al., 2024). The pleasantness of the soundscape of birds seems to buffer the effects of traffic noise (Uebel et al., 2022). Levenhagen et al. (2020) found that in areas with lower anthropogenic noise pollution, the number of birds perceived by visitors is higher than in noisy areas. Park et al. (2010) [edit: Citation was not displayed correctly in original publication] found that park soundscapes with many different bird songs and minimal traffic noise offer the greatest perceived restoration (Uebel et al., 2021). But on the other hand, there was no significant difference in stress recovery between bird song, bird song and traffic noise, traffic noise treatments in a virtual reality setting (Hedblom et al., 2019). But still, in the study by Ratcliffe et al. (2013), bird songs and calls were found to be the natural sound most commonly associated with perceived stress recovery and attention restoration. Listening to bird song improved anxiety, and medium-sized birdsong soundscapes were related to reduced paranoia (Stobbe et al., 2022). This is why bird diversity and its perception are to be varied in this study using bird song.

Awareness.

This mismatch of positive effect between actual and perceived biodiversity could be due to differences in perception and awareness. Perception is the cognitive and sensory reception of impressions (Merikle et al., 2001), in our case of biodiversity. It corresponds to what people can see, hear or otherwise perceive, which does not necessarily need to happen consciously. The assessment of bird diversity by lay people, for example, is similar but not identical to actual bird diversity (Vanhöfen et al., 2022). Biologists fare better in this kind of task than lay people (Breitschopf & Bråthen, 2023). This is possibly due to the increased awareness of professionals. Awareness encompasses the conscious knowledge and understanding of a topic (Merikle et al., 2001). In the study by Breitschopf & Bråthen (2023), the appreciation of biodiversity correlated more strongly with perceived biodiversity than with actual biodiversity of plants. This suggests that people often value what they perceive as diverse, regardless of objective biodiversity. Therefore, active perception is the foundation on which awareness can be built. In our study, we define awareness to be, in contrast to perception, a conscious state of mind deeply processing the topic (Graziano & Kastner, 2011). It can therefore be trained/enhanced. It also plays a crucial role in its positive effects on mental well-being. Colléony et al. (2020), for example, used cues to enhance interaction with nature and positive affect. Mindfulness –another term used often in this context- leads to greater awareness and stronger connectedness with nature as well as less negative emotions (Nisbet et al., 2019).

Perception and awareness are therefore strongly linked to the nature experience of people. People receiving psychological benefits of being out in nature often also report a high connectedness to nature (Mayer et al., 2009). Nature experience is not limited to nature connectedness but has also been connected to appreciation (Wolsko & Lindberg, 2013), time spent in nature, and awareness (Breitschopf & Bråthen, 2023).

Since, to our knowledge, there are only a few studies connecting increased awareness with mental well-being, it is still not clear whether increased instructions that raise the awareness of bird diversity are useful to increase mental well-being. Or if an artificial increase in bird diversity is more/similarly helpful. Therefore, the goal of the present study was to establish an experimental relationship. The subjectively perceived well-being and objectively measured stress parameters of park users were connected to varying bird soundscapes of an area and verbal awareness cues. This short-term experiment in a controlled park-like environment is unique in that it combines psychological and physiological well-being as well as perception variables to test the effects of bird diversity on humans.

To see which factors influence mental well-being, physiological variables, and perception, we first looked at the effects of the unguided bird walk 1) on mental well-being and 2) on physiological stress markers. Secondly, we analyzed the question if enhanced bird sound during the walk influences 1) mental well-being, 2) physiological stress markers or 3) subjective nature experience. Lastly, we examined if raising awareness of bird song before the walk influences 1) mental well-being, 2) physiological stress markers or 3) subjective nature experience.

Material & methods

We developed a 2x2 experimental design with an additional negative control. Participants were randomly divided into these five experimental groups. For two groups, bird sound richness (species richness) was manipulated through the placement of speakers (Ferraro et al., 2020). Two groups were manipulated by raising awareness and asking participants to "please pay attention to the beautiful bird calls". The control groups were not subject to either form of manipulation. For an additional negative control, participants wore noise-cancelling headphones (Philips TAPH805).

Variables and parameters collected

The questionnaire included a total of 27 questions. Demographic variables were age in years, gender (male/female/diverse), and the highest level of education (graduation).

For an overview of the concepts and constructs used in the survey, their sources and respective Cronbach's α, please see Table 7.

Additionally, we asked for the **perceived bird species richness** on a categorical scale with nine categories (0–5; 6–10; 11–20; 21–30; 31–40; 41–50; 51–60; 61–70; over 70 species present; adapted after Ferraro et al. (2020) and Southon et al. (2018). **Perceived naturalness** (Schebella et al., 2019a) was asked for on a scale from 1 (unnatural) to 5 (very natural).

With perceived bird species richness, a subjective value is measured which can be related to the actual value recorded by the bird survey. **Bird species knowledge** (Randler & Heil, 2021), which indicates the extent to which birdwatching is a hobby and how actively it is practiced, was also surveyed. **Perception of birds** (Belaire et al., 2015) measures the role of birds in people's lives and can be considered an attitudinal variable.

Nature experience is adapted from Wyles et al. (2019), assessing the experience of nature ("taken time", "learned new things") together with nature connectedness ("felt close to nature").

Table 7.
Detailed Overview of the constructs and items used in the pre- and post-test survey. Participants were asked in German; we here provide a short English translation.

Concept	**Items (translated)**	**Source**	**Pre-test**	**Post-test**	**Cronbach's alpha**
Bird species knowledge	How many birds can you identify by Appearance? How many birds can you identify by Song? Ornithological skill self-report.	Lee & Scott (2004) Randler (2021a) Randler & Heil (2021)	x		0.724
Perception of birds (5-point Likert scale)	I like birds because they… Are beautiful. Have a nice song. Make me Feel Good	Belaire et al. (2015)	x		0.656
Nature experience (5-point Likert scale)	I have… Taken time to appreciate. Learned new things. Felt close to nature.	Wyles et al. (2019)		x	0.525
Satisfaction (5-point Likert scale)	How satisfied are you?	Arlinghaus (2006)		x	
Emotions (5-point Likert scale)	I feel… Calm and relaxed Peaceful Refreshed	White et al. (2013) Wyles et al. (2019)	x	x	Pretest: 0.646 Posttest: 0.674
Self-reported restoration (6 categories)	How recovered do you feel?	Young et al. (2020)		x	
Perceived restoration	This place is relaxing. This place is fascinating. This place is organized. This place is without restrictions. I can do what I want in this place.	Berto (2005), according to PRS by Korpela & Hartig (1996)		x	0.534

Outcome variables: mental well-being

Mental well-being as an outcome variable is measured in line with our previously conducted "Biodiversity and well-being" study (Vanhöfen et al., 2025a), again with questions on emotions, satisfaction, and restoration (self-reported / perceived). These scales are intended to show the extent to which the treatment influences positive feelings (emotions) and causes a situational recovery function (restoration). The satisfaction variable is intended to measure satisfaction with the visit.

Self-reported restoration after the visit was asked with one item, on a categorical scale with 6 categories ("significantly more recovered", "somewhat recovered", "about the same", "less recovered", "significantly less recovered", "cannot say"), adapted from Young et al. (2020). For better comparability between the scales in our study, we recoded the self-reported restoration scale into a 0 ("cannot say") to a 5 ("significantly more recovered") Likert scale, with 0 being considered as missing data.

Physiological Parameters: cortisol, blood pressure and heart rate

Additionally, participants' stress hormone cortisol, blood pressure and heart rate (HR) were measured. Blood pressure and HR are non-invasive common measurement methods used in studies on health effects (see, for example, Li et al. (2021); Park et al. (2010); Polk et al. (2005)). Salivary cortisol sampling was chosen as it has been shown to accurately represent circulating cortisol levels in the blood, allows for repeated measurements, is non-invasive and can be self-administered, presenting no harm to participants (Kirschbaum & Hellhammer, 1989).

Cortisol secretion follows a well-studied daily pattern, starting with a steep increase in secretion levels before awakening, followed by the so-called cortisol awakening response (CAR) period and a following decline of mean cortisol levels during the remainder of the day (Stalder et al., 2016; Veldhuis et al., 1989; Weitzman et al., 1971).

As we do not want to measure the cortisol awakening response, the saliva samples were taken after 09:00 at the earliest (Opdahl et al., 2021; Stalder et al., 2016) after a commute to the study site. It can be assumed that most, if not all, participants were already awake for at least an hour if not more, before arriving at the study site.

Salivettes© by Sarstedt (Sarstedt AG & Co. KG, Germany) were used according to instructions. Saliva samples were frozen and stored at −20 degrees Celsius until analysis. After thawing, samples were centrifuged at 3,000 rpm for 5 min, which resulted in a clear supernatant of low viscosity. Salivary cortisol concentrations were measured using commercially available chemiluminescence immunoassays with high sensitivity (Tecan − IBL International, Hamburg, Germany; catalogue number R62111). The intra- and interassay coefficients of variance were below 9 %.

Blood pressure and HR were recorded using the BM27 blood pressure monitor from Breuer GmbH (Germany), which measures both parameters simultaneously.

Bird species richness and environmental variables

Current bird species richness was assessed by recording bird songs and calls for 15 min every morning during the study period using four Song Meter Mini devices (Wildlife Acoustics Inc., MA – USA) along the way (passive auditory monitoring, PAM). Ornithologists listened to the audio recordings and identified the number of bird species for every study day in the respective **daily bird count** (Table 26 in the appendix). The total bird count over all days was 36 species.

To enhance the natural bird sound richness, we additionally played bird sounds via loudspeakers. These speakers (Boom 3, Portable Bluetooth speaker, Ultimate Ears − Logitech, USA) were placed along the path in the park at a roughly even distribution with a 200–250 m distance between them. They were connected via cable to multimedia players (either Digital Music Player A2G, AGPTEK, China or PMP 30 8 GB Multimedia Portable Player, ECG, China), playing one bird song per speaker. The selection of additional bird species for playback was done due to their ranking in the study "Beauty of Birds in Song and Image" (Lukanowski, 2023). We chose bird species that were ranked highest in the perception of human listeners. Additionally, we also only used bird species that were not present in the area to not disturb possible territories and or breeding pairs (Dallimer et al., 2012; Kleist et al., 2016; Lindemann-Matthies, 2017; Lindemann-Matthies & Matthies, 2018), using our recordings and the local eBird hotspot checklists (ebird.org/hotspot/L14078036). Following this selection process, the following seven species were selected for playback: Tree pipit (*Anthus trivialis*), Common linnet (*Carduelis cannabina*), Garden Warbler (*Sylvia borin*), Common cuckoo (*Cuculus canorus*), Mistle thrush (*Turdus viscivorus*), Common nightingale (*Luscinia megarhynchos*), and Eurasian golden oriole (*Oriolus oriolus*).

The weather was nice and fair on all days without any rain and winds lower than 1 Bft (< 5 km/h). We also recorded daily **temperature** at the start and the end of the study day and used the mean to control for temperature. A Sound Level Meter (PeakTech© 8005, PeakTech GmbH, Germany) was used to record the **mean sound level** in dB over 2 min and the maximum and minimum sound levels in the middle of the study period of a day.

Bird-walk procedure and location

Data was collected from May to June of 2023, on 11 days. Participants walked through a controlled park environment – the arboretum of the Eberhard Karls University Tübingen's botanical gardens, in Baden-Württemberg, Germany (Figure 9).

The study was approved by the management of the botanical gardens and the ethics commission of the Eberhard Karls University Tübingen (AZ.: A2.5.4-279_bi).

Participants were recruited via a university mailing list, the local newspaper, and the newsletter for "Friends of the Botanical Gardens" and were compensated either with a bird identification book (Dierschke, 2020) or a textbook about animal behavior (Randler, 2018).

Participants received an anonymous code after arriving at the study site. They then completed the first survey on their current emotions and behavior. Immediately afterwards, saliva for cortisol analysis was collected for the first time using Salivettes© (blue cap, SARSTEDT AG & Co.KG, Germany). Blood pressure and heart rate were measured using a medical blood pressure monitoring device (BM27, Beurer GmbH, Germany). Then they went on a roughly 30-minute-long, unguided, free-roaming walk through the study site following the paths. This duration is sufficient to measure changes in cortisol levels and to reap the benefits of being in nature (Nghiem et al., 2021; Nisbet et al., 2019; Park et al., 2010; White et al., 2019). Due to the size of the study area and the minimum duration of the walk, participants had plenty of time to be exposed to the bird song, either natural or enhanced.

After the walk, participants' saliva was collected again, and the measurements of blood pressure and heart rate were repeated. They also completed the second survey on their current emotions and behavior.

Figure 9.
Pictures of the study area, the arboretum of the botanical gardens of the Eberhard Karls University Tübingen (c. JV).

Statistical analysis

The program SPSS (IBM Statistics, Version 29.0.1.1) was used for all statistical analyses. We first looked at the effects of the walk itself. For this, a paired sample *t*-test was conducted, comparing pre- and post-walk measurements in salivary cortisol, diastolic and systolic blood pressure, HR and Emotions over all experimental groups.

To see the effects of the experimental manipulation, we did an ANOVA to compare the experimental groups with each other. The significant results were further analyzed with a Tukey's HSD post hoc test.

A collinearity diagnostic of the four well-being outcome variables showed low collinearity (variance inflation factor, VIF < 1.7). The following Exploratory Factor analysis (EFA) with additional Principal Component Analysis (PCA) indicated the well-being outcome variables emotions posttest, satisfaction, self-reported restoration and perceived restoration to load strongly on one factor. To reduce the items to dimensions and to avoid inflating statistical testing, we summarize their regression scores (z-scores) into the variable mental well-being. With the regression scores as a dependent variable, a univariate general linear model was computed. Tukey's HSD post hoc tests were used afterwards to differentiate the effects on the single well-being items. This allowed us to check whether measurements possibly only affect restoration, satisfaction or emotions of participants.

To examine the effects on the physiological stress parameters, a multivariate GLM with dependent variables being the four physiological outcome parameters was carried out.

An EFA with PCA was also done for the three perception variables perceived naturalness, perceived species richness and nature experience. According to this analysis, perception was divided into two factors: perception of nature (composed of perceived naturalness and Nature experience) and perceived bird species richness. The following multivariate model was computed with the regression scores (z-scores) of both.

Results

A total of 233 people participated in this study. Most were female (65.7 %), roughly one-third were male (32.6 %), and 1.7 % answered diverse. The age ranged from 18 to 75 with a mean age of 31.49 ± 13.48 (SD). More than half of the participants reported having a university degree (53.9 % with and 46.1 % without). For the descriptive statistics of the variables, see Table 26 in the appendix. Table 8 shows the setup of the experimental groups, in addition to the number of participants belonging to them.

Table 8.
Set-up of the experimental groups used in this study. Presented here is the 2 x 2 factorial design and the additional negative control group, excluding audio signals from the environment.

	No cues	Raised awareness	Noise-cancelling headphones
Natural bird sounds	Control (C, N = 48)	Group 1 (G1, N = 47)	Negative Control (NC, N = 34)
Enhanced bird sounds	Group 2 (G2, N = 52)	Group 3 (G3, N = 42)	

Influence of the bird walk on mental well-being and physiological stress markers

Mental well-being

After the walk, emotions increased significantly from 3.58 ± 0.71 to 4.4 ± 0.52 (paired sample *t*-test $t = -21.33$, $df = 225$, $p < 0.001$). Therefore, participants generally felt more refreshed, calm, and peaceful after the walk.

Physiological stress markers

All physiological parameters decreased after the walk, meaning the bird walk had a generally positive effect on the participant's stress markers, cortisol, blood pressure and heart rate. The salivary cortisol concentration decreased by 32.8 % from 10.15 ± 6.50 nmol/L to 6.82 ± 4.71 nmol/L (paired sample *t*-test $t = 14.33$, $df = 231$, $p < 0.001$).

The mean diastolic blood pressure decreased significantly by 1.5 % from 83.11 ± 9.91 mmHg to 81.90 ± 9.10 mmHg (paired sample *t*-test $t = 2.27$, $df = 232$, $p = 0.024$). The systolic blood pressure also decreased by 0.91 % from 128.76 ± 16.22 mmHg to 127.53 ± 16.34 mmHg, which is a non-significant difference from pre-walk levels (paired sample *t*-test $t = 1.35$, $df = 232$, $p = 0.178$).

The heart rate decreased significantly by 2.6 % from 76.85 ± 12.47 bpm to 74.82 ± 12.78 bpm (paired sample *t*-test $t = 4.16$, $df = 232$, $p < 0.001$).

The effect of increased bird song during a bird walk on mental well-being, physiological stress markers and subjective nature experience

Mental well-being

According to ANOVA, there was no difference in mental well-being due to enhanced bird song (groups G2 and G3, Table 9).

Physiological stress markers

The ANOVA also showed no difference in physiological stress markers due to enhanced bird song (G2 and G3, Table 9).

Subjective nature experience

Looking at differences between the 5 experimental groups, there was a significant difference only in nature experience, daily bird count, sound level mean, and temperature (all $p < 0.005$, see Table 9). A Tukey's HSD post hoc test showed a significant difference between G1 (raised awareness, normal bird sounds) and Control

(C; $p = 0.001$) as well as G1 and negative Control (NC; $p = 0.031$) regarding situational nature experience. G1 had a more positive situational experience of nature than the two control groups. Due to the significant difference between experimental groups in daily bird count, sound level mean, and temperature, these variables were controlled for in the following GLMs.

The effect of raised awareness of bird song on mental well-being, physiological stress markers and subjective nature experience

Mental well-being

According to ANOVA, there was no difference in mental well-being due to raised awareness of bird song (G1 and G3, Table 9).

Physiological stress markers

According to ANOVA, there was no difference in mental well-being or physiological stress markers due to raised awareness (G1 and G3, Table 9).

The Multivariate GLM with dependent variables being the four physiological outcome parameters (Table 27 in the appendix) showed that gender was among the most impactful factors on the physiological parameters in the model (systole: $Eta^2 = 0.094$, diastole: $Eta^2 = 0.049$, HR: $Eta^2 = 0.039$). Additionally, perceived bird species richness had an impact on the HR posttest ($Eta^2 = 0.034$), as well as situational nature experience ($Eta^2 = 0.030$). A high perceived bird species richness led to a lower HR. In contrast, a high nature experience led to a high HR.

Table 9.
ANOVA for differences between experimental groups. Significant results are written in bold.

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Environmental control variables					
Daily bird count	**61.280**	**4**	**15.320**	**3.608**	**0.007**
Temperature	**454.185**	**4**	**113.546**	**13.102**	**0<.001**
Sound level mean	**995.277**	**4**	**248.819**	**13.150**	**0<.001**
Demographics					
Age	2.056	4	0.514	0.903	0.463
Gender	0.448	4	0.112	0.445	0.776
Graduation	0.704	4	0.176	0.702	0.591
Individual predictors (trait)					
Bird species knowledge	0.448	4	0.112	0.277	0.892
Perception of birds	1.471	4	0.368	0.812	0.518
Emotions pretest	4.520	4	1.130	2.269	0.063
Individual perception of nature (situational)					
Perceived bird species richness	5.741	4	1.435	0.772	0.544
Perceived naturalness	3.322	4	0.831	1.145	0.336
Nature experience	**6.034**	**4**	**1.508**	**4.160**	**0.003**
Mental well-being					
Satisfaction	1.386	4	0.347	0.865	0.486
Emotions posttest	1.553	4	0.388	1.446	0.220
Perceived restoration	1.224	4	0.306	1.056	0.379
Self-reported restoration	0.769	4	0.192	0.387	0.818
Physiological parameters					
Cortisol posttest	66.567	4	16.642	0.748	0.560
Systole posttest	978.496	4	244.624	0.914	0.456
Diastole posttest	169.683	4	42.421	0.508	0.730
HR posttetst	879.825	4	219.956	1.355	0.250

Situational nature experience

Nature experience was the most important factor for mental well-being ($Eta^2 = 0.274$, Table 10). According to Tukey's HSD post hoc test, participants reporting a higher nature experience were more satisfied. ($p < 0.001$). Additionally, participants reporting a higher nature experience also reported higher emotions post-test ($p < 0.001$) and higher perceived restoration ($p = 0.001$).

Perceived naturalness also positively affected the mental well-being of participants in the model ($Eta^2 = 0.033$). People reporting higher perceived naturalness values perceived their restoration as higher after the walk ($p = 0.001$ and $p = 0.034$).

Perception of nature itself was only influenced by the perception of birds (GLM, $F = 17.741$, $df = 1$, $p < 0.001$, partial $Eta^2 = 0.088$). Participants with a positive perception of birds had a higher nature experience than participants with a lower perception of birds. Perceived bird species richness did not influence mental well-being, nor was it influenced by any of our measured parameters (Table 28 in the Appendix). See also Figure 10 for a visualization of the positive relationship between perceived naturalness, nature experience, and perceived bird species richness with mental well-being.

Table 10.
GLM with the dependent variable being the summarized z-scores of satisfaction, emotions posttest, recalled restoration and perceived restoration as one factor called "mental well-being". a. R Squared = 0.443 (Adjusted R Squared = 0.390).

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	90.612[a]	17	5.330	8.498	0<.001	0.443
Intercept	17.165	1	17.165	27.368	0<.001	0.131
Demographics						
Age Group	0.775	2	0.388	0.618	0.540	0.007
Graduation	1.652	1	1.652	2.634	0.106	0.014
Gender	0.798	2	0.399	0.636	0.530	0.007
Group	3.693	4	0.923	1.472	0.212	0.031
Individual predictors of mental well-being						
Perceived bird species richness	0.004	1	0.004	0.007	0.935	0.000
Perceived naturalness	**3.838**	**1**	**3.838**	**6.119**	**0.014**	**0.033**
Nature experience	**43.120**	**1**	**43.120**	**68.751**	**0<.001**	**0.274**
Bird species knowledge	0.762	1	0.762	1.215	0.272	0.007
Perception of birds	1.135	1	1.135	1.809	0.180	0.010
Environmental control variables						
Daily bird count	0.455	1	0.455	0.725	0.396	0.004
Temperature	**3.384**	**1**	**3.384**	**5.396**	**0.021**	**0.029**
Sound level mean	2.417	1	2.417	3.854	0.051	0.021

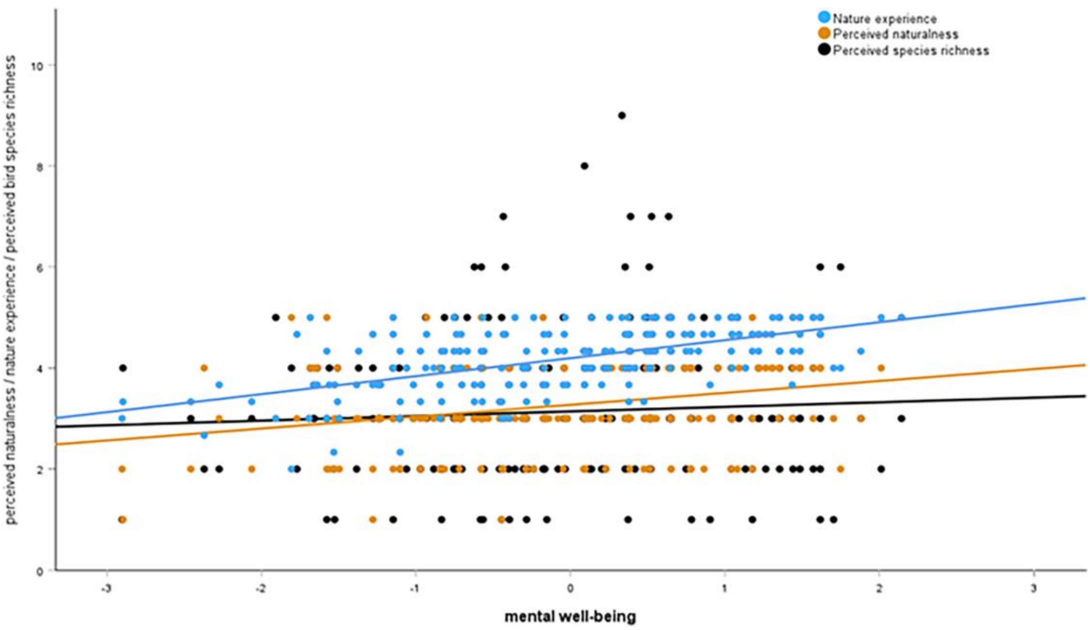


Figure 10.
The positive relationship between mental well-being (z-scores of satisfaction, emotions posttest, self-reported restoration and perceived restoration) with perceived bird species richness in black (R2 linear 0.004), nature experience* in light blue (R2 linear 0.336), and perceived naturalness* in orange (R2 linear 076). Stars indicate a significant relationship.

Discussion

The present study aimed to establish an experimental relationship between different bird soundscapes of an area, the subjectively perceived well-being of visitors to the area and objectively measured physiological variables.

Physiological stress markers

Independent of treatment, the walk itself had positive effects on the mental well-being of participants and led to reduced salivary cortisol levels as well as the heart rate of participants. Still, the effects on physiological parameters need to be discussed more closely.

Cortisol

The reduced salivary cortisol levels after the walk are suggestive but not definitive evidence of a reduced stress level. The CAR leads to a slow decrease of salivary cortisol levels over time (Stalder et al., 2016). Polk et al. (2005) established a slope for the decrease of salivary cortisol following the CAR as −0.11 (women) and −0.09 (men). Since the measured reduction in salivary cortisol in our study equals a slope of −0.52, it was stronger than expected for a normal CAR. Therefore, we can assume that the 30-minute nature walk of the present study generally has a cortisol-reducing effect, independent of treatment groups and independent of the CAR. Park et al. (2010) found that forest environments in Japan promote lower cortisol concentrations, lower heart rate and lower blood pressure than city environments. Instead, our study site is on the city's outskirts and in its park-like nature, not comparable with a forest treatment. But it can be argued that our park study site is closer to reality for most people in urban areas than leaving the city for a long forest stay. Even though in earlier studies positive affect was associated with lower cortisol concentrations and a negative affect with higher concentrations (Polk et al., 2005), a lot of additional variables, such as adrenal sensitivity, capacity, cortisol binding, etc. affect salivary cortisol levels and therefore perceived stress can only be moderately associated with salivary cortisol (Hellhammer et al., 2009).

Heart rate

The walk in the green park-like structure decreased the HR, which is indicative of lower stress levels. HR means of the study (Table 26) were generally in the normal adult resting heart rate range (Avram et al., 2019; Mason et al., 2007). The HR decreased in the post-test measurements, even though participants had just completed the physical activity of walking through a park. The park, being a green environment, makes this consistent with results found by the *meta*-analysis by Kondo et al. (2018), which found that green environments in differing countries significantly promote a lower heart rate than control environments.

Blood pressure

BP is showing only a little decrease after the walk, which is possibly indicative of a stress-reducing environment, but there is no definite evidence. Blood pressure means were also perfectly within the normal range (Lüscher, 2018; Williams et al., 2018) and decreased by a few percentage points after the physical activity of walking. Even though HR and BP seem to provide the most convincing evidence of stress-reducing properties in some earlier studies (Coventry et al., 2021; Kondo et al., 2018), they also found no association of nature-based interventions, like walking in green spaces, with lowering blood pressure.

The physiological stress parameters of blood pressure, heart rate and salivary cortisol levels were not affected by the treatments of enhanced bird song or raised awareness of bird song. The meta-analysis of Kondo et al. (2018) also found very inconsistent results regarding the connection between self-report stress measures and physiological stress measures, with most studies reporting differing results.

Nevertheless, the heart rate was influenced by nature experience and perceived species richness in the present study. Higher perceived bird species richness leads to lower HR, while higher nature experience leads to higher HR. It could be argued that this is due to green – and often biodiverse − environments being able to lower heart rate (Kondo et al., 2018) and that a certain amount of nature experience could have led to more excitement and therefore to a higher heart rate.

The general effect of a bird walk on mental well-being

People felt more refreshed, calm and peaceful after spending time walking in the green park-like environment which is in line with earlier studies reporting that participants who walked outdoors showed substantially better moods than those who walked indoors (Nisbet et al., 2019). Additionally, recreational walking in outdoor green spaces is not only an important part of physical health (Sugiyama et al., 2008) but is also associated with better mental well-being (White et al., 2013), as reinforced by our results.

The effect of increased bird song during a bird walk on mental well-being, and subjective nature experience

Enhanced bird song did not influence mental well-being or perception of the area as biodiverse or natural, possibly due to traffic noise. Since there is no difference in perceived species richness between groups, participants do not even seem to notice our manipulation of increased bird song. This was also the case in earlier studies with increased biodiversity in France (Shwartz et al., 2014). Since people in recreational areas seem to generally be able to roughly estimate present bird diversity in German recreational areas (Vanhöfen et al., 2022), they do not seem to base their judgment on birdsong. Still, the manipulation of bird song was relatively large in our study. Compared to an average number of 17 ± 2 bird species per day, we increased the soundscape by 41.18 %. Therefore, we consider this manipulation to be substantial, but it still may have been too small to be noticed by the participants. Or there was too much street noise, masking the bird song. The study area is a park-like structure of the botanical gardens, situated right next to the northern ring road of the city. The soundscape is possibly masked more strongly by street noise than expected, even though the sound level ranges are normal (Table 26 in the appendix). Noise pollution can negatively affect the physical and mental well-being and health of people (Gramann, 1999) by causing both physical and psychological stress (Ouis, 2001). Since the walk had a generally positive effect on people, the noise was not detrimental to participants mental well-being but could have masked the impact of the enhanced bird song treatment, since traffic noise is also related to higher depression (Stobbe et al., 2022). Therefore, the noise/soundscape perception of the area would need to be studied further for future follow-up studies. In the study by Ferraro et al. (2020), additional bird songs of 12 species also led to inconsistent results. In their study, depending on the trail (located in Colorado, USA), additional bird song increased perceived bird species diversity or not. Still, exposure to birdsong improved hikers' perceived psychological restoration, just as in our study.

Li et al. (2021) found in a meditation study that the natural sounds of the forest can make people relax physically and psychologically. The walk generally influenced participants in our study positively, but independent of additional bird songs. Even the control group with noise-cancelling headphones did not differ from the other groups. But, independent of treatment groups, a lower sound level was beneficial to the mental well-being of our participants (Table 10). People have expectations of how a location will sound, depending on their prior experience, and therefore, they expect certain types of sound to be present in a particular space (Bruce & Davies, 2014).

The effect of raised awareness of bird song on mental well-being and subjective nature experience

Raised awareness led to a better nature experience of participants and more positive emotions after the walk, indicating the perception of an important part of restorative benefits. The restorative benefits that people can derive from the experience of nature depend on how people interact with and treat nature (Colléony et al., 2020). In earlier intervention studies in Canada, participants asked to pay attention to their natural surroundings reported positive emotions and a general sense of connectedness to nature (Passmore & Holder, 2017; Passmore et al., 2022), compared with participants who did not receive instructions. Additionally, environment-oriented activities like walking can increase the perception of an area's restorative properties (Carrus et al., 2015). In the study by Nisbet et al. (2019), mindfulness led to greater awareness and stronger feelings of connectedness with nature. In our study, the raised awareness of the surrounding environment did not influence mental well-being, but it did influence the nature experience of participants: the group listening to normal bird song while being asked to pay attention reported a significantly higher nature experience than the control groups. Participants asked to pay attention not only had a better nature experience but also presented with more positive emotions after the walk. People seem to value what they perceive as diverse, independent of actual species richness (Breitschopf & Bråthen, 2023). But in our study, people did not realize the increased bird song as increased species richness. The positive effect is maybe due to a feeling of stronger nature connectedness (Nisbet et al., 2019), since people receiving psychological benefits of being outside also often report a higher connectedness to nature (Mayer et al., 2009).

The connection between situational nature experience and mental well-being

Biodiversity and being outside generally positively influence well-being. People in the UK seem to be generally happier when they are in nature, compared to when they are in a human-built environment (MacKerron & Mourato, 2013). In the present study, the perceived naturalness of the area and nature experience have significant positive effects on mental well-being, as well as the temperature. People perceiving the area as more natural also reported higher mental well-being. Perceived naturalness has been positively correlated with plant richness and flower cover in earlier studies in the Austrian and Swiss Alps (Hussain et al., 2019). The study area is a park-like structure of the botanical gardens of a big German university. It is very rich in a range of different plants but has its focus on the tree and shrub collection. It is therefore a highly managed environment. Naturalness perception in urban green spaces as managed environments has been connected to maintenance of facilities, vegetation structure and subjective estimations of biodiversity level (Felappi et al., 2024).

Additionally, people reporting a higher nature experience also had a higher mental well-being after the nature walk. Nature experience has been connected to raised awareness as well. It seems to be the most important factor for increased mental well-being. Participants reporting a higher nature experience are more satisfied after the bird walk. They also report higher emotions post-test and higher perceived restoration. In a recent study by Felappi et al. (2024), the naturalness perception and safety of an area affected the perceived restorativeness of a park visit.

Ward Thompson et al. (2012) found in the UK that people's perceived stress levels increased as the amount of green space in their local urban environment decreased. In earlier studies, high levels of biodiversity benefited the well-being and perceived restorativeness of an area (Carrus et al., 2015). Additionally, (Meng et al., 2024) found that nature-relatedness mediated the relationship between perceived biodiversity and mental well-being.

Additionally, higher temperatures had a positive impact on participants' mental well-being (Table 10). The study period, being in spring and early summer, led to a temperature range from 9 – 19 °C. Pleasant weather in spring is generally related to better mood (Keller et al., 2005).

As discussed above, perception of an area seems to be an important part of well-being and nature experience. Therefore, the question arises of how perception itself is influenced. In our study, participants perceive the area as more natural if their perception of birds is high, which could speak for a high mental affinity to nature. They also have a more positive nature experience. Interestingly, perceived species richness is not affected at all by our manipulation or any measured parameters.

