Biodiversity, mental health and well-being: psychological mechanisms and moderators of a complex relationship (BIOWELL)

Katja Liebal[‡], Vera Denzer[‡], Nico Eisenhauer[§,‡], Immo Fritsche[‡], Ute Kunzmann[‡], Linda Oña[‡], Martin F. Quaas[‡], Ingmar Staude[‡], Christian Wirth[‡]

‡ Leipzig University, Leipzig, Germany
§ German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany

Corresponding author: Katja Liebal (katja.liebal@uni-leipzig.de)

Abstract

Human activities and their consequences, such as environmental pollution, the exploitation of resources or deforestation, are major causes of biodiversity loss. However, humans depend on a biologically diverse and healthy environment in many ways, as it provides access to clean water, air and food. The loss of biodiversity is an ecological crisis that threatens human health, and ultimately their very existence. At the same time, there is an unwavering interest in the positive effects of "nature" on mental health. Although these examples point to a connection between biodiversity and health, little is known about the causal effects of different facets of biodiversity on mental health. Exploring these relationships and the underlying psychological mechanisms is a major goal of this project. We will build on the expertise of an interdisciplinary team involving scholars from psychology, biodiversity research, human geography, and behavioural economics and combine this expertise with a variety of methods, with a focus on quantitative research, experimental and intervention designs, and investigate participants from different age groups to understand the causal effects of different environments with varying degrees of biological diversity on mental health, and to identify the physical, social, and psychological boundary conditions of these causal effects.

Keywords

biodiversity, nature, human health, mental health, well-being

Project description

Biodiversity, defined as *variety of all living things on earth* (CBD 1992, Cardinale et al. 2012), is rapidly declining. Scientists warned that, within decades, a significant number of

the species worldwide – one million out of eight million – might become extinct (IPBES 2019). This loss of biodiversity is almost exclusively caused by human activity, such as pollution, exploitation of resources (e.g., over-fishing) or deforestation and other forms of intensified land use.

Humans, however, also heavily depend on biologically diverse and healthy ecosystems, as they provide us with water, air, and food (Isbell et al. 2017). The rapid loss of biodiversity, therefore, presents a major ecological crisis (IPBES 2019), with possible drastic impact on human health. In fact, it may threaten the existence of human civilisation (Isbell et al. 2017, Pörtner et al. 2021, Karaliuniene et al. 2022). It also comes with significant economic costs and challenges for long-term economic sustainability (Dasgupta 2021). The resulting "...chronic fear of environmental doom..." (Clayton 2020), coined as "eco-anxiety", has attracted the attention of clinical, social and environmental psychologists interested in the link between ecological crises and mental health (Pihkala 2020, Léger-Goodes et al. 2022), defined not only as the *absence of psychological disorders and negative affect, but also the presence of positive mental states, such as life satisfaction, positive affect, and a sense of meaning and purpose in life* (World Health Organization 2004, Kunzmann et al. 2013). Importantly, most of this research focusses on the impact of climate change threat on mental health and interpersonal relationships (Fritsche et al. 2012, Barth et al. 2018, Ogunbode et al. 2022), but not on one of its consequences, the loss of biodiversity (Usher et al. 2019).

At the same time, there is an unabating interest in the positive impact of 'nature' on human well-being and psychological health, in both science and society. Research addresses the impact of 'experiencing nature' and spending time outdoors on mental health and well-being (Hartig et al. 2011) and the role of green spaces in urban environments with focus on the effectiveness of "nature-based solutions" for mental health (Callaghan et al. 2021). Health effects of nature have been explained in terms of stress-reducing and attention-restoring effects of natural surroundings (van den Berg et al. 2018) and different biodiversity variables have been found to positively influence self-reported life satisfaction (Bertram and Rehdanz 2015, Krekel et al. 2016, Methorst et al. 2021). Forest bathing (Shinrin-yoku), with a longstanding tradition in Japan, has become increasingly popular in Western societies, and studies report an impact on both psychological and physical health (Wen et al. 2019). "Nature connectedness" plays an essential role in environmental education (Otto and Pensini 2017) and has been linked to mindfulness, mental health and well-being (Howell et al. 2011), also in the context of ecological crises (Curll et al. 2022). Furthermore, there is a strong link between how humans perceive and value biodiversity from an aesthetic point of view and how the generated emotions influence human mental health (Marselle et al. 2021). Interestingly, particularly in psychological studies and in science education, plants have been largely neglected, as research on human-nature-relationships has often focused on interactions with animals (Balding and Williams 2016).

The seemingly plausible conclusion from these studies is that human health and "nature" are closely intertwined, as engaging with different forms of "nature" seems to have a positive influence on mental health and well-being, while events threatening "nature"

have a negative impact. However, the storyline is not that simple. First, reviews and meta-analyses on the positive effects of interacting with nature highlight inconsistent findings across studies and point to methodological weaknesses, thus questioning positive effects on mental health (van den Berg and Konijnendijk 2019). Second, the majority of studies reports correlational effects between "nature" and mental health, while causal relationships and the nature of directional effects are not addressed (Stier-Jarmer et al. 2021). Third, many studies link mental health to rather ill-defined or multi-dimensional entities, such as "nature connectedness", which makes it impossible to identify the specific factors and to experimentally test their influence on mental health. Fourth, and related to this, the role of biodiversity has been largely neglected in this research, as the focus is often on "nature" or ecosystems or landscapes as a whole, such as "forests" or "green space". The unique advantage of focusing on biodiversity is that it can be used as a graded variable with varying degrees of complexity (e.g., biologically less versus more complex habitats) to experimentally investigate its causal effects on mental health. Furthermore, biodiversity can be measured as "species identity" in the form of different species (animals, plants, fungi, etc.) and their morphological and functional traits, and in different "habitats" (e.g. urban versus rural, water versus soil, natural versus artificial environments), which reduces, the multi-dimensional construct of "nature" to separate and less complex units. Fifth, while a positive effect of healthy and rich habitats and their biological constituents on mental health is commonly assumed, it is currently unknown if biologically diverse environments could also have a negative effect, since "wilderness" might be experienced as overwhelming or even threatening given psychological motives for uncertainty reduction and control (Fritsche and Hoppe 2019, van den Berg and Konijnendijk 2019). Sixth, it is largely unclear whether the effect of experiencing biodiversity affects all aspects of mental health equally. Seventh, the existing research has focused on young adults mostly. From a developmental perspective, however, it is possible that the effects of biodiversity on mental health vary across the lifespan.

Objectives

Taken together, there is a lack of systematic, carefully controlled studies to investigate the causal relationships between different facets of biodiversity and human health and the different factors that might moderate these relationships. We will mostly focus on plants and we specifically address mental health. To grasp the multiple dimensions of human-nature-relationships, we will build on the expertise of an interdisciplinary team involving scholars from environmental, social, and developmental psychology, biodiversity research, human geography, and behavioural economics. Furthermore, we will use a mixed-method approach, with a focus on quantitative research, experimental, intervention and explorative designs, and investigate participants from different age groups (children, adolescents, and adults) to understand the psychological mechanisms underlying human-nature-relationships. We will combine basic and applied research, since this approach is ideally suited to address how biodiversity and mental health mutually influence each other.

We aim at pursuing five major objectives, which will be addressed in the following work packages (Fig. 1):

1. To study the causal effects of varying degrees of biological diversity on mental health, in various target groups differing in chronological age.
2. To identify the physical and social factors that limit or enhance of these causal effects on the relationship between biodiversity and mental health.
3. To investigate the influence of different environments (e.g., forests, gardens, green spaces) on mental health.
4. To collaborate with educational institutions and other stakeholders to generate data and to implement findings of this project into teaching activities, urban development, and health care.
5. To develop a model, based on our findings, for the causal relationships between important aspects of biodiversity and mental health and their boundary conditions.

Objective 1: To study the causal effects of varying degrees of biological diversity on mental health.