In earlier studies, participants reporting positive perceptions of the environment and engagement with it experienced more positive effects (Farris et al., 2024). In the same online experiment by Farris et al. (2024), increasing the levels of bird diversity through birdsong in a video of a UK woodland location had no additional significant effect on the affective response of participants. We affirm in vivo that greater bird diversity by additional birdsong does not affect mental well-being, nor on perception. Perceived quality seems to have more positive effects than objective quantity (Flowers et al., 2016). This is similar to earlier studies, in which people showed a preference for high levels of biodiversity, but were not able to distinguish them (Shwartz et al., 2014).

Limitations

Even though our study is one of few examining the relationship between soundscapes and physiological stress parameters in the field and in addition to mental well-being parameters (Buxton et al., 2021), there are some limitations to note. Most earlier studies have been done in the laboratory, but for nature conservation implications, we see the analysis of benefits to being outside as most important. Most of the limitations are due to the nature of the study being carried out in the field.

First, to assess possible effects on cortisol levels, other studies looked at the daily rhythm (Polk et al., 2005). In our short intervention study, it has not been possible to analyze all-day levels of cortisol due to time constraints. But this could be an interesting aspect of future larger-scale interventions. Another problem regarding the salivary cortisol sampling that future studies should keep in mind is that participants were not told to avoid coffee or drinking in the morning before the study. Still, most people had at least a 20–30-minute journey to the study location, buffering the worst confounding effects. Only one extreme outlier of cortisol (in the pretest sample, a humanly impossible value) had to be taken out of the analysis.

Additionally, future studies would need to define the walking path to control for participants to hear the treatment. The study location is a small urban park; therefore, we can assume that most, if not all, people received the treatment as intended. But for future studies, being able to control this would be better.

Another limitation is the masking of our treatment by traffic noise. If the focus of future studies is on the effect of additional bird song, they should make sure the bird song can be heard and not masked by other factors. In our case, city dwellers often do not have the choice not to hear traffic noise. Therefore, we see our study location as a real-world example in which additional bird song is not helping in enhancing mental well-being or reducing physiological stress parameters. On the other hand, increasing awareness of bird song is helping in these circumstances. Therefore, future studies should look at possible awareness increases and their effect on mental well-being in urban parks.

Conclusion

A walk in a nature-like recreational park benefits both, psychological and physiological well-being of people. The mental well-being of people was primarily influenced by their nature experience, which in turn is influenced by increased awareness of the environment. Asking people to pay attention can help with this.

But playing additional birds' song as playback did not enhance neither mental well-being nor nature experience. The manipulation of birdsong also had no effect on the perceived bird species richness in the area, therefore, participants most likely did not register it. But since perceived bird species richness had no impact on mental well-being or physiological parameters, an artificial increase of bird song is probably unnecessary anyway. It is more important to increase to possibility for a nature experience. We were able to show that asking people to pay attention to their surroundings can help tremendously with that. This is an important piece of knowledge for the structuring of restorative park facilities in cities. Additionally, raising awareness and enabling possibility for nature experiences could help for raising approval for nature conservation goals in public and officials.

Manuscript 4

Two treatments of birdsong awareness and their influence on human mental well-being in an urban park environment.

Vanhöfen, Janina; Härtel, Talia; Teufel, Louisa; Schaffer, Laura & Christoph Randler (2026). Two treatments of birdsong awareness and their influence on human mental well-being in an urban park environment. *Journal of Urban Ecology*, *12*(1), juag013.

Abstract

Going outside for a bird or nature walk has a positive impact on people's well-being. In a quasi-experimental setting, we compared verbal and visual guidance related to birdsong regarding their effects on mental well-being, physiological stress parameters, and the subjective experience of nature. A total of 47 people participated in a study conducted in the controlled environment of an arboretum within a botanical garden. We applied two interventions in a pre-post design: 20 participants received a verbal awareness treatment, and 27 received a visual awareness treatment. Data were collected over 7 days from May to June 2024. Situational mental well-being was measured using psychometrically validated questionnaire scales. In addition to mental well-being, physiological stress parameters, including heart rate, blood pressure, and salivary cortisol levels, were also measured. At the experimental level, the statistical models indicate that the walk had a positive influence on mental well-being and reduced physiological stress parameters. Furthermore, the group receiving visual awareness treatment reported a higher perceived restorativeness of the ambient sound and a more acute perception of birdsong. On the individual level, participants with better bird species knowledge and nature experience expressed improved mental well-being. Participants who scored higher on the subjective trait variable 'perception of birds' reported improved mental well-being and an enhanced perception of biodiversity after the walk. The study provides evidence for the influence of personal or individual traits on mental well-being, in addition to the general effects of the intervention.

Keywords: nature experience, mental well-being, nature awareness, attention intervention, urban recreational area

Introduction

As the global population increases, so does urbanization. More people live in urban areas than in rural areas, namely 55% in 2018 (United Nations, 2019). By 2050, ~ 68% of the world's population is expected to live in urban areas (Montgomery, 2007; United Nations, 2019). According to the United Nations (2019), 74% of Europeans lived in urban areas in 2018. Therefore, cities are increasingly becoming the primary living environments for many people. Their ecological infrastructure mostly consists of parks, gardens, open spaces, and water catchment areas, including their respective ecosystems and biodiversity (Elmqvist et al., 2013).

Urban green spaces, such as parks or gardens, provide valuable ecosystem services and benefit human health since they can help mitigate the negative impacts of air, noise, and heat pollution (Sarkar et al., 2018). Urban green spaces are not only associated with benefits for people's physical health (de Brito et al., 2019) but also their mental well-being (Jimenez et al., 2021). Additionally, they have increasingly been associated not only with improved mental well-being in general (White et al., 2013) but also with lower stress levels, depression, and anxiety (Aerts et al., 2018; Beyer et al., 2014). A walk in the park, for example, can build and restore mental capacities by promoting physical activity (Marselle et al., 2021a) and allowing for recovery from attentional fatigue (Kaplan, 1995), since walking in natural environments is associated with stronger restorative effects than walking in residential environments (Gidlow et al., 2016).

Negative emotions and high stress levels are generally associated with higher cortisol concentrations (Polk et al., 2005). Hartig et al. (2003) found a decrease in blood pressure and a greater stress reduction in people exposed to natural settings. Forest environments are also associated with lower cortisol levels, heart rate, and blood pressure than urban environments (Park et al., 2010). Opdahl et al. (2021) demonstrated that hikers spending time in species-rich areas and areas with high perceived aesthetic values respond with a reduction in salivary cortisol and improved well-being. This effect persists even when controlling for physical activity, such as walking in the gym and viewing nature on TV (Olafsdottir et al., 2020).

The composition of urban green spaces influences their ability to support mental well-being, as high levels of biodiversity likely enhance psychophysiological stress recovery (Ulrich, 1983; Ulrich et al., 1991) and are generally related to better mental well-being (Marselle et al., 2019; Randler et al., 2023a) and greater happiness (Cameron et al., 2020). However, an individual's perception of nature and biodiversity may also play a crucial role in its positive effects on mental well-being. Earlier studies showed a strong positive relationship between the mental well-being of people and the perceived biodiversity of an area. For example, Fisher et al. (2021) showed that locations that are perceived as biodiverse are also perceived as more restful, which in turn leads to improved well-being. Nghiem et al. (2021) found that a high level of perceived animal diversity contributes to the perceived (psychological) restfulness of the area. Additionally, perceived naturalness and perceived bird diversity were also positively associated with the mental well-being of people in recreational areas (Vanhöfen et al., 2025a). In general, perceived biodiversity was consistently positively associated with well-being, be it physical or mental.

Birds in particular are well perceived by humans due to their coloration, movement, and song (Woods, 1998) and can be observed and experienced, both consciously and unconsciously, throughout the year, mostly during the day. As a taxonomic group, birds are generally well-liked since they are relatively easy to identify and observe, even for laypeople (Cox & Gaston, 2015). Bird song contributes an immense part of the natural soundscape in urban parks, especially during spring (Whelan et al., 2015). Therefore, their songs are the main way people perceive birds, either consciously or subconsciously. Bird sounds have also been suggested as the natural sound most associated with stress recovery and attention restoration (Ratcliffe et al., 2013), enhancing the perceived pleasantness of an area's soundscape (Coensel et al., 2011). Pleasant soundscapes, in turn, are positively associated with psychological well-being (Erfanian et al., 2021).

Paying attention to one's surroundings leads to greater awareness and stronger connectedness with nature as well as less prevalent negative emotions (Nisbet et al., 2019). Still, the role of awareness and perception of an area on subjective mental well-being is unclear. Awareness could additionally be enhanced by different cues, for directed attention and therefore deeper interaction with nature and a following positive affect (Colléony et al., 2020). However, the effectiveness of such awareness cues remains unclear. When tasked with paying attention to and photographing nature, people experienced increased individual well-being and a heightened sense of connectedness to nature when compared to human-built conditions (Passmore & Holder, 2017). Given the demonstrated positive effect of directing attention toward nature (Vanhöfen et al., 2025b), the question remains how this can be done most effectively. How do different cues for raising awareness affect mental well-being? Is there a difference between verbal guidance or is a visual approach more effective? Also, the role of awareness on stress reduction measured by physiological parameters is still unclear. This is because most earlier studies used actual biodiversity or general nature settings. In this study, we additionally link physiological parameters to the effectiveness of attention-enhancing interventions.

As described, walking in nature and/or listening to bird song can promote psychological restoration, but the factors influencing this effect are still unclear. Equally, the impact of awareness of one's surroundings in connection with bird song and mental well-being remains unclear.

To address this gap, the following research questions are to be answered:

1) To what extent do variations in individuals' subjective experiences of nature and personal traits influence their mental well-being?
2) Does increased awareness of natural bird song, triggered by verbal cues or signage, impact participants' mental well-being, experience of nature, or physiological stress levels?

Material & Methods

The research was conducted as a field-based experimental study, using quantitative survey methods. Forty-seven participants took part in the study, aged between 19 and 80 years old ($M = 37.77 \pm 16.7$). Of these, 59.6% identified as female and 40.4% as male, 72.3% reported a university degree, and 27.7% reported no university degree. Subjective mental well-being was assessed using quantitative questionnaires. Physiological well-being was assessed via stress parameters including heart rate, blood pressure and salivary cortisol levels. This study received ethical approval by the ethics committee of the Faculty of Social Sciences and Economics of the University of Tübingen (Ref.: A2.5.4-279.1_hb).

Procedure and location

The study took place in the arboretum of the University of Tübingen's Botanical Garden (Figure 11) and was carried out over seven days in May-June 2024. The survey took place in the morning, as natural birdsong is most pronounced at this time of day.

The participants were recruited via an internal university mailing list. To ensure anonymity, each participant received a wristband with a random number. This number was noted both on the questionnaires and when taking samples for cortisol, blood pressure and heart rate. As compensation for participation, each participant received a bird identification guide (Dierschke, 2020). After data collection was completed, participants received the debriefing via e-mail.

Both subjective and objective parameters of well-being were assessed using a pre-post design before and after a walk through the park-like Arboretum.

Figure 11.
Picture of the study area, the Arboretum of the Botanical Gardens of the University of Tübingen, Germany (c. J. Vanhöfen).

Physiological stress parameters

The deactivation of the body's stress response system can be measured using markers such as heart rate, salivary cortisol levels, or blood pressure (Kondo et al., 2018), which are also indicative of stress reduction (Kaplan & Kaplan, 1989; Kaplan, 1995; Ulrich, 1983; Ulrich et al., 1991). Salivary cortisol as a stress hormone (Sheridan et al., 1994) can be collected using a convenient, non-invasive, and painless sample method (Hellhammer et al., 2009), which has been extensively used as a stress biomarker in research settings (Inder et al., 2012).

Blood pressure, measured during the heart's contraction (systolic) and relaxation (diastolic), is a reliable marker of the state of the cardiovascular system (Whelton & Carey, 2017). The number of heartbeats per minute not only indicates physical effort but also reflects the response to the neurohormonal activity (Kondo et al., 2018). Both indicators can be easily measured in a non-invasive way and are frequently used in assessing stress or recovery.

The participants' *blood pressure* (BP, in mmHg) and *heart rate* (HR, in beats per minute) were measured using an upper-arm blood pressure monitor (BM27, Beurer GmbH, Germany). To measure the stress hormone *cortisol* in saliva (in ng/ml), a Salivette® (Blue cap, Sarstedt AG & Co. KG, Germany) was used according to the manufacturer's instructions, then stored frozen until analysis (LabService GmbH, Dresden, Germany). Intra- and inter-assay coefficients of variation were <5%.

Awareness treatment groups

The participants were randomly assigned to two groups, a *verbal group* (N = 20) and a *visual group* (N = 27). The verbal group received a simple instruction before the walk ("*Pay attention to the beautiful birdsong during the walk*"). In contrast, the visual group received additional visual cues during the walk. Five signs were placed along the route, prompting participants to stop briefly and listen to the birdsong. Walks started individually between 08:08 and 09:28, lasting between 22 and 57 minutes, since the changes in salivary cortisol can be measured after 20-30 minutes (Bozovic et al., 2013; Kirschbaum & Hellhammer, 1994).

Questionnaire

Demographic variables included age in years, gender (male/female/diverse), and academic qualifications (*university degree,* yes/no), as these served as control variables for potential sociodemographic confounders. Whilst participants possessed a high level of general education, those without specific expertise in ornithology, related disciplines, or birdwatching hobbies may still lack relevant ecological knowledge. And since the effect of birdsong may depend on the individual *knowledge about birds* (Randler, 2021a, 2021b) and their *perception* (Belaire et al., 2015), these personal traits were also included as covariates.

The experience of a natural area can depend on various factors, many of which are related to perception of biodiversity (e.g. Marselle et al., 2019) or naturalness (Schebella et al., 2019a), for example. Therefore, we also collected data on *perceived bird diversity, perceived naturalness* and situational *nature experience*. As our study design focuses on birdsong, we also included questions about the *perceived soundscape* (Uebel et al., 2022). Accordingly, situational *perception* is divided into two categories. The first reflects the participants' subjective *nature experience*. The second focuses on the subjectively *perceived restorativeness* of place and sound.

For an overview of the constructs used in the survey, their sources and – if a scale consists of more than one item – the respective Cronbach´s α, please see Table 11.

Subjectively reported *mental well-being* was assessed using the variables *satisfaction*, *emotions,* and *self-reported restoration*. Due to the ordinal nature of the variables, non-parametric Spearman's rho correlation analysis was used to check for a relationship between physiological and subjective well-being variables. No significant correlations were found between self-reported mental well-being variables and physiological parameters (all $p \geq 0.134$); they should therefore be analyzed separately.

Table 11.
Overview of constructs and items used in the pre-and post-test questionnaire. Participants were originally surveyed in German; a brief English translation is provided here.

Construct	Survey items	Pre-test	Post-test	Cronbach´s alpha	Source
Personal trait variables					
Bird species knowledge	How many birds can you identify by appearance? How many birds can you identify by song? Ornithological skill self-report.	x		0.79	Lee & Scott (2004) Randler (2021a, 2021b) Randler & Heil (2021)
Perception of birds (5-point Likert scale)	I like birds because they... Are beautiful. Have a nice song. Make me Feel Good	x		0.60	Belaire et al. (2015)
Mental well-being					
Satisfaction (5-point Likert Scale)	How satisfied are you?		x		Arlinghaus (2006)
Emotions (5-point Likert Scale)	I feel… Calm and relaxed Peaceful Refreshed	x	x	Pretest: 0.65 Posttest: 0.72	White et al. (2020) Wyles et al. (2019)
Self-reported restoration (6-point Likert scale)	How recovered do you feel?		x		Young et al. (2020)
Perceived bird diversity					
Estimated bird richness (open question)	How many bird species do you estimate to be present?		x		Ferraro et al. (2020) Southon et al. (2018)
Perceived bird song (7 categories)	How many bird songs have you noticed?		x		Uebel et al. (2022)
Perception of the natural area					
Nature experience (5-point Likert Scale)	I have… Taken time to appreciate. Learned new things. Felt close to nature.		x	0.64	Wyles et al. (2019)
Perceived naturalness (place) (5 categories)	How natural does the area seem to you?		x		Schebella et al. (2019a)
Perceived naturalness (sound) (10 categories)	How do you rate the naturalness of the soundscape?		x		Carrus et al. (2015)
Perceived restorativeness (place) (5-point Likert scale)	This place is relaxing. This place is fascinating. This place is organized. This place is without restrictions. I can do what I want in this place.		x	0.72	Berto (2005) Korpela & Hartig (1996)

Perceived restorativeness (sound) (5-point Likert scale)	The soundscape in this place… Is fascinating. Provides me with a good change from my daily routine. Goes well together. Fits with activities I like to do. Suggests that there is a lot to explore and discover.		x	0.88	Payne (2013); Uebel et al. (2022)

Bird census and environmental variables

Participants were instructed to pay attention to the birdsong in the area. It was expected that their assessments of bird diversity would roughly align with those of ornithologists (Vanhöfen et al., 2022). To validate this, actual bird diversity was assessed by recording bird songs and calls for 15 minutes every morning during the study period using four Song Meter Mini devices (Wildlife Acoustics Inc., MA – USA) placed along the route (passive auditory monitoring, PAM). An experienced ornithologist (N.S.) analyzed the recordings and identified the number of bird species present on each study day, which was recorded as the *daily bird count* variable. A total of 34 bird species were recorded across all study days.

On each study day, we also recorded daily *temperature* (in °C, weather station 146 Unterjesingen – Tübingen, for the hours of data collection) as well as ambient *sound level* (in dB) using a Sound Level Meter (PeakTech© 8005, PeakTech GmbH, Germany).

As some data collection days were rainy, weather conditions were categorized into two *weather* groups (1 = rainy conditions (44.7%), 2 = dry conditions (55.3%)). This variable was strongly correlated with temperature and sound level and was therefore included as a control variable in the statistical models.

Statistical Analysis

Statistical analyses were done using SPSS (Version 29.0.2.0 (20)). Distribution was inspected visually using a QQ-Plot. All outcome variables were determined to follow a normal distribution. Levene's test for homogeneity of variances showed sufficient homogeneity of variances.

1) To assess the effect of the walk on physiological parameters and emotions, paired sample t-tests were conducted for pre-post differences across both experimental groups. Additionally, a two-level general linear model (GLM) was computed to assess the influence on the physiological parameters (Cortisol, HR, BP).
2) Factor analysis resulted in a **mental well-being** factor, formed by the post-test variables emotions, satisfaction, and self-reported restoration (for the component matrix, see Table 29 in the Appendix). The corresponding regression scores were saved under the variable "mental well-being" for further analyses.

3) To analyze the effects on mental well-being, a univariate GLM was computed, controlling for age, gender, university degree, and weather conditions. Independent variables included perceived species richness, perceived birdsong, perceived naturalness of place and sound, and perceived restorativeness of place and sound (RQ1).
4) Since factor analysis also revealed the factors of **perceived restorative potential** (combining perceived restoration place, together with perceived restoration sound; see Table 30 in the Appendix) and **perceived biodiversity** (combining estimated bird richness, perceived bird song, perceived naturalness place, perceived naturalness sound; see Table 31 in the Appendix), their corresponding regression scores were saved for further analysis, including for the variable **nature experience** (RQ2).
5) The effects of the attention-intervention, daily bird count, bird species knowledge, and perception of birds on mental well-being, perceived biodiversity, nature experience, and perceived restorative potential were tested using a multivariate GLM (RQ1 and RQ2), controlling for age, gender, university degree, and weather conditions.
6) Finally, an ANOVA was conducted for differences between the attention-intervention groups (RQ2).

Results

The descriptive statistics for the outcome variables are presented in Table 12.

General effects of the bird walk on stress parameters and emotions.

The positive emotions increased significantly after the walk, by 21.28% (paired sample t-test, $t(45) = -9.654$, $p < 0.001$).

All physiological parameters decreased during the walk (Table 12), indicating that the bird walk had a positive effect on participants' stress markers, including cortisol, blood pressure, and heart rate.

First, salivary cortisol levels decreased significantly after the walk by 37.93% (paired sample t-test, $t(46) = 8.689$, $p < .001$). Additionally, blood pressure was generally lower after the walk. The systolic blood pressure decreased by 2.68% (paired sample t-test, $t(46) = 2.137$, $p = 0.038$), while diastolic blood pressure decreased by 3.17% (paired sample t-test, $t(46) = 2.617$, $p = 0.012$). Finally, heart rate decreased by 3.35% (paired sample t-test, $t(45) = 1.966$, $p = .055$).

Table 12.
Descriptive statistics for the outcome variables included in the study.

	N	Minimum	Maximum	Mean	Std. Deviation
Personal trait variables					
Bird species knowledge	47	1.00	4.00	2.06	0.87
Perception of birds	46	3.00	5.00	4.23	0.61
Mental well-being					
Emotions (pretest)	46	2.33	5.00	3.76	0.65
Emotions (posttest)	47	3.33	5.00	4.56	0.45
Satisfaction (posttest)	47	2.00	5.00	4.45	0.69
Self-reported restoration (posttest)	47	0.00	5.00	4.06	0.79
Perceived bird diversity					
Estimated bird richness	44	0.00	84.00	21.55	17.03
Perceived bird song	47	1.00	7.00	5.04	1.37
Perception of the natural area					
Nature experience	47	2.67	5.00	4.34	0.61
Perceived naturalness (place)	47	1.00	5.00	3.53	1.06
Perceived naturalness (sound)	47	2.00	10.00	6.72	1.87
Perceived restorativeness (place)	47	2.20	5.00	3.82	0.60
Perceived restorativeness (sound)	47	1.60	5.00	3.62	0.82
Physiological stress parameters					
Systole (pretest) [mmHg]	47	102.00	173.00	134.53	15.37
Systole (posttest) [mmHg]	47	95.00	195.00	130.92	18.07
Diastole (pretest) [mmHg]	47	69.00	113.00	88.11	9.92
Diastole (posttest) [mmHg]	47	68.00	109.00	85.32	10.08
HR (pretest) [bpm]	47	54.00	103.00	73.92	10.20
HR (posttest [bpm]	46	49.00	107.00	71.44	10.79
Cortisol (pretest) [nmol/L]	47	1.79	18.08	8.12	4.46
Cortisol (posttest) [nmol/L]	47	1.30	10.73	5.04	2.47
Environmental measures					
Sound level mean (dB)	36	50.45	57.10	55.23	1.93
Temperature (°C)	47	12.00	15.00	13.04	1.22
Daily bird count	47	14.00	23.00	20.34	2.93

Influence on mental well-being

Participants' mental well-being was positively associated with their knowledge of bird species and situational nature experience in the univariate GLM with mental well-being as the dependent variable (see Table 13).

Table 13.
Univariate GLM, with dependent factor mental well-being. R Squared = .564 (Adjusted R Squared = .330).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	25.292[a]	15	1.686	2.413	0.021
Intercept	4.152	1	4.152	5.942	0.021
Group	0.022	1	0.022	0.031	0.862
Gender	0.964	1	0.964	1.379	0.250
University degree	0.328	1	0.328	0.469	0.499
Daily bird count	0.156	1	0.156	0.223	0.641
Age	1.105	1	1.105	1.581	0.219
Bird species knowledge	**3.217**	**1**	**3.217**	**4.603**	**0.041**
Perception of birds	1.351	1	1.351	1.933	0.175
Weather	0.148	1	0.148	0.212	0.649
Perceived bird diversity	0.011	1	0.011	0.016	0.902
Perceived bird song	0.010	1	0.010	0.014	0.907
Perceived naturalness (place)	0.001	1	0.001	0.001	0.971
Perceived naturalness (sound)	0.518	1	0.518	0.741	0.397
Perceived restoration (place)	0.048	1	0.048	0.068	0.796
Perceived restoration (sound)	0.156	1	0.156	0.223	0.641
Nature experience	**3.224**	**1**	**3.224**	**4.614**	**0.041**

Influence on situational nature experience, perceived biodiversity, and restorative potential

In the multivariate GLM (Table 32 in the Appendix) with the factor scores of mental well-being, perceived biodiversity, perceived restorative potential, and nature experience as dependent variables, the perception of birds positively influenced mental well-being (GLM, $F(1) = 6.445$, $p = .028$) and perceived biodiversity (GLM, $F(1) = 6.728$, $p = .025$). The scatterplot (Fig. 12) shows that perception of birds has a more positive effect on mental well-being and a more negative effect on perceived biodiversity.

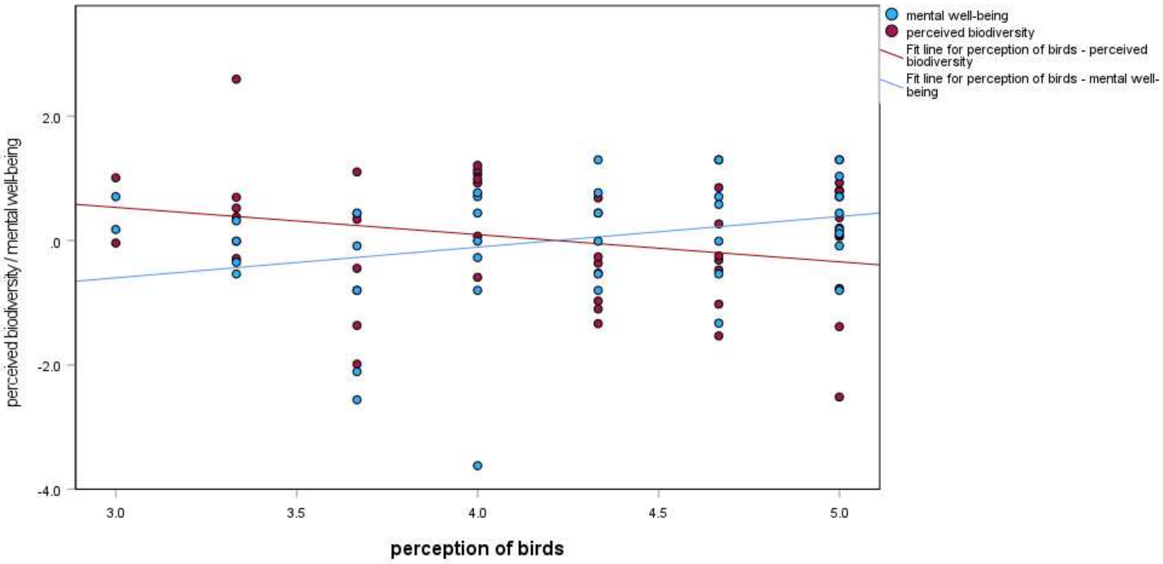


Figure 12.
Scatterplot of the relationship between perception of birds and mental well-being (blue) and perceived biodiversity (red). Fit lines show a positive direction for the relationship with mental well-being and a negative direction for the relationship with perceived biodiversity.

Influences on physiological parameters

No significant effects on physiological parameters were found in the two-level GLMs (Table 33, Table 34, Table 35 in the appendix). Neither the experimental group nor the nature experience affected the physiological stress parameters.

Effect of the awareness intervention

The awareness treatment groups (verbal/visual) showed no significant effects on mental well-being or perception outcome variables (see Table 36 in the Appendix). However, the visual awareness group reported higher perceived biodiversity (ANOVA $F(1) = 4.229$, $p = 0.046$). Environmental parameters also differed between the groups (Weather, ANOVA $F(1) = 10.701$, $p = 0.002$) but did not affect physiological parameters or mental well-being, as described above. Figure 13 shows the differences between the two awareness treatments, especially the significant difference in perceived biodiversity.

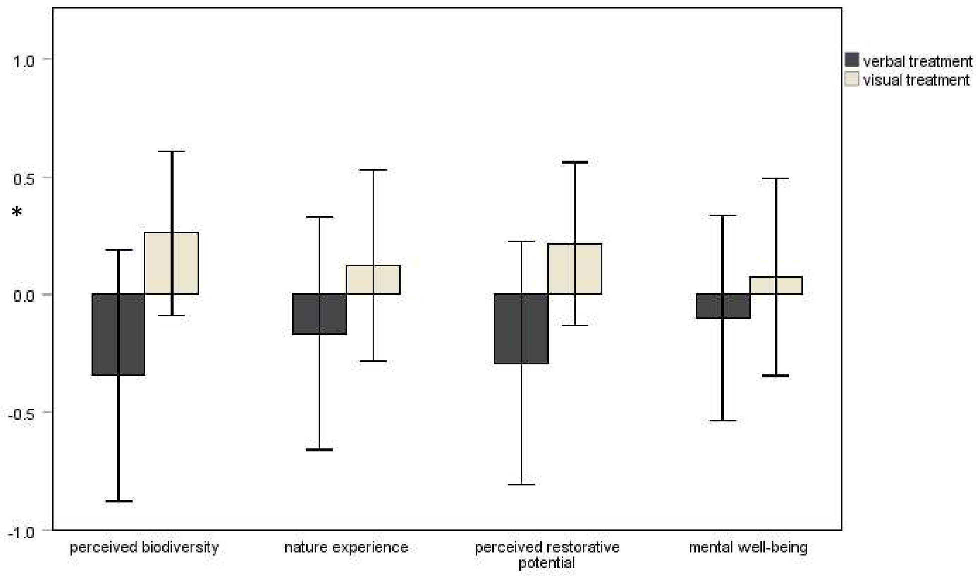


Figure 13.
Bar plot showing differences between the two awareness treatment groups (verbal = dark, visual = light). Shown are the mean z-scores of nature experience, perceived restorative potential, perceived biodiversity, and mental well-being. Groups differ significantly in the perceived biodiversity variable (*). Error Bars: 95% CI.

Discussion

The study analyzed the effects of an unguided bird walk in a controlled environment on participants' mental well-being and physiological stress parameters of participants. Additionally, participants were divided into two groups that differed in the type of instruction provided (i.e. visual or verbal instructions to listen to the birdsong), aimed at creating awareness of their surroundings. Following the unguided nature walk, participants showed increased positive emotions and decreased physiological stress parameters. Figure 14 shows a conceptual representation of the results of this study. The outcome variables of mental well-being have been summarized into one factor and related to influencing variables. Results show that mental well-being was influenced by personal trait variables as well as the situational nature experience. Environmental variables, the experimental group, perceived biodiversity and perceived restorative potential showed no effect on mental well-being. Additionally, participants in the visual awareness treatment reported higher perceived biodiversity and perceived restorative potential. A higher perception of birds (personal trait variable) also led to a higher perceived biodiversity.

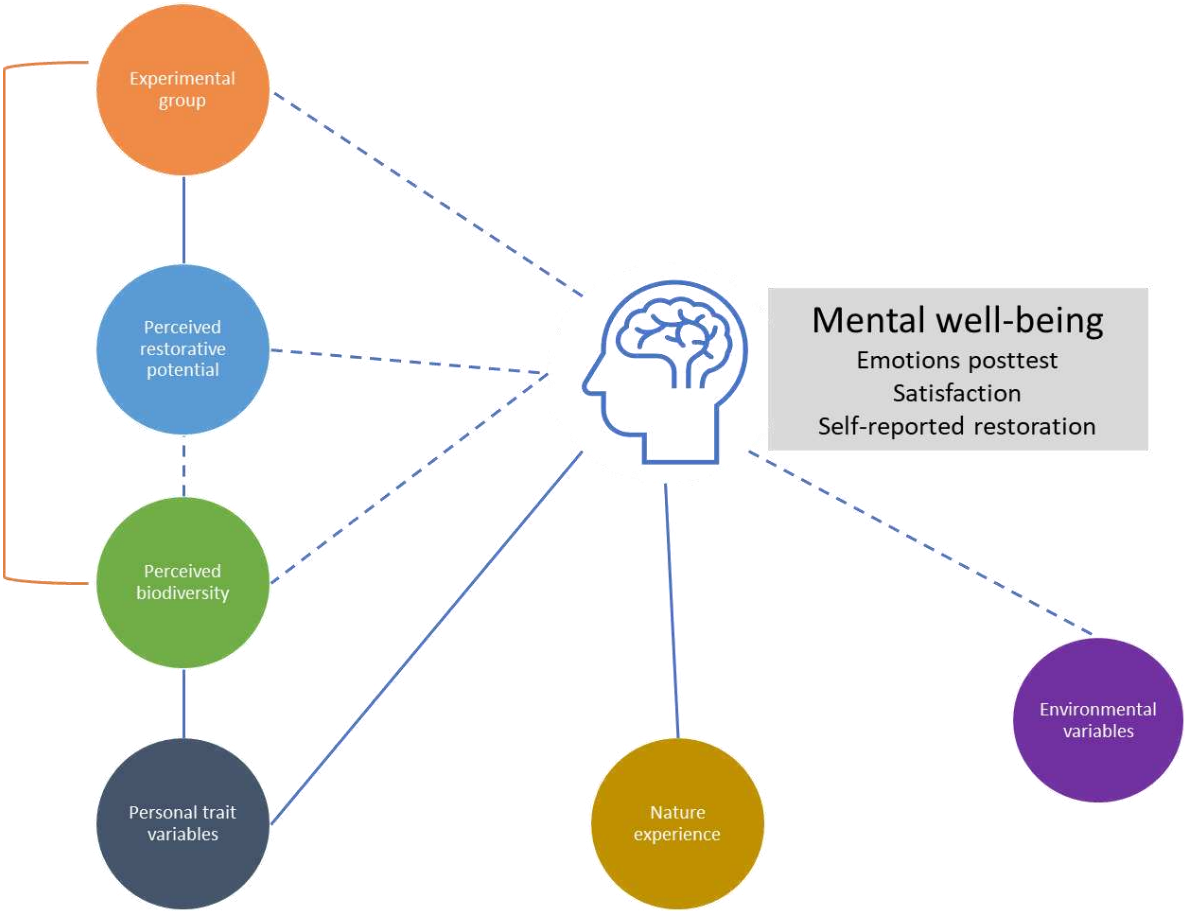


Figure 14.
Participants went on a 30-minute nature walk in a controlled environment. Mental well-being was influenced by the personal trait variables, perception of birds, bird species knowledge and the situational nature experience. Environmental variables, the experimental group, perceived biodiversity and perceived restorative potential showed no effect on mental well-being. Additionally, participants in the visual awareness treatment reported higher perceived biodiversity and perceived restorative potential (sound). A higher perception of birds also led to a higher perceived biodiversity. Significant relationships are indicated by solid lines, theorized but not significant relationships are represented by dotted lines.

Influences of the bird walk on physiological parameters.