WP1.1: Aesthetic preferences for and perception of biodiversity

Goal: We will examine participants' perception of different plant species and if they prefer biologically diverse versus less diverse settings.

Method: We use different methods to investigate children, adolescents, and adults in two unique outdoor laboratories near Leipzig (MyDiv experiment, ARBOfun), in schools and laboratories at Leipzig University. Interviews and questionnaires are used to investigate which plants (in particular trees) participants prefer and to understand the reasons for their preferences. Discrete choice experiments are conducted to quantify the relative preference for biological diversity relative to other attributes of the choice alternatives, such as accessibility or costs of making contact with the plant species. Eye-tracking is applied to investigate participants' gazing patterns on stimuli depicting plants with different shapes, colours, and sizes and to differentiate if they pay more attention to biologically diverse over less diverse habitats. This is combined with physiological measures (skin conductance) and questionnaires to examine the influence of perceiving biologically diverse versus less diverse habitats on the participants' physiological reactions and emotions. Phase 1 will be dedicated to recruiting participants and to piloting the different methods, and phase 2 to collecting, analysing and publishing the data.

Results: By combining two different experiments, one realising a gradient in tree richness and one exhibiting a wide range of trees in isolation, it is possible to disentangle preferences for diversity per se from preferences for individual tree characteristics. These results enable us to identify participants' preferences for specific species or specific degrees of diversity, which may vary depending on age, and to use this knowledge to design the appropriate stimuli and scenarios for other WPs (2.1, 3.3, 4).

WP1.2: The perceived value of forest diversity

Goal: We aim to examine children's and adults' behaviours, and preferences in forests with experimentally controlled, varying degrees of diversity (specific tree species, tree species richness, and functional diversity) to investigate if they prefer biologically more diverse forests over less diverse forests in an experimental framework that carefully controls for ecological and social variables.

Method: One part of the project will be conducted at the MyDiv experiment, which provides a unique opportunity to study the effects of tree diversity on human behaviour, as it contains plots with varying, but controlled species richness, including monocultures as well as two- and four-species mixtures (Ferlian et al. 2018). We compare diversity-focused attitudes and preferences across cohorts of primary school children, adolescents, and young adults and combine different methods to investigate what they know about species diversity in forests and the services it provides for humans (interviews, questionnaires), in which forest they spend most time (movement tracking), their reported emotions and well-being (questionnaires) after spending time in a forest, and which value they assign to less diverse as compared to more diverse forests (choice experiments). A complementary study will be conducted at ARBOfun, a research arboretum with 100 tree species planted five times in blocks. Within blocks, the trees are arranged randomly with a wide spacing of 5.8 m x 5.8 m. The species represent the tree flora of Central Europe plus selected foreign species regularly planted in cities and plantations. Each tree individual can be perceived individually with its unique shape, texture, colour, phenology and size which is the ideal setting for choice experiments. We will relate preferences for tree species to tree traits and features of service provision such as economic values, ability to cast shade, climate change resilience to provide a selection criterion for future trees, based on aesthetic appreciation and mental health effects. To do so, we will build an image database including different perspectives and distances of inspection (tree, branch, leaf) of each of these 100 trees, at different times of the year.

Results: The results will enable us to identify if participants' preferences for certain trees and specific (controlled) types of forests, and if they recognise, and appreciate more diverse over less diverse forests.

Objective 2: To identify the physical, social, and psychological factors that moderate the causal effects on the relationship between biodiversity and mental health.

WP2.1: Biodiversity as a potential threat to well-being

Goal: We will investigate if and why biologically very diverse habitats ("wilderness") may be perceived as threatening and whether (groups of) people, who are subjectively and objectively vulnerable to threat, will thus respond negatively and with reduced well-being to biodiversity. We also aim to address whether societal crises (e.g., economic crisis, environmental crisis) may affect the appraisal and health effects of biodiversity. We suspect that aspects of biodiversity could explain ambivalence of nature given that a diverse environment may reduce certainty, restrict perceived control and enhance mortality salience. At the same time, high levels of biodiversity might be associated with

resources and opportunities for exploration. Unfortunately, the different motivational accounts of aversion towards nature have never yet been tested concurrently (Fritsche and Hoppe 2019). Therefore, we wil, in a first step, focus on certain selected (theoretically relevant) aspects and implications of biodiversity and, if applicable, extend our selection to other threat-relevant subjective associations with biodiversity (e.g., increase in allergies, risk from zoonoses). This WP project will also determine those boundary conditions of ambivalence towards biodiversity in nature.

Method: In phase 1, will use questionnaires to investigate which aspects of diverse habitats might be experienced as negative by both children and adults and which motive-related appraisals are elicited (see WP 1.1, 1.2). Furthermore, we will use the questionnaires that were used in WPs 1 (e.g., aesthetic preferences) to evaluate potential positive associations. In phase 2, we will conduct experiments (in the laboratory and in the field, at the MyDiv experiment) to differentiate between different motivational explanations (e.g., uncertainty, control) for the perceived threat of biologically diverse environments and to identify boundary conditions (e.g., environmental identity, social norms). In these studies, we will experimentally manipulate different qualities of threat, the biodiversity of natural environments, and boundary conditions, such as environmental identity and social norms.

Results: Knowing the motivational drivers of ambivalence towards biodiversity will enable possible interventions (WP3.3), such as providing certainty and control, even in diverse natural environments or highlighting the aspects of biodiversity that foster need satisfaction, such as control.

Objective 3: To investigate the influence of different environments on mental health.

WP3.1: Urban green spaces and their impact on well-being

Goal: We aim to examine the perception and experience of humans in different urban green spaces with different degrees of biodiversity (e.g., manicured green spaces, urban wilderness, floodplain forest) to understand how these sites impact humans' self-assessment of well-being. Investigating these effects in everyday green spaces will serve as a valuable addition to findings from WP1 and 2, which predominantly focus on experimentally controlled environments.

Methods: We have access to forests, green spaces, brownfields and gardens across Leipzig (conventional and remote-sensing based). Based on this, we will select different urban spaces with varying degrees of biodiversity (orthogonal variation of structural and taxonomic variation and controlling for acoustic and visual features of the surrounding area) and use additional qualitative methods (participatory observations, field walks, go-along interviews, group discussions with collaborative sketch mapping) to explore the various relationships between everyday practice in urban spaces with varying degrees of biodiversity and their impact on mental well-being. Furthermore, we will use the questionnaires used in WPs 1 to evaluate, for example, aesthetic preferences. Qualitatively collected data can also be transformed into quantitative insights through two

distinct approaches: (i) employing "emotional mapping," which combines with biodiversity mapping, atmospheric depiction, and emotional symbolism within the mapping process; and (ii) utilising lexicometric techniques to create word clouds and unveil connotations within words and terms sourced from non-standardised interviews.

Results: Our findings will offer a deeper understanding of how different urban spaces with varying degrees of biodiversity lead to specific settings of mental well-being. We will identify key variables and their interactions exerting a positive impact which can guide future urban planning practices towards more healthy urban environments.

WP3.2: Effects of gardening on mental health

Goal: With about 17 million private gardens, gardening is extremely popular in Germany, and it has been shown to promote stress reduction and mental health (Odeh et al. 2022). To best exploit this intervention potential, we aim to investigate whether different types of gardens differ in their impact on mental health. Specifically, we investigate whether conservation gardens, which focus on preserving biodiversity by planting native, often declining plant species (Segar et al. 2022), differ from conventional gardens with regard to multiple correlates of mental health (Marselle et al. 2021).

Methods: We will partner with local Registered Environmental Non-Profit Organisations (NGOs) to recruit owners of conservation gardens and conventional gardens. In phase 1, we will use questionnaires with individual attitude statements to investigate whether aspects like physical activity, social cohesion, and place attachment differ between gardeners of conservation and conventional gardens. After scoping for differences in these predictors of mental health in phase 1, we will measure mental health more directly in phase 2. We will conduct interviews (followed by semantic analyses) and quantify garden owners' rumination scores before and after gardening to compare the effect of different types of gardening across individuals.