The meta-analysis of Kondo et al. (2018) found inconsistent results regarding the relationship between self-reported stress measures of mental well-being and physiological stress indicators. Previous studies showed that walking in nature improved mood and physiological stress markers more than just watching nature scenes on TV or engaging in indoor physical exercise (Olafsdottir et al., 2020). Birdsong has also been discussed in literature for its positive and calming effects (Buxton et al., 2021), potentially contributing to the stress-reducing benefits of being in natural environments (Ulrich, 1991). Hikers exposed to phantom birdsong have reported restorative benefits (Ferraro et al., 2020), which could also affect physiological parameters. For example, Opdahl et al. (2021) demonstrated a decrease in salivary cortisol among hikers in more biodiverse areas. However, in the study by Hussain et al. (2019), BP and HR did not differ between high and low biodiversity conditions. Overall, the literature remains inconclusive on the effect of nature on physiological stress response (Corazon et al., 2019).

In our study, these measures were also not related, which is why we analyzed them separately. Additionally, these instruments assess different constructs, namely mental well-being and physiological stress markers, comparing objective measurements to subjective ones. Future studies should approach this distinction with care before drawing conclusions. Therefore, we recommend including both types of measures in future studies to get a more comprehensive understanding.

After the walk in the arboretum, participants' physiological stress parameters decreased significantly. The levels of the stress hormone cortisol decreased with a slope of -0.51, suggesting a substantial effect of the nature walk. Although the study took place in the morning when cortisol levels may have been masked by the cortisol awakening response (CAR: an initial increase shortly after waking, followed by a decline), this is unlikely. Polk et al. (2005) identified a natural slope for the decrease of salivary cortisol of -0.11 in women and -0.09 in men during the first few hours after the CAR. Therefore, the decrease in salivary cortisol observed in our participants is stronger than could be expected naturally and can potentially be attributed to the nature walk. Blood pressure also decreased, even though participants walked for ~ 30 minutes. The physical activity of walking (Sugiyama et al., 2008) may also explain the reduction in heart rate which is only marginally insignificant. HR and BP still decreased slightly, likely due to the calming effect of green environments already reported in earlier studies (Kondo et al., 2018).

Influence of the bird walk on mental well-being, perceived biodiversity, nature experience and perceived restorative potential.

Since positive emotions increased during the walk, participants felt more refreshed, calm and peaceful. Previous studies also reported improvements in mood and mental well-being after walking in nature (Nghiem et al., 2021; Nisbet et al., 2019).

The personal trait variable perception of birds influenced the mental well-being of participants, together with the situationally perceived biodiversity of the study area. Mental well-being was additionally influenced by participants' nature experience and bird species knowledge. Participants with a high perception of birds and species knowledge may possibly be people with a higher nature connectedness, as a positive species sentiment has been linked to the human-nature connection (Hayes Hursh et al., 2024). It is possible that benefits received from being in natural spaces increased since people with a greater nature connectedness have been shown to report more positive nature experiences in earlier studies (Härtel et al., 2023). These participants may therefore benefit more from spending time outside in a green space (Camacho-Guzmán et al., 2023; Ferraro et al., 2020). In our study, a better nature experience also contributed positively to the mental well-being of participants. Additionally, participants perceiving nature scenes as more biodiverse reported a higher positive affect (Farris et al., 2024). Notably, Farris et al. (2024) found that noticing and engaging with biodiversity is key to receiving these benefits. Participants with a greater perception of birds perceived the study area as less biodiverse on the other hand. Participants with a greater perception of birds could possibly have a better ecological knowledge in general (independent of specific bird species knowledge), being able to see the study area as a curated urban park and knowing that other recreational areas in the region present with more bird species. Whilst participants possessing a high level of general education generally are expected to possess more knowledge, those without specific expertise in ornithology, related disciplines, or birdwatching hobbies may still lack significant ecological knowledge. Additionally, participants having a high perception of birds and a lot of ornithological knowledge do not necessarily possess a high level of general education, as was shown by the lack of effect of a university degree in all models. This shows the importance of including questions for domain-specific knowledge into questionnaires in addition to general educational questions. But it also shows that positive effects of birdwatching and nature experience are independent of education and accessible to many people.

Perceived biodiversity and nature experience were not influenced by any of the environmental variables measured in this study. The perceived restorative potential of the area was also independent of the measured variables. Therefore, the perception of a place is probably influenced by factors we did not measure here. Such factors could include, for example, the tree cover (Jiang et al., 2020) or aesthetic value (Kothencz et al., 2017). Additionally, merely listening to forest sounds can promote physical and psychological relaxation (Li et al., 2021), even though a strong connection between the pleasantness of sound and visuals exists (Bogdanov et al., 2022).

Effect of the awareness intervention

The treatment groups had no significant effect on mental well-being, physiological parameters, or experience. Still, they differed in perceived biodiversity of the area. The group that received visual cues (signage) to listen to birdsong along the route reported higher perceived restoration (sound) values and more perceived birdsong, which in turn leads to more perceived biodiversity than the group that was verbally instructed.

Environment-oriented activities such as walking can increase the perception of an area's restorative qualities (Carrus et al., 2015). In a study by Nisbet et al. (2019), mindfulness led to greater awareness and stronger feelings of connectedness with nature. Since the group with visual cues was regularly reminded to pay attention to birdsong, their awareness was likely heightened, which may have helped increase feelings of connectedness to nature.

In our study, awareness was associated with the perceived restorativeness (sound) of the area. People expect certain types of sound to be present in a specific environment based on their prior experiences (Bruce & Davies, 2014). Auditory pleasantness also increases in the presence of natural, rather than urban, visual environments (Bogdanov et al., 2022). The study area is a park-like section of the botanical garden, situated right next to the often-frequented northern ring road of the city. The sound level ranged from 50 – 57 dB, placing them within the moderate range of everyday ambient noise. Noise pollution can generally have a negative impact on the physical and mental well-being of people (Gramann, 1999) by causing both physical and psychological stress (Ouis, 2001). Since the walk generally had a positive effect on emotions and physiological stress parameters, the ambient noise probably did not harm participants´ mental well-being, although it may have masked the impact of the birdsong on some days.

Perceived biodiversity is related to the perception of birds and nature connectedness, as described previously. These participants likely also benefited more from the intervention. This effect appears to be linked to our awareness treatment, as the group receiving visual cues reported higher perceived birdsong. In previous nature-based interventions, participants paying attention to their natural surroundings reported increased positive emotions and a stronger sense of connectedness to nature as well (Passmore & Holder, 2017; Passmore et al., 2022). According to the Attention Restoration Theory (Kaplan & Kaplan 1989; Kaplan 1995), being in nature can allow for recovery from attentional fatigue, replenishing attentional capacity by being non-demanding. The present study tasked participants to pay intentional attention to birdsong and they still reported positive emotional and physiological stress reductional benefits. The group being reminded by visual signage to pay attention even reported more restorative potential of the area, indicating that not only unconscious experience of green spaces and nature can have positive effects, but also conscious experience is helpful. Therefore, urban parks could positively influence well-being of visitors by installing respective guidance signage.

Limitations & Implications

The main limitations of this study are the non-representative sample and the influence of weather conditions. Nearly two-thirds of participants identified as women, and more than 70% reported holding a university degree. This is likely due to the study site being part of a university's botanical garden. Thus, the generalization of the results to other populations and cultural groups should be done with caution. However, positive effects of nature-based interventions appear to be present across diverse populations (Coventry et al., 2021). Therefore, the positive effect of our unguided bird walk may cautiously be assumed to be robust, even though more women participated than men.

Some study days were impacted by high amounts of precipitation prior to data collection. The natural soundscape may have been significantly masked by street noise for some participants due to the wet road conditions near the park. However, weather conditions in the statistical models did not affect any outcome variables, nor was any interaction effect with the treatment groups found, even though weather differed between groups. This should be considered when interpreting group differences.

Additionally, a true control group receiving neither a verbal nor a visual cue could have allowed for clearer attribution of effects. Earlier studies (Vanhöfen et al., 2025b) saw, that raising awareness for bird song improved positive emotions and nature experience, which is why we focused on the method of delivery of raised awareness in the present study. Since the perceived benefits of bird song can vary across different types of green space (Yi et al., 2024), further research could investigate how the perception of birdsong varies across different urban green spaces also considering the diverse acoustic types and psychoacoustic characteristics influencing public perception (Hong et al., 2025; Yi et al., 2025).

Nonetheless, the nature walk had positive effects on mental well-being and physiological stress markers of participants. Enhancing the restorative quality of an area's soundscape through increasing awareness could easily be achieved by placing signs in selected locations. Since nature in urban parks benefits not only urban biodiversity but also human well-being, it is vital to conserve it and facilitate access to it.

Conclusion

Taking a nature walk outdoors positively affects most people's well-being, even in urban settings. Previous studies have shown that raising awareness of commonly present birdsong benefits mental well-being and reduces stress. However, awareness can be raised in different ways and may be mediated by subjective trait variables.

In an experimental setting, we compared the effects of verbal and visual awareness of birdsong on mental well-being, physiological stress parameters, and participants' subjective nature experience. The results indicate that the walk had a generally positive impact on mental well-being and contributed to a reduction in physiological stress parameters. Participants with a higher expression of the subjective trait variables perception of birds and bird species knowledge reported improved mental well-being and an enhanced biodiversity perception after the walk, which was also linked to their nature experience. Notably, the group stopping at signs for a visual attention-enhancing treatment reported a higher perceived restorativeness of sound and a heightened perception of bird song.

Therefore, recreational areas such as urban parks should integrate opportunities for nature experiences. The sense of connectedness to nature should also be promoted among the general public, as it may lead to even larger mental well-being benefits when spending time outdoors. Since biodiversity perception and heightened awareness are key factors in enhancing mental well-being and reducing stress, these human-centered benefits should be considered when arguing for the conservation of biodiversity.

Manuscript 5

Bird species traits in recreational areas – building a human restoration value of bird species and connecting it to the mental well-being of recreationists in Germany

Vanhöfen, Janina; Kalb, Nadine & Randler, Christoph (2026). Bird species traits in recreational areas–building a human restoration value of bird species and connecting it to the mental well-being of recreationists in Germany. *Frontiers in Bird Science*, *5*, 1740187.

Abstract

Preferences for animal species and their popularity vary significantly between species, even within a taxonomic group such as birds. Understanding which characteristics influence human preferences for certain bird species can help to promote targeted conservation measures and define so-called 'flagship species' for conservation programs. However, the extent to which such species-specific characteristics also affect human psychological well-being remains largely unclear. The positive impact of interacting with birds on the human psyche is currently being researched. However, a grey goose could potentially have a different impact on the human experience of nature and, thus, also on psychological well-being in local recreation areas than, for example, a blue tit or a nightingale. Which species-specific characteristics play a role in this is still largely unclear. We therefore compiled data on species-specific characteristics for 118 bird species that were mapped in 40 different areas in southwest Germany. One factor was summarized from four species traits in a principal component analysis, building the human restoration value. An index was calculated for each location (HRV = human restoration value of bird species). In a second step, these indices were then correlated with the mental well-being and place attachment of 1,184 people in the 40 project areas. The results show a positive correlation between the HRV and satisfaction. Compiling species-specific characteristics relevant to human well-being into one factor, such as the HRV presented here, might enable future projects to investigate the recreational value of nature areas based on bird abundance.

Keywords: bird species traits, human restoration value, human-bird interaction, mental well-being, recreational areas

Introduction

Well-being and mental health research is a rapidly growing field of study within the area of birds and ecology. One of the prominent ideas is that being outside in nature often leads to increased mental well-being among recreationists, with research typically focusing on the characteristics of the area or landscape. Earlier studies have also theorized that biodiversity is one of the main drivers of this phenomenon (see, for example, but not exclusively, Adjei & Agyei (2015); De Vries & Snep (2019); Houlden et al. (2021)). Research has shown mixed results between the effects of biodiversity, perceived biodiversity, and experimentally increased biodiversity. We propose here that birds, as a key component of an area's characteristics, play an important role in this. Birds can be perceived both directly and unconsciously. They are a taxonomic group that is easily recognized and observed by people (Cox & Gaston, 2015), regardless of ornithological knowledge. Additionally, they are a common and well-studied taxon, sensitive to anthropogenic influences (Gregory et al., 2008) and therefore valuable indicators of biological diversity, ecological conditions, and environmental status (Randler & Koch, 2025). Their species characteristics are closely linked to their habitat and ecosystem services (Sekercioglu, 2006), and they are well-suited to connect urban residents with nature (Belaire et al., 2015). In contrast to many mammals and reptiles, birds are mostly diurnal, and many are found in urban areas. Some are also extremely common in city settings.

Birds have been linked to increased happiness (White et al., 2023) and improved mental health (Xie et al., 2023) in people. Their sounds play a crucial role (Chen et al., 2022) in stress relief, though not all bird sounds are equally beneficial (Ratcliffe et al., 2013). Earlier studies often focused on bird species richness (Methorst et al., 2021a). Some also looked at the effects of bird observation (Cox & Gaston, 2015), or bird song (Stobbe et al., 2022), sometimes even attempting to artificially increase bird song to foster well-being (Ferraro et al., 2020). However, some research has found no association of bird species richness with people's mental well-being (Cox et al., 2017a; Taylor et al., 2018). Some only found a relationship with perceived bird diversity instead of actual biodiversity measures (Dallimer et al., 2012). This inconsistent relationship between bird diversity, perceived bird diversity, and human mental health (Lovell et al., 2014) renders it difficult to measure if and how conservation efforts in nature could boost mental well-being. Since experiencing biodiverse urban green spaces can evidently bring joy (Douglas & Evans, 2021) and generally has positive effects (Carrus et al., 2015), it's important to look beyond general assessments of bird diversity and maybe look at the composition of bird species in an area.

To our knowledge, no studies have yet assessed the bird species characteristics and traits that may be responsible for the mental well-being of recreationists. Additionally, only a few studies have considered that not all bird species equally affect people (see, for example, Fisher et al. (2023); Garnett et al. (2018); Randler & Koch (2025); Randler et al. (2023b); Ratcliffe et al. (2013)). This might be important because there is a large variation in the perception, likeability, and preferences of bird species (Albert et al., 2018; Veríssimo et al., 2014; White et al., 2023) as well as in the bird species themselves. Aesthetically pleasing animals are often considered charismatic (Prokop et al., 2025; Veríssimo et al., 2014), and small and vividly colored birds are often perceived as more beautiful (Haukka et al., 2023; Santangeli et al., 2023). Most people also share a preference for birdsong (Chen et al., 2022), but some songs and calls can also annoy urban residents (Belaire et al., 2015; Pejchar et al., 2025). Some bird species, such as the hooded crow, for example, are also associated with problems such as trash scattering, noise disturbance, and aggressive behavior (Kövér et al., 2022). Lisǩová & Frynta (2013) have already emphasized that finding the traits that determine human preference towards birds may help promote conservation programs. Earlier studies on flagship species have suggested certain species characteristics of liked animal species, with a high body mass (Santarém et al., 2019; Smith et al., 2012), and a large body size often being linked to charisma (Albert et al., 2018; Callaghan et al., 2021).

Finding the species traits important for human mental well-being may explain the discrepancies between studies, since not all birds are present in all study areas similarly. The study by Garnett et al. (2018), for example, found a preference for small colorful birds with melodious song, but participants then nominated mostly large and well-known species as most attractive. According to Haukka et al. (2023), aesthetic attraction is dependent on a set of features that make something interesting or likable, usually composed of visual and emotional cues. This is why many liked species exhibit a bright appearance, colors, or color patterns (Santarém et al., 2019; Veríssimo et al., 2014). Aesthetic attraction seems to be highest for smaller birds, with vivid colors and extreme ornaments (Santangeli et al., 2023). Other factors seemingly playing a role are visibility, rarity, familiarity, or encounter rate (Santangeli et al., 2023; Schlegel & Rupf, 2010; Veríssimo et al., 2014). Some charismatic species are also considered "sweet" or "cute" (Albert et al., 2018; Borgi et al., 2014). The concept of cuteness is based on the baby schema by Lorenz (1943), which sums up characteristics that are supposed to trigger an innate caring behavior in humans. These characteristics consist of a large head in relation to body size, short and thick extremities, a large set of eyes, a large, rounded forehead, and round, protruding, chubby cheeks (Lorenz, 1943). Animals exhibiting the baby schema are often perceived as cute and draw the viewer's attention (Albert et al., 2018). Bird species perceived as cute elicited a higher willingness to protect, as well as a bright coloration (Randler & Koch, 2025).

We hypothesize that the human perception of birds is strongly linked to mental well-being, and therefore, the species composition in an area may determine the mental well-being benefits received when visiting. In this study, we investigate the link between human perception of bird traits and well-being to determine if and how species composition in recreational areas affects place attachment and well-being of visitors.

Method

This study consists of two parts. First, a survey was conducted among people in recreational areas to assess their mental well-being. In the same areas, the bird species were recorded. In a second step, the well-being data were related to the bird species characteristics.

Mental well-being

The pen-and-paper survey took place in May-June 2022 in 40 recreational areas between Rottenburg am Neckar and Stuttgart in Baden-Württemberg, southwest Germany. Using voluntary response sampling, pedestrians over the age of 18 were invited to participate in the questionnaire if they had already been in the respective area for a while. They answered the survey once, for a situational assessment after being in the study area. The study had 1184 participants. 54.9% of them identified as female, 44.1% as male (0.2% identified as diverse, 0.8% preferred not to answer the question). The age ranged from 18 to 89 years old (1.9% did not answer), with the mean age being 43.34 ± 17.75 years. For more details on the questionnaire, see Table 14 and Vanhöfen et al. (2025a).

Three subjective measures for assessing mental well-being were used: recalled restoration, emotions, and satisfaction.

Recalled restoration after the visit was asked for with one item, on a categorical scale with 6 categories adapted from Young et al. (2020). For better comparability between the scales in our study, we recoded the recalled restoration Scale into a 0 (“cannot say”) to 5 (“significantly more recovered”) Likert scale, with 0 being considered as missing data.

Emotions or self-reported restoration were measured with three items on a 5-point Likert scale, adapted from White et al. (2020) and Wyles et al. (2019). Items included questions for a situational positive state of mind. The scale had a Cronbach’s alpha of 0.77 in our study.

Satisfaction was asked for with one item (Overall, how satisfied were you with your visit today?) on a categorical 5-point Likert scale adapted from Arlinghaus (2006).

Additionally, we asked for place attachment on a 5-point Likert scale (full scale with a Cronbach’s alpha = 0.88, Vanhöfen et al. (2025a)). Place attachment is the emotional bond humans form with a place. It has been influenced by visit satisfaction in earlier studies (Prayag & Ryan, 2011). Bryce et al. (2016) identified constructs of place identity and therapeutic value as cultural ecosystem services, benefitting people’s well-being. According to them, most benefits associated with visiting nature can depend on specific habitats and landscapes. It could also possibly be connected to the bird species present in the area and their traits. According to factor analysis, the place attachment scale can be split into two variables, namely place attachment identity and place attachment recovery. The recovery scale (Cronbach’s alpha = 0.86) is derived from the therapeutic value by the place attachment assessment of Bryce et al. (2016). The identity scale (Cronbach’s alpha = 0.87) is derived from the abbreviated three-item place identity scale of Boley et al. (2021).

Table 14.
Mental well-being items for the biodiversity and health survey. For more information on the survey, see also Vanhöfen et al. (2025a).

Concept	**Item**	**Source**
Satisfaction (5-point Likert scale)	Overall, how satisfied were you with your visit today?	Arlinghaus (2006)
Emotions (5-point Likert scale)	I feel… Calm and relaxed Peaceful Refreshed	White et al. (2013) Wyles et al. (2019)
Recalled Restoration (5- point Likert scale)	How refreshed do you feel now compared to before your visit?	Young et al. (2020)
Place attachment - Identity (5-point Likert scale)	I feel very connected to this area here This area is very special to me. I can identify well with this area.	Boley et al. (2021)
Place attachment - Recovery (5-point Likert scale)	Visiting this place gives me a feeling of freedom. I can clear my head here. Being here helps me to feel healthy.	Bryce et al. (2016)

Bird species traits

Bird species selection

The avifauna of Germany is typical of central Europe. The total list of bird species for Germany contains 527 bird species (including vagrants), of which about 250 are regular breeders. In addition, there are about 20 non-native breeding species (Barthel & Krüger, 2019). Since only birds present in a respective area can be experienced by people, bird species and their abundance were recorded by ornithologists via the standard procedure of Bibby et al. (2000). Bird surveys were carried out two times in the morning and once in the afternoon, with each morning survey having at least 3 weeks in between. In a 250m radius on footpaths, all individuals seen and heard in the span of 15 minutes were recorded. Data was then compiled into a list of all species recorded at each site, and the highest species frequency present was used further.

This data resulted in a total of 118 species present in the 40 study areas during the duration of the pen-and-paper survey (Vanhöfen et al., 2025a), for which the trait data were collected.

Variable selection and data collection

Cuteness data were taken from the study by Randler & Koch (2025), in which the participants were asked to rate the cuteness of bird pictures on a 5-point Likert-type scale, following Borgi et al. (2014).

Brightness data were taken from Randler et al. (2023b). In this study, 769 people estimated the brightness of the male breeding plumage on a scale from 0 to 100.

In another survey study (Lukanowski, 2023), participants were asked to rate bird song on their beauty on a Likert-type scale from 1 to 5, resulting in the data for the beauty of song. The audio was taken from Bergmann et al. (2020).

Lastly, data on visual attractiveness were taken from the iRateBirds study by Haukka et al. (2023), using the iRateBirds database. In this study, respondents (n = 6,212) were asked to rate the appearance of bird species on a scale from 1 (low) to 10 (high) based on photographs from the Cornell Lab of Ornithology's Macaulay Library.

Statistical procedure

Statistical procedures and analyses were performed using SPSS (version 29.0.2.0) and Excel. For assessing internal consistency, we used Cronbach's a. For the exploratory factor analysis, we used a principal component analysis with a varimax extraction. And finally, for the correlation of factor scores with mental well-being data, we used Spearman's rho correlations.

Factor analysis of variables

Based on a principal component analysis, the variables visual attractiveness, brightness, cuteness, and beauty of song were combined into a single factor, which was then saved as a standardized regression score, now labeled $HRV_{species}$ = human restoration value of the respective bird species.

All variables load strongly on one factor (see Table 15) allowing for continuing with only one component extracted.

Table 15.
Component matrix. Extraction method: Principal Component Analysis. One component was extracted.

	Component 1
Cuteness	.855
Brightness	.618
iRateBirds (visual attractiveness)	.599
Beauty of song	.552

Value per place

The factor was then used to calculate values for each study area. For this value on the place level, the frequency of the respective bird species was used as well to account for mass or rarity occurrences of specific species. Every study area, therefore, receives a specific value for the HRV_{place}.

$$HRV_{Place} = Mean\left(\sum_{species=1}^{118} \left(HRV_{species} * frequency_{species} \right) \right)$$

Correlation with mental well-being

Finally, the HRV_{place} was correlated with the mental well-being of people at the place level using a non-parametric Spearman-rho correlation analysis.

Results

The factor values for the HRV of the respective bird species are shown in Table 16. The bird species are ranked from highest to lowest by their $HRV_{species}$ score. A high $HRV_{species}$ score means a positive evaluation of species traits.

For the correlation with mental well-being, the HRV significantly correlated with satisfaction (Table 17). However, the other correlations failed significance only marginally.

With increasing HRV_{place}, satisfaction with the visit increased significantly (Figure 15). This also means that bird species with a high $HRV_{species}$ (for example, *Erithacus rubecula* or *Cyanistes caeruleus*) have a positive effect on satisfaction after the visit. In contrast, species like Carrion Crow (*Corvus corone*) or Feral Pigeon (*Columba livia f. domestica*) negatively affect the satisfactory value of a given place. By using the species frequency in the HRV_{place} calculation, we were able to account for mass aggregations, which are often found in geese, pigeons, or crows, and which are a reality for urban parks.

Table 16.
Bird species ranked according to their factor values of the $HRV_{species}$.

Nr.	Species	$HRV_{species}$	Nr.	Species	$HRV_{species}$
1	*Erithacus rubecula*	2.71	60	*Motacilla alba*	0.03
2	*Cyanistes caeruleus*	2.69	61	*Picus canus*	0.00
3	*Parus major*	2.05	62	*Tadorna tadorna*	0.00
4	*Regulus ignicapilla*	1.87	63	*Acrocephalus arundinaceus*	0.00
5	*Pyrrhula pyrrhula*	1.70	64	*Larus michahellis*	0.00
6	*Emberiza citrinella*	1.47	65	*Muscicapa stiata*	-0.01
7	*Poecile montanus*	1.46	66	*Certhia brachydactyla*	-0.03
8	*Carduelis carduelis*	1.43	67	*Mergus merganser*	-0.03
9	*Alcedo atthis*	1.31	68	*Aythya fuligula*	-0.05
10	*Regulus regulus*	1.27	69	*Fringilla montifringilla*	-0.07
11	*Hirundo rustica*	1.26	70	*Lullula arborea*	-0.07
12	*Fringilla coelebs*	1.24	71	*Milvus migrans*	-0.08
13	*Periparus ater*	1.15	72	*Tadorna ferruginea*	-0.08
14	*Oriolus oriolus*	1.08	73	*Passer domesticus*	-0.12
15	*Poecile palustris*	0.99	74	*Acrocephalus scirpaceus*	-0.15
16	*Aegithalos caudatus*	0.92	75	*Circus aeruginosus*	-0.18
17	*Picus viridis*	0.91	76	*Coturnix coturnix*	-0.22
18	*Aix galericulata*	0.91	77	*Turdus merula*	-0.22
19	*Coccothraustes coccothraustes*	0.91	78	*Falco subbuteo*	-0.24
20	*Phoenicurus phoenicurus*	0.89	79	*Accipter nisus*	-0.24
21	*Ficedula hypoleuca*	0.81	80	*Pernis apivorus*	-0.26
22	*Phylloscopus trochilus*	0.81	81	*Garrulus glandarius*	-0.29
23	*Dendrocopos major*	0.80	82	*Sturnus vulgaris*	-0.30
24	*Falco tinnunculus*	0.79	83	*Prunella modularis*	-0.33
25	*Leiopicus medius*	0.77	84	*Sylvia atricapilla*	-0.34
26	*Saxicola rubicola*	0.76	85	*Anthus spinoletta*	-0.36
27	*Delichon urbicum*	0.68	86	*Turdus pilaris*	-0.39
28	*Sitta europea*	0.66	87	*Anas crecca*	-0.41
29	*Vanellus vanellus*	0.63	88	*Tachybaptus ruficollis*	-0.46
30	*Spinus spinus*	0.63	89	*Cuculus canorus*	-0.46
31	*Troglodytes troglodytes*	0.58	90	*Aythya ferina*	-0.49

32	*Motacilla flava*	0.53	91	*Passer montanus*	-0.51
33	*Lophophanes cristatus*	0.51	92	*Acrocephalus palustris*	-0.51
34	*Certhia familiaris*	0.49	93	*Anas platyrhynchos*	-0.61
35	*Turdus viscivorus*	0.37	94	*Streptopelia decaocto*	-0.66
36	*Anser indicus*	0.36	95	*Anthus pratensis*	-0.67
37	*Motacilla cinerea*	0.33	96	*Milvus milvus*	-0.69
38	*Serinus serinus*	0.33	97	*Alauda arvensis*	-0.73
39	*Phylloscopus collybita*	0.32	98	*Cygnus olor*	-0.77
40	*Asio otus*	0.28	99	*Dryocopus martius*	-0.79
41	*Phalacrocorax carbo*	0.28	100	*Pica pica*	-0.85
42	*Phylloscopus sibilatrix*	0.27	101	*Ciconia ciconia*	-1.00
43	*Sylvia borin*	0.27	102	*Fulica atra*	-1.04
44	*Emberiza schoeniclus*	0.25	103	*Gallinula chloropus*	-1.11
45	*Netta rufina*	0.21	104	*Chroicocephalus ribibundus*	-1.13
46	*Ficedula albicollis*	0.21	105	*Apus apus*	-1.22
47	*Sylvia curruca*	0.20	106	*Columba oenas*	-1.33
48	*Chloris chloris*	0.15	107	*Jynx torquilla*	-1.34
49	*Phoenicurus ochruros*	0.14	108	*Buteo buteo*	-1.40
50	*Lanius collurio*	0.12	109	*Alopochen aegyptiaca*	-1.41
51	*Sylvia communis*	0.10	110	*Anser anser*	-1.71
52	*Ardea alba*	0.10	111	*Columba palumbus*	-1.76
53	*Emberiza hortilana*	0.10	112	*Corvus corone*	-1.82
54	*Anthus trivialis*	0.10	113	*Columba livia*	-2.15
55	*Linaria cannabina*	0.10	114	*Ardea cinerea*	-2.15
56	*Charadrius dubius*	0.08	115	*Corvus corax*	-2.17
57	*Luscinia megarhynchoss*	0.08	116	*Circus cyaneus*	-2.32
58	*Turdus philomelos*	0.07	117	*Coloeus monedula*	-2.43
59	*Podiceps cristatus*	0.06	118	*Corvus frugilegus*	-2.45

Table 17.
Pearson correlation of the mental well-being variables with the subjective HRV on the place level (N=40). *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

		HRV_{place}
Emotions	Correlation Coefficient	.289
	Sig. (2-tailed)	.071
Satisfaction	Correlation Coefficient	**.357***
	Sig. (2-tailed)	**.024**
Restoration	Correlation Coefficient	.283
	Sig. (2-tailed)	.076
Place Attachment Identity	Pearson Correlation	.127
	Sig. (2-tailed)	.433
Place Attachment Recovery	Correlation Coefficient	.269
	Sig. (2-tailed)	093

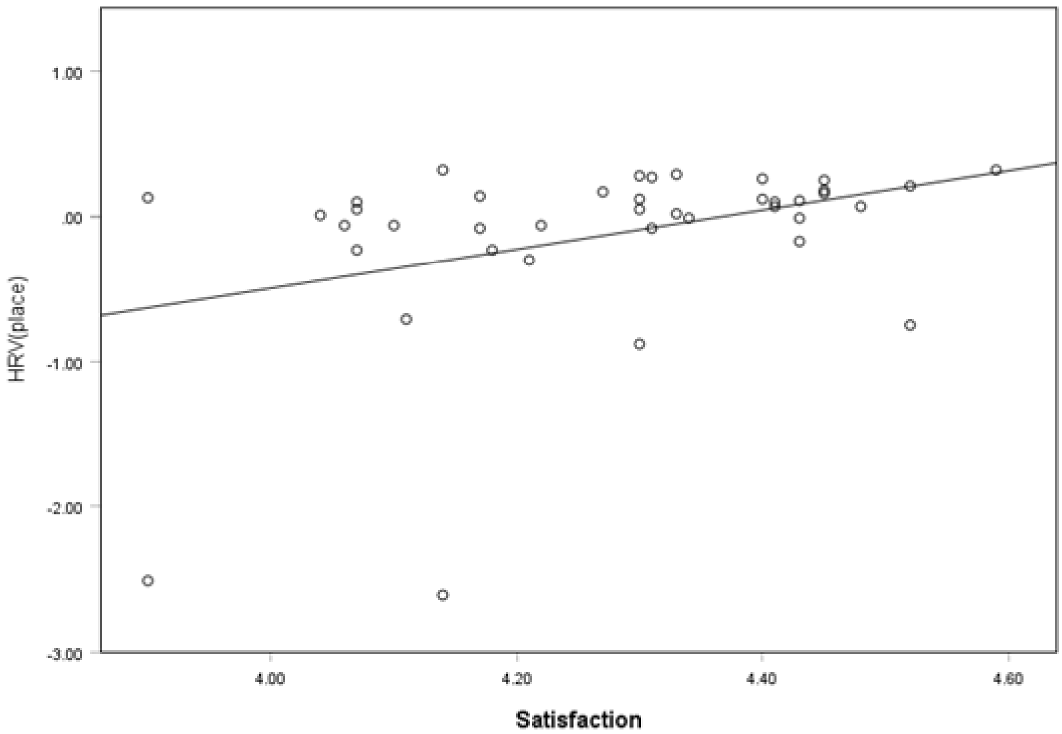


Figure 15.

Scatter plot of the positive relationship between HRV_{place} and Satisfaction.

Discussion

We here propose a new measure, the Human Restoration Value, to assess the beneficial influence of birds on human well-being. For this value, bird species traits were combined into one value and then related to the mental well-being of humans. This method could potentially be used for many other conservation questions, as discussed below. Each bird species was assigned a value that is based on previous studies on likeability, pleasantness, and attractiveness. Thus, more likable species receive a higher value. This factor can now be used to determine which bird species are perceived favorably by people.

Moreover, based on field work on 40 different places, we were able to assign a well-being value based on the species traits and the bird diversity to each of the areas. This value has been connected to on-site data of well-being in human participants to investigate how species composition affects mental well-being.

Bird species receiving a higher HRV score are mostly species commonly rated as cute, colorful, visually attractive, and with a nice song. Therefore, it is not surprising that this factor significantly correlates with satisfaction. High biodiversity levels are theorized to help with psychophysiological stress recovery, according to the Stress Reduction Theory (= SRT (Ulrich, 1983; Ulrich et al., 1991)). Additionally, spending time in nature, according to the Attention Restoration Theory (ART), facilitates recovery from attentional fatigue (Kaplan and Kaplan, 1989; Kaplan, 1995). Areas with more beneficial bird species could therefore help with stress reduction and restoration.

Bird song has been associated with stress reduction (Ratcliffe et al., 2013), being able to buffer the negative effects of traffic noise (Uebel et al., 2022), and improving anxiety (Stobbe et al., 2022), making them a very important part of urban soundscapes. A perceptively beautiful bird song is important for the HRV and mental well-being of people, since sounds are one of the most important factors for stimulating well-being responses (Fisher et al., 2023), underscoring the notion that birds singing beautifully have a positive impact and birds screaming or warning have a more negative one. Bird diversity is also often perceived by humans in the form of bird song (Ferraro et al., 2020).