Results: If different types of gardening do, indeed, result in different health benefits, this has important implications for the design of health intervention tools, but also for gardeners themselves, and may result in the increased promotion of conservation gardens. There is a potential to find so-called spill-over effects: The commitment to biodiversity in one's own garden could lead to increased personal perceptions of effectiveness in environmental protection, which can not only increase well-being (control, sense; see WP2.1), but also intentions to act in other areas of environmental protection.

WP3.3: Factors that enhance the psychological effects of biodiversity

Goal: We will investigate how the experience of biodiversity affects mental health in the context of randomised, controlled intervention study using a pre-post design, and whether such effects can be boosted by employing mindfulness.

Method: The intervention will be comprised of three groups, a regular walking group, a mindful regular walking group, and a passive control group. The two intervention groups

will regularly walk during a biodiverse-rich environment for six weeks. The mindful regular walking group will receive a mindfulness-based intervention in addition to the walks, enabling the members of this group to walk through biodiverse rich environments in a mindful state. We predict that the members of the two intervention groups, who experience biologically diverse environments regularly, will experience an increase in mental health during the time of the intervention, while this will not be the case for members of the passive control group. In addition, because mindfulness exercises sharpen sensory perceptions, we predict that the mindfulness group will experience a greater increase in mental health than the regular walking group. To examine these predictions, we will assess various facets of mental health in pre- and post-intervention surveys and, in addition, investigate the positive short-term effects of biodiversity experiences on mental health in the two intervention groups by assessing the participants' momentary subjective well-being shortly before and after their walks via a course app. Furthermore, we will measure the personal threat status (e.g., socio-economic deprivation, personal helplessness, etc.; WP3.3) of the participants in both groups, analogous to the measurements in WP2.1. In phase 1, we adapt a mindfulness-based intervention format, which we have already developed and validated, for our purposes, specifically incorporating meditation exercises that promote the experience of biodiversity. In phase 2, we conduct the intervention study with young, middle-aged, and older adults randomly assigned to the three study groups.

Results: Our results will further our understanding of how to construct interventions that aim at increasing mental health through experiencing biodiversity in adults of different ages.

Objective 4: To collaborate with educational institutions and other stakeholders to generate data and to implement findings of this project into both teaching activities and urban development.

WP4: Children's perspective on the relationships between biodiversity and mental health

Goal: The aim is to collaborate with the Botanical School of the Botanical Garden in Leipzig and potentially other educational institutions (Zoo School Leipzig, different schools) to work with children and adolescents as part of WP1.1, 1.2 and potentially also in WP2.1 and 3.3. during phase 1. In phase 2, we will involve additional local Registered Environmental NGOs. By promoting collaboration with educational institutions and stakeholders, this work package aims to not only generate data, but also integrate the project's outcomes into educational curricula and, over the long run, contribute to urban development.

Methods: A range of different methods will be used to investigate children's and adolescents' preferences for different species and degrees of diversity (see WP1.1). In phase 1, we will use the children's feedback after they participated in the pilot studies to improve the design and stimuli of the different experiments, to adjust them to the needs of the different age groups.

Results: The findings will be implemented into the teaching activities at schools, for examplel, to address plant blindness in science and education (Jose et al. 2019), and to increase awareness for the importance and benefits of biodiversity. Furthermore, findings will guide future urban planning practices to create more healthy urban environments, which also consider the perspective and needs of children.

Objective 5: To develop a model, based on our findings, for the causal relationships between important aspects of biodiversity and mental health and their boundary conditions.

WP5: A model for relationships between facets of biodiversity and mental health

In phase 1, we will identify different concepts of biodiversity, mental health and well-being used by different scholars and how these terms are implemented across disciplines. Based on this integrative review, we will develop working definitions, which are applicable across the disciplines involved in this project, as these shared definitions of biodiversity, mental health and well-being represent the foundation for WP1-4. In phase 2, based on the findings of WP1-4, we will suggest a model illustrating the causal relationships between environments with varying degrees of biodiversity and mental health, with focus on plants, different age groups, and the factors influencing these relationships. Therefore, the overarching goal of this work package will be to integrate the results of the single work packages and build a synthesised model at the end of the project term.

Results: The model can be used to derive additional hypotheses and to verify them in future projects.

Own preliminary work

Vera **Denzer** investigates the socio-spatial interrelations in the perception of green spaces in urban landscapes and their importance for human health and well-being by means of qualitative methods, such as walking interviews, sketch mapping and group discussions, to investigate multisensory spatial perceptions and the construction of space (Denzer 2019, Kühne et al. 2022, Köllner in press). She also uses geographic-artistic methods to explore, re-relate and re-imagine a variety of aesthetic and semiotic spatial perceptions (Bauer and Nöthen 2021), and has conducted projects with different stakeholders on the importance of public spaces as meeting and integration places in urban landscapes (Dietrich et al. 2016).

Nico **Eisenhauer** is a world-leading biodiversity researcher and the head of the MyDiv experiment, which is an open experimental platform within iDiv. It contains different tree species, organised in 80 plots with varying degrees of tree diversity (between one and four species, (Ferlian et al. 2018)). So far, it has been used for ecological and biodiversity research (Isbell et al. 2015, Lange et al. 2015, Meyer et al. 2018, Dietrich et al. 2022, Eisenhauer et al. 2022). However, because of its controlled settings consisting of different plots with varying degrees of tree diversity, it provides the unique opportunity to also

function as an "outdoor lab" for psychological research investigating the impact of more diverse as compared to less diverse plots on human behaviour, preferences, and emotions.

Immo **Fritsche** contributes 10 years of empirical psychological research and theory development on humans' ambivalence towards nature under conditions of threat and the role of different basic psychological motives to explain this (Fritsche and Häfner 2012, Hoppe et al. 2018, Fritsche and Hoppe 2019). More recently, he began to pit against each other the motives of managing death concerns and experiencing control as parallel accounts of distancing from nature under conditions of personal threat. For this purpose, together with Fabian Hess and Annedore Hoppe, he developed an experimental research paradigm to disentangle the effects of salient mortality and personal control loss on attitudes towards nature, extending earlier findings (Hess 2020).

Ute **Kunzmann** is a lifespan developmental psychologist focusing on developmental trajectories of key aspects of mental health, such as affective well-being, emotion regulation, wisdom, and compassion from adolescence to old age (Kunzmann et al. 2013 , Wieck and Kunzmann 2015, Rohr et al. 2017, Wirth and Kunzmann 2018, Kunzmann et al. 2019, Kunzmann in press). In a current project funded by AOK PLUS, "Mindfulness in Educational and University Culture, ABiK" (Principal Investigator: Susanne Krämer), Ute Kunzmann is, together with Dr. Blanke, responsible for the scientific evaluation of a mindfulness-based intervention format, developed by Susanne Krämer, to promote mindfulness, self-compassion, and sustainable environmental behaviour amongst members of Leipzig University. She also cooperates with colleagues from the Charitè, Dr. Kessler and Dr. Jeitler, who are experts in nature therapy and interventions related to integrative mind-body medicine and forest bathing.

Katja **Liebal** is a comparative psychologist and conducts research with children in different cultural contexts by combining observational and experimental methods (Liebal et al. 2011, Liebal and Haun 2018, Mühlenbeck et al. 2020). In the interdisciplinary project "Children & Nature", she investigates children's relationships with animals and plants, and how those vary across ages and cultural contexts. She established a research network with 50 collaborators from 30 different communities in 15 countries, involving scientists, as well as people working in conservation and education (Thajib et al. under revision). Linda **Oña** is a developmental psychologist investigating the social cognitive abilities and selective learning strategies of young children within regard to their knowledge about plants (Fantasia et al. 2021). She studies the plant-relevant learning rules that young children use to acquire information in naturalistic settings. Methodologically, she is using a combination of naturalistic observations and laboratory studies. Additionally, by the use of comparative methods, she studies humans and other primate species in order to determine the evolutionary and developmental factors that play a role in the development of social cognitive capacities in humans.