The appearance of a bird species, on the other hand, is also very important as the second way in which people mostly perceive birds: visually. In the study by Fisher et al. (2023), colors and behavior followed behind sound as a determinant of well-being. Attractive birds are colorful, with a bright appearance, and big ornaments (Santangeli et al., 2023; Santarém et al., 2019; Veríssimo et al., 2014). Bigger birds, on the other hand, are often seen as less attractive (Santangeli et al., 2023). These differing factors have to be kept in mind when looking at the “attractiveness” of birds, since attractiveness is a subjective feeling. This is why we added cuteness, brightness, and the beauty of song as variables. All of them are variables, which are subjectively perceived by people experiencing birds

The HRV is correlated with the well-being variable satisfaction. Emotions, on the other hand, as well as recalled restoration, and the two place-attachment scales are not. Place attachment is strongly linked to perceived restorativeness and perceived restorative potential of an area (Menatti et al., 2019). It consists of two constructs: place attachment identity and place attachment recovery, with the place attachment recovery scale asking for feelings of freedom, clear head, and health (Bryce et al., 2016). Differing to that, recalled restoration asked for feelings of being refreshed (Young et al., 2020). Therefore, beautiful bird song, visual attractivity, cuteness, and brightness do not actually influence refreshment or positive emotions, but satisfaction with a visit. Therefore, bird species like *Erithacus rubecula* or *Cyanistes caeruleus* may themselves have a positive impact, or they go together with positively connoted habitats or structures. This could be since people do not consciously experience bird diversity in the study areas but more unconsciously (Vanhöfen et al., 2025a, Vanhöfen et al., 2022) and needs to be studied further. Also, the sheer amount of positively perceived birds present in the area could play a role, since areas with high numbers of bird species are also more satisfying to live in, which is an unconscious mechanism (Hepburn et al., 2021).

As can be seen in Figure 15, two areas especially have a negative impact. These two parks especially present with large aggregations of "negative" species, resulting in a very low HRV_{place}. One location, for example, had more than 100 greylag geese (*Anser anser*) aggregating, and another had a flock of more than 100 feral pigeons (*Columba livia f. domestica*). This is important to note, since birds accumulating in large groups could also be perceived as threatening, especially if they are big and noisy. Many abundant species that form large aggregations, like geese, pigeons, and corvids, are associated with aggression (Belaire et al., 2015), dirt/ defecation (Leong et al., 2020), and disease transmission (Pejchar et al., 2025). Especially large birds, like greylag geese, egyptian geese (*Alopochen aegyptiaca*), mute swans (*Cygnus olor*), and great cormorants (*Phalacrocorax carbo*), are often perceived as a nuisance since they are loud, do not sing beautifully (Lukanowski, 2023), and oftentimes, people are even scared of them. These accumulations of birds need to be considered, which is why we used the species frequency in calculating our factor. But this is also one of the limitations of this analysis, since these two parks have a high impact on our analysis and therefore need not be overlooked. The large body size of birds has not been connected to a higher willingness to protect in earlier studies on birds (Randler & Koch, 2025), which is probably why birds with a low factor score are less beneficial for our mental well-being. On the other hand, colorful, cute birds increase positive feelings, especially in combination with beautiful bird song.

To conclude, attractive birds have a positive effect on people's mental well-being, namely satisfaction. This is important to know for improving human mental health and biodiversity conservation. Protecting aesthetically attractive and nicely singing species helps not only nature but also society. These birds can possibly function as a flagship or umbrella species, leading to conservation benefits for their whole habitat. It has been shown before that charisma and aesthetic attractiveness of species impact the allocation of conservation funding and efforts (Garnett et al., 2018; Lisǩová and Frynta, 2013). But also, some important flagship species, especially with birds, are dull-looking, small species, strongly impacted by humans. The HRV, as we propose it, is probably not

a useful measure for these species. It is a tool for urban species, able to enhance people's awareness of the benefits of biodiversity. If a bird species has as high HRV as we propose it, it is aesthetically attractive, has a beautiful song, is cute, and colorful. They are species that are able to elicit interest in people, even without a strong conservation background, and are a gateway into conservation and biodiversity awareness. It can also be a reason for planners to improve urban green spaces to attract these species and, therefore, not only create habitat for birds but also improve human mental well-being. But the method of calculating the HRV can surely be used for other applications as well. Using more or other variables in the calculation could help explore other patterns. For example, habitat affinity, foraging strategy, and nest types could be tested for differences between groups, conservation success, among other things. Future studies might therefore investigate the relationship between the HRV and other metrics, including population status, IUCN ranking of certain species, or shed light on relationships between conservation and HRV.

In the context of this study, it is essential to acknowledge that there is also a widely recognized connection between culture and the perceived value or awareness of biodiversity (Ladle et al., 2019; Millard et al., 2021). In many cultures, birds are connected to religion/folklore. This means that one species could be perceived as positive in one country and negative in another. Hummel et al. (2015), for example, found that there are significant differences between countries regarding the presence of myths surrounding birds.

This is why the present results need to be taken to a larger scale in further studies, in addition to being carefully interpreted in a cultural context. Right now, this study presents a method of analyzing bird species traits and connecting them with the well-being of recreationists, based in south-west Germany. Expanding the survey to other countries would result in more robust results regarding the connection of the HRV to human well-being. Nevertheless, our results are a promising start, showing that species traits of birds are indeed related to the human experience in recreational areas.

4. Summary of the results

All studies had predominantly female participants, aged young to middle-aged, with above-average levels of education. This is most likely due to recruitment style and participation bias. The results are therefore to be interpreted carefully with this in mind. In all studies, the mental well-being of participants was measured with the variables recalled restoration, emotions, satisfaction (with the visit), place attachment-identity, and place attachment-recovery.

In **Manuscript 1**, participants of the biodiversity and health study in 40 areas in southwest Germany were asked about their assessment of bird species richness. This was then compared to the assessment of ornithologists. Results showed that lay people systematically underestimate bird diversity. Nevertheless, their estimates correlate weakly with counts of ornithologists. A higher knowledge of birds led to more accurate predictions of bird diversity.

In **Manuscript 2**, perceived naturalness and bird diversity have been shown to be significant predictors of mental well-being. Additionally, high human impact on the area was associated with lower mental well-being. Places with greater perceived bird diversity resulted in higher recalled restoration ratings from participants. A positive perception of birds enhanced mental well-being, whereas a high level of birding specialization was associated with lower recalled restoration. Furthermore, ratings from the online survey (restoration and beauty) were associated with positive emotions experienced on-site, suggesting that virtual perception corresponds with real-world experiences. Again, a visible high human impact was related to lower ratings for beauty, perceived amounts of biodiversity, perceived naturalness and perceived restorativeness in the virtual study.

Perceived naturalness increased with bird diversity and decreased with high levels of human impact. In all manuscripts, this measurement was positively correlated with dimensions of mental well-being. People perceived places as more natural if they present a higher bird diversity with a small human impact.

The experimental studies in **Manuscripts 3 and 4** showed that the bird walks in general had positive effects on emotional and physiological stress parameters, but there was no significant effect of treatments on physiological stress markers (BP, HR, salivary Cortisol). They were conducted in a controlled environment, either artificially increasing bird song via speaker, or increasing the awareness of birdsong in participants.

The results showed that the awareness of birdsong is more crucial than actual species diversity. Additionally, visual cues (in form of signs) were slightly more effective than verbal ones. Therefore, raising awareness of birdsong, especially through visual signals, promotes the experience of nature and has a positive effect on well-being.

Raising awareness about the natural birdsong did lead to a better nature experience, which in turn was the primary influence on mental well-being. Perceived bird diversity did not differ between groups and did not impact either mental well-being or nature experience. This implies that awareness of, and not the actual species richness, is paramount for well-being benefits. Additionally, a better bird species knowledge and a positive nature experience led to improved mental well-being, as did a positive perception of birds and a higher estimated bird diversity.

Nature experience has emerged as a very important factor for mental well-being. Participants reporting a higher nature experience were more satisfied and reported higher emotions post-test and higher perceived restoration. People reporting higher perceived naturalness values perceived their restoration as higher after the walk. Participants with a positive perception of birds had a higher nature experience than participants with a lower perception of birds.

Participants' mental well-being was positively associated with their knowledge of bird species and situational nature experience. Additionally, the perception of birds positively influenced mental well-being and perceived biodiversity.

Manuscript 5 successfully related bird species traits of cuteness, attractivity, beauty of song and brightness (called HRV) to the mental well-being of recreationists in the 40 study areas of the biodiversity and health study. Bird species with a high HRV, such as the European Robin or Blue tit, have a positive effect on the place attachment and satisfaction of visitors. Species like Carrion Crow or Pigeons, on the other hand, may possibly even have a negative effect on people.

5. General Discussion

Experiencing nature is known to improve people's health and well-being. According to Keniger et al. (2013), it not only has a positive impact on physical health by way of stress reduction (Rozario et al., 2024), reduced blood pressure (Li et al., 2021; Pretty et al., 2005; Ulrich et al., 1991), and reduced cortisol levels (Opdahl et al., 2021; Park et al., 2010; Rozario et al., 2024; Van den Berg et al., 2015): It has also been shown to have a positive effect on mental processes, including improved mood (Cameron et al., 2020; Pretty et al., 2005) and psychological well-being (Kaplan, 2001; Kaplan, 1995; Wyles et al., 2019; Young et al., 2020), as well as benefitting cognitive processes, such as attentional restoration (Fuller et al., 2007; Hartig et al., 1991) and reduced mental fatigue (Moore et al., 2006). Additionally, experiencing nature can reduce anxiety and improve complex working memory performance (Bratman et al., 2015). Together these results emphasize the significance of human interaction with the environment in promoting mental well-being (Moser, 2009).

Impact of perception and landscape features on mental well-being

For the mental well-being of visitors in recreational areas, perceived naturalness and perceived bird diversity were significant predictors of improvement. Mental well-being decreased as human influence increased. Perceived naturalness correlated positively with actual bird diversity and negatively with the human impact factor (HFI). Interestingly, actual bird diversity or the number of biotope types was not directly linked to mental well-being. It appears that the experience of nature is the decisive factor, with perceived biodiversity being more important for mental well-being than actual bird diversity.

Bird species richness

Birds can provide both positive and negative interactions with humans, including beneficial ecosystem services like song as well as adverse effects such as aggression or pollution (Cox et al., 2018a). To analyze the effects of bird diversity on humans, it is vital to understand whether people are aware of - or even perceive - bird diversity. Literature shows mixed results, with some studies indicating that people cannot accurately assess biodiversity, particularly bird diversity (Dallimer et al., 2012), while others suggest the opposite (Fisher et al., 2021). This is why we asked our participants to estimate the number of birds they thought were present in the respective area and compared their estimates to those of ornithologists. The bird assessment was done in the morning and afternoon. Even though afternoon bird abundances were previously positively associated with a lower prevalence of depression, anxiety, and stress (Cox et al., 2017b), fewer birds are present during this time of day. However, it is also the time of day when people tend to go outside and experience nature most.

Results showed that the participants' estimated bird species richness was consistently lower than that of professionals, but proportionally similar. On average, their estimates were between professional morning and afternoon counts. This is similar to the study by Fisher et al. (2021), who found that participants could accurately estimate bird species richness in their immediate surroundings. Shwartz et al. (2014, 2023) also found that participants underestimated species richness and that there was no connection between observed and estimated species richness. Since the perceived bird diversity in the areas by participants in our survey was relatively accurate for the mean throughout the day, their assessment of bird diversity is likely due to factors other than direct observation, as people were mostly surveyed in the afternoon. They reported that more species were present at that time of day than the ornithologists had recorded. This mismatch in perception could be due to individual knowledge or the environment: people know that some habitats should harbor more species, even though they do not experience the birds themselves. People seem to perceive naturalness and biodiversity visually (Gonçalves et al., 2021), mostly concentrating on vegetation (Meng et al., 2024) and especially noticing trees (McEwan et al., 2020). Cameron et al. (2020) found that avian biodiversity was closely correlated with the participants' perception of biodiversity. Cues for estimating bird species richness could be vegetation height, evenness, and colorfulness, which were previously positively associated with perception of richness (Southon et al., 2018). Additionally, people's awareness is especially biased toward the most abundant species. They therefore estimate bird diversity as lower because they only perceive a small fraction of the overall diversity (Belaire et al., 2015; Celis-Diez et al., 2017). Both the individual's personal characteristics and the species' ecological traits determine park users' recognition of local biodiversity (Ishibashi et al., 2020).

It has to be kept in mind that professional ornithologists went out to specifically look for birds; meanwhile, lay people did not. Moreover, lay people were surveyed once, while ornithologists went out more often to get a complete picture of the bird diversity present. Recreationists mostly went out for relaxation purposes. Their surveys were mostly done in the afternoon, but participants estimated bird diversity higher than the ornithologist's afternoon count and lower than morning and total count. If recreationists went outside looking specifically for birds, their assessment could have probably been even closer to the professional counts. In the literature, there are differing results regarding the effects of actual and/or perceived species richness on human mental well-being. Some studies show a positive effect of actual biodiversity on the mental well-being of people (Dallimer et al., 2012; Fuller et al., 2007; Marselle et al., 2019). The large-scale survey study by Methorst et al. (2021a) found a significant positive relationship between bird species richness and mental health in Germany. Other studies show no effect of biodiversity or of actual bird species richness on mental well-being (Cox et al., 2017b; Dallimer et al., 2012; Taylor et al., 2018; Wu et al., 2024). Many studies are somewhat difficult to compare, since they do not use the same measure of biodiversity: Some focus on plants (Cox et al., 2017b; Marselle et al., 2020), while others examine different animal species like insects (Hussain et al., 2019) or birds (Fuller et al., 2013). Some even use a combination of biodiversity measurements (Dallimer et al., 2012).

In the present dissertation, the actual bird diversity did not affect participants' mental well-being or place attachment outcomes. Other studies also found no association between bird diversity, emotions and anxiety in urban mountain parks (Xu et al., 2022). Bird species richness does not improve mental well-being directly on-site, but still could have an indirect or delayed positive impact on people, since generally, having more species in a neighborhood has been shown to have a positive effect (Cox & Gaston, 2015; Fuller et al., 2013; Fuller et al., 2007; Methorst et al., 2021a). Having more bird species in the environment and being able to observe them has a positive effect on mental well-being (Cox & Gaston, 2015; Fuller et al., 2007). Listening to their songs helps to restore alertness and recover from stress (Ratcliffe et al., 2013), even though people's inability to sense and detect biodiversity may lead to a disconnect between biodiversity and their mental well-being (Marselle et al., 2020; Wu et al., 2024). Still, bird species richness was associated with increased life expectancy and overall health as well as decreased mortality in the US (Chen et al., 2023), connecting birds with positive effects on the environment of people. The abundance of bird species providing positive ecosystem services is highest in areas with medium population density, species providing disservices like aggression increase in abundance with increasing urbanization, lowering the chance for positive nature interaction even further in densely populated, socio-economically disadvantaged areas (Cox et al., 2018a).

In the presented study, a higher perceived bird diversity did lead to greater feelings of restoration in the participants. Additionally, a high perceived naturalness of the area led to more positive emotions, improved feelings of restoration as well as place attachment-identity and place attachment- recovery. The places perceived as more diverse in bird species also had higher recalled restoration rates of participants. Places with higher actual bird counts were perceived as more natural, and places with a higher human impact factor as less natural. This fits the study showing that small urban green spaces incorporating a variety of habitats and native plants support songbird richness well, sometimes even similarly to larger green spaces (Hayes Hursh et al., 2024). A high perceived naturalness of an area led to more positive emotions, higher recalled restoration, and place attachment of participants in our study, while also being areas supporting songbird richness. Similar to the study by Schebella et al. (2019b), the perceived measures of biodiversity are impacting well-being instead of actual/objective measures (e.g., actual bird diversity). Our participants did perceive places with more species actually present as more diverse in bird species, even though the numbers did not perfectly match up. This adds to the theory that their perception of bird species is assessed by factors other than actual birds observed. They probably have a mental image of what a biodiverse space should look like (e.g., from TV) and are therefore able to guess based on these preconcepts. Pett et al. (2016) call this the "people-biodiversity paradox": the mismatch between people's preferences for biodiversity and their actual perception, as well as the impact on subjective well-being. Gifford (2009) already hypothesized that biodiversity does probably not impact human health linearly, since some studies revealed that people benefit from higher plant diversity at certain levels, which decreased when these levels were exceeded (Lindemann-Matthies & Matthies, 2018; Schebella et al., 2020). Bratman et al. (2019) characterized the elements of nature potentially influencing mental health into area size, composition and configuration, and added tree canopy density, vegetation structure, species composition, and biodiversity as further factors.

Landscape characteristics and human impact

People in nature seem to be generally happier compared to when they are in a human-built environment (MacKerron & Mourato, 2013). Ward Thompson et al. (2012) found that people's perceived stress levels increased as the amount of green space in their local urban environment decreased. Wyles et al. (2019) demonstrated that the quality of recreational areas influences how effective they are in eliciting mental well-being benefits. They argue that recreational areas with protected status were linked to higher levels of recalled restoration and nature connectedness compared to locations without this status. Also, runners have been shown to prefer a park or green environment and rate it as more relaxing than a purely urban environment (Bodin & Hartig, 2003). Protected areas are often associated with greater ecosystem richness, which may indicate evolutionary advantages (Wilson, 1986), but also shows that natural environments differ in their restorative potential (Han, 2010). In other studies, high levels of biodiversity benefited the well-being and perceived restorativeness of an area (Carrus et al., 2015) as positive perceptions like calm and clear mind (Corney et al., 2019).

In addition to ecological data of biotope type (= habitats) diversity and bird diversity, we therefore assessed data on the HFI, urban/rural, blue/green/mixed (= area type), infrastructure, structure, and incivilities for the landscape characteristics. The amount of different vegetation-biotope types (habitats) and actual bird diversity present in the study areas were not connected to the mental well-being of participants. The number of biotopes and bird diversity correlated with each other, showing that both factors measure a similar thing: they are an approximation for the biodiversity present in the area. The literature on the effect of vegetation mostly paints a positive picture: Vegetation cover was connected to a lower prevalence of depression, anxiety and stress (Zhao et al., 2020), probably because these are the natural features that are most visible during the day and therefore most likely to be experienced by people (Cox et al., 2017b). Lower habitat diversity, reduced water cover and greater grass cover was associated with decreased general health (Mears et al., 2019), indicating positive effects of greater habitat diversity. Lindemann-Matthies et al. (2010) and Lindemann-Matthies & Matthies (2018) showed that plant diversity has a positive effect on restoration and that aesthetic appreciation increases with plant diversity, but also with the evenness and regular patterns. Landscape heterogeneity and habitat diversity have been shown to be positively associated with restoration, as reported by Cameron et al. (2020) and Houlden et al. (2021).

Most people prefer moderate biodiversity levels in urban areas, avoiding both sparse and overly dense vegetation, which can be seen as neglected (Phillips & Lindquist, 2021). The structural and visual complexity provided by moderately biodiverse areas and especially vegetation could provide restoration from directed attention, leading to improved mental health and restored cognitive function (Shanahan et al., 2015a). The naturalness perception in urban green spaces has been connected to maintenance of facilities, vegetation structure, and subjective estimations of biodiversity level before (Felappi et al., 2024), meaning that people mostly prefer a medium-managed area over a completely wild one.

Other than biodiversity, the present dissertation looked at additional landscape characteristics. Many intensively managed recreational areas situated in urban areas, including city parks or forests, but also rural areas are managed and shaped by humans. Pretty et al. (2005) showed that outdoor exercise in more rural, pleasant environments has more positive effects on mood, self-esteem, and blood pressure in comparison to physical activity in urban, unpleasant environments. Urban "natural" areas exist just as there are rural areas with a high human impact, which is why we use the classification of urban/rural only as a measure of the density of human settlements in the area. One should also consider the fluid transitions between these categories and the difference in classification depending on social and cultural background. Urban and rural can mean very different things in Germany or the USA. This is why we also used the HFI for a more objective measurement of human impact in our study areas. As another factor, Infrastructure, as presented here, is a combination of the present means of connections, accessibility, car parks, hiking routes, signposting, benches, playgrounds, and so on. The areas differ in their amount of infrastructure, even though most are well-developed and popular recreational areas. The HFI and infrastructure significantly influenced mental well-being in the biodiversity and health study. In places with higher HFI, the emotions and place attachment-identity ratings were lower. Additionally, more infrastructure led to lower place attachment values. Areas with more infrastructure and HFI are visited by more people and could be perceived as noisier, deprived, and polluted. Perceived road traffic, for example, was negatively related to restoration in a study by Subiza-Pérez et al. (2021). A great human impact may even be harmful to restoration since restoration as a concept is seen as an evolutionary-based response to certain landscapes by many (Kaplan & Kaplan, 1989; Ulrich et al., 1991).

Infrastructure and HFI are higher in more urban areas, but the differentiation of urban/rural did not matter for well-being outcomes, possibly indicating that instead of such a rigid and subjective two-dimensional classification, measures like the HFI are better for a more nuanced understanding of anthropogenic impacts. Interestingly, incivilities, such as trash, graffiti or feces, did not affect well-being outcomes. This is probably due to their rare occurrence, since most of the recreational areas are regularly cleaned by municipality workers. Structures have been present more often, meaning man-made things like buildings, roads, bridges, etc., which are necessary for access to the areas but not part of infrastructure, and a common sight for people. They also did not affect well-being outcomes, possibly being perceived as neutral by participants.

In literature, there is often a distinction between green spaces and blue spaces. Subiza-Pérez et al. (2020a) compared urban parks and beaches and found that users of beaches reported higher levels of attachment, identification, and experienced restoration than the participants surveyed in urban parks, even though the physical features of the environment and the routines of use made a negligible contribution to restoration outcomes. They instead found that the most important predictors for restoration were perceived restorativeness, attachment, and identification. In southwest Germany, blue spaces are not beaches but lakes and rivers of differing sizes. It could well be that the presence of beaches would have made an actual difference in mental well-being outcomes. For our participants, there was no difference between visiting a blue or a green space. The most important factor seems to be that it is an outside or natural area (Li et al., 2021). It also must be kept in mind that most landscapes are not always one type or the other, as most consist of many different characteristics and biotopes, which in turn can influence mental well-being and perception.

Perceived naturalness

The studies presented in this dissertation showed that areas perceived as more natural helped to increase the mental well-being of participants, possibly due to their stress-reducing or attention-restoring properties. The perceived naturalness correlates positively with actual bird diversity and negatively with the HFI. Additionally, areas with high human impact have been scored low in bird diversity. The number of habitats is correlated with estimated biodiversity richness and estimated beauty from the online study. Even though there was no direct connection between our measures of biodiversity and mental well-being, it could still be possible that places sporting a high biodiversity also have other beneficial landscape properties, which are actually important (Methorst et al., 2021b). People may differentiate or experience the landscape in terms of vegetation in general, leading to stress reduction (Cox et al., 2017b), since more varied green spaces were related to better mental well-being in previous studies (Marselle et al., 2019; Marselle et al., 2021b; Methorst et al., 2021a). Another possibility is that recreationists only found the “larger picture” of the landscape to be beneficial to their mental health (Ward Thompson et al., 2012).

Instead of environmental variables, the perception seems to be most important for the well-being of humans, which is very personal and subjective, as already proposed by Ratcliffe & Korpela (2016, 2018). They claim that the popular notion of considering psychological restoration as a universal evolutionary-based response triggered by certain environmental features is strongly limited by the neglect of personal variables that could also possibly account for this response. The experience of restoration is influenced by the extent to which a person sees a place as restorative (Subiza-Pérez et al., 2020a). The perceived restorative potential of a place, along with place attachment, has been shown to be a strong predictor for subjective restoration (Subiza-Pérez et al., 2021). In the study by Subiza-Pérez et al. (2021), favorite outdoor places have mainly been reported to be parks, urban forests, and bodies of water, all of them being rated higher in subjective restoration outcomes. Perceived restorative qualities and psychological bonding to a place stayed strongly associated with experienced restoration, even when looking at only urban squares (Subiza-Pérez et al., 2020b).

Neither the Structures, nor infrastructure, nor incivilities correlated with perception nor nature experience. In their perception of an area, people mostly concentrate on vegetation (Meng et al., 2024) and especially on trees (McEwan et al., 2020), leading to the presented results. Earlier studies showed that perception of species richness in an area is important for human mental well-being (Dallimer et al., 2012; Fuller et al., 2007; Marselle et al., 2019). In the surveys presented here, a higher perceived bird diversity in the areas led to better restoration for participants. But even more importantly, areas perceived as more natural evoked more positive emotions and a higher recalled restoration as well as place attachment in our participants. People seem to perceive their surrounding biodiversity mostly visually, since larger green spaces with taller and more colorful plants are perceived to be more diverse than smaller areas with shorter vegetation and fewer colors, irrespective of their actual plant diversity levels (Gonçalves et al., 2021; Hoyle et al., 2019; Southon et al., 2018). Tree cover (Jiang et al., 2020) or aesthetic value (Kothencz et al., 2017) could have been the more important factors influencing the perception of the areas as natural. The HFI is negatively correlated with the perceived naturalness of a place, which means that areas with less infrastructure and a lower human impact are perceived as more natural and therefore doubly impact well-being, since many people see "natural" as a direct counterpart of "anthropogenic" (Hartig et al., 2014). But there are nearly no completely undisturbed "natural" areas left in Germany, even the 16 national parks are not completely unmanaged (BfN, 2022). Our study areas are by no means perfectly "natural" by the definition of being "untouched". Completely wild areas are not the focus of this dissertation, since they are often not easily accessible and require preparation by recreationists.

The focus of the present dissertation is on recreational areas enabling some form of nature experience for many people, be it urban or rural, some in the middle of a bigger city, in smaller cities, their outskirts and villages. Additionally, for many people, some area management seems desirable, as sites left completely untouched are often perceived as less aesthetic than extensively managed sites (Martens et al., 2011). Managed alpine meadows, for example, had a more positive impact on stress reduction than abandoned meadows (Hussain et al., 2019). This could also have to do with feelings of safety, since according to Felappi et al. (2024), the perception of security is important to well-being. Additionally, Wilson's theory of biophilia states humans feel most at home and are best able to flourish in places that mimic the natural spaces in which the species evolved (Wilson, 1986). Therefore, the home areas could and should be different for many cultures, and the personal definition of "natural" could be quite different and depend strongly on the socialization of participants. For example, forests are perceived as more threatening by Hispanic Americans, African Americans, and women, whereas European Americans and men perceived them as less threatening (Scannell & Gifford, 2010). The perceptions of naturalness could also differ between cultures, which is why the results of this study should be interpreted cautiously when the areas of interest are in a different cultural area than southwest Germany.

Online survey

In the virtual survey, answers to the questions for restoration and beauty correlated with positive emotions experienced on-site, suggesting that virtual perception corresponds with real-world experiences. We showed participants pictures of the survey areas, asking for their perception of the places. Their estimates of biodiversity richness, naturalness and restoration value all correlated with the on-site perceived naturalness of the areas. This adds to the point that people do not need to experience bird species for roughly estimating the species richness in an area, as well as for perceptions of naturalness – they use visual cues, most probably looking at vegetation cover (Meng et al., 2024). Not surprisingly, other studies found positive connections between viewing virtual nature on the mental health of participants (Luo et al., 2022). Areas with greater ecological diversity were rated as more natural. Such areas were positively associated with greater perceived restorativeness in the study by Chang et al. (2024). Additionally, areas with more diversity in habitats and bird species were rated not only as more biodiverse but also as more beautiful. Areas perceived to be more natural do have higher bird diversity and are also similarly perceived as natural by of participants surveyed on-site. This strengthens the idea that people estimate biodiversity independently of their experience of it. Again, the HFI was also related to virtually rated biodiversity richness, naturalness, restoration value and beauty, giving further evidence that people do perceive a place similarly, regardless of experience: they do not need to be physically present to estimate naturalness and species richness. Additionally, subjective feelings of restoration have been connected to perceived restorative potential of a place, place attachment and place identification before (Subiza-Pérez et al., 2021). As Gifford (2009) already pointed out: "*The environment may not be in the head, as Wohlwill (1973) pointed out long ago, but people's assessments of the environments (which are in their heads) are absolutely important to their mental and physical health".* This is in line with earlier studies, reporting that participants perceiving nature scenes as more biodiverse received more positive results (Farris et al., 2024). In their study, they found that noticing and engaging with biodiversity is key to receiving its benefits.

Experimental effects of bird walks and awareness

Both the quantity and quality of vegetation in cities correlate with health. Physical activity on the other hand has been found to be less significant than greening (De Vries et al., 2013). Increasing urbanization leads to a lower availability of nature, meaning that interventions are needed for people to still be able to gain the benefits of experiencing nature. Shanahan et al. (2015a) found that the response to such interventions is not linear: Short expositions can bring immediate benefits while longer exposure times are needed for sustainable, long-lasting improvements. We concentrated on short-term exposure, trying to find out if benefits can be amplified using bird diversity. Generally, the intervention was a 30-minute-long bird walk through an urban park on the outskirts of the city. In both of our experimental studies, participants reported improved mood and showed reduced physiological stress parameters directly afterwards. Walking and physical activity have a general positive effect on physical (Sugiyama et al., 2008) and mental (White et al., 2013) health. In earlier studies, participants who walked outdoors showed substantially better moods than those who walked indoors (Nisbet et al., 2019). Longer walks correlated with higher positive effects, while more people present at the scene had a negative effect on mood (Nghiem et al., 2021).

Mental well-being was mainly influenced by participants' experience of nature. Additionally, directing attention toward natural birdsong through verbal cues led to an enhanced nature experience. Adding supplemental birdsong via playback, however, had no positive effect on mental well-being or the nature experience compared to natural song. In comparison of two attentional interventions, the visual attention treatment led to higher perceived sound recovery and a stronger perception of birdsong than the verbal instruction. On an individual level, nature experience, knowledge of bird species, and positive perceptions of birds were all positively correlated with improved mental well-being. Participants with a more positive perception of birds also reported higher perceived biodiversity in the area.

Physiological stress parameters

Outdoor exercise led to significant improvements in blood pressure, mood and self-esteem in earlier studies (Pretty et al., 2005). Even short, regular activities in natural environments have significant positive benefits for mental health (Barton & Pretty, 2010). In the two experimental studies shown in this dissertation, physiological stress parameters, blood pressure, heart rate and salivary cortisol levels were reduced after the walk. They were not correlated with the mental well-being variables we asked for as a subjective well-being assessment. Kondo et al. (2018) also found very inconsistent results regarding the connection between self-report stress measures and physiological stress measures, with most studies analyzed in the meta-analysis reporting differing results. Overall, the literature remains inconclusive on the effect of nature on physiological stress response (Corazon et al., 2019). Birdsong has been highlighted for its calming effects in literature (Buxton et al., 2021) and may play a role in the stress-reducing benefits of natural environments (Ulrich et al., 1991). Artificially increasing the amount of birdsong with a “phantom chorus” has been reported for its restorative benefits (Ferraro et al., 2020), which was not reproduced in the similar study of this dissertation. In this study, there was a gender effect for HR and BP, and perceived bird species richness and situational nature experience impacted the post-test heart rate.

Cortisol

After the walks, salivary cortisol levels generally decreased. This may suggest but is not indicative of a physiologically reduced stress level. In earlier studies, positive effects were associated with lower cortisol and a negative effect with higher concentrations (Polk et al., 2005), which could also be connected to the environment people are in. Opdahl et al. (2021) demonstrated a decrease in salivary cortisol among hikers in more biodiverse areas. A lot of additional variables, such as adrenal sensitivity, capacity, and cortisol binding affect salivary cortisol levels, which is why perceived stress can only be moderately associated with them (Hellhammer et al., 2009).

The decrease in salivary cortisol levels was significant in both studies and with a steeper slope than would be a normal cortisol awakening response (CAR). The CAR is an established mechanism which exhibits a sharp increase right after waking from sleep, followed by a slow and steady decrease in salivary cortisol levels over time (Stalder et al., 2016), which could potentially mask experimental effects since the studies took place in the morning. Polk et al. (2005) established a slope for the decrease of salivary cortisol following the CAR as -0.11 (women) and -0.09 (men). In both studies, participants exhibited a significantly steeper decrease (−0.52 and -0.51, respectively), meaning that we can assume some stress-reducing effects of the bird walks independent of treatment groups and of the CAR. Forest environments have been shown to promote lower cortisol concentrations, heart rate and blood pressure relative to city environments (Park et al., 2010). The study site in the present experiments is on the city's outskirts and is of park-like nature. Such parks are a reality for most people seeking restoration in green spaces, since they are more easily accessible than a big forest area, for example. We could show positive effects of the walks, even though the physiological variables were not correlated with the subjective well-being variables nor influenced by the experimental treatments.

Heart rate

The heart rate (HR) was significantly lower after the walk in the first experimental study and showed a marginal non-significant decrease in the second one. A lowered HR is indicative of lower stress levels, especially since participants have just completed the physical activity of walking for 30 minutes (Sugiyama et al., 2008). A high perceived bird species richness led to a lower HR, and a higher nature experience led to an increased HR. It could be argued that this is due to green – and often biodiverse − environments being able to lower heart rate (Kondo et al., 2018) and that a certain amount of nature experience could have led to more excitement and therefore to a higher heart rate.

Blood pressure

The blood pressure only decreased slightly in both studies, which was the most inconsistent result we found. The decrease was not significant compared to pre-walk levels in the first experimental study, but in the second. Even though HR and BP seem to provide the most convincing evidence of stress-reducing properties in some earlier studies (Coventry et al., 2021), Kondo et al. (2018) found no association of nature-based interventions, like walking in green spaces, with lowering blood pressure.

Artificial increase in bird species richness

Natural sounds can make people relax physically and psychologically (Li et al., 2021). Soundscapes generally have two main attributes for people: pleasantness and eventfulness (Erfanian et al., 2021). Soundscape pleasantness is the emotional part of the sound perception, while soundscape eventfulness is the intensity of the sound perception (Erfanian et al., 2019). Additionally, people have expectations of how a location will sound, depending on their prior experience, and therefore, they anticipate certain types of sound to be present in a particular space (Bruce & Davies, 2014).