Martin **Quaas**, head of the biodiversity economics group at the German Centre for Integrative Biodiversity Research (iDiv), has extensive experience in modelling the relationships between biodiversity and economic well-being, and conducting

experimental research, with focus on the quantitative assessment of preferences for nature, such as choice experiments used to quantify preferences for sustainably harvested seafood (Bronnmann et al. 2021), and for the naturalness of urban green space (Bronnmann et al. 2023). He also studies the effect of environmental variables, such as urban green space and plant diversity, on self-reported life satisfaction (Kassouri et al. 2022).

Ingmar **Staude** investigates plant diversity in urban environments (Holz et al. 2022) and is interested in the question if and how it is possible to promote plant conservation in urban areas (Segar et al. 2022). He recently published a paper as senior author that received world-wide media attention (Munschek et al. 2023). It presents an app that helps identifying, selecting and purchasing regionally endangered plant species for cultivation in gardens. He is also interested in the impact of plant diversity on human health.

Christian **Wirth** is the speaker of iDiv and is a leading figure in biodiversity research, with focus on functional diversity of trees and forests (Huang et al. 2018, Schnabel et al. 2021). He serves as the director of the Botanical Garden of Leipzig University and he also directs the ARBOfun research arboretum, which is an open-air laboratory suitable for determining humans' aesthetic and emotional perception in response to biodiversity. Unlike at the MyDiv experiment, where biodiversity is visible at the population level, ARBOfun enables research at the level of individual tree species from close to 100 tree species (species identity). He also engages in several transfer activities (e.g., in the Botanical Garden) and with stakeholders to find solutions for protecting biodiversity, and he advices regional and national state agencies in biodiversity conservation on a regular basis.

Initial analysis of the relevant potential stakeholders

Christian Wirth has tight connections with regional stakeholders including the Amt für Stadtgrün und Gewässer (joint BfN project "Lebendige Luppe", joint "Duft- und Tastgarten" for visually handicapped visitors), the Amt für Umweltschutz, and the Sachsenforst, the forest service of the Federal State of Saxony. He is member of the working group "city forests" and interacts regularly with local environmental NGOs, and advises the environmental agency and the Environmental Minister of the Federal State of Saxony. He has also been appointed as a advisor of the federal government in September 2023. As the Director of the Botanical Garden, he has established the Botanical School, which is a collaboration between education authority supported with two half-time teachers (including Antje Hutschenreuther) to provide teaching offers for all schools of Leipzig, and the project "Kindergarten-Gartenkinder" for pre-school children with a local kindergarten. He also closely works with Rolf Engelmann, who is the coordinator for transfer at the Botanical Garden of the University of Leipzig, responsible for knowledge transfer between natural sciences and society (Engelmann et al. 2022, Engelmann et al. 2023). Ute Kunzmann is already collaborating with AOK Plus, and they showed great interest in translating biodiversity research into applied settings. Katja Liebal has, as part of the Children and Nature project, established a network of

kindergartens and schools interested in participating in studies targeting child-nature-relationships. This also includes the Zooschule Leipzig at Leipzig Zoo, directed by Dr. Alex Kästner, who organises a variety of activities for more than 10,000 pupils per year, including projects on biodiversity and nature conservation. Immo Fritsche has longstanding collaborations with Dr. Andreas W. Mues, Bund für Naturschutz and with Untere Naturschutzbehörde, Leipzig.