In the first experimental study, experienceable bird species richness was artificially increased by playing additional birdsong via speakers. Shwartz et al. (2014) enhanced urban biodiversity by planting flowers and providing additional resources for their other target taxa (birds, pollinators). Their participants expressed a preference for a rich diversity of species, but did not notice it, underestimating species richness. Similarly in our study, the perceived bird diversity did not differ between groups and did not impact either mental well-being or nature experience. As the perceived bird species richness did not differ between the groups, most people did not realize there was more birdsong than normal. The artificial increase in bird species was possibly not large enough. Because there is a strong connection between the pleasantness of sound and visuals (Bogdanov et al., 2022), the pleasing and relaxing visuals of our study area may not have been overridden by our treatment - "only" 7 additional native species were used. Laboratory studies could test if this is the case, and if so, also ask where the threshold is for "enough" artificial birdsong to get an effect. The soundscape may have been masked more strongly by street noise than expected, even though the sound level ranges have been checked and were in the normal range. The study area is a park-like structure of the botanical gardens, situated right next to the northern ring road of the city. Noise pollution is possible and can have negative effects on the physical and mental well-being and health of people (Gramann, 1999) by causing both physical and psychological stress (Ouis, 2001) and also being related to a higher prevalence of depression (Stobbe et al., 2022).

While playing additional birdsong did not affect mental well-being, raising awareness about natural birdsong did lead to a better nature experience, which in turn was the primary influence on mental well-being. This implies that awareness, and not the actual species richness, is important for receiving benefits. In the study by Ferraro et al. (2020), playing additional birdsong along a hiking trail improved psychological restoration, but results regarding noticing were inconsistent, with only some participants reporting correctly. In the online experiment by Farris et al. (2024), increasing the levels of bird diversity through birdsong in a video of a UK woodland location had no additional significant effect on the affective response of participants. Perceived quality of a birdsong seems to have more positive effects than objective quantity (Flowers et al., 2016).

Heightened awareness through verbal or visual cues

As discussed, people seem to value what they perceive as diverse, independent of actual species richness (Breitschopf & Bråthen, 2023). Environment-oriented activities like walking can increase the perception of an area's restorative properties (Carrus et al., 2015), but this is not guaranteed, since most nature interactions happen passively (Cox et al., 2017a). Most people do not directly interact with nature, as such nature interactions are primarily indirect, e.g. through a window (Cox et al., 2017a). Often, these situations are incidental when a person is physically present in nature, but the interaction is an unintended result of another activity, which is different to intentional ones in which the participant has the aim to interact with nature (Keniger et al., 2013). People actively paying attention to natural aspects such as scents or birdsong reported greater well-being and better relaxation, which underlines the importance of active, emotional engagement with nature for maximizing health benefits (Harries et al., 2025).

In the first experimental Arboretum-study, raised awareness through verbal cues led to a better nature experience of participants and more positive emotions after the walk. The groups receiving a visual prompt in the second experimental study reported higher perceived restorativeness of ambient sound and birdsong than the group receiving a verbal cue. In both experimental studies, a raised awareness of the environment mainly influenced the nature experience of participants, instead of mental well-being or physiological stress parameters. Since the group with visual reminders was more regularly reminded to pay attention along the way, their awareness was probably repeatedly triggered, instead of the group receiving one verbal reminder at the beginning of the walk. Being more mindful has led to greater awareness and stronger feelings of connectedness with nature (Nisbet et al., 2019). Heightened awareness was associated with a more positive perceived restorativeness (sound) of the study area in our experimental studies as well. Participants noted their surroundings more and profited from the presence of natural features, as auditory pleasantness increases in the presence of natural, rather than urban, visual environments (Bogdanov et al., 2022). They also reported more perceived birdsong. In previous nature-based interventions, participants paying attention to their natural surroundings reported increased positive emotions and a stronger sense of connectedness to nature (Passmore & Holder, 2017; Passmore et al., 2022). In the study by Shwartz et al. (2014), participants only noticed the increased native flower richness in gardens using advertisements and public involvement. In other intervention studies, participants who were asked to pay attention to their natural surroundings reported positive emotions and a general sense of connectedness to nature (Passmore & Holder, 2017; Passmore et al., 2022).

Individual traits and nature experience

Individual personality traits also play an important role because the restorative benefits people derive from nature experiences depend on how they interact with and treat nature (Colléony et al., 2020). The connection with nature correlates with psychological well-being, a sense of purpose and vitality (Cervinka et al., 2012). Experiences of nature are complex, they are a process and embedded in social and cultural contexts (Clayton et al., 2017). Additionally, mental well-being is subjective, especially considering the measurements assessed in the present dissertation: positive emotions, satisfaction with the visit, and feeling restored, in addition to place attachment.

Nature experience can be influenced by many personal factors, such as birding knowledge, a positive perception of birds, and nature connectedness. In the two experimental studies, mental well-being was affected by participants' nature experience and bird species knowledge. Direct nature experience helps as a catalyst to transform knowledge into actual action and positive attitudes, whereby perceived freedom in direct experiences is an important factor for their effectiveness (Duerden & Witt, 2010).

Traits such as species knowledge are influenced by things like age or education (Hooykaas et al., 2019; Randler & Heil, 2021), older people or people who have spent more time in the educational system also have more time to learn about their surroundings. Graduation level or university degree did not impact the reported perceived species count, which is not surprising - everyone can experience nature independently of education. Randler & Heil (2021) and Rögele et al. (2022) were able to show that the self-reported birding knowledge correlates strongly with scores from knowledge tests. This is why self-reported bird knowledge strongly correlated with the estimated number of species, meaning that people who think of themselves as having more knowledge of birds made more correct estimates of the bird species present. Dallimer et al. (2012) were also able to show that people with higher identification skills are more likely to perceive species richness accurately. Gender was also weakly related to the perceived number of bird species, with men tending to report higher numbers. Other studies concluded that men are more interested in birding (Moore et al., 2008; Randler, 2021a). In contrast, female participants reported a higher recalled restoration and higher place attachment-recovery than male participants. This is probably due to individual differences predisposing some females to higher restoration benefits from green space (Feng et al., 2022). Barton & Pretty (2010) noted that men and women experience similar effects on self-esteem, even though the effects on mood differed. In addition, older participants rated their recalled restoration and place attachment-identity higher than younger participants in our study, which could be due to older/middle-aged people benefiting most from positive mood effects (Barton & Pretty, 2010).

Individual traits, such as positive perception of birds, high birding specialization, and bird species knowledge, are connected to a positive nature experience. Participants with a high perception of birds and species knowledge may possibly be people with a higher nature connectedness, as a positive species sentiment has been linked to the human-nature connection (Hayes Hursh et al., 2024). Improving the personal nature experience also means improving the mental well-being of people. On an individual level, a better understanding of birds and a more positive perception of them are correlated with improved mental well-being among participants. Self-assessed birding knowledge and perception of birds show us the people who know what they're talking about. Interest in birds is connected to the opportunity to encounter birds in the wild (Mittermeier et al., 2021). Recreationists with more specialized knowledge may be able to assess the situation more accurately. Additionally, general awareness of biodiversity is increasing (Millard et al., 2021).

A high birding knowledge was linked to lower recalled restoration. There could be frustration at play with seasoned birders, like when the target species is not seen on the day. Randler et al. (2023a) were able to show that non-birders benefit more from outings in satisfaction and restoration than serious birders, as the potential for frustration is higher for more professional ornithologists, whereas feelings of success arrive earlier for novice or non-birders. Still, they benefit from the outing in nature, which is shown by the high levels of positive emotions. Participants with a more positive perception of birds rated their emotions more positively and presented with a higher recalled restoration and place attachment. Participants with a higher perception of birds reported the highest ratings of bird diversity in the biodiversity and health survey. They also reported better mental well-being in the experimental studies. A higher perceived bird diversity was connected to better mental well-being as well. The positive effect may be due to feelings of stronger nature connectedness (Nisbet et al., 2019), since people receiving psychological benefits of being outside also often report a higher connectedness to nature (Mayer et al., 2009). A high level of perceived restorativeness has been associated with a sense of connection to nature (Berto et al., 2018). This emotional connectedness can influence participation in nature-based activities (Cheng & Monroe, 2012). They may therefore benefit more from spending time outside in a green space (Camacho-Guzmán et al., 2023; Ferraro et al., 2020). People with a higher nature relatedness have more motivation to use the urban parks in their neighborhoods (Lin et al., 2014).

Nature experience has been connected to increased awareness in the experimental studies as well. Participants reporting a better nature experience were also more satisfied with their visit after the walk, reporting higher positive emotions and perceived restoration values as well. Meng et al. (2024) found that nature-relatedness mediated the relationship between perceived biodiversity and mental well-being. In the experimental studies, participants perceived the area as more natural if their perception of birds is high, which could speak for a high mental affinity to nature. They also have a more positive nature experience. People who have a high connectedness to nature benefit more from being outside. People with a greater nature connectedness have been shown to report more positive nature experiences in earlier studies (Härtel et al., 2023), and in our experimental studies, a better nature experience also contributed positively to the mental well-being of participants. In the study by Berto et al. (2018), individuals with differing degrees of connection to nature sought different degrees of restorativeness in their preferred recreational areas. In the biodiversity and health study, we mostly surveyed people already outside, who are likely to have a higher general preference for nature and outdoor activities than those we could have surveyed in the city. Nonetheless, the theories of ART and SRT are based on the notion that we have a built-in evolutionary preference for certain natural features (Kaplan & Kaplan, 1989; Ulrich, 1983), which may help explain why our study areas had a more positive effect the more natural they were perceived to be. However, this remains a subjective perception and the "natural" areas are still easily accessible recreational locations in southwest Germany. Additionally, nature experience is not limited to nature connectedness but has also been linked to appreciation (Wolsko & Lindberg, 2013), time spent in nature, and awareness (Breitschopf & Bråthen, 2023). In the study by Subiza-Pérez et al. (2021), personality traits did not play a significant role in restorative experiences. But in their study, nature-orientedness and urban-orientedness were important and both positively associated with subjective restoration in outdoor environments, while only nature-orientedness was negatively associated with subjective restoration in indoor settings. Stronger nature orientation was a predictor of better mental health, social cohesion and positive physical activity (Cox et al., 2018b). In the study by Cox et al. (2017a), regular contact with nature was more the exception than the rule. Contact with nature has been highest in rural areas, decreasing with increasing urbanization, which is why city people with low nature contact have the highest potential for health improvements through spending time in nature (Cox et al., 2018b). Prévot et al. (2018) found that taking part in nature experiences with a focus on biodiversity leads to significantly more knowledge about biodiversity than experiences with an implicit focus. They also were able to show that regular nature experiences lead to a stronger connection with nature, and this connection is even more pronounced in people with an explicit focus on biodiversity.

Bird species traits

Human engagement with birds is determined by a combination of visual stimuli, psychological mechanisms, and a degree of familiarity. Birds are often associated with feelings of freedom or thoughts of their chirping, i.e. mostly positive connoted (Eylering et al., 2025). In the study by Eylering et al. (2025), the Eurasian blackbird was identified as the most recognized bird species in Germany on the species level. To assess the beneficial influence of birds like the blackbird on human well-being, we also looked at the species traits possibly influencing the effects. Birdsong, for example, is one of the most important factors for stimulating well-being responses and stress reduction (Fisher et al., 2023), underscoring the notion that birds singing beautifully have a positive impact and birds screaming or warning have a more negative one. Birdsong has even been shown to be able to buffer the negative effects of traffic noise (Uebel et al., 2022) and improve anxiety (Stobbe et al., 2022), which makes it a very important part of urban soundscapes. A greater variety of birdsong is perceived as more attractive in urban areas and increases psychological well-being (Ferraro et al., 2020) as listening to birdsong promotes stress management and attention restoration (Ferraro et al., 2020; Ratcliffe et al., 2013). People, therefore, associate birdsong with good mood (Eylering et al., 2025; Ferraro et al., 2020).

Since birds are often difficult to see in urban environments, their song is the primary way in which they are perceived (Ratcliffe et al., 2013). But not all birdsongs are equally appreciated. Their attractiveness depends heavily on the characteristics of the song: a greater variety is perceived as more pleasant and leads to increased well-being, which contrasts with monosyllabic songs (da Silva et al., 2022; Ferraro et al., 2020; Hedblom et al., 2014). Melodic songs are clearly preferred over harsher ones (Garnett et al., 2018). Calls from magpies, crows, gulls, and geese, for example, are even perceived as stressful since they are associated with aggressive behaviors (Hedblom et al., 2014; Ratcliffe et al., 2013).

The other way in which birds are perceived is visually. Stoudt et al. (2022) found that opportunistic birders mostly engaged with larger, more colorful birds, often with a wider range. Colors and behavior follow behind sound as a determinant of well-being (Fisher et al., 2023). Colorfulness, bright appearance, and big ornaments have also been associated with the attractiveness of birds (Santangeli et al., 2023; Santarém et al., 2019; Veríssimo et al., 2014). Small birds are often more positively connotated than bigger birds (Randler & Koch, 2025; Santangeli et al., 2023). Additionally, the willingness to protect or donate to a species does not primarily depend on its rarity or status: human preferences for protection are determined more by charisma than by rarity or threat (Albert et al., 2018). Factors such as subjective cuteness, coloring, and species knowledge have a positive influence on willingness to protect (Randler & Koch, 2025). It has been shown before that charisma and aesthetic attractiveness of species impact the allocation of conservation funding and efforts (Garnett et al., 2018; Lišková & Frynta, 2013).

Big and noisy birds accumulating in groups could be perceived as threatening. Species like graylag geese (*Anser anser*), egyptian geese (*Alopochen aegyptiaca*), mute swans (*Cygnus olor*), and great cormorant

(*Phalacrocorax carbo*) are often perceived as nuisance since they are loud and do not sing melodically (Lukanowski, 2023). When forming large aggregations, they are also often associated with aggression (Belaire et al., 2015), dirt/defecation (Leong et al., 2020), and disease transmission (Pejchar et al., 2025). Bird species receiving a high human restoration value (HRV) score are mostly species commonly rated as cute, colorful, visually attractive, and with a nice song. They are the species that elicit interest in people, even without a strong conservation background, and are a gateway into conservation and biodiversity awareness. The HRV correlates with satisfaction, and both place attachment scales of the biodiversity and health study. Areas with more beneficial bird species can therefore help with stress reduction in line with the ideas of ART and SRT. But since the HRV only correlates with place attachment and satisfaction and not with restoration or emotions, the effect on cognitive restoration remains unclear. It has been shown that nature experiences have a positive influence on concentration, but not unequivocally for all kinds of cognitive tests, meaning that there are still questions as to which attention capacities are recuperated with nature contact (Ohly et al., 2016).

It is essential to acknowledge that there is a widely recognized connection between culture and the perceived value or awareness of biodiversity (Ladle et al., 2019; Millard et al., 2021). In many cultures, birds are connected to folklore. This means that one species could be perceived as positive in one country and negative in another. Hummel et al. (2015), for example, found that there are significant differences between countries regarding the presence of myths surrounding birds. In many cultures, prominent birds are linked to human feeding, recognized as food or a threat to crops, as well as abundance, color and detectability (Ortega-Álvarez & Casas, 2023).

Implications and Limitations

The results of this dissertation have broad implications for urban planning, nature conservation, public health, and environmental education. Local biodiversity loss has similar effects on ecosystem processes as other global stress factors, such as global warming or rising CO_2 levels (Hooper et al., 2012), which is why nature conservation is a key factor in preventing loss of ecosystem services. Pro-ecological behavior can be promoted by repeated interactions with everyday nature and individual knowledge (Cosquer et al., 2012). A wide range of experiences with nature is necessary to develop a deeper connection to nature, biodiversity, and nature conservation (Clayton et al., 2017). Current and childhood experiences with nature correlate positively with an appreciation of biodiversity. The increasing loss of daily interaction is a major problem for nature conservation (Soga et al., 2016). Even though there already is strong biophilia in western countries, with people attributing high intrinsic value to nature and great importance to its significance for human health (Van den Born et al., 2001), planners and conservationists can use arguments for human (mental) health benefits to justify further measures.

The present dissertation was able to show again that walking in park-like environments improved mental and physiological well-being. Physiological stress parameters of Cortisol, BP, and HR decrease, and participants feel refreshed, calmer, and more peaceful. This is only a situational assessment of well-being, instead of classical psychological data like anxiety or depression tests. Subjective well-being measures like emotions or satisfaction have been shown to be valuable data in practical research (Arlinghaus, 2006; White et al., 2023). There is even a growing practice in preventive medicine called *forest bathing* (Ideno et al., 2017). It has been suggested that exposure to green vegetation and nature helps with various health outcomes, including cardiovascular diseases (James et al., 2015; Kondo et al., 2018) and stress reduction (Park et al., 2010). Looking at our results of walking in an urban park, people seeking health benefits do not need to directly go to forests but can easily use the green spaces in front of their door. This positive effect depends on the availability of green spaces in neighborhoods and their ability to support natural structures which in turn can be used by humans. Since lay people are relatively good at assessing biodiversity collectively, visitor data in recreational areas can be used as a valuable indicator of the perceived biological quality of an area. They were able to roughly estimate the diversity of bird species, but underestimated the actual numbers compared to ornithologists who were counting in the morning, in contrast to participants being mainly out and about at midday and in the afternoon.

For well-being outcomes, the perceived naturalness and diversity of species were more decisive than the data collected by biologists. A high human footprint and a lot of infrastructure correlated negatively with well-being and perceived naturalness. Increasing perceived bird diversity and naturalness while lowering human impact can promote mental well-being in recreational areas. Green spaces can and should be accessible for all and therefore provide a positive influence on people´s well-being on the community level. The study of Nutsford et al. (2013) suggests that a certain proximity to green spaces and the proportion of green in the neighborhood are associated with a lower incidence of anxiety and mood disorders. But according to them, the immediate surroundings are less influential than the neighborhood, highlighting the importance of the visual perception of green spaces. The motivation to use urban parks depends more on nature connectedness and relatedness than on the actual availability of green spaces (Lin et al., 2014). As it has been shown that infrastructure and HFI have shown negative effects on emotions and place attachment, recreational areas should be designed in such a way that anthropogenic influences are minimized. In addition, an increase in urban green space helps with conservation, as such areas can be steppingstones for biodiversity while simultaneously benefiting human well-being.

Bird species that are perceived as cute, colorful, visually attractive or possessing a beautiful song promote satisfaction and place attachment to a location. Therefore, urban green spaces could be developed in such a way that they specifically attract bird species with such positive characteristics to maximize well-being. However, when many ecologically important species do not exhibit a high HRV, this value should never be the only deciding factor for habitat creation measures. It could be used as an argument for planners to improve urban spaces to attract beneficial species and, therefore, not only create habitat for birds but also improve human mental well-being. Areas with high numbers of bird species are also more satisfying to live in (Hepburn et al., 2021).

Participants who were encouraged by signs to pay attention to birdsong reported a higher perceived restorative sound and a more intense perception of birdsong. However, playing additional birdsong did not lead to a further increase in well-being compared to natural song. Therefore, the protection of real and intact soundscapes is of more importance. Signs are more effective than verbal instructions alone in enhancing the restorative effect. We do have to keep in mind that the verbal instructions were given only once in the beginning. They are not comparable to bird field trips with an expert.

Individual factors played a significant role in how much people benefit from nature. People with positive attitudes towards bird species or greater species knowledge reported a greater experience of nature and better mental well-being. A lack of ecological knowledge could lead to growing alienation from nature, which could reduce support for conservational efforts. necessitating educational and social interventions to raise awareness and appreciation of biodiversity (Pett et al., 2016). To achieve this, positive interactions with nature could help in increasing sympathy for conservation goals (Miller, 2005), providing the required strong public support to encourage governments to implement effective conservation policies (WHO, 2005b). People with nature experience are more likely to implement pro-biodiversity practices (Prévot et al., 2018). As subjective nature experience seems to be the key to improving mental well-being, it is probably more helpful to increase nature connection or an emotional connectedness to nature instead of focusing on cold, hard species knowledge. Still, both go hand in hand. Emotional connectedness is higher with more knowledge. This is why ongoing research must take greater account of individual factors such as attachment to birds or species knowledge, as experts and lay people react differently to natural stimuli. Participants in the biodiversity and health survey study were people already present in the area. Therefore, they were probably already personally inclined towards nature. We did not ask about the connectedness to nature or nature-relatedness (Nisbet et al., 2009), which could have helped in interpreting the data. Because people were already outside, we can assume that there was some kind of connectedness to nature, so it remains unclear if we have data for people not feeling connected to nature. Checking if urban-oriented people also received the benefits we showed here would be interesting.

The studies presented in this thesis are based on southwest Germany, a landscape heavily influenced by humans. The study areas differ in biodiversity but are otherwise similar on a global scale. In this area, many negative effects from wildlife are not imminent. There are no (dangerously) poisonous snakes or many zoonotic diseases dangerous for humans present. Such factors increase in importance towards the tropics, for example (Grace et al., 2012) and need to be considered when studying the effects on people in these regions. Keniger et al. (2013) found a bias towards higher latitudes in studies regarding the effects of nature on humans. This bias could affect the intensity and the types of benefits studied, since cultural and socio-economic characteristics may also influence responses to interactions with nature (Teel et al., 2007; Warber & Irvine, 2006). Negative effects from being in nature have also not been part of this dissertation project.

The present thesis did not assess possible trade-offs or disservices, masking potential benefits. A full understanding of effects requires acknowledging potential trade-offs and the presence of ecosystem disservices (Ulrich et al., 2023). We looked at human disservices, like incivilities or feces, but not at possibilities of wildlife attacks or disease transmission, and not at direct physical impacts like pollution.

In summary, it can be said that protecting biodiversity is not only an ecological goal, but also a direct investment in the mental and physical health of people, with the way in which people perceive nature being the decisive mechanism of action. This is particularly true for urban areas that are still less developed in ecological terms.

6. Conclusion and Outlook

The present dissertation aimed to understand how birds can influence people's mental well-being. It found that lay people underestimate the actual bird diversity present and do not realize an artificially increased species richness. Determinants of mental well-being are perceived naturalness, perceived bird diversity and a positive perception of birds. Additionally, there is a negative effect of human impact and infrastructure on mental well-being, place attachment and perception.

An unguided bird walk in urban park recreational areas improves emotions and physiological stress parameters. This means that the perception of nature or its parts, such as naturalness or bird diversity, is a key factor influencing mental well-being when in recreational areas. Areas that are perceived as more natural, with less human impact, have a more positive effect. Increasing awareness of one's surroundings further enhances the experience of nature and subsequently mental well-being. For this, visual cues, such as signage, have been proven to work adequately well.

This thesis presents an important result for city planning and conservation practices alike. Areas that are perceived as more natural have a positive effect not only on wildlife but also on human mental well-being. Therefore, appropriate management helps both sides – it could even be argued that there are no sides in this matter. Further studies could look closely into what is perceived as "natural" and how to improve such perceptions, in addition to maintaining habitats for biodiversity. It is also important to further raise awareness of nature and biodiversity, not only in school but in everyday life. This means getting people to go outside and experience nature in the first place. Once outdoors, individuals' awareness of their surroundings significantly affects their experience and can also be used to foster place attachment and a sense of ownership. Further studies could check how signage can be optimized for increasing knowledge, since many people ignore it in parks.

Another interesting point raised is the question of whether different bird species effect people differently. In a first attempt, Manuscript 5 shows that there is a difference between a goose or swan, for example, from a nightingale or a blue tit. These effects of bird species traits may be the missing link between perceived and real bird diversity, as well as their contribution to people's mental well-being and are an promising direction for further research.

In summary, the results indicate that the perception of naturalness and biodiversity, as well as the promotion of positive experiences of nature, are the decisive factors for increasing mental well-being in recreational areas. This applies especially where human influence is low. Birds are mostly present in natural areas, which in turn also positively influences humans. Increasing awareness of their song also increases recreational benefits, although species traits also play a role, the extent of which still needs to be determined. Most importantly, people should be encouraged to not only go outside, but also to experience nature intentionally, helping to raise awareness for biodiversity and to retain natural and biodiverse areas.

References

Aardal, E., & Holm, A.-C. (1995). Cortisol in saliva-reference ranges and relation to cortisol in serum.

Aardal-Eriksson, E., Karlberg, B. E., & Holm, A.-C. (1998). Salivary Cortisol - an Alternative to Serum Cortisol Determinations in Dynamic Function Tests. *36*(4), 215–222. https://doi.org/doi:10.1515/CCLM.1998.037

Adjei, P. O.-W., & Agyei, F. K. (2015). Biodiversity, environmental health and human well-being: analysis of linkages and pathways. *Environment, development and sustainability*, *17*, 1085–1102.

Aerts, R., Honnay, O., & Van Nieuwenhuyse, A. (2018). Biodiversity and human health: mechanisms and evidence of the positive health effects of diversity in nature and green spaces. *British Medical Bulletin*, *127*(1), 5–22. https://doi.org/10.1093/bmb/ldy021

Albert, C., Luque, G. M., & Courchamp, F. (2018). The twenty most charismatic species. *PloS one*, *13*(7), e0199149.

Arlinghaus, R. (2006). On the apparently striking disconnect between motivation and satisfaction in recreational fishing: the case of catch orientation of German anglers. *North American Journal of Fisheries Management*, *26*(3), 592–605.

Aronson, M. F., La Sorte, F. A., Nilon, C. H., Katti, M., Goddard, M. A., Lepczyk, C. A., Warren, P. S., Williams, N. S., Cilliers, S., & Clarkson, B. (2014). A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings of the Royal Society B: Biological Sciences*, *281*(1780), 2013333

Askerlund, P., Almers, E., Tuvendal, M., & Waite, S. (2024). Growing nature connection through greening schoolyards: Preschool teachers' response to ecosystem services innovations. *Education 3-13*, *52*(8), 1341–1352.

Avram, R., Tison, G. H., Aschbacher, K., Kuhar, P., Vittinghoff, E., Butzner, M., Runge, R., Wu, N., Pletcher, M. J., Marcus, G. M., & Olgin, J. (2019). Real-world heart rate norms in the Health eHeart study. *NPJ Digit Med*, *2*, 58. https://doi.org/10.1038/s41746-019-0134-9

Barthel, P. H., & Krüger, T. (2019). *Liste der Vögel Deutschlands: Version 3.2*. Deutsche Ornithologische Gesellschaft

Barton, J., & Pretty, J. (2010). What is the best dose of nature and green exercise for improving mental health? A multi-study analysis. *Environmental science & technology*, *44*(10), 3947–3955.

Belaire, J. A., Westphal, L. M., Whelan, C. J., & Minor, E. S. (2015). Urban residents' perceptions of birds in the neighborhood: Biodiversity, cultural ecosystem services, and disservices. *The Condor*, *117*(2), 192–202. https://doi.org/10.1650/condor-14-128.1

Bergmann, H.-H., Engländer, W., & Baumann, S. (2020). *Die Stimmen der Vögel Europas auf DVD*, AULA-Verlag.

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science*, *19*(12), 1207–1212.

Berman, M. G., Kross, E., Krpan, K. M., Askren, M. K., Burson, A., Deldin, P. J., ... & Jonides, J. (2012). Interacting with nature improves cognition and affect for individuals with depression. *Journal of affective disorders*, *140*(3), 300-305.

Berto, R. (2005). Exposure to restorative environments helps restore attentional capacity. *Journal of Environmental Psychology*, *25*(3), 249–259.

Berto, R., Barbiero, G., Barbiero, P., & Senes, G. (2018). An individual's connection to nature can affect perceived restorativeness of natural environments. Some observations about biophilia. *Behavioral Sciences*, *8*(3), 34.

Beyer, K. M., Kaltenbach, A., Szabo, A., Bogar, S., Nieto, F. J., & Malecki, K. M. (2014). Exposure to neighborhood green space and mental health: evidence from the survey of the health of Wisconsin. *International journal of environmental research and public health*, *11*(3), 3453–3472.

BfN, (2022). Nationalparke in Deutschland (Stand: Januar 2022). https://www.bfn.de/nationalparke). Last assessed 05.12.2025.

Bibby, C. J., Burgess, N. D., Ecologists, E. A., Hillis, D. M., Hill, D. A., Ornithology, B. T. f., Mustoe, S., Birds, R. S. f. t. P. o., Lambton, S., & International, B. (2000). *Bird Census Techniques*. Elsevier Science. https://books.google.de/books?id=Ld5wkzPp49cC

BirdLife International (2026) Country factsheet: Germany. Downloaded from https://datazone.birdlife.org/country/factsheet/germany on 02/02/2026.

Boakes, E. H., McGowan, P. J., Fuller, R. A., Chang-qing, D., Clark, N. E., O'Connor, K., & Mace, G. M. (2010). Distorted views of biodiversity: spatial and temporal bias in species occurrence data. *PLoS biology*, *8*(6), e1000385.

Bodin, M., & Hartig, T. (2003). Does the outdoor environment matter for psychological restoration gained through running? *Psychology of sport and exercise*, *4*(2), 141–153.

Bogdanov, V., Marquis-Favre, C., Cottet, M., Beffara, B., Perrin, F., Dumortier, D., & Ellermeier, W. (2022). Nature and the City: Audiovisual interactions in pleasantness and psychophysiological reactions. *Applied Acoustics*, *193*, 108762.

Boley, B. B., Strzelecka, M., Yeager, E. P., Ribeiro, M. A., Aleshinloye, K. D., Woosnam, K. M., & Mimbs, B. P. (2021). Measuring place attachment with the abbreviated place attachment scale (APAS). *Journal of Environmental Psychology*, *74*, 101577.

Borgi, M., Cogliati-Dezza, I., Brelsford, V., Meints, K., & Cirulli, F. (2014). Baby schema in human and animal faces induces cuteness perception and gaze allocation in children. *Frontiers in Psychology*, *5*, 411.

Bozovic, D., Racic, M., & Ivkovic, N. (2013). Salivary cortisol levels as a biological marker of stress reaction. *Med Arch*, *67*(5), 374–377.

Bratman, G. N., Daily, G. C., Levy, B. J., & Gross, J. J. (2015). The benefits of nature experience: Improved affect and cognition. *Landscape and Urban Planning*, *138*, 41–50.

Bratman, G. N., Anderson, C. B., Berman, M. G., Cochran, B., De Vries, S., Flanders, J., Folke, C., Frumkin, H., Gross, J. J., & Hartig, T. (2019). Nature and mental health: An ecosystem service perspective. *Science advances*, *5*(7), eaax0903.

Breitschopf, E., & Bråthen, K. A. (2023). Perception and appreciation of plant biodiversity among experts and laypeople. *People and Nature*, *5*(2), 826–838.

Brown, C., & Grant, M. (2005). Biodiversity and human health: What role for nature in healthy urban planning? *Built Environment*, *31*(4), 326–338.

Bruce, N. S., & Davies, W. J. (2014). The effects of expectation on the perception of soundscapes. *Applied Acoustics*, *85*, 1–11. https://doi.org/https://doi.org/10.1016/j.apacoust.2014.03.016

Bryce, R., Irvine, K. N., Church, A., Fish, R., Ranger, S., & Kenter, J. O. (2016). Subjective well-being indicators for large-scale assessment of cultural ecosystem services. *Ecosystem Services*, *21*, 258–269. https://doi.org/https://doi.org/10.1016/j.ecoser.2016.07.015

BKG - Bundesamt für Kartographie und Geodäsie. (2023). Produkte und Dienste. Assessed 30 Aug, 2024; https://gdz.bkg.bund.de.

Butler, S. J., Boccaccio, L., Gregory, R., Vorisek, P., & Norris, K. (2010). Quantifying the impact of land-use change to European farmland bird populations. *Agriculture, Ecosystems & Environment*, *137*(3-4), 348–357.

Buxton, R. T., Pearson, A. L., Allou, C., Fristrup, K., & Wittemyer, G. (2021). A synthesis of health benefits of natural sounds and their distribution in national parks. *Proceedings of the National Academy of Sciences*, *118*(14), e2013097118.

Callaghan, C. T., Poore, A. G. B., Hofmann, M., Roberts, C. J., & Pereira, H. M. (2021). Large-bodied birds are over-represented in unstructured citizen science data. *Scientific Reports*, *11*(1), 19073. https://doi.org/10.1038/s41598-021-98584-7

Camacho-Guzmán, A., vila Akerberg, V. D. Ã., Martínez-Soto, J., Rodríguez-Soto, C., & Reyes, R. P. R. (2023). Connectedness to Nature, Well-Being and Presence of Birds. *Fronteira: Journal of Social, Technological and Environmental Science*, *12*(1), 248–264.

Cameron, R. W. F., Brindley, P., Mears, M., McEwan, K., Ferguson, F., Sheffield, D., Jorgensen, A., Riley, J., Goodrick, J., Ballard, L., & Richardson, M. (2020). Where the wild things are! Do urban green spaces with greater avian biodiversity promote more positive emotions in humans? *Urban Ecosystems*, *23*(2), 301–317. https://doi.org/10.1007/s11252-020-00929-z

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., Narwani, A., Mace, G. M., Tilman, D., & Wardle, D. A. (2012). Biodiversity loss and its impact on humanity. *Nature*, *486*(7401), 59–67.

Carrus, G., Scopelliti, M., Lafortezza, R., Colangelo, G., Ferrini, F., Salbitano, F., Agrimi, M., Portoghesi, L., Semenzato, P., & Sanesi, G. (2015). Go greener, feel better? The positive effects of biodiversity on the well-being of individuals visiting urban and peri-urban green areas. *Landscape and Urban Planning*, *134*, 221–228.

Celis-Diez, J. L., Muñoz, C. E., Abades, S., Marquet, P. A., & Armesto, J. J. (2017). Biocultural homogenization in urban settings: Public knowledge of birds in city parks of Santiago, Chile. *Sustainability*, *9*(4), 485.

Cervinka, R., Röderer, K., & Hefler, E. (2012). Are nature lovers happy? On various indicators of well-being and connectedness with nature. *Journal of health psychology*, *17*(3), 379–388.

Chang, J., Wu, C.-C., & Chang, C.-Y. (2024). Landscape naturalness and restoring benefit: a connection through bird diversity. *Urban Ecosystems*, *27*(1), 41–50. https://doi.org/10.1007/s11252-023-01425-w

Chen, Z., Hermes, J., Liu, J., & von Haaren, C. (2022). How to integrate the soundscape resource into landscape planning? A perspective from ecosystem services. *Ecological Indicators*, *141*, 109156.

Chen, Y., Zhao, P., Xu, Q., Qu, B., Li, D., Clement, S., & Li, L. (2023). Relating biodiversity with health disparities of human population: An ecological study across the United States. *One Health*, *16*, 100548.

Cheng, J. C.-H., & Monroe, M. C. (2012). Connection to nature: Children's affective attitude toward nature. *Environment and Behavior*, *44*(1), 31–49.

Clayton, S., Colléony, A., Conversy, P., Maclouf, E., Martin, L., Torres, A. C., Truong, M. X., & Prévot, A. C. (2017). Transformation of experience: Toward a new relationship with nature. *Conservation Letters*, *10*(5), 645–651.

Coensel, B. D., Vanwetswinkel, S., & Botteldooren, D. (2011). Effects of natural sounds on the perception of road traffic noise. *The Journal of the Acoustical Society of America*, *129*(4), EL148–EL153.

Colléony, A., Levontin, L., & Shwartz, A. (2020). Promoting meaningful and positive nature interactions for visitors to green spaces. *Conservation Biology*, *34*(6), 1373–1382. https://doi.org/https://doi.org/10.1111/cobi.13624

Collins, R. M., Spake, R., Brown, K. A., Ogutu, B. O., Smith, D., & Eigenbrod, F. (2020). A systematic map of research exploring the effect of greenspace on mental health. *Landscape and Urban Planning*, *201*, 103823.

Corazon, S. S., Sidenius, U., Poulsen, D. V., Gramkow, M. C., & Stigsdotter, U. K. (2019). Psycho-physiological stress recovery in outdoor nature-based interventions: A systematic review of the past eight years of research. *International journal of environmental research and public health*, *16*(10), 1711.

Corney, H., & Neave, M. (2019). I can hear the birds: using audio recordings to assess perceptions of amenity in urban riparian environments. *Urban Ecosystems*, *22*(2), 235-247.

Cosquer, A., Raymond, R., & Prevot-Julliard, A.-C. (2012). Observations of everyday biodiversity: a new perspective for conservation? *Ecology and Society*, *17*(4).

Coventry, P. A., Brown, J. E., Pervin, J., Brabyn, S., Pateman, R., Breedvelt, J., Gilbody, S., Stancliffe, R., McEachan, R., & White, P. L. (2021). Nature-based outdoor activities for mental and physical health: Systematic review and meta-analysis. *SSM-population health*, *16*, 100934.

Cox, D. T., & Gaston, K. J. (2015). Likeability of garden birds: Importance of species knowledge & richness in connecting people to nature. *PloS one*, *10*(11), e0141505.

Cox, D. T., Hudson, H. L., Shanahan, D. F., Fuller, R. A., & Gaston, K. J. (2017a). The rarity of direct experiences of nature in an urban population. *Landscape and Urban Planning*, *160*, 79–84.

Cox, D. T., Shanahan, D. F., Hudson, H. L., Plummer, K. E., Siriwardena, G. M., Fuller, R. A., Anderson, K., Hancock, S., & Gaston, K. J. (2017b). Doses of neighborhood nature: the benefits for mental health of living with nature. *BioScience*, *67*(2), 147–155.

Cox, D. T., Hudson, H. L., Plummer, K. E., Siriwardena, G. M., Anderson, K., Hancock, S., Devine-Wright, P., & Gaston, K. J. (2018a). Covariation in urban birds providing cultural services or disservices and people. *Journal of Applied Ecology*, *55*(5), 2308–2319.

Cox, D. T., Shanahan, D. F., Hudson, H. L., Fuller, R. A., & Gaston, K. J. (2018b). The impact of urbanisation on nature dose and the implications for human health. *Landscape and Urban Planning*, *179*, 72–80.

da Silva, O. C., Melo Santos, A. M., Schiel, N., & Souto, A. (2022). Like Music to our Ears: The Complexity of Bird Vocalizations as a Key Factor of Attractiveness. *Anthrozoös*, *35*(1), 91–104.

Daily, G. C., Polasky, S., Goldstein, J., Kareiva, P. M., Mooney, H. A., Pejchar, L., Ricketts, T. H., Salzman, J., & Shallenberger, R. (2009). Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment*, *7*(1), 21–28.

Dallimer, M., Irvine, K. N., Skinner, A. M., Davies, Z. G., Rouquette, J. R., Maltby, L. L., Warren, P. H., Armsworth, P. R., & Gaston, K. J. (2012). Biodiversity and the feel-good factor: understanding associations between self-reported human well-being and species richness. *BioScience*, *62*(1), 47–55.

de Brito, J. N., Pope, Z. C., Mitchell, N. R., Schneider, I. E., Larson, J. M., Horton, T. H., & Pereira, M. A. (2019). Changes in psychological and cognitive outcomes after green versus suburban walking: A pilot crossover study. *International journal of environmental research and public health*, *16*(16), 2894.

De Vries, S., Van Dillen, S. M., Groenewegen, P. P., & Spreeuwenberg, P. (2013). Streetscape greenery and health: Stress, social cohesion and physical activity as mediators. *Social Science & Medicine*, *94*, 26–33.

De Vries, S., & Snep, R. (2019). Biodiversity in the context of 'biodiversity–mental health'research. *Biodiversity and health in the face of climate change*, 159–173.

Deci, E. L., & Ryan, R. M. (2000). The" what" and" why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological inquiry*, *11*(4), 227–268.

Deci, E. L., & Ryan, R. M. (2012). Self-determination theory.

Dierschke, V. (2020). *Welcher Vogel ist das?* Kosmos.

Ding, Y., Xiong, L., Ji, F., Lu, J., Zhu, X., & Huang, H. (2022). Using citizen science data to improve regional bird species list: A case study in Shaanxi, China. *Avian Research*, *13*, 100045.

Douglas, J. W., & Evans, K. L. (2021). An experimental test of the impact of avian diversity on attentional benefits and enjoyment of people experiencing urban green-space. *People and Nature*.

Droseltis, O., & Vignoles, V. L. (2010). Towards an integrative model of place identification: Dimensionality and predictors of intrapersonal-level place preferences. *Journal of Environmental Psychology*, *30*(1), 23–34.

Duerden, M. D., & Witt, P. A. (2010). The impact of direct and indirect experiences on the development of environmental knowledge, attitudes, and behavior. *Journal of Environmental Psychology*, *30*(4), 379–392.

Duke, L., & Soulsbury, C. D. (2021). Human–wildlife interaction networks at urban blue spaces. *Area*, *53*(1), 122–133.

Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S., Schewenius, M., Sendstad, M., & Seto, K. C. (2013). *Urbanization, biodiversity and ecosystem services: challenges and opportunities: a global assessment*. Springer Nature.

Erfanian, M., Mitchell, A. J., Kang, J., & Aletta, F. (2019). The psychophysiological implications of soundscape: A systematic review of empirical literature and a research agenda. *International journal of environmental research and public health*, *16*(19), 3533.

Erfanian, M., Mitchell, A., Aletta, F., & Kang, J. (2021). Psychological well-being and demographic factors can mediate soundscape pleasantness and eventfulness: A large sample study. *Journal of Environmental Psychology*, *77*, 101660.

Eylering, A., Kampel, S., Röstermundt, L., Funk, M., Boldt, J., & Fiebelkorn, F. (2025). What Do People Associate With Birds? Exploring Social Representations in the German Public. *Anthrozoös*, *38*(2), 273–297.

Farina, A., Lattanzi, E., Malavasi, R., Pieretti, N., & Piccioli, L. (2011). Avian soundscapes and cognitive landscapes: theory, application and ecological perspectives. *Landscape ecology*, *26*, 1257–1267.

Farinha-Marques, P., Lameiras, J., Fernandes, C., Silva, S., & Guilherme, F. (2011). Urban biodiversity: a review of current concepts and contributions to multidisciplinary approaches. *Innovation: The European Journal of Social Science Research*, *24*(3), 247–271.

Farris, S., Dempsey, N., McEwan, K., Hoyle, H., & Cameron, R. (2024). Does increasing biodiversity in an urban woodland setting promote positive emotional responses in humans? A stress recovery experiment using 360-degree videos of an urban woodland. *PloS one*, *19*(2), e0297179.

Felappi, J. F., Sommer, J. H., Falkenberg, T., Terlau, W., & Kötter, T. (2024). Urban park qualities driving visitors mental well-being and wildlife conservation in a Neotropical megacity. *Scientific Reports*, *14*(1), 4856.

Feng, X., Astell-Burt, T., Standl, M., Flexeder, C., Heinrich, J., & Markevych, I. (2022). Green space quality and adolescent mental health: do personality traits matter? *Environmental Research*, *206*, 112591.

Ferraro, D. M., Miller, Z. D., Ferguson, L. A., Taff, B. D., Barber, J. R., Newman, P., & Francis, C. D. (2020). The phantom chorus: birdsong boosts human well-being in protected areas. *Proceedings of the Royal Society B: Biological Sciences*, *287*(1941), 20201811. https://doi.org/doi:10.1098/rspb.2020.1811

Fisher, J. C., Irvine, K. N., Bicknell, J. E., Hayes, W. M., Fernandes, D., Mistry, J., & Davies, Z. G. (2021). Perceived biodiversity, sound, naturalness and safety enhance the restorative quality and wellbeing benefits of green and blue space in a neotropical city. *Science of the Total Environment*, *755*, 143095.

Fisher, J. C., Rankin, E., Irvine, K. N., Goddard, M. A., Davies, Z. G., & Dallimer, M. (2022). Can biodiverse streetscapes mitigate the effects of noise and air pollution on human wellbeing? *Environmental Research*, *212*, 113154.

Fisher, J. C., Dallimer, M., Irvine, K. N., Aizlewood, S. G., Austen, G. E., Fish, R. D., King, P. M., & Davies, Z. G. (2023). Human well-being responses to species' traits. *Nature Sustainability*, *6*(10), 1219–1227. https://doi.org/10.1038/s41893-023-01151-3

Flowers, E. P., Freeman, P., & Gladwell, V. F. (2016). A cross-sectional study examining predictors of visit frequency to local green space and the impact this has on physical activity levels. *BMC Public Health*, *16*(1), 420. https://doi.org/10.1186/s12889-016-3050-9

Forster, P. M. (2010). A brief introduction to environmental psychology. *Date of access*, *22*(01), 2012.

Fredrickson, B. L. (1998). What good are positive emotions? *Review of general psychology*, *2*(3), 300–319.

Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H., & Gaston, K. J. (2007). Psychological benefits of greenspace increase with biodiversity. *Biology letters*, *3*(4), 390–394.

Fuller, R. A., Irvine, K. N., Davies, Z. G., Armsworth, P. R., & Gaston, K. J. (2013). Interactions between people and birds in urban landscapes.

Garnett, S. T., Ainsworth, G. B., & Zander, K. K. (2018). Are we choosing the right flagships? The bird species and traits Australians find most attractive. *PloS one*, *13*(6), e0199253.

Gerlach, B., R. Dröschmeister, T. Langgemach, K. Berlin, K. Borkenhagen, M. Busch, S. Davids, V. Dierschke, M. Hauswirth, T. Heinicke, F. Kunz, C. König, K. Koffijberg, K. Lindner, N. Markones, A. Morkovin, C. Pertl, S. Trautmann, J. Wahl,…Sudfeldt, C. (2025). Vögel in Deutschland–Bestandssituation 2025. *DDA, BfN, LAG VSW, Münster*.

Gidlow, C. J., Jones, M. V., Hurst, G., Masterson, D., Clark-Carter, D., Tarvainen, M. P., Smith, G., & Nieuwenhuijsen, M. (2016). Where to put your best foot forward: Psycho-physiological responses to walking in natural and urban environments. *Journal of Environmental Psychology*, *45*, 22–29.

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., Ellis, N., Hurst, G., Masterson, D., & Cirach, M. (2018). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening*, *29*, 322–333.

Gifford, R. (2009). Environmental psychology: Manifold visions, unity of purpose. *Journal of Environmental Psychology*, *29*(3), 387–389.

Gonçalves, P., Grilo, F., Mendes, R. C., Vierikko, K., Elands, B., Marques, T. A., & Santos-Reis, M. (2021). What's biodiversity got to do with it? Perceptions of biodiversity and restorativeness in urban parks. *Ecology and Society*, *26*(3).

Gorleri, F. C., Jordan, E. A., Roesler, I., Monteleone, D., & Areta, J. I. (2022). Using photographic records to quantify accuracy of bird identifications in citizen science data. *Ibis*, *n/a*(n/a). https://doi.org/https://doi.org/10.1111/ibi.13137

Grace, D., Mutua, F. K., Ochungo, P., Kruska, R. L., Jones, K., Brierley, L., Lapar, M. L., Said, M. Y., Herrero, M., & Phuc, P. (2012). Mapping of poverty and likely zoonoses hotspots.

Grahn, P., & Stigsdotter, U. A. (2003). Landscape planning and stress. *Urban Forestry & Urban Greening*, *2*(1), 1–18.

Gramann, D. J. (1999). The effect of mechanical noise and natural sound on visitor experiences in units of the national park system. *US Government Documents (Utah Regional Depository)*, 428.

Graziano, M. S., & Kastner, S. (2011). Human consciousness and its relationship to social neuroscience: A novel hypothesis. *Cognitive neuroscience*, *2*(2), 98–113.

Gregory, R. D., Voříšek, P., Noble, D. G., Van Strien, A., Klvaňová, A., Eaton, M., Meyling, A. W. G., Joys, A., Foppen, R. P., & Burfield, I. J. (2008). The generation and use of bird population indicators in Europe. *Bird Conservation International*, *18*(S1), S223–S244.

Gregory, R. D., & Van Strien, A. (2010). Wild bird indicators: using composite population trends of birds as measures of environmental health. *Ornithological Science*, *9*(1), 3–22.

Grellier, J., White, M. P., Albin, M., Bell, S., Elliott, L. R., Gascón, M., Gualdi, S., Mancini, L., Nieuwenhuijsen, M. J., & Sarigiannis, D. A. (2017). BlueHealth: a study programme protocol for mapping and quantifying the potential benefits to public health and well-being from Europe's blue spaces. *BMJ open*, *7*(6), e016188.

Gunnar, M., & Quevedo, K. (2007). The Neurobiology of Stress and Development. *Annual Review of Psychology*, *58*(Volume 58, 2007), 145–173. https://doi.org/https://doi.org/10.1146/annurev.psych.58.110405.085605

Ha, J., & Kim, H. J. (2021). The restorative effects of campus landscape biodiversity: Assessing visual and auditory perceptions among university students. *Urban Forestry & Urban Greening*, *64*, 127259.

Haahtela, T. (2019). A biodiversity hypothesis. *Allergy*, *74*(8), 1445–1456.

Han, K.-T. (2010). An exploration of relationships among the responses to natural scenes: Scenic beauty, preference, and restoration. *Environment and Behavior*, *42*(2), 243–270.

Harries, B., Chalmin-Pui, L. S., Gatersleben, B., Griffiths, A., & Ratcliffe, E. (2025). Noticing nature: The role of environmental awareness in promoting well-being. *People and Nature*, *7*(10), 2307–2319.

Härtel, T., Randler, C., & Baur, A. (2023). Using species knowledge to promote pro-environmental attitudes? The association among species knowledge, environmental system knowledge and attitude towards the environment in secondary school students. *Animals*, *13*(6), 972.

Hartig, T., Mang, M., & Evans, G. W. (1991). Restorative effects of natural environment experiences. *Environment and Behavior*, *23*(1), 3–26.

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S., & Gärling, T. (2003). Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology*, *23*(2), 109–123.

Hartig, T., Mitchell, R., De Vries, S., & Frumkin, H. (2014). Nature and health. *Annual review of public health*, *35*, 207–228.

Haukka, A., Lehikoinen, A., Mammola, S., Morris, W., & Santangeli, A. (2023). The iratebirds citizen science project: A dataset on birds' visual aesthetic attractiveness to humans. *Scientific data*, *10*(1), 297.

Hayes Hursh , S., Perry, E., & Drake, D. (2024). What informs human–nature connection? An exploration of factors in the context of urban park visitors and wildlife. *People and Nature*, *6*(1), 230–244.

Hedblom, M., Heyman, E., Antonsson, H., & Gunnarsson, B. (2014). Bird song diversity influences young people's appreciation of urban landscapes. *Urban Forestry & Urban Greening*, *13*(3), 469–474.

Hedblom, M., Gunnarsson, B., Schaefer, M., Knez, I., Thorsson, P., & Lundström, J. N. (2019). Sounds of nature in the city: No evidence of bird song improving stress recovery. *International journal of environmental research and public health*, *16*(8), 1390.

Hellhammer, D. H., Wüst, S., & Kudielka, B. M. (2009). Salivary cortisol as a biomarker in stress research. *Psychoneuroendocrinology*, *34*(2), 163–171.

Hepburn, L., Smith, A. C., Zelenski, J., & Fahrig, L. (2021). Bird Diversity Unconsciously Increases People's Satisfaction with Where They Live. *Land*, *10*(2), 153. https://www.mdpi.com/2073-445X/10/2/153

Höll, N., Gerstner, H., Raddatz, J., Murmann-Kristen, L., Mast, R., Breunig, T., & Demuth, S. (2009). Arten, Biotope, Landschaft. *Schlüssel zum Erfassen, Beschreiben, Bewerten. fourth ed. LUBW, Karlsruhe*.

Hong, J. Y., Lam, B., Ong, Z. T., Ooi, K., & Gan, W. S. (2025). Perceptual and psychoacoustical characteristics of birdsongs. *Applied Acoustics*, *239*, 110869.

Hooper, D. U., Adair, E. C., Cardinale, B. J., Byrnes, J. E., Hungate, B. A., Matulich, K. L., Gonzalez, A., Duffy, J. E., Gamfeldt, L., & O'Connor, M. I. (2012). A global synthesis reveals biodiversity loss as a major driver of ecosystem change. *Nature*, *486*(7401), 105–108.

Hooykaas, M. J., Schilthuizen, M., Aten, C., Hemelaar, E. M., Albers, C. J., & Smeets, I. (2019). Identification skills in biodiversity professionals and laypeople: A gap in species literacy. *Biological Conservation*, *238*, 108202.

Houlden, V., Jani, A., & Hong, A. (2021). Is biodiversity of greenspace important for human health and wellbeing? A bibliometric analysis and systematic literature review. *Urban Forestry & Urban Greening*, *66*, 127385.

Hoyle, H., Hitchmough, J., & Jorgensen, A. (2017). All about the 'wow factor'? The relationships between aesthetics, restorative effect and perceived biodiversity in designed urban planting. *Landscape and Urban Planning*, *164*, 109–123.

Hoyle, H., Jorgensen, A., & Hitchmough, J. D. (2019). What determines how we see nature? Perceptions of naturalness in designed urban green spaces. *People and Nature*, *1*(2), 167–180.

Huby, M., Cinderby, S., Crowe, A., Gillings, S., McClean, C., Moran, D., Owen, A., & White, P. (2006). The association of natural, social and economic factors with bird species richness in rural England. *Journal of Agricultural Economics*, *57*(2), 295–312.

Hummel, E., Fancovicová, J., Randler, C., Ozel, M., Usak, M., Medina-Jerez, W., & Prokop, P. (2015). Interest in Birds and its Relationship with Attitudes and Myths: A Cross-cultural Study in Countries with Different Levels of Economic Development. *Educational Sciences: Theory and Practice*, *15*(1), 285–296.

Hussain, R. I., Walcher, R., Eder, R., Allex, B., Wallner, P., Hutter, H.-P., Bauer, N., Arnberger, A., Zaller, J. G., & Frank, T. (2019). Management of mountainous meadows associated with biodiversity attributes, perceived health benefits and cultural ecosystem services. *Scientific Reports*, *9*(1), 14977.

Ideno, Y., Hayashi, K., Abe, Y., Ueda, K., Iso, H., Noda, M., Lee, J.-S., & Suzuki, S. (2017). Blood pressure-lowering effect of Shinrin-yoku (Forest bathing): A systematic review and meta-analysis. *BMC complementary and alternative medicine*, *17*, 1–12.

Inder, W. J., Dimeski, G., & Russell, A. (2012). Measurement of salivary cortisol in 2012–laboratory techniques and clinical indications. *Clinical endocrinology*, *77*(5), 645–651.

IPBES, I. S.-P. P. o. B. E. S. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services.

Irvine, K. N., & Warber, S. L. (2002). Greening healthcare: practicing as if the natural environment really mattered. *Alternative Therapies in Health & Medicine*, *8*(5).

Isbell, F., Craven, D., Connolly, J., Loreau, M., Schmid, B., Beierkuhnlein, C., Bezemer, T. M., Bonin, C., Bruelheide, H., & De Luca, E. (2015). Biodiversity increases the resistance of ecosystem productivity to climate extremes. *Nature*, *526*(7574), 574–577.

Ishibashi, S., Akasaka, M., Koyanagi, T. F., Yoshida, K. T., & Soga, M. (2020). Recognition of local flora and fauna by urban park users: Who notices which species? *Urban Forestry & Urban Greening*, *56*, 126867.

James, P., Banay, R. F., Hart, J. E., & Laden, F. (2015). A review of the health benefits of greenness. *Current epidemiology reports*, *2*(2), 131–142.

Jiang, X., Larsen, L., & Sullivan, W. (2020). Connections between daily greenness exposure and health outcomes. *International journal of environmental research and public health*, *17*(11), 3965.

Jimenez, M. P., DeVille, N. V., Elliott, E. G., Schiff, J. E., Wilt, G. E., Hart, J. E., & James, P. (2021). Associations between nature exposure and health: a review of the evidence. *International journal of environmental research and public health*, *18*(9), 4790.

Joye, Y., & De Block, A. (2011). 'Nature and I are two': A critical examination of the biophilia hypothesis. *Environmental Values*, *20*(2), 189–215.

Joye, Y., Pals, R., Steg, L., & Evans, B. L. (2013). New methods for assessing the fascinating nature of nature experiences. *PloS one*, *8*(7), e65332.

Joye, Y., & Dewitte, S. (2018). Nature's broken path to restoration. A critical look at Attention Restoration Theory. *Journal of Environmental Psychology*, *59*, 1–8.

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge university press.

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182. https://doi.org/https://doi.org/10.1016/0272-4944(95)90001-2

Kaplan, R. (2001). The nature of the view from home: Psychological benefits. *Environment and Behavior*, *33*(4), 507–542.

Kaplan, S., & Berman, M. G. (2010). Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on psychological science*, *5*(1), 43–57.

Keller, M. C., Fredrickson, B. L., Ybarra, O., Côté, S., Johnson, K., Mikels, J., Conway, A., & Wager, T. (2005). A Warm Heart and a Clear Head: The Contingent Effects of Weather on Mood and Cognition. *Psychological Science*, *16*(9), 724–731. https://doi.org/10.1111/j.1467-9280.2005.01602.x

Keniger, L. E., Gaston, K. J., Irvine, K. N., & Fuller, R. A. (2013). What are the benefits of interacting with nature? *International journal of environmental research and public health*, *10*(3), 913–935.

Kirschbaum, C., & Hellhammer, D. H. (1989). Salivary cortisol in psychobiological research: an overview. *Neuropsychobiology*, *22*(3), 150–169.

Kirschbaum, C., & Hellhammer, D. H. (1994). Salivary cortisol in psychoneuroendocrine research: recent developments and applications. *Psychoneuroendocrinology*, *19*(4), 313–333.

Kleist, N. J., Guralnick, R. P., Cruz, A., & Francis, C. D. (2016). Anthropogenic noise weakens territorial response to intruder's songs. *Ecosphere*, *7*(3), e01259. https://doi.org/https://doi.org/10.1002/ecs2.1259

Knobel, P., Maneja, R., Bartoll, X., Alonso, L., Bauwelinck, M., Valentin, A., Zijlema, W., Borrell, C., Nieuwenhuijsen, M., & Dadvand, P. (2021). Quality of urban green spaces influences residents' use of these spaces, physical activity, and overweight/obesity. *Environmental Pollution*, *271*, 116393.

Kondo, M. C., Jacoby, S. F., & South, E. C. (2018). Does spending time outdoors reduce stress? A review of real-time stress response to outdoor environments. *Health & place*, *51*, 136–150.

Korpela, K., & Hartig, T. (1996). Restorative qualities of favorite places. *Journal of Environmental Psychology*, *16*(3), 221–233.

Korpela, K. M., Ylén, M., Tyrväinen, L., & Silvennoinen, H. (2010). Favorite green, waterside and urban environments, restorative experiences and perceived health in Finland. *Health promotion international*, *25*(2), 200–209.

Korpela, K., Pasanen, T., & Ratcliffe, E. (2018). Biodiversity and psychological well-being. *Urban biodiversity. Routledge, New York*, 134–149.

Korpela, K., Korhonen, M., Nummi, T., Martos, T., & Sallay, V. (2020). Environmental self-regulation in favourite places of Finnish and Hungarian adults. *Journal of Environmental Psychology*, *67*, 1013.

Kothencz, G., Kolcsár, R., Cabrera-Barona, P., & Szilassi, P. (2017). Urban green space perception and its contribution to well-being. *International journal of environmental research and public health*, *14*(7), 766.

Kövér, L., Paládi, P., Benmazouz, I., Šorgo, A., Špur, N., Juhász, L., Czine, P., Balogh, P., & Lengyel, S. (2022). Is the Hitchcock story really true? Public opinion on hooded crows in cities as input to management. *Animals*, *12*(9), 1207.

Kowarik, I. (2011). Novel urban ecosystems, biodiversity, and conservation. *Environmental Pollution*, *159*(8-9), 1974–1983.

Krause, J., Ruxton, G. D., & Krause, S. (2010). Swarm intelligence in animals and humans. *Trends in ecology & evolution*, *25*(1), 28–34.

Kühne, O. (2019). Landscape Theories. A Brief Introduction. Springer Fachmedien Wiesbaden.

Kuo, F. E., Sullivan, W. C., Coley, R. L., & Brunson, L. (1998). Fertile ground for community: Inner-city neighborhood common spaces. *American journal of community psychology*, *26*(6), 823–851.

Ladle, R. J., Jepson, P., Correia, R. A., Malhado, A. C., & Gould, R. (2019). A culturomics approach to quantifying the salience of species on the global internet. *People Nat*, *1*(4), 524–532.

Ladle, R. J., Alves-Martins, F., Malhado, A. C., Reyes-García, V., Courchamp, F., Di Minin, E., Roll, U., Jarić, I., & Correia, R. A. (2023). Biocultural aspects of species extinctions. *Cambridge Prisms: Extinction*, *1*, e22.

Lee, J.-H., & Scott, D. (2004). Measuring Birding Specialization: A Confirmatory Factor Analysis. *Leisure Sciences*, *26*(3), 245–260. https://doi.org/10.1080/01490400490461387

Leong, R. A., Fung, T. K., Sachidhanandam, U., Drillet, Z., Edwards, P. J., & Richards, D. R. (2020). Use of structural equation modeling to explore influences on perceptions of ecosystem services and disservices attributed to birds in Singapore. *Ecosystem Services*, *46*, 101211.

Levenhagen, M. J., Miller, Z. D., Petrelli, A. R., Ferguson, L. A., Shr, Y. H., Gomes, D. G., Taff, B. D., White, C., Fristrup, K., & Monz, C. (2020). Ecosystem services enhanced through soundscape management link people and wildlife. *People Nat*, *3*, 176–189.

Lewicka, M. (2011). Place attachment: How far have we come in the last 40 years? *Journal of Environmental Psychology*, *31*(3), 207–230.

Li, J., Wang, G., Wang, Z., Wang, W., Chen, H., & He, M. (2021). Comparative study of the physiological and psychological effects of forest and urban auditory stimulus on humans. *International Journal of Geoheritage and Parks*, *9*(3), 363–373. https://doi.org/https://doi.org/10.1016/j.ijgeop.2021.09.001

Lin, B. B., Fuller, R. A., Bush, R., Gaston, K. J., & Shanahan, D. F. (2014). Opportunity or orientation? Who uses urban parks and why. *PloS one*, *9*(1), e87422.

Lindemann-Matthies, P., Junge, X., & Matthies, D. (2010). The influence of plant diversity on people's perception and aesthetic appreciation of grassland vegetation. *Biological Conservation*, *143*(1), 195–202.

Lindemann-Matthies, P. (2017). Perception of plant species richness by people with different nationalities—an experimental study. *Landscape Research*, *42*(5), 482–497. https://doi.org/10.1080/01426397.2017.1305343

Lindemann-Matthies, P., & Matthies, D. (2018). The influence of plant species richness on stress recovery of humans. *Web Ecology*, *18*(2), 121–128.

Linton, M.-J., Dieppe, P., & Medina-Lara, A. (2016). Review of 99 self-report measures for assessing well-being in adults: exploring dimensions of well-being and developments over time. *BMJ open*, *6*(7), e010641.

Lišková, S., & Frynta, D. (2013). What determines bird beauty in human eyes? *Anthrozoös*, *26*(1), 27–41.

Lorenz, K. (1943). Die angeborenen formen möglicher erfahrung. *Zeitschrift für Tierpsychologie*, *5*(2), 235–409.

Lovell, R., Wheeler, B. W., Higgins, S. L., Irvine, K. N., & Depledge, M. H. (2014). A systematic review of the health and well-being benefits of biodiverse environments. *Journal of Toxicology and Environmental Health, Part B*, *17*(1), 1–20.

Luck, G. W., Davidson, P., Boxall, D., & Smallbone, L. (2011). Relations between Urban Bird and Plant Communities and Human Well-Being and Connection to Nature. *Conservation Biology*, *25*(4), 816–826. https://doi.org/https://doi.org/10.1111/j.1523-1739.2011.01685.x

Lukanowski, J. (2023). Das Geschlecht und die persönliche Einstellung haben einen Einfluss auf die Wahrnehmung der Schönheit von Vögeln. In E. K. U. Tübingen (Ed.), *B.Sc. Graduation Thesis*.

Luo, S., Shi, J., Lu, T., & Furuya, K. (2022). Sit down and rest: Use of virtual reality to evaluate preferences and mental restoration in urban park pavilions. *Landscape and Urban Planning*, *220*, 104336. https://doi.org/https://doi.org/10.1016/j.landurbplan.2021.104336

Lüscher, T. F. (2018). What is a normal blood pressure? *European Heart Journal*, *39*(24), 2233–2240.

Maas, J., Verheij, R. A., Groenewegen, P. P., De Vries, S., & Spreeuwenberg, P. (2006). Green space, urbanity, and health: how strong is the relation? *Journal of epidemiology & community health*, *60*(7), 587–592.

Maas, J., Verheij, R. A., Spreeuwenberg, P., & Groenewegen, P. P. (2008). Physical activity as a possible mechanism behind the relationship between green space and health: a multilevel analysis. *BMC Public Health*, *8*(1), 206.

Maas, J., Verheij, R. A., de Vries, S., Spreeuwenberg, P., Schellevis, F. G., & Groenewegen, P. P. (2009). Morbidity is related to a green living environment. *Journal of epidemiology & community health*, *63*(12), 967–973.

MacKerron, G., & Mourato, S. (2013). Happiness is greater in natural environments. *Global environmental change*, *23*(5), 992–1000.

Maggino, F. (2015). Assessing the Subjective Wellbeing of Nations. In W. Glatzer, L. Camfield, V. Møller, & M. Rojas (Eds.), *Global Handbook of Quality of Life: Exploration of Well-Being of Nations and Continents* (pp. 803–822). Springer Netherlands. https://doi.org/10.1007/978-94-017-9178-6_37

Marselle, M. R., Irvine, K. N., Lorenzo-Arribas, A., & Warber, S. L. (2016). Does perceived restorativeness mediate the effects of perceived biodiversity and perceived naturalness on emotional well-being following group walks in nature? *Journal of Environmental Psychology*, *46*, 217–232.

Marselle, M. R., Martens, D., Dallimer, M., & Irvine, K. N. (2019). Review of the mental health and well-being benefits of biodiversity. *Biodiversity and health in the face of climate change*, 175–211.

Marselle, M. R., Bowler, D. E., Watzema, J., Eichenberg, D., Kirsten, T., & Bonn, A. (2020). Urban street tree biodiversity and antidepressant prescriptions. *Scientific Reports*, *10*(1), 22445.

Marselle, M. R., Hartig, T., Cox, D. T., De Bell, S., Knapp, S., Lindley, S., Triguero-Mas, M., Böhning-Gaese, K., Braubach, M., & Cook, P. A. (2021a). Pathways linking biodiversity to human health: A conceptual framework. *Environment International*, *150*, 106420.

Marselle, M. R., Lindley, S. J., Cook, P. A., & Bonn, A. (2021b). Biodiversity and health in the urban environment. *Current Environmental Health Reports*, *8*(2), 146–156.

Martens, D., Gutscher, H., & Bauer, N. (2011). Walking in “wild” and “tended” urban forests: The impact on psychological well-being. *Journal of Environmental Psychology*, *31*(1), 36–44.

Mason, J. W., Ramseth, D. J., Chanter, D. O., Moon, T. E., Goodman, D. B., & Mendzelevski, B. (2007). Electrocardiographic reference ranges derived from 79,743 ambulatory subjects. *Journal of Electrocardiology*, *40*(3), 228–234.e228. https://doi.org/https://doi.org/10.1016/j.jelectrocard.2006.09.003

Matsuoka, S. M., Bayne, E. M., Sólymos, P., Fontaine, P. C., Cumming, S. G., Schmiegelow, F. K., & Song, S. J. (2012). Using binomial distance-sampling models to estimate the effective detection radius of point-count surveys across boreal Canada. *The Auk*, *129*(2), 268–282.

Mayer, F. S., & Frantz, C. M. (2004). The connectedness to nature scale: A measure of individuals’ feeling in community with nature. *Journal of Environmental Psychology*, *24*(4), 503–515.