Opportunities and risks

BIOWELL provides the unique opportunity to realise an inherently interdisciplinary project, based on basic and applied research and by using a variety of different methods, to study the complex relationships of biodiversity and mental health, in both outdoor facilities and laboratories. If results provide evidence that biologically diverse environments have a positive impact on mental health, this might raise public awareness for both the importance of protecting biodiversity and its relevance for mental health. Regarding risks, interdisciplinary research is challenging, as it requires more time and tolerance for the different theoretical and methodological approaches of other disciplines. However, each applicant has experience in working in interdisciplinary settings and is aware of these challenges. Successful recruitment of participants, particularly for WP1.1 and 1.2, might be another challenge, since children and adolescents need to attend school. For WP requiring repeated participation (1.2, 3.3), high rates of dropouts might represent an additional risk. Finally, the Covid19-situation is still an issue, and future developments are impossible to foresee. However, given our experience in switching to lab- and online-settings, gained over the last two years, we are confident that a change in the epidemiological situation does not present a threat for the success of BIOWELL, neither in phase 1 nor 2.

Expected results

Regarding a *short-term perspective* (at the end of phase 1), we will have developed and piloted a set of experimental designs suitable for testing the influence of different facets of biodiversity on mental health, which can be translated to a wide range of other settings (field and lab settings, other ecosystems, national parks, etc.). As part of this, we have gathered substantial knowledge on aesthetic preferences (for species identity and extent of diversity) of different age groups. Based on this, we continue to work on the development of a set of stimuli (e.g., consisting of different tree shapes, colours, sizes) to be used in future studies (phase 2), which will be openly accessible for the scientific community. Regarding a *longer-term* perspective (at the end of phase 2), we will generate a preference score, based on mental health responses for the majority of native and common exotic tree species. This represents the basis for selecting tree species for cities and forest plantings. This is particularly important in the face of climate change, as the current forest mortality in Germany forces society to rethink forest management and to select suitable future tree species. Integrating mental health effects as non-material

ecosystem services in this selection process is of critical importance for planners. Based on this, and considering economic aspects, we aim to develop guidelines for tree species selection, as well as planting schemes for city forests that incorporate mental health as part of the ecological multifunctionality. This will improve the planning of green spaces and increase the well-being of citizens. The work will be realised in co-design with relevant local stakeholders, who will also support the knowledge transfer. By involving large numbers of participants in our study and with our outreach activities, which will be supported by media experts at iDiv, we will ensure visibility and create awareness for the importance of biodiversity for mental health. Based on this, we aim to develop the scientific basis for supporting decision-makers in Germany to take into account the benefits of biodiversity for human health in forestry and urban planning. Such method development requires close interdisciplinary collaboration, especially between biodiversity science, psychology, and behavioural economics. Since all proponents have extensive experience in interdisciplinary research, we consider the prospects for success to be very good.

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Conflicts of interest

The authors have declared that no competing interests exist.

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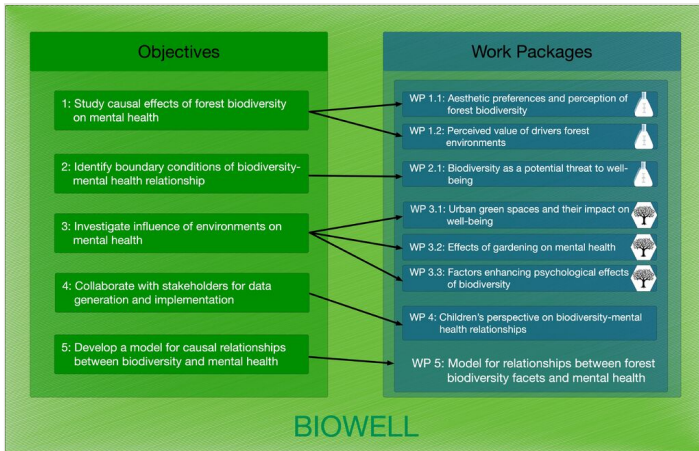
Figure 1.

BIOWELL objectives and related work packages. We will use a mixed-method approach collecting data in controlled experimental field settings, uncontrolled field settings (marked with tree: forests, green spaces, gardens) and in the laboratory (marked with conical flask: e.g., eye-tracking experiments). WP5 will integrate the results of the single work packages and build a synthesised model at the end of the project term.