Mayer, F. S., Frantz, C. M., Bruehlman-Senecal, E., & Dolliver, K. (2009). Why is nature beneficial? The role of connectedness to nature. *Environment and Behavior*, *41*(5), 607–643.

Mavoa, S., Davern, M., Breed, M., & Hahs, A. (2019). Higher levels of greenness and biodiversity associate with greater subjective wellbeing in adults living in Melbourne, Australia. *Health & place*, *57*, 321-329.

McDonald, R. I., Marcotullio, P. J., & Güneralp, B. (2013). Urbanization and global trends in biodiversity and ecosystem services. *Urbanization, biodiversity and ecosystem services: challenges and opportunities: a global assessment*, 31–52.

McDonald, R. I., Mansur, A. V., Ascensão, F., Colbert, M. l., Crossman, K., Elmqvist, T., Gonzalez, A., Güneralp, B., Haase, D., & Hamann, M. (2020). Research gaps in knowledge of the impact of urban growth on biodiversity. *Nature Sustainability*, *3*(1), 16–24.

McDonnell, M. J., & Hahs, A. K. (2015). Adaptation and adaptedness of organisms to urban environments. *Annual review of ecology, evolution, and systematics*, *46*(1), 261–280.

McEwan, K., Ferguson, F. J., Richardson, M., & Cameron, R. (2020). The good things in urban nature: A thematic framework for optimising urban planning for nature connectedness. *Landscape and Urban Planning*, *194*, 103687.

McMahan, E. A., & Estes, D. (2015). The effect of contact with natural environments on positive and negative affect: A meta-analysis. *The Journal of Positive Psychology*, *10*(6), 507–519.

Mears, M., Brindley, P., Jorgensen, A., Ersoy, E., & Maheswaran, R. (2019). Greenspace spatial characteristics and human health in an urban environment: An epidemiological study using landscape metrics in Sheffield, UK. *Ecological indicators*, *106*, 105464.

Menatti, L., Subiza-Pérez, M., Villalpando-Flores, A., Vozmediano, L., & San Juan, C. (2019). Place attachment and identification as predictors of expected landscape restorativeness. *Journal of Environmental Psychology*, *63*, 36–43.

Meng, L., Li, S., & Zhang, X. (2024). Exploring biodiversity’s impact on mental well-being through the social-ecological lens: Emphasizing the role of biodiversity characteristics and nature relatedness. *Environmental Impact Assessment Review*, *105*, 107454. https://doi.org/https://doi.org/10.1016/j.eiar.2024.107454

Merikle, P. M., Smilek, D., & Eastwood, J. D. (2001). Perception without awareness: Perspectives from cognitive psychology. *Cognition*, *79*(1-2), 115–134.

Methorst, J., Bonn, A., Marselle, M., Böhning-Gaese, K., & Rehdanz, K. (2021a). Species richness is positively related to mental health – A study for Germany. *Landscape and Urban Planning*, *211*, 104084. https://doi.org/https://doi.org/10.1016/j.landurbplan.2021.104084

Methorst, J., Rehdanz, K., Mueller, T., Hansjürgens, B., Bonn, A., & Böhning-Gaese, K. (2021b). The importance of species diversity for human well-being in Europe. *Ecological Economics*, *181*, 106917. https://doi.org/https://doi.org/10.1016/j.ecolecon.2020.106917

Millard, J. W., Gregory, R. D., Jones, K. E., & Freeman, R. (2021). The species awareness index as a conservation culturomics metric for public biodiversity awareness. *Conservation Biology*, *35*(2), 472–482.

Miller, J. R. (2005). Biodiversity conservation and the extinction of experience. *Trends in ecology & evolution*, *20*(8), 430–434.

Mittermeier, J. C., Roll, U., Matthews, T. J., Correia, R., & Grenyer, R. (2021). Birds that are more commonly encountered in the wild attract higher public interest online. *Conservation Science and Practice*, *3*(5), e340.

Montgomery, M. (2007). United Nations Population Fund: State of world population 2007: Unleashing the potential of urban growth. *Population and Development Review*, *33*(3), 639–641.

Moore, M., Townsend, M., & Oldroyd, J. (2006). Linking human and ecosystem health: The benefits of community involvement in conservation groups. *EcoHealth*, *3*(4), 255–261.

Moore, R. L., Scott, D., & Moore, A. (2008). Gender-based differences in birdwatchers' participation and commitment. *Human Dimensions of Wildlife*, *13*(2), 89–101.

Moser, G. (2009). Quality of life and sustainability: Toward person–environment congruity. *Journal of Environmental Psychology*, *29*(3), 351–357.

Nghiem, T., Wong, K., Jeevanandam, L., Chang, C., Tan, L., Goh, Y., & Carrasco, L. (2021). Biodiverse urban forests, happy people: Experimental evidence linking perceived biodiversity, restoration, and emotional wellbeing. *Urban Forestry & Urban Greening*, *59*, 127030.

Nieboer, A., Lindenberg, S., Boomsma, A., & Bruggen, A. C. V. (2005). Dimensions of well-being and their measurement: the SPF-IL scale. *Social indicators research*, *73*(3), 313–353.

Nisbet, E. K., Zelenski, J. M., & Murphy, S. A. (2009). The nature relatedness scale: Linking individuals' connection with nature to environmental concern and behavior. *Environment and Behavior*, *41*(5), 715–740.

Nisbet, E. K., & Zelenski, J. M. (2011). Underestimating nearby nature: Affective forecasting errors obscure the happy path to sustainability. *Psychological Science*, *22*(9), 1101–1106.

Nisbet, E. K., Zelenski, J. M., & Murphy, S. A. (2011). Happiness is in our nature: Exploring nature relatedness as a contributor to subjective well-being. *Journal of Happiness Studies*, *12*(2), 303–322.

Nisbet, E. K., Zelenski, J. M., & Grandpierre, Z. (2019). Mindfulness in nature enhances connectedness and mood. *Ecopsychology*, *11*(2), 81–91.

Nutsford, D., Pearson, A. L., & Kingham, S. (2013). An ecological study investigating the association between access to urban green space and mental health. *Public health*, *127*(11), 1005–1011.

Ohly, H., White, M. P., Wheeler, B. W., Bethel, A., Ukoumunne, O. C., Nikolaou, V., & Garside, R. (2016). Attention Restoration Theory: A systematic review of the attention restoration potential of exposure to natural environments. *Journal of Toxicology and Environmental Health, Part B*, *19*(7), 305–343.

Olafsdottir, G., Cloke, P., Schulz, A., Van Dyck, Z., Eysteinsson, T., Thorleifsdottir, B., & Vögele, C. (2020). Health benefits of walking in nature: A randomized controlled study under conditions of real-life stress. *Environment and Behavior*, *52*(3), 248–274.

Opdahl, E., Demps, K., & Heath, J. A. (2021). Decreased cortisol among hikers who preferentially visit and value biodiverse riparian zones. *Scientific Reports*, *11*(1), 848. https://doi.org/10.1038/s41598-020-79822-w

Ortega-Álvarez, R., & Casas, A. (2023). Biocultural salient birds: which biological and cultural factors define them? *Frontiers in Conservation Science*, *4*, 1215967.

Ottosson, J., & Grahn, P. (2005). A comparison of leisure time spent in a garden with leisure time spent indoors: On measures of restoration in residents in geriatric care. *Landscape Research*, *30*(1), 23–55.

Ouis, D. (2001). Annoyance from road traffic noise: a review. *Journal of Environmental Psychology*, *21*(1), 101–120.

Paker, Y., Yom-Tov, Y., Alon-Mozes, T., & Barnea, A. (2014). The effect of plant richness and urban garden structure on bird species richness, diversity and community structure. *Landscape and Urban Planning*, *122*, 186–195.

Park, B. J., Tsunetsugu, Y., Kasetani, T., Kagawa, T., & Miyazaki, Y. (2010). The physiological effects of Shinrin-yoku (taking in the forest atmosphere or forest bathing): evidence from field experiments in 24 forests across Japan. *Environmental Health and Preventive Medicine*, *15*(1), 18–26. https://doi.org/10.1007/s12199-009-0086-9

Parra-Saldívar, A., Abades, S., Celis-Diez, J. L., & Gelcich, S. (2020). Exploring perceived well-being from urban parks: Insights from a megacity in Latin America. *Sustainability*, *12*(18), 7586.

Passmore, H.-A., & Holder, M. D. (2017). Noticing nature: Individual and social benefits of a two-week intervention. *The Journal of Positive Psychology*, *12*(6), 537–546. https://doi.org/10.1080/17439760.2016.1221126

Passmore, H.-A., Yargeau, A., & Blench, J. (2022). Wellbeing in winter: Testing the Noticing Nature Intervention during winter months. *Frontiers in Psychology*, *13*, 840273.

Payne, S. R. (2013). The production of a Perceived Restorativeness Soundscape Scale. *Applied Acoustics*, *74*(2), 255–263. https://doi.org/https://doi.org/10.1016/j.apacoust.2011.11.005

Pejchar, L., Rega-Brodsky, C. C., Vázquez, L. B., & MacGregor-Fors, I. (2025). Bird-mediated ecosystem services and disservices in cities and towns. *Frontiers in Ecology and the Environment*, e2835.

Pett, T. J., Shwartz, A., Irvine, K. N., Dallimer, M., & Davies, Z. G. (2016). Unpacking the people–biodiversity paradox: a conceptual framework. *BioScience*, *66*(7), 576–583.

Phillips, D., & Lindquist, M. (2021). Just weeds? Comparing assessed and perceived biodiversity of urban spontaneous vegetation in informal greenspaces in the context of two American legacy cities. *Urban Forestry & Urban Greening*, *62*, 127151.

Pijanowski, B. C., Farina, A., Gage, S. H., Dumyahn, S. L., & Krause, B. L. (2011a). What is soundscape ecology? An introduction and overview of an emerging new science. *Landscape ecology*, *26*, 1213–1232.

Pijanowski, B. C., Villanueva-Rivera, L. J., Dumyahn, S. L., Farina, A., Krause, B. L., Napoletano, B. M., Gage, S. H., & Pieretti, N. (2011b). Soundscape ecology: the science of sound in the landscape. *BioScience*, *61*(3), 203–216.

Polk, D. E., Cohen, S., Doyle, W. J., Skoner, D. P., & Kirschbaum, C. (2005). State and trait affect as predictors of salivary cortisol in healthy adults. *Psychoneuroendocrinology*, *30*(3), 261–272.

Prayag, G., & Ryan, C. (2011). Antecedents of Tourists' Loyalty to Mauritius: The Role and Influence of Destination Image, Place Attachment, Personal Involvement, and Satisfaction. *Journal of Travel Research*, *51*(3), 342–356. https://doi.org/10.1177/0047287511410321

Pretty, J., Peacock, J., Sellens, M., & Griffin, M. (2005). The mental and physical health outcomes of green exercise. *International journal of environmental health research*, *15*(5), 319–337.

Prévot, A.-C., Cheval, H., Raymond, R., & Cosquer, A. (2018). Routine experiences of nature in cities can increase personal commitment toward biodiversity conservation. *Biological Conservation*, *226*, 1–8.

Prilleltensky, I., Dietz, S., Prilleltensky, O., Myers, N. D., Rubenstein, C. L., Jin, Y., & McMahon, A. (2015). Assessing multidimensional well-being: Development and validation of the I COPPE scale. *Journal of community psychology*, *43*(2), 199–226.

Prokop, P., Masarovič, R., & Vranovský, T. (2025). Human Preferences for Animals on YouTube. *Diversity*, *17*(10), 720.

Qiu, L., Lindberg, S., & Nielsen, A. B. (2013). Is biodiversity attractive?—On-site perception of recreational and biodiversity values in urban green space. *Landscape and Urban Planning*, *119*, 136–146.

Randler, C., Höllwarth, A., & Schaal, S. (2007). Urban Park Visitors and Their Knowledge of Animal Species. *Anthrozoös*, *20*(1), 65–74. https://doi.org/10.2752/089279307780216696

Randler, C. (2018). *Verhaltensbiologie*. Haupt Verlag.

Randler, C. (2021a). An Analysis of Heterogeneity in German Speaking Birdwatchers Reveals Three Distinct Clusters and Gender Differences. *Birds*, *2*(3), 250–260. https://www.mdpi.com/2673-6004/2/3/18

Randler, C. (2021b). Users of a citizen science platform for bird data collection differ from other birdwatchers in knowledge and degree of specialization. *Global Ecology and Conservation*, *27*, e01580. https://doi.org/https://doi.org/10.1016/j.gecco.2021.e01580

Randler, C., & Heil, F. (2021). Determinants of Bird Species Literacy—Activity/Interest and Specialization Are More Important Than Socio-Demographic Variables. *Animals*, *11*(6), 1595. https://www.mdpi.com/2076-2615/11/6/1595

Randler, C., Murawiec, S., & Tryjanowski, P. (2022). Committed Bird-Watchers Gain Greater Psychological Restorative Benefits Compared to Those Less Committed Regardless of Expertise. *Ecopsychology*.

Randler, C., Friedrich, S., & Koch, S. (2023a). Psychological restoration, place attachment and satisfaction in birders and non-birding visitors. *Journal of Outdoor Recreation and Tourism*, *44*, 100679.

Randler, C., Staller, N., Kalb, N., & Tryjanowski, P. (2023b). Charismatic species and birdwatching: Advanced birders prefer small, shy, dull, and rare species. *Anthrozoös*, *36*(3), 427–445.

Randler, C., Vanhöfen, J., Härtel, T., Neunhoeffer, F., Engeser, C., & Fischer, C. (2023c). Psychological restoration depends on curiosity, motivation, and species richness during a guided bird walk in a suburban blue space. *Frontiers in Psychology*, *14*, 1176202.

Randler, C., & Koch, S. (2025). Willingness to protect bird species depends on individual respondents' demographic and species traits. *Conservation Science and Practice*, *7*(1), e13277.

Ratcliffe, E., Gatersleben, B., & Sowden, P. T. (2013). Bird sounds and their contributions to perceived attention restoration and stress recovery. *Journal of Environmental Psychology*, *36*, 221–228.

Ratcliffe, E., & Korpela, K. M. (2016). Memory and place attachment as predictors of imagined restorative perceptions of favourite places. *Journal of Environmental Psychology*, *48*, 120–130.

Ratcliffe, E., & Korpela, K. M. (2018). Time-and self-related memories predict restorative perceptions of favorite places via place identity. *Environment and Behavior*, *50*(6), 690–720.

Reichert, G. (2022). *Interrelationships between humans and birds: How urbanization affects the ecape behaviour of birds and possible consequences in the Feel-Good Factor of nature space visitors* Eberhard Karls Universität Tübingen]. Unpublished.

Robinson, W. D., Hallman, T. A., & Hutchinson, R. A. (2021). Benchmark Bird Surveys Help Quantify Counting Accuracy in a Citizen-Science Database. *Frontiers in Ecology and Evolution*, *9*, 568278.

Roe, J., & Aspinall, P. (2011). The restorative benefits of walking in urban and rural settings in adults with good and poor mental health. *Health & place*, *17*(1), 103–113.

Rögele, A., Scheiter, K., & Randler, C. (2022). Can involvement induced by guidance foster scientific reasoning and knowledge of participants of a citizen science project? *International Journal of Science Education, Part B*, 1–17.

Rozario, K., Oh, R. R. Y., Marselle, M., Schröger, E., Gillerot, L., Ponette, Q., Godbold, D., Haluza, D., Kilpi, K., Müller, D., Roeber, U., Verheyen, K., Muys, B., Müller, S., Shaw, T., & Bonn, A. (2024). The more the merrier? Perceived forest biodiversity promotes short-term mental health and well-being—A multicentre study. *People and Nature*, *6*(1), 180–201. https://doi.org/https://doi.org/10.1002/pan3.10564

Ryan, R. M., & Deci, E. L. (2001). On happiness and human potentials: A review of research on hedonic and eudaimonic well-being. *Annual Review of Psychology*, *52*(1), 141–166.

Ryff, C. D., & Keyes, C. L. M. (1995). The structure of psychological well-being revisited. *Journal of Personality and Social Psychology*, *69*(4), 719.

Ryslavy, T., Bauer, H.-G., Gerlach B., Hüppop, O., Stahmer, J., Südbeck, P., & Sudfeldt, C. (2020). Rote Liste der Brutvögel Deutschlands, 6. Fassung. *Ber. Vogelschutz*, *57*, 13–112.

Sandifer, P. A., Sutton-Grier, A. E., & Ward, B. P. (2015). Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance health and biodiversity conservation. *Ecosystem Services*, *12*, 1–15.

Santangeli, A., Haukka, A., Morris, W., Arkkila, S., Delhey, K., Kempenaers, B., Valcu, M., Dale, J., Lehikoinen, A., & Mammola, S. (2023). What drives our aesthetic attraction to birds? *npj Biodiversity*, *2*(1), 20.

Santarém, F., Pereira, P., Saarinen, J., & Brito, J. C. (2019). New method to identify and map flagship fleets for promoting conservation and ecotourism. *Biological Conservation*, *229*, 113–124.

Sarkar, C., Webster, C., & Gallacher, J. (2018). Residential greenness and prevalence of major depressive disorders: a cross-sectional, observational, associational study of 94 879 adult UK Biobank participants. *The Lancet Planetary Health*, *2*(4), e162–e173.

Scannell, L., & Gifford, R. (2010). Defining place attachment: A tripartite organizing framework. *Journal of Environmental Psychology*, *30*(1), 1–10.

Schebella, M., Weber, D., Schultz, L., & Weinstein, P. (2019a). In Pursuit of Urban Sustainability: Predicting public perceptions of park biodiversity using simple assessment tools. *International Journal of Environmental Research*, *13*(4), 707–720.

Schebella, M. F., Weber, D., Schultz, L., & Weinstein, P. (2019b). The wellbeing benefits associated with perceived and measured biodiversity in Australian urban green spaces. *Sustainability*, *11*(3), 802.

Schebella, M. F., Weber, D., Schultz, L., & Weinstein, P. (2020). The nature of reality: Human stress recovery during exposure to biodiverse, multisensory virtual environments. *International Journal of Environmental Research and Public Health*, *17*(1), 56.

Schlegel, J., & Rupf, R. (2010). Attitudes towards potential animal flagship species in nature conservation: A survey among students of different educational institutions. *Journal for Nature Conservation*, *18*(4), 278–290.

Sekercioglu, C. H. (2006). Increasing awareness of avian ecological function. *Trends in ecology & evolution*, *21*(8), 464–471.

Shanahan, D. F., Fuller, R. A., Bush, R., Lin, B. B., & Gaston, K. J. (2015a). The Health Benefits of Urban Nature: How Much Do We Need? *BioScience*, *65*(5), 476–485. https://doi.org/10.1093/biosci/biv032

Shanahan, D. F., Lin, B. B., Bush, R., Gaston, K. J., Dean, J. H., Barber, E., & Fuller, R. A. (2015b). Toward improved public health outcomes from urban nature. *American journal of public health*, *105*(3), 470–477.

Sheridan, J. F., Dobbs, C., Brown, D., & Zwilling, B. (1994). Psychoneuroimmunology: stress effects on pathogenesis and immunity during infection. *Clinical microbiology reviews*, *7*(2), 200–212.

Shwartz, A., Turbé, A., Simon, L., & Julliard, R. (2014). Enhancing urban biodiversity and its influence on city-dwellers: An experiment. *Biological Conservation*, *171*, 82–90.

Shwartz, A., Tzunz, M., Gafter, L., & Colléony, A. (2023). One size does not fit all: The complex relationship between biodiversity and psychological well-being. *Urban Forestry & Urban Greening*, *86*, 128008. https://doi.org/https://doi.org/10.1016/j.ufug.2023.128008

Şimşek, Ö. F. (2011). An intentional model of emotional well-being: The development and initial validation of a measure of subjective well-being. *Journal of Happiness Studies*, *12*(3), 421–442.

Smith, R. J., Veríssimo, D., Isaac, N. J., & Jones, K. E. (2012). Identifying Cinderella species: uncovering mammals with conservation flagship appeal. *Conservation Letters*, *5*(3), 205–212.

Soga, M., & Gaston, K. J. (2016). Extinction of experience: the loss of human–nature interactions. *Frontiers in Ecology and the Environment*, *14*(2), 94–101.

Soga, M., Gaston, K. J., Koyanagi, T. F., Kurisu, K., & Hanaki, K. (2016). Urban residents' perceptions of neighbourhood nature: Does the extinction of experience matter? *Biological Conservation*, *203*, 143–150.

Song, C., Ikei, H., & Miyazaki, Y. (2016). Physiological effects of nature therapy: A review of the research in Japan. *International journal of environmental research and public health*, *13*(8), 781.

Southon, G. E., Jorgensen, A., Dunnett, N., Hoyle, H., & Evans, K. L. (2018). Perceived species-richness in urban green spaces: Cues, accuracy and well-being impacts. *Landscape and Urban Planning*, *172*, 1–10. https://doi.org/https://doi.org/10.1016/j.landurbplan.2017.12.002

Stalder, T., Kirschbaum, C., Kudielka, B. M., Adam, E. K., Pruessner, J. C., Wüst, S., Dockray, S., Smyth, N., Evans, P., & Hellhammer, D. H. (2016). Assessment of the cortisol awakening response: Expert consensus guidelines. *Psychoneuroendocrinology*, *63*, 414–432.

Stein, A., Gerstner, K., & Kreft, H. (2014). Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. *Ecology Letters*, *17*(7), 866–880. https://doi.org/https://doi.org/10.1111/ele.12277

Steptoe, A., Deaton, A., & Stone, A. A. (2015). Subjective wellbeing, health, and ageing. *The lancet*, *385*(9968), 640–648.

Stewart, L., Skinner, L., Weiss, M., & Middleton, J. (2015). Start well, live better—a manifesto for the public's health. In (Vol. 37, pp. 3–5): Oxford University Press.

Stobbe, E., Sundermann, J., Ascone, L., & Kühn, S. (2022). Birdsongs alleviate anxiety and paranoia in healthy participants. *Scientific Reports*, *12*(1), 16414.

Stoudt, S., Goldstein, B. R., & de Valpine, P. (2022). Identifying engaging bird species and traits with community science observations. *Proceedings of the National Academy of Sciences*, *119*(16), e2110156119.

Subiza-Pérez, M., Vozmediano, L., & San Juan, C. (2020a). Green and blue settings as providers of mental health ecosystem services: Comparing urban beaches and parks and building a predictive model of psychological restoration. *Landscape and Urban Planning*, *204*, 103926.

Subiza-Pérez, M., Vozmediano, L., & San Juan, C. (2020b). Welcome to your plaza: Assessing the restorative potential of urban squares through survey and objective evaluation methods. *Cities*, *100*, 102461.

Subiza-Pérez, M., Pasanen, T., Ratcliffe, E., Lee, K., Bornioli, A., de Bloom, J., & Korpela, K. (2021). Exploring psychological restoration in favorite indoor and outdoor urban places using a top-down perspective. *Journal of Environmental Psychology*, *78*, 101706.

Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2008). Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships? *Journal of epidemiology & community health*, *62*(5), e9–e9.

Sushinsky, J. R., Rhodes, J. R., Shanahan, D. F., Possingham, H. P., & Fuller, R. A. (2017). Maintaining experiences of nature as a city grows. *Ecology and Society*, *22*(3).

Tam, K.-P. (2013). Concepts and measures related to connection to nature: Similarities and differences. *Journal of Environmental Psychology*, *34*, 64–78.

Taylor, L., Hahs, A. K., & Hochuli, D. F. (2018). Wellbeing and urban living: nurtured by nature. *Urban Ecosystems*, *21*, 197–208.

Teel, T. L., Manfredo, M. J., & Stinchfield, H. M. (2007). The need and theoretical basis for exploring wildlife value orientations cross-culturally. *Human Dimensions of Wildlife*, *12*(5), 297–305.

Uebel, K., Marselle, M., Dean, A. J., Rhodes, J. R., & Bonn, A. (2021). Urban green space soundscapes and their perceived restorativeness. *People and Nature*, *3*(3), 756–769.

Uebel, K., Rhodes, J. R., Wilson, K., & Dean, A. J. (2022). Urban park soundscapes: Spatial and social factors influencing bird and traffic sound experiences. *People and Nature*, *4*(6), 1616–1628. https://doi.org/https://doi.org/10.1002/pan3.10409

Ulrich, R. S. (1979). Visual landscapes and psychological well-being. *Landscape research*, *4*(1), 17–23.

Ulrich, R. S. (1983). Aesthetic and affective response to natural environment. In *Behavior and the natural environment* (pp. 85–125). Springer.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, *11*(3), 201–230.

Ulrich, W., Batáry, P., Baudry, J., Beaumelle, L., Bucher, R., Čerevková, A., de la Riva, E. G., Felipe-Lucia, M. R., Gallé, R., Kesse-Guyot, E., Rembiałkowska, E., Rusch, A., Stanley, D., & Birkhofer, K. (2023). From biodiversity to health: Quantifying the impact of diverse ecosystems on human well-being. *People and Nature*, *5*(1), 69–83. https://doi.org/https://doi.org/10.1002/pan3.10421

UN-Habitat, U. N. H. S. P. (2008). *State of the world's cities 2010/2011: Bridging the urban divide*. Earthscan.

UN-Habitat, U. N. H. S. P. (2011). *Cities and Climate Change: Global Report on Human Settlements, 2011*. Routledge.

United Nations, department of economic and social affairs, population division. (2018). world urbanization prospects: The 2018 revision. *Online Edition*.

United Nations, D. o. E. a. S. A., Population Division. (2019). *World Urbanization Prospects: The 2018 Revision* (ST/ESA/SER.A/420, Issue.

Van den Berg, M., Wendel-Vos, W., van Poppel, M., Kemper, H., van Mechelen, W., & Maas, J. (2015). Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. *Urban Forestry & Urban Greening*, *14*(4), 806–816.

Van den Born, R. J., Lenders, R. H., De Groot, W. T., & Huijsman, E. (2001). The new biophilia: an exploration of visions of nature in Western countries. *Environmental conservation*, *28*(1), 65–75.

Van Der Plas, F. (2019). Biodiversity and ecosystem functioning in naturally assembled communities. *Biological Reviews*, *94*(4), 1220–1245.

van Riper, C. J., Kyle, G. T., Sherrouse, B. C., Bagstad, K. J., & Sutton, S. G. (2017). Toward an integrated understanding of perceived biodiversity values and environmental conditions in a national park. *Ecological Indicators*, *72*, 278–287.

Vanhöfen, J., Schöffski, N., Härtel, T., & Randler, C. (2022). Are lay people able to estimate breeding bird diversity? *Animals*, *12*(22), 3095.

Vanhöfen, J., Härtel, T., Reichert, G., & Randler, C. (2025). The relationship between perception and landscape characteristics of recreational places with human mental well-being. *Scientific Reports*, *15*(1), 4245.

Vanhöfen, J., Stuck, K., Haag, R., Härtel, T., & Randler, C. (2025b). Effects of nature experience on mental well-being and physiological stress parameters in an experimental bird walk setting–the role of bird song. Landscape and Urban Planning, 263, 105456.

Veldhuis, J. D., Iranmanesh, A., Lizarralde, G., & Johnson, M. L. (1989). Amplitude modulation of a burstlike mode of cortisol secretion subserves the circadian glucocorticoid rhythm. *American Journal of Physiology-Endocrinology and Metabolism*, *257*(1), E6–E14. https://doi.org/10.1152/ajpendo.1989.257.1.E6

Venter, O., Sanderson, E. W., Magrach, A., Allan, J. R., Beher, J., Jones, K. R., Possingham, H. P., Laurance, W. F., Wood, P., Fekete, B. M., Levy, M. A., & Watson, J. E. (2016). Sixteen Years of Change in the Global Terrestrial Human Footprint and Implications for Biodiversity Conservation. *Nature Communications*, 12558. https://doi.org/10.1038/ncomms12558

Venter, O., Sanderson, E. W., Magrach, A., Allan, J. R., Beher, J., Jones, K. R., Possingham, H. P., Laurance, W. F., Wood, P., Fekete, B. M., Levy, M. A., & Watson, J. E. (2018). *Last of the Wild Project, Version 3 (LWP-3): 2009 Human Footprint, 2018 Release* NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H46T0JQ4

Veríssimo, D., Pongiluppi, T., Santos, M. C. M., Develey, P. F., Fraser, I., Smith, R. J., & Macmilan, D. C. (2014). Using a Systematic Approach to Select Flagship Species for Bird Conservation. *Conservation Biology*, *28*(1), 269–277. https://doi.org/https://doi.org/10.1111/cobi.12142

Voigt, A., Kabisch, N., Wurster, D., Haase, D., & Breuste, J. (2014). Structural diversity: a multi-dimensional approach to assess recreational services in urban parks. *Ambio*, *43*(4), 480–491.

von Lindern, E. (2017). Perceived interdependencies between settings as constraints for self-reported restoration. *Journal of Environmental Psychology*, *49*, 8–17. https://doi.org/https://doi.org/10.1016/j.jenvp.2016.11.004

Warber, S. L., & Irvine, K. N. (2006). Relationship between People and Plants. *Natural Products from Plants*, 535–546.

Ward Thompson, C., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. *Landscape and Urban Planning*, *105*(3), 221–229. https://doi.org/https://doi.org/10.1016/j.landurbplan.2011.12.015

Wei, H., Zhang, J., Xu, Z., Hui, T., Guo, P., & Sun, Y. (2022). The association between plant diversity and perceived emotions for visitors in urban forests: A pilot study across 49 parks in China. *Urban Forestry & Urban Greening*, *73*, 127613. https://doi.org/https://doi.org/10.1016/j.ufug.2022.127613

Weitzman, E. D., Fukushima, D., Nogeire, C., Roffwarg, H., Gallagher, T. F., & Hellmann, L. (1971). Twenty-four Hour Pattern of the Episodic Secretion of Cortisol in Normal Subjects. *The Journal of Clinical Endocrinology & Metabolism*, *33*(1), 14–22. https://doi.org/10.1210/jcem-33-1-14

Wenny, D. G., DeVault, T. L., Johnson, M. D., Kelly, D., Sekercioglu, C. H., Tomback, D. F., & Whelan, C. J. (2011). The need to quantify ecosystem services provided by birds. *The Auk*, *128*(1), 1–14.

Wheeler, B. W., Lovell, R., Higgins, S. L., White, M. P., Alcock, I., Osborne, N. J., Husk, K., Sabel, C. E., & Depledge, M. H. (2015). Beyond greenspace: an ecological study of population general health and indicators of natural environment type and quality. *International journal of health geographics*, *14*, 1–17.

Whelan, C. J., Şekercioğlu, Ç. H., & Wenny, D. G. (2015). Why birds matter: from economic ornithology to ecosystem services. *Journal of Ornithology*, *156*(Suppl 1), 227–238.

Whelan, C. J., Şekercioğlu, Ç. H., & Wenny, D. G. (2016). Bird Ecosystem Services. *Why birds matter: avian ecological function and ecosystem services*, 1–26.

Whelton, P. K., & Carey, R. M. (2017). The 2017 clinical practice guideline for high blood pressure. *Jama*, *318*(21), 2073–2074.

White, M. E., Hamlin, I., Butler, C. W., & Richardson, M. (2023). The Joy of birds: the effect of rating for joy or counting garden bird species on wellbeing, anxiety, and nature connection. *Urban Ecosystems*. https://doi.org/10.1007/s11252-023-01334-y

White, M. P., Alcock, I., Wheeler, B. W., & Depledge, M. H. (2013). Would you be happier living in a greener urban area? A fixed-effects analysis of panel data. *Psychological science*, *24*(6), 920–928.

White, M. P., Weeks, A., Hooper, T., Bleakley, L., Cracknell, D., Lovell, R., & Jefferson, R. L. (2017). Marine wildlife as an important component of coastal visits: the role of perceived biodiversity and species behaviour. *Marine Policy*, *78*, 80–89.

White, M. P., Alcock, I., Grellier, J., Wheeler, B. W., Hartig, T., Warber, S. L., Bone, A., Depledge, M. H., & Fleming, L. E. (2019). Spending at least 120 minutes a week in nature is associated with good health and wellbeing. *Scientific Reports*, *9*(1), 7730. https://doi.org/10.1038/s41598-019-44097-3

White, M. P., Elliott, L. R., Gascon, M., Roberts, B., & Fleming, L. E. (2020). Blue space, health and well-being: A narrative overview and synthesis of potential benefits. *Environmental Research*, *191*, 110169. https://doi.org/https://doi.org/10.1016/j.envres.2020.110169

WHO – World Health Organisation. (1946). Constitution of the world health organization. 1946. *80*(12), 983. https://www.who.int/about/governance/constitution

WHO – World Health Organisation. (2002). Constitution of the world health organization. International Health Conference.

WHO – World Health Organisation. (2005a). Millenium Ecosystem Assessment. New York, US: Ecosystems and human wellbeing: Health synthesis report.

WHO – World Health Organisation. (2005b). Millenium ecosystem assessment. Ecosystems and human well-being: Biodiversity synthesis; World Resources Institute: Washington DC, USA.

WHO - World Health Organization. Regional Office for Europe. (2016). *Urban green spaces and health*. https://iris.who.int/handle/10665/345751

Williams, P. H., & Gaston, K. J. (1994). Measuring more of biodiversity: can higher-taxon richness predict wholesale species richness? *Biological conservation*, *67*(3), 211–217.

Williams, B., Mancia, G., Spiering, W., Agabiti Rosei, E., Azizi, M., Burnier, M., Clement, D. L., Coca, A., de Simone, G., Dominiczak, A., Kahan, T., Mahfoud, F., Redon, J., Ruilope, L., Zanchetti, A., Kerins, M., Kjeldsen, S. E., Kreutz, R., Laurent, S.,…Group, E. S. D. (2018). 2018 ESC/ESH Guidelines for the management of arterial hypertension: The Task Force for the management of arterial hypertension of the European Society of Cardiology (ESC) and the European Society of Hypertension (ESH). *European Heart Journal*, *39*(33), 3021–3104. https://doi.org/10.1093/eurheartj/ehy339

Wilson, E. O. (1986). *Biophilia*. Harvard university press.

Wilson, E. O. (2017). Biophilia and the conservation ethic. In *Evolutionary perspectives on environmental problems* (pp. 250–258). Routledge.

Wohlwill, J. F. (1973). The environment is not in the head. In W. F. G. Preiser (Ed.), Environmental design research association symposia and workshops, Vol. 2 (pp. 166–181). Stroudsberg, PA: Bowden, Hutchinson & Ross.

Wolf, L. J., Zu Ermgassen, S., Balmford, A., White, M., & Weinstein, N. (2017). Is variety the spice of life? An experimental investigation into the effects of species richness on self-reported mental well-being. *PloS one*, *12*(1), e0170225.

Wolsko, C., & Lindberg, K. (2013). Experiencing connection with nature: The matrix of psychological well-being, mindfulness, and outdoor recreation. *Ecopsychology*, *5*(2), 80–91.

Wood, E., Harsant, A., Dallimer, M., Cronin de Chavez, A., McEachan, R. R., & Hassall, C. (2018). Not all green space is created equal: Biodiversity predicts psychological restorative benefits from urban green space. *Frontiers in Psychology*, *9*, 2320.

Woods, B. (1998). Animals on display: Principles for interpreting captive wildlife. *Journal of Tourism Studies*, *9*(1), 28–39.

Wu, C.-C., O'Keefe, J., Ding, Y., & Sullivan, W. C. (2024). Biodiversity of urban green spaces and human health: a systematic review of recent research. *Frontiers in Ecology and Evolution*, *12*, 1467568.

Wyles, K. J., White, M. P., Hattam, C., Pahl, S., King, H., & Austen, M. (2019). Are some natural environments more psychologically beneficial than others? The importance of type and quality on connectedness to nature and psychological restoration. *Environment and Behavior*, *51*(2), 111–143.

Xie, S., Pan, Q., Zheng, H., Xiao, N., & Li, J. (2023). Key Factors Strengthening Residents' Psychological Well-Being and Critical Human-Nature Connections within the Living Spaces—An Example from Beijing. *Diversity*, *15*(3), 438.

Xu, W., Zheng, D., Huang, P., Yu, J., Chen, Z., Zhu, Z., ... & Fu, W. (2022). Does bird diversity affect public mental health in urban mountain parks?—a case study in Fuzhou City, China. *International Journal of Environmental Research and Public Health*, *19*(12), 7029.

Xu, J., Liu, N., Polemiti, E., Garcia-Mondragon, L., Tang, J., Liu, X., Lett, T., Yu, L., Nöthen, M. M., & Feng, J. (2023). Effects of urban living environments on mental health in adults. *Nature medicine*, *29*(6), 1456–1467.

Yi, K., Zhang, J., Zhang, Z., Shi, X., Du, W., Yang, L., & Wei, M. (2024). Differences in public perceptions of recovery in different urban forests based on birdsong. *Forests*, *15*(12), 2217.

Yi, K., Yang, W., Zhang, X., Zhang, Z., Gao, B., Ji, G., & Zhang, Z. (2025). Public's multi-dimensional response to different acoustic types of birdsong in urban parks based on auditory: A case study of Kunming, China. *Applied Acoustics*, *240*, 110898.

Young, C., Hofmann, M., Frey, D., Moretti, M., & Bauer, N. (2020). Psychological restoration in urban gardens related to garden type, biodiversity and garden-related stress. *Landscape and Urban Planning*, *198*, 103777. https://doi.org/https://doi.org/10.1016/j.landurbplan.2020.103777

Zhao, J., Wu, J., & Wang, H. (2020). Characteristics of urban streets in relation to perceived restorativeness. *Journal of exposure science & environmental epidemiology*, *30*(2), 309-319.

Zelenski, J. M., & Nisbet, E. K. (2014). Happiness and feeling connected: The distinct role of nature relatedness. *Environment and Behavior*, *46*(1), 3–23.

Zhu, R., Yuan, L., Pan, Y., Wang, Y., Xiu, D., & Liu, W. (2024). Effects of natural sound exposure on health recovery: A systematic review and meta-analysis. *Science of the Total Environment*, 171052.

Zumhof, B. J. (2019). *Understanding perceptions of urban biodiversity and its benefits* [University of Iowa].

Appendix

List of Tables

Study areas, Item catalogues and questionnaires

Items catalogues and questionnaires which are not present in the appendix of the respective study.

Table 18.
Study areas of the biodiversity and health study, their location and their categorization, as well as biodiversity make-up.

Name	**Commune**	**Urban/Rural**	**Area Type**	**Total bird count**	**Biotope types**
Alter Bota	Tübingen	Urban	Mixed	25	13
Ammerbrücke Freiacker	Tübingen	Urban	Blue	22	9
Ammertal	Tübingen	Rural	Green	39	22,5
Arboretum	Tübingen	Urban	Green	23	14
Bad Niedernau	Rottenburg	Rural	Green	36	16
Bota Morgenstelle	Tübingen	Urban	Mixed	22	20
Burgholzweg	Tübingen	Urban	Green	18	12
Galgenberg	Nürtingen	Urban	Green	22	10
Glemsstausee	Metzingen	Rural	Blue	37	13,5
Goldersbachtal	Tübingen	Rural	Blue	32	15
Gönninger Seen	Reutlingen	Rural	Blue	26	13,5
Heuberger Tor	Tübingen	Rural	Green	30	9
Hirschau Baggersee	Tübingen	Rural	Blue	34	14,5
Kapellenberg	Rottenburg	Rural	Green	29	14
Käpfle	Reutlingen	Rural	Green	32	11
Listhof	Reutlingen	Rural	Green	41	21,5
Lustnau Ammertal	Tübingen	Urban	Blue	24	10
Märchensee	Rottenburg	Rural	Green	32	16
Markwasen	Reutlingen	Urban	Green	37	18
Max Eyth See	Stuttgart	Urban	Blue	27	16
Merkelscher Park	Esslingen	Urban	Blue	23	13,5
Neckar Freibad	Tübingen	Urban	Blue	24	10
Neckar Gartenstraße	Tübingen	Urban	Blue	29	12,5
Neckarinsel	Tübingen	Urban	Blue	24	12
Österberg	Tübingen	Urban	Green	19	9,5
Pomologie	Reutlingen	Urban	Green	18	9
Quecksee+Bischoffsee	Tübingen	Rural	Blue	42	15,5
Rosensteinpark	Stuttgart	Urban	Green	29	10
Saurucken	Entringen	Rural	Green	30	11

Schänzle	Rottenburg	Urban	Blue	32	12
Schwärzlocher Hof	Tübingen	Rural	Green	22	16
Spielbühl	Rottenburg	Rural	Green	30	16
Stadtgarten RT	Reutlingen	Urban	Green	20	10
Steinlach Tü	Tübingen	Urban	Green	25	7
Vogelplattform	Kirchentellinsfurt	Rural	Blue	33	9,5
Weggental	Rottenburg	Rural	Green	35	22,5
Weiler Osterfeld	Rottenburg	Rural	Green	32	16,5
Weinberge Mtz	Metzingen	Rural	Green	27	8
Weinberge UJ	Tübingen	Rural	Green	26	14
Wernau Baggersee	Wernau	Rural	Blue	32	13

Appendix

Table 19.
Catalogue of items and constructs asked for in the experimental study on bird diversity and well-being in summer 2023.

Concept	Items	Source	Pre-test	Post-test	Cronbach's alpha
Bird species knowledge	How many birds can you identify by Appearance? How many birds can you identify by Song? Ornithological skill self-report.	Randler & Heil (2021) Lee & Scott (2004) Randler (2021a)	x		.724
Perception of Birds **(5-point Likert scale)**	I like birds because they... Are beautiful. Have a nice song. Make me Feel Good	Belaire et al. (2015)	x		.656
Nature experience **(5-point Likert scale)**	I have… Taken time to appreciate. Learned new things. Felt close to nature.	Wyles et al. (2019)		x	.525
Satisfaction **(5-point Likert scale)**	How satisfied are you?	Arlinghaus (2006)		x	
Emotions **(5-point Likert scale)**	I feel… Calm and relaxed Peaceful Refreshed	White et al. (2013) Wyles et al. (2019)	x	x	Pretest: .646 Posttest: .674
Self-reported Restoration **(6 categories)**	How recovered do you feel?	Young et al. (2020)		x	
Perceived Restoration	This place is relaxing. This place is fascinating. This place is Organized. This place is without restrictions. I can do what I want in this place.	Berto (2005) according to PRS by Korpela & Hartig (1996)		x	.534

Appendix

Table 20.
Catalogue of the constructs and items asked for in the experimental study of bird diversity awareness and mental well-being in summer 2024.

Construct	Items	Source	Pre-test	Post-test	Cronbach´s alpha
Bird species knowledge	How many birds can you identify by appearance? How many birds can you identify by song? Ornithological skill self-report.	Lee & Scott (2004) Randler (2021b) Randler & Heil (2021)	x		.79
Perception of birds	I like birds because they... Are beautiful. Have a nice song. Make me Feel Good.	Belaire et al. (2015)	x		.60
Satisfaction	How satisfied are you?	Arlinghaus (2006)		x	
Emotions	I feel… Calm and relaxed Peaceful Refreshed	White et al. (2020) Wyles et al. (2019)	x	x	Pretest: .65 Posttest: .72
Self-reported restoration	How recovered do you feel?	Young et al. (2020)		x	
Nature experience	I have… Taken time to appreciate. Learned new things. Felt close to nature.	Wyles et al. (2019)		x	.64
Perceived bird richness	How many bird species do you estimate to be present?	Ferraro et al. (2020) Southon et al. (2018)		x	
Perceived bird song	How many bird songs have you noticed?	Uebel et al. (2022)		x	
Perceived naturalness (place)	How natural does the area seem to you?	Schebella et al. (2019a)		x	
Perceived naturalness (sound)	How do you rate the naturalness of the soundscape?	Carrus et al. (2015)		x	
Perceived restorativeness (place)	This place is relaxing. This place is fascinating. This place is organized. This place is without restrictions. I can do what I want in this place.	Berto (2005) Korpela & Hartig (1996)		x	.72
Perceived restorativeness (sound)	The soundscape in this place… Is fascinating. Provides me with a good change from my daily routine. Goes well together. Fits with activities I like to do. Suggests that there is a lot to explore and discover.	Payne (2013) Uebel et al. (2021) Uebel et al. (2022)		x	.88

Appendix of Manuscript 2

Table 21.
Survey catalogue for the variables of the area perception on-site survey "Biodiversity and well-being", please note this is the whole survey catalogue, the present manuscript does not analyze all of these items.

Concept	Items	Sources
Reason for visit	What was the main goal of your visit today?	Own
Demographics	Age Gender University degree	Well-established
Birding Specialization	How many birds can you identify by Appearance?	Lee & Scott (2004) Randler (2021a) Randler & Heil (2021)
Place attachment - Identity (5-point Likert scale)	I feel very connected to this area here This area is very special to me. I can identify well with this area.	Boley et al. (2021)
Place attachment - Recovery (5-point Likert scale)	Visiting this place gives me a feeling of freedom. I can clear my head here. Being here helps me to feel healthy.	Bryce et al. (2016)
Loyalty (5-point Likert scale)	I would also recommend this place to friends.	Prayag & Ryan (2011)
Visitation frequency	How often do you visit this area?	Prayag & Ryan (2011) Randler et al. (2007)
Duration of visit	How long did you spend in this area today?	Own
Satisfaction (5 categories)	Overall, how satisfied were you with your visit today?	Adapted from Arlinghaus (2006)
Perceived bird diversity	Please estimate: How many bird species are present in this area today?	Ferraro et al. (2020) Southon et al. (2018)
Perceived naturalness (5-point Likert scale)	How natural does this area seem to you?	Schebella et al. (2019a)
Perception of Birds (5-point Likert scale)	I like birds because they... Are beautiful. Have a nice song. Make me Feel Good	Belaire et al. (2015)
Recalled Restoration	How refreshed do you feel now compared to before your visit?	Young et al. (2020)
Emotions (5-point-Likert scale)	I feel… Calm and relaxed Peaceful Refreshed	White et al. (2020) Wyles et al. (2019)
Bird knowledge	11 pictures of common bird species. Name the following bird species as accurately as possible.	Dallimer et al. (2012); Randler & Heil (2021); Randler et al. (2007)

Appendix

Table 22.
Biotic elements of the field survey. In accordance with the determining key catalogue “Arten, Biotope, Landschaft” from the nature conservation administration Baden-Württemberg (LUBW) which serves as a uniform reference system for biological data collection projects (Höll et al., 2009).

Concept	Umbrella terms	Surveyed terms
Bodies of water	Streams/running waters	Near-natural section of stream
		Developed section of stream
		semi-natural river section
		Developed river section
		Canal
		Ditch
	Still waters	Pond
		semi-natural area of a lake, pond or pond
		Non-natural area of a still water body
		Small non-natural water body
Special morphological forms of anthropogenic origin	Hollow path	
	Dry stone wall	
Meadows and pastures	Wet meadow	
	Farm meadow of medium sites	Fatty meadow
		Lean meadow
	Meadow of medium sites	
	Intensive grassland or grassland seeding	
	Stepping plants population	
	Ornamental grassland	
Submerged and floating-leaf vegetation, spring meadows, reedbeds and large sedge reeds	Spring meadow	Small reedbeds
		Reedbeds
		Large sedge reed
Fringing vegetation, dominant stands of tall herbaceous plants and ruderal vegetation	Fringing vegetation of medium locations	
	Fringing vegetation in dry, warm locations	
	Dominant stands of tall herbaceous plants	
	Tall herbaceous meadow	
	Ruderal vegetation	
Heaths, rough, sandy and dry grasslands	Juniper heath	
	Nutrient-poor grassland	
	Dry grassland	
Fields, special crops and field gardens	Agricultural field	
	Perennial special crops	Vineyard
		Tree nursery
	Field garden	

Woody areas and bushes	Field copses and field hedges	Field copse
		Field hedge
	Bushes	Scrub of dry and warm locations
		Scrub of medium locations
	Shrubbery and hedges not native to the natural habitat or location	Natural or non-natural scrub
		Hedge of natural or non-natural habitat
		Hedge fence
	Trees	Alley or row of trees
		Group of trees
		Single tree
		Scattered fruit trees
		Structurally rich forest edge
Forests	Marsh, swamp and riparian forests	Riparian forest strip alongside watercourses
	Forests of dry and warm locations	Oak or hornbeam-oak forest in dry, warm locations
		Beech forest in dry, warm locations
		Pine forest in dry, warm locations
	Beech-rich forests of medium locations	Beech forest of alkaline sites
	Oak and hornbeam-oak forests of medium habitats	
	Coniferous forests	
	Successional forests	Successional forest of deciduous trees
		Successional forest of deciduous and coniferous trees
		Successional forest of conifers
	Non-natural forest stands	

Table 23.
Abiotic elements of the field survey.

Source	Concept/Category	Umbrella terms	Surveyed terms
Höll et al. (2009)	**Buildings**	Areas covered by buildings	Houses/buildings
			Industry
		Observation towers	
		Track areas	
Categories in adherence to Gidlow et al. (2018) Schebella et al. (2019a) Schebella et al. (2019b)	**Structural Elements**	Roads/paths	Concrete/Asphalt
			Paving
			Gravel
			Field paths/unpaved paths
		Stairs	
		Bridges	
		Gardens	Leisure gardens
			Parks
	Infrastructure	Accessibility	Connection
			Inaccessible areas/spots
			Car parks
			Walking routes/paths
			Signposting
		Facilities	Benches
			Playground
			Barbecue area
			Toilets
			Lighting
			Kiosk/restaurant/vending machines
			Roofing
			Waste bins, also for dogs
	Incivilities	Incivilities	Rubbish
			Graffiti
			Vandalism
			Dog feces

Table 24.
Survey catalogue for variables of the Area Perception online-study “Beauty of recreational areas”

Concept	Items	Source
Demographics	Age Gender Highest degree	
Closeness to nature (5 point Likert scale)	How often do you go for walks in nature?	Randler & Heil (2021)
Area Assessment: 4 pictures per location and the following questions (5-point Likert scales):		
Beauty	How beautiful do you find this place?	Own
Naturalness	How natural does this area seem to you?	Schebella et al. (2019a)
Estimated Biodiversity	Would you say that this area has low, medium or high biodiversity compared to others in the Rottenburg am Neckar/Stuttgart area? (Species diversity means the number of animals and plants)	White et al. (2017)
Estimated restorativeness	How well would a visit to this place help you to feel refreshed and revitalized?	White et al. (2017)

Table 25.
Descriptive statistical information on the variables (N = 40).

		Variable	Min	Max	Mean	SD
Area Assessment On-Site	Ecological data	Bird diversity	18	42	28.05	6.28
		Biotope types	7	22.5	13.4	3.87
	Landscape characteristics	Structures	2	10	5.51	1.83
		Infrastructure	1.5	11	6.46	2.19
		Incivilities	0	6	1.33	1.21
Area Assessment Off-Site	Landscape characteristics	Urbanity	1	2	1.53	.51
		Area type	1	3	1.68	.57
		Human Footprint Index (HFI)	13	46	33.5	9.87
Pen-and-paper Survey of recreationists on-site	Area Perception On-site	Perceived bird diversity	2.55	4.77	3.55	.51
		Perceived naturalness	2.69	4.48	3.72	.39
	Mental well-being	Emotions	3.66	4.66	4.15	.22
		Recalled Restoration	3.5	4.52	4.03	.25
		Place Attachment-Recovery	3.58	4.46	4.06	.214
		Place Attachment - Identity	2.64	4.33	3.66	.38
Online Survey	Area perception online	Estimated beauty	2.56	4.61	3.65	.48
		Estimated naturalness	1.69	4.57	3.09	.77
		Estimated restoration value	2.36	4.49	3.49	.52
		Estimated biodiversity richness	1.94	4.43	3.2	.69

Appendix of Manuscript 3

Table 26.
Descriptive Statistics of the environmental and physiological measurements.

	N	Minimum	Maximum	Mean	Std. Deviation
Environmental Measures					
Daily bird count	233	14	21.0	17.20	2.11
Soundlevel min (dB)	208	40	55.0	47.84	4.48
Soundlevel max (dB)	208	53	70.0	64.25	6.12
Soundlevel mean (dB)	208	49	62.5	56.04	4.83
Temperature (°C)	233	9.0	19.0	14.66	3.24
Physiological measures					
Cortisol pretest (nmol/L)	232	1.72	35.73	10.15	6.51
Cortisol posttest (nmol/L)	232	1.07	31.76	6.82	4.71
Systole pretest (mmHg)	233	83.0	181	128.70	16.22
Systole posttest (mmHg)	233	81.0	174	127.53	16.34
Diastole pretest (mmHg)	233	56.0	121	83.11	9.91
Diastole posttest (mmHg)	233	57	126	81.90	9.10
HR pretest (bpm)	233	42	115	76.85	12.47
HR posttest (bpm)	233	47	114	74.82	12.78
Emotions pretest	228	1.33	5	3.579	.714
Emotions posttest	231	3	5	4.398	.520

Table 27.
Multivariate GLM with the physiological parameters as dependent variables. a. R Squared = .174 (Adjusted R Squared = .055); b. R Squared = .277 (Adjusted R Squared = .173); c. R Squared = .155 (Adjusted R Squared = .034); d. R Squared = .201 (Adjusted R Squared = .086).

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta^2
Corrected Model	Cortisol posttest	827.465[a]	25	33.099	1.467	.081	.174
	Systole posttest	15322.238[b]	25	612.890	2.663	<.001	.277
	Diastole posttest	2661.194[c]	25	106.448	1.278	.182	.155
	HR posttest	6396.984[d]	25	255.879	1.749	.020	.201
Intercept	Cortisol posttest	2.512	1	2.512	.111	.739	.001
	Systole posttest	224.345	1	224.345	.975	.325	.006
	Diastole posttest	199.089	1	199.089	2.390	.124	.014
	HR posttest	657.594	1	657.594	4.496	.035	.025
Age	Cortisol posttest	4.337	2	2.168	.096	.908	.001
	Systole posttest	686.395	2	343.198	1.491	.228	.017
	Diastole posttest	293.898	2	146.949	1.764	.174	.020
	HR posttest	495.848	2	247.924	1.695	.187	.019
Gender	Cortisol posttest	8.582	2	4.291	.190	.827	.002
	Systole posttest	**4158.985**	**2**	**2079.493**	**9.035**	**<.001**	**.094**
	Diastole posttest	**748.497**	**2**	**374.249**	**4.493**	**.013**	**.049**
	HR posttest	**1031.727**	**2**	**515.863**	**3.527**	**.032**	**.039**
Graduation	Cortisol posttest	25.977	1	25.977	1.151	.285	.007
	Systole posttest	484.441	1	484.441	2.105	.149	.012
	Diastole posttest	18.384	1	18.384	.221	.639	.001
	HR posttest	1.184	1	1.184	.008	.928	.000
Group	Cortisol posttest	52.881	4	13.220	.586	.673	.013
	Systole posttest	1023.970	4	255.993	1.112	.352	.025
	Diastole posttest	102.216	4	25.554	.307	.873	.007
	HR posttest	1203.948	4	300.987	2.058	.088	.045
Perceived bird species richness	Cortisol posttest	35.402	1	35.402	1.569	.212	.009
	Systole posttest	663.375	1	663.375	2.882	.091	.016
	Diastole posttest	39.209	1	39.209	.471	.494	.003
	HR posttest	**890.951**	**1**	**890.951**	**6.091**	**.015**	**.034**
Perceived naturalness	Cortisol posttest	1.307	1	1.307	.058	.810	.000
	Systole posttest	30.649	1	30.649	.133	.716	.001
	Diastole posttest	.975	1	.975	.012	.914	.000
	HR posttest	206.739	1	206.739	1.413	.236	.008
Bird species knowledge	Cortisol posttest	2.264	1	2.264	.100	.752	.001

	Systole posttest	543.805	1	543.805	2.363	.126	.013
	Diastole posttest	3.263	1	3.263	.039	.843	.000
	HR posttest	34.568	1	34.568	.236	.627	.001
Perception of birds	Cortisol posttest	.054	1	.054	.002	.961	.000
	Systole posttest	486.372	1	486.372	2.113	.148	.012
	Diastole posttest	1.941	1	1.941	.023	.879	.000
	HR posttest	92.981	1	92.981	.636	.426	.004
Nature experience	Cortisol posttest	45.739	1	45.739	2.027	.156	.012
	Systole posttest	137.105	1	137.105	.596	.441	.003
	Diastole posttest	2.573	1	2.573	.031	.861	.000
	HR posttest	**780.929**	**1**	**780.929**	**5.339**	**.022**	**.030**
Daily bird count	Cortisol posttest	.336	1	.336	.015	.903	.000
	Systole posttest	51.405	1	51.405	.223	.637	.001
	Diastole posttest	2.166	1	2.166	.026	.872	.000
	HR posttest	371.265	1	371.265	2.538	.113	.014
Temperature	Cortisol posttest	.200	1	.200	.009	.925	.000
	Systole posttest	7.359	1	7.359	.032	.858	.000
	Diastole posttest	28.049	1	28.049	.337	.562	.002
	HR posttest	185.201	1	185.201	1.266	.262	.007
Sound level mean	Cortisol posttest	.057	1	.057	.003	.960	.000
	Systole posttest	31.795	1	31.795	.138	.711	.001
	Diastole posttest	3.065	1	3.065	.037	.848	.000
	HR posttest	298.420	1	298.420	2.040	.155	.012
Daily bird count * Temperature * Sound level mean	Cortisol posttest	.001	1	.001	.000	.994	.000
	Systole posttest	14.772	1	14.772	.064	.800	.000
	Diastole posttest	6.640	1	6.640	.080	.778	.000
	HR posttest	245.359	1	245.359	1.677	.197	.010
Age Group * Gender * Graduation	Cortisol posttest	308.735	7	44.105	1.954	.064	.073
	Systole posttest	2830.412	7	404.345	1.757	.099	.066
	Diastole posttest	603.999	7	86.286	1.036	.408	.040
	HR posttest	240.150	7	34.307	.235	.976	.009

Table 28.
Univariate GLM, with dependent variables Perception of Nature and Perceived species richness. a. R Squared = .153 (Adjusted R Squared = .084); b. R Squared = .048 (Adjusted R Squared = -.029).

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	Perception of nature	32.037[a]	15	2.136	2.220	.007	.153
	Perceived bird species richness	10.026[b]	15	.668	.624	.853	.048
Intercept	Perception of nature	.775	1	.775	.806	.370	.004
	Perceived bird species richness	2.182	1	2.182	2.038	.155	.011
Age Group	Perception of nature	3.766	2	1.883	1.957	.144	.021
	Perceived bird species richness	1.378	2	.689	.644	.527	.007
Gender	Perception of nature	.927	2	.463	.482	.619	.005
	Perceived bird species richness	1.144	2	.572	.535	.587	.006
Graduation	Perception of nature	.398	1	.398	.414	.521	.002
	Perceived bird species richness	.749	1	.749	.700	.404	.004
Group	Perception of nature	2.319	4	.580	.603	.661	.013
	Perceived bird species richness	1.101	4	.275	.257	.905	.006
Bird species knowledge	Perception of nature	.196	1	.196	.203	.652	.001
	Perceived bird species richness	1.503	1	1.503	1.404	.238	.008
Perception of birds	**Perception of nature**	**17.067**	**1**	**17.067**	**17.741**	**<.001**	**.088**
	Perceived bird species richness	.023	1	.023	.022	.882	.000
Daily bird count	Perception of nature	.362	1	.362	.377	.540	.002
	Perceived bird species richness	1.901	1	1.901	1.775	.184	.010
Temperature	Perception of nature	.251	1	.251	.261	.610	.001
	Perceived bird species richness	2.520	1	2.520	2.354	.127	.013
Sound level mean	Perception of nature	.300	1	.300	.311	.577	.002
	Perceived bird species richness	2.056	1	2.056	1.921	.167	.010
Daily bird count * Temperature * Sound level mean	Perception of nature	.240	1	.240	.250	.618	.001
	Perceived bird species richness	2.553	1	2.553	2.385	.124	.013

Appendix of Manuscript 4

Table 29 .
Component matrix, showing the factor loadings of the three variables forming the mental well-being factor.

	Component 1
Emotions posttest	0.607
Satisfaction	0.835
Self reported restoration	0.797
Extraction Method: Principal Component Analysis.	
a. 1 components extracted.	

Table 30.
Component matrix, showing the factor loadings of the variables forming the factors of perceived restorative potential and perceived biodiversity.

		Component	
		1	2
Perceived restorative potential	Perceived restoration place	0.731	-0.450
	Perceived restoration sound	0.875	-0.185
Perceived biodiversity	estimated bird richness	0.410	0.673
	perceived bird song	0.445	0.700
	perceived naturalness place	0.684	-0.168
	perceived naturalness sound	0.874	0.020
Extraction Method: Principal Component Analysis. a. 2 components extracted.			

Table 31.
Component matrixa of the variables forming perceived biodiversity and nature experience.

		Component	
		1	2
	estimated bird richness	0.607	-0.373
Perceived biodiversity	perceived bird song	0.641	-0.481
	perceived naturalness place	0.687	0.440
	perceived naturalness sound	0.833	0.194
Nature experience	Nature experience	0.086	0.814
Extraction Method: Principal Component Analysis. a. 2 components extracted.			

Table 32.
Full table of the results for the multivariate GLM with dependent variables being the regression scores of mental well-being, perceived biodiversity, nature experience, and perceived restorative potential. a. R Squared = 0.863 (Adjusted R Squared = 0.464), b. R Squared = 0.870 (Adjusted R Squared = 0.493), c. R Squared = 0.907 (Adjusted R Squared = 0.637), d. R Squared = 0.859 (Adjusted R Squared = 0.449).

Predictors	**Dependent Variable**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	Mental well-being	38.710[a]	32	1.210	2.164	0.087
	Perceived biodiversity	37.419[b]	32	1.169	2.305	0.071
	Nature experience	39.010[c]	32	1.219	3.361	0.018
	Perceived restorative potential	37.952[d]	32	1.186	2.094	0.097
Intercept	Mental well-being	0.083	1	0.083	0.148	0.708
	Perceived biodiversity	1.205	1	1.205	2.376	0.152
	Nature experience	0.443	1	0.443	1.221	0.293
	Perceived restorative potential	2.158	1	2.158	3.810	0.077
Age	Mental well-being	26.376	24	1.099	1.966	0.121
	Perceived biodiversity	19.406	24	0.809	1.594	0.212
	Nature experience	20.834	24	0.868	2.393	0.067
	Perceived restorative potential	29.673	24	1.236	2.183	0.089
Gender	Mental well-being	1.974	1	1.974	3.532	0.087
	Perceived biodiversity	0.364	1	0.364	0.718	0.415
	Nature experience	0.756	1	0.756	2.084	0.177
	Perceived restorative potential	1.962	1	1.962	3.464	0.090
University degree	Mental well-being	1.318	1	1.318	2.358	0.153
	Perceived biodiversity	2.155	1	2.155	4.247	0.064
	Nature experience	0.011	1	0.011	0.030	0.865
	Perceived restorative potential	0.068	1	0.068	0.120	0.736
Weather	Mental well-being	0.405	1	0.405	0.725	0.413
	Perceived biodiversity	0.139	1	0.139	0.273	0.611
	Nature experience	0.123	1	0.123	0.338	0.573
	Perceived restorative potential	0.878	1	0.878	1.550	0.239
Group	Mental well-being	0.162	1	0.162	0.290	0.601
	Perceived biodiversity	0.248	1	0.248	0.488	0.499
	Nature experience	0.962	1	0.962	2.651	0.132
	Perceived restorative potential	1.942	1	1.942	3.429	0.091
Daily bird count	Mental well-being	0.271	1	0.271	0.485	0.501

	Perceived biodiversity	0.484	1	0.484	0.954	0.350
	Nature experience	0.581	1	0.581	1.602	0.232
	Perceived restorative potential	2.022	1	2.022	3.571	0.085
Bird species knowledge	Mental well-being	1.448	1	1.448	2.590	0.136
	Perceived biodiversity	0.299	1	0.299	0.589	0.459
	Nature experience	1.218	1	1.218	3.359	0.094
	Perceived restorative potential	0.004	1	0.004	0.007	0.936
Perception of birds	**Mental well-being**	**3.603**	**1**	**3.603**	**6.445**	**0.028**
	Perceived biodiversity	**3.413**	**1**	**3.413**	**6.728**	**0.025**
	Nature experience	0.844	1	0.844	2.326	0.155
	Perceived restorative potential	0.144	1	0.144	0.255	0.624
Weather * Group	Mental well-being	0.556	1	0.556	0.994	0.340
	Perceived biodiversity	0.224	1	0.224	0.441	0.520
	Nature experience	0.561	1	0.561	1.545	0.240
	Perceived restorative potential	2.125	1	2.125	3.752	0.079

Table 33.
Two-level GLM results for the cortisol measurements (pre-posttest).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	16.861	1	16.861	0.747	0.421
Estimated bird richness	56.369	1	56.369	2.496	0.165
Perceived bird song	29.239	1	29.239	1.295	0.299
Perceived naturalness (place)	33.211	1	33.211	1.471	0.271
Perceived naturalness (sound)	36.759	1	36.759	1.628	0.249
Nature experience	35.031	1	35.031	1.551	0.259
Bird species knowledge	24.180	1	24.180	1.071	0.341
Perception of birds	59.174	1	59.174	2.620	0.157
Age	566.875	24	23.620	1.046	0.525
Gender	101.786	1	101.786	4.507	0.078
University degree	9.795	1	9.795	0.434	0.535
Daily bird count	5.797	1	5.797	0.257	0.630
Group	8.586	1	8.586	0.380	0.560
Weather	4.488	1	4.488	0.199	0.671
Group * Weather	1.111	1	1.111	0.049	0.832

Table 34.
Two-level GLM results for the HR measurements (pre-posttest).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	348.853	1	348.853	2.405	0.182
Estimated bird richness	4.900	1	4.900	0.034	0.861
Perceived bird song	156.399	1	156.399	1.078	0.347
Perceived naturalness (place)	304.640	1	304.640	2.100	0.207
Perceived naturalness (sound)	161.179	1	161.179	1.111	0.340
Nature experience	169.341	1	169.341	1.167	0.329
Bird species knowledge	382.030	1	382.030	2.634	0.166
Perception of birds	318.397	1	318.397	2.195	0.199
Age	5391.692	24	224.654	1.549	0.333
Gender	270.187	1	270.187	1.863	0.231
University degree	43.263	1	43.263	0.298	0.608
Daily bird count	184.487	1	184.487	1.272	0.311
Group	557.447	1	557.447	3.843	0.107
Weather	42.546	1	42.546	0.293	0.611
Group * Weather	231.988	1	231.988	1.599	0.262

Table 35.
Two-level GLM results for the blood pressure measurements (pre-posttest).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	0.574	1	0.574	0.003	0.959
Estimated bird richness	212.434	1	212.434	1.067	0.341
Perceived bird song	729.065	1	729.065	3.662	0.104
Perceived naturalness (place)	166.937	1	166.937	0.838	0.395
Perceived naturalness (sound)	51.700	1	51.700	0.260	0.629
Nature experience	191.765	1	191.765	0.963	0.364
Bird species knowledge	125.827	1	125.827	0.632	0.457
Perception of birds	254.321	1	254.321	1.277	0.302
Age	11281.239	24	470.052	2.361	0.144
Gender	958.360	1	958.360	4.813	0.071
University degree	62.581	1	62.581	0.314	0.595
Daily bird count	62.825	1	62.825	0.316	0.595
Group	27.391	1	27.391	0.138	0.723
Weather	2.729	1	2.729	0.014	0.911
Group * Weather	50.229	1	50.229	0.252	0.633

Table 36.
ANOVA für differences between treatment groups

	Sum of Squares	df	Mean Square	F	Sig.
mental well-being	0.344	1	0.344	0.339	0.563
Perceived biodiversity	**3.934**	**1**	**3.934**	**4.229**	**0.046**
Nature Experience	0.903	1	0.903	0.901	0.348
Perceived restorative potential	2.940	1	2.940	3.072	0.086
Weather	**2.232**	**1**	**2.232**	**10.701**	**0.002**